Stellarium 0.20.1 User Guide

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Basic Use

1. Introduction

Stellarium is a software project that allows people to use their home computer as a virtual planetarium. It calculates the positions of the Sun and Moon, planets and stars, and draws how the sky would look to an observer depending on their location and the time. It can also draw the constellations and simulate astronomical phenomena such as meteor showers or comets, and solar or lunar eclipses.

Stellarium may be used as an educational tool for teaching about the night sky, as an observational aid for amateur astronomers wishing to plan a night's observing or even drive their telescopes to observing targets, or simply as a curiosity (it's fun!). Because of the high quality of the graphics that Stellarium produces, it is used in some real planetarium projector products and museum projection setups. Some amateur astronomy groups use it to create sky maps for describing regions of the sky in articles for newsletters and magazines, and the exchangeable sky cultures feature invites its use in the field of Cultural Astronomy research and outreach.

Stellarium is still under development, and by the time you read this guide, a newer version may have been released with even more features than those documented here. Check for updates to Stellarium at the Stellarium website[1].

If you have questions and/or comments about this guide, or about Stellarium itself, visit the Stellarium site at Github[2] or our Google Groups forum[3].

1.1 Historical notes

Fabien Chéreau started the project during the summer 2000, and throughout the years found continuous support by a small team of enthusiastic developers.

Here is a list of past and present major contributors sorted roughly by date of arrival on the project:

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[1]`https://stellarium.org`
[2]`https://github.com/Stellarium/stellarium`
[3]`https://groups.google.com/forum/#!forum/stellarium`

Fabien Chéreau original creator, maintainer, general development

Matthew Gates maintainer, original user guide, user support, general development

Johannes Gajdosik astronomical computations, large star catalogs support

Johan Meuris GUI design, website creation, drawings of our 88 Western constellations

Nigel Kerr Mac OSX port

Rob Spearman funding for planetarium support

Barry Gerdes user support, tester, Windows support. Barry passed away in October 2014 at age 80. He was a major contributor on the forums, wiki pages and mailing list where his good will and enthusiasm is strongly missed. RIP Barry.

Timothy Reaves ocular plugin

Bogdan Marinov GUI, telescope control, other plugins

Diego Marcos SVMT plugin

Guillaume Chéreau display, optimization, Qt upgrades, HiPS surveys

Alexander Wolf maintainer, DSO catalogs, user guide, general development

Georg Zotti astronomical computations, Scenery 3D and ArchaeoLines plugins, general development, user guide, user support

Marcos Cardinot MeteorShowers plugin

Florian Schaukowitsch Scenery 3D plugin, Remote Control plugin, RemoteSync plugin, OBJ rendering, Qt/OpenGL internals

Teresa Huertas Roldán Planetary nomenclature

Unfortunately time is evolving, and most members of the original development team are no longer able to devote most of their spare time to the project (some are still available for limited work which requires specific knowledge about the project).

As of 2017, the project's maintainer is Alexander Wolf, doing most maintenance and regular releases. Major new features are contributed mostly by Georg Zotti and his team focussing on extensions of Stellarium's applicability in the fields of historical and cultural astronomy research (which means Stellarium is getting more accurate) and outreach (making it usable for museum installations), but also on graphic items like comet tails or the Zodiacal Light. Some of Georg's work is in part supported by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Vienna, Austria.

A detailed track of development can be found in the `ChangeLog` file in the installation folder. A few important milestones for the project:

2000 first lines of code for the project

2001-06 first public mention (and users feedbacks!) of the software on the French newsgroup `fr.sci.astronomie.amateur` [4]

2003-01 Stellarium reviewed by Astronomy magazine

2003-07 funding for developing planetarium features (fisheye projection and other features)

2005-12 use accurate (and fast) planetary model

2006-05 Stellarium "Project Of the Month" on SourceForge

2006-08 large stars catalogs

2007-01 funding by ESO for development of professional astronomy extensions (VirGO)

2007-04 developers' meeting near Munich, Germany

2007-05 switch to the Qt library as main GUI and general purpose library

2009-09 plugin system, enabling a lot of new development

2010-07 Stellarium ported on Maemo mobile device

2010-11 artificial satellites plugin

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[4]`https://groups.google.com/d/topic/fr.sci.astronomie.amateur/OT7K8yogRlI/discussion`

2014-06 high quality satellites and Saturn rings shadows, normal mapping for moon craters

2014-07 v0.13.0: adapt to OpenGL evolutions in the Qt framework, now requires more modern graphic hardware than earlier versions

2015-04 v0.13.3: Scenery 3D plugin

2015-10 v0.14.0: Accurate precession

2016-07 v0.15.0: Remote Control plugin

2016-12 v0.15.1: DE430&DE431, AstroCalc, DSS layer, and Stellarium acting as SpoutSender

2017-06 v0.16.0: Remote Sync plugin, polygonal OBJ models for minor bodies, RTS2 telescope support

2017-09 v0.16.1: Standard and extended DSO catalog, new subcatalogues for DSO

2017-12 v0.17.0: Nomenclature labels for planets and moons, INDI telescope support

2018-03 v0.18.0: Multiple image surveys

2019-12 v0.19.3: ASCOM telescope support

Stellarium has been kindly supported by ESA in their Summer of Code in Space initiatives, which so far has resulted in better planetary rendering (2012), the Meteor Showers plugin (2013), the web-based remote control and an alternative solution for planetary positions based on the DE430/DE431 ephemeris (2015), the RemoteSync plugin and OBJ models (2016), and the planet nomenclature labels (2017).

This guide is based on the user guide written by Matthew Gates for version 0.10 around 2008. The guide was then ported to the Stellarium wiki and continuously updated by Barry Gerdes and Alexander Wolf up to version 0.12. Unfortunately, some new features were not properly documented in the wiki, and generally, without Barry the wiki started to fall out of sync with the actual program. In late 2015 we (Alexander and Georg) started porting the texts back to LaTeX and updated and added information where necessary, or wrote new chapters for the features which were introduced in the last years. We feel that a single book is the better format for offline reading. The PDF version of this guide has a clickable table of contents and clickable hyperlinks.

These new editions of the Guide (since V0.15) will not contain notes about using earlier versions than 0.13 or using very outdated hardware. New features are marked with a version number like 0.15.2 in the margin. Some references to previous versions may still be made for completeness, but if you are using earlier versions of Stellarium for particular reasons, please use the older guides.

2. Getting Started

2.1 System Requirements

Stellarium has been seen to run on most systems where Qt5 is available, from tiny ARM computers like the Raspberry Pi 2/3/4 or Odroid C1 to big museum installations with multiple projectors and planetaria with fish-eye projectors. The most important hardware requirement is a contemporary graphics subsystem.

2.1.1 Minimum

- Linux/Unix; Windows 7 and later; Mac OS X 10.10.0 and later
- 3D graphics capabilities which support OpenGL 3.0 and GLSL 1.3 (2008 GeForce 8xxx and later, ATI/AMD Radeon HD-2xxx and later; Intel HD graphics (Core-i 2xxx and later)) or OpenGL ES 2.0 and GLSL ES 1.0 (e.g., ARM SBCs like Raspberry Pi 2/3/4). On Windows, some older cards may be supported via ANGLE when they support DirectX10.
- Screen resolution 1024×768[1]
- 512 MB RAM
- 250 MB free on disk
- Keyboard

2.1.2 Recommended

- Linux/Unix; Windows 7 and later; Mac OS X 10.10.0 and later
- 3D graphics card which supports OpenGL 3.3 and above and GLSL1.3 and later

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[1] On Linux, an 800×600 screen can still be used by scaling the desktop e.g. to 1200×900:

```
xrandr --output HDMI-1 --scale 1.5x1.5
```

To reset after running Stellarium, run

```
xrandr --output HDMI-1 --scale 1x1
```

- FullHD (1920×1080 or 1920×1200) screen.[2]
- 1 GB RAM or more
- 1.5 GB free on disk (About 3GB extra required for the optional DE430/DE431 files).
- Keyboard and mouse or equivalent device (e.g. touchpad)
- A dark room for realistic rendering — details like the Milky Way, Zodiacal Light or star twinkling can't be seen in a bright room.

2.2 Downloading

Download the correct package for your operating system directly from the main page, `https://stellarium.org`. An archive of all available versions is available at `https://github.com/Stellarium/stellarium/releases`.

2.3 Installation

2.3.1 Windows

1. Double click on the installer file you downloaded:
   - `stellarium-0.20.1-win64.exe` for 64-bit Windows 7 and later.
   - `stellarium-0.20.1-win32.exe` for 32-bit Windows 7 and later.
2. Follow the on-screen instructions.

2.3.2 OS X

1. Locate the `Stellarium-0.20.1.dmg` file in Finder and double click on it or open it using the Disk Utility application. Now, a new disk appears on your desktop and Stellarium is in it.
2. Open the new disk and please take a moment to read the `ReadMe` file. Then drag `Stellarium` to the Applications folder.
3. Note: You should copy Stellarium to the Applications folder before running it — some users have reported problems running it directly from the disk image (`.dmg`).

2.3.3 Linux

Check if your distribution has a package for Stellarium already — if so you're probably best off using it. If not, you can download and build the source.

For Ubuntu we provide a package repository with the latest stable releases. Open a terminal and type:

```
sudo add-apt-repository ppa:stellarium/stellarium-releases
sudo apt-get update
sudo apt-get install stellarium
```

You can also download and run our AppImage package for 64-bit linuxes (we do not provide an AppImage for old 32-bit systems): `Stellarium-0.20.1-x86_64.AppImage`. To avoid possible conflicts due to architectural features of AppImage, please remove the stellarium package which you have installed from the repository.

Raspberry Pi 2/3/4

These tiny ARM-based computers are very popular for small and energy-efficient applications like controlling push-to Dobsonians. Stellarium requires Mesa 17 or later, available in the current Raspbian OS. To set up a Raspberry Pi 2 or 3 with Raspbian Buster for use with Stellarium, activate

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[2]HiDPI screens may work, but show occasional platform-dependent issues.

the OpenGL driver in **raspi-config**. The latest Raspberry Pi 4 comes with this driver by default and can even drive two HiDPI screens.

You must build Stellarium from sources. Please follow instructions from the wiki[3].

For Ubuntu 16.04 LTS, follow instructions[4].

Note that as of December 2019 the 3D planets do not work on Raspberry Pi 2/3, and DSS or HiPS surveys seem to cause issues after a while.

2.4 Running Stellarium

2.4.1 Windows

The Stellarium installer creates a whole list of items in the **Start Menu** under the **Programs/Stellarium** section. The list evolves over time, not all entries listed here may be installed on your system. Select one of these to run Stellarium:

Stellarium OpenGL version. This is the most efficient for modern PCs and should be used when you have installed appropriate OpenGL drivers. Note that some graphics cards are "blacklisted" by Qt to immediately run via ANGLE (Direct3D), you cannot force OpenGL in this case. This should not bother you.

Stellarium (ANGLE mode) Uses Direct3D translation of the OpenGL rendering via ANGLE library. Forces Direct3D version 9.

Stellarium (MESA mode) Uses software rendering via MESA library. This should work on any PC without dedicated graphics card.

On startup, a diagnostic check is performed to test whether the graphics hardware is capable of running. If all is fine, you will see nothing of it. Else you may see an error panel informing you that your computer is not capable of running Stellarium ("No OpenGL 2 found"), or a warning that there is only OpenGL 2.1 support. The latter means you will be able to see some graphics, but depending on the type of issue you will have some bad graphics. For example, on an Intel GMA4500 there is only a minor issue in Night Mode, while on other systems we had reports of missing planets or even crashes as soon as a planet comes into view. If you see this, try running in Direct3D 9 or MESA mode, or upgrade your system. The warning, once ignored, will not show again.

When you have found a mode that works on your system, you can delete the other links.

2.4.2 OS X

Double click on the *Stellarium* application. Add it to your **Dock** for quick access.

2.4.3 Linux

If your distribution had a package you'll probably already have an item in the GNOME or KDE application menus. If not, just open a terminal and type `stellarium`.

2.5 Troubleshooting

Stellarium writes startup and other diagnostic messages into a logfile. Please see section 5.3 where this file is located on your system. This file is *essential* in case when you feel you need to report a problem with your system which has not been found before.

If you don't succeed in running Stellarium, please see the online forum[5]. It includes FAQ

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[3]`https://github.com/Stellarium/stellarium/wiki/Raspberry-Pi`

[4]`https://ubuntu-mate.community/t/tutorial-activate-opengl-driver-for-ubuntu-mate-16-04/7094`

[5]`https://github.com/Stellarium/stellarium`

(Frequently Asked Questions, also Frequently Answered Questions) and a general question section which may include further hints. Please make sure you have read and understood the FAQ before asking the same questions again.

3. A First Tour

Figure 3.1: Stellarium main view. (Combination of day and night views.)

When Stellarium first starts, we see a green meadow under a sky. Depending on the time of day, it is either a day or night scene. If you are connected to the Internet, an automatic lookup will attempt to detect your approximate position.[1]

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[1]See section 4.2 if you want to switch this off.

At the bottom left of the screen, you can see the status bar. This shows the current observer location, vertical field of view (FOV), graphics performance in frames per second (FPS) and the current simulation date and time. If you move the mouse over the status bar, it will move up to reveal a tool bar which gives quick control over the program.

The rest of the view is devoted to rendering a realistic scene including a panoramic landscape and the sky. If the simulation time and observer location are such that it is night time, you will see stars, planets and the moon in the sky, all in the correct positions.

You can drag with the mouse on the sky to look around or use the cursor keys. You can zoom with the mouse wheel or the $\boxed{\text{Page}\uparrow}$ or $\boxed{\text{Page}\downarrow}$ keys.

Much of Stellarium can be controlled very intuitively with the mouse. Many settings can additionally be switched with shortcut keys (hotkeys). Advanced users will learn to use these shortcut keys. Sometimes a key combination will be used. For example, you can quit Stellarium by pressing $\boxed{\text{Ctrl}}$+$\boxed{\text{Q}}$ on Windows and Linux, and $\boxed{\text{⌘}}$+$\boxed{\text{Q}}$ on Mac OS X. For simplicity, we will show only the Windows/Linux version. We will present the default hotkeys in this guide. However, almost all hotkeys can be reconfigured to match your taste. Note that some listed shortkeys are only available as key combinations on international keyboard layouts, e.g., keys which require pressing $\boxed{\text{AltGr}}$ on a German keyboard. These must be reconfigured, please see 4.8 for details.

The way Stellarium is shown on the screen is primarily governed by the menus. These are accessed by dragging the mouse to the left or bottom edge of the screen, where the menus will slide out. In case you want to see the menu bars permanently, you can press the small buttons right in the lower left corner to keep them visible.

3.1 Time Travel

When Stellarium starts up, it sets its clock to the same time and date as the system clock. However, Stellarium's clock is not fixed to the same time and date as the system clock, or indeed to the same speed. We may tell Stellarium to change how fast time should pass, and even make time go backwards! So the first thing we shall do is to travel into the future! Let's take a look at the time control buttons on the right hand ride of the tool-bar. If you hover the mouse cursor over the buttons, a short description of the button's purpose and keyboard shortcut will appear.

Button	*Shortcut key*	*Description*
◀◀	$\boxed{\text{J}}$	Decrease the rate at which time passes
▶	$\boxed{\text{K}}$	Make time pass as normal
▶▶	$\boxed{\text{L}}$	Increase the rate at which time passes
⧖	$\boxed{8}$	Return to the current time & date

Table 3.1: Time Travel

OK, so lets go see the future! Click the mouse once on the increase time speed button $\boxed{\text{▶▶}}$. Not a whole lot seems to happen. However, take a look at the clock in the status bar. You should see the time going by faster than a normal clock! Click the button a second time. Now the time is going by faster than before. If it's night time, you might also notice that the stars have started to

move slightly across the sky. If it's daytime you might be able to see the sun moving (but it's less apparent than the movement of the stars). Increase the rate at which time passes again by clicking on the button a third time. Now time is really flying!

Let time move on at this fast speed for a little while. Notice how the stars move across the sky. If you wait a little while, you'll see the Sun rising and setting. It's a bit like a time-lapse movie.

Stellarium not only allows for moving forward through time – you can go backwards too! Click on the real time speed button ▶ . The stars and/or the Sun should stop scooting across the sky.

Now press the decrease time speed button ◀◀ once. Look at the clock. Time has stopped. Click the decrease time speed button four or five more times. Now we're falling back through time at quite a rate (about one day every ten seconds!).

Time Dragging, Time Scrolling

Another way to quickly change time is *time dragging*. Press Ctrl and slide the mouse along the direction of daily motion to go forward, or to the other direction to go backward.   v0.15.1

Similarly, pressing Ctrl and scrolling the mouse wheel will advance time by minutes, pressing Ctrl + ⇧ and scrolling the mouse wheel will advance time by hours, Ctrl + Alt by days, and finally Ctrl + ⇧ + Alt by calendar years.

Enough time travel for now. Wait until it's night time, and then click the real time speed button ▶ . With a little luck you will now be looking at the night sky.

3.2   Moving Around the Sky

Key	Description
Cursor keys ← → ↑ ↓	Pan the view left, right, up and down
Page↑/Page↓, Ctrl + ↑ /Ctrl + ↓	Zoom in and out
Left mouse button	Select an object in the sky
Right mouse button	Clear selected object
Centre mouse button (wheel press)	Centre selected object and start tracking
Mouse wheel	Zoom in and out
⎵	Centre view on selected object
Forward-slash (/)	Auto-zoom in to selected object
Backslash (\ )	Auto-zoom out to original field of view

Table 3.2: Moving Around the Sky

As well as travelling through time, Stellarium lets to look around the sky freely, and zoom in and out. There are several ways to accomplish this listed in table 3.2.

Let's try it. Use the cursors to move around left, right, up and down. Zoom in a little using the Page↑ key, and back out again using the Page↓. Press the \ key and see how Stellarium returns to the original field of view (how "zoomed in" the view is), and direction of view.

If you prefer stepwise zooming to fixed values for field of view, table 3.3 lists the keys to reach a certain field of view.

Most users prefer to move around using the mouse. If you left-click and drag somewhere on the sky, you can pull the view around.

Hotkey	*Field of view*	*Hotkey*	*Field of view*
Ctrl + Alt + 1	180°	Ctrl + Alt + 6	10°
Ctrl + Alt + 2	90°	Ctrl + Alt + 7	5°
Ctrl + Alt + 3	60°	Ctrl + Alt + 8	2°
Ctrl + Alt + 4	45°	Ctrl + Alt + 9	1°
Ctrl + Alt + 5	20°	Ctrl + Alt + 0	0.5°

Table 3.3: Hotkeys to set fixed vertical fields of view

Another method of moving is to select some object in the sky (left-click on the object), and press the Space key to centre the view on that object. Similarly, selecting an object and pressing the forward-slash key / will centre on the object and zoom right in on it.

The forward-slash / and backslash \ keys auto-zoom in an out to different zoom levels depending on what is selected. If the object selected is a planet or moon in a *sub-system* with a lot of moons (e.g. Jupiter), the initial zoom in will go to an intermediate level where the whole sub-system should be visible. A second zoom will go to the full zoom level on the selected object. Similarly, if you are fully zoomed in on a moon of Jupiter, the first auto-zoom out will go to the sub-system zoom level. Subsequent auto-zoom out will fully zoom out and return the initial direction of view. For objects that are not part of a sub-system, the initial auto-zoom in will zoom right in on the selected object (the exact field of view depending on the size/type of the selected object), and the initial auto-zoom out will return to the initial FOV and direction of view.

If you have a touch screen, you can even use one finger directly to drag the sky around and select objects, and two fingers to zoom. The support for touch screens is incomplete though, and more advanced use of the program requires the classical operation with keyboard and mouse.

3.3   The Main Tool Bar

Stellarium can do a whole lot more than just draw the stars. Figure 3.2 shows some of Stellarium's visual effects including constellation line and boundary drawing, constellation art, planet hints, and atmospheric halo around the bright Moon. The controls in the main tool bar provide a mechanism for turning on and off the visual effects.

When the mouse if moved to the bottom left of the screen, a second tool bar becomes visible. All the buttons in this side tool bar open and close dialog boxes which contain controls for further configuration of the program. The dialogs will be described in the next chapter.

Table 3.4 describes the operations of buttons on the main tool bar and the side tool bar, and gives their default keyboard shortcuts.
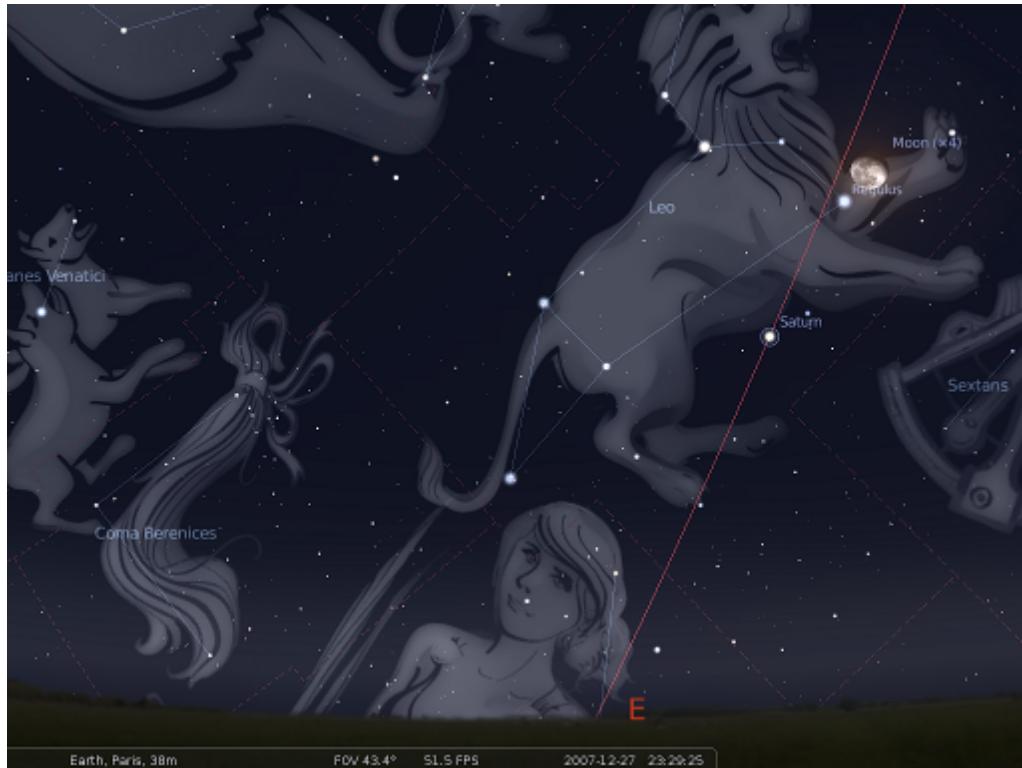
Figure 3.2: Night scene with constellation artwork and moon.

Feature	Button	Hotkey	Description
Constellations		C	Draw constellations as "stick figures"
Constellation Names		V	Draw name of the constellations
Constellation Art		R	Superimpose artistic representations of the constellations
Constellation Boundaries		B	Draw boundaries of the constellations[1]
Equatorial Grid		E	Draw grid lines for the equatorial coordinate system (RA/Dec)
Azimuth Grid		Z	Draw grid lines for the horizontal coordinate system (Alt/Azi)
Galactic Grid			Draw grid lines for the galactic coordinate system (Long/Lat)[1]
Equatorial J2000 Grid			Draw grid lines for the equatorial coordinate system at standard epoch J2000.0 (RA/Dec) [1]
Ecliptic Grid			Draw grid lines for the ecliptic coordinate system of date (Long/Lat)[1]

Toggle Ground		G	Toggle drawing of the ground. Turn this off to see objects that are below the horizon.
Toggle Cardinal Points		Q	Toggle marking of the North, South, East and West points on the horizon.
Toggle Atmosphere		A	Toggle atmospheric effects. Most notably makes the stars visible in the daytime.
Deep-Sky Objects		D	Toggle marking the positions of Deep-Sky Objects.
Planet Hints		P	Toggle indicators to show the position of planets.
Nebula images		I	Toggle "nebula images".[1]
Digitized Sky Survey			Toggle "Digitized Sky Survey" (TOAST).[1]
Hierarchical Progressive Surveys		Ctrl + Alt + D	Toggle "Hierarchical Progressive Surveys".[1]
Coordinate System		Ctrl + M	Toggle between horizontal (Alt/Azi) & equatorial (RA/Dec) coordinate systems.
Center			Center the view on the selected object
Night Mode		Ctrl + N	Toggle "night mode", which applies a red-only filter to the view to be easier on the dark-adapted eye.
Full Screen Mode		F11	Toggle full screen mode.
Bookmarks		Alt + B	Toggle bookmarks window.[1]
Flip view (horizontal)		Ctrl + ⇧ + H	Flip the image in the horizontal plane.[1]
Flip view (vertical)		Ctrl + ⇧ + V	Flip the image in the vertical plane.[1]
Quit Stellarium		Ctrl + Q	Close Stellarium.
Help Window		F1	Show the help window, with key bindings and other useful information
Configuration Window		F2	Show the configuration window
Search Window		F3 or Ctrl + F	Show the object search window
View Window		F4	Show the view window

Time Window	⊘	F5	Show the time window
Location Window	✴	F6	Show the observer location window (map)
AstroCalc Window	◉	F10	Show the astronomical calculations window

Table 3.4: Stellarium's standard menu buttons. Those marked [1] must be enabled first, see section 4.3.5.

3.4 Taking Screenshots

You can save what is on the screen to a file by pressing `Ctrl` + `S`. Screenshots are taken in PNG format, and have filenames like `stellarium-000.png`, `stellarium-001.png` (the number increments to prevent overwriting existing files).

The screenshots are stored to a directory depending on your operating system, see section 5.1 Files and Directories. See also section 4.3.5 for more screenshot options.

3.5 Bookmarks

You can store your favourite objects or views with a bookmark. Press `Alt` + `B` or ★ . If date and/or location are relevant, make sure you activate the respective buttons.
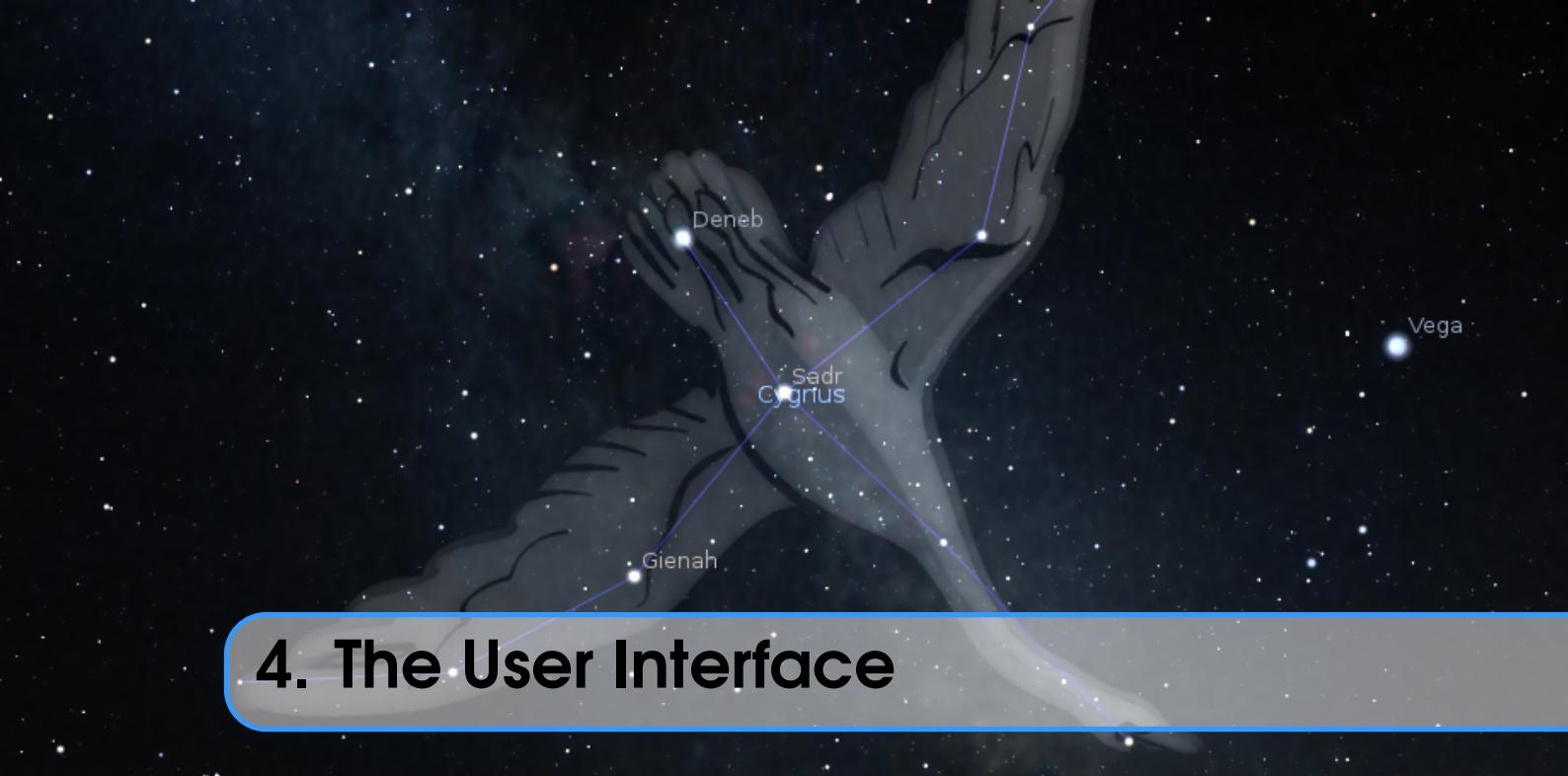
3.6 Custom Markers

You can set temporary markers anywhere in the screen. These may be useful for various purposes but cannot be stored.

Actions	*Description*
`Shift` & left click	Add custom marker
`Shift` & right click	Delete the one closest marker to mouse cursor
`Alt` + `⇧` & right click	Delete all custom markers

3.7 Copy Information

If you have selected an object and want to use the displayed information elsewhere, you may want to copy it to the system clipboard with `Ctrl` + `⇧` + `C`. However, note that the numerical accuracy of Stellarium is still not perfect, so that you should not attempt to create some high-precision almanach based on its numbers. See F for known limitations.

4. The User Interface

This chapter describes the dialog windows which can be accessed from the left menu bar.

Most of Stellarium's settings can be changed using the view window (press [icon] or F4) and the configuration window ([icon] or F2). Most settings have short labels. To learn more about some settings, more information is available as *tooltips*, small text boxes which appear when you hover the mouse cursor over a button.[1]

You can drag the windows around, and the position will be used again when you restart Stellarium. If this would mean the window is off-screen (because you start in windowed mode, or with a different screen), the window will be moved so that at least a part is visible.

v0.15

Some options are really rarely changed and therefore may only be configured by editing the configuration file. See 5.4 The Main Configuration File for more details.

4.1 Setting the Date and Time
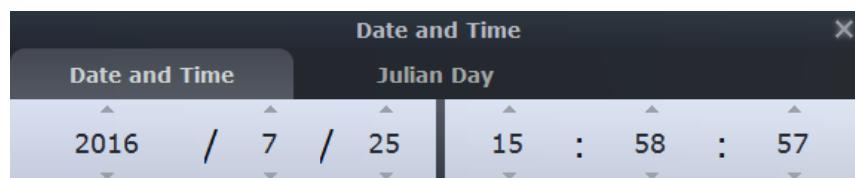
Figure 4.1: Date and Time dialog

In addition to the time rate control buttons on the main toolbar, you can use the date and time window (open with the [icon] button or F5) to set the simulation time. The values for year, month,

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[1]Unfortunately, on Windows 7 and later, with some NVidia and AMD GPUs in OpenGL mode, these tooltips often do not work.

day, hour, minutes and seconds may be modified by typing new values, by clicking the up and down arrows above and below the values, and by using the mouse wheel.

The other tab in this window allows you to see or set *Julian Day* and/or *Modified Julian Day* numbers (see 17.4.2).

4.2   Setting Your Location

Figure 4.2: Location window

The positions of the stars in the sky is dependent on your location on Earth (or other planet) as well as the time and date. For Stellarium to show accurately what is (or will be/was) in the sky, you must tell it where you are. You only need to do this once – Stellarium can save your location so you won't need to set it again until you move.

v0.13.1   After installation, Stellarium uses an online service which tries to find your approximate location based on the IP address you are using. This seems very practical, but if you feel this causes privacy issues, you may want to switch this feature off. You should also consider switching it off on a computer which does not move, to save network bandwidth.

To set your location more accurately, or if the lookup service fails, press F6 to open the location window (Fig. 4.2). There are a few ways you can set your location:

1. Just click on the map.
2. Search for a city where you live using the search edit box at the top right of the window, and select the right city from the list.
3. Click on the map to filter the list of cities in the vicinity of your click, then choose from the shortlist.
4. Enter a new location using the longitude, latitude and other data.

v0.16/0.18.1   5. Click on Get Location from GPS if you have a GPS receiver. You activate a periodic request for GPS fixes. After a few seconds, the button should change color and give a textual feedback. Green indicates a good position, yellow indicates a 2D-fix only, which means altitudes are not available. (Leave the GPS device running for a few minutes and/or search a place with better sky view.) You could leave it running if you are operating a fast-moving observatory platform, but rather switch it off when you see a good fix, so that other programs can use the

serial GPS connection. Red signals an error, and further positions are not retrieved but the
button is reset. You may press the button again to start over.

Sometimes you have to try several times or let it run for a while to get a green button
indicating a valid 3D fix including altitude. See section 5.5.4 for configuration details.

If you want to use the current location permanently, click on the "use as default" checkbox, disable
"Get location from Network", and close the location window.

4.2.1 Time Zones

Locations in Stellarium's location database include their respective time zone. When you click on v0.15.1/0.19.0
a location in the list, the time should be shown in the respective time zone. If daylight time rules
exist and you have selected "Enable daylight saving time", also this civilisatory development is
respected. Most users will want this setting active.

When you select "Use custom time zone", you can select other time zones. Those that start
with UTC have no daylight time rules.

Time zones were introduced in the 19th century, originally for purposes of railway traffic
synchronisation. The first such action was taken in 1847, and therefore Stellarium by default will
present Local Mean Solar Time (LMST) for dates before 1847, and ignore all configured time
zones unless you deliberately activate "Use custom time zone". The history of time zones and their
rules is very complicated, though, and Stellarium should not be expected to find the exact date
when time zone use was introduced at a certain location or country. Just be sure to use LMST when
replaying historical observations before the 20th century.

For even earlier observations, you can also set Local True Solar Time (LTST), which is the
time given by sundials. Here, 12 o'clock is the time when the sun transits the meridian, strictly,
daily. The difference between LMST and LTST is called *equation of time*. See section 12.3 for
more information.

When you click on the map to set your location, Stellarium has currently no way to guess the
timezone of the coordinate pair. In this case, Local Mean Solar Time is presented, which only
depends on longitude and was the "normal" time before the development of time zones. Either
select a city from the list or manually select a time zone.

4.3 The Configuration Window

The configuration window contains general program settings, and many other settings which do not
concern specific display options. Press the tool button $\boxed{\mathscr{I}^\star}$ or $\boxed{\text{F2}}$ to open.

4.3.1 The Main Tab

The Main tab in the configuration window (Fig. 4.3) provides controls for changing separately the
program and sky culture languages.

The next setting group allows to enable using DE430/DE431 ephemeris files. These files have
to be installed separately. Most users do not require this. See section 5.5.3 if you are interested.

The tab also provides the buttons for saving the current view direction as default for the next
startup, and for saving the program configuration. Most display settings have to be explicitly stored
to make a setting change permanent.

4.3.2 The Information Tab

The Information tab (Fig. 4.4) allows you to set the type and amount of information displayed about
a selected object.

- Ticking or unticking the relevant boxes will control this.
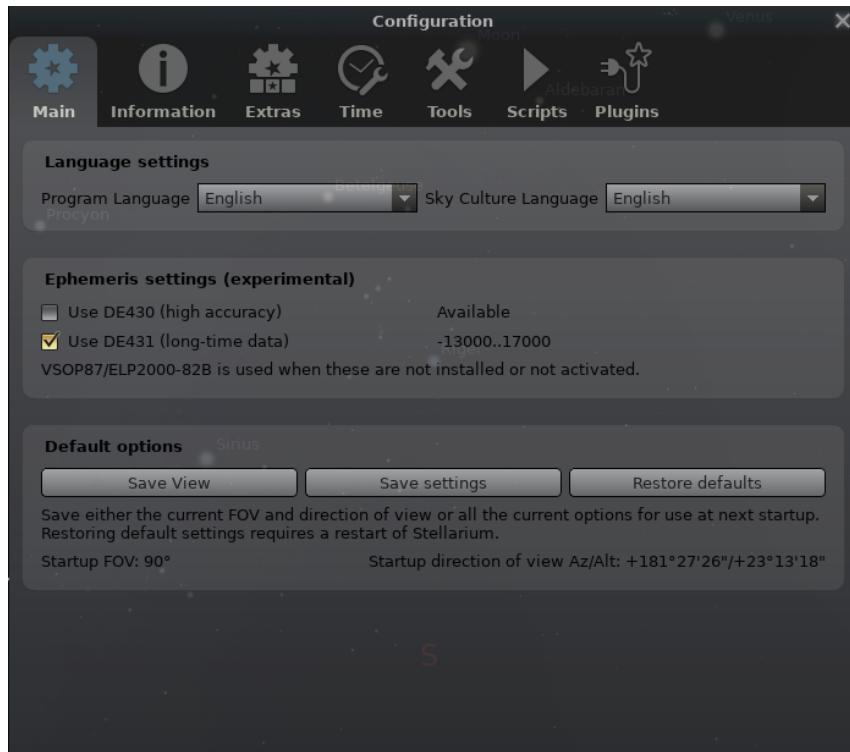
Figure 4.3: Configuration Window: Main Tab
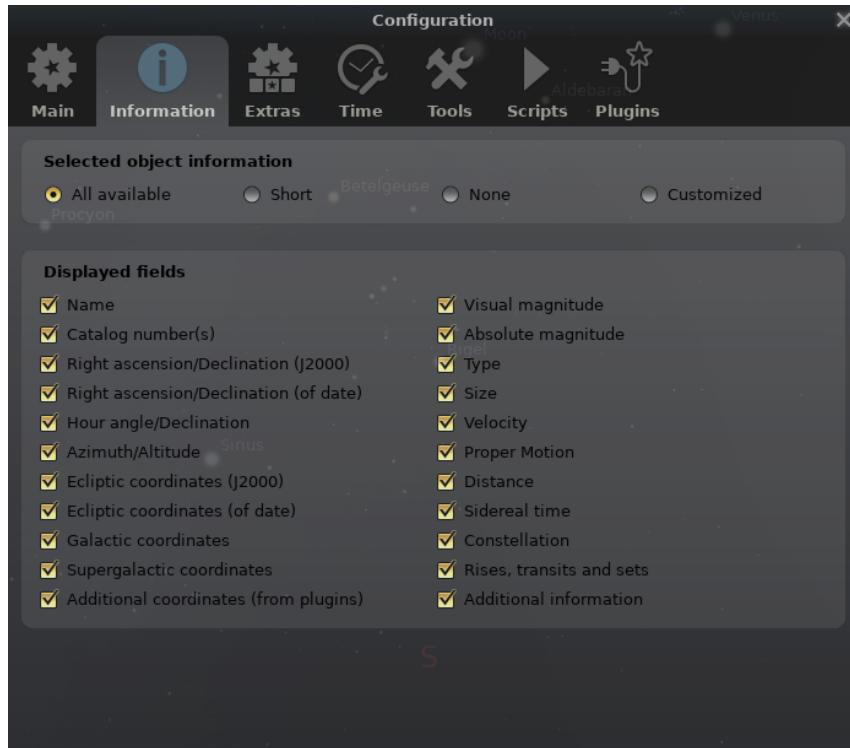
Figure 4.4: Configuration Window: Information Tab

• The information displays in various colours depending on the type and level of the stored data

4.3.3 The Extras Tab

Figure 4.5: Configuration Window: Extras Tab

The Extras tab (Fig. 4.5) allows you to customize information displayed about a selected object, download more star catalogs and also allows to hide or show additional buttons in the lower button bar.

Customization of information displays

The information display can be tweaked a bit with the options found in the GUI section "Additional information settings".

Customization of button visibility on bottom toolbar

If your screen is too narrow to show all buttons or you simply don't need them because you prefer the keyboard shortcuts, you can choose your optimal setup. The selection of buttons is stored immediately.

Show constellation boundaries button You can toggle display of constellation boundaries with this button.

Show asterism lines button You can toggle display of asterism lines with this button.

Show asterism labels button You can toggle display of asterism labels with this button.

Show ecliptic grid button You can toggle display of ecliptic coordinate grid with this button.

Show ICRS grid button You can toggle display of the International Coordinate Reference System (equatorial J2000 coordinate grid) with this button.

Show galactic grid button You can toggle display of galactic coordinate grid with this button.

Show centering button You can toggle display of the "center on selected object" button.

Show nightmode button You can toggle display of the nightmode button.

Show nebula background button You can toggle display of DSO photographs with this button.

Show flip buttons When enabled, two buttons will be added to the main tool bar which allow the main view to be mirrored in the vertical and horizontal directions. This is useful when observing through telecopes which may cause the image to be mirrored.

Show DSS button You can toggle display of Digitized Sky Survey with this button (see section 10.4).

Show HiPS button You can toggle display of Hierarchical Progressive Surveys with this button (see section 4.4.7).

Show bookmarks button You can enable display of Bookmarks dialog with this button.

Show fullscreen button You can toggle display of the fullscreen button.

Show Quit button You can toggle display of the button to quit Stellarium.

Use buttons background Applies a gray background under the buttons on the bottom bar.

Download more star catalogs

Stellarium comes with enough stars for casual stargazing with the unaided eye or binoculars. If you have a telescope and want to see more stars, here you can download more catalogs.

4.3.4 The Time Tab
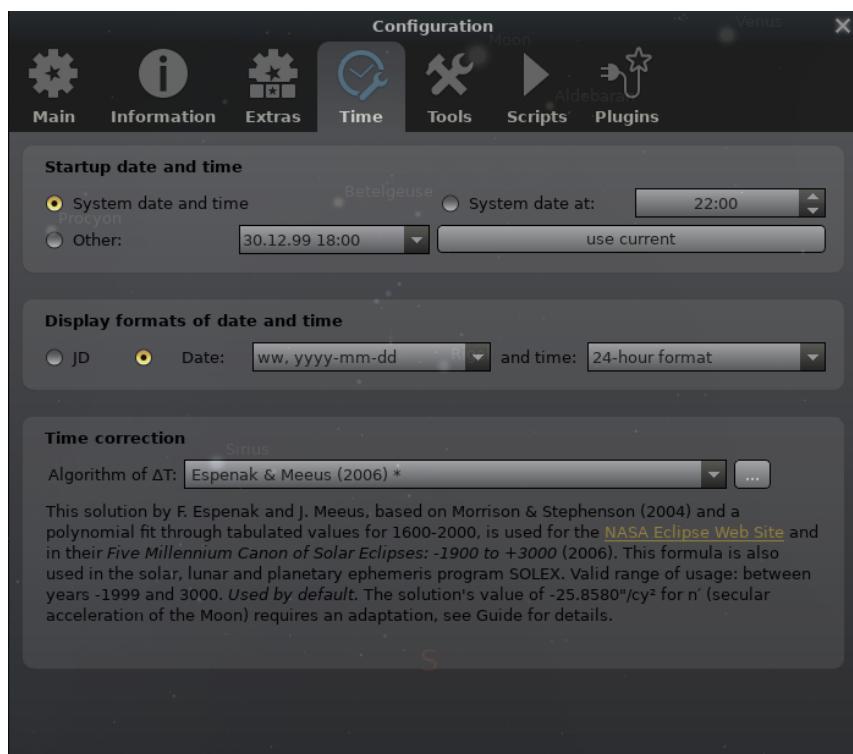
Figure 4.6: Configuration Window: Time Tab

The Time tab (Fig. 4.6) allows to specify what simulation time should be used when the program starts:

System date and time Stellarium will start with the simulation time equal to the operating system clock.

System date at Stellarium will start with the same date as the operating system clock, but the time will be fixed at the specified value. This is a useful setting for those people who use

Stellarium during the day to plan observing sessions for the upcoming evening.

Other some fixed time can be chosen which will be used every time Stellarium starts.

The middle field allows specify display formats for date and time on bottom toolbar:

JD Stellarium will display Julian Days (JD).

Date and time Stellarium will display date and time in selected format.

The lowest field allows selection of the correction model for the time correction ΔT (see section 17.4.3). Default is "Espenak and Meeus (2006)". Please use other values only if you know what you are doing.

4.3.5 The Tools Tab
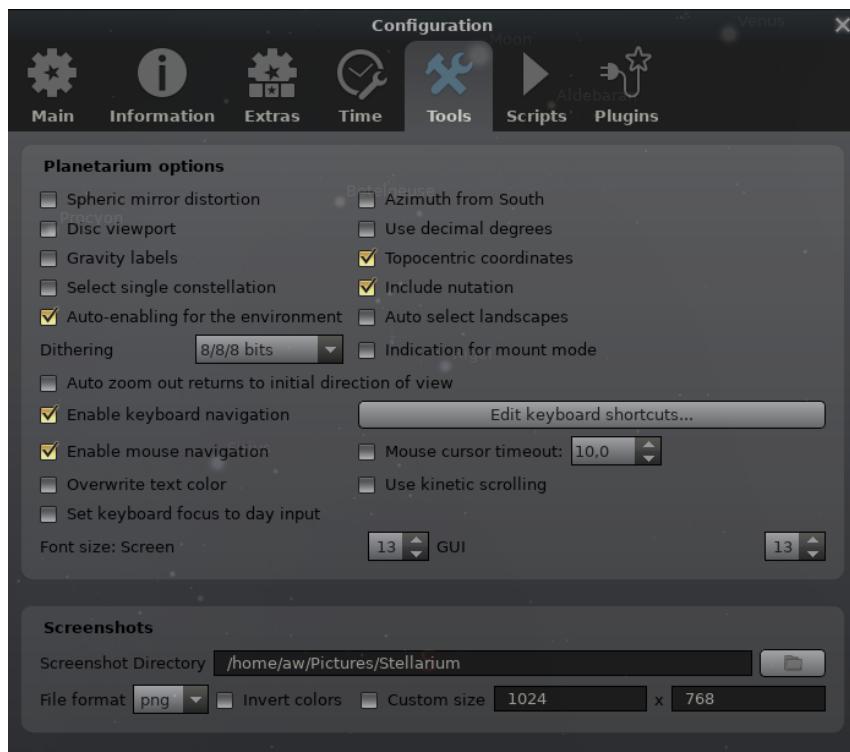
Figure 4.7: Configuration Window: Tools Tab

The Tools tab (Fig. 4.7) contains planetarium options (like enabling/disabling of keyboard shortcuts for panning and zooming the main view) and options for screenshots.

Spheric mirror distortion This option pre-warps the main view such that it may be projected onto a spherical mirror using a projector. The resulting image will be reflected up from the spherical mirror in such a way that it may shine onto a small planetarium dome (or even just the ceiling of your dining room), making a cheap planetarium projection system.

Disc viewport This option masks the main view producing the effect of a telescope eyepiece. It is also useful when projecting Stellarium's output with a fish-eye lens planetarium projector.

Gravity labels This option makes labels of objects in the main view align with the nearest horizon. This means that labels projected onto a dome are always aligned properly.

Select single constellation When active, clicking on a star that is member in the constellation lines will make the constellation stand out. See section 4.4.6 for details.

Auto-enabling for the atmosphere When changing planet during location change, atmosphere will be switched as required.

Dithering options to allow select better simulation of sky on different hardware.

Auto zoom out returns to initial direction of view When enabled, this option changes the behaviour of the zoom out key $\boxed{\backslash}$ so that it resets the initial direction of view in addition to the field of view.

Enable keyboard navigation

Enable mouse navigation

Azimuth from South Some users may be used to counting azimuth from south.

Use decimal degrees You can toggle usage of decimal degree format for coordinates.

Topocentric coordinates If you require planetocentric coordinates, you may switch this off. Usually it should be enabled. (See 17.9.1)

Include nutation Compute the slight wobble of earth's axis. This feature is active only about 500 years around J2000.0.

Auto select landscapes When changing the planet in the location panel, a fitting landscape panorama will be shown when available.

Indication for mount mode You can activate the short display of a message when switching type of used mount.

Edit keyboard shortcuts... See section 4.8.

Mouse cursor timeout You can decide whether, and when, the mouse cursor should disappear from view when not moved.

v0.18.3   **Use kinetic scrolling** Text fields in dialogs can either be moved on sidebar handles (with this switch disabled) or by dragging the text itself (enabled), as it is known from touch-enabled devices like smartphones.

v0.18.3   ## Font size and font selection

You can change the font sizes for on-screen text and GUI dialogs separately. For some purposes like presentations it may be helpful to enlarge screen font size while keeping GUI font regular, or vice versa. It also depends on your screen size whether all the object info fits on screen. This may also depend on the writing system and installed font. If you are using a non-Western character system and the default font looks bad, you can select another system font. For this, edit `config.ini` (see chapter 5.1): locate the `[gui]` section and set the key `flag_font_selection=true`. On next start of Stellarium, you will find two elements for font selection: one allows you to pre-select a writing system, the other will then allow selection of a font installed in your system that includes the characters used in the selected writing system. When you have found the best font, store your settings on the Main tab (see section 4.3.1) and you may edit `config.ini` again to disable the font selection switches.

Screenshots

v0.18.1   You can set the directory where screenshots will be stored, and also whether you want screenshots sized like Stellarium's window or some other, likely larger size. The maximum possible size depends on your hardware. 4096×4096 should be possible on most PCs, others may even create 16384×16384 images. The vertical field of view will be the same as in the current view.

v0.19.0   You can also set the file format. The exact selection depends on platform and version of the underlying Qt framework. Notable formats are PNG (lossless), JPG (lossy), JPEG (higher quality JPG), BMP (Windows Bitmap), WEBP, TIF (LZW compressed), TIFF (uncompressed), PBM, PGM, PPM, XBM, XPM, and ICO (thumbnails).

4.3.6 The Scripts Tab

The Scripts tab (Fig. 4.8) allows the selection of pre-assembled scripts bundled with Stellarium that can be run (See chapter 16 for an introduction to the scripting capabilities and language). This list can be expanded with your own scripts as required. See section 5.2 where to store your own scripts.
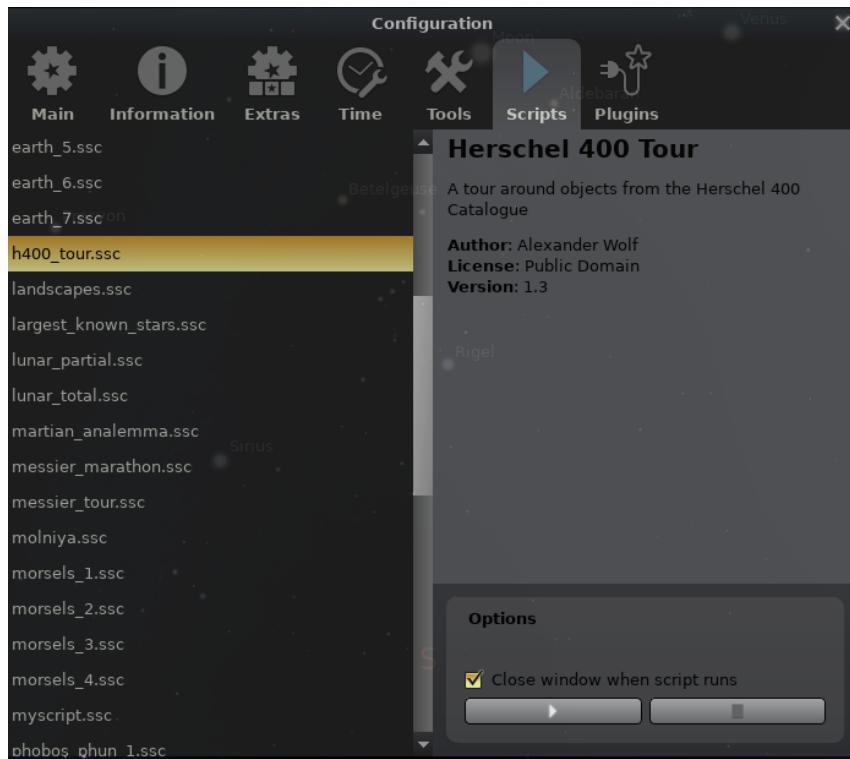
Figure 4.8: Configuration Window: Scripts Tab

When a script is selected it can be run by pressing the arrow button and stopped with the stop button. With some scripts the stop button is inhibited until the script is finished.

Scripts that use sound or embedded videos will need a version of Stellarium configured at compile time with multimedia support enabled. It must be pointed out here that sound or video codecs available depends on the sound and video capabilities of you computer platform and may not work.

4.3.7 The Plugins Tab

Plugins (see chapter 11 for an introduction) can be enabled here (Fig. 4.9) to be loaded the next time you start Stellarium. When loaded, many plugins allow additional configuration which is available by pressing the | configure | button on this tab.

4.4 The View Settings Window

The View settings window controls many display features of Stellarium which are not available via the main toolbar.

4.4.1 The Sky Tab

The Sky tab of the View window (Fig. 4.10) contains settings for changing the general appearance of the main sky view and projections. Some hightlights of sky field:

Dynamic eye adaptation When enabled this feature reduces the brightness of faint objects when a bright object is in the field of view. This simulates how the eye can be dazzled by a bright object such as the moon, making it harder to see faint stars and galaxies.

Light pollution In urban and suburban areas, the sky is brightned by terrestrial light pollution reflected in the atmophere. Stellarium simulates light pollution and is calibrated to the *Bortle*
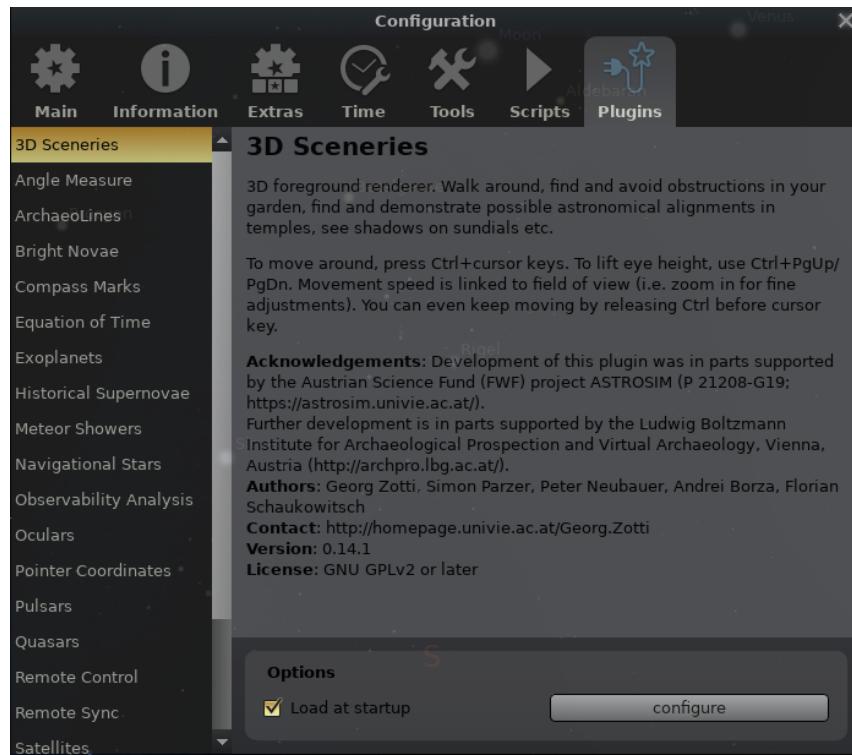
Figure 4.9: Configuration Window: Plugins Tab

Figure 4.10: View Settings Window: Sky Tab

Dark Sky Scale where 1 means a good dark sky, and 9 is a very badly light-polluted sky. See Appendix B for more information.

Some hightlights of stars field:

Absolute scale is the size of stars as rendered by Stellarium. If you increase this value, all stars will appear larger than before.

Relative scale determines the difference in size of bright stars compared to faint stars. Values higher than 1.00 will make the brightest stars appear much larger than they do in the sky. This is useful for creating star charts, or when learning the basic constellations.

Twinkle controls how much the stars twinkle when atmosphere is enabled (*scintillation*, see section 18.13.2). Since v0.15.0, the twinkling is reduced in higher altitudes, where the star light passes the atmosphere in a steeper angle and is less distorted.

Limit magnitude Inhibits automatic addition of fainter stars when zooming in. This may be helpful if you are interested in naked eye stars only.

Labels and markers you can independantly change the amount of labels displayed for stars. The further to the right the sliders are set, the more labels you will see. Note that more labels will also appear as you zoom in.

Projection field: Selecting items in this list changes the projection method which Stellarium uses to draw the sky (Snyder, 1987). Options are:

Perspective Perspective projection maps the horizon and other great circles like equator, ecliptic, hour lines, etc. into straight lines. The maximum field of view is 150°. The mathematical name for this projection method is *gnomonic projection.*

Stereographic Stereographic projection has been known since antiquity and was originally known as the planisphere projection. It preserves the angles at which curves cross each other but it does not preserve area. Else it is similar to fish-eye projection mode. The maximum field of view in this mode is 235°.

Fish-Eye Stellarium draws the sky using *azimuthal equidistant projection.* In fish-eye projection, straight lines become curves when they appear a large angular distance from the centre of the field of view (like the distortions seen with very wide angle camera lenses). This is more pronounced as the user zooms out. The maximum field of view in this mode is 180°.

Orthographic Orthographic projection is related to perspective projection, but the *point of perspective* is set to an infinite distance. The maximum field of view is 180°.

Equal Area The full name of this projection method is *Lambert azimuthal equal-area projection.* It preserves the area but not the angle. The maximum field of view is 360°.

Hammer-Aitoff The Hammer projection is an equal-area map projection, described by Ernst von Hammer (1858–1925) in 1892 and directly inspired by the Aitoff projection. The maximum field of view in this mode is 360°.

Sinusoidal The sinusoidal projection is a *pseudocylindrical equal-area map projection,* sometimes called the Sanson–Flamsteed or the Mercator equal-area projection. Meridians are mapped to sine curves.

Mercator Mercator projection is a cylindrical projection developed by Gerardus Mercator (1512–1594) which preserves the angles between objects, and the scale around an object is the same in all directions. The poles are mapped to infinity. The maximum field of view in this mode is 233°.

Miller cylindrical The Miller cylindrical projection is a modified Mercator projection, proposed by Osborn Maitland Miller (1897–1979) in 1942. The poles are no longer mapped to infinity.

Cylinder The full name of this simple projection mode is *cylindrical equidistant projection* or *Plate Carrée.* The maximum field of view in this mode is 233°.

4.4.2 The Solar System Objects (SSO) Tab

The Solar System Objects tab of the View window (Fig. 4.11) contains settings for changing the general appearance of the view of Solar system objects. Some hightlights:

Figure 4.11: View Settings Window: SSO Tab

Solar System objects this group of options lets you turn on and off various features related to the planets. Simulation of light speed will give more precise positions for planetary bodies which move rapidly against backround stars (e.g. the moons of Jupiter). The *Scale Moon* option will increase the apparent size of the moon in the sky, which can be nice for wide field of view shots.

Labels and markers you can independantly change the amount of labels displayed for Solar system objects. The further to the right the sliders are set, the more labels you will see. Note that more labels will also appear as you zoom in.

Shooting stars Stellarium has a simple meteor simulation option. This setting controls how many shooting stars will be shown. Note that shooting stars are only visible when the time rate is 1, and might not be visiable at some times of day. Meteor showers are not currently simulated.

Atmosphere settings

An auxiliary dialog contains detail settings for the atmosphere. Here you can set atmospheric pressure and temperature which influence refraction (see section 18.13.2), and the opacity factor k_v for extinction, *magnitude loss per airmass* (see section 18.13.1).

4.4.3 The Deep-Sky Objects (DSO) Tab

Deep-sky objects or DSO are extended objects which are external to the solar system, and are not point sources like stars. DSO include galaxies, planetary nebulae and star clusters. These objects may or may not have images associated with them. Stellarium comes with a catalogue of over 90,000 extended objects containing the combined data from many catalogues, with 200 images.

The DSO tab (Fig. 4.12) allows you to specify which catalogs or which object types you are interested in. This selection will also be respected in other parts of the program, most notably Search (section 4.5) and AstroCalc/WUT (section 4.6.6) will not find objects from catalogs which you have not selected here.

See chapter 8 for details about the catalog, and how to extend it with your own photographs.

Figure 4.12: View Settings Window: DSO Tab
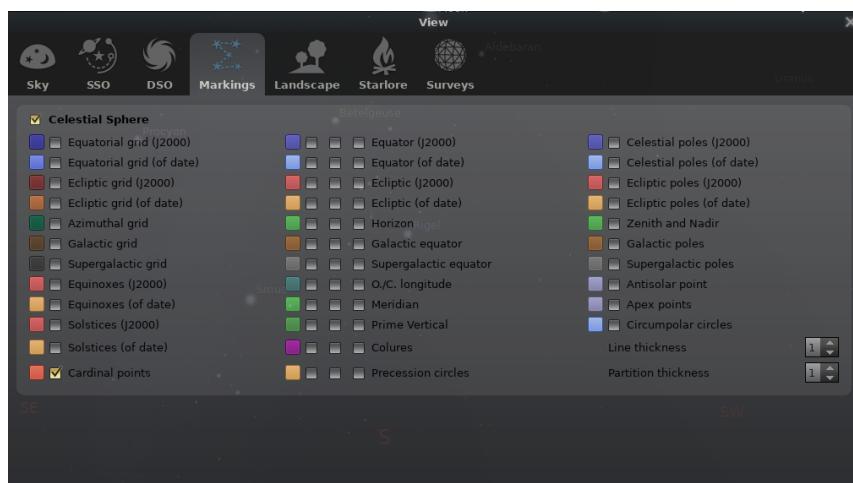
Figure 4.13: View Settings Window: Markings Tab

4.4.4 The Markings Tab

The Markings tab of the View window (Fig. 4.13) controls plot various grids and lines on celestial sphere. Colors for grids, lines and points can be adjusted by clicking on the corresponding colored square. The central column governs lines like equator, ecliptic, meridian etc., where each can optionally be fine-tuned to show partition marks and labels. Color settings are stored immediately,   v0.20.0 all other flags need an explicit saving of the settings (see section 4.3.1).

4.4.5 The Landscape Tab
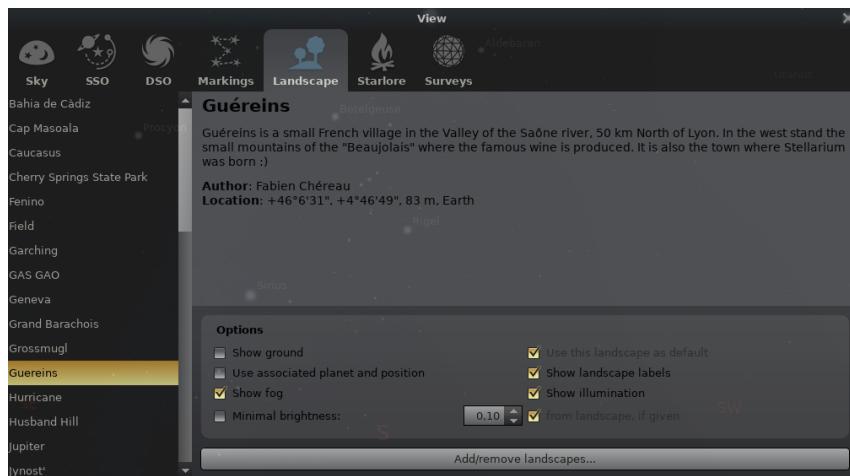
Figure 4.14: View Settings Window: Landscape Tab

The Landscape tab of the View window (Fig. 4.14) controls the landscape graphics (the horizon which surrounds you). To change the landscape graphics, select a landscape from the list on the left side of the window. A description of the landscape will be shown on the right.

Note that while a landscape can include information about where the landscape graphics were taken (planet, longitude, latitude and altitude), this location does not have to be the same as the location selected in the Location window, although you can set up Stellarium such that selection of a new landscape will alter the location for you.

The controls at the bottom right of the window operate as follows:

Show ground This turns on and off landscape rendering (same as the button [icon] in the main tool-bar).

Show_fog This turns on and off rendering of a band of fog/haze along the horizon, when available in this landscape.

Use associated planet and position When enabled, selecting a new landscape will automatically update the observer location.

Use this landscape as default Selecting this option will save the landscape into the program configuration file so that the current landscape will be the one used when Stellarium starts.

Minimal brightness Use some minimal brightness setting. Moonless night on very dark locations may appear too dark on your screen. You may want to configure some minimal brightness here.

from landscape, if given Landscape authors may decide to provide such a minimal brightness value in the landscape.ini file.

Show landscape labels Landscapes can be configured with a gazetteer of interesting points, e.g., mountain peaks, which can be labeled with this option.

Show illumination to reflect the ugly developments of our civilisation, landscapes can be config-
ured with a layer of light pollution, e.g., streetlamps, bright windows, or the sky glow of a
nearby city. This layer, if present, will be mixed in when it is dark enough.

Using the button `Add/remove landscapes…` , you can also install new landscapes from ZIP files
which you can download e.g. from the Stellarium website[2] or create yourself (see ch. 7 Landscapes),
or remove these custom landscapes.

v0.15.2   Loading large landscapes may take several seconds. If you like to switch rapidly between
several landscapes and have enough memory, you can increase the default cache size to keep more
landscapes loaded previously available in memory. Note that a large landscape can take up 200MB
or more! See section D.1.11.

4.4.6 The Starlore Tab
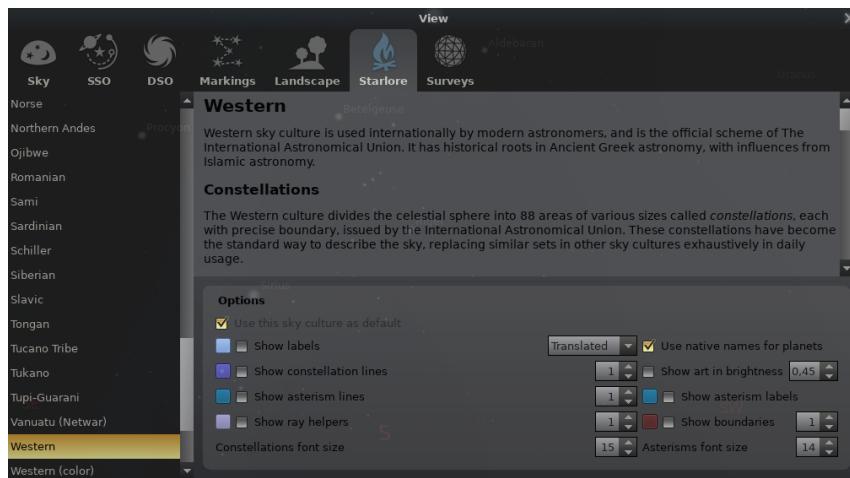
Figure 4.15: View Settings Window: Starlore Tab

The Starlore tab of the View window (Fig. 4.15) controls what culture's constellations and
bright star names will be used in the main display. Some cultures have constellation art (e.g.,
Western and Inuit), and the rest do not. Configurable options include

Use this skyculture as default Activate this option to load this skyculture when Stellarium starts.

Show labels Activate display of constellation labels, like $\boxed{\substack{\text{ }}}$ or $\boxed{V}$. You can further select
whether you want to display abbreviated, original or translated names.

Show lines with thickness… Activate display of stick figures, like $\boxed{\vphantom{N}N}$ or $\boxed{C}$, and you can
configure constellation line thickness here.

Show asterism lines… Activate display of asterism stick figures (like the shortcut $\boxed{\text{Alt}}$+$\boxed{A}$), and
v0.16.0   you can configure asterism line thickness here.

Show ray helpers… Activate display of special navigational lines which connect stars often from
different constellations (like the shortcut $\boxed{\text{Alt}}$+$\boxed{R}$), and you can configure thickness of those
v0.17.0   lines here.

Show boundaries Activate display of constellation boundaries, like $\boxed{B}$. Currently, boundaries
have been defined only for "Western" skycultures.

Use native names for planets If provided, show the planet names as used in this skyculture (also
shows modern planet name for reference).

Show art in brightness… Activate display of constellation art (if available), like $\boxed{\substack{\text{ }}}$ or $\boxed{R}$.
You can also select the brightness here.

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[2]https://stellarium.org/landscapes.html

Show asterism labels Activate display of asterism labels, like Alt + V .   v0.16.0

Select single constellations

Some presenters may want to explain a particular storyline about the constellations of a skyculture, which includes showing single constellations or showing a sequence of appearing constellations. To achieve this, first activate the single constellation mode (see section 4.7). Then, click on a star which is part of a constellation line set. Click another star which is part of another constellation to show that one.

If you explain a skyculture where constellations also have borders defined, a click anywhere in the constellation area is enough. For other skycultures, clicking onto a star which is not member of a constellation line will display all constellations.

Press W to remove all but the last selected constellation. If you had deleted selection (right mouse click) before pressing W , all constellations are hidden. Press W again to also hide the single displayed one, or click another star to select the next constellation. If you need to keep the single constellation visible, select the currently selected star again to select it again. Press Alt + W to show all constellations.

With a little training, you will be able to give inspiring constellation tours.

4.4.7   The Surveys Tab
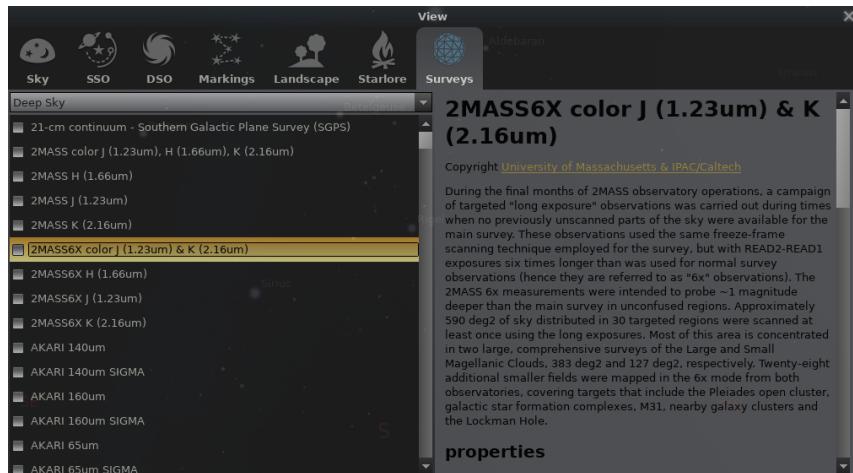
Figure 4.16: View Settings Window: Surveys Tab

The Surveys tab (Fig. 4.16) allows to toggle the visibility of online sky or solar system surveys   v0.18.0
(see chapter 10 for description of the surveys format). Currently, only HiPS surveys are supported.

On the left side of the window we see the list of available surveys from the configured sources (See section D.1.27 for how to change the default sources). On the right side a description of the selected survey and its properties are displayed.

Surveys are grouped by types. The top combobox allows to filter the listed surveys according to a given type (Deep Sky or Solar System).

You can toggle the visibility of a survey by checking the box on the left of the survey name in the list. (Note that as of v0.18.0, only a single deep sky survey can be rendered at a time, so it makes no sense to select more than one in the list!) Once a survey is visible you should be able to see its loading status in the loading bar area of the sky view.

Deep sky surveys will be rendered aligned with the sky view, while solar system surveys automatically map on the proper body.

4.5 The Object Search Window
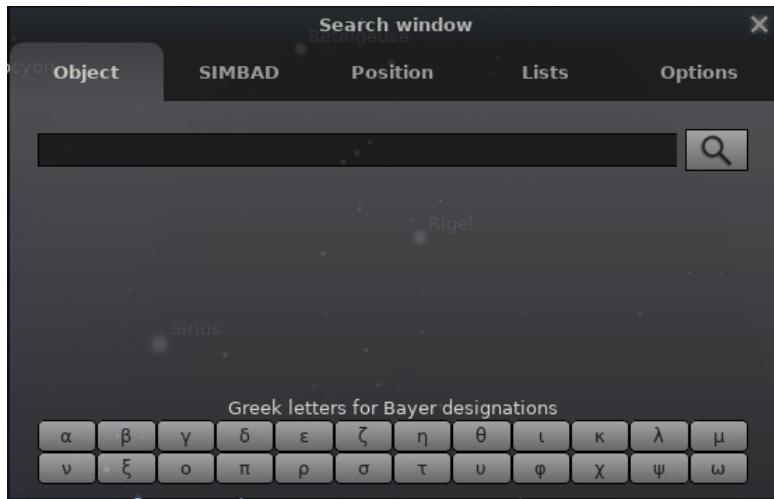
Figure 4.17: The Search Window: Objects
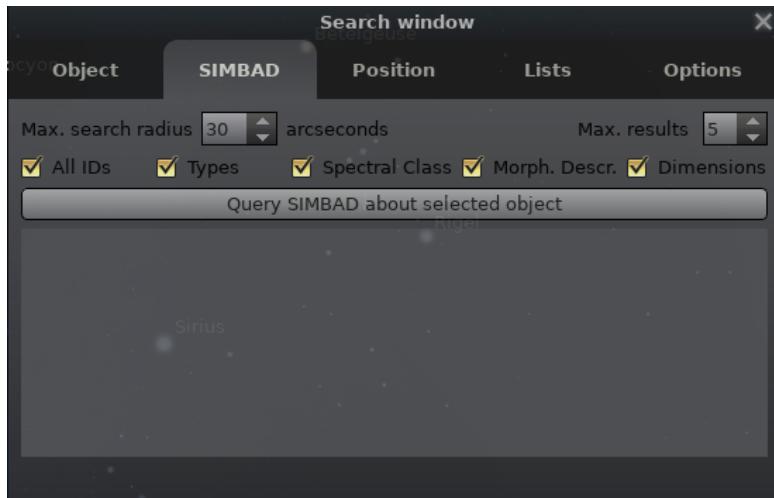
Figure 4.18: The Search Window: SIMBAD

The Object Search window provides a convenient way to locate objects in the sky. Simply type
in the name of an object to find, and press ⎆. Stellarium will point you at that object in the sky.

As you type, Stellarium will make a list of objects which contains what you have typed so far.
The first of the list of matching objects will be highlighted. If you press the ⇆ key, the selection
will change to the next item in the list. Hitting the ⎆ key will center on the currently highlighted
object and close the search dialog.

For example, suppose we want to locate Saturn's moon Mimas. Type the first letter of the name,
m, to see a list of objects whose name contains *m*: Hau*m*ea, *M*iranda, U*m*briel, . . .

You may want at this point to have Stellarium rather propose object names with start with the
string you enter. Do that in the Options tab of this panel. Now repeat searching (delete, and re-enter
m to start over). Now the list is shorter and contains only objects which start with *m*: *M*aia, *M*ars,
. . . The first item in this list, Maia, is highlighted. Pressing ⎆ now would go to Maia, but we
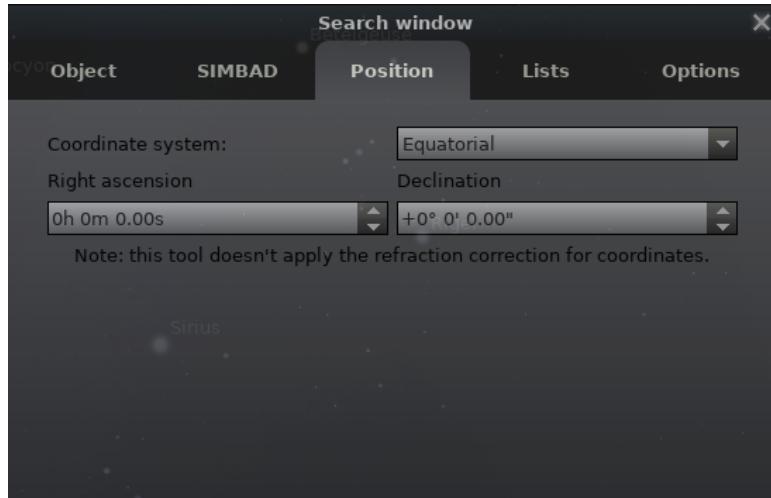
Figure 4.19: The Search Window: Positions
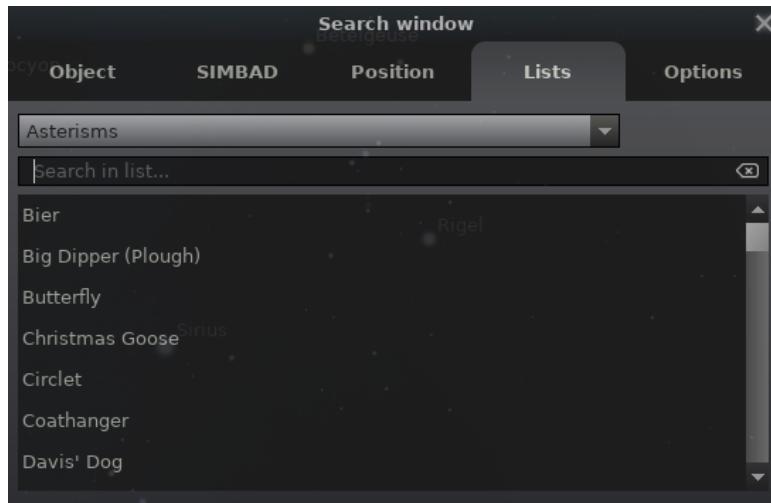
Figure 4.20: The Search Window: Lists

want Mimas. We can either press ⬚ a few times to highlight Mimas and then hit ⬚, or we can continue to type the name until it is the first/only object in the list.

The SIMBAD tab (Fig. 4.18) provides a convenient way to fetch and show a set of information for selected object from astronomical database SIMBADWenger et al., 2000.

The Position tab (Fig. 4.19) provides a convenient way to enter a set of coordinates.

The List Search tab (Fig. 4.21) allows selection of an object from predefined sets. The number of choices is governed by the loaded DSO catalogs and plug-ins. Scroll down the first window to select the type. Click on the name and Stellarium will center on that object.

The Options tab (Fig. 4.21) provides a few settings to fine-tune your search experience. When the name of an object to find is typed in the object window and you are connected to the internet and "Extend search" is ticked, Stellarium will search the SIMBAD on-line data bases for its coordinates. You can then click the ⬚ button or press return. Stellarium will point you at that object in the sky even if there is no object displayed on the screen. The SIMBAD server being used can be selected from the scroll window.
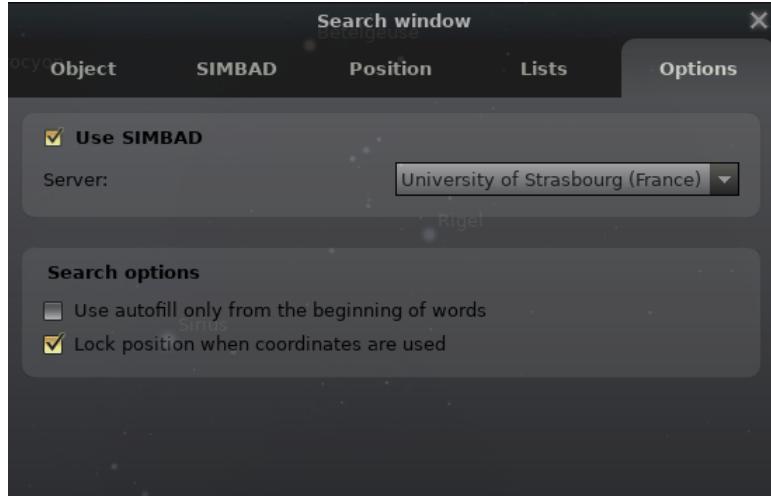
Figure 4.21: The Search Window: Options

4.6 The Astronomical Calculations Window

v0.15.0   This window provides advanced functionality, some of which is still in an experimental phase. You

can call it by pressing F10 or the button [⚬] on the left menu bar. The Astronomical Calculations window shows six tabs with different functionality.

v0.18.3   In version 0.18.3 we added exporting the data to XLSX files in addition to CSV files.

4.6.1 The Positions Tab

v0.16.0   This tab shows J2000.0 or horizontal positions, magnitudes and additional parameters (e.g. surface brightness for deep-sky objects or angular separation for double stars) for various lists of celestial objects above the horizon at the simulated time, filtered by magnitude. Double-clicking on an entry brings the object into focus (Fig. 4.22). You may also export the list of positions into an XLSX or CSV file.

Figure 4.22: Astronomical Calculations (AstroCalc): Celestial positions

Figure 4.23: Astronomical Calculations (AstroCalc): Plot trace of planet
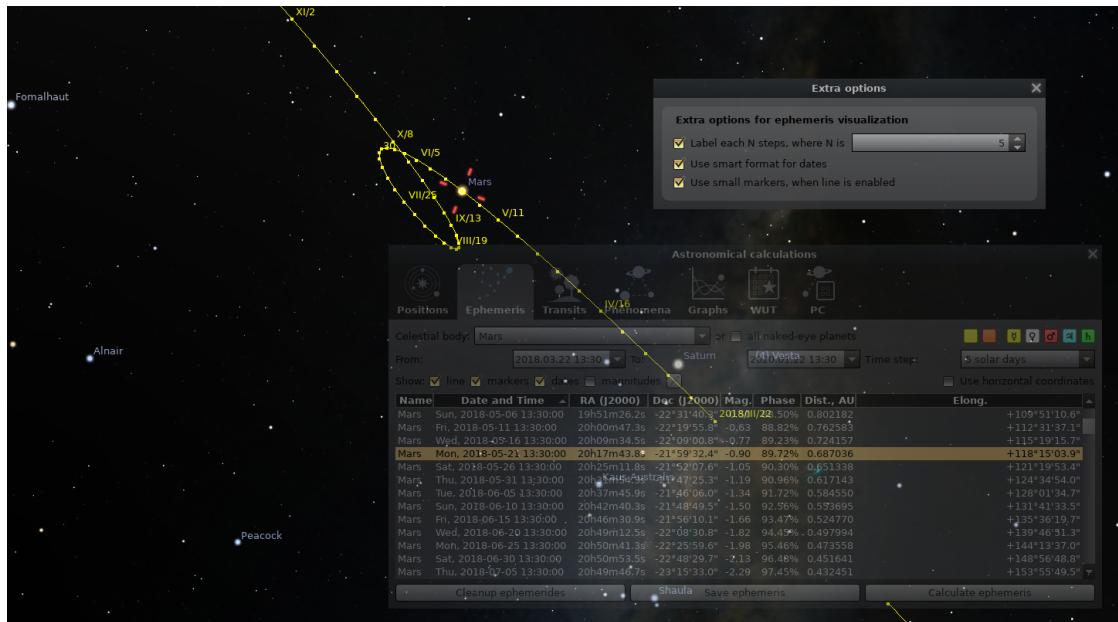
Figure 4.24: Astronomical Calculations (AstroCalc): Extra options for ephemeris

4.6.2 The Ephemeris Tab

Select an object, start and end time, and compute an ephemeris (list of positions and magnitudes evolving over time) for that object. The positions are marked in the sky with yellow disks (Fig. 4.23).

When you click on a date, an orange disk indicates this date and/or magnitude. Double-clicking sets the respective date and brings the object to focus. Dates and/or magnitudes will show near position markers when *Show dates* and/or *Show magnitudes* checkboxes are active. To show a line between markers please tick checkbox *Show line*. You may customize the format of displayed data near markers and their frequency in *Extra options* window (Fig. 4.24).

v0.19.2

You can export the calculated ephemeris into an XLSX or CSV file.

Another interesting option in this tool: using horizontal coordinates for plotting traces of the

Figure 4.25: Astronomical Calculations (AstroCalc): Analemma on the Earth

Solar system objects. In this mode, the circle marks are not linked to the sky, but to the horizontal coordinate system. For example, you can get an analemma of the Sun for any location (Fig. 4.25 and 4.26), or observe the visibility of Mercury, Venus or a comet in the twilight sky.

v0.19.2   Since version 0.19.2 you may define the color of markers and enable display markers for all naked-eye visible planets.

4.6.3 The Transits Tab

v0.19.3   This tab allows you to compute transits of selected celestial object (except unnamed stars and artificial satellites) for specific date range. The tool is proposed for planning observations and he suggest the best time and conditions for visual observations or astrophotography (Fig. 4.27).

You may also export the list of transits into an XLSX or CSV file.
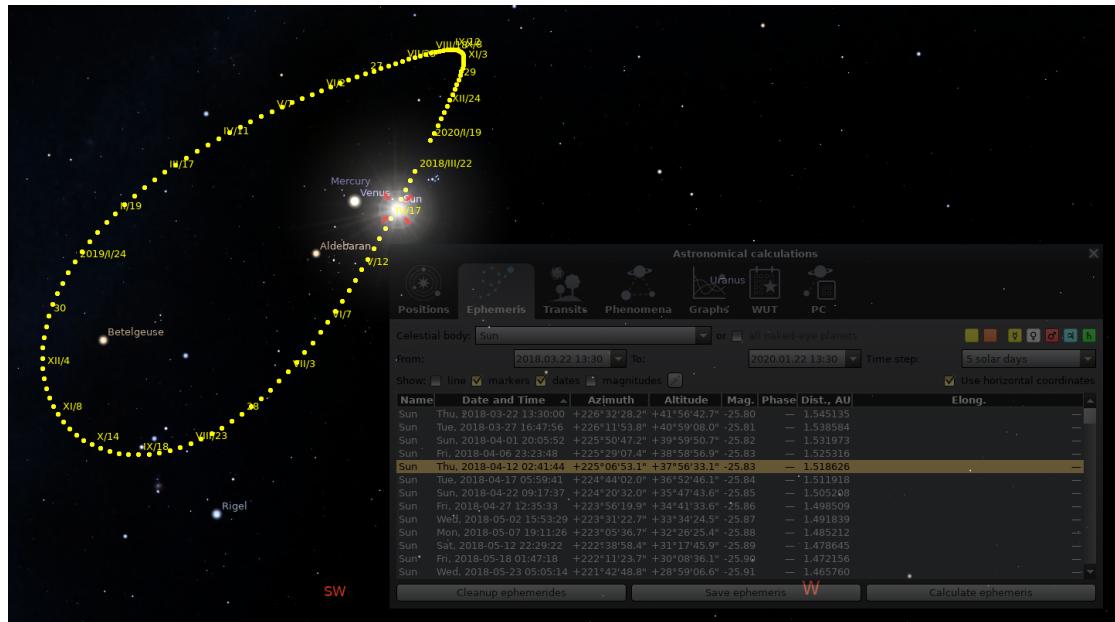
Figure 4.26: Astronomical Calculations (AstroCalc): Analemma on Mars
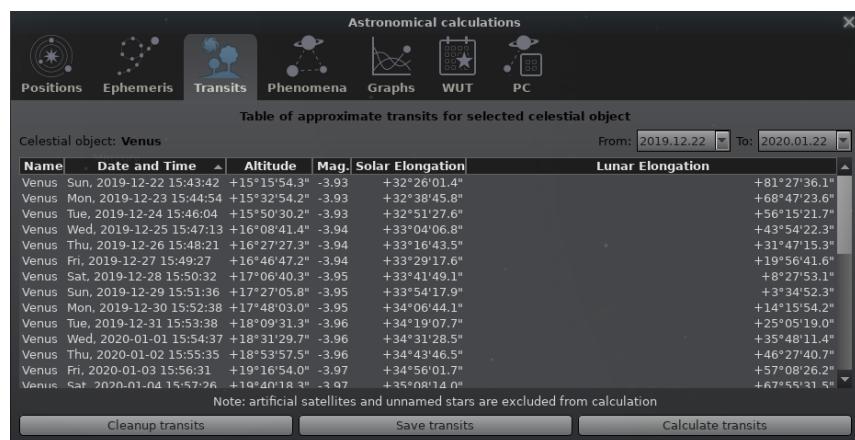
Figure 4.27: Astronomical Calculations (AstroCalc): Transits of selected celestial object

4.6.4 The Phenomena Tab

v0.19.3
This tab allows you to compute phenomena like conjunctions, oppositions, occultations and eclipses (in special cases) between planetary objects (Fig. 4.28). In version 0.19.3 we added computation greatest elongations for inner planets and stationary points for all planets in additional to exist phenomena. For all Solar system bodies, except the moons, we also propose compute perihelion and aphelion in addition to other phenomena.

You can export the calculated phenomena into an XLSX or CSV file.
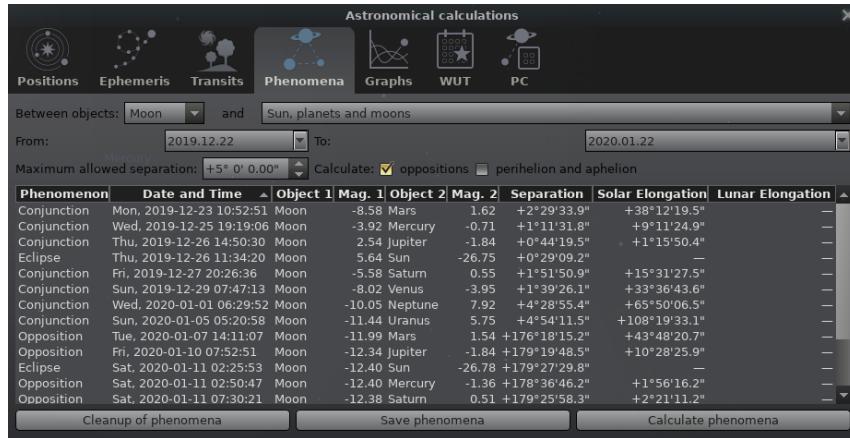
Figure 4.28: Astronomical Calculations (AstroCalc): Phenomena

Four columns in the table may be helpful for planning observation of phenomena:

v0.18.2/.3 **solar elongation** angular distance from the Sun

v0.18.2/.3 **lunar elongation** angular distance from the Moon

v0.19.3 **mag. 1** magnitude of first object

v0.19.3 **mag. 2** magnitude of second object

4.6.5 The Graphs Tab

v0.18.3
v0.19.0
This tab provides on several sub-tabs graphs which are helpful for monthly observation planning of deep-sky objects and analysis of changes between objects or changes of their positions.

The "Altitude vs. Time" Subtab

On this subtab (the first subtab and default view in the Graphs tab) you can compute the geometrical altitude of the currently selected object on the currently set date and draw it as a graph (Fig. 4.29).

Optional graphs for the Sun (with lines for civil, nautical and astronomical twilight) and the Moon (dashed) are also available.

The "Azimuth vs. Time" Subtab

v0.19.1
On this subtab you can compute the geometrical azimuth of the currently selected object on the currently set date and draw it as a graph (Fig. 4.30).

The "Monthly Elevation" Subtab

v0.18.0
This subtab can show a "Monthly Elevation" graph for the current year at the selected time. This tool was introduced for planning yearly observations (Fig. 4.31).

The "Graphs" Subtab

v0.16.0
v0.19.3
This subtab can show two functions over time for the current year or for up to 30 years and draw graphs for them in one screen (Fig. 4.32). You can select from
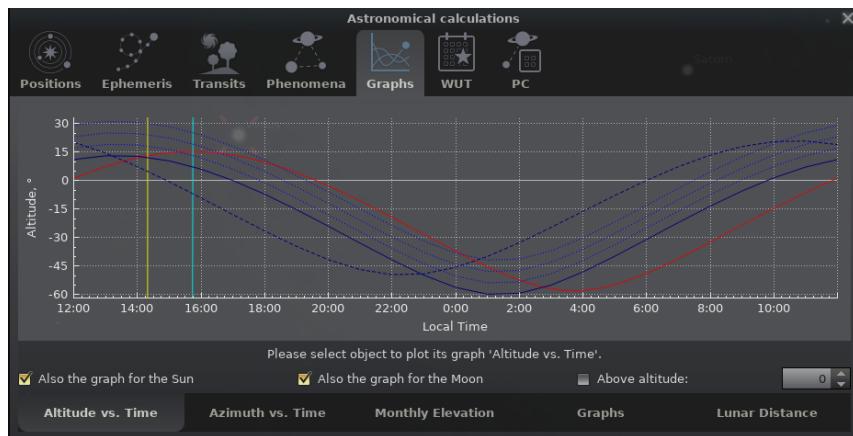
Figure 4.29: Astronomical Calculations (AstroCalc): Graphs / Altitude vs. Time
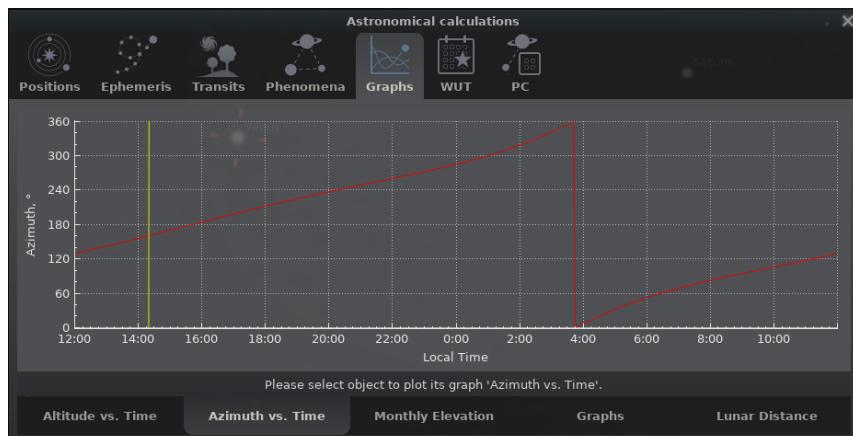
Figure 4.30: Astronomical Calculations (AstroCalc): Graphs / Azimuth vs. Time
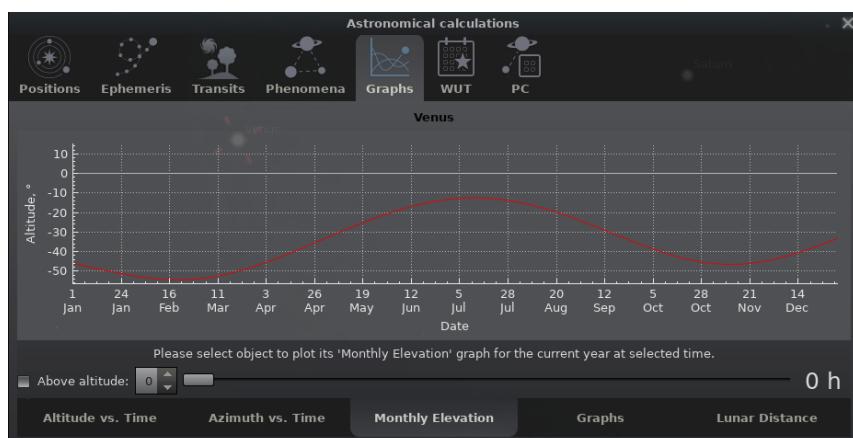
Figure 4.31: Astronomical Calculations (AstroCalc): Graphs / Monthly Elevation
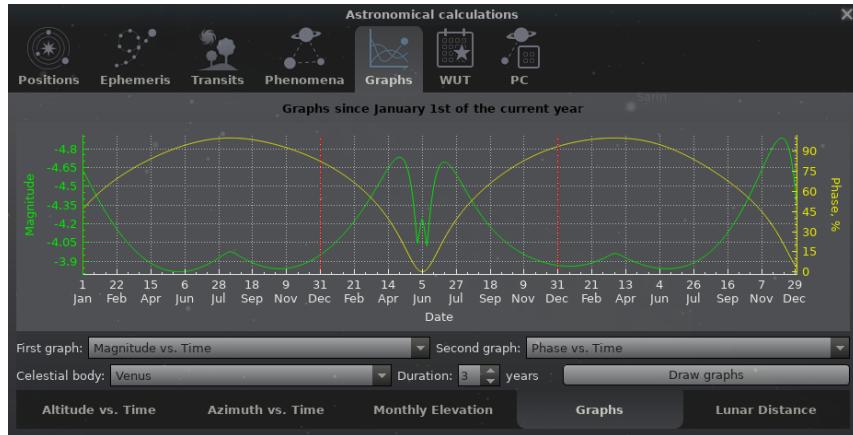
Figure 4.32: Astronomical Calculations (AstroCalc): Graphs

- Magnitude vs. Time
- Phase vs. Time
- Distance vs. Time
- Elongation vs. Time
- Angular size vs. Time
- Phase angle vs. Time
v0.18.2   • Heliocentric distance vs. Time
v0.19.0   • Transit altitude vs. Time
v0.19.3   • Right ascension vs. Time
v0.19.3   • Declination vs. Time

This tool may be very helpful for educational and statistics purposes.[3]

The "Lunar Distance" Subtab
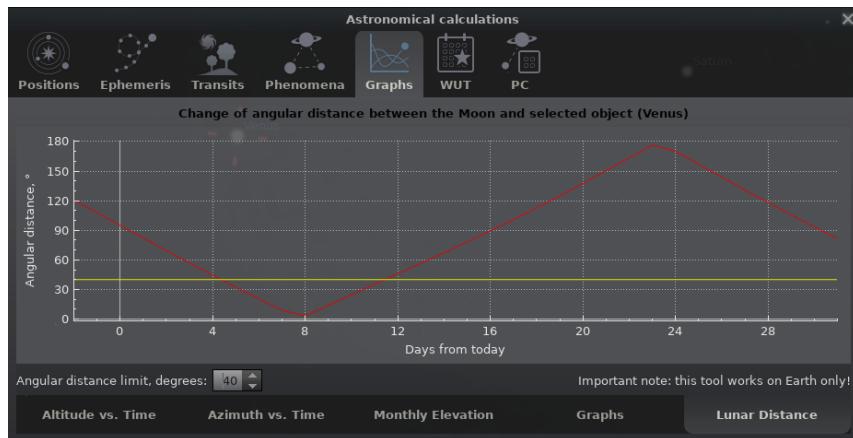
Figure 4.33: Astronomical Calculations (AstroCalc): Graphs / Lunar Distance

v0.18.3   This subtab (Fig. 4.33) can show a "Lunar Distance" (formerly "Angular Distance") graph — the change of angular distance between the Moon and the selected object (for example some deep-sky object) for the nearest 30 days. This tool was introduced for planning monthly observations.

---

[3]The idea for this tool has been obtained from **SkytechX**: http://www.skytechx.eu/

4.6.6 The "What's Up Tonight" (WUT) Tab

The "What's Up Tonight" (WUT) tool[4] displays a list of objects that will be visible at night for the current date and location.   v0.16.0
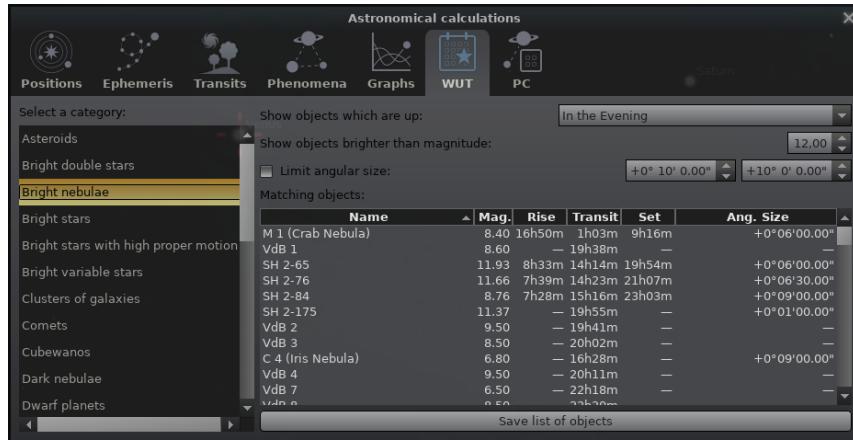
Figure 4.34: Astronomical Calculations (AstroCalc): What's Up Tonight (WUT)

The objects are organized into type categories. Select an object type in the box labeled *Select a Category*, and all objects of that type which are above the horizon on the selected night will be displayed in the box labeled *Matching Objects*. For example, in the screenshot, the Planets category has been selected, and three planets which are up in the selected night are displayed (Jupiter, Mars and Mercury).

By default, the WUT will display objects which are above the horizon between sunset and midnight (i.e. *in the evening*). You can choose to show objects which are up between midnight and dawn (*in the morning*), *around midnight*, or any time between dusk and dawn (*any time tonight*) using the combobox near the top of the window. You can also choose to see only those objects that are brighter than a certain magnitude by setting a minimum magnitude using the *Show objects brighter than magnitude* spinbox. You may center an object from the right list in the sky map just by selecting it.

Note that only DSO from catalogs which you have selected in the DSO panel (section 4.4.3) will be found.

In version 0.18.3 this tool has been refactored: the tool for searching items from list of *Matching Objects* was removed, the filter for magnitudes was moved to the right and we added a new filter here to limit the range of acceptable angular sizes of matched objects. In addition to the names we added 5 new sortable columns: magnitude, rising time, transit time, setting time and angular size of object.   v0.18.3

4.6.7 The "Planetary Calculator" (PC) Tab

The "Planetary Calculator" (PC) tool has been added after user requests. It computes the relations between two Solar system bodies for the current date and location — linear and angular distances, orbital resonances and orbital velocities.   v0.17.0

In version 0.18.2 we enhanced this tool with a new *Graphs* tab (Fig. 4.36), where you may see the change in the linear and angular distances between selected celestial bodies over a range of 600 days (centered on the current date) as graphs.   v0.18.2

---

[4]This tool has been partially ported from the **KStars** planetarium: https://edu.kde.org/kstars/
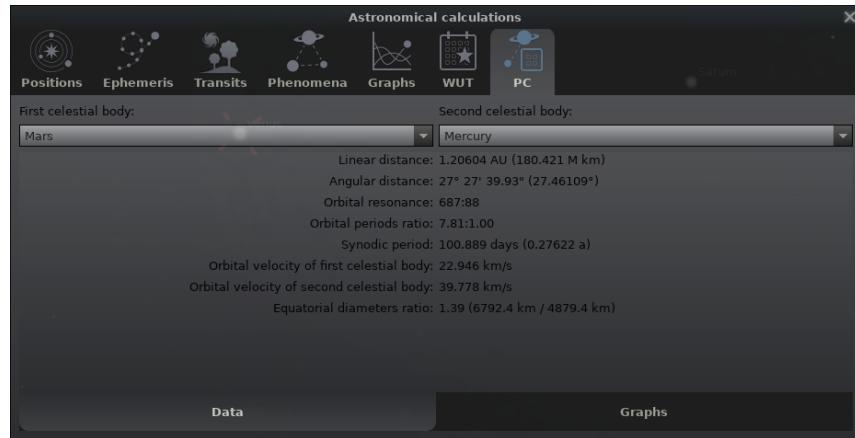
Figure 4.35: Astronomical Calculations (AstroCalc): Planetary Calculator (PC), Data Tab
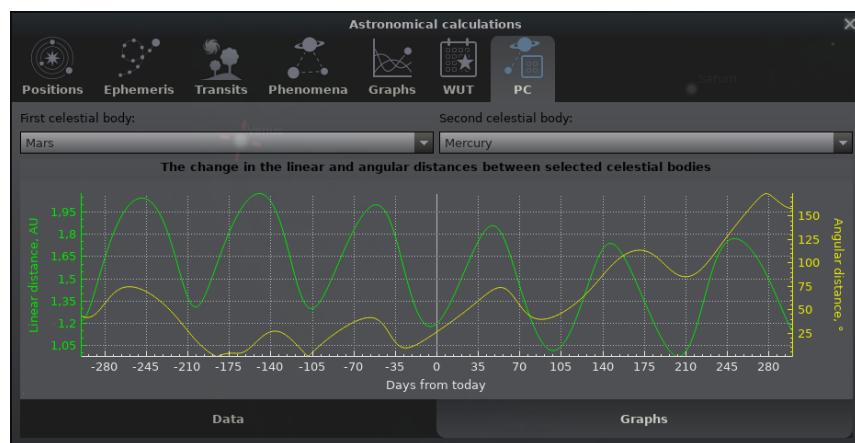
Figure 4.36: Astronomical Calculations (AstroCalc): Planetary Calculator (PC), Graphs Tab

4.7   Help Window

4.7.1   The Help Tab
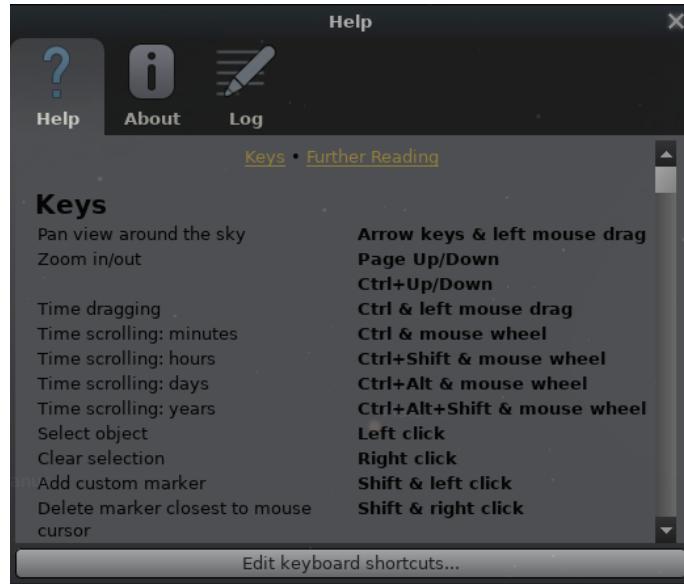
Figure 4.37: Help Window

The Help Tab lists all of Stellarium's keystrokes. Note that some features are only available as keystrokes, so it's a good idea to have a browse of the information in this window.

4.7.2   The About Tab
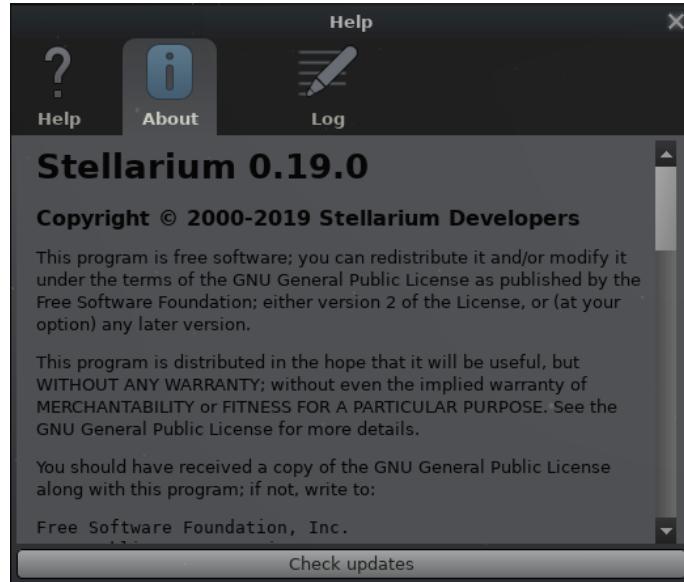
Figure 4.38: Help Window: About

The About Tab (Fig. 4.38) shows version and licensing information, and a list of people who helped to produce the program. Since version 0.18.3 this tab has tool to check for updates of Stellarium.   0.18.3

4.7.3 The Log Tab
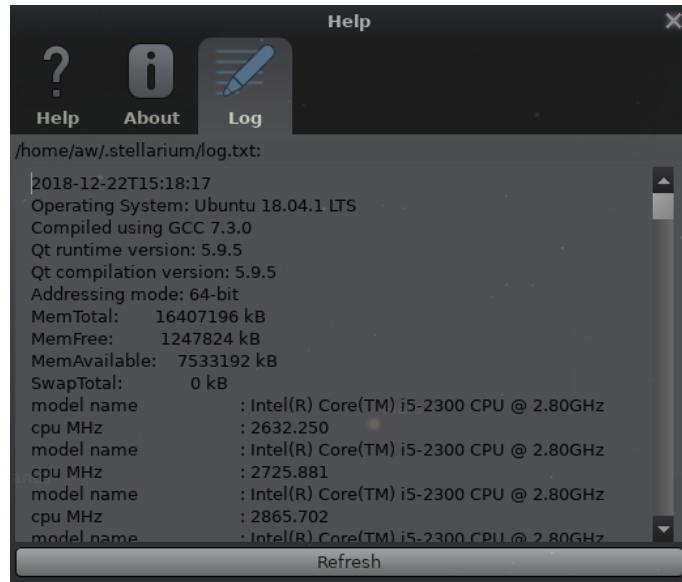
Figure 4.39: Help Window: Logfile

The Log Tab (Fig. 4.39) shows messages like the loading confirmations carried out when stellarium runs. It is useful to locate the files that stellarium writes to your computer. The same information is written to the file log.txt that you will find in your user directory (see 5.1).

4.8 Editing Keyboard Shortcuts

Figure 4.40: Keyboard Shortcuts
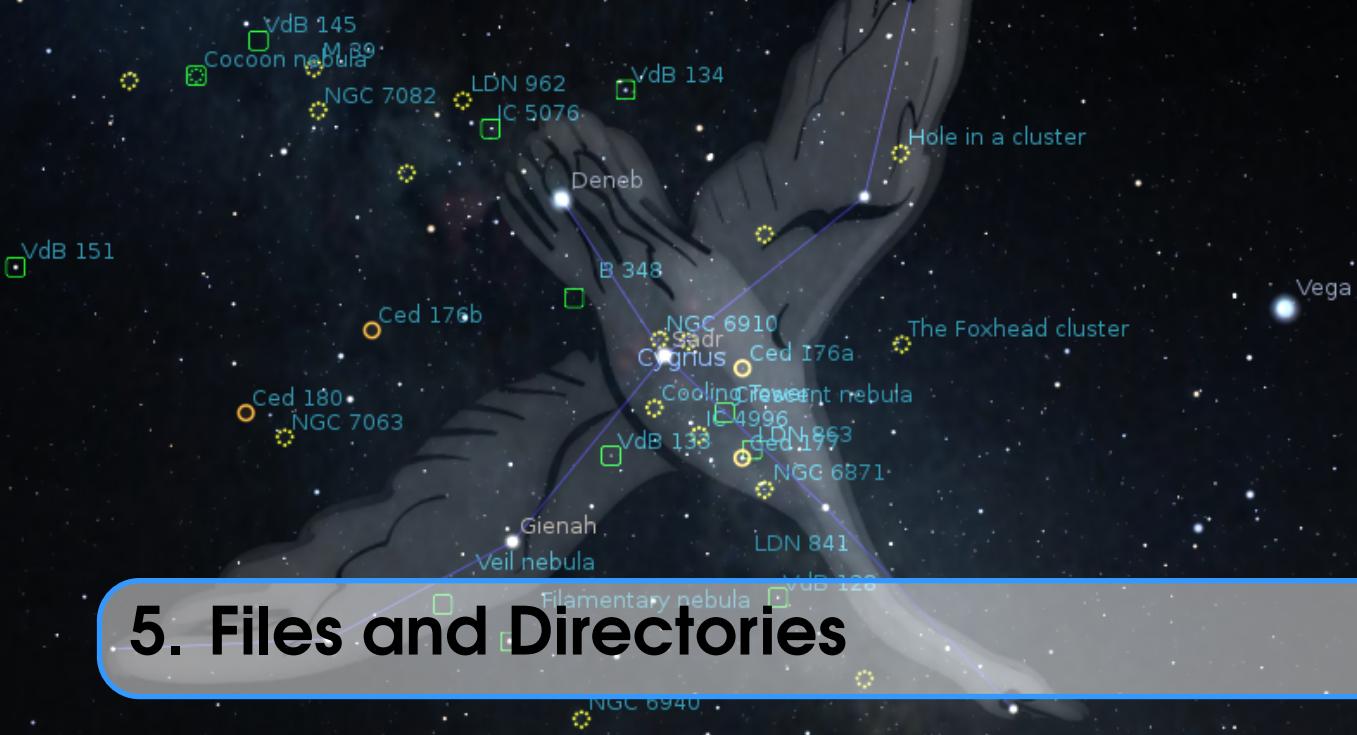
You can edit the shortcut keys here. Each available function can be configured with up to two key combinations. You may want to reconfigure keys for example if you have a non-English keyboard layout and some keys either do not work at all, or feel unintuitive for you, or if you are

familiar with other software and want to use the same hotkeys for similar functions. Simply select the function and click with the mouse into the edit field, then press your key of choice. If the key has been taken already, a message will tell you.

This tool is available through the Help Tab of the Help window (see section 4.7.1) and the Tools Tab of the Configuration window (see section 4.3.5).

Advanced Use

5. Files and Directories

5.1 Directories

Stellarium has many data files containing such things as star catalogue data, nebula images, button icons, font files and configuration files. When Stellarium looks for a file, it looks in two places. First, it looks in the *user directory* for the account which is running Stellarium. If the file is not found there, Stellarium looks in the *installation directory*[1]. Thus it is possible for Stellarium to be installed by an administrative user and yet have a writable configuration file for non-administrative users. Another benefit of this method is on multi-user systems: Stellarium can be installed by the administrator, and different users can maintain their own configuration and other files in their personal user accounts.

In addition to the main search path, Stellarium saves some files in other locations, for example screens shots and recorded scripts.

The locations of the user directory, installation directory, *screenshot save directory* and *script save directory* vary according to the operating system and installation options used. The following sections describe the locations for various operating systems.

5.1.1 Windows

installation directory By default this is `C:\Program Files\Stellarium\`, although this can be adjusted during the installation process.

user directory This is the Stellarium sub-folder in the Application Data folder for the user account which is used to run Stellarium. Depending on the version of Windows and its configuration, this could be any of the following (each of these is tried, if it fails, the next in the list if tried).

```
%APPDATA%\Stellarium\
%USERPROFILE%\Stellarium\
%HOMEDRIVE%\%HOMEPATH%\Stellarium\
%HOME%\Stellarium\
Stellarium's␣installation␣directory
```

---

[1]The installation directory was referred to as the config root directory in previous versions of this guide

Thus, on a typical Windows Vista/7/10 system with user "Bob Dobbs", the user directory will be:

```
C:\Users\Bob Dobbs\AppData\Roaming\Stellarium\
```

The user data directory is unfortunately hidden by default. To make it accessible in the Windows file explorer, open an **Explorer** window and select `Organize...` `Folder and search options`. Make sure folders marked as hidden are now displayed. Also, deselect the checkbox to "hide known file name endings".[2]

screenshot save directory Screenshots will be saved to the `Pictures/Stellarium` directory, although this can be changed in the GUI (see section 4.3.5) or with a command line option (see section 6).

5.1.2 Mac OS X

installation directory This is found inside the application bundle, `Stellarium.app`. See *Inside Application Bundles*[3] for more information.

user directory This is the sub-directory `Library/Preferences/Stellarium/` (or `~/Library/Application Support/Stellarium` on newest versions of Mac OS X) of the user's home directory.

screenshot save directory Screenshots are saved to the user's Desktop.

5.1.3 Linux

installation directory This is in the `share/stellarium` sub-directory of the installation prefix, i.e., usually `/usr/share/stellarium` or `/usr/local/share/stellarium/`.

user directory This is the `.stellarium` sub-directory of user's home directory, i.e., `~/.stellarium/`. This is a hidden folder, so if you are using a graphical file browser, you may want to change its settings to "display hidden folders".

screenshot save directory Screenshots are saved to the user's home directory.

5.1.4 Customized Location

v.0.19.0   Some users may prefer non-standard locations for their own data, for example when the Windows `C:` drive (which usually contains user data), or the Linux `/home` partition has become too small to hold tens of high-resolution landscapes or detailed 3D sceneries. You can move the entire directory elsewhere and use an environment variable `STEL_USERDIR` that contains the pathname.

5.2 Directory Structure

Within the *installation directory* and *user directory* defined in section 5.1, files are arranged in the following sub-directories.

`landscapes/` contains data files and textures used for Stellarium's various landscapes. Each landscape has its own sub-directory. The name of this sub-directory is called the *landscape ID*, which is used to specify the default landscape in the main configuration file, or in script commands.

---

[2]This is a very confusing default setting and in fact a security risk: Consider you receive an email with some file `funny.png.exe` attached. Your explorer displays this as `funny.png`. You double-click it, expecting to open some image browser with a funny image. However, you start some unknown program instead, and running this `.exe` executable program may turn out to be anything but funny!

[3]`http://www.mactipsandtricks.com/articles/Wiley_HT_appBundles.lasso`

`skycultures/` contains constellations, common star names and constellation artwork for Stellarium's many sky cultures. Each culture has its own sub-directory in the skycultures directory.

`nebulae/` contains data and image files for nebula textures. In the future Stellarium may be able to support multiple sets of nebula images and switch between them at runtime. This feature is not implemented for version 0.20.1, although the directory structure is in place - each set of nebula textures has its own sub-directory in the nebulae directory.

`stars/` contains Stellarium's star catalogues. In the future Stellarium may be able to support multiple star catalogues and switch between them at runtime. This feature is not implemented for version 0.20.1, although the directory structure is in place – each star catalogue has its own sub-directory in the stars directory.

`data/` contains miscellaneous data files including fonts, solar system data, city locations, etc.

`textures/` contains miscellaneous texture files, such as the graphics for the toolbar buttons, planet texture maps, etc.

`ephem/` (optional) may contain data files for planetary ephemerides DE430 and DE431 (see 5.5.3).

If any file exists in both the installation directory and user directory, the version in the user directory will be used. Thus it is possible to override settings which are part of the main Stellarium installation by copying the relevant file to the user area and modifying it there.

It is recommended to add new landscapes or sky cultures by creating the relevant files and directories within the user directory, leaving the installation directory unchanged. In this manner different users on a multi-user system can customise Stellarium without affecting the other users, and updating Stellarium will not risk the loss of your own data.

5.3 The Logfile

Stellarium reports various events and confirmations to a logfile, `log.txt`, in the *user directory*. This has the same content as you can see on the console on Linux when you start Stellarium on the command line. Normally you don't need to bother with its contents, however, if Stellarium behaves unexpectedly, crashes, or shows other problems, a quick look into this file may help to identify the problem. Also when you report a problem to the developers in the hope that they (we) can 'fix' anything, this logfile is an essential ingredient to your report. The logfile can also be displayed within the program: press F1 to call the help panel, and select the Logfile tab.

5.4 The Main Configuration File

The main configuration file is read each time Stellarium starts, and settings such as the observer's location and display preferences are taken from it. Ideally this mechanism should be totally transparent to the user – anything that is configurable should be configured "in" the program GUI. However, at time of writing Stellarium isn't quite complete in this respect, despite improvements in each version. Some settings, esp. color values for lines, grids, etc. can only be changed by directly editing the configuration file.[4] This section describes some of the settings a user may wish to modify in this way, and how to do it.

If the configuration file does not exist in the *user directory* when Stellarium is started (e.g., the first time the user starts the program), one will be created with default values for all settings (refer to section 5 Files and Directories for the location of the user directory on your operating system). The name of the configuration file is `config.ini`[5].

---

[4]Color values can be edited interactively by the Text User Interface plugin (see 12.5).

[5]It is possible to specify a different name for the main configuration file using the `--config-file` command line option. See section 6 Command Line Options for details.

The configuration file is a regular text file, so all you need to edit it is a text editor like **Notepad** on Windows, **Text Edit** on the Mac, or **nano/vi/gedit/emacs/leafpad** etc. on Linux.

A complete list of configuration file options and values may be found in appendix D.1.

5.5 Getting Extra Data

5.5.1 More Stars

Stellarium is packaged with over 600 thousand stars in the normal program download, but much larger star catalogues may be downloaded in the *Tools* tab of the *Configuration* dialog ([⚲] or [F2]).

5.5.2 More Deep-Sky Objects

v0.16.1   Stellarium is packaged with over 94 thousand deep-sky objects[6] in the normal program download (the standard edition of Stellarium DSO catalog, see section 8.1), but an extended DSO catalog with over one million objects (up to 20.0^m for galaxies) may be downloaded from Stellarium's Github website[7]:

Version	Filename	MD5 hash	Size
3.9; extended edition	`catalog.dat`	06bef36c980c6e0088f3dcecee3947b7	27MB

The file can be placed in a folder named `nebulae/default` inside either the *installation directory* (replacing of standard catalog) or the *user directory* (see section 5.2).

5.5.3 Alternative Planet Ephemerides: DE430, DE431

v0.15.0   By default, Stellarium uses the *VSOP87* planetary theory, an analytical solution which is able to deliver planetary positions for any input date (P. Bretagnon and Francou, 1988). However, its use is recommended only for the year range $-4000\ldots+8000$. Outside this range, it seems to be usable for a few more millennia without too great errors, but with degrading accuracy. Likewise for the moon, Stellarium by default uses ELP 2000-82B (Chapront-Touze, 1982; Chapront-Touzé and Chapront, 1983; Chapront-Touzé and Chapront, 1988b).

Since v0.15.0 you can install extra data files which allow access to the numerical integration runs *DE430* and *DE431* from NASA's Jet Propulsion Laboratory (JPL) (Folkner et al., 2014). The data files have to be downloaded separately, and most users will likely not need them. DE430 provides highly accurate data for the years $+1550\ldots+2650$, while DE431 covers years $-13000\ldots+17000$, which allows e.g. archaeoastronomical research on Mesolithic landscapes. Outside these year ranges, positional computation falls back to VSOP87.

The integration of this feature is still somewhat experimental, and some other current approximations will lead to numerical data which differ slightly from best possible ephemerides. Please at least compare with JPL Horizons[8] for dependable results.

To enable use of these data, download the files from JPL[9]:

Ephemeris	Filename	MD5 hash	Size
DE430	`linux_p1550p2650.430`	707c4262533d52d59abaaaa5e69c5738	97.5 MB
DE431	`lnxm13000p17000.431`	fad0f432ae18c330f9e14915fbf8960a	2.59 GB

---

[6]Over 83 thousand deep-sky objects in version 0.16.0.

[7]`https://github.com/Stellarium/stellarium-data/releases/tag/dso-3.9`

[8]`https://ssd.jpl.nasa.gov/horizons.cgi`

[9]`ftp://ssd.jpl.nasa.gov/pub/eph/planets/Linux/`. (Also download from this directory if you are not running Linux!)

The files can be placed in a folder named `ephem` inside either the *installation directory* or the *user directory* (see 5.2). Alternatively, if you have them already stored elsewhere, you may add the path to `config.ini` like:

```
[astro]
de430_path = C:/Astrodata/JPL_DE43x/linux_p1550p2650.430
de431_path = C:/Astrodata/JPL_DE43x/lnxm13000p17000.431
```

For fast access avoid storing them on a network drive or USB pendrive!

You activate use of either ephemeris in the *Configuration* panel (F2). If you activate both, preference will be given for DE430 if the simulation time allows it. Outside of the valid times, VSOP87 will always be used.

Acknowledgement

The optional use of DE430/431 has been supported by the ESA Summer of Code in Space 2015 initiative.

5.5.4 GPS Position

In the *Location* panel (see section 4.2) you can receive your location from a *GPS* device. The exact way to receive GPS location depends on your operating system.   0.16/0.18.1

GPSD (Linux, Mac OS X only)

On Linux, Mac-OS X and other Unixoid platforms, Stellarium preferrably should not connect directly to a GPS USB device, serial device, bluetooth device, etc., but use a connection to the **gpsd** daemon running on a computer in your network which provides GPS services concurrently for any interested application. In most cases, this will be a **gpsd** running on your localhost, receiving data from some GPS device plugged in via USB. Please follow instructions by the **gpsd** authors[10] to properly configure this system daemon. A few hints:

- On Ubuntu 16.04 and likely other systems, USB hotplug devices are handled by the **udev** daemon which detects newly plugged-in devices and creates device files in the `/dev` directory. Unfortunately, most GPS devices use the Prolific 2303 chipset in their serial-to-USB converter and are identified as such, without other unique information like serial numbers. This chipset is also used in other Serial-to-USB converter cables, and to avoid conflicts the according rule has been disabled by the release managers of Ubuntu. In `/lib/udev/60-gpsd.rules`, find the commented line and re-activate it.
- If you have such an USB GPS mouse and USB-to-serial converters for other purposes like for your telescope control, you must solve the "**udev** crisis" in some other way to get **gpsd** running. You may be able to find some property in your device to uniquely identify this device and write an **udev** rule to create the symlink in `/dev/gps0` to which **gpsd** can then connect.
- You can also connect to another computer which runs **gpsd**. This could be a little Raspberry Pi computer which happens to be in your WiFi to allow localisation and time service. To configure this, you must manually edit `config.ini`. Find the `[gui]` section and edit

```
[gui]
# These values are used on non-Windows systems
# supporting GPSD
gpsd_hostname   = localhost
gpsd_port       = 2947
```

---

[10]`http://catb.org/gpsd/index.html`

Also, **gpsd** must be started with the `-G` parameter to enable this.

- Even your smartphone can be used as GPS data source[11]: Apps like **BlueNMEA** can provide these data for **gpsd**, but you must make sure to configure hostname/IP Address and port number correctly, for example

```
sudo gpsd -n -D8 -S 1001 tcp://192.168.1.101:4352
```

which means

-n to start without a device connection

-D8 maximum debug level. When it works, use what suits you

-S 1001 provide service on port 1001

tcp Use this address:port combination to receive data from (IP of your smartphone, port shown on **BlueNMEA** screen).

- In case you really don't want to use the **gpsd**, you can use a directly connected device, see below. This is however not recommended when you have **gpsd** available.

NMEA Device

This mode is primarily for Windows users, but also for Linux and Mac users who don't want to use **gpsd**.

Virtually all GPS receivers are able to emit the standardized *NMEA*-0183 messages which encode time, position, speed, satellite information and other data. The standard originally required connection settings of 4800 baud, 8 bit, no parity, one stop bit (8N1), however some devices come with faster transfer.

Compatible devices today are connected on a "virtual COM port" via USB. Unfortunately the COM number seems to depend on the USB plug where you attach the receiver. You can identify the port name (COM3, COM4, . . .) in the Windows system configuration (Device Manager) or with the software that came with your device.[12]

If this is the only serial device, Stellarium should automatically connect to it regardless of configuration entries. If you have a device with non-standard baudrate or several serial devices on serial ports (e.g., your telescope?), you must find out which serial port is used by the GPS device and manually edit `config.ini`. Find the `[gui]` section and edit

```
[gui]
# These values are used on Windows primarily.
gps_interface     = COM3
gps_baudrate      = 4800
```

From now on, always use the same USB plug configuration to connect GPS and telescope.[13]

If GPS lookup fails, run Stellarium with the `-verbose` option and see the logfile for diagnostic messages.
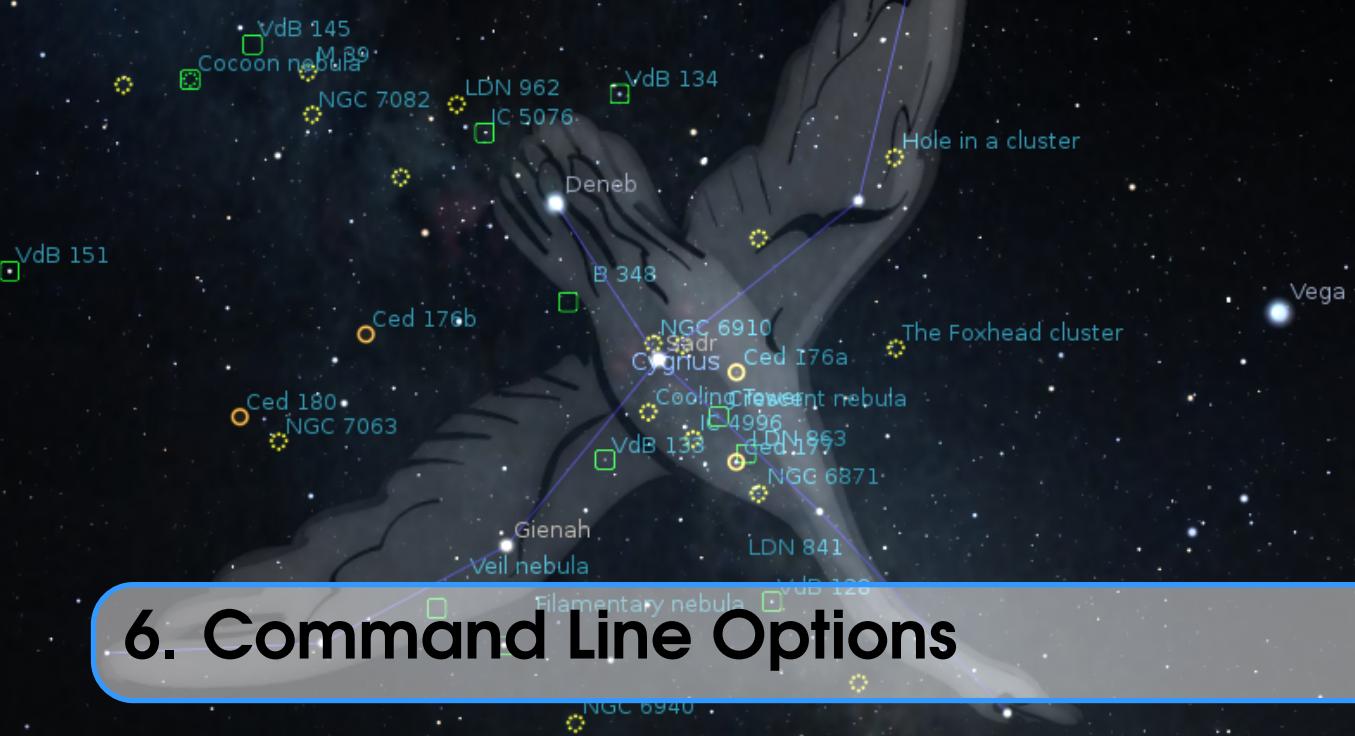
Bluetooth GPS

Most smartphones provide GPS and Bluetooth hardware. You can install a virtual COM port in your Windows Bluetooth settings and use a smartphone app like **BlueNMEA** to provide the NMEA strings.

---

[11]Thanks to user Caysho for this hint.

[12]On Linux, this may read `/dev/ttyUSB0`, `/dev/gps0` or similar.

[13]Again, for Linux the port number is defined in order of hotplugging by **udev**. You should develop an **udev** rule which adds a unique name and use this. In this case, you may also need to add your user to the `dialout` group (or whichever group owns your serial port). Better yet, use **gpsd** (see above).

6. Command Line Options

Stellarium's behaviour can be modified by providing parameters to the program when it is called via the command line. See table for a full list:

Option	Option Parameter	Description
--help or -h	[none]	Print a quick command line help message, and exit.
--version or -v	[none]	Print the program name and version information, and exit.
--config-file or -c	config file name	Specify the configuration file name. The default value is `config.ini`. The parameter can be a full path (which will be used verbatim) or a partial path. Partial paths will be searched for inside the regular search paths unless they start with a ".", which may be used to explicitly specify a file in the current directory or similar. For example, using the option `-c my_config.ini` would resolve to the file `<user directory>/my_config.ini` whereas `-c ./my_config.ini` can be used to explicitly say the file `my_config.ini` in the current working directory.
--restore-defaults	[none]	Stellarium will start with the default configuration. Note: The old configuration file will be overwritten.
--user-dir	path	Specify the user data directory.

--screenshot-dir	path	Specify the directory to which screenshots will be saved.
--full-screen	yes or no	Over-rides the full screen setting in the config file.
--home-planet --longitude --latitude --altitude	planet longitude latitude altitude	Specify observer planet (English name). Specify latitude, e.g. +53d58'16.65" Specify longitude, e.g. -1d4'27.48" Specify observer altitude in meters.
--list-landscapes --landscape	[none] landscape ID	Print a list of available landscape IDs and exit. Start using landscape whose ID matches the passed parameter (dir name of landscape).
--sky-date --sky-time	date time	The initial date in `yyyymmdd` format. The initial time in `hh:mm:ss` format.
--startup-script	script name	The name of a script to run after the program has started. [`startup.ssc`]
--fov	angle	The initial vertical field of view in degrees.
--projection-type	ptype	The initial projection type (e.g. `perspective`).
--spout or -S --spout-name	all or sky name	Act as Spout sender (See section 6.2.1).[1][2] Use `name` as name of the Spout sender. Default name: `Stellarium`.[1]
--verbose --dump-opengl-details or -d	 [none]	Even more diagnostic output in logfile (esp. multimedia handling) Dump information about OpenGL support to logfile. Use this is you have graphics problems and want to send a bug report.
--angle-mode or -a --angle-d3d9 or -9 --angle-d3d11 --angle-warp --mesa-mode or -m --safe-mode or -s --compat33 or -C	[none] [none] [none] [none] [none] [none] [none]	Use ANGLE as OpenGL ES2 rendering engine (autodetect Direct3D version).[1] Force use Direct3D 9 for ANGLE OpenGL ES2 rendering engine.[1] Force use Direct3D 11 for ANGLE OpenGL ES2 rendering engine.[1] Force use the Direct3D 11 software rasterizer for ANGLE OpenGL ES2 rendering engine.[1] Use MESA as software OpenGL rendering engine.[1] Synonymous to --mesa-mode.[1] Request OpenGL 3.3 Compatibility Profile. May help for certain driver configurations. Mac?

---

[1]On Windows only

[2]This function requires running in OpenGL mode.

--fix-text or -t	[none]	Alternative way of creating the Info text, required on some systems.[3]

If you want to avoid adding the same switch every time when you start Stellarium from the command line, you can also set an environment variable STEL_OPTS with your default options.

<div style="text-align: right">0.15</div>

6.1 Examples

- To start Stellarium using the configuration file, `configuration_one.ini` situated in the user directory (use either of these):

```
stellarium --config-file=configuration_one.ini
stellarium -c configuration_one.ini
```

- To list the available landscapes, and then start using the landscape with the ID "ocean"

```
stellarium --list-landscapes
stellarium --landscape=ocean
```

Note that console output (like `--list-landscapes`) on Windows is not possible.

6.2 Special Options

6.2.1 Spout

<div style="text-align: right">v0.15.1</div>

Apart from stand-alone use, Stellarium can be used as multimedia source in larger installations, in museums or science exhibitions. **Spout**[4] is a technology which enables use of Stellarium's output window as texture in DirectX applications on Windows. Simply start Stellarium with the `--spout=sky` command line option. (Currently **Spout** output is limited to the main window without GUI panels, but this may change in future versions.) Your master application must obviously embed a **Spout** receiver. The default name of the **Spout** sender is `Stellarium`. If you need more than one instance of Stellarium acting as source, you can use option `--spout-name=StelSpout2` in addition to create another **Spout** sender without a name conflict. In such cases, it may be useful to also have separate user data directories and use option `--user-dir`.

This mode does not work in ANGLE mode and requires modern graphics hardware with the `WGL_NV_DX_interop` driver extension running in OpenGL mode. Some NVidia GPUs work without this extension listed explicitly. On a notebook with NVidia Optimus technology, make sure to launch Stellarium on the NVidia hardware. For permanent setting, use the NVidia configuration dialog to configure Stellarium explicitly to run always on the NVidia card.

---

[3]E.g., Raspberry Pi 2/3 with Raspbian Jessie and VC4 drivers from Mesa 11 (2016).
[4]`http://spout.zeal.co/`

7. Landscapes

GEORG ZOTTI

Landscapes are one of the key features that make Stellarium popular. Originally just used for decoration, since version 10.6 they can be configured accurately for research and demonstration in "skyscape astronomy", a term which describes the connection of landscape, the sky above, and the observer (Brown, 2015). Configured properly, they can act as reliable proxies of the real landscapes, so that you can take e.g. measurements of sunrise or stellar alignments (Zotti and Neubauer, 2015), or prepare your next moonrise photograph, as though you were on-site.

In this chapter you can find relevant information required to accurately configure Stellarium landscapes, using panoramas created from photographs taken on-site, optionally supported by horizon measurements with a theodolite.

Creating an accurate panorama requires some experience with photography and image processing. However, great open-source tools have been developed to help you on the job. If you already know other tools, you should be able to easily transfer the presented concepts to those other tools.

While you are editing a landscape, you may want to reload it frequently. Turn off caching by editing the `config.ini`:

```
[landscape]
cache_size_mb = 0
```

7.1 Stellarium Landscapes

As of version 0.15, the available landscape types are:

polygonal A point list of measured azimuth/altitude pairs, used to define a sharp horizon polygon. The area below the horizon line is colored in a single color (Section 7.1.2).

spherical The simple form to configure a photo-based panorama: A single image is used as texture map for the horizon (Section 7.1.3).

old_style The original photo panorama. This is the most difficult to configure, but allows highest resolution by using several texture maps (Section 7.1.4).

fisheye Another 1-texture approach, utilizing an image made with a fisheye lens. This landscape suffers from calibration uncertainties and can only be recommended for decoration (Section 7.1.5).

A landscape consists of a `landscape.ini` plus the data files that are referenced from there, like a coordinate list or the textures. Those reside in a subdirectory of the `landscape` folder inside the Stellarium program directory, or, for own work, in a subdirectory of the `landscape` folder inside your Stellarium user data directory (see section 5.1).

Let us assume we want to create a landscape for a place called Rosenburg. The location for the files of our new custom landscape *Rosenburg* depends on the operating system (see 5.1). Create a new subdirectory, and for maximum compatibility, use small letters and no spaces:

Windows   `C:/Users/YOU/AppData/Roaming/Stellarium/landscapes/rosenburg`
Linux   `~/.stellarium/landscapes/rosenburg`
Mac   `$HOME/Library/Application Support/Stellarium/landscapes/rosenburg`

7.1.1 Location information

This optional section in `landscape.ini` allows automatic loading of site coordinates if this option is activated in the program GUI (see 4.4.5). For our purposes we should consider especially the coordinates in the location section mandatory!

```
[location]
planet = Earth
country = Austria
name = KGA Rosenburg
latitude = +48d38'3.3"
longitude = +15d38'2.8"
altitude = 266
timezone = Europe/Vienna
light_pollution = 1
atmospheric_extinction_coefficient = 0.2
display_fog = 0
atmospheric_temperature = 10.0
atmospheric_pressure = 1013.0
```

Where:

`planet` Is the English name of the solar system body for the landscape.

`latitude` Is the latitude of site of the landscape in degrees, minutes and seconds. Positive values represent North of the equator, negative values South of the equator.

`longitude` Is the longitude of site of the landscape. Positive values represent East of the Greenwich Meridian on Earth (or equivalent on other bodies), Negative values represent Western longitude.

`altitude` Is the altitude of the site of the landscape in meters.

`country` (optional) Name of the country the location is in.

`state` (optional) Name of the state the location is in.

v0.18.3   `timezone` (optional) IANA Timezone code

`name` (optional) Name of the location. This may contain spaces, but keep it short to have it fully visible in the selection box.

Since v0.11.0, there are a few more optional parameters that can be loaded if the according switch is active in the landscape selection panel. If they are missing, the parameters do not change to

defaults.

`light_pollution` (optional) Light pollution of the site, given on the Bortle Scale (1: none ... 9: metropolitan; see Appendix B). If negative or absent, no change will be made.

`atmospheric_extinction_coefficient` (optional, no change if absent.) Extinction coefficient (mag/airmass) for this site.

`atmospheric_temperature` (optional, no change if absent.) Surface air temperature (Degrees Celsius). Used for refraction. Set to -1000 to explicitly declare "no change".

`atmospheric_pressure` (optional, no change if absent.) Surface air pressure (mbar; would be 1013 for "normal" sea-level conditions). Used for refraction. Set to -2 to declare "no change", or -1 to compute from altitude.

`display_fog` (optional, -1/0/1, default=-1) You may want to preconfigure setting 0 for a landscape on the Moon. Set -1 to declare "no change".

7.1.2 Polygonal landscape

This landscape type has been added only recently (since 0.13) to allow the use of measured horizons. Users of **Cartes du Ciel**[1] will be happy to hear that the format of the list of measurements is compatible.

This is the technically simplest of the landscapes, but may be used to describe accurately measured horizon profiles. The file that encodes horizon altitudes can also be used in all other landscape types. If present there, it will be used to define object visibility (instead of the opacity of the landscape photo textures) and, if `horizon_line_color` is defined, will be plotted.

There is a small caveat: Sometimes, there may appear vertical lines from some corners towards the zenith or the mathematical horizon, e.g. if there is a vertex including azimuth 0 or 180. If this irritates you, just offset this azimuth minimally (e.g., 180.00001).

The `landscape.ini` file for a polygonal type landscape looks like this (this example is based on the *Geneve* landscape which was borrowed from **Cartes du Ciel** and comes with Stellarium):

```
[landscape]
name = Geneve
type = polygonal
author = Georg Zotti; Horizon definition by Patrick Chevalley
description = Horizon line of Geneve.
              Demonstrates compatibility with
              horizon descriptions from Cartes du Ciel.
polygonal_horizon_list = horizon_Geneve.txt
polygonal_angle_rotatez = 0
ground_color = .15,.45,.45
horizon_line_color = .75,.45,.45
```

Where:

`name` appears in the landscape tab of the configuration window.

`type` identifies the method used for this landscape. `polygonal` in this case.

`author` lists the author(s) responsible for images and composition.

`description` gives a short description visible in the selection panel. The text can be superseded by optional `description.<lang>.utf8` files.

`polygonal_horizon_list` is the name of the horizon data file for this landscape.

`polygonal_horizon_list_mode` (optional) the two first columns in the list are numbers: azimuth and altitude or zenith distance, in either degrees or radians or gradians(gon). The value

---

[1]SkyChart / Cartes du Ciel planetarium: `http://www.ap-i.net/skychart/en/start`

must be one of `azDeg_altDeg`, `azDeg_zdDeg`, `azRad_altRad`, `azRad_zdRad`, `azGrad_altGrad`, `azGrad_zdGrad`. Default: `azDeg_altDeg`

`polygonal_angle_rotatez` (optional, default=0) Angle (degrees) to adjust azimuth. This may be used to apply a (usually) small offset rotation, e.g. when you have measured the horizon in a grid-based coordinate system like UTM and have to compensate for the meridian convergence.

`ground_color` (optional, default=0,0,0, i.e., black) Color for the area below the horizon line. Each R,G,B component is a float within 0..1.

`horizon_line_color` (optional, default: invisible) used to draw a polygonal horizon line. Each R,G,B component is a float within 0..1.

`minimal_brightness` (optional) Some minimum brightness to keep landscape visible. Default=-1, i.e., use `minimal_brightness` from the `[landscape]` section in the global `config.ini`.

`minimal_altitude` (optional, default=-2) Some sky elements, e.g. stars, are not drawn below this altitude to increase performance. Under certain circumstances you may want to specify something else here. (since v0.14.0)

`polygonal_horizon_inverted` (optional, default=false) In rare cases like horizon lines for high mountain peaks with many negative horizon values this should be set to true. (since v0.15.0)

Artificial Polygonal Panoramas

The online service **HeyWhatsThat**[2] allows an SRTM-based analysis of the viewshed (the visible topographic area) for an observing location which also gives names for the mountain peaks visible at a given location. A data download option provides users inclined to do some programming with the necessary data to create a polygonal landscape for Stellarium.

In addition, BRIAN DOYLE has created another online service, **horiZONE**[3], which does just this work for you.

1. When your viewshed analysis has been created in **HeyWhatsThat**, enter the "all panoramas" tab, and on the map click the marker associated with the panorama. Select "make public".
2. Then, take the landscape key given to you by **HeyWhatsThat**[4], add a few lines of description that will become visible in Stellarium, and you receive a ZIP file ready for installation in Stellarium (see section 4.4.5).

7.1.3 Spherical landscape

This method uses a more usual type of panorama – the kind which is produced directly from software such as **autostitch** or **Hugin**[5]. The *Moon* landscape which comes with Stellarium provides a minimal example of a `landscape.ini` file for a spherical type landscape:

```
[landscape]
name = Moon
type = spherical
maptex = apollo17.png
```

A more elaborate example is found with the *Grossmugl* landscape:

```
[landscape]
name = Grossmugl
type = spherical
```

---

[2]`https://www.heywhatsthat.com/`
[3]`https://briandoylegit.github.io/horiZONE/`
[4]in the line `https://www.heywhatsthat.com/?view=N15ABXY`
[5]`http://hugin.sourceforge.net/`

```
author = Guenther Wuchterl, Kuffner-Sternwarte.at;
         Lightscape: Georg Zotti
description = Field near Leeberg, Grossmugl (Riesentumulus),
             Austria - Primary Observing Spot of the Grossmugl
             Starlight Oasis - http://starlightoasis.org
maptex = grossmugl_leeberg_crop11.25.png
maptex_top=11.25
maptex_fog = grossmugl_leeberg_fog_crop22.5.png
maptex_fog_top = 22.5
maptex_fog_bottom = -22.5
maptex_illum = grossmugl_leeberg_illum_crop0.png
maptex_illum_bottom = 0
angle_rotatez=-89.1
minimal_brightness = 0.0075
polygonal_horizon_list = horizon_grossmugl.txt
polygonal_angle_rotatez=0
horizon_line_color =  .75,.45,.45
minimal_altitude = -1
```

Where:

name appears in the landscape tab of the configuration window. This name may be translated.

type identifies the method used for this landscape. spherical in this case.

author lists the author(s) responsible for images and composition.

description gives a short description visible in the selection panel. The text will be superseded by optional description.<lang>.utf8 files.

maptex is the name of the image file for this landscape.

maptex_top (optional; default=90) is the altitude angle of the top edge.

maptex_bottom (optional; default=-90) is the altitude angle of the bottom edge. Usually you will not require this, or else there will be a hole at your feet, unless you also specify

bottom_cap_color (optional; default=-1.0,0.0,0.0 to signal "no color"). If set, this is used to close any hole in the nadir area (if maptex_bottom higher than -90).   v0.19.0

maptex_fog (optional; default: no fog) is the name of the fog image file for this landscape.

maptex_fog_top (optional; default=90) is the altitude angle of the top edge of the fog texture. Useful to crop away parts of the image to conserve texture memory.

maptex_fog_bottom (optional; default=-90) is the altitude angle of the bottom edge.

maptex_illum (optional; default: no illumination layer) is the name of the nocturnal illumination/light pollution image file for this landscape.

maptex_illum_top (optional; default=90) is the altitude angle of the top edge, if you have light pollution only close to the horizon.

maptex_illum_bottom (optional; default=-90) is the altitude angle of the bottom edge.

angle_rotatez (optional, default=0) Angle (degrees) to adjust azimuth. If 0, the left/right edge is due east.

tesselate_rows (optional, default=20) This is the number of rows for the maptex. If straight vertical edges in your landscape appear broken, try increasing this value, but higher values require more computing power. Fog and illumination textures will have a similar vertical resolution.

tesselate_cols (optional, default=40) If straight horizontal edges in your landscape appear broken, try increasing.

polygonal_horizon_list (optional) is the name of the (measured) horizon data file for this

Figure 7.1: Old_style landscape: eight parts delivering a high-resolution panorama. The bottom (ground) texture, drawn on a flat plane, is not shown here.

landscape. Can be used to define the exact position of the horizon. If missing, the texture can be queried for horizon transparency (for accurate object rising/setting times)

`polygonal_horizon_list_mode` (optional) see 7.1.2

`polygonal_angle_rotatez` (optional, default=0) see 7.1.2

`horizon_line_color` see 7.1.2

`minimal_brightness` see 7.1.2

v0.14.0   `minimal_altitude` (optional, default=-2) Some sky elements, e.g. stars, are not drawn below this altitude for efficiency. Under certain circumstances (e.g. for space station panoramas where you may have sky below your feet, or for deep valleys/high mountains, you may want to specify something else here.

To save texture memory, you can trim away the transparent sky and define the angle `maptex_top`. Likewise, `fogtex_top`, `fogtex_bottom`, `maptex_illum_top` and `maptex_illum_bottom`. You should then stretch the texture to a full power of 2 for maximum compatibility, like 4096×1024 (but note that some hardware is even limited to 2048 pixels). The easiest method to create perfectly aligned fog and illumination layers is with an image editor that supports layers like the **GIMP** or **Photoshop**. Fog and Light images should have black background.

7.1.4 High resolution ("Old Style") landscape

The `old_style` or multiple image method works by having the $360°$panorama of the horizon (without wasting too much texture memory with the sky) split into a number of reasonably small *side textures*, and a separate *ground texture*. This has the advantage over the single-image method that the detail level of the horizon can be increased without ending up with a single very large image file, so this is usable for either very high-resolution panoramas or for older hardware with limited capabilities. The ground texture can be a different resolution than the side textures. Memory usage may be more efficient because there are no unused texture parts like the corners of the texture file in the fish-eye method. It is even possible to repeat the horizon several times (for purely decorative purpose). The side textures are mapped onto curved (spherical ring or cylinder) walls (Fig. 7.1).

On the negative side, it is more difficult to create this type of landscape – merging the ground

texture with the side textures can prove tricky. (**Hugin** can be used to create also this file, though. And on the other hand, you can replace this by something else like a site map.) The contents of the `landscape.ini` file for this landscape type is also somewhat more complicated than for other landscape types. Here is the `landscape.ini` file which describes our *Rosenburg* landscape[6]:

```
[landscape]
name = KGA Rosenburg
author = Georg Zotti, VIAS/ASTROSIM
description = KGA Rosenburg
type = old_style
nbsidetex = 8
tex0 = Horiz-0.png
tex1 = Horiz-1.png
tex2 = Horiz-2.png
tex3 = Horiz-3.png
tex4 = Horiz-4.png
tex5 = Horiz-5.png
tex6 = Horiz-6.png
tex7 = Horiz-7.png
nbside = 8
side0 = tex0:0:0:1:1
side1 = tex1:0:0:1:1
side2 = tex2:0:0:1:1
side3 = tex3:0:0:1:1
side4 = tex4:0:0:1:1
side5 = tex5:0:0:1:1
side6 = tex6:0:0:1:1
side7 = tex7:0:0:1:1
groundtex = grassground.png
ground = groundtex:0:0:1:1
nb_decor_repeat = 1
decor_alt_angle =   82
decor_angle_shift = -62
; Rotatez deviates from -90 by the Meridian Convergence.
; The original landscape pano is grid-aligned,
; not north-aligned!
decor_angle_rotatez =   -90.525837223
ground_angle_shift = -62
ground_angle_rotatez =   44.474162777
draw_ground_first = 1
fogtex = fog.png
fog_alt_angle = 20
fog_angle_shift = -3
fog = fogtex:0:0:1:1
calibrated = true
[location]
planet = Earth
latitude = +48d38'3.3"
```

---

[6]the `groundtex` `grassground.png` mentioned here has been taken from the *Guereins* landscape.

```
longitude␣=␣+15d38'2.8"
altitude␣=␣266
light_pollution␣=␣1
atmospheric_extinction_coefficient␣=␣0.2
display_fog␣=␣0
atmospheric_temperature␣=␣10.0
atmospheric_pressure␣=␣1013.0
```

Where:

name is the name that will appear in the landscape tab of the configuration window for this landscape

type should be `old_style` for the multiple image method.

author lists the author(s) responsible for images and composition.

description gives a short description visible in the selection panel. The text will be superseded by optional `description.<lang>.utf8` files.

nbsidetex is the number of side textures for the landscape.

tex0 ... tex<nbsidetex-1> are the side texture file names. These should exist in the `textures / landscapes / landscape` directory in PNG format.

v0.13.1   light0 ... light<nbsidetex-1> are optional textures. If they exist, they are used as overlays on top of the respective `tex<...>` files and represent nocturnal illumination, e.g. street lamps, lit windows, red dots on towers, sky glow by city light pollution, ... Empty (black) panels can be omitted. They are rendered exactly over the `tex<...>` files even when the PNG files have different size. If you need your light pollution higher in the sky, you must use a spherical or fisheye landscape.

nbside is the number of side textures

side0 ...side<nbside-1> are the descriptions of how the side textures should be arranged in the program. Each description contains five fields separated by colon characters (`:`). The first field is the ID of the texture (e.g. `tex0`), the remaining fields are the texture coordinates (`x0:y0:x1:y1`) used to place the texture in the scene. If you want to use all of the image, this will just be `0:0:1:1`.

groundtex is the name of the ground texture file. (This could also be a diagram e.g. indicating the mountain peaks!)

fogtex is the name of the texture file for fog in this landscape. Fog is mapped onto a simple cylinder.[7] Note that for this landscape, accurate overlay of fog and landscape is only guaranteed if `calibrated=true` and `tan_mode=true`.

nb_decor_repeat is the number of times to repeat the side textures in the 360 panorama. (Useful photo panoramas should have 1 here)

decor_alt_angle (degrees) is the vertical angular extent of the textures (i.e. how many degrees of the full altitude range they span).

decor_angle_shift (degrees) vertical angular offset of the scenery textures, at which height the bottom line of the side textures is placed.

decor_angle_rotatez (degrees) angular rotation of the panorama around the vertical axis. This is handy for rotating the landscape so North is in the correct direction. Note that for historical reasons, a landscape with this value set to zero degrees has its leftmost edge pointing towards east.

ground_angle_shift (degrees) vertical angular offset of the ground texture, at which height the ground texture is placed. Values above -10 are not recommended for non-photographic content (e.g., a map) due to high distortion.

---

[7]In very wide-angle views, the fog cylinder may become visible in the corners.

`ground_angle_rotatez` (degrees) angular rotation of the ground texture around the vertical axis. When the sides are rotated, the ground texture may need to be rotated as well to match up with the sides. If 0, east is up. if North is up in your image, set this to 90. Note that adjustments of `decor_angle_rotatez` require adjustments of this angle in the opposite direction!

`fog_alt_angle` (degrees) vertical angular size of the fog cylinder - how fog looks. Accurate vertical size requires `calibrated=true`.

`fog_angle_shift` (degrees) vertical angular offset of the fog texture - at what height is it drawn. Accurate vertical placement requires `calibrated=true`.

`draw_ground_first` if `true` or 1[8] the ground is drawn in front of the scenery, i.e. the side textures will overlap over the ground texture if `ground_angle_shift` > `decor_angle_shift`.

`calibrated` (optional). Only if true, `decor_alt_angle` etc. really work as documented above. The (buggy) old code was left to work with the landscapes already existing. Note that with "uncalibrated" landscapes, sunrise computations and similar functionality which requires an accurate horizon line will not work.   v0.10.6

`tan_mode` (optional, not used in this file). If true, the panorama image must be in in cylindrical, not equirectangular projection. Finding `decor_alt_angle` and `decor_angle_shift` may be a bit more difficult with this, but now (v0.13.0) works also with calibrated. A fog image created as overlay on the pano will be perfectly placed.

`polygonal_horizon_list` (optional) see 7.1.3

`polygonal_horizon_list_mode` (optional) see 7.1.2

`polygonal_angle_rotatez` (optional, default=0) see 7.1.2

`horizon_line_color` (optional) see 7.1.2

`minimal_brightness` (optional) see 7.1.2

`minimal_altitude` (optional) see 7.1.2

7.1.5 Fisheye landscape

The *Trees* landscape that is provided with Stellarium is an example of the single fish-eye method, and provides a good illustration. The centre of the image is the spot directly above the observer (the zenith). The point below the observer (the nadir) becomes a circle that just touches the edges of the image. The remaining areas of the image (the corners outside the circle) are not used.

The image file (Fig. 7.2) should be saved in PNG format with alpha transparency. Whereever the image is transparent Stellarium will render the sky.

The `landscape.ini` file for a fish-eye type landscape looks like this (this example is based on the *Trees* landscape which comes with Stellarium):

```
[landscape]
name = Trees
type = fisheye
author = Robert Spearman. Light pollution image: Georg Zotti
description = Trees in Greenlake Park, Seattle
maptex = trees_512.png
maptex_illum = trees_illum_512.png
maptex_fog = trees_fog_512.png
texturefov = 210
angle_rotatez = 17
tesselate_rows = 28
tesselate_cols = 60
```

---

[8]Boolean values `true|false` preferred since V0.19.3, but `0|1` are still accepted.

Figure 7.2: Texture for the *Trees* Fisheye landscape.

Where:

`name` appears in the landscape tab of the configuration window.

`type` identifies the method used for this landscape. `fisheye` in this case.

`author` lists the author(s) responsible for images and composition.

`description` gives a short description visible in the selection panel. The text will be superseded by optional `description.<lang>.utf8` files.

`maptex` is the name of the image file for this landscape.

`maptex_fog` (optional) is the name of the fog image file for this landscape.

`maptex_illum` (optional) is the name of the nocturnal illumination/light pollution image file for this landscape.

`texturefov` is the field of view that the image covers in degrees.

`angle_rotatez` (optional) Angle (degrees) to adjust azimuth.

`tesselate_rows` (optional, default=20) If straight edges in your landscape appear broken, try increasing.

`tesselate_cols` (optional, default=40) If straight edges in your landscape appear broken, try increasing.

`polygonal_horizon_list` (optional) see 7.1.3

`polygonal_horizon_list_mode` (optional) see 7.1.2

`polygonal_angle_rotatez` (optional, default=0) see 7.1.2

`horizon_line_color` (optional) see 7.1.2

`minimal_brightness` (optional) see 7.1.2

`minimal_altitude` (optional) see 7.1.2

7.1.6 Description

The short `description` entry in `landscape.ini` will be replaced by the contents of an optional file `description.<LANG>.utf8`. `<LANG>` is the ISO 639-1 language code, or its extension which contains language and country code, like `pt_BR` for Brazilian Portuguese. The long description requires the file `description.en.utf8`, this is en=english text with optional HTML tags for sections, tables, etc. You can also have embedded images in the HTML (Views of sacred landscapes, other informative images, ...?), just make them PNG format please. The length of the description texts is not limited, you have room for a good description, links to external resources, whatever seems suitable.

If you can provide other languages supported by Stellarium, you can provide translations yourself, else Stellarium translators *may* translate the English version for you. (It may take years though.) The file ending `.utf8` indicates that for special characters like ÄÖÜßáé you should use UTF8 encoding. If you write only English/ASCII, this may not be relevant.

7.1.7 Gazetteer

0.14

An optional feature for landscapes is a gazetteer function, i.e., labels for landscape features. The *Grossmugl* landscape demonstrates an example and should be self-explanatory. This is again multilingual, so the files are called `gazetteer.<LANG>.utf8`.

```
# demo gazetteer for Grossmugl landscape.
# Can be used to better describe the landscape,
# i.e. show labels on landscape features.
# Fields must be separated by vertical line,
# label must not have such a vertical line.
# Comments have this hash mark in first column.
# coordinates in degrees from true North.
# line towards zenith draws a single line strictly upward.
# label is centered on line endpoint.
# Azimuth / Altitude / degrees          / azimuth / label
#         /          / towards zenith / shift   /
113.66   | 5.5      |      4         |   -6    | Leeberg
35       | 1.5      |      2.5       |    0    | Grossmugl
335      | 2        |      2         |    0    | Steinabrunn
305      | 2        |      1         |    0    | Ringendorf
180      | 2        |      2         |    0    | Vienna (30km)
135      | 2        |      0.5       |    0    | Wind power plant Strasshof
```

7.1.8 Packing and Publishing

You likely have developed your landscape already in your own Stellarium user data directory, but when you are happy with your work, you may consider sharing it with other users. For easy distribution and installation via Stellarium's GUI (see section 4.4.5), you should create a ZIP file. This must contain `landscape.ini` and any textures and auxiliary files described above (`description.en.utf8`, `gazetteer.en.utf8` and their translations, horizon files, images for the description ...) used by your landscape. If you want to release the landscape for download,

consider adding a `README.txt` clarifying license and usage conditions. It does not matter whether the ZIP file contains a directory name inside the ZIP. If not, the directory name (ID) of the landscape will be taken from the ZIP file name.

7.2   Creating Panorama Photographs for Stellarium

7.2.1   Panorama Photography

Traditional film-based panorama photography required dedicated cameras with curved film holders and specialized lenses (Figure 7.3).

Digital photography has brought a revolution also in this field, and it has become quite easy to create panoramas simply by taking a series of photographs with a regular camera on the same spot and combining them with dedicated software.

A complete panorama photo visually encloses the observer like the mental image that astronomers have been using for millennia: the celestial sphere. If we want to document the view, say, in a big hall like a church, optimal results will be gained with a camera on a tripod with a specialized panorama head (Figure 7.4) which assures the camera rotates around the *entrance pupil*[9] of the lens in order to avoid errors by the parallax shift observed on photographs taken on adjacent but separate positions.

Often however, both the upper half of the observer's environment (the sky) and the ground the photographer is standing on, are regarded of lesser importance, and only a series of laterally adjacent photographs is taken and combined into a cylindrical or spherical ring that shows the landscape horizon, i.e., where ground and sky meet. If the closest object of interest is farther away that a few metres, requirements on parallax avoidance are far less critical, and the author has taken lots of landscape panoramas with a camera on the usual tripod screw, and even more entirely without a tripod. However, any visible errors that are caused by a shifted camera will require more effort in postprocessing.

When you have no tripod, note that *you must not rotate the camera on your outstretched arm!* Rather, the camera's entrance pupil must be rotated, so you should appear to dance around the camera!

The images should match in brightness and white balance. If you can shoot in RAW, do so to be able to change white balance later. If the camera can only create JPG, ensure you have set the camera to a suitable white balance before taking the photos and not to "auto", because this may find different settings and thus give colour mismatches. Exposure brightness differences can be largely removed during stitching, but good, well-exposed original shots always give better results.

As a general recommendation, the images of a panorama should be taken from left to right, else please accordingly invert some of the instructions given below.

There are several panorama making programs. Often they are included in the software that comes with a digital camera and allow the creation of simple panoramas. Other software titles are available for purchase. However, there is one cost-free open-source program that does everything we need for our task, and much more:

---

[9]In many references you will find "Nodal Point" mentioned here. But see these: `http://en.wik ipedia.org/wiki/Cardinal_point_%28optics%29#Nodal_points`, `http://web.archive. org/web/20060513074042/http://doug.kerr.home.att.net/pumpkin/Pivot_Point.pdf`, `http://www.janrik.net/PanoPostings/NoParallaxPoint/TheoryOfTheNoParallaxPoint.pdf`

Figure 7.3: Zenit "Horizon 202" panorama camera with rotating lens for 35mm film. (Source: Wikipedia, "Horizon202" by BillC - Own Work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - `https://commons.wikimedia.org/wiki/File:Horizon202.jpg`)

Figure 7.4: Automated panorama head. (Source: Wikipedia `https://commons.wikimedia.org/wiki/File:Rodeon_vr_head_01.jpg`)

7.2.2   Hugin Panorama Software

Hugin[10], named after one of the ravens that sits on Odin's shoulder and tells him about the world, is a user-friendly catch-all package with graphical user interface that allows creating panoramas with a single application. Actually, **Hugin** is a GUI application which calls several specialized sub-programs with fitting parameters. The instructions are based on **Hugin V2014.0** and **2015.0**.

Typically digital images come in JPG format with information about camera, lens, and settings stored in invisible metadata in the EXIF format. When **Hugin** reads such images, it can automatically derive focal length, field of view, and exposure differences (exposure time, aperture, color balance) to create panoramas as easily as possible.

After starting **Hugin** for the first time, select [Interface $\rangle$ Expert] to release several options not visible to "beginners". In the Preferences dialog ([Files $\rangle$ Preferences]), edit number of CPU to match the number of cores in your computer and allow parallel processing. E.g., if you have an Intel Core-i7, you usually can set up to 8 cores (4 cores with hyperthreading; but maybe leave one core for your other tasks while you wait for a processing job?). If your PC is equipped with a modern programmable graphics card, you can enable its use in the [Programs] tab with activating "Use GPU for remapping".

After that, we are ready for creating our panoramas.

7.2.3   Regular creation of panoramas

The graphical user interface (GUI) consists of a main menu, symbols, and 4 tabs. We start on the tab Photos.

- [Add images...] Opens a file browser. Select the images which you want to stitch. Usually, lens data (focal length, horizontal field of view[11], ...) are read from the EXIF data. If those are not available (e.g. cheap cameras, images scanned from film), you can enter those data on loading or later. The images are now listed in the file list, and you can edit image parameters by marking one or more, and then choosing from the context menu which you get from pressing the right mouse button. In case you have used different lenses (or inadvertently used different focal lengths of a zoom lens), you can assign separate lenses to the images. Caveat: If you have resized the images, or produced copied on your RAW converter with non-native resolution, the horizontal Field of View (FoV) in **Hugin** may be misidentified. You must edit lens parameters and fill in the field of view from a full-size image. Else the first round of optimisation will run into unsolvable trouble.
- Select one image as *position anchor* (usually the center image), and one as *exposure anchor* (this can be the same image). For our purpose, *the anchor image should face south*.
- Next, we must find common feature points. The next field below provides the required settings. It is recommended to use the **CPFind** command. To avoid finding control points in (moving) clouds, select setting [Hugin's CPFind + Celeste][12]. Then press [Create control points]. This opens a dialog box in which you can see output of the selected feature point extractor. It should finish with a box telling you the number of identified points. In rare cases some images cannot be linked to others, you will have to manually add or edit feature points in those cases.
- Now it's time to start optimisations. On the [Geometric Optimimisation] combo, start with the button [Positions, incremental from anchor], and press [Calculate]. Moments later, a first rough match is available for inspection.
- First open the Preview window (press [Ctrl]+[P] or click the blue icon). Assumed your

---

[10]http://hugin.sourceforge.net/

[11]contrary to Stellarium, field of view (FoV) in **Hugin** means the *horizontal* extent in degrees.

[12]If you forget this, you can remove cloud points by calling **Celeste** in the control point editor later

images cover the full horizon, the window shows an equirectangular area (360 degrees along the horizon and 180 degrees from zenith to nadir). The anchor image should be close to the image center, and the other images should be already well-aligned to both sides. You can set the exact center point by clicking it in the image. If the horizon appears badly warped, use the right mouse key and click on the horizon roughly near -90 or $+90$ degrees (halfway to the left or right).

• Open the OpenGL preview window (press $\boxed{\text{Ctrl}}$+$\boxed{\text{Shift}}$+$\boxed{\text{P}}$ or click the blue icon with GL inside). This panel provides several important views:

   – The $\boxed{\text{Preview}}$ tab is similar to the non-OpenGL preview. You can display an overlay of the control points, which are colored according to match quality. Also, with button $\boxed{\text{Identify}}$ activated, you see the overlapping image frames when you move the mouse over the image.
   – The $\boxed{\text{Layout}}$ tab helps finding links between images.
   – The $\boxed{\text{Move/Drag}}$ dialog may help to interactively adjust a panorama.

   Sometimes the preview image may however be distorted and unusable.

• Open the *Control Points Table* dialog (press $\boxed{\text{F3}}$ or click the "table" button). Here you see the points listed which link two images. Clicking a column label sorts by this column. It is recommended that only neighboring overlapping images should be included here. If you have very large overlap, it is possible that points are found between two images which are not directly adjacent. In the OpenGL preview window, you can use the $\boxed{\text{Preview}}$ or the $\boxed{\text{Layout}}$ tabs to identify those image pairs. Such points should be deleted. In the point table, click on columns "Right Img.", then "Left Img.", and then find pairs like 0/2, 1/3, 2/4 etc. Mark those lines, and delete the points.

• To re-run the optimisation, press the double-arrow icon or the $\boxed{\text{calculate}}$ button in the Optimise/Geometric area.

Preliminary Geometric Optimisation

Now the (usually) longest part begins: Iterative optimisation of the photo matchpoints. If your images were taken on a panorama tripod head, there should only be very few bad matchpoints, e.g. those found on persons or clouds[13] which have moved between photos. For handheld photos, the following considerations should be observed.

The most important line which we want to create in all perfection is the visible horizon, where sky and earth meet. The foreground, usually grassy or rocky, is of lesser interest, and stitching errors in those areas may not even be relevant.

Therefore, matchpoints with large errors in the foreground can be safely removed, while, if necessary, points on the horizon should be added manually. Use the $\boxed{\text{Control Points}}$ tab, select adjacent images (start with 0 on the left and 1 on the right side), and delete the worst-fitting matchpoints closest to the camera (near the bottom of the images). We now start a long phase of re-optimizing and deletion of ill-matching points as long as those are far from the horizon. When all near matchpoints are deleted, the result should already look not too bad.

For continued optimisation, the number of parameters to optimize can be extended. To begin, I recommend $\boxed{\text{Positions and View (y, p, r, v)}}$, which may find a new focal length slightly different from the data in the EXIF tags. Again, delete further foreground points. If after a few rounds you still have bad point distances, try $\boxed{\text{Positions and Barrel Distortion (y, p, r, b)}}$ to balance distortion by bad optics, or even go up to $\boxed{\text{Everything without translation}}$. Optimisation can only reach perfect results if you did not move between exposures. Else, find a solution which shows the least error.

In case you took your photos not on a tripod and moved too much, you may even want to play with the translation options, but errors will be increasingly hard to avoid.

---

[13] You should have created control points with the **Celeste** option!

Using Straight Edges as Guides

If the panorama contains straight lines like vertical edges of buildings, these can be used to automatically get a correctly levelled horizon: Vertical lines are mapped to vertical lines in equirectangular panos! In the Control Points tab, select the image with the vertical edge in both subframes, and mark points on the vertical edge. (switch off auto-estimate!). Likewise, horizontal lines may help, but make sure lines like rooves are perpendicular to your line of view, else the perspective effect causes an inclination.

Multi-ring Panoramas

If you are trying to create a panorama with several rings (horizon, one or two rings below, and nadir area), you must try to create/keep control points that best give a result without visible seams. In this case, and esp. if you have only used a regular tripod or even dared to go for a free-handed panorama, you may observe that it is best to remove control points in neighboring photos in the lower rings, but keep only the "vertical" links between images with similar azimuth.

In total, and if the foreground is not important but only grassy or sandy, the rule of thumb is that the horizon images must be strongly linked with good quality (small errors), while images in the lower rings should be linked mostly to their respective upper photos, but not necessarily to the images to its sides. The resulting panorama will then show a good horizon line, while stitching artifacts in a grassy or otherwise only decorative ground will usually be acceptable and can, if needed, be camouflaged in postprocessing.

This optimisation and editing of control points is likely a longish iterative process, and these are the late night hours where you will finally wish you had used a panorama head...

Masking

If you have images with overlapping areas, you can usually not force **Hugin** to take pixels from the image which you find best. you can however mask off an area from an image which you don't want to see in the output under any circumstances, e.g. a person's arm or foot in one image. Just open the image in the Mask tab and either press **Add new mask** and draw the mask polygon covering the unwanted area, or use the crop settings to define rectangular areas to use.

Exposure disbalance

In the Photos tab, select **Photometric parameters** on the right side. The EV column lists the *Exposure Value*. If you see disbalance here and in the preview window, you can run a photometric optimisation with the lowest button on the Photos tab. Simply select Low dynamic range and press Calculate. The preview should now show a seamless image. If all else fails, you can edit the EV values directly.

Advanced photographers may want to correct exposures in their RAW images before creating JPG or TIF images to combine with **Hugin**. This unfortunately may create exposure disbalance because the EXIF tags may not be adjusted accordingly, so based on different exposure/f-stop conbinations **Hugin** may think it has to re-balance the values. In these cases, don't run the photometric optimiser. Some image exposure values have to be changed manually, and the effect supervised in the preview window. Usually the smooth blending in the subprogam **enblend** called by **Hugin** will hide remaining differences.

Stitching

When you are happy with the panorama in the preview window and the matchpoints promise a good fit, it is time to finally create the panorama image. **Hugin** can create a large number of different projections which all have their application. For Stellarium, we can only use the equirectangular projection. You still have 2 options:

spherical landscapes (see 7.1.3) require single equirectangular images, the maximum size depends on your graphics hardware and **Qt** limitations and is likely not larger than 8192×4096 pixels.

old_style landscapes (see 7.1.4) can use several textures for the ring along the horizon, and one image for the nadir zone. If you need high resolution, you should aim for creating this one.

Sometimes, creating the nadir zone is difficult: this is where usually the view is blocked by the tripod, and we are not interested in views of tripod or our own feet. For our purpose it is usually enough to fill in the feet area using the clone stamp, or a monochrome color, or, for `old_style` landscapes, you can instead insert an oriented site map or wind rose.

There is a button | create optimal size | in **Hugin**. It may recommend a panorama width around 13.000 pixels for an average camera and photos taken with a wide-angle lens. Increasing this size will most likely not lead to higher optical resolution! The panorama width which you can most usefully create depends on the resolution of the source images (which leads to the result given by **Hugin**) and on your needs. If you need arcminute resolution, you would aim for $360 \times 60 = 21600$ pixels, which cannot be loaded into graphics memory in a single piece, i.e., is too large for Stellarium, and must be configured as `old_style` landscape. In this case, 10 or 11 tiles of 2048×2048 pixels (totalling 20480 or 22528 pixels) is the closest meaningful setting, i.e., you could create an image of 20480 pixels width and cut this into usable pieces. Usually, a size of 4096×2048 or 8192×4096 pixels (for better computers) is enough, and can be used in a `spherical` landscape.

We have to edit the file after stitching, therefore select creation of an image in the TIFF format. LZW compression is non-lossy, so use this to keep file size reasonably small.

For regular images, it is enough to create "Exposure corrected, low dynamic range". If you have a problem with persons that have moved between your images, you may want to post-process the final result with import of the distorted sub-images and manually defining the best blending line. For this, find the "Remapped Images" group and again activate "Exposure corrected, low dynamic range".

Now, press the | Stitch! | button in the lower right corner. This opens a helper program which supervises the stitching process. Depending on your computer and size of the image, it will require a few minutes of processing.

In case stitching fails with a cryptic error message, try to add the option --fine-mask to the **enblend** options.

Store a copy of the **Hugin** project file to always be able to go back to the settings you used to create the last panorama. We will get back to it when we want to make a truly calibrated panorama (see 7.3.3).

7.3 Panorama Postprocessing

The image created has to be further processed to be used in Stellarium. The most obvious change is the need for a transparent sky, which we can easily create in programs like **Adobe Photoshop** or the free and open-source **GIMP**. I will describe only the free and open-source solution.

After that, we have to bring the image into shape for Stellarium, which may include some trimming. While we could also slice an image with interactive tools, higher accuracy and repeatable results can be achieved with command-line programs, which makes the **ImageMagick** suite the tool of our choice.

7.3.1 The GIMP

The **GIMP** (GNU Image Manipulation Program) has been developed as free alternative to the leading commercial product, **Adobe Photoshop**. While it may look a bit different, basic concepts

are similar. Not everybody can (or wants to) afford **Photoshop**, therefore let's use the **GIMP**.

Like **Photoshop**, the **GIMP** is a layer-aware image editor. To understand the concept, it is easiest to imagine you operate on a growing stack of overhead slides. You can put a new transparent slide ("layer") on top of the stack and paint on this without modifying the lower layers.

A few important commands:

Zooming Ctrl + Mouse Wheel

Layer visibility and transparency Make sure to have layer dialog shown (Windows ≫ Dockable Dialogs).

A gray bar indicates opacity for the currently active layer. Note the mouse cursor in this opacity bar (often also called transparency bar): near the top of the bar the upward pointer immediately sets percentage. A bit lower the pointer looks different and can be used for fine-tuning.

The most obvious postprocessing need for our panorama is making the sky transparent. The optimal tool usually is the "Fuzzy Select", which is equivalent to the "Magic Wand" tool in **Photoshop**. Simply mark the sky, and then delete it. The checkerboard background indicates transparent pixels.

It sometimes helps to put an intensive bright red or blue background layer under the panorama photo to see the last remaining clouds and other specks. In the layer dialog, create a new layer, bucket-fill with blue or red, and drag it in the layer dialog below the pano layer. Write-protect this layer, work on the image layer, and before exporting the image layer with transparent sky to PNG, don't forget to switch off the background.

We need this layer functionality especially to align the panorama on a calibration grid, see section 7.3.3.

7.3.2 ImageMagick

ImageMagick (**IM**)[14] can be described as "Swiss Army Knife of image manipulation". It can do most operations usually applied to images in a GUI program, but is called from the command line. This allows also to include **IM** in your own command scripts[15]. We will use it to do our final cut and resize operations. I cannot give an exhaustive tutorial about more than a few of **IM**'s functions, but the commands given here should be enough for our purpose.

To open a command window (console, a.k.a. DOS window), press the Windows key and enter cmd, then press ↵ . (On Linux and Mac, you surely know how to open a console window.)

There are some things you might need to know:

- The command line is not your enemy, but a way to call expert tools.
- The Windows command line processor **cmd.exe** is far from user friendly.
- There are remedies and alternatives. See notes on **clink** (7.4.3) for a considerable improvement, and **Cygwin** (7.4.4) for experts.

Command-line magick for spherical landscapes

Let's start with the commands for final dressing of an equirectangular panorama to be used as spherical landscape which has been created in size 4096×2048, but where you have seen that nothing interesting is in the image above $11.25°$. This means we can cut away the sky area and compress the image to 4096×1024 to save graphics memory.[16]

To understand the numbers in the example, consider that in a panorama image of 4096×2048 pixels, 1024 pixels represent $90°$, 512px $= 45°$, 256px $= 22.5°$, 128px $= 11.25°$. To keep a top

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[14]http://www.imagemagick.org/

[15]These may typically be .BAT files on Windows, or various shell scripts on Linux or Mac.

[16]Most modern graphics cards no longer require the "powers of two" image sizes, but we keep this practice to increase compatibility.

line of 11.25°, we keep an image height of $1024 + 128 = 1152$px, but the crop starts at pixel $Y = 1024 - 128 = 896$.

```
convert  landscape.png -crop 4096x1152+0+896
         -resize 4096x1024! landscape_cropped.png
```

Note the exclamation mark in the -resize argument, which is required to stretch the image in a non-proportional way.

Alternatively, you can operate with **IM**'s "gravity", which indicates the corner or edge geometric offsets are referred to. Given that we want the lower part of the image to exist completely, you only need to compute the size of the cropped image:

```
convert  landscape.png -gravity SouthWest -crop 4096x1152+0+0
         -resize 4096x1024! landscape_cropped.png
```

You still need the addition +0+0 in the -crop option, else the image will be cut into several pieces. In the file landscape.ini, you then have to set maptex_top=11.25.

Command-line magick for old_style landscapes

Let us assume we want to create a high-resolution landscape from a pano image of width 16384 which we have carefully aligned and calibrated on an oversized grid template that also shows a measured horizon line (see 7.3.3). Usually it is not necessary to create the full-size image, but only the horizon range, in this high resolution. Assume this image has been aligned and justified on our grid image and is HEIGHT pixels high, the left border is at pixel X_LEFT, and top border (i.e., the point where relevant content like the highest tree is visible) is on pixel Y_TOP. Assume our graphics card is a bit oldish or you aim for maximum compatibility, so we can load only textures of at most 2048 pixels in size. Given that the horizon area usually only covers a few degrees, a vertical extent of 2048px seem a pretty good range for that most interesting zone. The ground can then be filled with some low-resolution image of grass, soil, or a properly oriented site map, or you can use **Hugin** to create a ground image (and using the maximum of 2048×2048 also here usually is far more than enough).

In **GIMP** (or **Photoshop**, ...), we must find the values for X_LEFT, Y_TOP and HEIGHT. HEIGHT is being resized to 2048, strictly, by the exclamation mark in the resize command. We can create our image tiles now with this singular beast of a command line (write all in 1 line!), which puts our files directly into STELLARIUM_LANDSCAPEPATH/LANDSCAPE_NAME:

```
convert PANO.png  -crop 16384xHEIGHT+X_LEFT+Y_TOP +repage
      -resize 16384x2048!
      -type TrueColorMatte -depth 8
      -crop 2048x2048 +repage
       png:STELLARIUM_LANDSCAPEPATH/LANDSCAPE_NAME/Horiz-%d.png
```

This creates 8 images. See section 7.1.4 for the landscape.ini where these images can be referenced. Don't forget to read off top and bottom lines (altitudes in degrees) from your grid, the vertical extent will form the decor_alt_angle, and the bottom line the decor_angle_shift entries in this file.

Creating a ground image for old_style landscapes

When you want a good ground image for an old_style landscape from your panorama and not just fill the groundtex with a monochrome texture or a map, you have to create a ground view in **Hugin**. But you may have already created a huge pano! This can also be used as source image, and a ground shot can be extracted with a reversed operation. In principle, all you need to know is the field of view around the nadir. Figure 7.5 shows a simple configuration file.

```
# hugin project file
#hugin_ptoversion 2
p f0 w2048 h2048 v92 E0 R0 n"TIFF_m␣c:LZW␣r:CROP"
m g1 i0 f0 m2 p0.00784314


# image lines
#-hugin  cropFactor=1
i w16384 h8192 f4 v360 Ra0 Rb0 Rc0 Rd0 Re0 Eev0 Er1 Eb1 r0
  p90 y0 TrX0 TrY0 TrZ0 Tpy0 Tpp0 j0 a0 b0 c0 d0 e0 g0 t0
  Va1 Vb0 Vc0 Vd0 Vx0 Vy0  Vm5 n"Eqirect_Pano360.png"
```

Figure 7.5: Project file `ground.pto` usable to create the ground image with **Hugin** or, on the command line, its **nona** stitcher. The last line, starting with `i`, has been wrapped, but must be 1 line.

Say, the side panels extend down to `decor_angle_shift=-44` degrees, which means you must close the ground with a Nadir $FoV = 2 \times (90 - 44) = 92$. For maximum compatibility, we will again make an image of width and height both 2048px. These values can be found in the p line in Figure 7.5. The i line describes the input image, which is our full equirectangular pano of width `w=` 16384 and height `h=` 8192. The last argument of that line is the image file name.

For processing, we do not use the **Hugin** GUI, but simply the command line. The actual program to call is **nona**. If your stitched panorama is a 16-bit TIFF, **nona** will also make a 16-bit image, but our textures are limited to 8-bit PNGs. We apply our most useful tool, **convert** from the **ImageMagick** suite.

```
nona -v -m PNG  ground.pto -o ground.png
convert ground.png -depth 8 ground_8bit.png
```

The file `ground_8bit.png` is then used in the `groundtex` field on `landscape.ini`.

7.3.3 Final Calibration

The creation of a *calibrated panorama* (which can be regarded as dependable proxy for further measurements taken inside Stellarium) requires reference measurements to match the photos against. We must take azimuth/altitude measurements with a theodolite or total station, in the optimal case along the full horizon, and in addition I recommend to take azimuth and altitudes of some distinct features along the horizon which must also be visible in the photographs: mountain summits, electrical towers, church towers, . . .

I recommend you create grid templates of the sizes you are going to create, e.g. 4096, 8192, 16386 and 20480 pixels wide with some diagram tool. On these, you can then also draw the measured horizon line.

Now, load a panorama on top of this in the **GIMP**, i.e., copy it into a separate layer over the grid image, and set it semi-transparent.

Try to align the center of the image (where the geometric anchor has been defined; remember: this should be the image pointing south!) with the measured horizon line or the distinct features.

The optimal solution consists of a photo panorama which aligns perfectly with the measured line and features. We now have to iteratively bring deviations to a minimum. The process depends on processor speed, image size, your training and – most of all – your requirements in accuracy!

In the **GIMP**, load your grid image with horizon line. Now select `File ≫ Open as Layers. . .`, load your photo panorama, and then set layer transparency in the `Layers` dialog to about 50%.
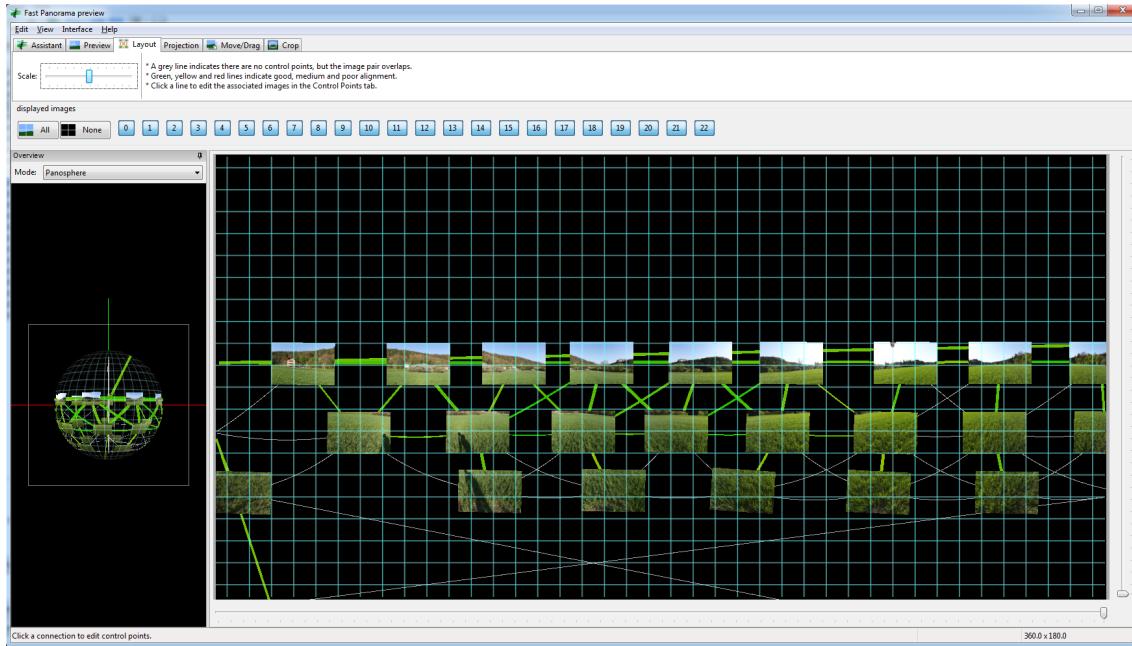
Figure 7.6: **Hugin**'s Fast Panorama Preview can be used to check which images are connected to its neighbours. Most important are good matches along the horizon, the images in the lower rows are clearly less important. If captured on a tripod, they should still match.

Select the double-arrow tool to move the panorama via mouse drag and cursor keys over the grid, and align the outline of the photo horizon's southern point with the measured line. Now it's time to estimate the quality of the panorama.

In **Hugin**'s Photos tab, select the Positions view on the right side. Now you see "Yaw", "Pitch" and "Roll" values of camera-to-world orientation listed in the photos list. It should now be possible, by changing the values *only for the anchor image* and re-optimizing, to come to a panorama with only minimal error. In the process, start with Optimising Positions incremental from anchor, then go for view and barrel optimisation, and so on. Always try to remove foreground match points which have large error and are irrelevant for the task to match the horizon. Those are especially cross-matches of horizon and subhorizon rows of images. Only vertically and horizontally adjacent images should be required to match. For handheld panoramas, also links between adjacent images in the non-horizontal rows are usually too erroneous to be useful, just remove these match points. Use the Layout tab in the Fast Panorama Preview to see the relations between images (Fig. 7.6): Red lines have big errors, green lines are good, thin gray lines indicate possible overlap without specified match points. After each optimisation step, export a new pano image, load as layer in **GIMP**, and check again.

Basic rules to observe (use obvious inverses).
- If image aligns well in azimuth but overshoots the grid to the right: Increase yaw accordingly ($0.022°$/pixel if image is 16384 pixels wide).
- If the north end (left and right borders) is higher than the southern contact point: Increase pitch angle.
- If north and south points are OK, but the western (right) half is higher than the eastern (left) half: Increase Roll angle.

The corrections required for pitch and roll may be surprisingly small!

Within a few rounds of adjustments, panorama creation, adding as layer in the image editor, and comparing to the reference data, you should achieve a match to fit your needs.

In case you have taken photographs in several rings but without a panorama tripod, you may have to first align only the horizontal images (deselect the lower images to exclude from optimisation), and when the horizon ring is aligned perfectly, deactivate further optimisation in **Hugin** for those photos while "attaching" (optimising) the lower photos. In **Hugin**'s Photos tab, select Optimise 〉 Geometric 〉 Custom Parameters . This opens an extra tab Optimiser , where you can fine-tune your needs: Switch off all variables for the photos in the horizon ring, and make sure the lower photos fit in the preview after optimisation.

It may even help to define that the lower rows have been taken with a different Lens, so the field of view and distortion settings of the horizon row will be used as it had been found during the horizon-only match.

By now you should have enough experience what level of error may be acceptable for you.

7.3.4 Artificial Panoramas

I have created a website[17] where you can enter geographical coordinates and download a file `pano.kml` which helps with image creation from **Google Earth** imagery. Store this file for a site, let us call it *MYPLACE*, into a new directory `GE_MYPLACE` inside your `landscapes` directory.

Store all scenes visible from the respective viewpoint *MYPLACE* as picture into one common folder in your `landscapes/GE_MYPLACE` under the viewpoint name, e.g., `75-30.jpg`, which means 75 degrees from Nadir, azimuth 30 degrees. Also, double-click the pano entry or the marker in **Google Earth** to open a window with the basic content of your `landscape.ini`. Copy and paste from there into a new file `landscape.ini` and adjust the obvious entries. Complete as required with the entries described in section 7.1.3.

On loading of the images, Hugin will not be able to detect any EXIF lens data and ask you for the horizontal field of view. Enter 60 degrees, which is the standard value for **Google Earth** screenshots[18].

The viewpoint names translate almost directly to the yaw and pitch angles which you can enter in the image list in **Hugin**'s Photos tab. For example, switch to the Positions display on the right window edge in the Photo tab, mark all images that start with `25-` and assign a pitch angle of $-90 + 25 = -65$. The second part of the names is directly the azimuth. In this case, don't run the optimizer, but you can immediately set an output resolution and stitch (see 7.2.3). To get rid of the image decorations (compass etc), apply masks[19]. Postprocessing steps are the same as for photo-panoramas: make sky invisible, crop, etc.

It is also interesting to switch on the 3D buildings layer before creating the images. If temples or other buildings are accurate, this will give an even closer approximation to what would be visible on-site. Note however that not every building will be modelled in usable quality, and that usually vegetation is not included in the 3D buildings layer. Also, if you are too close to buildings, they may be cut away by the *near clipping plane* of the rendering.

These images, based on **Google Earth** imagery and the SRTM topographic model, seem usable as *first rough approximation* to a photo-based or surveyed panorama. Note that it is definitely not accurate enough for representing nearby horizon features or critically important mountain peaks, and please note that Google has image copyright which at least requires you to acknowledge when displaying these pictures.

---

[17]`http://homepage.univie.ac.at/Georg.Zotti/php/panoCam.php`

[18]Note that if you work with **Google Earth Pro**, you can create different FoV!

[19]There is a wide overlap in the images to allow generous trimming.

7.3.5 Nightscape Layer

Since version 0.13, Stellarium can simulate artificial illumination, like streetlamps, bright windows, or the skyglow over cities (Zotti and Wuchterl, 2016). One way to create this layer is to make 2 panorama series during the day and night and process these in the same **Hugin** project to align those photos, and then stitch two separate images by selecting either the daylight or the nighttime shots. The night panorama has to be processed to remove stars, airplanes, etc.

The other way is a simple layer overpainted in the image processing program. As rough recommendation, use several layers to prepare this feature:

- Put a semitransparent black layer over your daylight image, this helps you to place your painted pixels.
- Paint windows, street lamps, signs, ... You may apply a layer style to produce some glow.
- To draw an impression of more light in the atmosphere (city skyglow), use a gradient with some brownish color. Generally the color depends on the appropriate mix of city lights (sodium, mercury vapour, etc.). Note that on the city outskirts a simple vertical gradient will not work, towards the city the horizon is much brighter. Use a huge but weak brush to make a more spotty sky.
- Use the existing landscape as template for the layer mask for this gradient sky layer. (You want to hide skyglow by leaves in the foreground!)
- If you want to add only a few lights to an `old_style` landscape, you need to provide only the panels showing those lights. Just load a side panel for reference, place a new layer on top, and paint the lights on windows, lamps etc. There is no light option for the ground texture. This makes `old_style` landscapes best suited for localized light pollution, not city skyglow.

The resulting image is then declared in the `maptex_illum` line of `landscape.ini`. Try also to balance the global strength of light pollution with the `light_pollution` key, and a probable minimal brightness with the `minimal_brightness` key.

Try to match the visual appearance, not necessarily what photographs may have recorded. E.g., the *Grossmugl* sky shows horizon glow mostly towards the city of Vienna, where long-time exposures may already be saturated.

The possibilities seem limited only by your time and skills!

7.4 Other recommended software

Here is a short collection of other useful programs for (panorama) image manipulation and other tasks on Windows.

7.4.1 IrfanView

IrfanView is a free image viewer for Windows with many options. It can show almost any image format, including several camera RAW formats, in windowed and full-screen mode. It is definitely preferrable over any image viewer built into Windows. Unfortunately however, it has no panorama viewer function!

7.4.2 FSPViewer

FSPViewer[20] by Fulvio Senore is an excellent panorama viewer for equirectanglar images. Images centered along the horizon can be viewed directly, while settings for images with different minimum and maximum angles, as well as "hotspots" (similar to hyperlinks) which move to neighboring panoramas, can be configured in an `.FSV` text file like figure 7.7.

---

[20]Further details are available on its home page `http://www.fsoft.it/FSPViewer/`.

```
ImageName=Horizon_Rosenburg.jpg
WindowTitle=Horizon_Rosenburg
hFov=70
#Formula: HP=100*(h/2-upper)/(lower-upper) in Hugin crop, or
#         HP=100*zeroRow/imgHeight
HorizonPosition=33.8
```

Figure 7.7: FSP configuration file (example)

7.4.3 Clink

Clink[21] is a command line enhancement for Windows developed by Martin Ridgers. If you have ever worked under a Linux **bash**-like command line, you will easily feel that Windows' **cmd.exe** is extremely limited. **Clink** provides several useful features, most notably a really usable command-line completion. It is not essential for our tasks, but a general improvement of usability of the Windows command line which else has not caused me any trouble.

7.4.4 Cygwin

Compared to Linux, the command line of Windows can be a humbling experience. None of the wonderful helpers taken for granted on Linux are available. **Cygwin**[22] provides a command line console with **bash** shell and all the niceties like **make**, **awk**, **sed**, etc. which seem essential for routine work. If you are used to Linux tools, use inline scripts in your Makefiles and need more than **Clink** can offer, you should install **Cygwin**.

7.4.5 GNUWin32
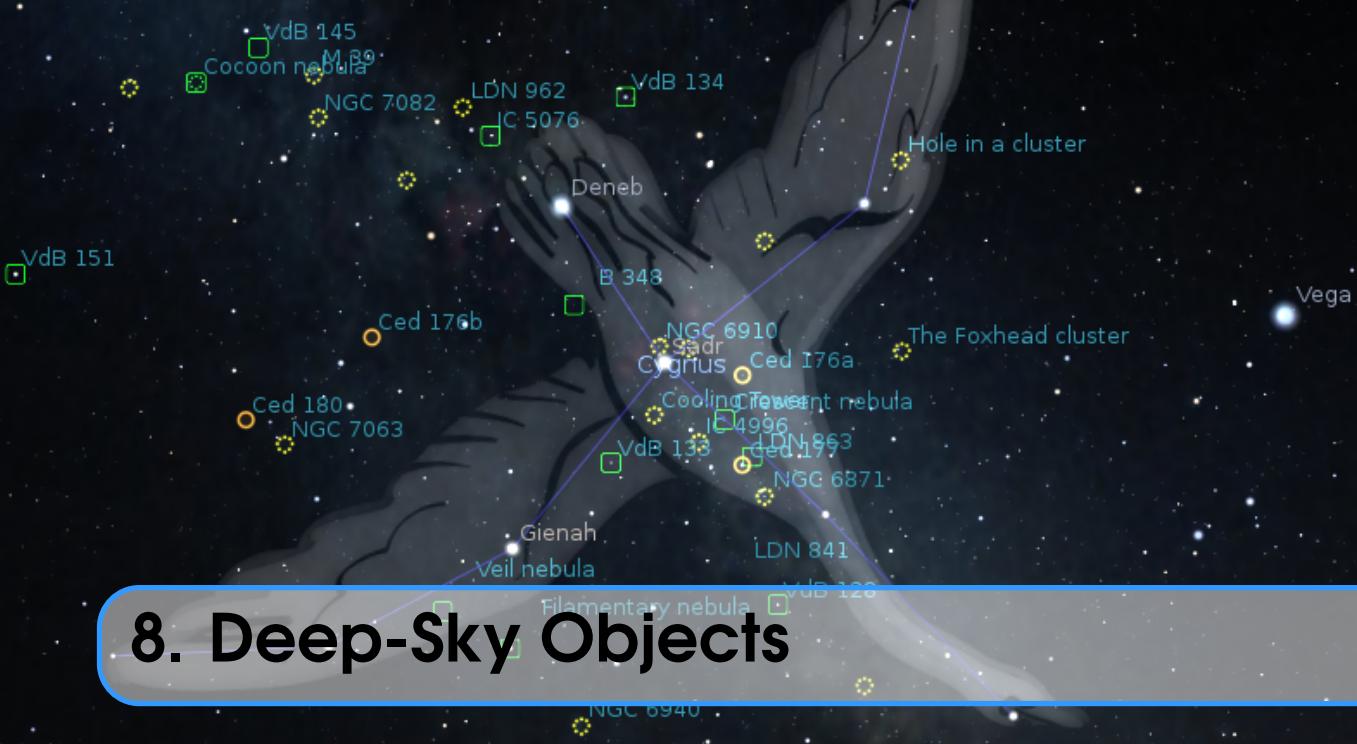
Alternative to **Cygwin**, several of those nice tools (**sed**, **awk** etc.) have also been made available as standalone commands for Windows. If you don't need the inline scripting capabilities in Makefiles which you would get from **Cygwin** but just want to call **awk** or **sed** inside your **.BAT** scripts, maybe this is enough.

7.4.6 WSL – Windows Subsystem for Linux

Finally, the 64-bit editions of Windows 10 come with an optional feature that allows you to install a complete Linux distribution like Ubuntu inside your Windows system. While you cannot run graphic applications, all the command-line tools are available.

---

[21]http://mridgers.github.io/clink/
[22]https://cygwin.com/index.html

8. Deep-Sky Objects

Since version 0.10.0 Stellarium uses the "json" cataloguing system of configuring textures. At the same time the Simbad online catalogue was added to the search feature, making the catalog somewhat redundant and used now only as a first search point or if there is no Internet connection.

If the object has a name (not just a catalogue number), you should add one or more records to the `.../nebulae/default/names.dat` file (where `...` is either the installation directory or (preferrably) the user directory). See section 8.1.2 Modifying `names.dat` for details of the file format.

If you wish to associate a texture (image) with the object, you must add a record to the `.../nebulae/default/textures.json` file. See section 8.1.3 for details.

If you wish to associate an outline with the object, you must add the series of lines to the `.../nebulae/default/outlines.dat` file. See section 8.1.4 for details.

8.1 Stellarium DSO Catalog

Stellarium's DSO Catalog contains over 94000 objects[1] (up to 15.5^m for galaxies) and is available for end users as collection of files:

`catalog.txt`	Stellarium DSO Catalog in ASCII format for editing data
`catalog.dat`	Stellarium DSO Catalog in zipped binary format for usage within Stellarium
`names.dat`	List of proper names of the objects from file `catalog.dat`

An edited ASCII file can be converted into binary format through enabling an option in the file `config.ini` (See 5.4):

```
[devel]
convert_dso_catalog = true
```

---

[1] An extended edition of this catalog with over one million objects may be downloaded and installed manually (see section 5.5.2).

The file `catalog.txt` should be put into the directory `.../nebulae/default/` and you should create an empty file `catalog.pack` to storing the binary catalog. After converting the data into binary format you should gzip them by the command

```
gzip -nc catalog.pack > catalog.dat
```

Stellarium DSO Catalog contains data and supports the designations for follow catalogues[2]:

NGC	New General Catalogue
IC	Index Catalogue
M	Messier Catalog
C	Caldwell Catalogue
B	Barnard Catalogue (Barnard, 1927)
SH2	Sharpless Catalogue (Sharpless, 1959)
VdB	Van den Bergh Catalogue of reflection nebulae (van den Bergh, 1966)
RCW	A catalogue of Hα-emission regions in the southern Milky Way (Rodgers, Campbell, and Whiteoak, 1960)
LDN	Lynds' Catalogue of Dark Nebulae (Lynds, 1962)
LBN	Lynds' Catalogue of Bright Nebulae (Lynds, 1965)
Cr	Collinder Catalogue (Collinder, 1931)
Mel	Melotte Catalogue of Deep Sky Objects (Melotte, 1915)
PGC	HYPERLEDA. I. Catalog of galaxies[3]
UGC	The Uppsala General Catalogue of Galaxies
Ced	Cederblad Catalog of bright diffuse Galactic nebulae (Cederblad, 1946)

V0.16.0   **Arp** Atlas of peculiar galaxies (Arp, 1966)

VV The catalogue of interacting galaxies by Vorontsov-Velyaminov (Vorontsov-Velyaminov,
V0.16.0   Noskova, and Arkhipova, 2001)

V0.16.0   **PK** Version 2000 of the Catalogue of Galactic Planetary Nebulae (Kohoutek, 2001)

V0.16.1   **PN G** The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Acker et al., 1992)

V0.16.1   **SNR G** A catalogue of Galactic supernova remnants (Green, 2014)

V0.16.1   **Abell** A Catalog of Rich Clusters of Galaxies (Abell, Corwin, and Olowin, 1989)

V0.18.0   **HCG** Atlas of compact groups of galaxies (Hickson, 1993)

V0.18.2   **ESO** ESO/Uppsala Survey of the ESO(B) Atlas (Lauberts, 1982)

VdBH Catalogue of southern stars embedded in nebulosity (van den Bergh and Herbst,
V0.19.2   1975)

DWB Catalogue and distances of optically visible H II regions (Dickel, Wendker, and
V0.19.2   Bieritz, 1969)

Cross-index data for Stellarium's DSO Catalog is partially obtained from "Merged catalogue of reflection nebulae" (Magakian, 2003) and astronomical databases SIMBAD[4] (Wenger et al., 2000) and NED[5].

Distances for some deep-sky objects obtained from "The Magellanic Cloud Calibration of the Galactic Planetary Nebula Distance Scale" (Stanghellini, Shaw, and Villaver, 2008), "A 1.4 GHz Arecibo Survey for Pulsars in Globular Clusters" (Hessels et al., 2007), "Distance measurements of LYNDS galactic dark nebulae." (Hilton and Lahulla, 1995) and "A Catalog of Parameters for Globular Clusters in the Milky Way" (Harris, 1996).

---

[2]Abell Catalog of Planetary Nebulae has been added in v0.18.2 and removed in v0.20.1
[3]The PGC and UGC catalogues are partially supported
[4]SIMBAD Astronomical Database — `http://simbad.u-strasbg.fr/simbad/`
[5]NASA/IPAC Extragalactic Database (NED) — `https://ned.ipac.caltech.edu/`

8.1.1 Modifying catalog.dat

This section describes the inner structure of the files `catalog.dat` (binary format) and `catalog.txt` (ASCII format). Stellarium can convert ASCII file into the binary format file for faster usage within the program.

Each line contains one record, each record consisting of the following fields with *tab* char as delimiter:

Column	Type	Description
1	integer	Deep-Sky Object Identificator
2	float	RA (decimal degrees)
3	float	Dec (decimal degrees)
4	float	B magnitude
5	float	V magnitude
6	string	Object type (See section 8.1.1 for details).
7	string	Morphological type of object
8	float	Major axis size or radius (arcmin)
9	float	Minor axis size (arcmin)
10	integer	Orientation angle (degrees)
11	float	Redshift
12	float	Error of redshift
13	float	Parallax (mas)
14	float	Error of parallax (mas)
15	float	Non-redshift distance (Mpc for galaxies, kpc for other objects)
16	float	Error of non-redsift distance (Mpc for galaxies, kpc for other objects)
17	integer	NGC number (New General Catalogue)
18	integer	IC number (Index Catalogue)
19	integer	M number (Messier Catalog)
20	integer	C number (Caldwell Catalogue)
21	integer	B number (Barnard Catalogue)
22	integer	SH2 number (Sharpless Catalogue)
23	integer	VdB number (van den Bergh Catalogue of reflection nebulae)
24	integer	RCW number (A catalogue of Hα-emission regions in the southern Milky Way)
25	integer	LDN number (Lynds' Catalogue of Dark Nebulae)
26	integer	LBN number (Lynds' Catalogue of Bright Nebulae)
27	integer	Cr number (Collinder Catalogue)
28	integer	Mel number (Melotte Catalogue of Deep Sky Objects)
29	integer	PGC number (HYPERLEDA. I. Catalog of galaxies); partial
30	integer	UGC number (The Uppsala General Catalogue of Galaxies); partial
31	string	Ced identificator (Cederblad Catalog of bright diffuse Galactic nebulae)
32	integer	Arp number (Atlas of Peculiar Galaxies)
33	integer	VV number (The catalogue of interacting galaxies)
34	string	PK identificator (Catalogue of Galactic Planetary Nebulae)
35	string	PN G identificator (The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae)
36	string	SNR G identificator (A catalogue of Galactic supernova remnants)
37	string	Abell identificator (A Catalog of Rich Clusters of Galaxies)
38	string	HCG identificator (Atlas of compact groups of galaxies)
39	string	ESO identificator (ESO/Uppsala Survey of the ESO(B) Atlas)

40	string	VdBH identificator (Catalogue of southern stars embedded in nebulosity)
41	integer	DWB identificator (Catalogue and distances of optically visible H II regions)

Types of Objects

Possible values for type of objects in the file `catalog.dat`.

Type	Description
G	Galaxy
GX	Galaxy
AGX	Active Galaxy
RG	Radio Galaxy
IG	Interacting Galaxy
GC	Globular Cluster
OC	Open Cluster
NB	Nebula
PN	Planetary Nebula
DN	Dark Nebula
RN	Reflection Nebula
C+N	Cluster associated with nebulosity
HII	HII Region
SNR	Supernova Remnant
SNC	Supernova Candidate
SNRC	Supernova Remnant Candidate
BN	Bipolar Nebula
EN	Emission Nebula
SA	Stellar Association
SC	Star Cloud
CL	Cluster
IR	Infra-Red Object
QSO	Quasar
Q?	Possible Quasar
ISM	Interstellar Matter
EMO	Emission Object
LIN	LINEAR-type Active Galaxies
BLL	BL Lac Object
BLA	Blazar
MOC	Molecular Cloud
YSO	Young Stellar Object
PN?	Possible Planetary Nebula
PPN	Protoplanetary Nebula
*	Star
**	Double Star
MUL	Multiple Star
SY*	Symbiotic Star
EM*	Emission-line Star
CLG	Cluster of galaxies
empty	Unknown type, catalog errors, *Unidentified Southern Objects* etc.

8.1.2 Modifying names.dat

Each line in the file `names.dat` contains one record. A record relates an extended object catalogue number (from `catalog.dat`) with a name. A single catalogue number may have more than one record in this file.

The record structure is as follows:

Offset	Length	Type	Description
0	5	%5s	Designator for catalogue (prefix)
5	15	%d	Identificator for object in the catalog
20	60	%s	Proper name of the object (translatable)

If an object has more than one record in the file `names.dat`, the last record in the file will be used for the nebula label.

8.1.3 Modifying textures.json

This file is used to describe each nebula image. The file structure follows the JSON format, a detailed description of which may be found at `www.json.org`. The `textures.json` file which ships with Stellarium has the following structure:

serverCredits (optional) a structure containing the following key/value pairs:

    short a short identifier of a server where the json file is found, e.g. "ESO"

    full a longer description of a server, e.g. "ESO Online Digitised Sky Survey Server"

    infoURL a URL pointing at a page with information about the server

imageCredits a structure containing the same parts as a serverCredits structure but referring to the image data itself

shortName an identifier for the set of images, to be used inside Stellarium

minResolution minimum resolution, applies to all images in the set, unless otherwise specified at the image level

maxBrightness the maximum brightness of an image, applies to all images in the set, unless otherwise specified at the image level

subTiles a list of structures describing indiviual image tiles, or referring to another json file. Each subTile may contain:

    minResolution

    maxBrightness

    worldCoords

    subTiles

    imageCredits

    imageUrl

    textureCoords

shortName (name for the whole set of images, e.g. "Nebulae")

miniResolution (applies to all images in set)

alphaBlend (applies to all images in set)

subTiles list of images. Each image record has the following properties:

    imageCredits (itself a list of key/pairs)

    imageUrl (e.g. file name)

    worldCoords (a list of four pairs of coordinates representing the corners of the image)

    textureCoords (a list of four pairs of corner descriptions. i.e. which is top left of image etc)

    minResolution (over-rides file-level setting)

    maxBrightness

Items enclosed in Quotation marks are strings for use in the program. Syntax is extremely

important. Look at the file with a text editor to see the format. Items in <> are user provided strings and values to suit the texture and source.

```
{
  "imageCredits"   : { "short" : "<author␣name>" ,
                       "infoUrl" : "http://<mysite.org>"
                     },
  "imageUrl"       : "<myPhoto.png>",
  "worldCoords"    : [[[ X0, Y0], [ X1, Y1], [ X2, Y2], [ X3, Y3] ]],
  "textureCoords"  : [[[ 0,0],[1,0],[1,1],[0,1]]],
  "MinResolution"  : 0.2148810463,
  "maxBrightness"  : <mag>
},
```

where

worldCoords Decimal numerical values of the J2000 coordinates (RA and dec both in degrees) of the corners of the texture. These values are usually given to 4 decimal places.

textureCoords Where 0,0 is South Left, 1,0 the South Right, 1,1 North Right, 0,1 North Left corners of the texture.

minResolution UNDOCUMENTED VALUE! Sorry!

maxBrightness total object brightness, magnitude

Calculating of the coords of the corners of the images (plate solving) is a time consuming project and needs to be fine tuned from the screen display. As most images will be two dimensional, display on a spherical display will limit the size to about 1 degree before distortion becomes evident. Larger images should be sectioned into a mosaic of smaller textures for a more accurate display.

8.1.4 Modifying outlines.dat

V0.16.1   Each line in the file outlines.dat contains three "columns" of data for outline elements. The structure for each line is as follows:

Offset	Length	Type	Description
0	8	%d	Right ascension (decimal hours)
10	18	%d	Declination (decimal degrees)
20	60	%s	Command

Coordinates for each point of outline is represented in the equatorial coordinate system for epoch J2000.0. The possible values of the third "column" (*Command*) are:

start This command marks a start point of the outline. This command should also contain the designation of the deep-sky object.

vertex This command marks an intermediate point of the outline.

end This command marks an end point of the outline.

Example for outline of M42:

```
05.56401  -05.49880  start   M 42
05.56759  -05.39201  vertex
05.56635  -05.31749  vertex
05.57158  -05.21922  vertex
05.57601  -05.21716  vertex
05.58830  -05.30164  vertex
05.59140  -05.34341  vertex
05.59028  -05.37076  vertex
05.59008  -05.38175  vertex
05.59581  -05.37159  vertex
05.59943  -05.47123  vertex
05.59912  -05.65838  vertex
```

```
05.59520  -05.73212 vertex
05.58490  -05.68102 vertex
05.56948  -05.57675 end
```

The format of the file `outlines.dat` is compatible with the similar file of the **SkyChart/-Cartes du Ciel** planetarium.

8.2 Adding Extra Nebula Images

GLENN NEWELL

Figure 8.1: Screen shot of nebula images displayed in Stellarium

In previous versions of this guide, the technique for preparing Deep Space Object (DSO) images for inclusion in Stellarium involved *plate solving* the image to find its center on the sky, and then calculating the corners of the image in the World Coordinate System (WCS[6]) using the scale of the image, arcseconds/pixel.

The problem with that approach is that it did not account for any spatial distortion in the image, due to telescope optics or sensor tilt, etc. This resulted in a labor intensive manual process of trial and error to adjust the WCS corners of the image until the stars in the image aligned with those displayed in Stellarium.

Fortunately, this problem has been solved for us by astronomers with similar needs, extending *FITS*[7] file headers to include information on how to map every pixel in an image correctly onto WCS coordinates. This information can be added to your image when you plate solve it on **nova.astrometry.net**, or similar services (local copies of **astrometry.net**, such as **ansvr**, or in **Pixinsight**, etc.). This system of correcting for distortions in astronomical images was refined for the Spitzer Space Telescope[8].

It is now possible to utilize this pixel to WCS transformation data included in plate solved images to prepare images for Stellarium that map perfectly to the Stellarium sky without manual WCS corner adjustments.

---

[6]https://fits.gsfc.nasa.gov/fits_wcs.html

[7]The *Flexible Image Transport System* is the dominating image format used in astronomy.

[8]https://www.cs.helsinki.fi/group/goa/viewing/viewtransf/viewTrans.html

There are **Python** libraries, namely **astropy** and a related "channel" **astroquery**, that can automate some or all of the needed steps, and there are both manual and fully automated scripts for that purpose available on Stellarium's Github site. These scripts can be run on Windows, Mac, or Linux platforms, using the **Anaconda Python** distribution.

8.2.1 Image requirements for inclusion in Stellarium

The final image must be aligned with the equatorial (J2000.0) coordinate system so that north is directly up and not inverted side to side or up and down as can happen with photos taken with a diagonal mirror in the path (In the WCS system, "Parity" must be 1.)

Next you will need to crop and/or rescale the picture, setting the main feature at the center and making the cropped size a power of 2, e.g. 64, 128, 256, 512, 1024 or 2048 pixels square (or elongated like 512×1024). If this requirement is not met, your textures may not be visible, or graphics performance may be seriously impacted on some systems. Textures larger than 2048 may only be supported on high-end hardware. Images must be in PNG format. When cropping, make sure you leave at least six prominent background stars for *plate solving*). The next step is to process your photo to make the background black, really black. This will ensure that your background will meld with the Stellarium background and not be noticed as ugly gray square. Do not use "transparent" pixels available in the PNG format as they will show as white, not black, in Stellarium.

Images covering more than 10 degrees of sky should be divided into separate images, and images with pixel scales less than 1 arcsec per pixel should be rescaled so as to have a pixel scale of 1 arcsec per pixel or larger.

8.2.2 Processing requirements

- **Python 3.7** (Anaconda 64 bit installer[9]) During installation, follow directions, taking defaults to install for just your user (vs. everyone on your computer)
- **Astropy** (included in Anaconda)
- **Astroquery** (latest version) To install on Windows, open an "Anaconda Prompt". On Mac and Linux, just open a terminal. At the prompt, enter:

```
pip install --pre --upgrade astroquery
```

- For the fully automated process:
  - An API Key from your account at `http://nova.astrometry.net`:
    * Create an account (or log in with google, etc.) at `http://nova.astrometry.net`
    * On the API tab, copy your API key (shown in green)
    * Using a text editor (e.g., **Notepad++** on Windows, **Text Wrangler** on Mac OS), paste that key over the X's in `Stellarium_Nebulae_Images_Prep.py`'s `ast.api_key = 'XXXXXXXXXXXXXXXX'`
- For the more manual process:
  - Images plate solved at `http://nova.astrometry.net` (or **Pixinsight** – not yet tested) so that WCS data is created
  - Graphics software to flip, rotate, scale, etc. and save as `.png`, e.g., **Photoshop**, **GIMP**, **Pixinsight**, etc.

Script and Shortcut placement

Download the Python scripts from Stellarium's site at Github[10]:
- `WCS_corners.py` script

---

[9]`https://www.anaconda.com/distribution/`
[10]`https://github.com/Stellarium/stellarium-data/adding-nebula-images`

- `Stellarium_Nebulae_Image_Prep.py` script

Windows

- Place the two `.py` and `.bat` scripts into `%USERPROFILE%\Anaconda3\`
- Place the two Shortcuts on your desktop or an `astro tools` folder (optional)
- You can now drag and drop one or more images or `wcs.fits` files onto the shortcuts (or `.bat` scripts) for processing

Mac

- Place the two `.py` script files in the `anaconda3` directory, which should be inside your home directory (the directory with your username).
- Place the two `.app` files on your desktop or an `astro tools` folder (optional)
- You can now drag and drop one or more images or `wcs.fits` files onto the **Automator** app icons for processing

Linux

- Place the two `.py` script files in the `anaconda3` directory, which should be inside your home directory (the directory with your username).
- Place the two `.desktop` files on your desktop or an `astro tools` folder (optional)
- You can now drag and drop one or more images or `wcs.fits` files onto the desktop icons for processing

8.2.3 Manual processing

We present the more manual of the two workflows and script first, **WCS_Corners.py**, so you understand the process, before introducing the completely automated image processing pipeline. It is also possible that if plate solving fails in the fully automated script, you could continue, using this manual process:

Plate Solve

- Plate solve your image @ `nova.astrometry.net` (Fig. 8.2)
- Note *pixel scale* and *orientation*

Adjust Parity

- Download the `wcs.fits` file from the "Results" page and run **WCS_Corners.py** on it (Fig. 8.3).
- If *Parity* is -1, flip your image horizontally (do this before rotate step below)

Rotate Rotate your image so "up" is exactly "North". i.e., if the orientation of your image was "261 degrees East of North" then rotate your image 261 degrees CW.

"Blacken" Sky Fill in the blank areas of your rotated image with black pixels, and set your "sky" background to be black.

Crop Crop your image so that both *x* and *y* dimensions are powers of two pixels, e.g. 512×512, 1024×1024, 2048×2048, 1024×2048, etc.

Save PNG

- Save your image as `.png` file
- Place a copy into the `%USERDIR%/nebulae/default` directory

Plate Solve final image

- Plate Solve your flipped, rotated, and cropped image again @ `nova.astrometry.net`
- Download the new `wcs.fits` file.

Calculate WCS corners

- Run **WCS_Corners.py** on the final `wcs.fits` file
- Edit Stellarium's `textures.json` with the image file name and the generated world coordinates

Finalize image Try to minimize the number of stars visible around your nebula in your image. Stellarium draws its own stars, and a rectangle of excessive stars may look bad. Just blacken

them out.

Restart Stellarium View your image in Stellarium (and adjust `maxBrightness` in `textures.json` if needed)
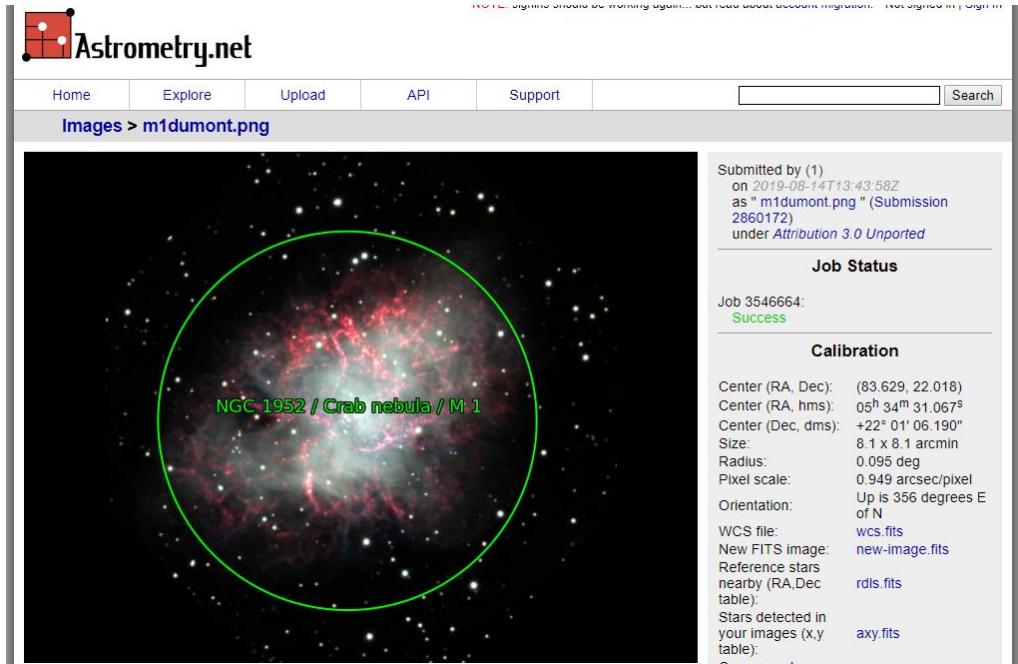
Figure 8.2: Online plate solving

Figure 8.3: Python processing. If you just leave a space after `python WCS_corners.py`, you can drag and drop your `wcs.fits` file into Windows' Anaconda Prompt window.

Some additional information you should be aware of:

- Images in Stellarium are NOT tied to an object, just placed on the sky by `worldCoords`
  - So multiple image can overlap. E.g., the bubble nebula has overlapping textures
  - Black is rendered transparent
  - "Transparent" areas of `.png` show as white
- See section 5.1 on Directories for where to put your own copy of the default images + yours, so yours won't get overwritten by Stellarium Updates
- If plate solve fails: adjust gamma/blackpoint so "only" stars are showing (Fig. 8.4)

$\rightarrow$
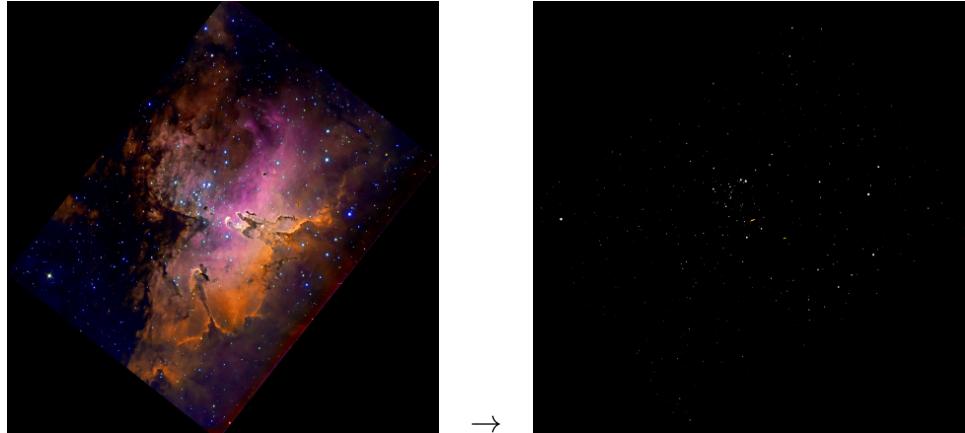
Figure 8.4: Reduce gamma to temporarily help the plate solving algorithm finding stars.

Stellarium keyboard shortcuts you may find useful when adding images:

F3	brings up object search – Tab through search results
G	to remove ground (in case your object is currently behind the landscape)
A	to remove atmosphere (in case it is daytime)
I	to toggle nebulae images on and off – use to test star alignment
M	to toggle Milky Way on and off
/	to zoom into selected object
\	to zoom back out

8.2.4 Automated processing

With the recent addition of **astrometry.net** queries to the Python **astroquery** library it is now possible to automate the entire image processing pipeline as well as automatically create full `.json`

Figure 8.5: Automated Python processing with **Stellarium_Nebulae_Image_Prep.py**

entries for each image for inclusion in the `textures.json` file. The python script for this is **Stellarium_Nebulae_Image_Prep.py**. Wrapper scripts **Stellarium_Nebulae_Image_Prep.bat** and **Stellarium_Nebulae_Image_Prep.sh** are also included so you can process multiple images at once. With the desktop links you can even process one or more `.jpg` or `.tiff` files by drag and drop, on Windows, Mac, and Linux systems.

Figure 8.5 is an example run of **Stellarium_Nebulae_Image_Prep.py**. This converts (rotates, scales, etc.) the JPEG image as seen in Fig. 8.6, and a `.json` file for inclusion in `textures.json` (Fig. 8.7), along with two "unstretched" `_stars.jpg` images used for plate solving, which can be deleted.
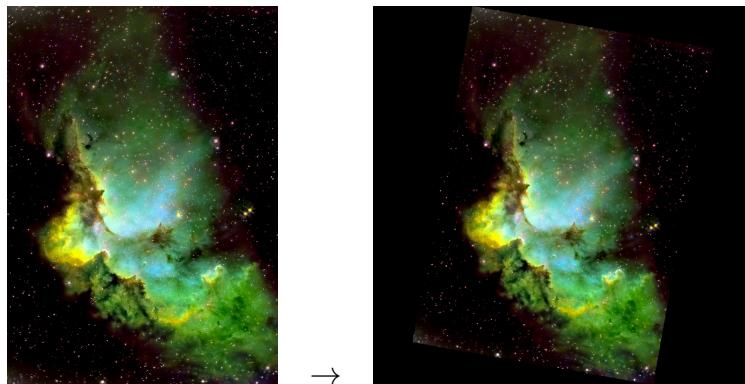
Figure 8.6: Automatic processing of a DSO image.

Figure 8.7: `.json` result from processing with **Stellarium_Nebulae_Image_Prep.py**

8.2.5 Troubleshooting

If no images show up in Stellarium, chances are you have introduced one or more errors in the `textures.json` file. You can use **Json Lint** [11] to check for problems.
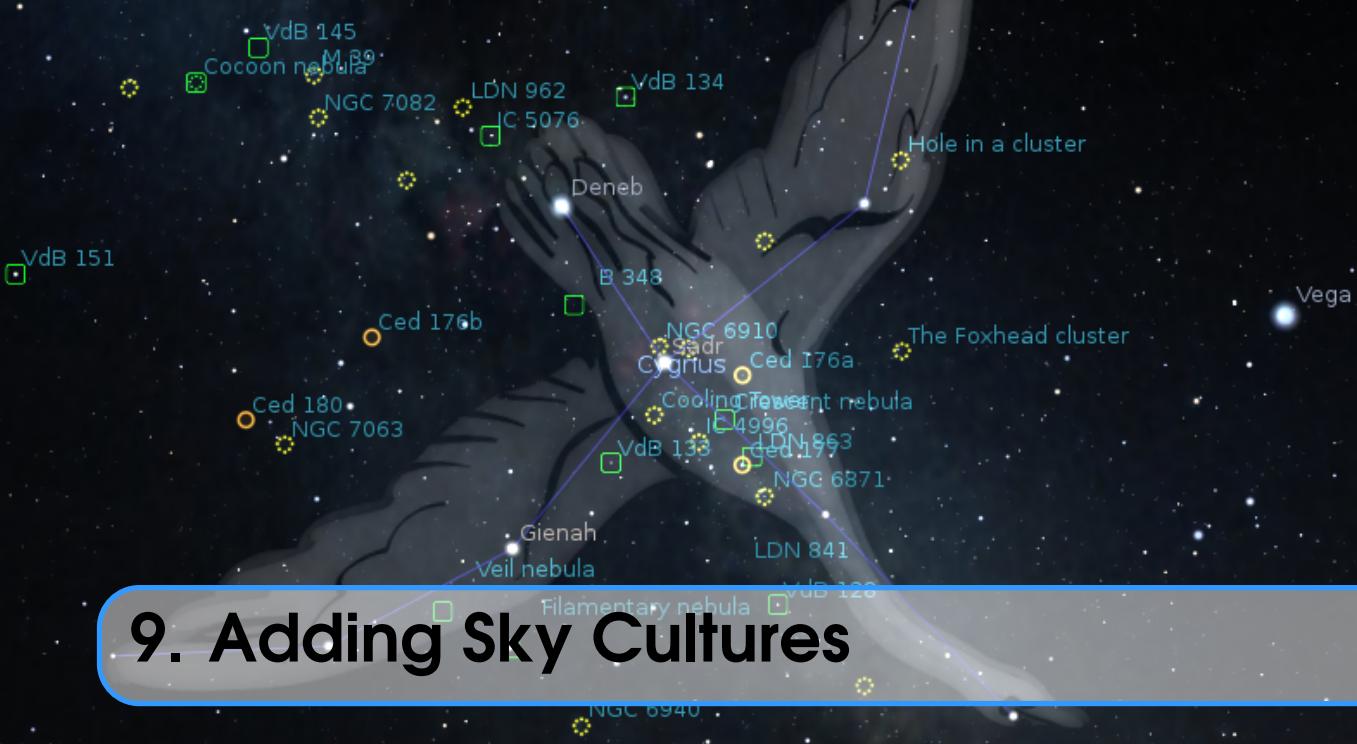
Just paste the entire contents of the file in and press "Validate JSON".

However, the original `textures.json` file as shipped in v0.19.1 also fails:

- Missing leading zeros in front of decimal points
- White space (a tab in this case) before `http` in `infoUrl` entries

These minor issues seem however not to irritate Stellarium.

---

[11] An online service available at `https://jsonlint.com/`

9. Adding Sky Cultures

GEORG ZOTTI, WITH ADDITIONS BY ALEXANDER WOLF

Stellarium comes with a nice set of skycultures. For ethnographers or historians of science it may be a worthwile consideration to illustrate the sky culture of the people they are studying. It is not very hard to do so, but depending on your data, may require some skills in image processing.

Some features regarding translation and multilinguality have evolved over the years, and not all skycultures currently included in Stellarium adhere to the standards described in the following sections. Skycultures will also see continuous development in the coming versions. If you add a new skyculture, please adhere to this description for an optimal result!

In the Stellarium program folder you can see a folder `skycultures`. Let us assume you work on Windows and want to create a new Skyculture, say, *myCulture*.

You can take the `inuit` directory as template to start with. Just copy the folder `C:\Program Files\Stellarium\skycultures\inuit` to `C:\Users\[YOU]\AppData\Roaming\Stellarium\skycultures\myculture`

In the folder you see image files for the constellation artwork, and all other files with various extensions are text files.

9.1 Basic Information

In `myculture\info.ini`, change the entries to

```
[info]
name=myCulture
author=me
boundaries=none
classification=personal
```

(or what seems best for you). The name is used for the list entry in the Starlore tab in the View dialog (see 4.4.6).

The option "boundaries" is optional and may contain the follow values:

none — this value is enabled by default and it designates that this culture doesn't have boundaries of constellations.

iau — use this value for variants of "western" cultures to enable using default (IAU) boundaries.

own — please use it for culture who has own set of boundaries for constellations.

v0.19.0   The option "classification" is also optional. It allows some form of quality control:

personal – this is a personally developed skyculture which is not founded in published historical or ethnological research. Stellarium may include it when it is "pretty enough" without really approving its contents.

traditional – (default value) content represents "common" knowledge by several members of an ethnic community, and the skyculture has been developed by members of such community. Our "Western" skyculture is a key example: it has evolved for about 2500 years, and modern astronomers use it.

ethnographic – provided by ethnographic researchers based on interviews of indigenous people.

historical – based on historical written sources from a (usually short) period of the past.

single – represents a single source like a historical atlas, or publications of a single author.

9.2   Skyculture Description Files

In order to have translated texts we have files `description.<LANG>.utf8`, where `<LANG>` is the two-letter ISO 639-1 language code, or its extension which contains language and country code, like `pt_BR` for Brazilian Portuguese. A minimum skyculture must contain the file `description.en.utf8`, this is en=english text with optional HTML tags for sections, tables, etc. You can also have embedded images in the HTML (your book cover? Views of sacred landscapes/buildings/artwork/. . . ?), just make them PNG format please. The length of the description texts is not limited, you have room for a good description, tables of names/translations, links to external resources, whatever seems suitable. When you started from a copied skyculture, delete the other `description.*.utf8` files.

If you can provide other languages supported by Stellarium, you can provide translations yourself, else Stellarium translators *may* translate the English version for you. (It may take years though.) The file ending `.utf8` indicates that for special characters like ÄÖÜßáé you should use UTF8 encoding. If you write only English/ASCII, this may not be relevant.

9.3   Constellation Names

The native constellations are listed in `constellation_names.eng.fab`. It consists of 3 simple columns: Abbreviation (or just a serial number), native name, and english translation. The writing `_("name")` allows automatic translation of the English strings to other languages. These strings will be used as constellation labels.

0.19.2   You can add a reference comment after each 3-column entry. Just add a whitespace, and then a comma-separated list of numerical references to the books listed in `reference.fab`.

The first column (abbreviation) in the Western sky culture provides the canonical 3-letter abbreviation for constellations as used by the International Astronomical Union. Such abbreviations may not be available for the skyculture you are working with, so you must invent your own. These abbreviations are used as keys in the other files, so they must be unique within your skyculture. It is not necessary to have 3-letter keys.

The keys can be displayed on screen when labels are requested in the Starlore GUI (section 4.4.6). If you want to prevent certain abbreviations from being displayed, let them start with a dot. See the effect in the `Western (H.A.Rey)` skyculture: In Abbreviated mode, only the official

abbreviations are displayed. In ⸢Native⸣ mode, the second column of `constellation_names.eng.fab` is shown. Only with setting ⸢Translated⸣, the text translated from the text shown in the third column is shown. If your skyculture is a variant of the Western skyculture, please use the canonical Latin names, they have all been translated already.

If your skyculture is not a variant of the generally known Western skyculture, please include an English translation to the name given in the native language. Else translators will not be able to translate the name. See a good example in the Mongolian skyculture.

9.4 Star Names

The file `star_names.fab` contains a list of HIP catalogue numbers and common names for those stars. Each line of the file contains one record of two fields (separated by the pipe character (|)) or three fields (the first pair is separated by the pipe character (|) and the last one separated by the space character). The first field is the Hipparcos catalogue number of the star, the second is the common name of the star in a format that enables translation support, the third is an optional list of references (see 9.11) to the source of the information about this name, e.g:

```
# Piscis Austrinus (PsA)
113368|_("Fomalhaut") 1,2,6,11,12
113368|_("Thalim")
```

In the sample you can see 3 lines: the first line is a comment, the second line has 3 fields and the third line has 2 fields. Both lines with data have the same Hipparcos number of the star — *Fomalhaut* is the well-known name of HIP 113368, and *Thalim* is an additional (not well-known) name of this star.

9.5 Planet Names

The file `planet_names.fab` contains a list of native names of the planets. Each line of the file contains one record of 3 fields, separated by the white space or tab character. The first field is the English name of the planet, the second is the native name of the planet (can be in the native language, but please for maximum utability use an english transliteration) and the third is the translatable version of the native name of the planet (translated into English). Here is an example from the Egyptian skyculture:

```
Mars    "Horus-Desher"  _("Red␣Horus␣(Mars)")
```

9.6 Deep-Sky Objects Names

The file `dso_names.fab` contains a list of native names for deep-sky objects (DSO). The format of this file is similar to the `star_names.fab` format (see 9.4). Each line of the file contains one record of two fields (separated by the pipe character (|)) or three fields (first pair is separated by the pipe character (|) and the last one separated by the space character). The first field is an identifier of the deep-sky object, the second is the native name of the DSO in a format that enables translation support, the optional third is a list of references (see 9.11) to the source of the information about this name, e.g.:

v0.15.1

```
PGC 17223|_("Native␣name␣for␣LMC") 1,2,3
NGC 292  |_("Native␣name␣for␣SMC") 1,3
NGC 292  |_("Small␣Magellanic␣Cloud")
```

9.7 Stick Figures

The modern-style stick figures are coded in `constellationship.fab`. Lines look like:

```
Abbr pairs pair1_star1 pair1_star2 pair2_star1 pair2_star2 ...
```

In this file,

Abbr is the abbreviation defined in `constellation_names.eng.fab`

pairs is the number of line pairs which follow.

pairN_starA Hipparcos numbers for the stars which form the constellation stick figure. We need
two entries per line, longer line segments are not supported. To find the HIP number, just
have Stellarium open and click on the star in Stellarium while editing this file.

Anything after the last star number is currently ignored. Comments can be given in lines starting
with # signs. Empty lines are ignored.

9.8 Constellation Boundaries

The optional file[1] `constellation_boundaries.dat` includes data for the boundary lines drawn
between constellations. The default boundaries for western constellations are defined in the
`data/constellation_boundaries.dat` file.

   The format for this file is a bit more difficult than the other files. It contains sections which may
consist of multiple lines, of the format:

```
N RA_1 DE_1 RA_2 DE_2 ... RA_N DE_N 2 CON1 CON2
```

where

N number of segments for boundary

RA_n, DE_n right ascension (decimal hours) and declination (decimal degrees) of the points of
segments in J2000 coordinates.

2 CON1 CON2 this data indicate "border between 2 constellations CON1 and CON2". They
are used to define isolated boundaries for each constellation (for proper working of the
Select single constellation option).

9.9 Constellation Artwork

Constellation artwork is optional, but may give your skyculture the final touch, if it requires artwork
at all. E.g., H. A. Rey's variant of the Western skyculture deliberately does not contain artwork.

   Each constellation artwork is linked to 3 stars in its constellation. This is programmed in the
file `constellationsart.fab`. You have to write lines

```
  Abbr  image_name.png x1 y1 HIP1 x2 y2 HIP2 x3 y3 HIP3
```

where

Abbr is the abbreviation defined in `constellation_names.eng.fab`

image_name.png is the file name of your texture. It should be sized in a power of two, like
512×512, 1024×2048 etc. Avoid dimensions larger than 2048, they are not supported on
all systems. You can distort images to better exploit the pixels, the texture will be stretched
back. The background of the artwork image must be absolutely black.

---

[1]Please define "boundaries = own" in the file `info.ini` to enable using custom boundaries.

x*n*, **y***n*, **HIP***n* ($n \in [1, 2, 3]$) pixel locations of the star in the constellation drawing (find those in any image editor) and HIP*n* is the star number in the Hipparcos catalog, which you find when you click on the star in Stellarium.

In case the artwork is only available in a certain projection (e.g., an all-sky map), or is otherwise heavily distorted so that the match is not satisfactory, you may have to reproject the image somehow. For aligning, you should switch Stellarium to Stereographic projection for optimal results.

You don't have to shutdown and restart Stellarium during creation/matching, just switch skyculture to something else and back to the new one to reload.

9.10 Seasonal Rules

File `seasonal_rules.fab` (optional) contains possible seasonal rules for the visibility of constellations. There is one rule per line. Each rule contains three elements separated with white space (or tab character): constellation ID, start of visibility (month) and end of visibility (month), e.g:

```
Emu 6 3
```

This specifies that constellation Emu (abbreviated also as "Emu") is visible only from June to March.

9.11 References

The file `reference.fab` contains a list of information sources. Each line of the file contains one record of 3 fields, separated by the pipe character (|) — number of source, description of source and optional URL, e.g.: — v0.15.1

```
9|Kruger 60|https://en.wikipedia.org/wiki/Kruger_60
```

This file will be used in future versions. It is most important for "traditional" skycultures collected from various sources to provide traceable references.

9.12 Asterisms and help rays

Sometimes there is a need to extract some part of a constellation into a figure in its own right, or to merge parts from different constellations into one big figure — e.g. "Big Dipper" as part of Ursa Major or the "Summer Triangle" consisting of 3 stars from the constellations Cygnus, Lyra and Aquila. Those features are called "asterisms". — v0.16.1

Other simple figures might be used as navigation helpers — the help rays. As example to help in orientation in the sky the additional lines between constellations Ursa Major, Ursa Minor and Cassiopeia might be useful. The asterisms and help rays are listed in `asterism_names.eng.fab`. This file consists of 2 simple columns: Abbreviation (or just a serial number) and English name of asterism. The writing `_("name")` allows automatic translation of the English strings to other languages. These strings will be used as asterisms labels. In addition, after a hash mark (#) marking a comment sign, some reference information can be added in comment lines, like "List found at . . . ". Also, you can again add a reference comment after each 2-column entry. Just add a whitespace, — 0.19.2 and then a comma-separated list of numerical references to the books listed in `reference.fab`. Collecting sources and giving such references is always a good idea. Some later versions of Stellarium may use and display this information.

The stick figures of asterisms are coded in `asterism_lines.fab` which looks similar to the entries for the constellation figures. Lines look like:

```
Abbr type pairs pair1_star1 pair1_star2 pair2_star1 pair2_star2 ...
```

or

```
Abbr 2 pairs pair1_RA1 pair1_DE1 pair1_RA2 pair1_DE2 pair2_RA1 ..
```

In this file,

Abbr is the abbreviation defined in `asterism_names.eng.fab`

type is the type of line. Use 1 or 2 to define an asterism and 0 for the help rays (0 and 1 uses HIP numbers, and 2 uses coordinates).

pairs is the number of line pairs which follow.

pairN_starA Hipparcos numbers for the stars which form the asterism/help ray stick figure (similar to constellations), or equatorial coordinates for epoch J2000.0 of the stars (decimal hours for right ascension and decimal degrees for declination). The help rays are actually a special form of asterisms in Stellarium.
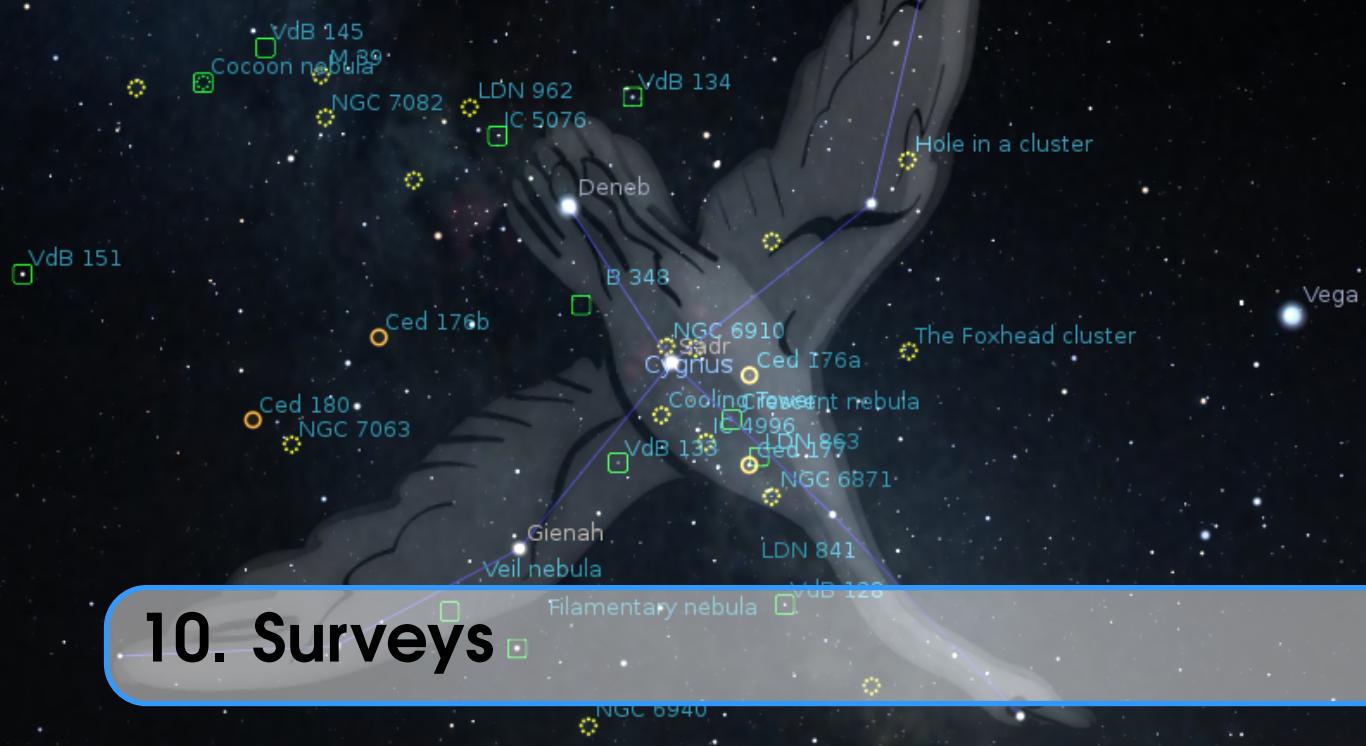
9.13 Publish Your Work

If you are willing to let other users enjoy the result of your hard work (and we certainly hope you do!), when you are done, please write a note in the Forum or at Github. We will decide about acceptability and classification, and may ask for better descriptions for the benefit of our users.

Please be prepared to put the imagery and text under some compatible open-source license (Creative Commons). Else the skyculture cannot be hosted by us. While we cannot be held responsible for legal problems, it seems that CC BY 4.0 International[2] or CC BY-SA 4.0 International[3] licenses are best suited.

---

[2]`https://creativecommons.org/licenses/by/4.0/`
[3]`https://creativecommons.org/licenses/by-sa/4.0/`

10. Surveys

GUILLAUME CHÉREAU

10.1 Introduction

A *sky survey* is a map of the sky stored as a hierarchical set of a potentially large number of smaller images (called tiles). The advantage compared to a regular texture is that we need to render only the visible tiles of a potentially gigantic image at the lowest resolution needed. This is particularly interesting for rendering online images that can be stored on a server, while the client only has to download the parts he currently uses.

v0.18.0

Since version 0.18.0, Stellarium added some preliminary support for loading and rendering online surveys in the *Hierarchical Progressive Surveys* (HiPS) format, developed by the *International Virtual Observatory Alliance*. A full description of the format can be found on the IVOA website[1].

10.2 Hipslist file and default surveys

Hipslist files are text files used to describe catalogs of HiPS surveys. The full specification is part of the HiPS format, and looks like that:

```
# Example of a hipslist file.
# Date: 2018-03-19

hips_service_url  = https://data.stellarium.org/surveys/callisto
hips_release_date = 2018-03-18T14:01Z
hips_status       = public mirror clonableOnce
```

As of v0.18.0, by default Stellarium tries to load HiPS from two sources: `http://alaskybis.unistra.fr/hipslist` and `https://data.stellarium.org/surveys/hipslist`. This can be changed with the hips/sources options in the configuration file (see also section D.1.27). For example:

---

[1]`http://www.ivoa.net/documents/HiPS/20170519/REC-HIPS-1.0-20170519.pdf`

```
[hips]
sources/size = 1
sources/1/url = "https://myownhips/hipslist"
```

10.3 Solar system HiPS survey

Though not specified in the HiPS standard, Stellarium recognises HiPS surveys representing planet textures, as opposed to sky surveys. If the `obs_frame` property of a survey is set to the name of a planet or other solar system body, Stellarium will render it in place of the default texture used for the body.

10.4 Digitized Sky Survey 2 (TOAST Survey)

GEORG ZOTTI, ALEXANDER WOLF

The older way to provide a tessellated all-sky survey uses the TOAST encoding[2]. Stellarium provides access to the Digitized Sky Survey 2, a combination of high-resolution scans of red- and blue-sensitive photographic plates taken in 1983–2006 at Palomar Observatory and the Anglo-Australian Observatory.[3]

To enable access to the DSS layer, see section 4.3.3 and enable the DSS button. Then just press that DSS button in the lower button bar, wait a moment, zoom in and enjoy!

10.4.1 Local Installation

This display normally requires access to the Internet. However, in some situations like frequent and extensive use in fixed observatories, or use in the field when Internet connection is not possible, you can download all image tiles to your local harddisk for local use. Please be considerate, don't waste bandwidth, and do this only if you really need it.

The images are stored in subdirectories that increase in size and number of files (see Table 10.1). Zooming in loads the next level if available.

For partial downloads, you can limit the maximally used level (e.g. 9 or 10). The difference from level 10 to 11 is really hardly noticeable, yet level 11 contains almost 75% of all data. On a small system like Raspberry Pi 3, you may run into troubles with too little texture memory when level is more than 7.

Another issue: the level 11 subdirectory holds over 4 million files. Windows **Explorer** is not optimized to open and display this number of files and will take a long time to open. Just unpack this archive, but don't access the folder with **Explorer**.

If all that does not discourage you, you can download the archives at `https://dss.stellarium.org/offline/`.

Then add a few entries to the `[astro]` section in Stellarium's `config.ini`. On Windows, if you have a harddisk `T:` with path `T:\StelDSS` that contains the unpacked image subdirectories 0, 1, 2, ..., 10, the section may look like

```
[astro]
toast_survey_directory =StelDSS
toast_survey_host=T:/
```

---

[2]Please see `http://montage.ipac.caltech.edu/docs/WWT/` for details

[3]The original data are available at `http://archive.stsci.edu/cgi-bin/dss_form`.
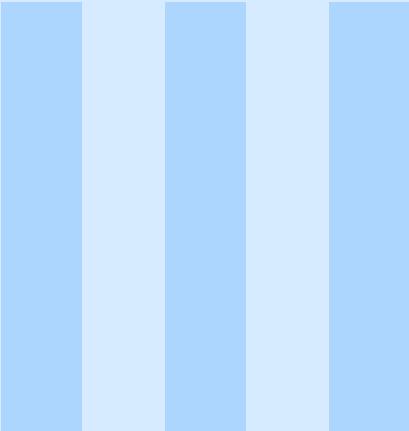
```
toast_survey_levels=10
```

On Linux, with the files stored in /usr/local/share/Stellarium/StelDSS, the same section could look like

```
[astro]
toast_survey_directory =usr/local/share/Stellarium/StelDSS
toast_survey_host =/
toast_survey_levels =10
```
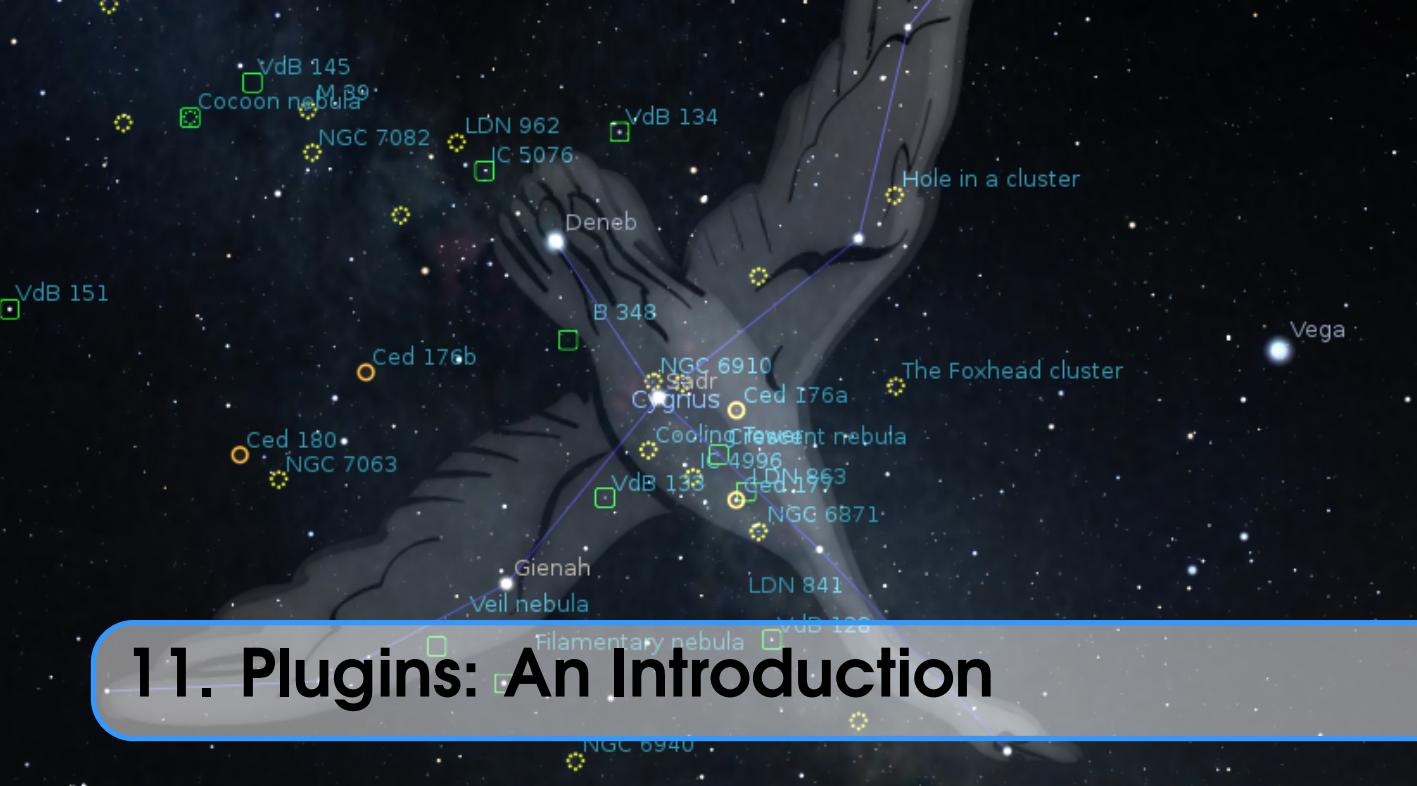
Level	No of files	Filespace (kB)
0	1	32
1	4	124
2	16	472
3	64	1.820
4	256	7.172
5	1.024	27.920
6	4.096	109.628
7	16.384	429.800
8	65.536	1.661.808
9	262.144	6.119.092
10	1.048.576	20.250.216
11	4.194.305	83.583.724

Table 10.1: Number of files and storage requirements for local DSS TOAST installation

III

Extending Stellarium

11. Plugins: An Introduction

Starting with version 0.10.3, Stellarium's packages have included a steadily growing number of optional extensions called plug-ins: Angle Measure, Compass Marks, Oculars, Telescope Control, Text User Interface, Satellites, Solar System Editor, Historical Novae and Supernovae, Quasars, Pulsars, Exoplanets, Observability analysis, ArchaeoLines, Scenery3D, RemoteControl, Navigation Stars and RemoteSync. All these plug-ins are "built-in" in the standard Stellarium distribution and don't need to be downloaded separately.

11.1 Enabling plugins

To enable a plugin:

1. Open the **Configuration dialog** (press F2 or use the left tool bar button 🔧)
2. Select the **Plugins** tab
3. Select the plugin you want to enable from the list
4. Check the **Load at startup** option
5. Restart Stellarium

If the plugin has configuration options, the **configuration** button will be enabled when the plugin has been loaded and clicking it will open the plugin's configuration dialog. When you only just activated loading of a plugin, you must restart Stellarium to access the plugin's configuration dialog.

11.2 Data for plugins

Some plugins contain files with different data, e.g., catalogs. JSON is a typical format for those files, and you can edit its contents manually. Of course, each plugin has a specific format of data for its own catalogs, and you should read the documentation for the plugin before editing its catalog.

You can read some common instructions for editing catalogs of plugins below. In this example we use file name `catalog.json` for identification of the catalog for a typical plugin.

You can modify the `catalog.json` files manually using a text editor. **If you are using**

Windows, it is strongly recommended to use an advanced text editor such as Notepad++[1] to avoid problems with end-of-line characters. (It will also color the JSON code and make it easier to read.)

    Warning: Before editing your `catalog.json` file, make a backup copy. Leaving out the smallest detail (such as a comma or forgetting to close a curly bracket) may prevent Stellarium from starting.

    As stated in section 5, the path to the directory[2] which contains `catalog.json` file is something like:

Windows C:\Users**UserName**\AppData\Roaming\Stellarium\modules*PluginName*
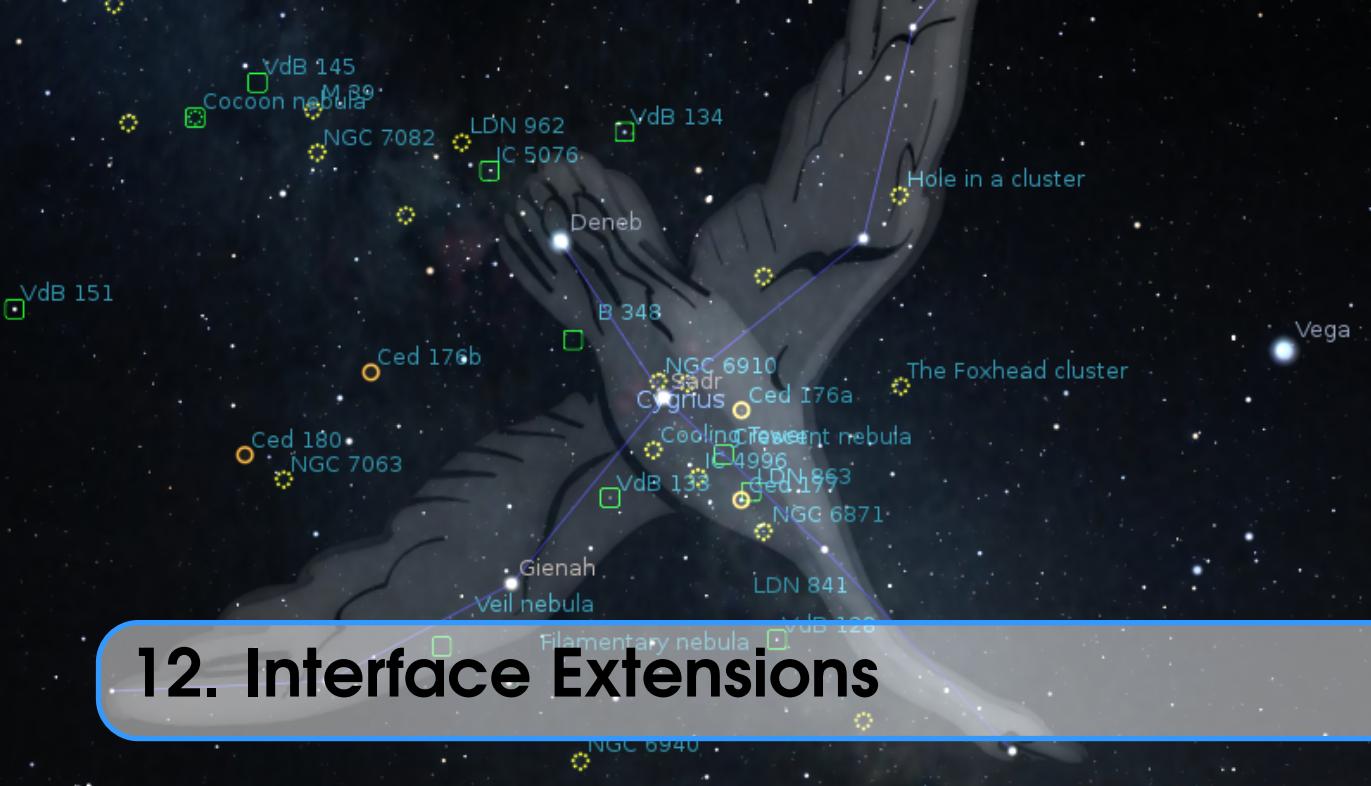
Mac OS X HomeDirectory/Library/Application Support/Stellarium/modules/*PluginName*

Linux and UNIX-like OS ~/.stellarium/modules/*PluginName*

---

[1]`http://notepad-plus-plus.org/`

[2]This is a hidden folder, so in order to find it you may need to change your computer's settings to display hidden files and folders.

VdB 145
M 39
Cocoon nebula
NGC 7082
LDN 962
IC 5076
VdB 134
Hole in a cluster
Deneb
VdB 151
B 343
Vega
Ced 176b
NGC 6910
Sadr
Cygnus
Ced 176a
The Foxhead cluster
Cooling Tower
Crescent nebula
Ced 180
IC 4996
Ced 171
NGC 7063
VdB 133
LDN 863
NGC 6871
Gienah
LDN 841
Veil nebula
VdB 126
Filamentary nebula
NGC 6940

12. Interface Extensions

Most users will soon be familiar with the usual user interface. A few plugins are available which extend the regular user interface with a few small additions which are presented first. However, some applications and installations of Stellarium require completely different user interfaces. Mostly, these serve to avoid showing the user interface panels to an audience, be that in your astronomy club presentations, a domed planetarium or in a museum installation.

12.1 Angle Measure Plugin

> *goes misty eyed*
> I recall measuring the size of the Cassini Division when I was a student. It was not the high academic glamor one might expect. . . It was cloudy. . . It was rainy. . . The observatory lab had some old scopes set up at one end, pointing at a *photograph* of Saturn at the other end of the lab. We measured. We calculated. We wished we were in Hawaii. A picture is worth a thousand words.

The Angle Measure plugin is a small tool which is used to measure the angular distance between two points on the sky.

1. Enable the tool by clicking the tool-bar button, or by pressing `Ctrl`+`A`. A message will appear at the bottom of the screen to tell you that the tool is active.
2. Drag a line from the first point to the second point using the left mouse button
3. To clear the measurement, click the right mouse button
4. To deactivate the angle measure tool, press the tool-bar button again, or press `Ctrl`+`A` on the keyboard.

In the configuration dialog, you can configure if you want to have distances given on the rotating sphere, or in horizontal (alt-azimuthal) coordinates. You can also link one point to the resting horizon, the other to the sky and observe how angles change.

12.2   Compass Marks Plugin

Stellarium helps the user get their bearings using the cardinal point feature – the North, South, East and West markers on the horizon. Compass Marks takes this idea and extends it to add markings every few degrees along the horizon, and includes compass bearing values in degrees.

When activated (see section 11.1), there is a tool bar button ⟨▭⟩ for toggling the compass markings. Note that when you enable compass marks, the cardinal points will be turned off.

Figure 12.1: Markings of Compass Marks Plugin

12.3 Equation of Time Plugin
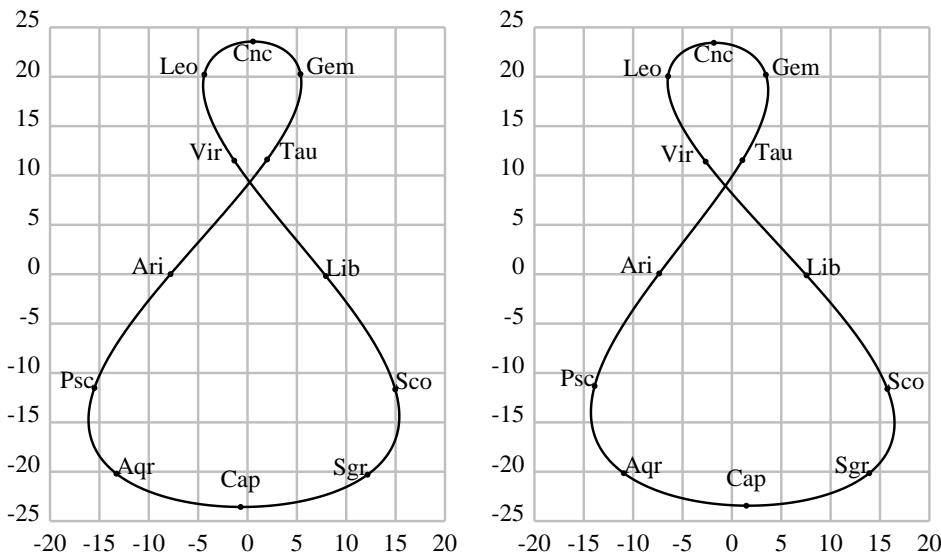
Figure 12.2: Figure-8 plots for Equation of Time, for years 1000 (left) and 2000 (right). These plots, often found on sundials, link solar declination (vertical axis) and its deviation at mean noon from the meridian, in minutes. Labeled dots indicate when the sun entered the respective Zodiacal sign (30°section of the ecliptic). Figures by Georg Zotti.

The Equation of Time plugin shows the solution of the equation of time. This describes the discrepancy between two kinds of solar time:

Apparent solar time directly tracks the motion of the sun. Most sundials show this time.

Mean solar time tracks a fictitious "mean" sun with noons 24 hours apart.

There is no universally accepted definition of the sign of the equation of time. Some publications show it as positive when a sundial is ahead of a clock; others when the clock is ahead of the sundial. In the English-speaking world, the former usage is the more common, but is not always followed. Anyone who makes use of a published table or graph should first check its sign usage.

If enabled (see section 11.1), click on the Equation of Time button on the bottom toolbar to display the value for the equation of time on top of the screen.

12.3.1 Section [EquationOfTime] in config.ini file

You can edit config.ini file by yourself for changes of the settings for the Equation of Time plugin – just make it carefully!

ID	Type	Description
enable_at_startup	bool	Display solution of the equation of time at startup of Stellarium
flag_use_ms_format	bool	Set format for the displayed solution – minutes and seconds or decimal minutes
flag_use_inverted_value	bool	Change sign of the equation of time
flag_show_button	bool	Show the tool's button on the bottom toolbar
text_color	R,G,B	Font color for the displayed solution of the equation of time
font_size	int	Font size for the displayed solution of the equation of time

12.4   Pointer Coordinates Plugin
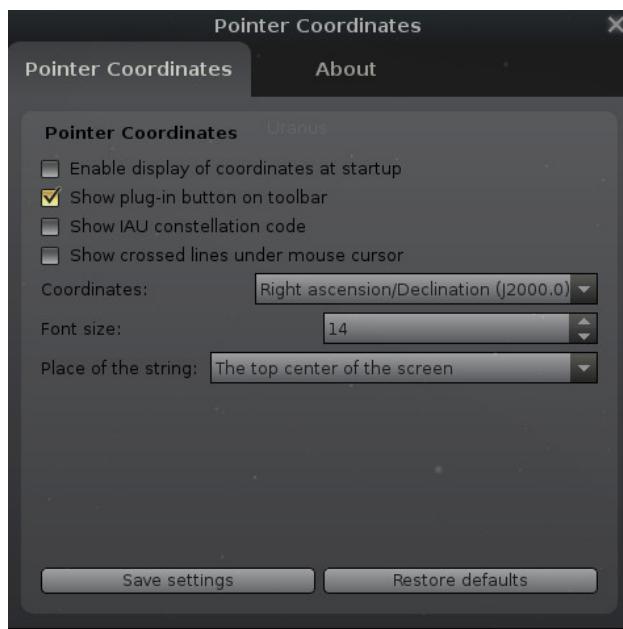
Figure 12.3: Interface of Pointer Coordinates plugin

The Pointer Coordinates plugin shows the coordinates of the mouse pointer. If enabled, click on the plugin button ⌊⌋ on the bottom toolbar to display the coordinates of the mouse pointer.

12.4.1   Section [PointerCoordinates] in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Pointer Coordinates plugin – just make it carefully!

ID	Type	Description
enable_at_startup	bool	Enable displaying mouse pointer coordinates at program startup
flag_show_button	bool	Show the plugin's tool button on the bottom toolbar
text_color	R,G,B	Color for coordinates text of the mouse pointer
font_size	int	Font size for the displayed mouse pointer coordinates
current_displaying_place	string	Specifies the place of displaying coordinates of the mouse pointer. *Possible values*: `TopRight`, `TopCenter`, `RightBottomCorner`, `Custom`. *Default value*: `TopRight`.
custom_coordinates	int,int	Specifies the screen coordinates of the custom place for displaying coordinates of the mouse pointer
current_coordinate_system	string	Specifies the coordinate system. *Possible values*: `RaDecJ2000`, `RaDec`, `HourAngle`, `Ecliptic`, `AltAzi`, `Galactic`. *Default value*: `RaDecJ2000`.
flag_show_constellation	bool	Add the 3-letter IAU abbreviation for the constellation of the mouse pointer location (Roman, 1987).
flag_show_crossed_lines	bool	Show crossed lines under mouse cursor.

12.5 Text User Interface Plugin

This plugin re-implements the "TUI" of the pre-0.10 versions of Stellarium, an unobtrusive menu used primarily by planetarium system operators to change settings, run scripts and so on.

Given that color configuration for lines and texts cannot be found elsewhere, an interesting part for general use (at least for extended configuration sessions) is the way to interactively select colors in this menu.

A full list of the commands for the TUI plugin is given in section 12.5.2.

12.5.1 Using the Text User Interface

1. Activate the text menu using the ⌈Alt⌉+⌈T⌉ key.[1]
2. Navigate the menu using the cursors keys.
3. To edit a value, press the right cursor until the value you wish to change it highlighted with > and < marks, e.g. >3.142<. Then press the cursor keys ⌈↑⌉ and ⌈↓⌉ to change the value. You may also type in a new value with the other keys on the keyboard.

12.5.2 TUI Commands

1	Location	(menu group)
1.1	Latitude	Set the latitude of the observer in degrees
1.2	Longitude	Set the longitude of the observer in degrees
1.3	Altitude	Set the altitude of the observer in meters
1.4	Solar System Body	Select the solar system body on which the observer is
2	Set Time	(menu group)
2.1	Current date/time	Set the time and date for which Stellarium will generate the view
2.2	Set Time Zone	(disabled in 0.15)
2.3	Days keys	(disabled in 0.15)
2.4	Startup date/time preset	Select the time which Stellarium starts with (if the "Sky Time At Start-up" setting is "Preset Time"
2.5	Startup date and time	The setting "system" sets Stellarium's time to the computer clock when Stellarium runs. The setting "preset" selects a time set in menu item "2.4 - Startup date/time preset"
2.6	Date Display Format	Change how Stellarium formats date values. "system_default" takes the format from the computer settings, or it is possible to select "yyyymmdd", "ddmmyyyy" or "mmddyyyy" modes
2.7	Time Display Format	Change how Stellarium formats time values. "system_default" takes the format from the computer settings, or it is possible to select "24h" or "12h" clock modes
3	General	(menu group)
3.1	Starlore	Select the sky culture to use (changes constellation lines, names, artwork)

[1] This used to be hard-coded to ⌈M⌉ before version 0.15, but ⌈Alt⌉+⌈T⌉ is better to remember as it runs parallel with ⌈Ctrl⌉+⌈T⌉ for switching the GUI panels, and frees up ⌈M⌉ for the Milky Way. The ⌈Alt⌉+⌈T⌉ keybinding is hardcoded, i.e., cannot be reconfigured by the user, and should not be used for another function.

3.2	Sky Language	Change the language used to describe objects in the sky
3.3	App Language	Change the application language (used in GUIs)
4	Stars	(menu group)
4.1	Show stars	Turn on/off star rendering
4.2	Relative Scale	Change the relative brightness of the stars. Larger values make bright stars much larger.
4.3	Absolute Scale	Change the absolute brightness of the stars. Large values show more stars. Leave at 1 for realistic views.
4.4	Twinkle	Sets how strong the star twinkling effect is - zero is off, the higher the value the more the stars will twinkle.
5	Colors	(menu group) change color/brightness of the…
5.1	Constellation lines	constellation lines
5.2	Constellation labels	labels used to name stars
5.3	Art brightness	constellation art
5.4	Constellation boundaries	constellation boundary lines
5.5	Cardinal points	cardinal points markers
5.6	Planet labels	labels for planets
5.7	Planet orbits	orbital guide lines for planets
5.8	Planet trails	planet trails lines
5.9	Meridian Line	meridian line
5.10	Azimuthal Grid	lines and labels for the azimuthal grid
5.11	Equatorial Grid	lines and labels for the equatorial grid
5.12	Equatorial J2000 Grid	lines and labels for the equatorial J2000.0 grid
5.13	Equator Line	equator line
5.14	Ecliptic Line	ecliptic line
5.15	Ecliptic Line (J2000)	J2000 ecliptic line
5.16	Nebula names	labels for nebulae
5.17	Nebula hints	circles used to mark positions of unspecified nebulae
5.18	Galaxy hints	ellipses used to mark positions of galaxies
5.19	Bright nebula hints	squares used to mark positions of bright nebulae
5.20	Dark nebula hints	squares used to mark positions of dark nebulae
5.21	Clusters hints	symbols used to mark positions of clusters
5.22	Horizon line	horizon line
5.23	Galactic grid	galactic grid
5.24	Galactic equator line	galactic equator line
5.25	Opposition/conjunction longitude line	opposition/conjunction line
5.26	Sky background	sky background. Note that anything but black is only useful for artistic works.
6	Effects	(menu group)
6.1	Light Pollution	Changes the intensity of the light pollution (see Appendix B Bortle Scale index)
6.2	Landscape	Select the landscape which Stellarium draws when ground drawing is enabled. Press ↵ to activate.
6.3	Setting Landscape Sets Location	If "Yes" then changing the landscape will move the observer location to the location for that landscape (if one is known). Setting this to "No" means the observer location is not modified when the landscape is changed.

6.4	Auto zoom out returns to initial ... view	Changes the behaviour when zooming out from a selected object. When set to "Off", selected object will stay in center. When set to "On", view will return to startup view.
6.5	Zoom Duration	Sets the time for zoom operations to take (in seconds)
6.6	Milky Way intensity	Changes the brightness of the Milky Way
6.7	Zodiacal light intensity	Changes the brightness of the Zodiacal light
7	Scripts	(menu group)
7.1	Run local script	Run a script from the scripts sub-directory of the User Directory or Installation Directory (see section 5 (Files and Directories))
7.1	Stop running script	Stop execution of a currently running script
8	Administration	(menu group)
8.1	Load default configuration	Reset all settings according to the main configuration file
8.2	Save current configuration	Save the current settings to the main configuration file
8.3	Shutdown	Emits a command configured in

12.5.3 Section [tui] in config.ini file

The section in config.ini for this plugin is named only [tui] for historical reasons. As always, be careful when editing!

ID	Type	Description
tui_font_color	R,G,B	Font color for TUI text
tui_font_size	int	Font size for the TUI
flag_show_gravity_ui	bool	Bend menu text around the screen center. May be useful in planetarium setups, and should then be used together with "Disc viewport" in the configuration menu (see 4.3.5).
flag_show_tui_datetime	bool	Show date and time in lower center.
flag_show_tui_short_obj_info	bool	Show some object info in lower right, or (in planetarium setups with "Disc viewport" active,) wrapped along the outer circle border.
admin_shutdown_cmd	string	executable command to shutdown your system. Best used on Linux or Mac systems. E.g. `shutdown -h now`

12.6   Remote Control Plugin

The Remote Control plugin enables the user to control Stellarium through an external web interface using a standard web browser like Firefox or Chrome, instead of using the main GUI. This works on the same computer Stellarium runs as well as over the network. Even more, multiple "remote controls" can access the same Stellarium instance at the same time, without getting in the way of each other. Apart from system configuration options, most of the functionality the main interface provides is available through it (Zotti, Schaukowitsch, and Wimmer, 2017).

The plugin may be most useful for presentation scenarios, hiding the GUI from the audience and allowing the presenter to change settings on a separate monitor without showing distracting dialog windows. It also allows to start and stop scripts remotely.

Because the web interface can be customized (or completely replaced) with some knowledge of HTML, CSS and JavaScript, another possibility is a kiosk mode, where untrusted users can execute a variety of predefined actions (like starting recorded tours) without having access to all Stellarium settings. The web API can also be accessed directly (without using a browser and the HTML interface), allowing control of Stellarium with external programs and scripts using HTTP calls like with the tools `wget` and `curl`.

This plugin allows also interfacing other programs with Stellarium.

12.6.1   Using the plugin
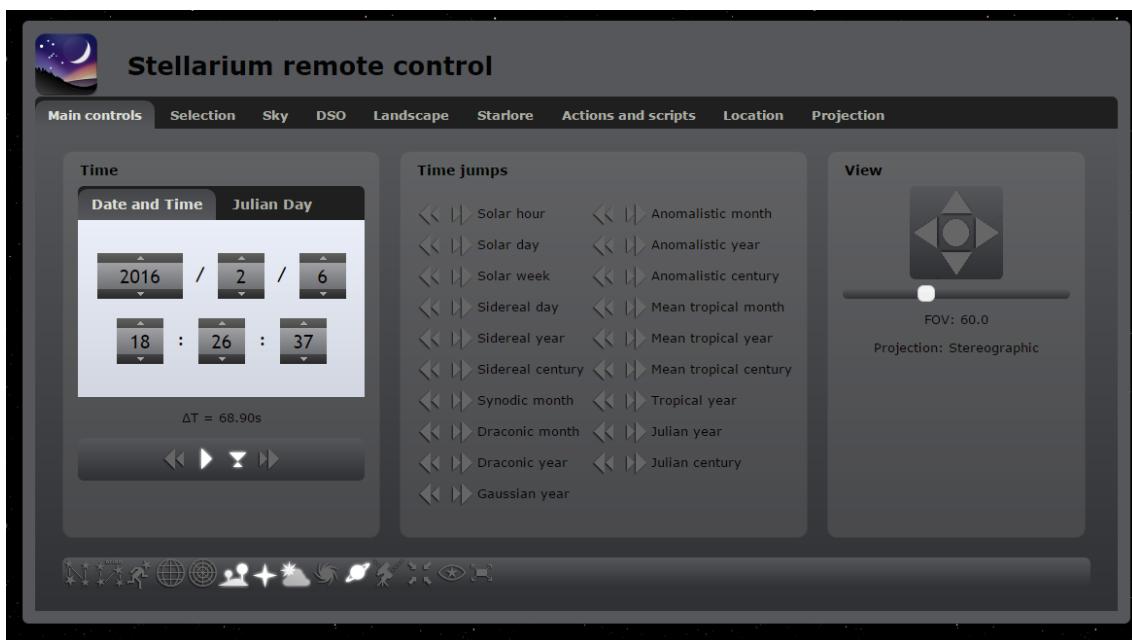
Figure 12.4: The default remote control web interface

After enabling the plugin, you can set it up through the configuration dialog. You can configure it to start the web server automatically whenever Stellarium starts or manually start/stop the server using the "Server enabled" checkbox or the button [icon] in the toolbar.

The plugin starts an HTTP server on the specified port. The default port is 8090, so you should reach the remote control after enabling it by starting a web browser on the same computer and entering `http://localhost:8090` in the address bar. When trying to access the remote control from another computer, you need the IP address or the hostname of the server on which Stellarium runs. On a small tablet, you may want to use `http://myserver:8090/tablet7in.html` instead.

The plugin shows the locally detected address, but depending on your network or if you need external access you might need to use a different one — contact your network administrator if you need help with that.

Password

The access to the remote control may optionally be restricted with a simple password.

Warning: *currently no network encryption is used, meaning that an attacker having access to your network can easily find out the password by waiting for a user entering it. Access from the Internet to the plugin should generally be restricted, except if countermeasures such as VPN usage are taken! If you are in a home network using NAT (network access translation), this should be enough for basic security except if port forwarding or a DMZ is configured.*

CORS

The Web API also supports Cross-Origin Resource Sharing (CORS). By enabling CORS, compatible websites and web apps can be used to control your Stellarium server.

Enable CORS by checking the "Enable CORS for the following origin" option in the configuration dialog. Then, enter the URL of the website you'd like to use to control Stellarium – e.g. `https://telescopius.com`. Specify "*" to let any website take control. Do this at your own risk.

12.6.2 Remote Control Web Interface

If you are familiar with the main Stellarium interface, you should easily find your way around the web interface. The remote control automatically uses the same language as set in the main program. Tabs at the top allow access to different settings and controls.

Main Contains the time controls and most of the buttons of the main bottom toolbar. An additional control allows moving the view like when dragging the mouse or using the arrow keys in Stellarium, and a slider enables the changing of the field of view. There are also buttons to quickly execute time jumps using the commonly used astronomical time intervals.

Selection Allows searching and selecting objects like in section 4.5. SIMBAD search is also supported. Quick select buttons are available for the primary solar system objects. It also displays the information text for current selection.

Sky Settings related to the sky display as shown in the "View" dialog as shown in subsection 4.4.1.

DSO The deep-sky object catalog, filter and display settings like in subsection 4.4.4.

Landscape Changing and configuring the background landscape, see subsection 4.4.5

Actions and scripts Lists all registered actions, and allows starting and stopping of scripts (chapter 16). If there is no button for the action you want in another tab, you can find all actions which can be configured as a keyboard shortcut (section 4.3) here.

Location Allows changing the location, like in section 4.2. Custom location saving is currently not supported.

Projection Switch the projection method used, like subsection 4.4.4.

12.6.3 Remote Control Commandline API

Apart from retrieving quick object info in your browser with e.g. `http://localhost:8090/api /objects/info?format=json&name=Sun`, it is also possible to send commands via command line[2], e.g.,

```
wget -q --post-data 'id=show.ssc' http://stella:8090/api/scripts/run >/dev/null 2>&1
curl --data 'id=myScript.ssc' http://localhost:8090/api/scripts/run >/dev/null 2>&1
```

---

[2]Depending on your operating system or command shell, you may have to use double quotes in the `--data` argument to `curl`.

```
curl -d      'id=myScript.ssc' http://localhost:8090/api/scripts/run >/dev/null 2>&1
curl -d 'id=LandscapeMgr.fogDisplayed&value=false' \
      http://localhost:8090/api/stelproperty/set
```

This allows triggering automatic show setups for museums etc. via some centralized schedulers like `cron`.

To get a complete pretty-printed list of properties, use:

```
curl -G -d 'id=propId=-1&actionId=-2' http://localhost:8090/api/main/status | \
      python -m json.tool
```

12.6.4 Developer information

If you are a developer and would like to add functionality to the Remote Control API, customize the web interface or access the API through another program, further information can be found in the plugin's developer documentation[3].

12.6.5 Acknowledgements

This plugin was created by Florian Schaukowitsch in the 2015 campaign of the *ESA Summer of Code in Space*[4] programme.

If you are using this plugin in your scientific publications, please cite Zotti, Schaukowitsch, and Wimmer (2017).

---

[3]http://stellarium.org/doc/head/remoteControlDoc.html
[4]http://sophia.estec.esa.int/socis/

12.7 Remote Sync Plugin

The Remote Sync plugin enables setups which connect several instances of Stellarium running on a   v0.16.0
network. This may be useful in installations where one presenter wants to allow a larger audience
to follow the actions on several dim screens (e.g., when you need to avoid a projector's bright light
in a public observatory). The actions performed on a "master" instance, which acts as a server, are
automatically replicated on all connected clients. These clients may run on the same device the
server runs, or may access the server over a network.

The plugin is still quite experimental, but is provided for testing purposes. You can configure it
through the standard plugin settings dialog (Figure 12.5). One Stellarium instance can either run in
the server mode or connect to an existing server as a client. A custom TCP protocol is used for the
connection. The port used by the server is configurable, and the clients must know the IP address
or host name and the port of the server.
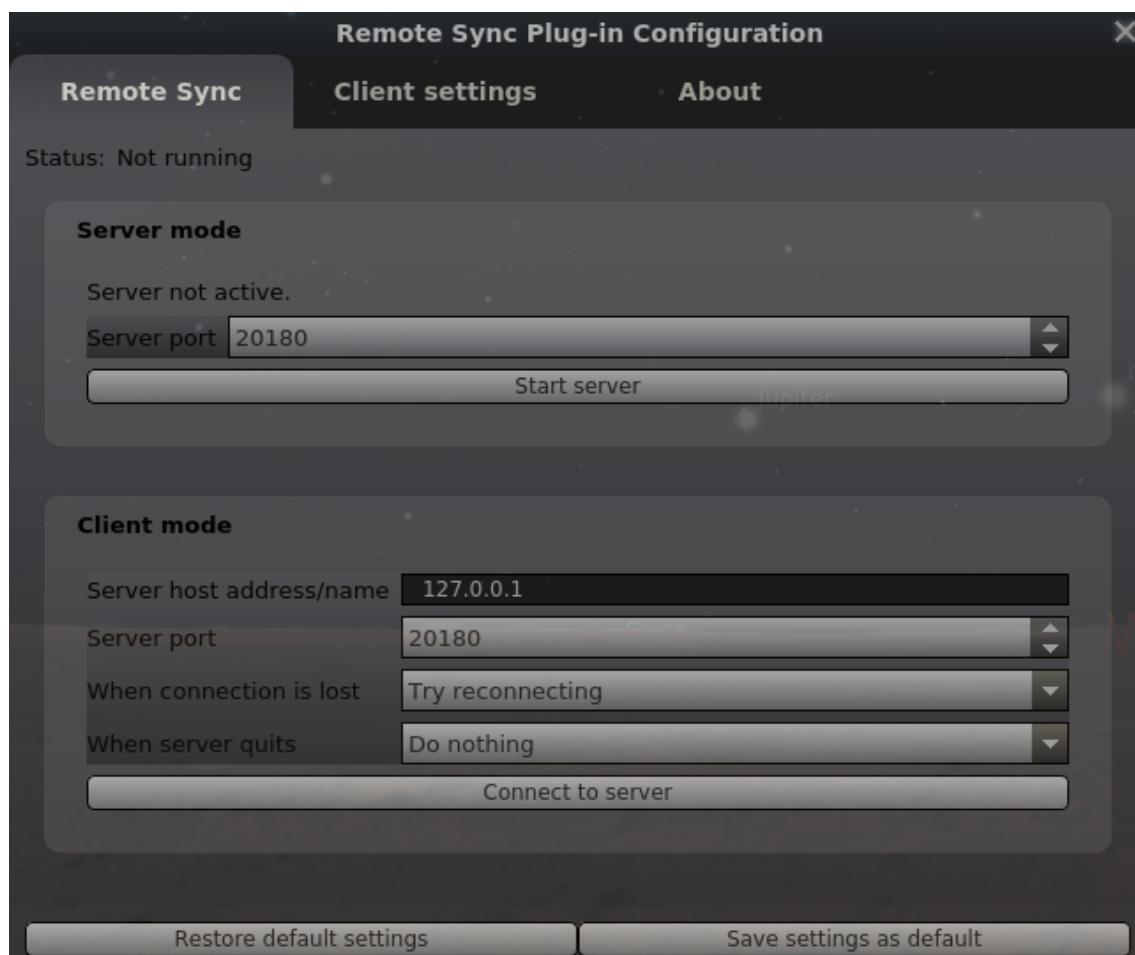
Figure 12.5: RemoteSync settings window

Alternatively, you may start the plugin through command line arguments. This is useful
for automated setups or when multiple instances are running on the same computer. To start
the instance as a server, use the `--syncMode=server` argument with the optional `--syncPort`
parameter to specify the port to listen on. To start a client instance, use `--syncMode=client` and
use `--syncHost` and `--syncPort` to specify the server to connect to.

In the settings window, you can also specify what should happen when the client loses the
connection to its server, and what to do when the server quits normally. You can choose between

Do nothing: connection is lost and will not be re-established. Stellarium client keeps running in whatever state it was, waiting for keyboard/mouse interaction.

Try reconnecting: Assume Stellarium is switched off on the server but may come back online again, or assume some temporary network problem. Stellarium client just keeps running in whatever state it was, but tries to reconnect.

Quit: Assume the server always runs until switched off at the end of operating hours. This is intended for pure client screens without keyboards. When the server is shut down, assume this is the end of the day, and exit Stellarium. An enclosing run script can then shutdown the client computer before power is switched off with some main switch.

By default, the following things are synchronized:

- simulation time
- viewer location
- the selected object
- view direction
- current field of view
- all StelProperty-based settings except for GUI-related properties. This includes almost all settings visible in the configuration dialogs such as projection type, sky and view options, landscape settings, line colors, etc.

Because there is currently no full time synchronisation implemented, for the best results all client computers should make sure their system clocks are set as close as possible to the server computer's clock (preferably a few milliseconds difference at most). This can be done for example by using an NTP server.[5] If all your Stellarium instances run on the same device, this is of course not necessary.

It is also possible to exclude some state from being synchronized. On each client, the client configuration GUI (Figure 12.6) allows to disable specific settings from being synchronized on this client.

The lower part of this dialog allows you to fine-tune which named StelProperties (which hold parts of the internal program state) should be excluded from synchronization. The configuration dialog lists all available properties which usually have easy to understand names on the left side. Highlight one or more properties which you don't want synchronized and press the arrow button to move them to the list of excluded properties.

For historic reasons there are two kinds of Properties: Actions (Boolean switches, for which also hotkeys can be assigned) and (genuine) StelProperties. The latter have names indicating which module they belong to and may have other data types (numbers, colors, ...). Note that the actions frequently are just alias names of Boolean StelProperties, so in order to inhibit a certain property from being synchronized, you must find both entries.

Properties of plugins will only be visible when the respective plugin has been enabled. When a plugin has been disabled, its properties may vanish from the stored list of non-synchronized properties.

Each client can have different settings. This could allow installations with several screens where on one screen you show the constellation figures, another screen shows the distribution of deep-sky objects in the same frame, and a third screen may show a close-up view of the currently centered object. Or just show several sky cultures, or show the sky at different locations, ...

The names of all available StelProperties from which you might want to select a few to exclude from synchronisation can also be found with a little scripting (see chapter 16). Open the script console $\boxed{\text{F12}}$ and enter the following call:

---

[5]Instructions on how to use the public NTP server pool for the most common operating systems can be found at `http://www.pool.ntp.org/en/use.html`.
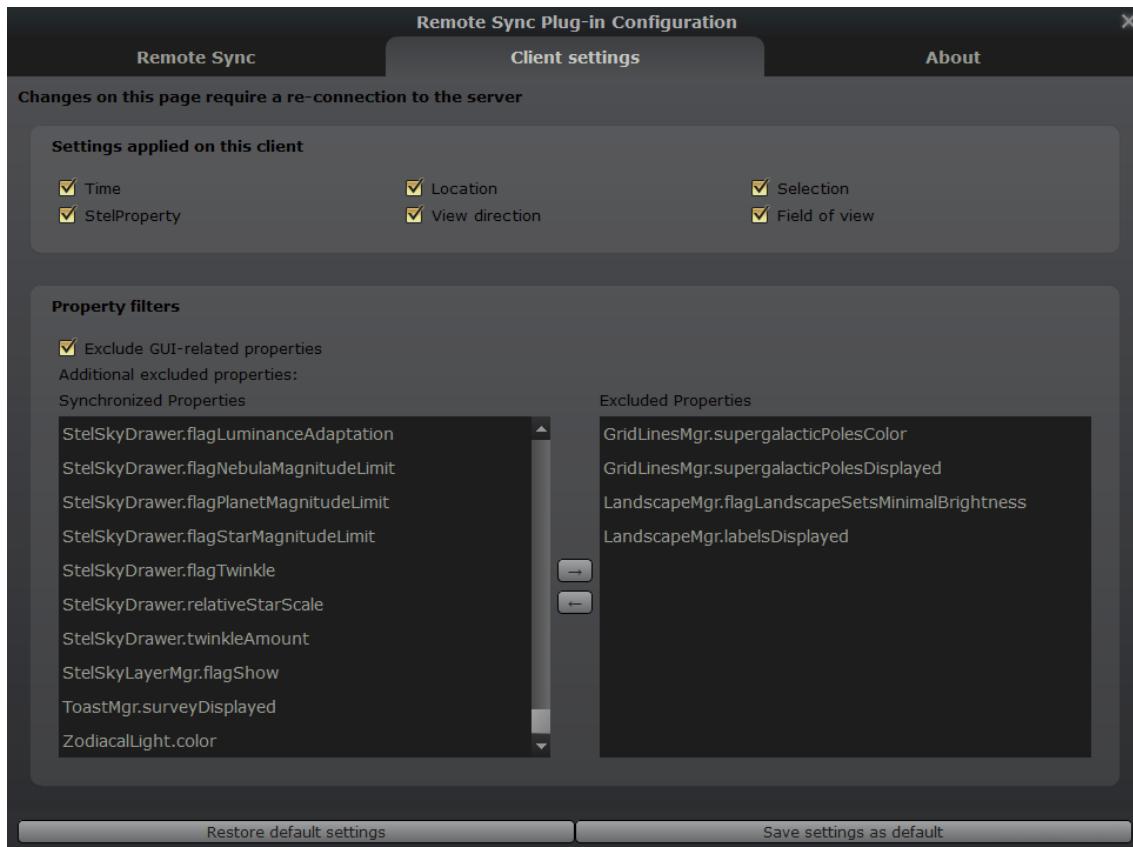
Figure 12.6: RemoteSync client settings window

```
core.output(core.getPropertyList());
```

Run the script and inspect the output tab. It may take a little guesswork to select the right names, but the general structure of property names like `<Module>.<Property>` should help you to find your way around.

Author and Acknowledgements

This plugin was created mostly by Florian Schaukowitsch in the 2015-16 campaigns of the *ESA Summer of Code in Space*[6] programme.

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[6]`http://sophia.estec.esa.int/socis/`

12.8 Solar System Editor Plugin

Stellarium stores its data (orbital elements and other details) about solar system objects (planets, their moons, minor bodies) in two files. File `data/ssystem_major.ini` in the installation directory contains data for the planets and their moons. File `data/ssystem_minor.ini` contains data for minor bodies, i.e., planetoids and comets. The file will be taken from the user data directory if it also exists there, which means, users can add minor planets or comets as they become observable by editing this file.

This plugin provides a window to the Minor Planet Center (MPC[7]) where the latest Solar System information can be found. When this plugin is loaded (see section 11.1) and you call the configuration dialog, the first tab allows to import, export or reset your `ssystem_minor.ini`, and also to load extra data for minor bodies in Stellarium's `.ini` format. For example, the installation directory contains a file `ssystem_1000comets.ini` which contains data for over 1000 historical comets. Currently it is not possible to select only a few from that, so try loading this only on a reasonably fast computer, and think about deleting comets again (or resetting the file) when you don't require them.

The second tab lists all currently loaded minor bodies (see figure 12.8). It is recommended to remove old entries of yesteryear's comets if you don't need them any longer. Just select one or more objects and press Remove . If you have a very weak computer, you may want to reduce the number of minor bodies to just a handful to improve performance.

On this tab, you also find the option to connect to the MPC and download current orbital elements, or load a text file in the format provided by MPC (see figures 12.9 and 12.10).
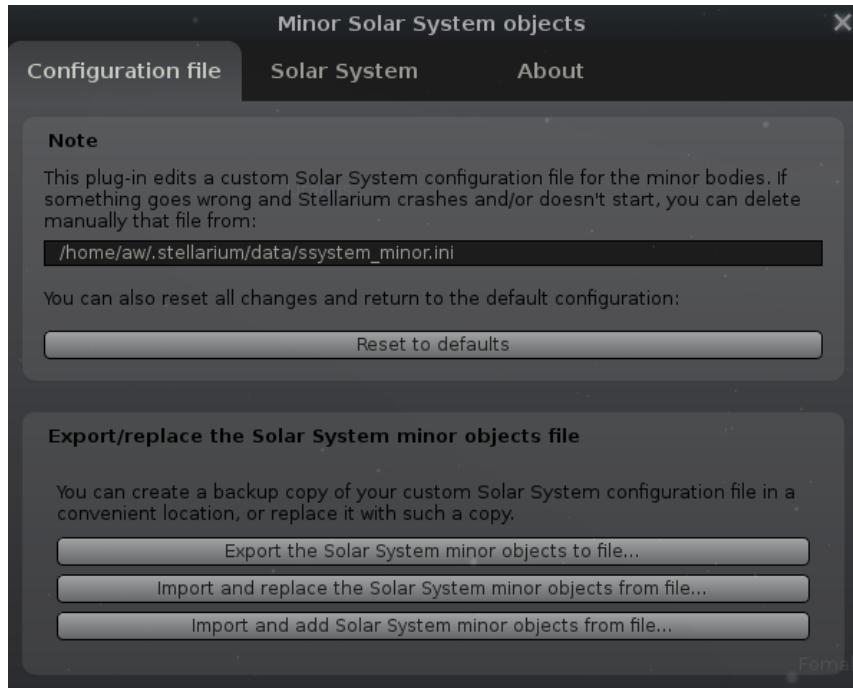
Figure 12.7: Interface of Solar System Editor plugin: Configuration file tab

---

[7]`https://www.minorplanetcenter.net`
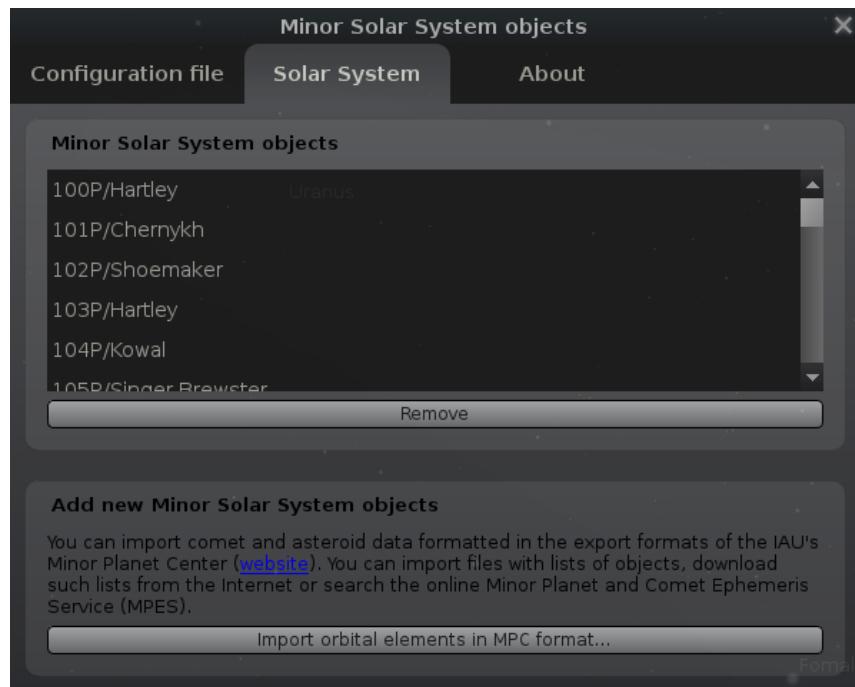
Figure 12.8: Interface of Solar System Editor plugin: Solar System tab
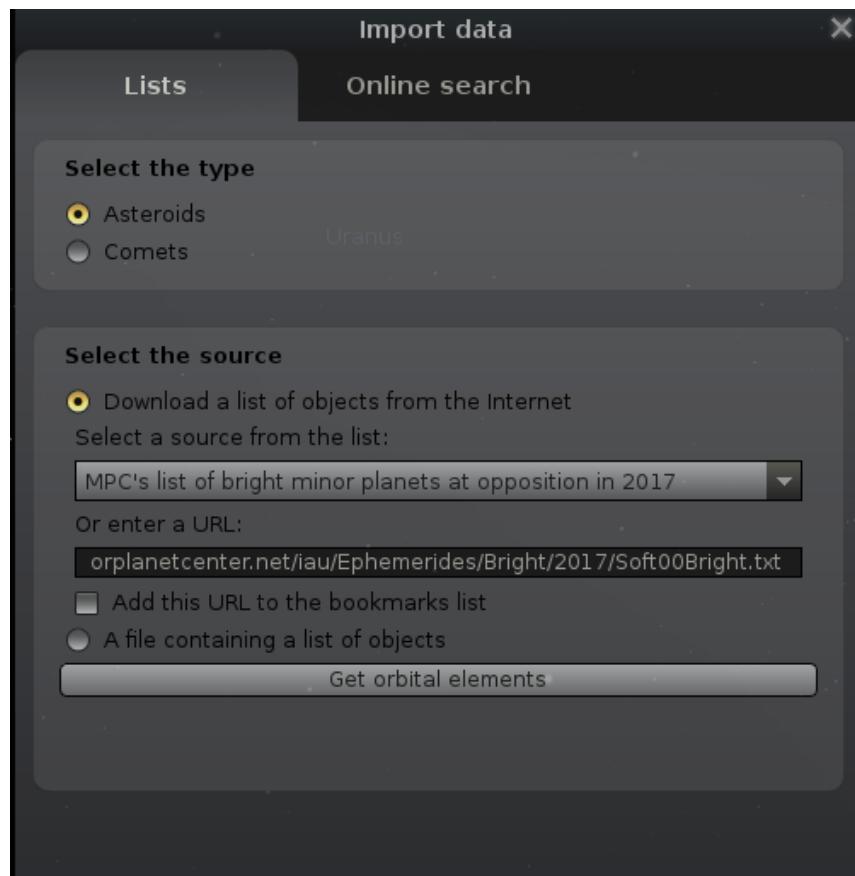
Figure 12.9: Interface of Solar System Editor plugin: Import data dialog
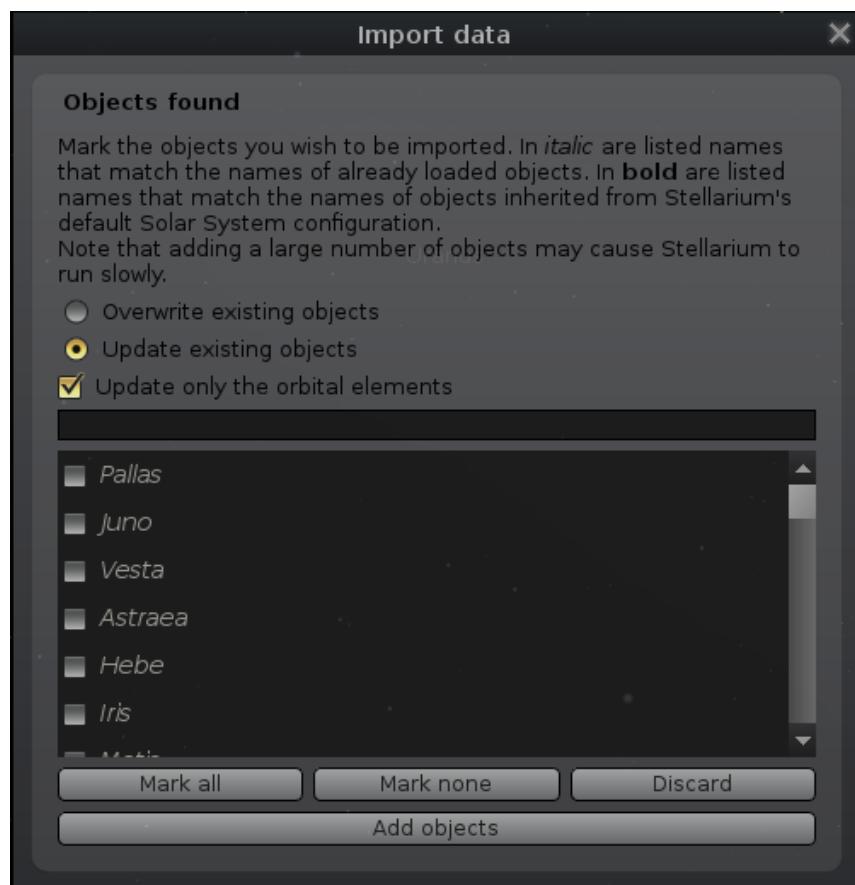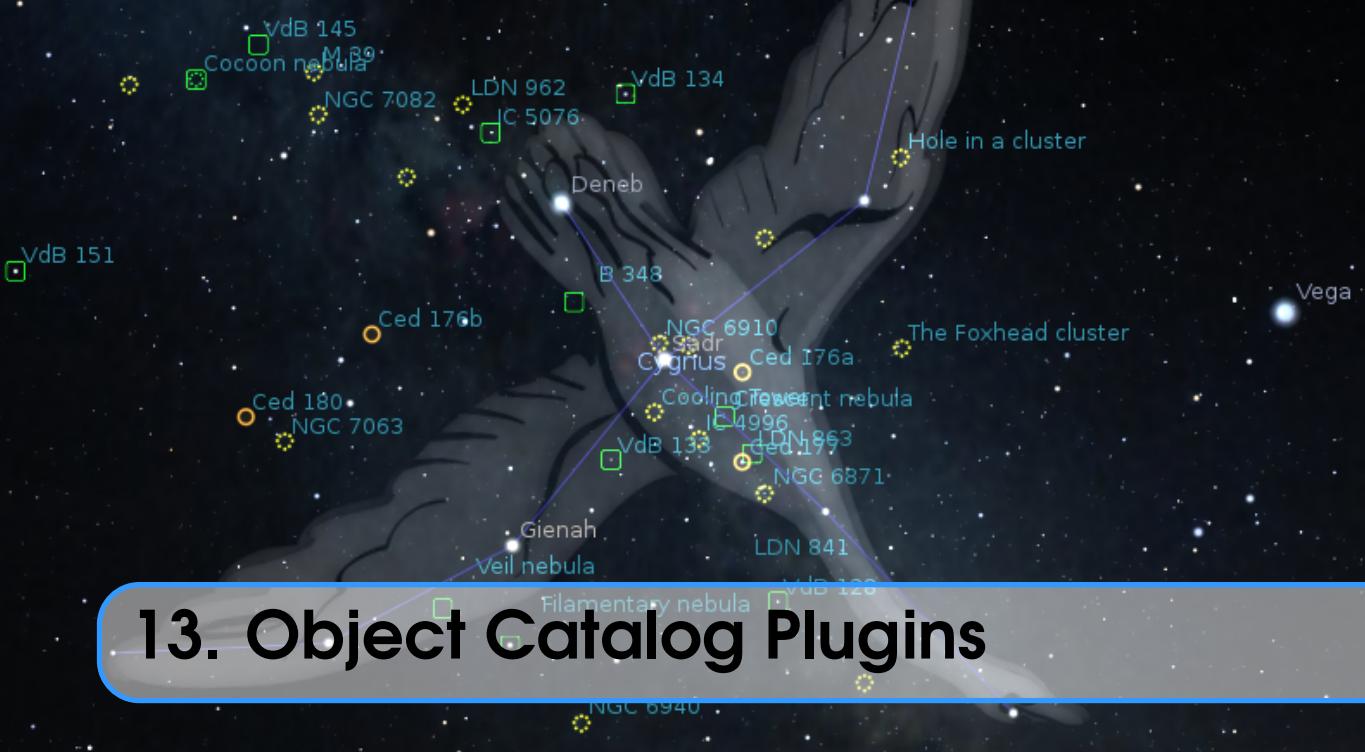
Figure 12.10: Interface of Solar System Editor plugin: Import data dialog — view after downloading and parsing the MPC data.

13. Object Catalog Plugins

Several plugins provide users with some more object classes.

13.1 Bright Novae Plugin
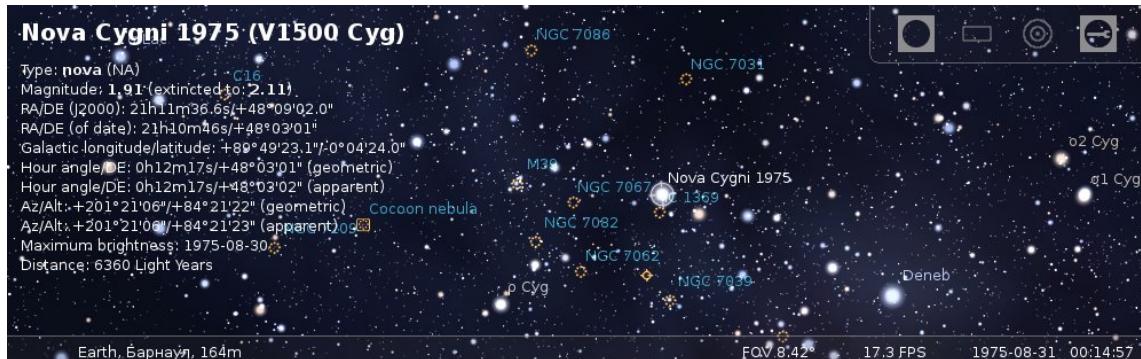
Figure 13.1: Nova Cygni 1975 (also known as **V1500 Cyg**)

The Bright Novae plugin provides visualization of some bright novae in the Milky Way galaxy. If enabled (see section 11.1), bright novae from the past will be presented in the sky at the correct times. For example, set date and time to 30 August 1975, look at the constellation *Cygnus* to see *Nova Cygni 1975*[1] (Fig. 13.1).

13.1.1 Section [Novae] in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Bright Novae plugin – just make it carefully!

---

[1] http://en.wikipedia.org/wiki/V1500_Cygni

ID	Type	Description
last_update	string	Date and time of last update
update_frequency_days	int	Frequency of updates, in days
updates_enable	bool	Enable updates of bright novae catalog from Internet
url	string	URL of bright novae catalog

13.1.2 Format of bright novae catalog

To add a new nova, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Nova␣designation":
{
    "name": "name␣of␣nova",
    "type": "type␣of␣nova",
    "maxMagnitude": value of maximal visual magnitude,
    "minMagnitude": value of minimal visual magnitude,
    "peakJD": JD for maximal visual magnitude,
    "m2": Time to decline by 2mag from maximum (in days),
    "m3": Time to decline by 3mag from maximum (in days),
    "m6": Time to decline by 6mag from maximum (in days),
    "m9": Time to decline by 9mag from maximum (in days),
    "distance": value of distance between nova and
                Earth (in thousands of Light Years),
    "RA": "Right␣ascension␣(J2000)",
    "Dec": "Declination␣(J2000)"
},
```

For example, the record for **Nova Cygni 1975** (**V1500 Cyg**) looks like:

```
"V1500␣Cyg":
{
    "name": "Nova␣Cygni␣1975",
    "type": "NA",
    "maxMagnitude": 1.69,
    "minMagnitude": 21,
    "peakJD": 2442655,
    "m2": 2,
    "m3": 4,
    "m6": 32,
    "m9": 263
    "distance": 6.36,
    "RA": "21h11m36.6s",
    "Dec": "48d09m02s"
},
```

13.1.3 Light curves

This plugin uses a very simple model for calculation of light curves for novae stars. This model is based on time for decay by N magnitudes from the maximum value, where N is 2, 3, 6 and 9. If a nova has no values for decay of magnitude then this plugin will use generalized values for it.

13.2   Historical Supernovae Plugin

Figure 13.2: Supernova 1604 (also known as **Kepler's Supernova**, **Kepler's Nova** or **Kepler's Star**)

Similar to the Historical Novae plugin (section 13.1), the Historical Supernovae plugin provides visualization of bright historical supernovae (Fig. 13.2) from the table below. If enabled (see section 11.1), bright supernovae from the past will be presented in the sky at the correct times. For example, set date and time to 29 April 1006, and look at the constellation *Lupus* to see *SN 1006A*.

13.2.1   List of supernovae in default catalog

Supernova	*Date of max. brightness*	*Max. apparent mag.*	*Type*	*Name*
SN 185A[2]	7 December	-6.0	Ia	
SN 386A	24 April	1.5	II	
SN 1006A[3]	29 April	-7.5	I	
SN 1054A[4]	3 July	-6.0	II	
SN 1181A[5]	4 August	-2.0	II	
SN 1572A[6]	5 November	-4.0	I	Tycho's Supernova
SN 1604A[7]	8 October	-2.0	I	Kepler's Supernova

---

[2]https://en.wikipedia.org/wiki/SN_185
[3]https://en.wikipedia.org/wiki/SN_1006
[4]https://en.wikipedia.org/wiki/SN_1054
[5]https://en.wikipedia.org/wiki/SN_1181
[6]https://en.wikipedia.org/wiki/SN_1572
[7]https://en.wikipedia.org/wiki/SN_1604

SN 1680A[8]	15 August	6.0	IIb	Cassiopeia A
SN 1885A[9]	17 August	5.8	IPec	S Andromedae
SN 1895B	5 July	8.0	I	
SN 1919A	14 March	11.0	I	
SN 1920A	17 December	11.7	II	
SN 1921C	11 December	11.0	I	
SN 1937C	21 August	8.5	Ia	
SN 1937D	15 September	11.87	Ia	
SN 1960F	21 April	11.6	Ia	
SN 1960R	19 December	12.0	I	
SN 1961H	8 May	11.8	Ia	
SN 1962M	26 November	11.5	II	
SN 1965I	19 Juni	11.8	Ia	
SN 1966J	2 December	11.3	I	
SN 1968L	12 July	11.9	IIP	
SN 1970G	30 July	11.4	IIL	
SN 1971I	29 May	11.9	Ia	
SN 1972E[10]	8 May	8.4	Ia	
SN 1974G	27 April	11.8	Ia	
SN 1979C	15 April	11.6	IIL	
SN 1980K	31 October	11.6	IIL	
SN 1981B	9 March	12.0	Ia	
SN 1983N	17 July	11.4	Ib	
SN 1986G	12 May	11.44	Ia Pec	
SN 1987A[11]	24 February	2.9	IIPec	
SN 1989B	6 February	11.9	Ia	
SN 1991T	26 April	11.6	IaPec	
SN 1993J[12]	30 March	10.8	IIb	
SN 1994ae	12 January	12.0	Ia	
SN 1994D	31 March	11.8	Ia	
SN 1998bu	21 May	11.9	Ia	
SN 2004dj	31 July	11.3	IIP	
SN 2004et	2 October	11.57	II	
SN 2011fe[13]	13 September	10.06	Ia	
SN 2012cg	6 Juni	11.954	Ia	
SN 2012fr	16 November	11.95	Ia	
SN 2013aa	13 February	11.9	Ia	
SN 2014j	30 January	10.5	Ia	

---

[8]https://en.wikipedia.org/wiki/Cassiopeia_A
[9]https://en.wikipedia.org/wiki/S_Andromedae
[10]https://en.wikipedia.org/wiki/SN1972e
[11]https://en.wikipedia.org/wiki/SN_1987A
[12]https://en.wikipedia.org/wiki/SN_1993J
[13]https://en.wikipedia.org/wiki/SN_2011fe

SN 2017cbv	22 March	11.5	Ia	

13.2.2 Light curves

In this plugin a simple model of light curves for different supernovae has been implemented (Figure 13.3). While Type I supernovae show a peak and slow but steady decay, Type II supernovae show a longer "plateau" in the decay curve.
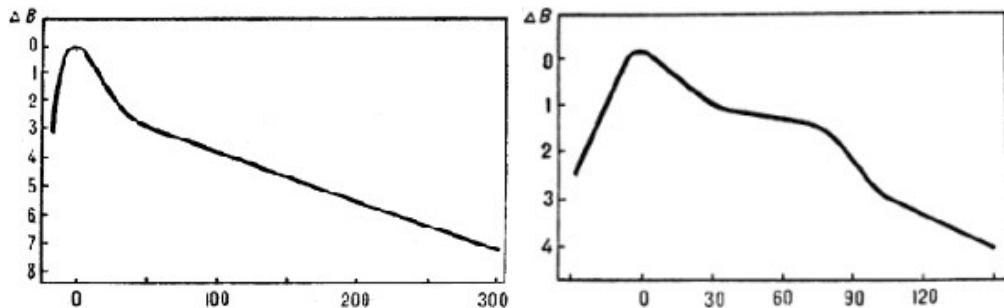
Figure 13.3: Light Curves of Supernovae Types I (left) and II (right)

In both images for light curves the maximum brightness is marked as day 0.

13.2.3 Section [Supernovae] in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Historical Supernovae plugin – just make it carefully!

ID	Type	Description
last_update	string	Date and time of last update
update_frequency_days	int	Frequency of updates, in days
updates_enable	bool	Enable updates of bright novae catalog from Internet
url	string	URL of bright novae catalog

13.2.4   Format of historical supernovae catalog

To add a new nova, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Supernova␣designation":
{
    "type": "type␣of␣supernova",
    "maxMagnitude": value of maximal visual magnitude,
    "peakJD": JD for maximal visual magnitude,
    "alpha": "Right␣ascension␣(J2000)",
    "delta": "Declination␣(J2000)",
    "distance": value of distance between supernova and
                Earth (in thousands of Light Years),
    "note": "notes␣for␣supernova"
},
```

For example, the record for **SN 1604A** (**Kepler's Supernova**) looks like:

```
"1604A":
{
    "type": "I",
    "maxMagnitude": -2,
    "peakJD": 2307190,
    "alpha": "17h30m36.00s",
    "delta": "-21d29m00.0s",
    "distance": 14,
    "note": "Kepler's␣Supernova"
},
```

13.3 Exoplanets Plugin

Figure 13.4: Planetary system τ Ceti

This plugin plots the position of stars with exoplanets. Exoplanets data is derived from "The Extrasolar Planets Encyclopaedia"[14]. List of potential habitable exoplanets and data about them were taken from "The Habitable Exoplanets Catalog"[15] by the Planetary Habitability Laboratory[16].

If enabled (see section 11.1), just click on the Exoplanet button [⠏] on the bottom toolbar to display markers for the stars with known exoplanets. You can then either click on such a marked star or find the stars with exoplanets by their designation (e.g., *24 Sex*) in the F3 dialog (see 4.5).

13.3.1 Potential habitable exoplanets

This plugin can display potential habitable exoplanets (orange marker) and some information about those planets.

Planetary Class Planet classification from host star spectral type (F, G, K, M; see section 18.2.4), habitable zone (hot, warm, cold) and size (miniterran, subterran, terran, superterran, jovian, neptunian) (Earth = G-Warm Terran).

Equilibrium Temperature The planetary equilibrium temperature[17] is a theoretical temperature (in °C) that the planet would be at when considered simply as if it were a black body being heated only by its parent star (assuming a 0.3 bond albedo). As example the planetary equilibrium temperature of Earth is -18.15°C (255 K).

Earth Similarity Index (ESI) Similarity to Earth[18] on a scale from 0 to 1, with 1 being the most Earth-like. ESI depends on the planet's radius, density, escape velocity, and surface temperature.

---

[14]http://exoplanet.eu/
[15]http://phl.upr.edu/projects/habitable-exoplanets-catalog
[16]http://phl.upr.edu/home
[17]http://lasp.colorado.edu/~bagenal/3720/CLASS6/6EquilibriumTemp.html
[18]http://phl.upr.edu/projects/earth-similarity-index-esi

13.3.2 Proper names

In December 2015[19] and in December 2019[20], the International Astronomical Union (IAU) has officially approved names for several exoplanets after a public vote.

Veritate * (14 And) – From the latin Veritas, truth. The ablative form means *where there is truth*[21].

Spe * (14 And b) – From the latin Spes, hope. The ablative form means *where there is hope*.

Musica (18 Del) – Musica is Latin for *music*.

Arion (18 Del b) – Arion was a genius of poetry and music in ancient Greece. According to legend, his life was saved at sea by dolphins after attracting their attention by the playing of his kithara.

Fafnir (42 Dra) – Fafnir was a Norse mythological dwarf who turned into a dragon.

Orbitar (42 Dra b) – Orbitar is a contrived word paying homage to the space launch and orbital operations of NASA.

Chalawan (47 UMa) – Chalawan is a mythological crocodile king from a Thai folktale.

Taphao Thong (47 UMa b) – Taphao Thong is one of two sisters associated with the Thai folk tale of Chalawan.

Taphao Kaew (47 UMa c) – Taphao Kae is one of two sisters associated with the Thai folk tale of Chalawan.

Helvetios (51 Peg) – Helvetios is Celtic for the *Helvetian* and refers to the Celtic tribe that lived in Switzerland during antiquity.

Dimidium (51 Peg b) – Dimidium is Latin for *half*, referring to the planet's mass of at least half the mass of Jupiter.

Copernicus (55 Cnc) – Nicolaus Copernicus or Mikolaj Kopernik (1473-1543) was a Polish astronomer who proposed the heliocentric model of the solar system in his book "De revolutionibus orbium coelestium".

Galileo (55 Cnc b) – Galileo Galilei (1564-1642) was an Italian astronomer and physicist often called the *father of observational astronomy* and the *father of modern physics*. Using a telescope, he discovered the four largest satellites of Jupiter, and the reported the first telescopic observations of the phases of Venus, among other discoveries.

Brahe (55 Cnc c) – Tycho Brahe (1546-1601) was a Danish astronomer and nobleman who recorded accurate astronomical observations of the stars and planets. These observations were critical to Kepler's formulation of his three laws of planetary motion.

Lipperhey * (55 Cnc d) – Hans Lipperhey (1570-1619) was a German-Dutch lens grinder and spectacle maker who is often attributed with the invention of the refracting telescope in 1608[22].

Janssen (55 Cnc e) – Zacharias Janssen (1580s-1630s) was a Dutch spectacle maker who is often attributed with invention of the microscope, and more controversially with the invention of the telescope.

Harriot (55 Cnc f) – Thomas Harriot (ca. 1560-1621) was an English astronomer, mathematician, ethnographer, and translator, who is attributed with the first drawing of the Moon through telescopic observations.

Amateru * (ε Tau b) – *Amateru* is a common Japanese appellation for shrines when they enshrine Amaterasu, the Shinto goddess of the Sun, born from the left eye of the god Izanagi[23].

---

[19]https://www.iau.org/news/pressreleases/detail/iau1514/

[20]https://www.iau.org/news/pressreleases/detail/iau1912/

[21]The original name proposed, Veritas, is that of an asteroid important for the study of the solar system.

[22]The original spelling of Lippershey was corrected to Lipperhey on 15.01.2016. The commonly seen spelling Lippershey (with an s) results in fact from a typographical error dating back from 1831, thus should be avoided.

[23]The name originally proposed, Amaterasu, is already used for an asteroid.

Hypatia (ι Dra b) – Hypatia was a famous Greek astronomer, mathematician, and philosopher. She was head of the Neo-Platonic school at Alexandria in the early 5th century, until murdered by a Christian mob in 415.

Ran * (ε Eri) – Ran is the Norse goddess of the sea, who stirs up the waves and captures sailors with her net.

AEgir * (ε Eri b) – Ægir is Ran's husband, the personified god of the ocean. *Ægir* and *Ran* both represent the *Jotuns* who reign in the outer Universe; together they had nine daughters[24].

Tadmor * (γ Cep b) – Ancient Semitic name and modern Arabic name for the city of Palmyra, a UNESCO World Heritage Site.

Dagon (α PsA b) – Dagon was a Semitic deity, often represented as half-man, half-fish.

Tonatiuh (HD 104985) – Tonatiuh was the Aztec god of the Sun.

Meztli (HD 104985 b) – Meztli was the Aztec goddess of the Moon.

Ogma * (HD 149026) – Ogma was a deity of eloquence, writing, and great physical strength in the Celtic mythologies of Ireland and Scotland, and may be related to the Gallo-Roman deity *Ogmios*[25].

Smertrios (HD 149026 b) – Smertrios was a Gallic deity of war.

Intercrus (HD 81688) – Intercrus means *between the legs* in Latin style, referring to the star's position in the constellation Ursa Major.

Arkas (HD 81688 b) – Arkas was the son of Callisto (Ursa Major) in Greek mythology.

Cervantes (μ Ara) – Miguel de Cervantes Saavedra (1547-1616) was a famous Spanish writer and author of "El Ingenioso Hidalgo Don Quixote de la Mancha".

Quijote (μ Ara b) – Lead fictional character from Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

Dulcinea (μ Ara c) — Fictional character and love interest of Don Quijote (or Quixote) in Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

Rocinante (μ Ara d) – Fictional horse of Don Quijote in Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

Sancho (μ Ara e) – Fictional squire of Don Quijote in Cervantes's "El Ingenioso Hidalgo Don Quixote de la Mancha".

Thestias * (β Gem b) – Thestias is the patronym of Leda and her sister Althaea, the daughters of Thestius. Leda was a Greek queen, mother of Pollux and of his twin Castor, and of Helen and Clytemnestra[26].

Lich (PSR B1257+12) – Lich is a fictional undead creature known for controlling other undead creatures with magic.

Draugr (PSR B1257+12 b) – Draugr refers to undead creatures in Norse mythology.

Poltergeist (PSR B1257+12 c) – Poltergeist is a name for supernatural beings that create physical disturbances, from German for noisy ghost.

Phobetor (PSR B1257+12 d) – Phobetor is a Greek mythological deity of nightmares, the son of Nyx, the primordial deity of night.

Titawin (υ And) – Titawin (also known as Medina of Tetouan) is a settlement in northern Morocco and UNESCO World Heritage Site. Historically it was an important point of contact between two civilizations (Spanish and Arab) and two continents (Europe and Africa) after the 8th century.

Saffar (υ And b) – Saffar is named for Abu al-Qasim Ahmed Ibn-Abd Allah Ibn-Omar al Ghafiqi

---

[24]Note the typographical difference between Ægir and Aegir, the Norwegian transliteration. The same name, with the spelling Aegir, has been attributed to one of Saturn's satellites, discovered in 2004.

[25]Ogmios is a name already attributed to an asteroid.

[26]The original proposed name Leda is already attributed to an asteroid and to one of Jupiter's satellites. The name Althaea is also attributed to an asteroid.

Ibn-al-Saffar, who taught arithmetic, geometry, and astronomy in 11th century Cordova in Andalusia (modern Spain), and wrote an influential treatise on the uses of the astrolabe.

Samh (υ And c) – Samh is named for Abu al-Qasim 'Asbagh ibn Muhammad ibn al-Samh al-Mahri (or Ibn al-Samh), a noted 11th century astronomer and mathematician in the school of al Majriti in Cordova (Andalusia, now modern Spain).

Majriti (υ And d) – Majriti is named for Abu al-Qasim al-Qurtubi al-Majriti, a notable mathematician, astronomer, scholar, and teacher in 10th century and early 11th century Andalusia (modern Spain).

Libertas * (ξ Aql) – Libertas is Latin for liberty. Liberty refers to social and political freedoms, and a reminder that there are people deprived of liberty in the world even today. The constellation Aquila represents an eagle – a popular symbol of liberty.

Fortitudo * (ξ Aql b) – Fortitudo is Latin for fortitude. Fortitude means emotional and mental strength in the face of adversity, as embodied by the eagle (represented by the constellation Aquila).

Illyrian (HD 82886) – Historians largely believe that the Albanians are descendants of the Illyrians, a term Albanians proudly call themselves.

Arber (HD 82886 b) – Arber is the term for the inhabitants of Albania during the middle ages.

Hoggar (HD 28678) – Hoggar is the name of the main mountain range in the Sahara Desert in southern Algeria.

Tassili (HD 28678 b) – Tassili is a UNESCO World Heritage Site situated in the Sahara Desert and is renowned for its prehistoric cave art and scenic geological formations.

Arcalís (HD 131496) – Arcalis is a famous peak in the north of Andorra, where the Sun passes through a hole in the mountain twice a year at fixed dates. It was used as a primitive solar calendar and reference point for shepherds and early inhabitants of Andorra.

Madriu (HD 131496 b) – Madriu (*Mare del riu* in Catalan, *Mother of the River* in English) is the name of a glacial valley and of the river that runs through it in the southeast of Andorra. It is the main part of the Madriu-Perafita-Claror UNESCO World Heritage Site.

Nosaxa (HD 48265) – Nosaxa means *spring* in the Moqoit language. The word comes from a combination of nosahuec, which means renew, and ñaaxa, which means *year*.

Naqaya (HD 48265 b) – Naqaya means *brother-family-relative* in the Moqoit language and leads us to call all humans, indigenous or non-indigenous, brother.

Malmok (WASP-39) – Malmok is an indigenous name given to a beach in Aruba with a narrow sandy stretch that interrupts the limestone and rocky terrace along the coast. Its shallow clear Caribbean waters make it a popular snorkelling spot.

Bocaprins (WASP-39 b) – Boca Prins is a secluded beach with white dunes and iconic scenery situated in Arikok National Park along the northeast coast of Aruba. It is named after Plantation Prins where coconuts are cultivated.

Bubup (HD 38283) – Bubup is the Boonwurrung word for child.

Yanyan (HD 38283 b) – YanYan is the Boonwurrung word for boy.

Franz (HAT-P-14) – Franz is a character in the movie "Sissi" embodying an emperor of Austria in the 19th century. The role is played by the actor Karlheinz Böhm.

Sissi (HAT-P-14 b) – Sissi is a character in the movie "Sissi", who is married with Franz. The role is played by the actress Romy Schneider.

Mahsati (HD 152581) – Mahsati Ganjavi (1089–1159) is one of the brightest shining stars of Azerbaijani poetry. She was said to have associated with both Omar Khayyam and Nizami and was well educated and talented and played numerous musical instruments.

Ganja (HD 152581 b) – Ganja is an ancient city of Azerbaijan, and is the birth place of many prominent people such as the poets Mahsati and Nizami. It is the ancient capital of Azerbaijan, the first capital of the Azerbaijan Democratic Republic and the city with the spirit of

wisdom and freedom.

Timir (HD 148427) – Timir means darkness in Bengali language, alluding to the star being far away in the darkness of space.

Tondra (HD 148427 b) – Tondra means *nap* in Bengali language, alluding to the symbolic notion that the planet was asleep until discovered.

Nervia (HD 49674) – Nervia, adapted from Nervii, was a prominent Belgian Celtic tribe.

Eburonia (HD 49674 b) – Eburonia, adapted from Eburones, was a prominent Belgian Celtic tribe.

Gakyid (HD 73534) – Gakyid means *happiness*. Gross National Happiness is the development philosophy conceived and followed in Bhutan and is one of Bhutan's contributions to the world.

Drukyul (HD 73534 b) – Drukyul (land of the thunder dragon) is the native name for Bhutan, the country that came up with the philosophy of Gross National Happiness.

Tapecue (HD 63765) – Tapecue means *eternal path* in Guarani and represents the Milky Way through which the first inhabitants of the Earth arrived and could return.

Yvaga (HD 63765 b) – Yvaga means *paradise* for the Guarani and the Milky Way was known as the road to Yvaga or paradise.

Bosona (HD 206610) – Bosona is the name given to the territory of Bosnia in the 10th century. Later, the name was transformed to Bosnia originating from the name of the Bosna river.

Naron (HD 206610 b) – Naron is one of the names given to the Neretva river in Herzegovina (and partly in Croatia) in antiquity orginating with the Celts who called it Nera Etwa which means the Flowing Divinity.

Tupi (HD 23079) – Tupi is the name of the most populous Indigenous People living on the eastern coast of South America, before the Portuguese arrived in the 16th century.

Guarani (HD 23079 b) – Guarani is the name of the most populous Indigenous people living in South Brazil and parts of Argentina, Paraguay and Uruguay.

Gumala (HD 179949) – Gumala is a Malay word, which means a magic bezoar stone found in snakes, dragons, etc.

Mastika (HD 179949 b) – Mastika is a Malay word, which means *a gem, precious stone, jewel* or *the prettiest, the most beautiful*.

Tangra (WASP-21) – Tangra is the supreme celestial god that early Bulgars worshiped.

Bendida (WASP-21 b) – Bendida is the Great Mother Goddess of the Thracians. She was especially revered as a goddess of marriage and living nature.

Mouhoun (HD 30856) – Mouhoun, also called Volta Noire, is the largest river in Burkina Faso and plays an important role in the lives of the people in the areas it passes through.

Nakanbé (HD 30856 b) – The Nakanbé, also called Volta Blanche, is the second largest river in Burkina Faso. Its source is in the heart of the Sahara Burkinabe and ends in Ghana.

Nikawiy (HD 136418) – Nikawiy is the word for mother in the Indigenous Cree language of Canada.

Awasis (HD 136418 b) – Awasis is the word for child in the Indigenous Cree language of Canada.

Pincoya (HD 164604) – Pincoya is a female water spirit from southern Chilean mythology who is said to bring drowned sailors to the Caleuche so that they can live in the afterlife.

Caleuche (HD 164604 b) – Caleuche is a large ghost ship from southern Chilean mythology which sails the seas around the island of Chiloé at night.

Lionrock (HD 212771) – Lion Rock is a lion-shaped peak overlooking Hong Kong and is a cultural symbol with deep respect from the local community.

Victoriapeak (HD 212771 b) – Victoria Peak overlooks the bustling Victoria Harbour and is regarded as an ambassadorial gateway for foreign visitors wishing to experience Hong Kong first hand.

Xihe (HD 173416) – Xiheis the goddess of the sun in the Chinese mythology and also represents the earliest astronomers and developers of calendars in ancient China.

Wangshu (HD 173416 b) – Wangshu is the goddess who drives for the Moon and also represents the Moon in Chinese mythology.

Formosa (HD 100655) – Formosa is the historical name of Taiwan used in the 17th century, meaning beautiful in Latin.

Sazum (HD 100655 b) – Sazum is the traditional name of Yuchi, a Township in Nantou county, in which the famous Sun-Moon Lake lies. Sazum means water in the language of the Thao people who are a tribe of Taiwanese aborigines who lived in the region for hundreds of years.

Macondo (HD 93083) – Macondo is the mythical village of the novel "One Hundred Years of Solitude" ("Cien años de soledad") the classic novel by Gabriel García Marquez. Macondo is a fictional place where magic and reality are mixed.

Melquíades (HD 93083 b) – Melquíades is a fictional character that walks around Macondo, like a planet orbiting a star, connecting it with the external world by introducing new knowledge using his inventions as well as his stories.

Poerava (HD 221287) – Poerava is the word in the Cook Islands Maori language for a large mystical black pearl of utter beauty and perfection.

Pipitea (HD 221287 b) – Pipitea is a small, white and gold pearl found in Penrhyn lagoon in the northern group of the Cook Islands.

Dìwö (WASP-17) – Dìwö in Bribri language means *the sun (bigger than the sun we know)* and that never turns off.

Ditsö (WASP-17 b) – Ditsö is the name that the god Sibö gave to the first Bribri people.

Stribor (HD 75898) – Stribor is God of winds in Slavic mythology, as well as a literature character in the book Priče iz davnine (Croatian Tales of Long Ago) by the Croatian author Ivana Brlić-Mažuranić.

Veles (HD 75898 b) – Veles is a major Slavic god of earth, waters and the underworld.

Felixvarela (BD-17 63) – Felix Varela (1788–1853) was the first to teach science in Cuba at the San Carlos and San Ambrosio Seminary. He opened the way to education for all, and began the experimental teaching of physics in Cuba.

Finlay (BD-17 63 b) – Carlos Juan Finlay (1833–1915) was an epidemiologist recognized as a pioneer in the research of yellow fever, determining that it was transmitted through mosquitoes.

Alasia (HD 168746) – Alasia is the first historically recorded name of Cyprus, dating back to mid-fifteenth century BC.

Onasilos (HD 168746 b) – Onasilos is the oldest historically recorded doctor in Cyprus, inscribed on the fifth century BC Idalion Tablet. Also known as the Onasilou Plate, it is considered as the oldest legal contract found in the world.

Absolutno (XO-5) – Absolutno is a fictional miraculous substance in the sci-fi novel "Továrna na absolutno" ("The Factory for the Absolute") by influential Czech writer Karel Čapek.

Makropulos (XO-5 b) – Makropulos is the name from Karel Čapek's play Věc Makropulos (The Makropulos Affair), dealing with problems of immortality and consequences of an artificial prolongation of life.

Muspelheim (HAT-P-29) – Muspelheim is the Norse mythological realm of fire. The first gods used the sparks of Muspelheim to form the sun, moon, planets, and stars.

Surt (HAT-P-29 b) – Surt is the ruler of Muspelheim and the fire giants there in Norse mythology. At Ragnarok, the end of the world, he will lead the attack on our world and destroy it in flames.

Márohu (WASP-6) – Márohu the god of drought is the protector of the Sun and is engraved at a higher position on the stalagmite than Boinayel in the El Puente cave, where the Sun makes

its way down every 21 December.

Boinayel (WASP-6 b) – Boinayel the god of rain that fertilizes the soil is engraved on the stalagmite at a lower position than Márohu in the El Puente cave.

Nenque (HD 6434) – Nenque means *the Sun* in the language spoken by the Indigenous Waorani tribes of the Amazon regions of Ecuador

Eyeke (HD 6434 b) – Eyeke means *near* in the language spoken by the Indigenous Waorani tribes of the Amazon regions of Ecuador. This word is suggested for the exoplanet owing to the proximity of the planet to the host star.

Citalá (HD 52265) – Citalá means *River of stars* in the native Nahuat language.

Cayahuanca (HD 52265 b) – Cayahuanca means *The rock looking at the stars* in the native Nahuat language.

Koit (XO-4) – Koit is Estonian for the time when the Sun rises in the morning (dawn).

Hämarik (XO-4 b) – Hämarik is Estonian for the time when the Sun goes down in the evening (twilight).

Buna (HD 16175) – Buna is the commonly used word for coffee in Ethiopia.

Abol (HD 16175 b) – Abol is the first of three rounds of coffee in the Ethiopian traditional coffee ceremony.

Horna (HAT-P-38) – Horna is hell or the underworld from Finnic mythology.

Hiisi (HAT-P-38 b) – Hiisi represents sacred localities and later evil spirits from Finnic mythology.

Bélénos (HD 8574) – Bélénos was the god of light, of the Sun, and of health in Gaulish mythology.

Bélisama (HD 8574 b) – Bélisama was the goddess of fire, notably of the hearth and of metallurgy and glasswork, in Gaulish mythology.

Itonda (HD 208487) – Itonda, in the Myene tongue, corresponds to all that is beautiful.

Mintome (HD 208487 b) – Mintome, in the Fang tongue, is a mythical land where a brotherhood of brave men live.

Mago (HD 32518) – Mago is a National Park in Ethiopia noted for its giraffes. The star also happens to be in the constellation of Camelopardis (the giraffe).

Neri (HD 32518 b) – The Neri river in Ethiopia runs through parts of the Mago National park.

Sika (HD 181720) – Sika means *gold* in the Ewe language and gold is one of Ghana's principal exports.

Toge (HD 181720 b) – Toge means *earring* in the Ewe language.

Lerna (HAT-P-42) – Lerna was the name of a lake in the eastern Peloponnese, where the Lernaean Hydra, an immortal mythical nine-headed beast lived. The star lies in the constellation of Hydra.

Iolaus (HAT-P-42 b) – Iolaus was the nephew of Heracles from Greek mythology, moving around lake Lerna in helping Heracles to exterminate the Lernaean Hydra. Similarly this exoplanet in the constellation of Hydra moves around its parent star.

Tojil (WASP-22) – Tojil is the name of one of the Mayan deities related to rain, storms, and fire.

Koyopa' (WASP-22 b) – Koyopa' is the word associated with lightning in K'iche' (Quiché) Mayan language.

Citadelle (HD 1502) – The Citadelle is a large mountaintop fortress in Nord, Haiti built after Haiti's independence, and was designated a UNESCO World Heritage site along with the nearby Sans-Souci Palace.

Indépendance (HD 1502 b) – Indépendance is named after the Haitian Declaration of Independence on 1 January 1804, when Haiti became the first independent black republic.

Hunahpú (HD 98219) – Hunahpú was one of the twin gods who became the Sun in K'iche' (Quiché) Mayan mythology as recounted in the Popol Vuh.

Ixbalanqué (HD 98219 b) – Ixbalanqué was one of the twin gods who became the Moon in K'iche' (Quiché) Mayan mythology as recounted in the Popol Vuh.

Hunor (HAT-P-2) – Hunor was a legendary ancestor of the Huns and the Hungarian nation, and brother of Magor.

Magor (HAT-P-2 b) – Magor was a legendary ancestor of the Magyar people and the Hungarian nation, and brother of Hunor.

Funi (HD 109246) – Funi is an old Icelandic word meaning *fire* or *blaze*.

Fold (HD 109246 b) – Fold is an old Icelandic word meaning *earth* or *soil*.

Bibhā (HD 86081) – Bibhā is the Bengali pronunciation of the Sanskrit word Vibha, which means *a bright beam of light*.

Santamasa (HD 86081 b) – Santamasa in Sanskrit means *clouded*, which alludes to the exoplanet's atmosphere.

Dofida (HD 117618) – Dofida means *our star* in Nias language.

Noifasui (HD 117618 b) – Noifasui means *revolve around* in Nias language, derived from the word ifasui, meaning *to revolve around*, and no, indicating that the action occurred in the past and continued to the present time.

Kaveh (HD 175541) – Kaveh is one of the heroes of Shahnameh, the epic poem composed by Persian poet Ferdowsi between 977 and 1010 CE. Kaveh is a blacksmith who symbolises justice.

Kavian (HD 175541 b) – Kaveh carries a banner called Derafsh Kaviani (Derafsh: banner, Kaviani: relating to Kaveh).

Uruk (HD 231701) – Uruk was an ancient city of the Sumer and Babylonian civilizations in Mesopotamia situated along an ancient channel of the Euphrates river in modern-day Iraq.

Babylonia (HD 231701 b) – Babylonia was a key kingdom in ancient Mesopotamia from the 18th to 6th centuries BC whose name-giving capital city was built on the Euphrates river.

Tuiren (HAT-P-36) – Tuiren was the aunt of the hunterwarrior Fionn mac Cumhaill of Irish legend, who was turned into a hound by the jealous fairy Uchtdealbh.

Bran (HAT-P-36 b) – Tuiren's son Bran was a hound and cousin of the hunterwarrior Fionn mac Cumhaill of Irish legend.

Tevel (HAT-P-9) – Tevel means *Universe* or *everything* and begins with the letter Taf, the last letter in the Hebrew alphabet.

Alef (HAT-P-9 b) – Alef is the first letter in the Hebrew alphabet and also means bull.

Flegetonte (HD 102195) – Flegetonte is the underworld river of fire from Greek Mythology in the Italian narrative poem on the afterlife "Divina Commedia" ("Divine Commedy") by Dante Alighieri, chosen as an allusion to the star's fiery nature.

Lete (HD 102195 b) – Lete is the oblivion river made of fog from Greek Mythology in the Italian narrative poem on the afterlife "Divina Commedia" ("Divine Commedy") by Dante Alighieri, chosen as an allusion to the planet's gaseous nature.

Nyamien (WASP-15) – Nyamien refers to the supreme creator deity of Akan mythology.

Asye (WASP-15 b) – Asye refers to the Earth goddess of Akan mythology.

Kamui (HD 145457) – Kamui is a word in the Ainu language denoting a supernatural entity possessing spiritual energy.

Chura (HD 145457 b) – Chura is a word in the Ryukyuan/Okinawan language meaning *natural beauty*.

Petra (WASP-80) – Petra is a historical and archaeological city in southern Jordan and a UNESCO World Heritage site.

Wadirum (WASP-80 b) – Wadi Rum (Valley of the Moon) is located at the far south of Jordan, it is the largest valley in Jordan, set on the high plateau at the western edge of the Arabian Desert.

Kalausi (HD 83443) – The word Kalausi means *a very strong whirling column of wind* in the Dholuo language of Kenya.

Buru (HD 83443 b) – Buru means *dust* in the Dholuo language of Kenya and is typically associated with wind storms.

Liesma (HD 118203) – Liesma means *flame*, and it is the name of a character from the Latvian poem Staburags un Liesma.

Staburags (HD 118203 b) – Staburags is the name of a character from the Latvian poem Staburags un Liesma, and denotes a rock with symbolic meaning in literature and history.

Phoenicia (HD 192263) – Phoenicia was an ancient thalassocratic civilisation of the Mediterranean that originated from the area of modern-day Lebanon.

Beirut (HD 192263 b) – Beirut is one of the oldest continuously inhabited cities in the world and was a Phoenician port. Beirut is now the capital and largest city of Lebanon.

Pipoltr (TrES-3) – In the local dialect of Triesenberg, Pipoltr is a bright and visible butterfly, alluding to the properties of a star.

Umbäässa (TrES-3 b) – In the local dialect of southern Liechtenstein, Umbäässa is a small and barely visible ant, alluding to the properties of a planet with respect to its star.

Taika (HAT-P-40) – Taika means *peace* in the Lithuanian language.

Vytis (HAT-P-40 b) – Vytis is the symbol of the Lithuanian coat of arms.

Lucilinburhuc (HD 45350) – The Lucilinburhuc fortress was built in 963 by the founder of Luxembourg, Count Siegfried.

Peitruss (HD 45350 b) – Peitruss is derived from the name of the Luxembourg river Pétrusse, with the river's bend around Lucilinburhuc fortress alluding to the orbit of the planet around its star.

Rapeto (HD 153950) – Rapeto is a giant creature from Malagasy tales.

Trimobe (HD 153950 b) – Trimobe is a rich ogre from Malagasy tales.

Intan (HD 20868) – Intan means *diamond* in the Malay language (Bahasa Melayu), alluding to the shining of a star.

Baiduri (HD 20868 b) – Baiduri means *opal* in Malay language (Bahasa Melayu), alluding to the mysterious beauty of the planet.

Sansuna (HAT-P-34) – Sansuna is the name of the mythological giant from traditional Maltese folk tales that carried the stones of the Gozo megalithic temples on her head.

Ġgantija (HAT-P-34 b) – Ġgantija means *giantess*: the megalithic temple complex on the island of Gozo, which alludes to the grandeur of this gas giant exoplanet.

Diya (WASP-72) – Diya is an oil lamp that is brought by Indian ancestors to Mauritius in the 1820's, and is used for lighting during special occasions, including the light festival of Diwali.

Cuptor (WASP-72 b) – Cuptor is a thermally insulated chamber used for baking or drying substances, that has long disappeared in Mauritius and has been replaced by more sophisticated ovens.

Axólotl (HD 224693) – Axólotl means *water animal* in the native Nahuatl language, which is a unique and culturally significant endemic amphibious species from the basin of Mexico.

Xólotl (HD 224693 b) – Xólotl means *animal* in the native Nahuatl language and was an Aztec deity associated with the evening star (Venus).

Tislit (WASP-161) – Tislit is the name of a lake in the Atlas mountains of Morocco. It means *the bride* in the Amazigh language and it is associated with a heartbroken beautiful girl in an ancient local legend.

Isli (WASP-161 b) – Isli is the name of a lake in the Atlas mountains of Morocco. It means *the groom* in the Amazigh language and it is associated with a heartbroken handsome boy in an ancient local legend.

Emiw (HD 7199) – Emiw represents love in the local Makhuwa language of the northern region of Mozambique.

Hairu (HD 7199 b) – Hairu represents unity in the local Makhuwa language of the northern region of Mozambique.

Ayeyarwady (HD 18742) – Ayeyarwady is the largest and most important river in Myanmar.

Bagan (HD 18742 b) – Bagan is one of Myanmar's ancient cities that lies beside the Ayeyarwardy river.

Sagarmatha (HD 100777) – Sagarmatha is the Nepali name for the highest peak in the world (also known as Mount Everest) and symbol of national pride of Nepal.

Laligurans (HD 100777 b) – Laligurans are the Nepali variation of the rhododendron flower and is the national flower of Nepal.

Sterrennacht (HAT-P-6) – The Sterrennacht (Starry Night) is a world-famous painting by Dutch grand master Van Gogh that was painted in France in 1889 and now belongs to the permanent collection of New York's Museum of Modern Art.

Nachtwacht (HAT-P-6 b) – The Nachtwacht (Night Watch) is a world-famous painting by Dutch grand master Rembrandt that was completed in 1642 and now belongs to the collection of the Rijksmuseum in Amsterdam.

Karaka (HD 137388) – Karaka is the word in the Māori language for a plant endemic to New Zealand that produces a bright orange, fleshy fruit.

Kererū (HD 137388 b) – Kererū is the word in the Māori language for a large bush pigeon native to New Zealand.

Cocibolca (HD 4208) – Cocibolca is the Nahualt name for the largest lake in Central America in Nicaragua.

Xolotlan (HD 4208 b) – Xolotlan is the name of the second largest lake of Nicaragua and its name is from the Nahualt language of the indigenous tribe that settled in Nicaragua, which symbolises a native god and a refuge for animals.

Amadioha (HD 43197) – Amadioha is the god of thunder in Igbo mythology. As well as representing justice, Amadioha is also a god of love, peace and unity.

Equiano (HD 43197 b) – Equiano was a writer and abolitionist from Ihiala, Nigeria who fought injustice and the elimination of the slave trade.

Násti (HD 68988) – Násti means *star* in the Northern Sami language of Norway.

Albmi (HD 68988 b) – Albmi means *sky* in the Northern Sami language of Norway.

Shama (HAT-P-23) – Shama is an Urdu literary term meaning *a small lamp* or *flame*, symbolic of the light of the star.

Perwana (HAT-P-23 b) – Perwana means *moth* in Urdu, alluding to the eternal love of an object circling the source of light (the lamp).

Moriah (HD 99109) – Moriah is an ancient name for the mountain within the Old City of Jerusalem.

Jebus (HD 99109 b) – Jebus was the ancient name of Jerusalem in 2nd millennium BC when populated by the Canaanite tribe of Jebusites.

Montuno (WASP-79) – Montuno is the traditional costume the man wears in the "El Punto", a Panamanian dance in which a man and woman dance to the sound of drums.

Pollera (WASP-79 b) – Pollera is the traditional costume the woman wears in the El Punto, a Panamanian dance in which a man and woman dance to the sound of drums.

Tupã (HD 108147) – Tupã is one of four principle gods of the Guarani Cosmogony in popular Paraguayan folklore that helped the supreme god Ñamandu to create the Universe.

Tumearandu (HD 108147 b) – Tume Arandu is a son of Rupavê and Sypavê, the original man and woman of the Universe, who is known as the Father of Wisdom in popular Paraguayan folklore.

Inquill (HD 156411) – Inquil was one half of the couple involved in the tragic love story Way to the Sun by famous Peruvian writer Abraham Valdelomar.

Sumajmajta (HD 156411 b) – Sumaj Majta was one half of the couple involved in a tragic love story Way to the Sun by famous Peruvian writer Abraham Valdelomar.

Amansinaya (WASP-34) – Aman Sinaya is one of the two trinity deities of the Philippine's Tagalog mythology, and is the primordial deity of the ocean and protector of fisherman.

Haik (WASP-34 b) – Haik is the successor of the primordial Aman Sinaya as the God of the Sea of the Philippine's Tagalog mythology.

Uklun (HD 102117) – Uklun means *us* or *we* in the Pitkern language of the people of Pitcairn Islands.

Leklsullun (HD 102117 b) – Lekl Sullun means *child* or children in the Pitkern language of the people of Pitcairn Islands.

Solaris (BD+14 4559) – Solaris is the title of a 1961 science fiction novel about an ocean-covered exoplanet by Polish writer Stanislaw Lem.

Pirx (BD+14 4559 b) – Pirx is a fictional character from books by Polish science-fiction writer Stanislaw Lem.

Lusitânia (HD 45652) – Lusitânia is the ancient name of the western region of the Iberic Peninsula where the Lusitanian people lived and where most of modern-day Portugal is situated.

Viriato (HD 45652 b) – Viriato was a legendary leader of the Lusitanian people, a herdsman and hunter who led the resistance against Roman invaders during 2nd century B.C.

Koeia (HIP 12961) – Koeia was the word for star in the language of the Taíno Indigenous People of the Caribbean.

Aumatex (HIP 12961 b) – Aumatex was the God of Wind in the mythology of the Taíno Indigenous People of the Caribbean.

Moldoveanu (XO-1) – Moldoveanu is the highest peak in Romania of the Făgăraș mountain range with an altitude of 2544 metres.

Negoiu (XO-1 b) – Negoiu is the second highest peak in Romania of the Făgăraș mountain range with an altitude of 2535 metres.

Dombay (HAT-P-3) – Dombay is a resort region in the North Caucasus mountains that is enclosed by mountain forests and rich wildlife, including bears (as this star lies in the constellation Ursa Major, the great bear).

Teberda (HAT-P-3 b) – Teberda is a mountain river in Dombay region with a rapid water flow, symbolising the planet's rapid motion around its host star.

Belel (HD 181342) – Belel is a rare source of water in the north of Senegal.

Dopere (HD 181342 b) – Dopere is an expansive historical area in the north of Senegal where Belel was located.

Morava (WASP-60) – Morava is the longest river system in Serbia.

Vlasina (WASP-60 b) – Vlasina is one of the most significant tributaries of the South Morava river.

Parumleo (WASP-32) – Parumleo is a Latin term for little lion, symbolising Singapore's struggle for independence.

Viculus (WASP-32 b) – Viculus is a Latin term for little village, embodying the spirit of the Singaporean people.

Chasoň (HAT-P-5) – Chasoň is an ancient Slovak term for Sun.

Kráľomoc (HAT-P-5 b) – Kráľomoc is an ancient Slovak term for the planet Jupiter.

Irena (WASP-38) – Irena is a leading character in the novel "Under the Free Sun: a Story of the Ancient Grandfathers" by Slovene writer Fran Saleški Finžgar. Irena is a woman of the court.

Iztok (WASP-38 b) – Iztok is a leading character in the novel "Under the Free Sun: a Story of the Ancient Grandfathers" by Slovene writer Fran Saleški Finžgar. Iztok is a freedom fighter for the Slavic people.

Naledi (WASP-62) – Naledi means *star* in the Sesotho, SeTswana and SePedi languages and is typically given as a name to girls in the hope that they will bring light, joy and peace to their communities.

Krotoa (WASP-62 b) – Krotoa is considered the Mother of Africa and member of the indigenous Khoi people, who was a community builder and educator during colonial times.

Baekdu (8 Umi) – Baekdu is the highest mountain on the Korean peninsula, situated in North Korea, and symbolises the national spirit of Korea.

Halla (8 Umi b) – Halla is the highest mountain in South Korea and is regarded as a sacred place in the region.

Rosalíadecastro (HD 149143) – Rosalía de Castro was a significant figure of Galician culture and prominent Spanish writer, whose pioneeting work often referenced the night and celestial objects.

Riosar (HD 149143 b) – Rio Sar is the name of a river that was present in much of the literary work of the pioneering Spanish author Rosalía de Castro.

Sāmaya (HD 205739) – Sāmaya means *peace* in the Sinhalese language.

Samagiya (HD 205739 b) – Samagiya means *togetherness and unity* in the Sinhalese language.

Aniara (HD 102956) – Aniara is the name of a spaceship in the epic poem Aniara by Swedish author Harry Martinson.

Isagel (HD 102956 b) – Isagel is the name of the spaceship pilot in the epic science fiction poem Aniara written by Swedish author Harry Martinson.

Mönch (HD 130322) – Mönch is one of the prominent peaks of the Bernese Alps in Switzerland.

Eiger (HD 130322 b) – Eiger is one of the prominent peaks of the Bernese Alps, in the Jungfrau-Aletsch protected area.

Ebla (HD 218566) – Ebla was one of the earliest kingdoms in Syria, and served as a prominent region in the 2nd and 3rd millenia B.C.

Ugarit (HD 218566 b) – Ugarit was a city where its scribes devised the Ugaritic alphabet around 1400 B.C. The alphabet was made up of thirty letters and was inscribed on clay tablets.

Mpingo (WASP-71) – Mpingo is a famous tree that grows in southern Tanzania and produces ebony wood used for musical instruments and curios.

Tanzanite (WASP-71 b) – Tanzanite is the name of a precious stone mined in Tanzania and is treasured worldwide.

Chaophraya (WASP-50) – Chao Phraya is the great river of Thailand.

Maeping (WASP-50 b) – Mae Ping is one of the tributaries of Thailand's great river Chao Phraya.

Atakoraka (WASP-64) – Atakoraka means *the chain* of the Atacora: the largest mountain range in Togo.

Agouto (WASP-64 b) – Agouto (Mount Agou) is the highest mountain in Togo and a treasured region of the Atakoraka.

Dingolay (HD 96063) – Dingolay means *to dance, twist and turn in elaborate movements*, symbolising the culture and language of the ancestors of the people of Trinidad and Tobago.

Ramajay (HD 96063 b) – Ramajay means *to sing and make music in a steelpan style*, representing the love of culture and languages of the ancestors of the people of Trinidad and Tobago.

Chechia (HD 192699) – Chechia is a flat-surfaced, traditional red wool hat worn by men and women, symbolising the country's rich traditions and is considered as the national headdress for in Tunisia.

Khomsa (HD 192699 b) – Khomsa is a palm-shaped amulet that is popular in Tunisia, used in jewelry and decorations. It depicts an open right hand and is often found in modern designs.

Anadolu (WASP-52) – Anadolu is the primary homeland of Turkey and refers to the motherland in Turkish culture.

Göktürk (WASP-52 b) – Göktürk refers to the historical origin of the Turkish people, as it was the

first established state in Turkey in 5th century AD. It is also the name of a Turkish satellite and is the combination of two words, of which "Gök" means *sky*.

Berehinya (HAT-P-15) – Berehinya was a Slavic deity of waters and riverbanks but in more recent times her status has been promoted to that of a national goddess — "hearth mother, protectress of the earth".

Tryzub (HAT-P-15 b) – Tryzub is the most recognised ancient symbol of Ukraine, that was minted on the coins of Prince Volodymyr the Great and today remains one of the country's state symbols (a small coat).

Sharjah (HIP 79431) – Sharjah is the cultural capital of United Arab Emirates, and considered the city of knowledge due to its many educational centers, institutes, museums, libraries and heritage centers.

Barajeel (HIP 79431 b) – A barajeel is a wind tower used to direct the flow of the wind so that air can be recirculated as a form of air conditioning.

Gloas (WASP-13) – In Manx Gaelic, Gloas means *to shine* (like a star).

Cruinlagh (WASP-13 b) – In Manx Gaelic, Cruinlagh means *to orbit* (like a planet around its star).

Nushagak (HD 17156) – Nushagak is a regional river near Dilingham, Alaska, which is famous for its wild salmon that sustain local Indigenous communities.

Mulchatna (HD 17156 b) – The Mulchatna River is a tributary of the Nushagak River in southwestern Alaska, USA.

Ceibo (HD 63454) – Ceibo is the name of the native tree of Uruguay that gives rise to the national flower.

Ibirapitá (HD 63454 b) – Ibirapitá is the name of a native tree that is characteristic of the country of Uruguay, and is also known as Artigas' tree, after the national hero.

Natasha (HD 85390) – Natasha means *thank you* in many languages of Zambia.

Madalitso (HD 85390 b) – Madalitso means *blessings* in the native language of Nyanja in Zambia.

All names with asterix mark (*) are modified based on the original proposals, to be consistent with the IAU rules.

13.3.3 Section [Exoplanets] in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Exoplanets plugin – just make it carefully!

ID	Type	Description
last_update	string	Date and time of last update
update_frequency_hours	int	Frequency of updates, in hours
updates_enable	bool	Enable updates of exoplanets catalog from Internet
url	string	URL of exoplanets catalog
flag_show_exoplanets_button	bool	Enable showing button of exoplanets on bottom bar
distribution_enabled	bool	Enable distribution mode of display
timeline_enabled	bool	Enable timeline mode of display
habitable_enabled	bool	Enable habitable mode of display
enable_at_startup	bool	Enable displaying exoplanets at startup of the plugin
exoplanet_marker_color	R,G,B	Color for marker of star with planetary system
habitable_exoplanet_marker_color	R,G,B	Color for marker of star with planetary system with potential habitable exoplanets
temperature_scale	string	Temperature scale for equilibrium temperature of exoplanets. Possible values: *Kelvin*, *Celsius*, *Fahrenheit*. Default value: *Celsius*.

13.3.4 Format of exoplanets catalog

To add a new exoplanet system, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Star␣designation":
{
        "exoplanets":
        [
        {
                "mass": mass of exoplanet (M jup),
                "radius": radius of exoplanet (R jup),
                "period": period of exoplanet (days),
                "semiAxis": semi-major axis (AU),
                "eccentricity": orbit's␣eccentricity,
␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣"inclination":␣orbit's inclination (degree),
                "angleDistance": angle distance from star
                                (arcseconds),
                "discovered": exoplanet discovered year,
                "detectionMethod": "exoplanet␣detection␣method",
                "pclass": "planetary␣class",
                "EqTemp": equilibrium temperature (K),
                "conservative": conservative or optimistic
                                habitability of the exoplanet,
                "ESI": Earth Similarity Index (*100),
                "planetProperName": "proper␣name␣of␣planet",
                "planetName": "designation␣of␣planet"
        },
        {
                "mass": mass of exoplanet (M jup),
                "radius": radius of exoplanet (R jup),
                "period": period of exoplanet (days),
                "semiAxis": semi-major axis (AU),
                "eccentricity": orbit's␣eccentricity,
␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣"inclination":␣orbit's inclination (degree),
                "angleDistance": angle distance from star
                                (arcseconds),
                "discovered": exoplanet discovered year,
                "detectionMethod": "exoplanet␣detection␣method",
                "pclass": "planetary␣class",
                "EqTemp": equilibrium temperature (K),
                "conservative": conservative or optimistic
                                habitability of the exoplanet,
                "ESI": Earth Similarity Index (*100),
                "planetProperName": "proper␣name␣of␣planet",
                "planetName": "designation␣of␣planet"
        }
        ],
        "distance": value of distance to star (pc),
        "stype": "spectral␣type␣of␣star",
        "smass": value of mass of star (M sun),
```

```
        "smetal": value of metallicity of star,
        "Vmag": value of visual magnitude of star,
        "sradius": value of radius of star (R sun),
        "effectiveTemp": value of effective temperature
                          of star (K),
        "starProperName": "proper␣name␣of␣the␣star",
        "hasHP": boolean (has potential habitable planets),
        "RA": "Right␣ascension␣(J2000)",
        "DE": "Declination␣(J2000)"
},
```

For example, the record for *24 Sex* looks like:

```
"24␣Sex":
{
                "exoplanets":
                [
                {
                        "mass": 1.99,
                        "period": 452.8,
                        "semiAxis": 1.333,
                        "eccentricity": 0.09,
                        "angleDistance": 0.017821,
                        "discovered": 2010,
                        "planetName": "b"
                },
                {
                        "mass": 0.86,
                        "period": 883.0,
                        "semiAxis": 2.08,
                        "eccentricity": 0.29,
                        "angleDistance": 0.027807,
                        "discovered": 2010,
                        "planetName": "c"
                }
                ],
                "distance": 74.8,
                "stype": "G5",
                "smass": 1.54,
                "smetal": -0.03,
                "Vmag": 7.38,
                "sradius": 4.9,
                "effectiveTemp": 5098,
                "RA": "10h23m28s",
                "DE": "-00d54m08s"
},
```

13.4 Pulsars Plugin
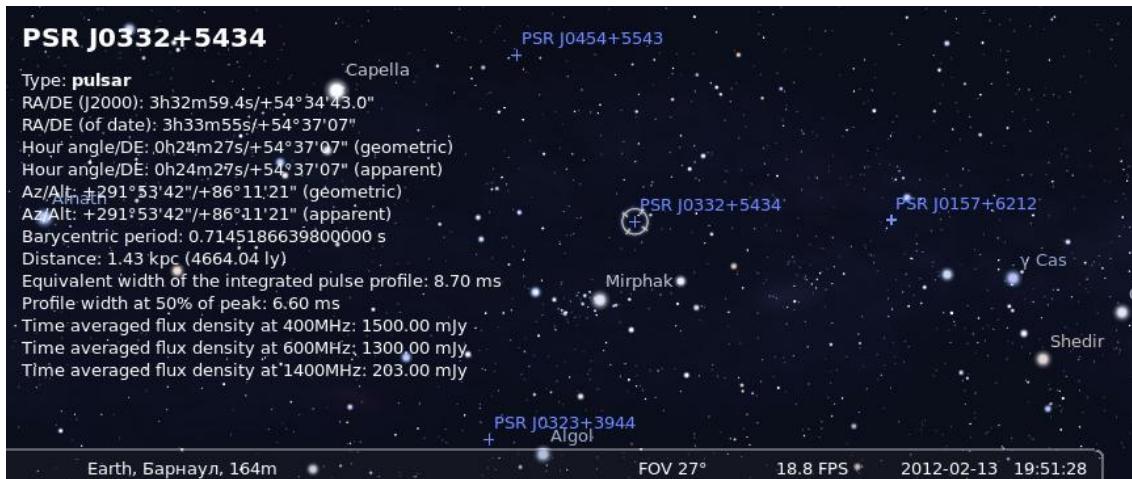
Figure 13.5: PSR J0332-5434

This plugin plots the position of various pulsars, with object information about each one. Pulsar data is derived from "The Australia Telescope National Facility Pulsar Catalogue" (Manchester et al., 2005).

If enabled (see section 11.1), use the PSR button to activate display of pulsars. The GUI allows a few configuration options. You can also find a pulsar (F3) by its designation (e.g., *PSR J0437-4715*).

13.4.1 Section ⸢Pulsars⸣ in config.ini file

ID	Type	Description
last_update	string	Date and time of last update
update_frequency_days	int	Frequency of updates [days]
updates_enable	bool	Enable updates of pulsars catalog from Internet
url	string	URL of pulsars catalog
enable_at_startup	bool	Enable displaying of pulsars at startup of Stellarium
distribution_enabled	bool	Enable distribution mode for the pulsars
flag_show_pulsars_button	bool	Enable displaying pulsars button on toolbar
marker_color	R,G,B	Color for marker of the pulsars
glitch_color	R,G,B	Color for marker of the pulsars with glitches
use_separate_colors	bool	Use separate colors for different types of the pulsars

13.4.2 Format of pulsars catalog

To add a new pulsar, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Pulsar designation":
{
    "RA": "Right ascension (J2000)",
    "DE": "Declination (J2000)",
    "notes": "type of pulsar",
    "distance": value of distance based on electron density
                model (kpc),
    "period": value of barycentric period of the pulsar (s),
    "parallax": value of annular parallax (mas),
    "bperiod": value of binary period of pulsar (days),
    "pderivative": value of time derivative of barcycentric
                   period,
    "dmeasure": value of dispersion measure (pc/(cm*cm*cm)),
    "frequency": value of barycentric rotation frequency (Hz),
    "pfrequency": value of time derivative of barycentric
                  rotation frequency (1/(s*s))
    "eccentricity": value of eccentricity,
    "w50": value of profile width at 50% of peak (ms),
    "s400": value of time averaged flux density at
            400 MHz (mJy),
    "s600": value of time averaged flux density at
            600 MHz (mJy),
    "s1400": value of time averaged flux density at
             1400 MHz (mJy)
},
```

For example, the record for **PSR J0014+4746** looks like:

```
"PSR J0014+4746":
{
    "distance": 1.82,
    "dmeasure": 30.85,
    "frequency": 0.805997239145,
    "pfrequency": -3.6669E-16,
    "w50": 88.7,
    "s400": 14,
    "s600": 9,
    "s1400": 3,
    "RA": "00h14m17.75s",
    "DE": "47d46m33.4s"
},
```

13.5 Quasars Plugin

The Quasars plugin provides visualization of some quasars brighter than 16 visual magnitude. The catalogue of quasars has been compiled from "A catalogue of quasars and active nuclei: 13th edition" (Véron-Cetty and Véron, 2010).
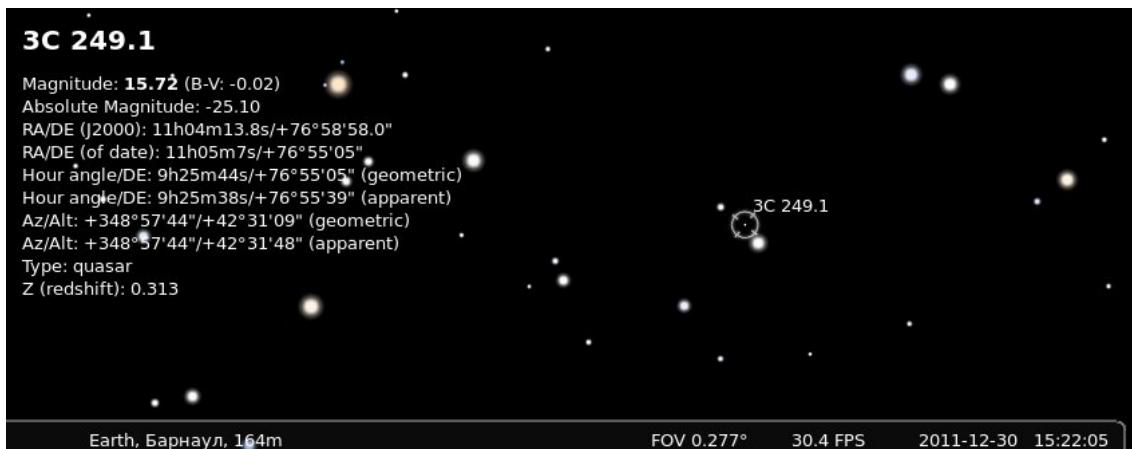
Figure 13.6: 3C 249.1, also known as LEDA 2821945 or 4C 77.09

If enabled (see section 11.1), use the QSO button to activate display of quasars. The GUI allows a few configuration options. You can also find a quasar (F3) by its designation (e.g., *3C 273*).

13.5.1 Section [Quasars] in config.ini file

ID	Type	Description
last_update	string	Date and time of last update
update_frequency_days	int	Frequency of updates, in days
updates_enable	bool	Enable updates of quasars catalog from Internet
url	string	URL of quasars catalog
enable_at_startup	bool	Enable displaying of quasars at startup of Stellarium
distribution_enabled	bool	Enable distribution mode for the quasars
flag_show_quasars_button	bool	Enable displaying quasars button on toolbar
marker_color	R,G,B	Color for marker of the quasars

13.5.2 Format of quasars catalog

To add a new quasar, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"Quasar␣designation":
{
    "RA": "Right␣ascension␣(J2000)",
    "DE": "Declination␣(J2000)",
    "Amag": value of absolute magnitude,
    "Vmag": value of visual magnitude,
    "z": value of Z (redshift),
    "bV": value of B-V colour
},
```

For example, the record for **3C 249.1** looks like:

```
"3C␣249.1":
{
    "RA": "11h04m13.8s",
    "DE": "+76d58m58s",
    "Amag": -25.1,
    "Vmag": 15.72,
    "z": 0.313,
    "bV": -0.02
},
```

13.6 Meteor Showers Plugin

Figure 13.7: The 1833 Leonids replayed with the Meteor Showers plugin.

In contrast and extension of the random *shooting stars* feature of Stellarium (see section 18.6), this plugin provides data for real meteor showers and a marker for each active and inactive radiant, showing real information about its activity. If enabled (see section 11.1), just click on the Meteor Showers button [icon] on the bottom toolbar to display markers for the radiants.

13.6.1 Terms

Meteor shower

A *meteor shower* is a celestial event in which a number of meteors are observed to radiate, or originate, from one point in the night sky. These meteors are caused by streams of cosmic debris called *meteoroids* entering Earth's atmosphere at extremely high speeds on parallel trajectories. Most meteors are smaller than a grain of sand, so almost all of them disintegrate and never hit the Earth's surface. Intense or unusual meteor showers are known as meteor outbursts and meteor storms, which may produce greater than 1,000 meteors an hour.

Radiant

The *radiant* or *apparent radiant* of a meteor shower is the point in the sky from which (to a planetary observer) meteors appear to originate. The Perseids, for example, are meteors which appear to come from a point within the constellation of Perseus.

An observer might see such a meteor anywhere in the sky but the direction of motion, when traced back, will point to the radiant. A meteor that does not point back to the known radiant for a given shower is known as a sporadic and is not considered part of that shower.

Many showers have a radiant point that changes position during the interval when it appears. For example, the radiant point for the Delta Aurigids drifts by more than a degree per night.

Zenithal Hourly Rate (ZHR)

The *Zenithal Hourly Rate* (ZHR) of a meteor shower is the number of meteors a single observer would see in one hour under a clear, dark sky (limiting apparent magnitude of 6.5) if the radiant of the shower were at the zenith. The rate that can effectively be seen is nearly always lower and decreases the closer the radiant is to the horizon.

Population index

The *population index* indicates the magnitude distribution of the meteor showers. Values below 2.5 correspond to distributions where bright meteors are more frequent than average, while values above 3.0 mean that the share of faint meteors is larger than usual.

13.6.2 Section ⌈MeteorShowers⌋ in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Meteor Showers plugin – just make it carefully!

ID	Type	Description
last_update	string	Date and time of last update
update_frequency_hours	int	Frequency of updates, in hours
updates_enable	bool	Enable updates of the meteor showers catalog from Internet
url	string	URL of the meteor showers catalog
flag_show_ms_button	bool	Enable showing button of the meteor showers on bottom bar
flag_show_radiants	bool	Enable displaying markers for the radiants of the meteor showers
flag_active_radiants	bool	Flag for displaying markers for the radiants of the active meteor showers only
enable_at_startup	bool	Enable displaying meteor showers at starup plugin
show_radiants_labels	bool	Flag for displaying labels near markers of the radiants of the meteor showers
font_size	int	Font size for label of markers of the radiants of the meteor showers
colorARG	R,G,B	Color for marker of active meteor showers with generic data
colorARR	R,G,B	Color for marker of active meteor showers with real data
colorIR	R,G,B	Color for marker of inactive meteor showers

13.6.3 Format of Meteor Showers catalog

To add a new meteor shower, you just need to:
1. Copy the code of some valid meteor shower;
2. Paste it in the line 6 (right after the "showers": {}) of the showers.json document;
3. Replace the information according with your needs.

Note commas and brackets, they are very important! For example, below is a record for *Northern Taurids*:

```
"NTA":
        {
                "designation": "Northern␣Taurids",
                "activity":
                [
                {
                        "year": "generic",
                        "zhr": 5,
                        "start": "09.25",
                        "finish": "11.25",
                        "peak": "11.12"
                },
                {
                        "year": "2014",
                        "start": "10.20",
                        "finish": "12.10"
                },
                {
                        "year": "2013",
                        "start": "10.20",
                        "finish": "12.10"
                },
                {
                        "year": "2012",
                        "start": "10.20",
                        "finish": "12.10"
                },
                {
                        "year": "2011",
                        "start": "10.20",
                        "finish": "12.10"
                }
                ],
                "speed": 29,
                "radiantAlpha": "58",
                "radiantDelta": "+22",
                "driftAlpha": "5",
                "driftDelta": "1",
                "colors":
                [
                {
                        "color": "yellow",
```

```
                        "intensity": 80
            },
            {

                        "color": "white",
                        "intensity": 20
            }
            ],
            "parentObj": "Comet␣C/1917␣F1␣(Mellish)",
            "pidx": 2.3
      },
```

13.6.4 Further Information

You can get more info about meteor showers here:
- Wikipedia about Meteor showers: `https://en.wikipedia.org/wiki/Meteor_Showers`
- International Meteor Organization: `http://www.imo.net/`

Acknowledgements

This plugin was created as project of ESA Summer of Code in Space 2013[27].

13.7 Navigational Stars Plugin
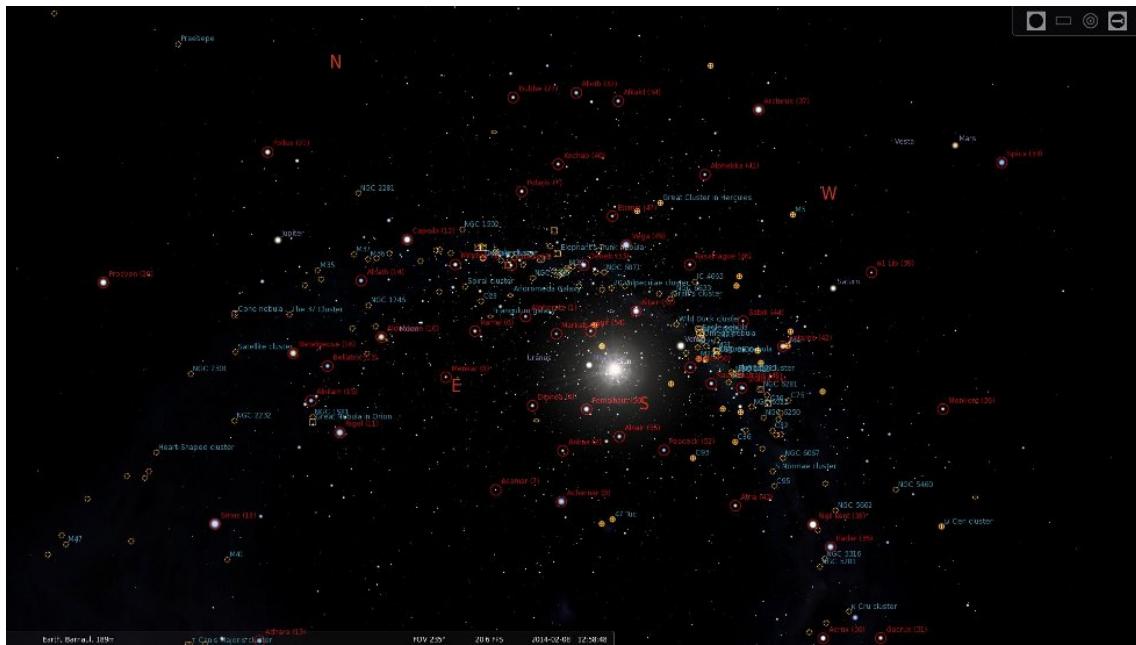
Figure 13.8: Navigational stars on the screen

This plugin marks navigational stars from a selected set:

Anglo-American — the 57 "selected stars" that are listed in *The Nautical Almanac*[28] jointly published by Her Majesty's Nautical Almanac Office and the US Naval Observatory since 1958; consequently, these stars are also used in navigational aids such as the *2102-D Star Finder*[29] and *Identifier*.

French — the 81 stars that are listed in the *Ephémérides Nautiques* published by the French Bureau des Longitudes.

Russian — the 160 stars that are listed in the Russian Nautical Almanac.

If enabled (see section 11.1), just click on the Sextant button ⚖ on the bottom toolbar to display markers for the navigational stars. This can help you in training your skills in astronomical navigation before you cruise the ocean in the traditional way, with your sextant and chronometer.

13.7.1 Section ⎡NavigationalStars⎤ in config.ini file

You can edit `config.ini` file by yourself for changes of the settings for the Navigational Stars plugin – just make it carefully!

ID	Type	Description
navstars_color	R,G,B	Color of markers of navigational stars
enable_at_startup	bool	Set to *true* to display navigational stars at startup of planetarium
current_ns_set	string	Current set of navigational stars. Possible values: *AngloAmerican*, *French* and *Russian*.

---

[28]The Nautical Almanac website – `http://aa.usno.navy.mil/publications/docs/na.php`

[29]Rude Starfinder 2102-D description and usage instruction – `http://oceannavigation.blogspot.ru/2008/12/rude-starfinder-2102-d.html`

13.8   Satellites Plugin

The Satellites plugin displays the positions of artifical satellites in Earth's orbit based on a catalog of orbital data. It allows automatic updates from online sources and manages a list of update file URLs.

To calculate satellite positions, the plugin uses an implementation of the SGP4/SDP4 algorithms (J.L. Canales' **gsat** library), using as its input data in NORAD's two-line element set (TLE[30]) format. Lists with TLEs for hundreds of satellites are available online and are regularly updated. The plugin downloads the lists prepared by http://celestrak.com to keep itself up-to-date, but the users can specify other sources online or load updates from local files.

If enabled (see section 11.1), just click on the Satellite button $\boxed{\diagdown}$ on the bottom toolbar to display markers for the satellites.

It should now be possible to search for artificial satellites using the regular search dialog ($\boxed{\text{F3}}$). Note that at any given time, most Satellites will be below the horizon.
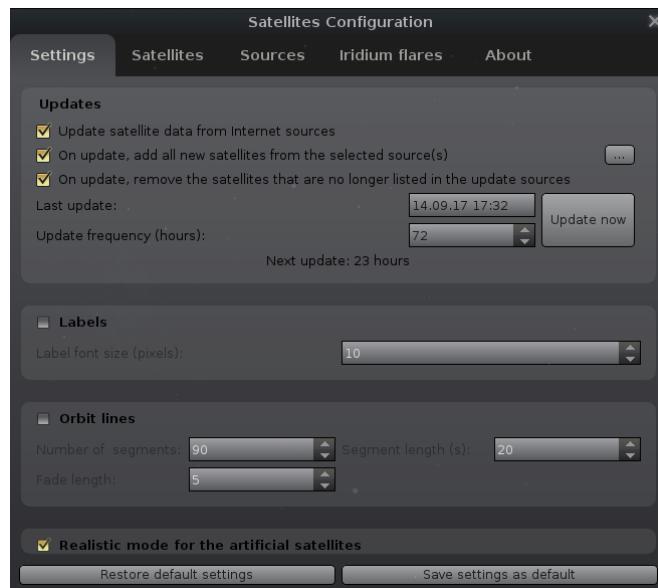
Figure 13.9: Configuration of the Satellites plugin.

13.8.1   Satellite Properties

Name and identifiers Each satellite has a name. It's displayed as a label of the satellite hint and in the list of satellites. Names are not unique though, so they are used only for presentation purposes.

Satellite Catalog In the *Satellite Catalog* satellites are uniquely identified by their NORAD number, which is encoded in TLEs.

Grouping A satellite can belong to one or more groups such as "amateur", "geostationary" or "navigation". They have no other function but to help the user organize the satellite collection. Group names are arbitrary strings defined in the Satellite Catalog for each satellite and are more similar to the concept of tags than a hierarchical grouping. A satellite may also not belong to any group at all.

By convention, group names are in lowercase. The GUI translates some of the groups used in the default catalog.

---

[30]TLE: https://en.wikipedia.org/wiki/Two-line_element_set

13.8.2 Iridium Flares prediction

The Satellite plugin might predict Iridium flares for the current location up to 2 weeks in the future from the current moment. The calculations of visual magnitude based on standard magnitude, orientation of satellite and places an observer and Sun. Of course all predictions can be saved in the CSV file (Figure 13.10).

Figure 13.10: Prediction of Iridium flares in the Satellites plugin.

13.8.3 Satellite Catalog

The satellite catalog is stored on the disk in JSON[31] format, in a file named `satellites.json`. A default copy is embedded in the plug-in at compile time. A working copy is kept in the user data directory.

To add a new satellite, open a new line after line 5 and paste the following, note commas and brackets, they are important:

```
"NORAD number":
{
  "name": "name of the satellite"
  "description": "description goes here",
  "comms": [
      {
        "description": "downlink 1",
        "frequency": 437.49,
        "modulation": "AFSK 1200 bps"
      },
      {
        "description": "downlink 2",
        "frequency": 145.825
      }
  ],
  "groups": ["group1", "group2"],
  "stdMag": 2.0,
  "tle1": "1 12345U 90005D    09080.85236265   .00000014   00000-0   20602-4 0   5632",
  "tle2": "2 12345 98.2700   53.2702 0011918   71.1776 289.0705 14.31818920    653",
  "visible": true
},
```

---

[31] http://www.json.org/

Explanation of the fields:

NORAD number required parameter, surrounded by double quotes ("), followed by a colon (:). It is used internally to identify the satellite. You should replace the text `"NORAD number"` with the first number on both lines of the TLE set (in this case, `"12345"`). It must match the number of the satellite in the source you are adding from if you want the TLE to be automatically updated.

The remaining parameters should be listed between two curly brackets and the closing curly bracket must be followed by a comma to separate it from the next satellite in the list:

name required parameter. It will be displayed on the screen and used when searching for the satellite with the Find window. Use the description field for a more readable name if you like. (The description field can accept HTML tags such as `<br/>` (new line), `<b></b>` (bold), etc.)

description optional parameter, double quoted. Appears when you click on the satellite

comms optional parameter, square bracketed list of curly bracketed communications information.

groups optional parameter, comma separated list of double quoted group names contained in square brackets. Used for grouping satellites in the drop down box on the config (see above)

tle1 required, line 1 of the TLE, must be contained in double quotes and begin with `"1  "`

tle2 required, line 2 of the TLE, must be contained in double quotes and begin with `"2  "`

visible required parameter, set to true if you want to see it, this can be toggled from the configuration window once the satellite is loaded.

stdMag optional parameter, contained standard magnitude of satellite.

You can edit the tags for a satellite, modify the description and comms data, and even add new satellites.

13.8.4 Configuration

The plug-in's configuration data is stored in Stellarium's main configuration file.

13.8.5 Sources for TLE data

Celestrak [32] used as default update source, it also has TLE lists beyond those included by default in Satellite plug-in

TLE.info [33]

Space Track [34] the definitive source, requires signup, operated by United States Department of Defense

---

[32] http://celestrak.com/NORAD/elements/
[33] http://www.tle.info/joomla/index.php
[34] http://www.space-track.org/

13.9 ArchaeoLines Plugin

GEORG ZOTTI

Figure 13.11: Declination Lines provided by the ArchaeoLines plugin

13.9.1 Introduction

In the archaeoastronomical literature, several astronomically derived orientation schemes are prevalent. Often prehistoric and historical buildings are described as having been built with a main axis pointing to a sunrise on summer or winter solstice. There can hardly be a better tool than Scenery3D (see chapter 14) to investigate a 3D model of such a building, and this plugin has been introduced in version 0.13.3 as a further tool in the archaeoastronomer's toolbox (Zotti, 2016b).

When activated (see section 11.1), you can find a a tool bar button $\boxed{\text{⊓}}$ (in the shape of a *trilithon* with the sun shining through it). Press this, or $\boxed{\text{Ctrl}}$+$\boxed{\text{U}}$, to display the currently selected set of characteristical diurnal arcs.

13.9.2 Characteristic Declinations

The ArchaeoLines plugin displays any combination of declination arcs δ most relevant to archaeo- or ethnoastronomical studies. Of course, principles used in this context are derived from natural observations, and many of these declinations are still important in everyday astronomy.

- Declinations of equinoxes (i.e., the equator, $\delta = 0$) and the solstices ($\delta = \pm\varepsilon$)
- Declinations of the crossquarter days (days between solstices and equinoxes, $\delta = \pm\varepsilon/\sqrt{2}$)
- Declinations of the Major Lunar Standstills ($\delta = \pm(\varepsilon + i)$)
- Declinations of the Minor Lunar Standstills ($\delta = \pm(\varepsilon - i)$)
- Declination of the Zenith passage ($\delta = \varphi$)
- Declination of the Nadir passage ($\delta = -\varphi$)
- Declination δ of the currently selected object
- Current declination $\delta_{\odot}$ of the sun
- Current declination $\delta_{\leftmoon}$ of the moon
- Current declination δ_P of a naked-eye planet
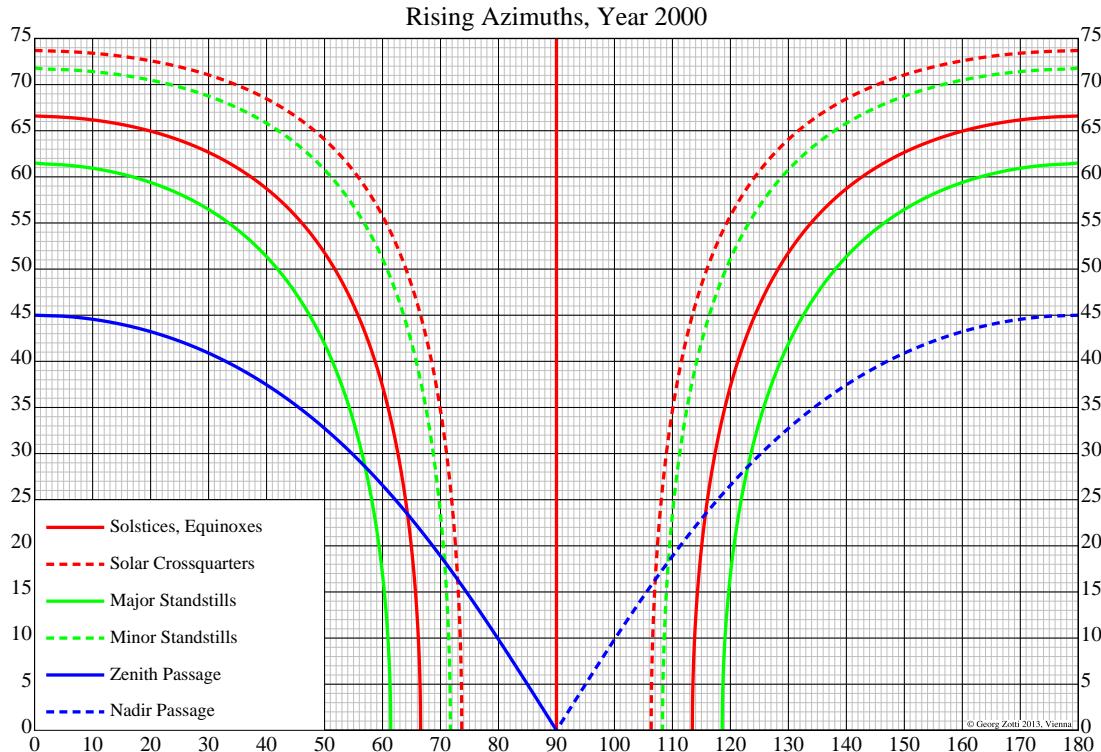
Figure 13.12: Rising azimuths of a few important events for sun and moon, and zenith and nadir passages depending on geographic latitudes (vertical axis).

The principal relation between declinations δ, geographic latitude φ, and the rising azimuth A is computed from

$$\cos A = -\frac{\sin \delta}{\cos \varphi}. \tag{13.1}$$

This formula does not take into account local horizon elevation nor atmospheric refraction nor lunar parallax correction. The effect applied to characteristic declinations is shown graphically for the present time (J2000.0) in figure 13.12. For example, in a latitude of $30°$, an object which goes through the zenith rises at azimuth $55°$. Lunar major standstill risings occur at azimuths $56.7°$ and $123.5°$, lunar minor standstill risings at azimuths $69°$ and $111°$. The summer sun rises at $62.6°$, the winter sun at $117.3°$. An object which goes through the nadir rises at $125°$.

The blue lines seem to vanish at $\varphi = 45°$: while there are still objects going through the zenith in higher latitudes, they are circumpolar and do not cross the horizon.

For the lunar events, there are two lines each drawn by the plugin, for maximum and minimum distance of the moon. The lunar extreme declinations are computed taking horizon parallax effects into account. For technical reasons however, the derived declinations are then used to draw *small circles* of constant declinations on the sphere, without taking the change of lunar horizontal parallax into account. Note that therefore the observed declination of the moon at the major standstill can exceed the indicated limits if it is high in the sky. The main purpose of this plugin is however to show an indication of the intersection of the standstill lines with the horizon.

It may be very instructive to let the time run quite fast and observe the declination line of "current moon" swinging between its north and south limits each month. These limits grow and shrink between the Major and Minor Standstills in the course of 18.6 years.

The sun likewise swings between the solstices. Over centuries, the solstice declinations very slightly move as well due to the slightly changing obliquity of the ecliptic.

13.9.3 Azimuth Lines

Some religions, e.g., Islam or Bahai, adhere to a practice of observing a prayer direction towards a particular location. Azimuth lines for two locations can be shown, these lines indicate the great circle direction towards the locations which can be edited in the configuration window. Default locations are Mecca (Kaaba) and Jerusalem. The azimuth q towards a location $T = (\lambda_T, \varphi_T)$ can be computed for an observer at $O = (\lambda_O, \varphi_O)$ based on spherical trigonometry on a spherical Earth (Abdali, 1997) as

$$q = \arctan \frac{\sin(\lambda_T - \lambda_O)}{\cos\varphi_O \tan\varphi_T - sin\varphi_O \cos(\lambda_T - \lambda_O)} \tag{13.2}$$

In addition, up to two vertical lines with arbitrary azimuth and custom label can be shown.

13.9.4 Arbitrary Declination Lines

Up to two arbitrary declination lines can be shown with a custom label.   v0.15.1

13.9.5 Configuration Options

The configuration dialog allows the selection of the lines which are of interest to you. In addition, you can select the color of the lines by clicking on the color swatches.[35]

Section $\boxed{\text{ArchaeoLines}}$ in config.ini file

Apart from changing settings using the plugin configuration dialog, you can also edit the `config.ini` file to change settings for the ArchaeoLines plugin – just make it carefully!
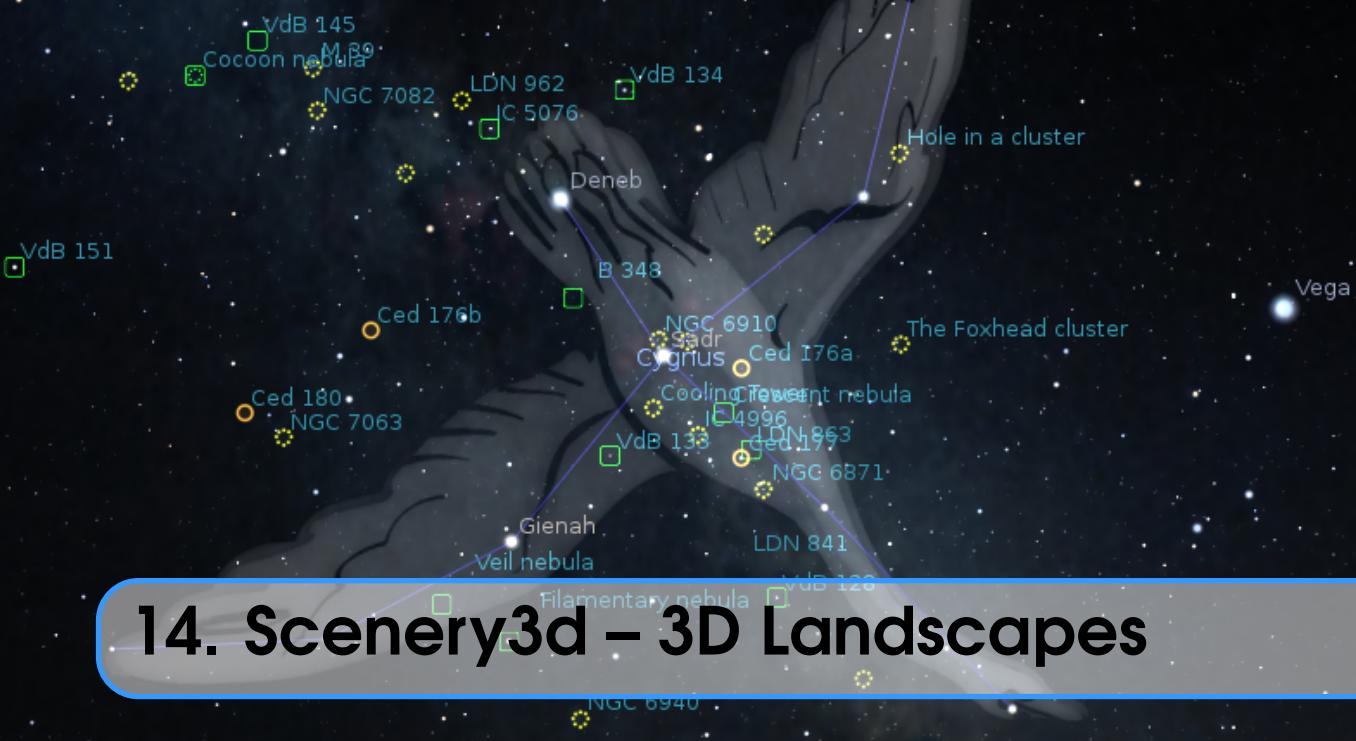
ID	Type	Default	
enable_at_startup	bool	false	
line_thickness	int	1	
color_equinox	float R,G,B	1.00,1.00,0.50	
color_solstices	float R,G,B	1.00,1.00,0.25	
color_crossquarters	float R,G,B	1.00,0.75,0.25	
color_major_standstill	float R,G,B	0.25,1.00,0.25	
color_minor_standstill	float R,G,B	0.20,0.75,0.20	
color_zenith_passage	float R,G,B	1.00,0.75,0.75	
color_nadir_passage	float R,G,B	1.00,0.75,0.75	
color_selected_object	float R,G,B	1.00,1.00,1.00	
color_current_sun	float R,G,B	1.00,1.00,0.75	
color_current_moon	float R,G,B	0.50,1.00,0.50	
color_current_planet	float R,G,B	0.25,0.80,1.00	
color_geographic_location_1	float R,G,B	0.25,1.00,0.25	
color_geographic_location_2	float R,G,B	0.25,0.25,1.00	
color_custom_azimuth_1	float R,G,B	0.25,1.00,0.25	

---

[35]Unfortunately, on some systems with Windows in OpenGL mode, the color dialog hides behind the Stellarium window when in fullscreen mode. So, before editing line colors, please leave fullscreen mode!

color_custom_azimuth_2	float R,G,B	0.25,0.50,0.75	
color_custom_declination_1	float R,G,B	0.45,1.00,0.15	
color_custom_declination_2	float R,G,B	0.45,0.50,0.65	
show_equinox	bool	true	
show_solstices	bool	true	
show_crossquarters	bool	true	
show_major_standstills	bool	true	
show_minor_standstills	bool	true	
show_zenith_passage	bool	true	
show_nadir_passage	bool	true	
show_selected_object	bool	true	
show_current_sun	bool	true	
show_current_moon	bool	true	
show_current_planet	string	none	
show_geographic_location_1	bool	false	
show_geographic_location_2	bool	false	
geographic_location_1_longitude	double	39.826175	
geographic_location_1_latitude	double	21.4276	
geographic_location_1_label	string	Mecca (Qibla)	
geographic_location_2_longitude	double	35.235774	
geographic_location_2_latitude	double	31.778087	
geographic_location_2_label	string	Jerusalem	
show_custom_azimuth_1	bool	false	
show_custom_azimuth_2	bool	false	
custom_azimuth_1_angle	double	0.0	
custom_azimuth_2_angle	double	0.0	
custom_azimuth_1_label	string	custAzi1	
custom_azimuth_2_label	string	custAzi2	
custom_altitude_1_angle	double	0.0	
custom_altitude_2_angle	double	0.0	
custom_altitude_1_label	string	custAlt1	
custom_altitude_2_label	string	custAlt2	
show_custom_declination_1	bool	false	
show_custom_declination_2	bool	false	
custom_declination_1_angle	double	0.0	
custom_declination_1_label	string	custDec1	
custom_declination_2_angle	double	0.0	
custom_declination_2_label	string	custDec2	

13.9.6 Acknowledgements

If you are using this plugin in scientific publications, please cite Zotti (2016b).

14. Scenery3d – 3D Landscapes

Georg Zotti and Florian Schaukowitsch

14.1 Introduction

Have you ever wished to be able to walk through Stonehenge or other ancient building structures described as being constructed with astronomical orientation in mind, and experience such orientation in a 3D virtual environment that also provides a good sky simulation?

The Stellarium Scenery3d plugin allows you to see architectural 3D models embedded in a landscape combined with the excellent representation of the sky provided by Stellarium. You can walk around, check for (or demonstrate) possible astronomical alignments of ancient architecture, see sundials and other shadow casters in action, etc.

14.2 Usage

You activate the plugin with the *circular enclosure* button ◎ at screen bottom or by pressing Ctrl+W. The other button with circular enclosure and tool icon ⌾ (or Ctrl+⇧+W) opens the settings dialog. Once loaded and displaying, you can walk around pressing Ctrl plus cursor keys. Change eye height with Ctrl+Page↑/Ctrl+Page↓ keys. Adding ⇧ key increases speed by 10, adding Alt multiplies by 5 (pressing both keys multiplies by 50!). If you release Ctrl before the cursor key, animation will continue. (Press Ctrl+any cursor key to stop moving.)

Further key bindings exist which can be configured using the Stellarium default key-binding interface. Some options are also available in the Scenery3d dialog. For example, coordinate display can be enabled with Ctrl+R+T. If your models are georeferenced in a true geographical coordinate grid, e.g. UTM or Gauss-Krueger, you will especially like this, and this makes the plugin usable for scientific purposes. Display shows grid name, Easting, Northing, Altitude of ground, and eye height above ground.

Other features include a virtual "torchlight", which can be enabled with Ctrl+R+L to give

additional local illumination around the viewer to help to see in the dark. Interesting points of view can be saved and restored later by the user, including a description of the view. Scene authors can also distribute predefined viewpoints in their scene.

The plugin also simulates the shadows of the scene's objects cast by the Sun, Moon and even Venus (only 1 shadow caster used at a time, you will never see shadows cast by Venus in moonlight), so you could use it for examining sundials, or analyze and simulate light-and-shadow interactions in archaeological structures.

14.3 Hardware Requirements & Performance

In order to work with the non-linear projection models in Stellarium, this plugin uses a trick to create the foreground renderings: it renders the scene into the six planes of a so-called cubemap, which is then correctly reprojected onto the sides of a cube, depending on the current projection settings. Your graphics card must be able to do this, i.e. it must support the OpenGL extension called `EXT_framebuffer_object`. Typical modern 3D cards (by NVidia or ATI/AMD) support this extension. In case your graphics hardware does not suppport it, the plugin will still work, but you are limited to perspective projection.

You can influence rendering quality, but also speed, using the plugin's GUI, which provides some options such as enabling the use of shadows, bumpmapping (provides more realistic surface lighting) or configuring the sizes of the textures used for the cubemap or shadowmaps. Larger values there improve the quality, but require faster hardware and more video memory for smooth results.

Because the "cubemap trick" requires quite a large amount of performance (in essence, the scene has to be rendered 6 times), there are some options available that try to reduce this burden. The first option is to change the type of the "cubemap". The most compatible setting is *6 textures*, which seems to work best on older integrated Intel GPUs. The recommended default is the second setting, *Cubemap*, which uses a more modern OpenGL feature and generally works a bit faster than *6 textures* on more modern graphics cards. Finally, the *Geometry shader* option tries to render all 6 cube faces at once. This requires a more recent GPU + drivers (at least OpenGL 3.2 must be supported), the setting is disabled otherwise. Depending on your hardware and the scene's complexity, this method may give a speedup or may be slower, you must find this out yourself.

Another option prevents re-rendering of the cubemap if nothing relevant has changed. You can define the interval (in Stellarium's simulation time) in which nothing is updated in the GUI. You can still rotate the camera without causing a re-draw, giving a subjective performance that is close to Stellarium's performance without Scenery3d. When moving, the cubemap will be updated. You can enable another option that only causes 1 or 2 sides of the cubemap to be updated while you move, giving a speedup but causing some parts of the image to be outdated and discontinuous. The cubemap will be completed again when you stop moving.

Shadow rendering may also cause quite a performance impact. The *Simple shadows* option can speed this up a lot, at the cost of shadow quality especially in larger scenes. Another performance/quality factor is shadow filtering. The sharpest (and fastest) possible shadows are achieved with filtering *Off*, but depending on shadowmap resolution and scene size the shadows may look quite "blocky". *Hardware* shadow filtering is usually very fast, but may not improve appearance a lot. Therefore, there are additional filter options available, the *High* filter option is relatively expensive. Finally, the *PCSS* option allows to approximate the increase of solar and lunar shadow penumbras relative to the distance from their shadow casters, i.e. shadows are sharp near contact points, and more blurred further away. This again requires quite a bit of performance, and only works if the shadow filter option is set to *Low* or *High* (without *Hardware*).

The configuration GUI shows tooltips for most of its settings, which can explain what a setting

Geometry	Yes
Lights	Yes
Clay	No
Photomatched	Yes
DefaultUVs	No
Instanced	No

Table 14.1: Kerkythea Export Settings

does. All settings are saved automatically, and restored when you reopen Stellarium.

14.3.1 Performance notes

This plugin clearly runs better with proper 3D graphics cards. On reasonably good hardware (tested on a notebook PC with NVidia M960), models with over 10.000.000 triangles are working nicely with shadows and bumpmaps, although your mileage may vary. On very small hardware like single-board computers with native OpenGL ES2, models may be limited to 64k vertices (points). If display is too slow, switch to perspective projection: all other projections require almost sixfold effort! Or try the "lazy" cubemap mode and lazy updates of tiles, where the scene is only rendered in specific timesteps or when movement happens.

14.4 Model Configuration

The model format supported in Scenery3d is Wavefront .OBJ, which is pretty common for 3D models. You can use several modeling programs to build your models. Software such as **Blender**, **Maya**, **3D Studio Max** etc. can export OBJ.

14.4.1 Exporting OBJ from Sketchup

A simple to use and cost-free modeling program is **Sketchup**, commonly used to create the 3D buildings seen in **Google Earth**. It can be used to create georeferenced models. OBJ is not a native export format for the standard version of **Sketchup**. If you are not willing to afford **Sketchup Pro**, you have to find another way to export a textured OBJ model.

One good exporter is available in the **Kerkythea** renderer project[1]. You need **SU2KT 3.17** or better, and **KT2OBJ 1.1.0** or better. Deselect any selection, then export your model to the **Kerkythea** XML format with settings shown in 14.1. (Or, with selection enabled, make sure settings are No-Yes-Yes-No-Yes-No-No.) You do not have to launch **Kerkythea** unless you want to create nice renderings of your model. Then, use the **KT2OBJ** converter to create an OBJ. You can delete the XML after the conversion. Note that some texture coordinates may not be exported correctly. The setting `Photomatched:Yes` seems now to have corrected this issue, esp. with distorted/manually shifted textures.

Another free OBJ exporter has been made available by TIG: `OBJexporter.rb`[2]. This is the only OBJ exporter tested so far capable of handling large TIN landscapes (> 450.000 triangles). As of version 2.6 it seems to be the best OBJ exporter available for **Sketchup**.

This exporter swaps Y/Z coordinates, but you can add a key to the config file to correct swapped axes, see below. Other exporters may also provide coordinates in any order of X, Y, Z – all those can be properly configured.

---

[1] Available at `http://www.kerkythea.net/cms/`
[2] Available from `http://forums.sketchucation.com/viewtopic.php?f=323&t=33448`

Another quirk has to be fixed manually though: in the material description file (MTL), TIG's exporter writes both `d` and `Tr` lines with the same value. Actually, $Tr = 1.0 - d$ according to OBJ/MTL documentation, so you should edit away one line, or else the later line overwrites the value given earlier. Moreover, given that `Tr=1` should actually specify fully transparent objects, such a line will make your object entirely invisible!

Another (almost) working alternative: `ObjExporter.rb` by author Honing. Here, export with settings `0xxx00`. This will not create a `TX...` folder but dump all textures in the same directory as the OBJ and MTL files. Unfortunately, currently some material assignments seem to be bad.

14.4.2   Notes on OBJ file format limitations

The OBJ format supported is only a subset of the full OBJ format: Only (optionally textured) triangle meshes are supported, i.e., only lines containing statements: `mtllib`, `usemtl`, `v`, `vn`, `vt`, `f` (with three elements only!), `g`. Negative vertex numbers (i.e., a specification of relative positions) are not supported.

A further recommendation for correct illumination is that all vertices should have vertex normals. **Sketchup** models exported with the **Kerkythea** or TIG plugins should have correct normals. If your model does not provide them, default normals can be reconstructed from the triangle edges, resulting in a faceted look.

If possible, the model should also be triangulated, but the current loader may also work with non-triangle geometry. The correct use of objects (`o`) and groups (`g`) will improve performance: it is best if you pre-combine all objects that use the same material into a single one. The loader will try to optimize it anyways if this is not the case, but can do this only partly (to combine 2 objects with the same material into 1, it requires them to follow directly after each other in the OBJ). A simple guide to use **Blender**[3] for this task follows:

1. File ⟩ Import ⟩ Wavefront .obj - you may need to change the forward/up axes for correct orientation, try "-Y forward" and "Z up"
2. Select an object which has a shared material
3. Press ⇧ + L and select 'By Material'
4. Select 'Join' in the left (main) tool window
5. Repeat for other objects that have shared materials
6. Export the .obj, making sure to select the same forward/up axes as in the import, also make sure "Write Normals", "Write Materials" and "Include UVs" are checked

For transparent objects (with a `d` or `Tr` value, alpha testing does NOT need this), this recommendation does NOT hold: for optimal results, each separate transparent object should be exported as a separate "OBJ object". This is because they need to be sorted during rendering to achieve correct transparency. If the objects are combined already, you can separate them using **Blender**:

1. Import .obj (see above)
2. Select the combined transparent object
3. Enter "Edit" mode with ⇆ and make sure everything is selected (press A if not)
4. Press P and select "By loose parts", this should separate the object into its unconnected regions
5. Export .obj (see above), also check "Objects as OBJ Objects"

The MTL file specified by `mtllib` contains the material parameters. The minimum that should be specified is either `map_Kd` or a `Kd` line specifying color values used for the respective faces. But there are other options in MTL files, and the supported parameters and defaults are listed in Table 14.2.

If no ambient color is specified, the diffuse color values are taken for the ambient color. An optional emissive term `Ke` can be added, which is modulated to only be visible during nighttime.

---

[3] `http://www.blender.org`

Parameter	Default	Range	Meaning
Ka	set to Kd values	0...1 each	R/G/B Ambient color
Kd	0.8 0.8 0.8	0...1 each	R/G/B Diffuse color
Ke	0.0 0.0 0.0	0...1 each	R/G/B Emissive color
Ks	0.0 0.0 0.0	0...1 each	R/G/B Specular color
Ns	8.0	0...∞	shinyness
d or Tr	1.0	0...1	opacity
bAlphatest	0	0 or 1	perform alpha test
bBackface	0	0 or 1	render backface
map_Kd	(none)	filename	texture map to be mixed with Ka, Kd
map_Ke	(none)	filename	texture map to be mixed with Ke
map_bump	(none)	filename	normal map for surface roughness
illum	2	integer	illumination mode in the standard MTL format.
vis_fadeIn	(none)	double	see 14.4.5
vis_fadeOut	(none)	double	see 14.4.5

Table 14.2: MTL parameters evaluated

This also requires the landscape's self-illumination layer to be enabled. It allows to model self-illuminating objects such as street lights, windows etc. It can optionally also be modulated by the emissive texture map_Ke.

If a value for Ks is specified, specularity is evaluated using the Phong reflection model[4] with Ns as the exponential shininess constant. Larger shininess means smaller specular highlights (more metal-like appearance). Specularity is not modulated by the texture maps. Unfortunately, some 3D editors export unusable default value combinations for Ks and Ns. **Blender** may create lines with Ks=1/1/1 and Ns=0. This creates a look of "partial overexposed snow fields". While the values are allowed in the specification, in most cases the result looks ugly. *Make sure to set Ns to 1 or higher, or disable those two lines.*

If a value for d or Tr exists, alpha blending is enabled for this material. This simulates transparency effects. Transparency can be further controlled using the alpha channel of the map_Kd texture.

A simpler and usually more performant way to achieve simple "cutout" transparency effects is alpha-testing, by setting bAlphatest to 1. This simply discards all pixels of the model where the alpha value of the map_Kd is below the transparency_threshold value from scenery3d.ini, making "holes" in the model. This also produces better shadows for such objects. If required, alpha testing can be combined with "real" blending-based transparency.

Sometimes, exported objects only have a single side ("paper wall"), and are only visible from one side when looked at in Scenery3d. This is caused by an optimization called *back-face culling*[5], which skips drawing the back sides of objects because they are usually not visible anyway. If possible, avoid such "thin" geometry, this will also produce better shadows on the object. As a workaround, you can also set bBackface to 1 to disable back-face culling for this material.

The optional map_bump enables the use of a tangent-space normal maps[6], which provides a dramatic improvement in surface detail under illumination.

---

[4]https://en.wikipedia.org/wiki/Phong_reflection_model
[5]https://en.wikipedia.org/wiki/Back-face_culling
[6]https://en.wikipedia.org/wiki/Normal_mapping

14.4.3 Configuring OBJ for Scenery3d

The walkaround in your scene can use a ground level (piece of terrain) on which the observer can walk. The observer eye will always stay "eye height" above ground. Currently, there is no collision detection with walls implemented, so you can easily walk through walls, or jump on high towers, if their platform or roof is exported in the ground layer. If your model has no explicit ground layer, walk will be on the highest surface of the scenery layer. If you use the special name `NULL` as ground layer, walk will be above `zero_ground_height` level.

Technically, if your model has cavities or doors, you should export your model twice. Once, just the ground plane, i.e. where you will walk. Of course, for a temple or other building, this includes its socket above soil, and any steps, but pillars should not be included. This plane is required to compute eye position above ground. Note that it is not possible to walk in several floors of a building, or in a multi-plane staircase. You may have to export several "ground" planes and configure several scenery directories for those rare cases. For optimal performance, the ground model should consist of as few triangles as you can tolerate.

The second export includes all visible model parts, and will be used for rendering. Of course, this requires the ground plane again, but also all building elements, walls, roofs, etc.

If you have not done so by yourself, it is recommended to separate ground and buildings into Sketchup layers (or similar concepts in whichever editor you are using) in order to easily switch the model to the right state prior to exporting.

Filename recommendations:

`<Temple>.skp`	Name of a Sketchup Model file. (The `<>` brackets signal "use your own name here!") The SKP file is not used by Scenery3d, but you may want to leave it in the folder for later improvements.
`<Temple>.obj`	Model in OBJ format.
`<Temple>_ground.obj`	Ground layer, if different from Model file.

OBJ export may also create folders `TX_<Temple>` and `TX_<Temple>_ground`. You can delete the `TX_<Temple>_ground` folder, `<Temple>_ground.obj` is just used to compute vertical height.

Put the OBJ, MTL and TX directories into a subdirectory of your user directory (see section 5.1), e.g. `<USERDATA>/Stellarium/scenery3d/<Temple>`, and add a text file into it called `scenery3d.ini` (This name is mandatory!) with content described as follows.

```
[model]
```

`name=<Temple>`	Unique ID within all models in scenery3d directory. Recommendation: use directory name.
`landscape=<landscapename>`	Name of an available Stellarium landscape.

This is required if the landscape file includes geographical coordinates and your model does not: First, the location coordinates of the `landscape.ini` file are used, then location coordinates given here. The landscape also provides the background image of your scenery. If you want a zero-height (mathematical) horizon, use the provided landscape called `Zero Horizon`.

`scenery=<Temple>.obj`	The complete model, including visible ground.
`ground=<Temple>_ground.obj`	Optional: separate ground plane. (NULL for zero altitude.)
`description=<Description>`	A basic scene description (including HTML tags)

The `scenery3d.ini` may contain a simple scene description, but it is recommended to use the *localizable* description format: in the scene's directory (which contains `scenery3d.ini`) create files in the format `description.<lang>.utf8` which can contain arbitrary UTF-8–encoded HTML content. `<lang>` stands for the ISO 639 language code.

```
author=<Your Name yourname@yourplace.com>
copyright=<Copyright Info>
```

`obj_order=XYZ`	Use this if you have used an exporter which swaps Y/Z coordinates. Defaults to `XYZ`, other options: `XZY, YZX, YXZ, ZXY, ZYX`
`camNearZ=0.3`	This defines the distance of the camera near plane, default 0.3. Everything closer than this value to the camera can not be displayed. Must be larger than zero. It may seem tempting to set this very small, but this will lead to accuracy issues. Recommendation is not to go under 0.1
`camFarZ=10000`	Defines the maximal viewing distance, default 10000.
`shadowDistance=<val>`	The maximal distance shadows are displayed. If left out, the value from `camFarZ` is used here. If this is set to a smaller value, this may increase the quality of the shadows that are still visible.
`shadowSplitWeight=0..1`	Decimal value for further shadow tweaking. If you require better shadows up close, try setting this to higher values. The default is calculated using a heuristic that incorporates scene size.

`[general]`

The general section defines some further import/rendering options.

`transparency_threshold=0.5`	Defines the alpha threshold for alpha-testing, as described in section 14.4.2. Default `0.5`
`scenery_generate_normals=0`	Boolean, if true normals are recalculated by the plugin, instead of imported. Default `false`
`ground_generate_normals=0`	Boolean, same as above, for ground model. Default `false`.

`[location]`

Optional section to specify geographic longitude λ, latitude φ, and altitude. The section is required if `coord/convergence_angle=from_grid`, else location is inherited from landscape.

`planet = Earth`

`latitude = +48d31'30.4"`	Required if `coord/convergence_angle=from_grid`
`longitude = +16d12'25.5"`	`"−"`
`altitude =from_model|<int>`	altitude (for astronomical computations) can be computed from the model: if `from_model`, it is computed as $(z_{min} + z_{max})/2 + $ `orig_H`, i.e. from the model bounding box centre height.

`display_fog = 0`
`atmospheric_extinction_coefficient = 0.2`
`atmospheric_temperature = 10.0`
`atmospheric_pressure = -1`
`light_pollution = 1`
`[coord]`

Entries in the `[coord]` section are again optional, default to zero when not specified, but are required if you want to display meaningful eye coordinates in your survey (world) coordinate system, like UTM or Gauss-Krüger.

`grid_name=<string>`	Name of grid coordinates, e.g. `"UTM 33 U (WGS 84)"`, `"Gauss-Krüger M34"` or `"Relative to <Center>"` This name is only displayed, there is no evaluation of its contents.
`orig_E=<double> | (Easting)`	East-West-distance to zone central meridian

```
orig_N=<double> | (Northing)     North distance from Equator
orig_H=<double> | (Height)       Altitude above Mean Sea Level of model origin
```

These entries describe the offset, in metres, of the model coordinates relative to coordinates in a geographic grid, like Gauss-Krüger or UTM. If you have your model vertices specified in grid coordinates, do not specify `orig_...` data, but please definitely add `start_...` data, below.

Note that using grid coordinates without offset for the vertices is usually a bad idea for real-world applications like surveyed sites in UTM coordinates. Coordinate values are often very large numbers (ranging into millions of meters from equator and many thousands from the zone meridian). If you want to assign millimetre values to model vertices, you will hit numerical problems with the usual single-precision floating point arithmetic. Therefore we can specify this offset which is only necessary for coordinate display.

Typically, digital elevation models and building structures built on those are survey-grid aligned, so true geographical north for a place with geographical longitude λ and latitude φ will in general not coincide with grid north, the difference is known as *meridian convergence*[7].

$$\gamma(\lambda, \varphi) = \arctan(\tan(\lambda - \lambda_0) \sin \varphi) \tag{14.1}$$

This amount can be given in `convergence_angle` (degrees), so that your model will be rotated clockwise by this amount around the vertical axis to be aligned with True North[8].

```
convergence_angle=from_grid|<double>
grid_meridian=<double>|+<int>d<int>'<float>"
```

`grid_meridian` is the central meridian λ_0 of grid zone, e.g. for UTM or Gauss-Krüger, and is only required to compute convergence angle if `convergence_angle=from_grid`.

```
zero_ground_height=<double>
```

height of terrain outside `<Temple>_ground.OBJ`, or if `ground=NULL`. Allows smooth approach from outside. This value is relative to the model origin, or typically close to zero, i.e., use a Z value in model coordinates, not world coordinates! (If you want the terrain height surrounding your model to be `orig_H`, use 0, not the correct mean height above sea level!) Defaults to minimum of height of ground level (or model, resp.) bounding box.

```
    start_E=<double>
    start_N=<double>
    start_H=<double>        only meaningful if ground==NULL, else H is derived from ground
    start_Eye=<double>   default: 1.65m
    start_az_alt_fov=<az_deg>,<alt_deg>,<fov_deg>
                            initial view direction and field of view.
```
`start_...` defines the view position to be set after loading the scenery. Defaults to center of model boundingbox.

It is advisable to use the grid coordinates of the location of the panoramic photo (landscape) as `start_...` coordinates, or the correct coordinates and some carefully selected `start_az_alt_fov` in case of certain view corridors (temple axes, ...).

---

[7]http://en.wikipedia.org/wiki/Transverse_Mercator_projection
[8]Note that Sketchup's *georeferencing dictionary* provides a NorthAngle entry, which is $360 -$ `convergence_angle`.

14.4.4 Concatenating OBJ files

Some automated workflows may involve tiled landscape areas, e.g. to overcome texture limitations or triangle count limits in simpler tools like **Sketchup**. In this case you can create separate meshes in the same coordinate system, but you need to concatenate them. One powerful program to assemble your parts is again **Blender**.

In **Blender**, import the OBJ files File 〉 Import 〉 Wavefront .obj . If your OBJ coordinates have Z as vertical axis (common for terrestrial models), use "Z up", "-Y Forward" as import settings for the coordinate axes. The model will appear south-up. Switch on textured view if required (Alt + Z). If the scene looks almost black now, reconfigure the light to be sunlight. If you have created a VRML of some structures in **ArcScene**, export that without shifting to center, and import the WRL file in **Blender** with default orientation "Y up", "Z forward". Models from other sources may still be different. In the end, all parts should fit neatly together. **Blender** is a very powerful program, you can enhance your model as you wish.

In the end, select all relevant parts which you want to have visible in Stellarium (click on the lines in the outline view containing the object names to light them up gray, then Rightclick-Select) and press Ctrl + J to optionally join them, then export to a single OBJ File 〉 Export 〉 Wavefront .obj . In the export options, apply "Selection Only", and "-Y Forward" and "Z Up"[9]. In the export options, apply "Selection Only", and "-Y Forward" and "Z Up"[9].

Verify the new model loads correctly, e.g. in **Meshlab**[10]!

14.4.5 Beyond 3D: Temporally evolving Models

Stellarium working as "time machine" can display the sky for any calendar date in its range of valid dates. Also landscapes and human-built structures evolve. Temples are being rebuilt, changed, re-dedicated or repurposed, new windows are cut, old windows closed. To show landscape and buildings in the right shape for the time in question, we can make material transparent, so that parts of the model are not displayed. To allow for archaeological uncertainties in dating construction and destruction, we can gradually fade in and fade out the model parts in question (Zotti, Schaukowitsch, and Wimmer, 2018).

v0.16.1

To enable this magic, you must combine all your models into one (see section 14.4.4), export as one OBJ/MTL as usual, and manually edit the MTL file. It is wise to give the material for the parts in question a reasonable name that you can later identify in the MTL file. Then you simply add one or both of the new keywords `vis_fadeIn` or `vis_fadeOut` to the material description, with 2 arguments which are the Julian days of begin and end of a phase transition. For sharp transitions, just use the same JD dates.

```
# Some structure has been put up around -3100/-3000
vis_fadeIn  588783.5 625308.5
# Fade away between 500AD/700AD
vis_fadeOut 1903682.5 1976732.5
```

14.4.6 Working with non-georeferenced OBJ files

There exists modeling software which produces nice models, but without concept of georeference. One spectacular example is **AutoDesk PhotoFly**, a cloud application which delivers 3D models from a bunch of photos uploaded via its program interface. This "technological preview" is in version 2 and free of cost as of mid-2011.

The problem with these models is that you cannot assign surveyed coordinates to points in the model, so either you can georeference the models in other applications, or you must find the

---

[9]http://blender.stackexchange.com/questions/3352/merging-multiple-obj-files
[10]http://www.meshlab.org

correct transformation matrix. Importing the OBJ in **Sketchup** may take a long time for detailed photo-generated models, and the texturing may suffer, so you can cut the model down to the minimum necessary e.g. in **Meshlab**, and import just a stub required to georeference the model in **Sketchup**.

Now, how would you find the proper orientation? The easiest chance would be with a structure visible in the photo layer of **Google Earth**. So, start a new model and immediately add location from the **Google Earth** interface. Then you can import the OBJ with TIG's importer plugin. If the imported model looks perfect, you may just place the model into the **Sketchup** landscape and export a complete landscape just like above. If not, or if you had to cut/simplify the OBJ to be able to import it, you can rotate/scale the OBJ (it must be grouped!). If you see a shadow in the photos, you may want to set the date/time of the original photos in the scene and verify that the shadows created by **Sketchup** illuminating the model match those in the model's photo texture. When you are satisfied with placement/orientation, you create a `scenery3d.ini` like above with the command Plugins ≫ ASTROSIM/Stellarium scenery3d helpers ≫ Create scenery3d.ini .

Then, you select the OBJ group, open the Windows ≫ Ruby Console and readout data by calling Plugins ≫ ASTROSIM/Stellarium scenery3d helpers ≫ Export transformation of selected group .

On the Ruby console, you will find a line of numbers (the 4×4 transformation matrix) which you copy/paste (all in one line!) into the `[model]` section in `scenery3d.ini`.

```
obj2grid_trafo=<a11>,<a12>,<a13>,<a14>,<a21>,<a22>,<a23>,<a24>,
               <a31>,<a32>,<a33>,<a34>,<a41>,<a42>,<a43>,<a44>
```

You edit the `scenery3d.ini` to use your full (unmodified) **PhotoFly** model and, if you don't have a panorama, take `Zero Horizon` landscape as (no-)background. It depends on the model if you want to be able to step on it, or to declare `ground=NULL` for a constant-height ground. Run Stellarum once and adjust the `start_N`, `start_E` and `zero_ground_height`.

14.4.7 Rotating OBJs with recognized survey points

If you have survey points measured in a survey grid plus an image-based model with those points visible, you can use Meshlab to find the model vertex coordinates in the photo model, and some other program like **CoordTrans** in the **JavaGraticule3D** suite to find either the matrix values to enter in `scenery3d.ini` or even rotate the OBJ points. However, this involves more math than can be described here; if you came that far, you likely know the required steps. Here it really helps if you know how to operate automatic text processors like **AWK**.

14.5 Predefined views

You can also configure and distribute some predefined views with your model in a `viewpoints.ini` file. The viewpoints can be loaded and stored with the viewpoint dialog which you can call with the

⊚ button. See the provided "Sterngarten" scene for an example. These entries are not editable by the user through the interface. The user can always save his own views, they will be saved into the file `userviews.ini` in the user's Stellarium user directory, and are editable.

```
[StoredViews]
size=<int>              Defines how many entries are in this file.
                        Prefix each entry with its index!
1/label=<string>        The name of this entry
1/description=<string>  A description of this entry (can include HTML)
1/position=<x,y,z,h>    The x,y,z grid coordinates
                        (like orig_* or start_* in scenery3d.ini)
                        + the current eye height h
1/view_fov=<az_deg,alt_deg,fov_deg>  The view direction + FOV
                                     (like start_az_alt_fov in scenery3d.ini)
```

```
; an example for a second entry (note the 2 at the beginning of each line!)
2/label       = Signs
2/description = Two signs that describe the Sterngarten
2/position    = 593155.2421,5333348.6304,325.7295809038,0.8805
2/view_fov    = 84.315399,-8.187078,83.000000
```

14.6 Example

Let us add a quick example here. A recent paper (Pollard, 2017) claims that the Uffington White
Horse, a geoglyph carved into a hillsite in England during the Bronze Age, may depict the mythical
"Sun Horse", a common conception of that period.

Unfortunately, as of 2017, the official UK Lidar repository does not include the Uffington
area, so a detailed GIS-based model is not available. We could use EUdem25 data with aerial
imagery, or for a quick look, we just use **Sketchup**. Yet another unfortunate development: Trimble
declared that after the 5-year transition period from Google to Trimble is over in May 2017, terrain
modelling will be limited to **Sketchup Pro**. But note that a fresh installation comes with a 30-day
Pro trial time, this should be enough for this example.

First, locate the site in **Google Earth** at $\lambda = -1.56718, \varphi = 51.582843$. (Or just search for
"Uffington".) Try to identify which parts of the landscape may be visible from your site, so you
can estimate which parts of terrain should be included in the model. Open **Sketchup**, select the
meter-based "Landscape Architecture" template, add View⟩Toolbars…: Locations. Click on the
"Add Location" button of that toolbar. Enter "Uffington" into the location search dialog. This brings
you close to our site of interest. Clip a part of terrain to import it to Sketchup. Optionally, add more
terrain.

If installed, TIG's OBJ exporter is available from the File menu, or you can use **Sketchup Pro**'s
built-in OBJ export. Export `UffingtonHorse.obj` to a subdirectory `scenery3d/Uffington` in
your Stellarium user data directory. The geolocation is stored in an "AttributeDictionary". To read
this, press Window⟩Ruby Console to open the Ruby Console. Then write a few lines of Ruby to
get access to the `Georeference` dictionary and other data:

```
model=Sketchup.active_model
attrdicts=model.attribute_dictionaries
attrdicts.each {|d|
  puts "AttributeDictionary:␣%s" % d.name
  d.each_pair { |k, v| puts "␣␣%s=%s" % [k, v] }
}
model.shadow_info.each{|k,v| puts "␣#{k}␣#{v}"}
utm=model.point_to_utm Geom::Point3d.new(0,0,0)
puts("grid_name=UTM␣%i␣%s␣(%s)" %
    [ utm.zone_number, utm.zone_letter, model.get_datum])
```

Note the `ModelTranslation` values. Those are inches (of all units!) in the UTM reference
frame and define the model coordinate origin in world coordinates. (Actually, it uses the negative
values.) Multiplication by 2.54 gives cm, and by 0.0254, meters in the UTM coordinate system. We
will use the negatives of these values as `orig_E`, `orig_N`, `orig_H`. Additionally, we have found
information about meridian convergence correction (**Sketchup**'s `NorthAngle`), UTM zone number
etc. All this goes into our configuration file. Create this file `scenery3d.ini` with the content seen
in fig. 14.1

```
[model]
name=UffingtonHorse
;Either a fitting landscape or just 'Zero␣Horizon':
landscape=Zero Horizon
scenery=UffingtonHorse.obj
;activate the next line if you have a separate ground layer
;ground=UffingtonHorse_ground.obj
;If model Y-axis points up, activate the next line
;obj_order=XZY
author=Georg Zotti
copyright=(c) 2017 Georg Zotti
description=Uffington Horse may represent the Sun Horse. \
        See Joshua Pollard in Antiquity 91 356(2017): 406-20.
[location]
name=UffingtonHorse
country=UK
planetName=Earth
;Set the following to a fitting landscape
landscapeKey=Zero Horizon
longitude=-1.56718254089355
latitude=51.5828432749823
altitude=137
[coord]
grid_name=UTM 30 U (WGS 84)
gridType=UTM
orig_E=599273.02119578
orig_N=5715615.15079106
orig_H=136.295297626736
convergence_angle=1.12284363771988
;Height used outside the terrain, to not "fall␣off" the rim.
zero_ground_height=137
;You may want to reset these coordinates.
;Observer is set to those on loading the scenery.
start_E=599273.02119578
start_N=5715615.15079106
start_az_alt_fov=50,10,83
```

Figure 14.1: scenery3d.ini for the Uffington example.

Authors and Acknowledgements

Scenery3d was conceived by Georg Zotti for the ASTROSIM[11] project. A first prototype was implemented in 2010/2011 by Simon Parzer and Peter Neubauer as student work supervised by Michael Wimmer (TU Wien). Models for accuracy tests (Sterngarten, Testscene), and later improvements in integration, user interaction, `.ini` option handling, OBJ/MTL loader bugfixes and georeference testing by Georg Zotti.

Andrei Borza in 2011/12 further improved rendering quality (shadow mapping, normal mapping) and speed (Zotti, 2015; Zotti and Neubauer, 2012a; Zotti and Neubauer, 2012b).
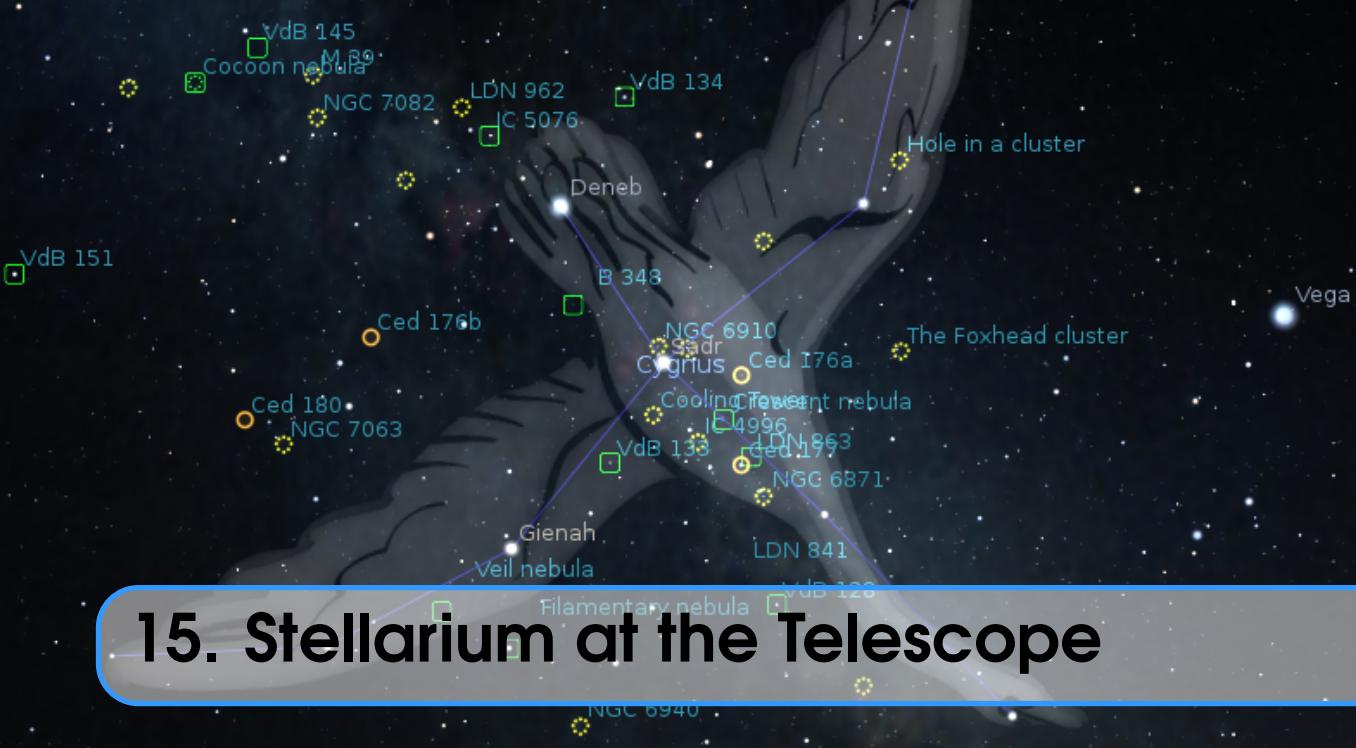
In 2014–17, Florian Schaukowitsch adapted the code to work with Qt 5 and the Stellarium 0.13 codebase, replaced the renderer with a more efficient, fully shader-based system, implemented various performance, quality and usability enhancements, and did some code cleanup. Both Andrei and Florian were again supervised by Michael Wimmer (Zotti, 2016a; Zotti, 2016b; Zotti, Schaukowitsch, and Wimmer, 2018).

This work has been originally created during the ASTROSIM project supported 2008-2012 by the Austrian Science Fund (FWF) under grant number P 21208-G19. Further development is partially supported by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology in Vienna, Austria[12].

If you are using this plugin in scientific work, please cite: (Zotti, 2016a; Zotti, 2016b; Zotti, 2019; Zotti, Frischer, et al., 2019; Zotti, Schaukowitsch, and Wimmer, 2018).

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[11]http://astrosim.univie.ac.at
[12]http://archpro.lbg.ac.at

15. Stellarium at the Telescope

Stellarium is great for indoor use on the desktop, but it is also very useful outdoors under the real sky, and several plugins enhance its usability particularly for observers.

Two plugins are bundled with Stellarium which are designed to be used at the telescope: Oculars (section 15.1), which provides field of view hints for telescopes, oculars and sensors, and TelescopeControl (section 15.2), which allows you to send GOTO commands to most motorized telescope mounts. Other GOTO telescopes are supported by external programs which you must install separately: **RTS2** (section 15.3), **INDI** (section 15.4) or **ASCOM** (section 15.5). This can also help DIY hardware tinkerers who like to build their own control systems (section 15.7).

In addition, the Observability plugin (section 15.8) can be used for planning the best times to observe your favourite objects.

15.1 Oculars Plugin

Timothy Reaves, with additions by Alexander Wolf

This plugin serves several purposes:

- to see what the sky looks like through a particular combination of eyepiece, lense (Barlow or Shapley types) and telescope. This plugin helps to get an idea of what you should see when looking through a physical telescope, and understand why one eyepiece may be better suited to observe a particular target than another. This can also be very useful for deciding what telescope is best suited to a style of viewing. And with the support for binoculars, you also have the ability to understand just about any type of optics-enhanced visual observing.
- to show what a particular combination of camera and lens or telescope would be able to photograph of the sky.
- lastly, with the help of the Telrad sight, understand where object in the sky are in relation to each other. This can be helpful for star-hopping with a non-GOTO telescope.

None of these activities can take the place of hands-on experience, but they are a good way to supplement your visual astronomy interests.
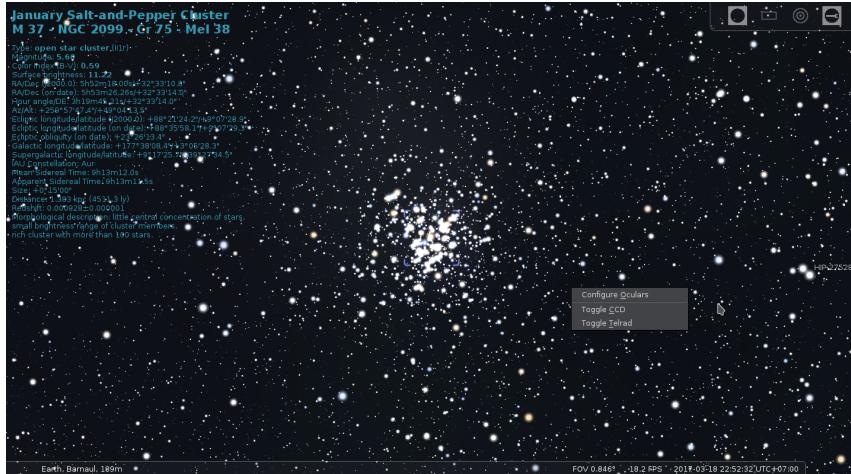
Figure 15.1: The on-screen menu (top right) and popup menu (lower right) of the Oculars plugin.

15.1.1 Using the Ocular plugin

The plugin is controlled through a popup menu or through an on-screen control panel (see top right corner on screens in fig. 15.17). By default, the hot key to display the popup is $\boxed{\text{Alt}}$ + $\boxed{\text{O}}$ ($\boxed{\text{Option}}$ + $\boxed{\text{O}}$ for Mac users). This can be changed in the $\boxed{\text{Editing Keyboard Shortcuts}}$ window (see section 4.8). The menu will popup where your cursor is located.

   The options available in the popup menu depend on what you are currently doing. In the default menu, you can choose to configure the plugin, activate a CCD, or activate the Telrad finder (see fig. 15.1). The menu is navigated by either the arrow keys on your keyboard or by your mouse. The $\boxed{\uparrow}$ and $\boxed{\downarrow}$ arrow keys move the selection up or down the menu, and the $\boxed{\leftarrow}$ and $\boxed{\rightarrow}$ arrow keys display or hide sub-menus. $\boxed{\leftarrow\!\shortmid}$ activates an option.

Telrad Finder

The Telrad view can be used without defining any of the items below. As a reflex sight is non-magnifying, this feature can only be enabled when no eyepiece is selected. You still may want to zoom in a bit to better see which stars are in the circles (fig. 15.2). The three circles that appear in the center of the screen are 0.5°, 2.0°, and 4.0° in diameter. They stay centered in the screen, so move the "telescope" (click-drag the background) to center the circles on the object of interest.

   While the Telrad finder is active, you can not activate a CCD with the popup menu, but only with the on-screen menu.

Figure 15.2: The left image is the default 60°, and the right one is 40°.

CCD Sensors
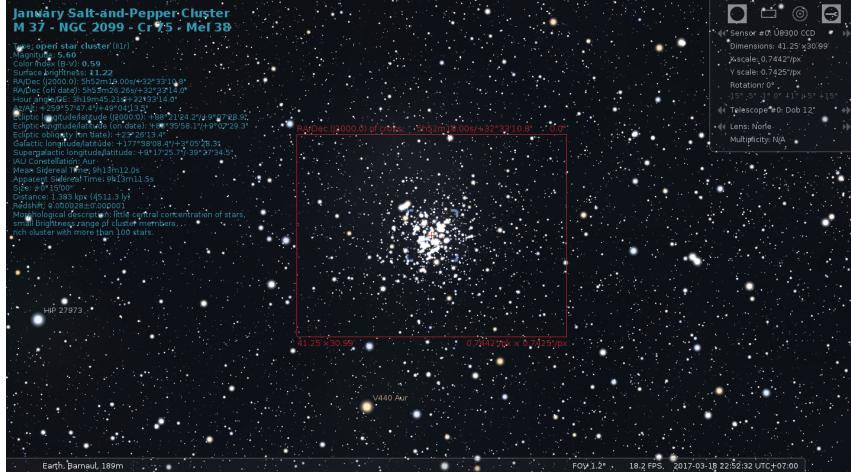
Figure 15.3: View of M37 through a CCD sensor of the Oculars plugin.
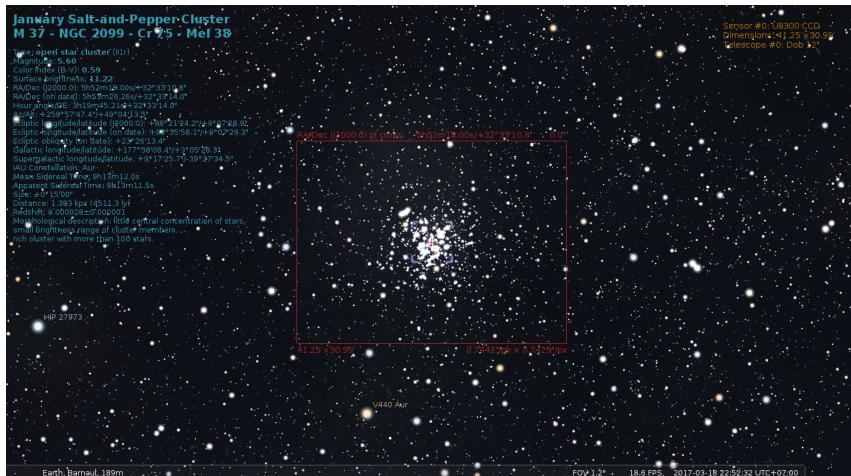
Figure 15.4: View of M37 through a CCD sensor of the Oculars plugin (without on-screen control panel).

This is a great way to get an idea of what a particular camera will be able to capture when attached to a particular telescope or lens. For using camera lenses, you must describe them as telescope with the appropriate values for the lens. When active, this feature will display a red bounding box of the area that will be captured, as well as zoom in to give a better view of the surroundings. You can manually zoom in or out from there.

The default CCD view will appear similar to fig. 15.3 or, when you are working without the on-screen control panel, the information area in the upper right hand corner also shows angular size captured by the CCD (see fig. 15.4).

When a CCD view is displayed, the popup menu changes as seen in fig. 15.5. You can select what telescope to use, as well as progress to the previous or next CCD, or go to a specific CCD. You can also rotate the CCD to better frame your subject, or to see if the CCD can be rotated in such a way as to catch your area of interest (see fig. 15.6). Once rotated, the CCD frame on screen displays the new orientation (see fig. 15.7).
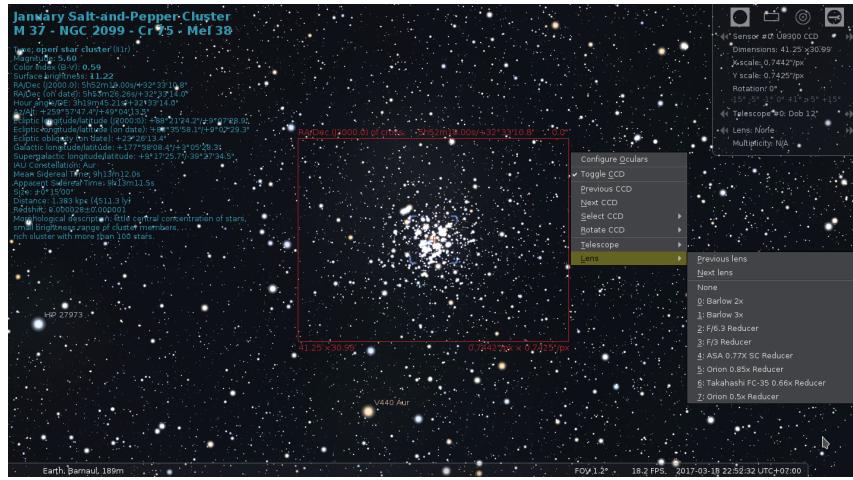
Figure 15.5: The CCD sensor popup menu of the Oculars plugin.
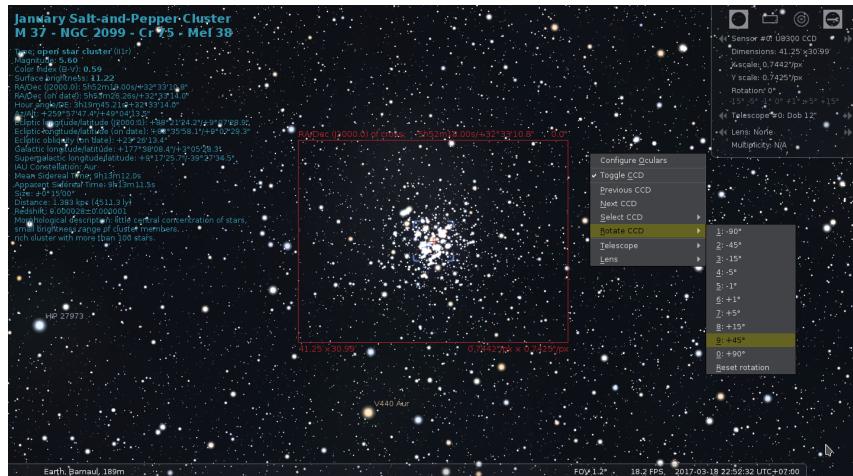
Figure 15.6: Setting rotation of CCD sensor in the popup menu.

Figure 15.7: A rotated CCD sensor frame of the Oculars plugin.

Oculars

- Define some eyepieces and telescope (see section 15.1.2).
- Select an object to view (i.e. a star, planet, etc.)
- Click the toolbar button ⬜ for toggling the Ocular view, or press Ctrl + O (⌘ + O for Mac users).
- Swap between eye pieces and telescopes to see how the view changes.

This is really the area of interest to most telescopic observers. It is a great way to compare different eyepiece/telescope combinations, to see how they change the view of the sky. And it is easy to do so with binoculars too. To show this, let us use the M37 cluster as target. Through a pair of Celestron 15x70 binoculars, it would look like in fig. 15.8.
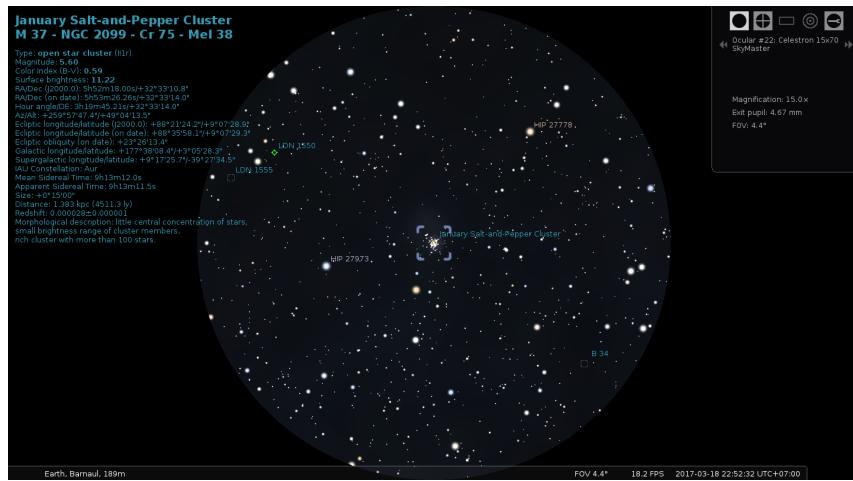
Figure 15.8: The M37 cluster through a Celestron 15x70 binocular.

A very pretty sight. Now, what would it look like through a Celestron 80 mm EDF finder 'scope, with an Explore Scientific 14 mm 100° eyepiece? See fig. 15.9!
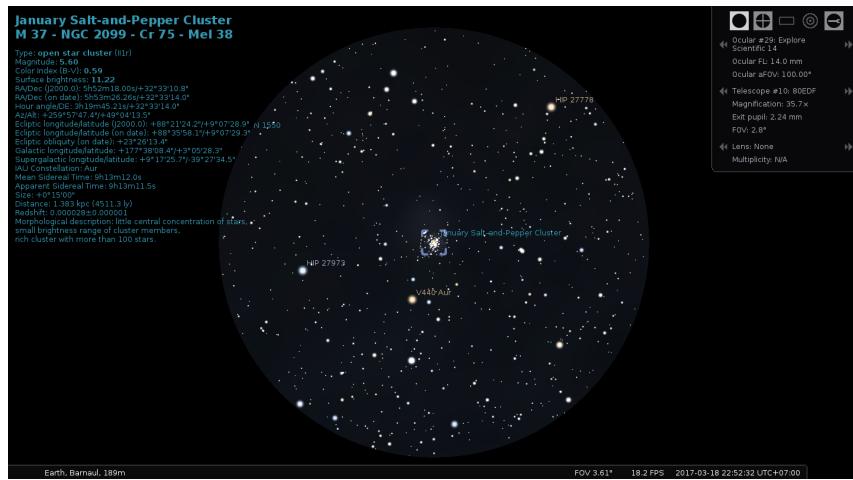
Figure 15.9: The M37 cluster through a Celestron 80 mm EDF with Explore Scientific 14 mm eyepiece.

Not bad at all. But we like to see more! So we move the eyepiece to a C1400. See fig. 15.10 for the resulting view.
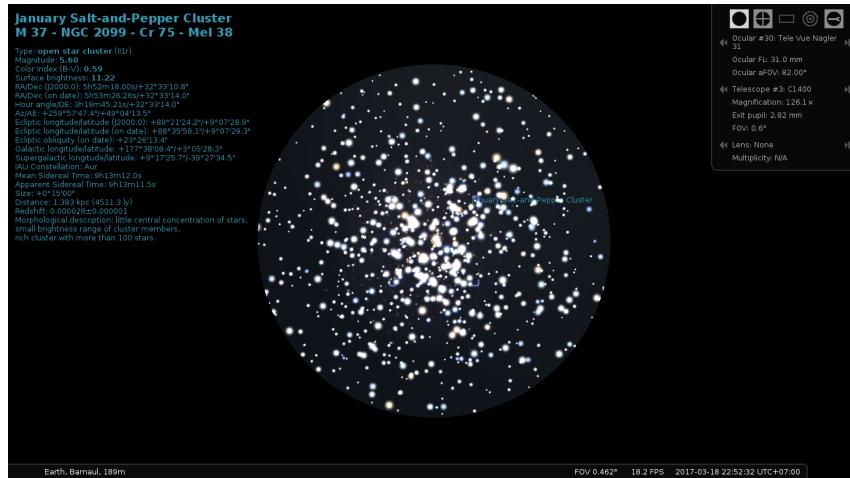
Figure 15.10: The M37 cluster through a Celestron C1400 with Tele Vue Nagler 31 mm eyepiece.

Very nice indeed! So for this target, the C1400 is going to be the best bet. However, if my target was the Pleiades, the C1400 with that eyepiece would not be good – the 80EDF would do much better!

When an eyepiece is active, the popup menu again changes. With a non-binocular eyepiece selected, you also have the ability to select a particular eyepiece or telescope. When a binocular is active, you can not select a telescope, as it is not relevant. Changing the eyepiece to a non-binocular will again allow the telescope to be selected. Also notice that when your mouse cursor is very near the right hand border of the screen, the popup menu's sub-menus display to the left, not the right.

v0.16.0 **Star Scales**

As you know from section 4.4.1, the number and relative size of stars of various magnitudes can be adjusted to your personal preferences in the view settings window to approximate the appearance of the stars as seen by the naked eye. Some observers prefer to have a simulated ocular view with very small, or more, stars, quite different from what Stellarium usually shows. The Oculars plugin therefore keeps two additional sets of scaling values for ocular views and CCD views, which are activated automatically when you switch to ocular or CCD view, and which are stored immediately and permanently in the plugin's `ocular.ini` file.[1]

15.1.2 Configuration

All configuration is done through the user interface in the application. To open the configuration dialog hit the ⎇Alt+O key, or click the `configure` button on the plugin setup dialog (available in the `Plugins` tab of Stellarium's Configuration window (opened by pressing F2 or the 🔧 button in the left toolbar)), or the rightmost button of the on-screen panel (if displayed in the top right corner of screen). There are six tabs in the configuration dialog: *General*, *Eyepieces*, *Lenses*, *Sensors*, *Telescopes*, and *About*. The first five are the ones we are interested in here.

---

[1]The appearance of stars may depend on various other factors: telescope type, ocular type, quality of optics, seeing, . . . Such details with all combinations cannot meaningfully be stored, though. These values should allow a rapid toggle on any single night.

General

The first option allows you to define the general behaviour of the plugin. The options are grouped by areas of usage: *Interface*, *Ocular view*, *Sensor view* and *Telrad view* (see figure 15.11).

Figure 15.11: General tab of the Oculars plugin configuration dialog.

Interface: this group of options allows to change behaviour of the plugin in general.

    On-screen control panel: show an additional GUI panel in the top-right corner of the screen to allow switching features of the plugin (in addition to the popup window).

    Restore FOV to initial values and

    Restore direction to initial values options allow restoration field of view and direction of view, resp., to the initial values at program start at the end of the plugin usage (e.g., when disabling the view through CCD frame).

    Show resolution criteria compute and show Rayleigh criterion, Dawes', Abbe's and Sparrow's limits for combination of telescope, lens and eyepiece. In addition, this option will show visual resolution for selected "setup". This option may be very helpful for double star observers.

    Show oculars button on toolbar option allows to toggle visibility the plugin button on main toolbar.   v0.19.0

    Arrow button scale allows to change the size of the arrow buttons in the ocular GUI panel.

    Line Color Select color for ocular and sensor outlines and their labels.   v0.20.0

    Text Color Select color for screen messages which are shown only when the on-screen control panel is not shown.   v0.20.0

Ocular view is a group of options that allows to change the plugin's behaviour in visual observation mode.

    Enable only if an object is selected – uncheck this option if you want to use the visual observation mode when no object is selected.

    Limit stellar magnitude allows to hide faint stars, which are invisible for the selected combination of eyepiece, lens and telescope.

    Hide grids and lines when enabled allows to hide grids and lines when you observe the sky through the eyepiece and re-enables their visibility when leaving visual observation mode.

Scale image circle option allows you to define whether or not to scale the images based on apparent FOV. When deactivated, the image circle will fill your screen. In general, we recommend you not select this, unless you have a need to, because it can really reduce the image size on the screen. It can however be very useful in comparing two eyepieces. If you set this option, the on-screen image will be scaled based on the eyepieces and telescopes you define. See section 15.1.3 for information on what scaling means, and why you might want to use it.

Use semi-transparent mask: uncheck this option if you want to see visible field of view as in real telescope.

Sensor view is group of options allows to change behaviour of the plugin for photographic observations mode.

Use degrees and minutes for FOV of CCD – for many cases the use of decimal degrees for the value of the field of view is not comfortable, and this option allows to use the more human readable format for FOV.

Enable automatic switch of mount type allows to store the CCD frame orientation when the type of telescope mount is changed.

v0.19.0   **Show sensor crop overlay** option toggle drawing a crop box within the CCD frame.

v0.19.0   **Telrad view** is a group of options which allows to change behaviour of the plugin for Telrad mode.

Enable scaling FOV for Telrad option allows you to define whether or not to scale the Telrad circles to half of apparent FOV. When activated, the Telrad circles will fill your screen.

Eyepieces

This is the tab used to enter your own eyepieces (see figures 15.12 and 15.13). By default, a few sample ones have been added; feel free to delete those once you've entered your own.

The fields on this tab are:

Name – a free-text description of the eye piece. You could modify this to match your personal descriptions of eyepieces.

aFOV – apparent field of view in degrees.

Focal Length – eyepiece focal length in mm.

Field Stop – the field stop of the eyepiece in mm. This is used to calculate the true field of view of an eyepiece. If you do not know what it is just leave it the default zero. Not all manufacturers provide this value; TeleVue is one that does.

Binoculars – selecting this checkbox tells the system that this eyepiece is binoculars or finders; this means that this eyepiece can be used without defining a telescope.

Has permanent cross-hairs – selecting this checkbox tells the system that this eyepiece or binocular (finder) has also simple cross-hairs[2].

When Binoculars are described, the relevant fields change to

tFOV – true field of view in degrees.

Magnification factor – the magnification of the binocular.

Diameter – the diameter of the binocular objective in mm.

Lenses

This is the tab used to enter your own lenses (see figure 15.14). By default, a few sample ones have been added; feel free to delete them once you've entered your own.

The fields on this tab are:

---

[2]The Oculars plugin supports eyepieces with reticle patterns – both special eyepieces are available in the default list of eyepieces, and the option *Has permanent cross-hairs* is not related to those eyepieces.

Figure 15.12: Eyepieces tab of Oculars plugin configuration dialog.
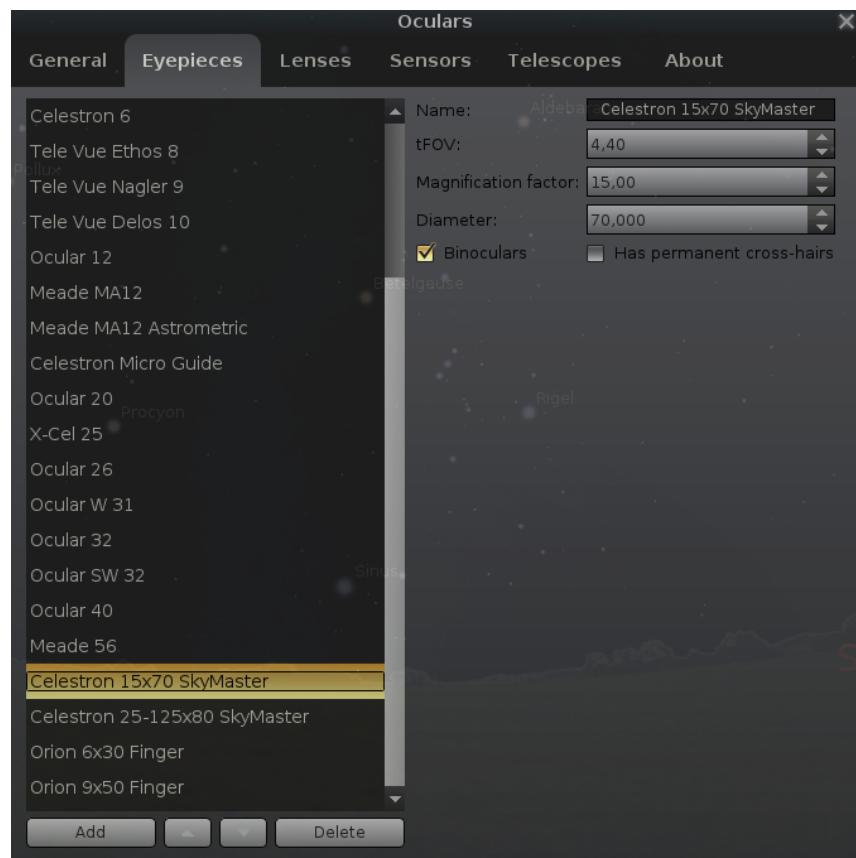
Figure 15.13: Eyepieces tab of Oculars plugin configuration dialog (settings for binocular).
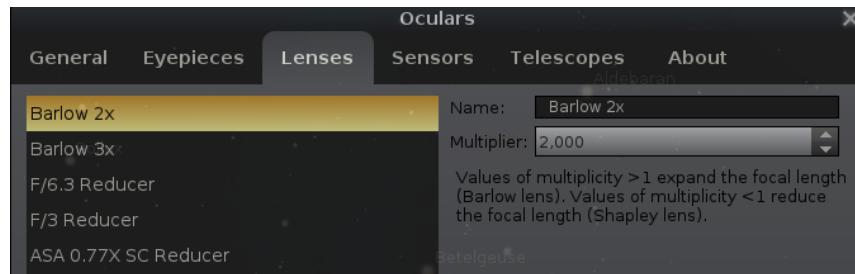
Figure 15.14: Lenses tab of Oculars plugin configuration dialog.

Name – a free-text description of the lense. You could modify this to match your personal descriptions of lenses.

Multiplier – a factor larger than 1 expands the focal length, and lenses with this type are named Barlow lense; a factor less than 1 reduces the focal length, and lenses with this type are named Shapley lense or focus reducer.

Sensors

This tab allows you to define sensors for any camera you may have (see figure 15.15). When defined and selected, this will draw a red bounding rectangle in the center of the eye piece view, showing what the CCD will capture. Because of the way floating point numbers are stored, sometimes you may see one of your defined values change (for example from 2.2 to 2.19999) but this should not affect what you see.

Figure 15.15: Sensors tab of Oculars plugin configuration dialog.

The fields on this tab are:

Name – A free-text description of the sensor.
Resolution x – the width of the sensor in pixels.
Resolution y – the height of the sensor in pixels.
Chip width – the width of the sensor in mm.

Chip height – the height of the sensor in mm.
Pixel width – the width of an individual pixel, in μm.
Pixel height – the height of an individual pixel, in μm.
Rotation Angle – the rotation angle of the sensor, in degrees.
Binning x – the binning factor for the width of the sensor.
Binning y – the binning factor for the height of the sensor.
Off-Axis guider – selecting this checkbox tells the system that this sensor has support an off-axis
guider also.
Prism/CCD distance – distance between center of prism/CCD of Off-Axis Guider and optical
axis of telescope in mm.
Prism/CCD width – the width of the prism/CCD of Off-Axis Guider in mm.
Prism/CCD height – the height of the prism/CCD of Off-Axis Guider in mm.
Position Angle – the position angle of the prism/CCD of Off-Axis Guider, in degrees.

The resolution is easy to find: these are simply the image dimensions of a (non-binned) frame. The chip size and pixel size may be more difficult, but the manual, or searching the Internet, should turn up these values. For a "full-frame" DSLR, this should be close to 36x24 mm, while APS-C should be around 22.5x15 mm. Pixel size is simply image size divided by resolution. Some cameras may have unsquare pixels.

Telescopes

This is the tab used to enter your own telescopes (see fig. 15.16). The fields on this tab are:
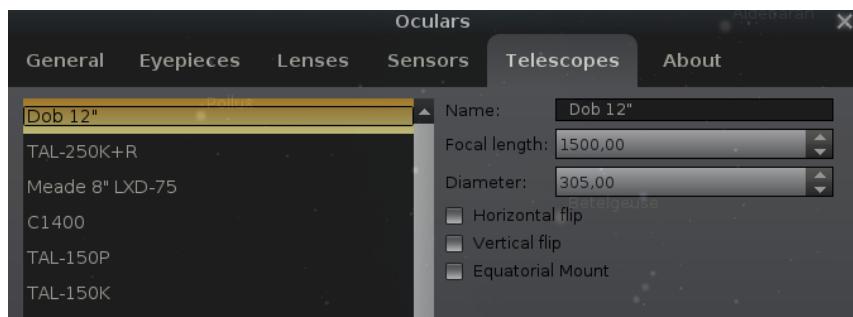
Figure 15.16: Telescopes tab of Oculars plugin configuration dialog.

Name – A free-text description of the telescope.
Focal Length – telescope focal length in mm.
Diameter – telescope diameter (aperture) in mm.
Horizontal flip – if the view through this telescope should flip horizontally.
Vertical flip – if the view through this telescope should flip vertically.
Equatorial Mount – select it if this telescope has an equatorial mount.

15.1.3 Scaling the eyepiece view

I (TR) would like to thank Al Nagler over at TeleVue[3] for helping to set me straight on the topic of eyepieces. They are a lot more complicated than you might think!

By default, the view drawn on your computer screen when the plugin is active fills the screen. That is, there is a circle drawn to represent the view through the eyepiece, and this circle will fill the screen. For general use, this is what most people would want. There will be times that it's not.

If you are going to be observing any deep space object, it can be very important to choose the best eyepiece for that object. You will typically want an eyepiece that will magnify the object as

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[3]http://televue.com/

much as possible, while showing all of the object in the eyepiece view. Getting this can be tricky, especially if you do not like changing eyepieces at the telescope. Or maybe you want to understand why one type of telescope may be better than another type for observing what you are interested in. This is where you will want to scale the image on screen based on your eyepiece.

Different eyepieces generally have a different apparent field of view (aFOV). An easy way to think about this is: the larger the aFOV, the bigger the picture you see in the eyepiece. Older types of eyepiece (some types still built and in wide use today have been constructed in the 19th century) generally have their aFOV in the 50° range. Today, there are massive eyepieces available with 82°, and recently even 100° aFOV! These eyepieces are huge, as they require a lot of very special glass to achieve their incredible fields of view. An eyepiece of the same focal length with a 100° aFOV will produce an image through the eyepiece that is twice as wide as one produced by a 50° eyepiece.

Different telescopes, with an eyepiece of a given aFOV, will also produce a different true field of view. This is the actual size of the piece of sky that you see through the eyepiece. Getting these two "just right" can be very important. It's easy to assume that you want the biggest telescope you can get, with the eyepiece that gives you the highest magnification. This is never true in reality. Depending on where you live, and especially what you like to look at, a 100-120 mm quality refractor with a wide aFOV eyepiece may very well be better than a large SCT with the same eyepiece. This is something I learned the hard way.

So how does scaling the eyepiece view help? The plugin will find the eyepiece you have with the largest aFOV. This aFOV becomes 100% of the computer screen diameter. Then, any other eyepiece will have its aFOV compared, and the view on screen will be scaled down accordingly. These 100° aFOV eyepieces makes the math here easy. If you have one, then when that eyepiece is used, the circle that represents the view through the eyepiece will take up 100% of the screen diameter. Next, if you select an eyepiece with an 82° aFOV, its view will be scaled to 82% of the screen, and a 62° aFOV eyepiece will be scaled to 62% of the screen.

Example in action

This is easier to understand in action, so let us look at an example that uses three eyepieces all with the same 17 mm focal length, so they all produce the same level of magnification (well, one has an 17.3 mm focal length, but its magnification is nearly identical) and see how the view changes. These example all use a Celestron C8 8" SCT telescope, and the target is the Great Orion Nebula.

We can see from the images in fig. 15.17 that the target is all three images is the same size. The 100° image fills the screen, the 82° is smaller, and the 62° is smallest yet, filling 62% of the computer screen. Note that in each image, the field of view that you see changes. The larger the aFOV, the more you can see of the sky. So in this example, if you had an 8" telescope, you would want to use the 17 mm 100° Ethos eyepiece to see as much of the nebula as possible.
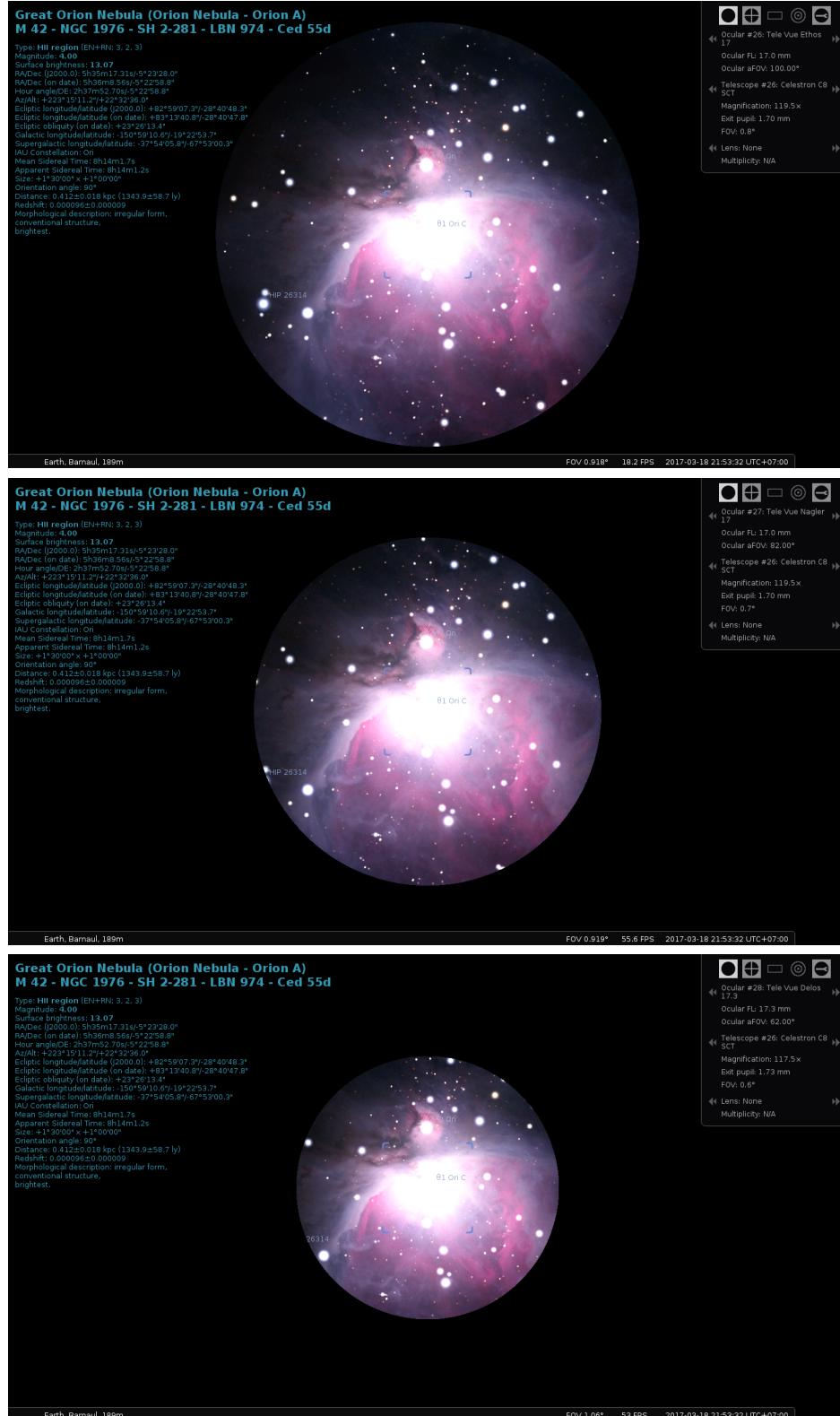
Figure 15.17: Comparing apparent fields of view of (top) a 17 mm Tele Vue Ethos eyepiece with an aFOV of 100°. Magnification is 119.5×. (center) a 17 mm Tele Vue Nagler eyepiece with an aFOV of 82°. Magnification is 119.5×. (bottom) a 17.3 mm Tele Vue Delos eyepiece with an aFOV of 62°. Magnification is 117.5×.

15.2 TelescopeControl Plugin

This plugin provides a simple control mechanism for motorised telescope mounts. The user selects
an object (i.e. by clicking on something – a planet, a star etc.) and presses the telescope go-to key,
and the telescope will be guided to the object.

Multiple telescopes may be controlled simultaneously.

WARNING

*Stellarium cannot prevent your telescope from being pointed at the Sun. It is up to you to ensure
proper filtering and safety measures are applied!*

Never point your telescope at the Sun without a proper solar filter installed. The powerful light
amplified by the telescope WILL cause *irreversible damage* to your eyes and/or your equipment.

Even if you don't do it deliberately, a slew during daylight hours may cause your telescope to
point at the sun on its way to the given destination, so it is strongly recommended to avoid using
the telescope control feature before sunset without appropriate protection.

15.2.1 Abilities and limitations

This plug-in allows Stellarium to send 'slew' ('go to') commands to the device and to receive its
current position. There are some scopes which additionally support 'sync' commands to be received
in order to update the internal pointing model of the mount. Some scopes also have the ability
to abort a previous slew command. However, users should always be aware of the possibility for
mount collisions and similar situations. You should always make sure that a slew does not cause
parts of the telescope to collide with the environment or mount itself.

Currently this plug-in does not allow satellite tracking unless the controlled telescope is an
RTS2 system (see section 15.3), and is not very suitable for lunar or planetary observations. Many
mounts can be set to a 'lunar' tracking speed, you may prefer this.

15.2.2 Using this plug-in

Here are two general ways to control a device with this plug-in, depending on the situation:

DIRECT CONNECTION A device supported by the plug-in is connected with a cable to the
computer running Stellarium

INDIRECT CONNECTION

local A device is connected to the same computer but it is driven by a stand-alone telescope
server program or a third-party application that can 'talk' to Stellarium;

remote A device is connected to a remote computer and the software that drives it can
'talk' to Stellarium over the network; this software can be either one of Stellarium's
stand-alone telescope servers, or a third party application.

Most older telescopes use cables that connect to a serial port (RS-232), the newer ones use USB
(Universal Serial Bus). On Linux and Max OS X, both cases are handled identically by the plug-in.
On Windows, a USB connection may require a 'virtual serial port' software, if it is not supplied
with the cable or the telescope. Such a software creates a virtual ('fake') COM port that corresponds
to the real USB port so it can be used by the plug-in. On all three platforms, if the computer
has no 'classic' serial ports and the telescope can connect only to a serial port, a serial-to-USB
(RS-232-to-USB) adapter may be necessary.

Telescope set-up (setting geographical coordinates, performing alignment, etc.) should be done
before connecting the telescope to Stellarium.

15.2.3 Main window ('Telescopes')

The plug-in's main window can be opened:

- By pressing the `configure` button for the plug-in in the `Plugins` tab of Stellarium's Configuration window (opened by pressing `F2` or the `⚒` button in the left toolbar).
- By pressing the `Configure telescopes...` button in the `Slew to` window (opened by pressing `Ctrl`+`0` or the respective button on the bottom toolbar).

The `Telescopes` tab displays a list of the telescope connections that have been set up:

- The *number (#)* column shows the number used to control this telescope. For example, for slewing telescope #2, the shortcut is `Ctrl`+`2`.
- The *Status* column indicates if this connection is currently active or not. Unfortunately, there are some cases in which 'Connected' is displayed when no working connection exists.
- The *Type* field indicates what kind of connection this is:
  virtual means a virtual telescope (test mode).
  local, Stellarium means a DIRECT connection to the telescope (see above).
  local, external means an INDIRECT connection to a program running on the same computer.
  local, ASCOM means an INDIRECT connection to a ASCOM driver running on the same computer.
  remote, unknown means an INDIRECT connection over a network to a remote machine.
  remote, RTS2 means an INDIRECT connection over a network to an RTS2 server.
  remote, INDI means an INDIRECT connection over a network to an INDI server.

To set up a new telescope connection, press the `Add` button. To modify the configuration of an existing connection, select it in the list and press the `Configure` button. In both cases, a telescope connection configuration window will open.

15.2.4 Telescope configuration window

Connection type

The topmost field represents the choice between the types of connections (see section 15.2.2): Telescope controlled by:

Stellarium, directly through a serial port is the DIRECT case
External software or a remote computer is an INDIRECT case
RTS2 Telescope is another INDIRECT case — v0.16.0
INDI is another INDIRECT case — v0.17.0
ASCOM is another INDIRECT case — v0.19.3
Nothing, just simulate one (a moving reticle) is a *virtual telescope* (no connection)

Telescope properties

Name is the label that will be displayed on the screen next to the telescope reticle.
Connection delay If the movement of the telescope reticle on the screen is uneven, you can try increasing or decreasing this value.
Coordinate system Some Celestron telescopes have had their firmware updated and now interpret the coordinates they receive as coordinates that use the equinox of the date (EOD, also known as JNow), making necessary this setting. With ASCOM telescopes it's also possible to use this setting to override the default device preference.
Start/connect at startup Check this option if you want Stellarium to attempt to connect to the telescope immediately after it starts. Otherwise, to start the telescope, you need to open the main window, select that telescope and press the `Start/Connect` button.

Device settings

This section is active only for DIRECT connections (see above).

Serial port sets the serial port used by the telescope. There is a pop-up box that suggests some
  default values:

- On Windows, serial ports `COM1` to `COM10`
- On Linux, serial ports `/dev/ttyS0` to `/dev/ttyS3` and USB ports `/dev/ttyUSB0` to
  `/dev/ttyUSB3`. Make sure you have read/write access to the `tty` device. Depending
  on your flavour of Linux, this may e.g. require some group membership.
- On Mac OS X, the list is empty as it names its ports in a peculiar way. If you are using
  a USB cable, the default serial port of your telescope most probably is not in the list of
  suggestions. To list all valid serial port names in Mac OS X, open a terminal and type:

```
ls /dev/*
```

  This will list all devices, the full name of your serial port should be somewhere in the
  list (for example, `/dev/cu.usbserial-FTDFZVMK`).

Device model : see 15.2.5 Supported devices.

Connection settings

Both fields here refer to INDIRECT connections, which implies communication over a network
(TCP/IP).

Host can be either a host name or an IPv4 address such as '127.0.0.1'. The default value of
  'localhost' means 'this computer'.

  Modifying the default host name value makes sense only if you are attempting a remote
  connection over a network. In this case, it should be the name or IP address of the computer
  that runs a program that runs the telescope.

Port refers to the TCP port used for communication. The default value depends on the telescope
  number and ranges between 10001 and 10009.

RTS2 settings

v0.16.0   (see also 15.3) You will need access to an RTS2 HTTPD server through HTTP/JSON calls. Please
  see RTS2 documentation (man rts2-httpd) for details. You will as well need username and password
  for HTTPD. Please be aware that in order to move the telescope, your user must have the telescope
  in the list of allowed devices in the database. Please see `man rts2-user` for details on how to
  manipulate RTS2 users.

URL points to RTS2 HTTPD. Can include anything a URL can have - port (:8889) and prefix path
  for RTS2 access.

Username username used for login to RTS2 HTTPD.

Password password for login to RTS2 HTTPD.

INDI settings

v0.17.0   (see also 15.4) You will need access to an INDI server through a TCP/IP connection. Please see
  INDI documentation for details. You will need to select the correct INDI device to manage it.

ASCOM settings

v0.19.3   You can choose an ASCOM telescope driver installed in your system using the ASCOM chooser.
  Additionally you can choose how Stellarium is determining the coordinate system used to commu-
  nicate with the ASCOM mount. For more information, please see 15.5.

User Interface Settings: Field of view indicators

A series of circles representing different fields of view can be added around the telescope marker.
This is a relic from the times before the Oculars plug-in (see 15.1) existed.

  Activate the 'Use field of view indicators' option, then enter a list of values separated with
commas in the field below. The values are interpreted as degrees of arc.

These marks can be used in combination with a virtual telescope to display a moving reticle with the Telrad circles.

'Slew telescope to' window

The `Slew telescope to` window can be opened by pressing `Ctrl`+`0` or the respective button in the bottom toolbar.

It contains two fields for entering celestial coordinates, selectors for the preferred format (Hours-Minutes-Seconds, Degrees-Minutes-Seconds, or Decimal degrees), a drop-down list and two buttons.

The drop-down list contains the names of the currently connected devices. If no devices are connected, it will remain empty, and the `Slew` button will be disabled.

Pressing the `Slew` button slews the selected device to the selected set of coordinates. See the section about keyboard commands below for other ways of controlling the device.

Pressing the `Configure telescopes...` button opens the main window of the plug-in.

TIP: Inside the 'Slew' window, underlined letters indicate that pressing `Alt`+`underlined letter` can be used instead of clicking. For example, pressing `Alt`+`S` is equivalent to clicking the `Slew` button, pressing `Alt`+`E` switches to decimal degree format, etc.

Sending commands

Once a telescope is successfully started/connected, Stellarium displays a telescope reticle labelled with the telescope's name on its current position in the sky. The reticle is an object like every other in Stellarium - it can be selected with the mouse, it can be tracked and it appears as an object in the 'Search' window.

To point a device to an object: Select an object (e.g. a star) and press the number of the device while holding down the `Ctrl` key. (For example, `Ctrl`+`1` for telescope #1.) This will move the telescope to the selected object. Note that most telescopes can only execute a single command to move to that object's position, but if the telescope is an RTS2 telescope, you can even track a satellite (if the mount then is fast enough to support it).[4]

To point a device to the center of the view: Press the number of the device while holding down the Alt key. (For example, `Alt`+`1` for telescope #1.) This will slew the device to the point in the center of the current view. (If you move the view after issuing the command, the target won't change unless you issue another command.)

To point a device to a given set of coordinates: Use the `Slew to` window (press `Ctrl`+`0`).

15.2.5   Supported devices

Directly connected telescopes

All devices listed in the 'Device model' list are convenience definitions using one of the two built-in interfaces: the Meade LX200 (the Meade Autostar controller) interface and the Celestron NexStar interface.

The device list contains the following:

Celestron NexStar (compatible) Any device using the NexStar interface.

Losmandy G-11 A computerized telescope mount made by Losmandy (Meade LX-200/Autostar interface).

Meade Autostar compatible Any device using the LX-200/Autostar interface.

Meade ETX-70 (#494 Autostar, #506 CCS) The Meade ETX-70 telescope with the #494 Autostar controller and the #506 Connector Cable Set. According to the tester, it is a bit slow, so its default setting of 'Connection delay' is 1.5 seconds instead of 0.5 seconds.

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[4]Actually, the TLE orbital elements of the selected satellite are transmitted to RTS2, which does then compute the satellite position itself.

Meade LX200 (compatible) Any device using the LX-200/Autostar interface.

Sky-Watcher SynScan AZ mount The Sky-Watcher SynScan AZ GoTo mount is used in a number of telescopes.

Sky-Watcher SynScan (version 3 or later) SynScan is also the name of the hand controller used in other Sky-Watcher GoTo mounts, and it seems that any mount that uses a SynScan controller version 3.0 or greater is supported by the plug-in, as it uses the NexStar protocol.

Wildcard Innovations Argo Navis (Meade mode) Argo Navis is a 'Digital Telescope Computer' by Wildcard Innovations. It is an advanced digital setting circle that turns an ordinary telescope (for example, a dobsonian) into a 'Push To" telescope (a telescope that uses a computer to find targets and human power to move the telescope itself). Just don't forget to set it to Meade compatibility mode and set the baud rate to 9600B1.

RTS2 telescopes

v0.16.0

Setting up a robotic telescope and dome control system with RTS2 is beyond the scope of this handbook, but see section 15.3 for a few notes to be able to connect and command the telescope with Stellarium. Please refer to the RTS2 Web pages[5] for further details.

Please be aware that some RTS2 usernames might have only read-only access. If this is case for your username, the telescope marker will be painted red (or `color_telescope_readonly` from Stellarium's settings file).

INDI telescopes

v0.17.0

Setting up a robotic telescope and dome control system with INDI is beyond the scope of this handbook, but see section 15.4 for a few notes to be able to connect and command the telescope with Stellarium. Please refer to the INDI web pages[6] for further details.

ASCOM telescopes

v0.19.3

ASCOM specific settings can be configured when a ASCOM telescope was selected. Please see section 15.5 for futher information about configuration possibilities.

Virtual telescope

If you want to test this plug-in without an actual device connected to the computer, choose "Nothing, just simulate one (a moving reticle)" in the Telescope controlled by: field. It will show a telescope reticle that will react in the same way as the reticle of a real telescope controlled by the plug-in. See the section above about field of view indicators for a possible practical application (emulating 'Telrad' circles).

15.3 RTS2

v0.16.0

RTS2, the Remote Telescope System 2, is a complete robotic observatory control system for Linux by Petr Kubánek, who kindly provided the plugin code to make RTS2 interoperate with Stellarium. We cannot give a full manual or any further support for RTS2 here, please refer to its website[7] for complete instructions about dome control, cameras, filter wheels, weather sensors, etc. A few notes may be useful for beginners, though.

RTS2's central piece is a daemon. Start the system:

```
sudo service rts2 start
```

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[5] http://rts2.org/
[6] http://indilib.org
[7] http://rts2.org

RTS2's main control screen is text-based, **rts2-mon**. For a quick check, switch on the system using
F9 . Telescope T0 is a dummy telescope which you can select and operate with commands like
move 120 35 (this moves to RA=120°=8h, DEC=35°, but only when this position is above your
horizon).

Stellarium's Telescope plugin can communicate with RTS2 using the RTS2 web interface. You
must run **rts2-httpd** for this, which may require the right permissions to write the lock files in
/var/run. This program requires that a database has been created as described in the file RUN in
RTS2's source directory and on the RTS2 website[8]. Also, you must create a 'user' for RTS2. This
is not a regular Linux account, but an entry in the RTS2 database. Create a user with **rts2-user -a
<user>**. You should use a password different from your regular Linux password, as this will be
transmitted in plain text between the computer running Stellarium and the RTS2 control computer,
and may also be written into Stellarium's logfile. Then you can enable device control for the
respective user. If you want to send slew commands from Stellarium, make sure to allow access to
telescope T0. If not, Stellarium will be able to show the telescope marker, but you will not be able
to control the telescope. To enable control for existing users in the default stars database,

```
psql stars
update users set allowed_devices = '*';
```

In case you cannot properly connect to the RTS2 telescope or cannot send slew commands,
check Stellarium's logfile log.txt for some diagnostic messages.

RTS2 is the only type of telescope supported by Stellarium which can autonomously track
satellites. Tracking accuracy fully depends on Stellarium's TLE satellite elements being up-to-date
(see section 13.8) and the accuracy of your RTS2 installation.

15.4 INDI

INDI, the Instrument Neutral Distributed Interface, is a distributed control system (DCS) protocol   v0.17.0
to enable control, data acquisition and exchange among hardware devices and software front ends,
emphasizing astronomical instrumentation[9].

INDI client (v1.6.0) has been incorporated into Stellarium's Telescope Control plugin by
Alessandro Siniscalchi to allow Stellarium to communicate with INDI hardware drivers via INDI
server. INDI server is a hub that sits between drivers and clients. It reroutes traffic for control
and data across distributed networks. Each device or client in the network is a node and may
communicate with other nodes whenever desired. The server supports broadcasting, chaining, and
marshalling of data.

Stellarium only supports INDI mounts (no other INDI devices), and you will need to select the
correct INDI device to manage it at the stage of configuration of telescope. For this purpose the
plug-in has a tool to getting the list of connected devices from the INDI server (when the server is
working!). Please define hostname and port[10] in the "INDI Settings" block, press Refresh devices
and select the required device in the list "Devices".

List of telescope types supported by INDI[11]:
- Meade Autostar
- Meade LX200 (Classic/GPS/16)
- Celestron NexStar

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[8]http://rts2.org/faq.html

[9]https://en.wikipedia.org/wiki/Instrument_Neutral_Distributed_Interface

[10]The Internet Assigned Numbers Authority (IANA) has assigned to INDI the Transmission Control
Protocol and User Datagram Protocol (TCP/UDP) port 7624.

[11]http://indilib.org/devices/telescopes/all.html

- Celestron NexStar Evolution
- Orion Synscan Telescope
- EQ-6 MCU Update
- HEQ-5 MCU Update
- LittleFoot Vpower
- LittleFoot Elegance Photo
- Astro-Electronic FS-2
- EQMod
- Pulsar2
- SkySensor2000PC
- Takahashi Temma
- 10 Micron
- Losmandy Gemini
- Astrophysics
- Skywatcher Virtuoso (Alt/Az)
- IOptron IEQPro/CEM60
- IOptron ZEQ25/SmartEQ
- IOptron GotoNova Upgrade Kit 8400

15.5 ASCOM (Windows only)

v0.19.3 *ASCOM* is probably the most widely used way how to communicate with telescopes, mounts and other astronomy equipment on Microsoft Windows operating systems. The ASCOM platform aims to decouple device dependent specifics by introducing a common standard for communication between device drivers and applications. Almost every telescope mount comes with an ASCOM driver and most of the astronomy software and tools can communicate with ASCOM compatible devices.

The ASCOM telescope support has been added to Stellarium's Telescope Control plugin by Gion Kunz in version 0.19.3.

Note that in order for Stellarium to communicate with your ASCOM compatible mount, you will need to have the ASCOM platform installed on your Windows machine (version 6 or higher[12]). Also, the ASCOM driver of your telescope mount needs to be installed before you can start using the telescope in Stellarium.

Important: Most modern ASCOM drivers are written to run in 32bit and 64bit mode (any) and therefore are compatible with the 64bit and 32bit version of Stellarium. However, if you happen to have a 32bit or 64bit only driver for your telescope mount, you will also need to install the respective Stellarium version.

In order to use your ASCOM telescope you need to select the correct device in the ASCOM chooser by clicking the button $\boxed{\textsf{Choose ASCOM telescope}}$. The selected device is shown below that button.

By default, Stellarium is trying to ask the ASCOM driver in order to determine if JNow or J2000 coordinates should be used for communicating with the mount. If you'd like to override this behavior and tell the ASCOM telescope to communicate in the coordinate system configured in the section Telescope properties, you can switch the radio button $\boxed{\textsf{Let ASCOM device decide}}$ to $\boxed{\textsf{Use Stellarium settings}}$ in the ASCOM settings of the Configure Telescope dialog.

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[12]https://ascom-standards.org/Downloads/Index.htm

15.6 StellariumScope

StellariumScope is a free add-on that enables you to control your telescope with Stellarium.

Note that Stellarium supports ASCOM telescopes natively since version 0.19.3. There's no need to use StellariumScope in order to use your ASCOM telescopes with Stellarium anymore. We are encouraging our users to switch to the native ASCOM option going forward and the use of StellariumScope is most likely not recommended in the future.

Features

- Provides an interface between Stellarium and ASCOM telescope drivers.
- Provides the ability to both "Sync" and "Slew" the telescope. It's also possible to issue a stop/cancel command from Stellarium.
- You can easily host Stellarium on one computer linked to another control computer that hosts the telescope driver.
- The installation program will automatically install the documentation, but the link to the documentation is provided by developer[13] so you can read it before installation.
- There are earlier releases still available on the downloads page on Welsh Dragon Computing site.

The original **StellariumScope** program was designed and implemented by Scott of ByteArts and is still available for download[14]. If you have difficulties with the releases available on the Welsh Dragon Computing site[15], you may want to consider using the original version.

Figure 15.18 shows the interface and some of the options. Use this application (like all software that controls your mount) with supervision of your mount's movements.

15.7 Other telescope servers and Stellarium

Other developers have also been busy creating hard- and software often involving Arduino or Raspberry Pi boards which can control GOTO or PUSHTO (manually driven but position-aware, usually Dobsonian) telescopes and are ultimately controlled from Stellarium. Those are not related nor authored by the Stellarium team, so while we welcome such development (esp. open-sourced) in general, we cannot provide documentation nor any support.

A few examples:

iTelescope `http://simonbox.info/index.php/astronomy/93-raspberry-pi-itelescope`

node-telescope-server `https://www.npmjs.com/package/node-telescope-server`

OnStep `https://groups.io/g/onstep`

One anonymous user sent a troubleshooting solution when connecting Stellarium to the Celestron **NexRemote** software:
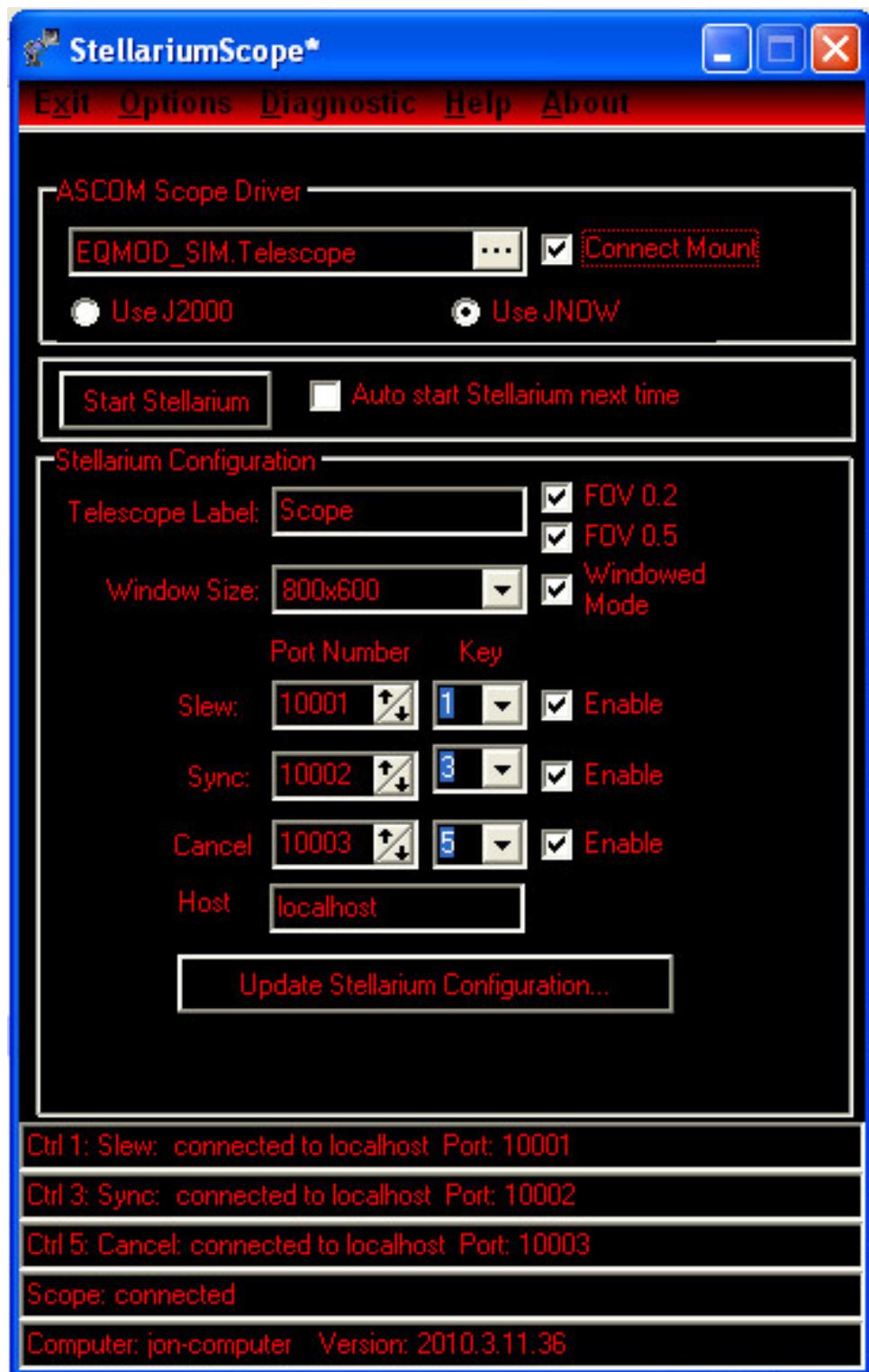
> One tricky Window XP issue I fixed was that my older laptop would transiently lose connection with Stellarium although the status would still be "Connected" and all looked normal. [. . .]
>
> I boosted the *NexRemote.exe* process in Windows XP to *High* under *Set Priority* under the **Windows Task Manager** via Ctrl + Alt + Del .

---

[13]**StellariumScope** User's Guide — `http://welshdragoncomputing.ca/x/st/misc/stellariumscope_user_guide.2015.10.24.pdf`

[14]`http://www.bytearts.com/stellarium/`

[15]`http://welshdragoncomputing.ca/x/index.php/home/stellariumscope/about-stellariumscope`

Figure 15.18: **StellariumScope** interface

All slews now proceed normally. Problem went away.[16]

---

[16]`https://sourceforge.net/p/stellarium/discussion/278769/thread/16e4c054/?limit=25#8ffa`

15.8 Observability Plugin

This Plugin is activated with the button ⟨icon⟩ . It analyzes the observability of the selected object (or the screen center, if no object is selected). The plugin can show rise, transit, and set times, as well as the best epoch of the year (i.e., largest angular separation from the Sun), the date range when the source is above the horizon at dark night, and the dates of Acronychal and Cosmical rise/set. Ephemerides of the Solar-System objects and parallax effects are taken into account.

Explanation of some parameters

Sun altitude at twilight Any celestial object will be considered visible when the Sun is below this altitude. The altitude at astronomical twilight ranges usually between -12 and -18 degrees. This parameter is only used for the estimate of the range of observable epochs (see below).

Horizon altitude Minimum observable altitude (due to mountains, buildings, or just a limited telescope mount).

Today ephemeris Self-explanatory. The program will show the rise, set, and culmination (transit) times. The exact times for these ephemeris are given in two ways: as time spans (referred to the current time) and as clock hours (in local time).

Acronychal/Cosmical/Heliacal rise/set The days of Cosmical rise/set of an object are estimated as the days when the object rises (or sets) together with the rise/set of the Sun. The exact dates of these ephemeris depend on the Observer's location. On the contrary, the Acronycal rise (or set) happens when the star rises/sets with the setting/rising of the Sun (i.e., opposite to the Sun). On the one hand, it is obvious that the source is hardly observable (or not observable at all) in the dates between Cosmical set and Cosmical rise. On the other hand, the dates around the Acronychal set and rise are those when the altitude of the celestial object uses to be high when the Sun is well below the horizon (hence the object can be well observed). The date of Heliacal rise is the first day of the year when a star becomes visible. It happens when the star is close to the eastern horizon roughly before the end of the astronomical night (i.e., at the astronomical twilight). In the following nights, the star will be visibile during longer periods of time, until it reaches its Heliacal set (i.e., the last night of the year when the star is still visible). At the Heliacal set, the star sets roughly after the beginning of the astronomical night.

Largest Sun separation Happens when the angular separation between the Sun and the celestial object are maximum. In most cases, this is equivalent to say that the Equatorial longitudes of the Sun and the object differ by 180 degrees, so the Sun is in opposition to the object. When an object is at its maximum possible angular separation from the Sun (no matter if it is a planet or a star), it culminates roughly at midnight, and on the darkest possible area of the Sky at that declination. Hence, that is the 'best' night to observe a particular object.

Nights with source above horizon The program computes the range of dates when the celestial object is above the horizon at least during one moment of the night. By 'night', the program considers the time span when the Sun altitude is below that of the twilight (which can be set by the user; see above). When the objects are fixed on the sky (or are exterior planets), the range of observable epochs for the current year can have two possible forms: either a range from one date to another (e.g., 20 Jan to 15 Sep) or in two steps (from 1 Jan to a given date and from another date to 31 Dec). In the first case, the first date (20 Jan in our example) shall be close to the so-called 'Heliacal rise of a star' and the second date (15 Sep in our example) shall be close to the 'Heliacal set'. In the second case (e.g., a range in the form 1 Jan to 20 May and 21 Sep to 31 Dec), the first date (20 May in our example) would be close to the Heliacal set and the second one (21 Sep in our example) to the Heliacal rise. More exact equations to estimate the Heliacal rise/set of stars and planets (which will not depend on the

mere input of a twilight Sun elevation by the user) will be implemented in future versions of this plugin.

Full Moon When the Moon is selected, the program can compute the exact closest dates of the Moon's opposition to the Sun.
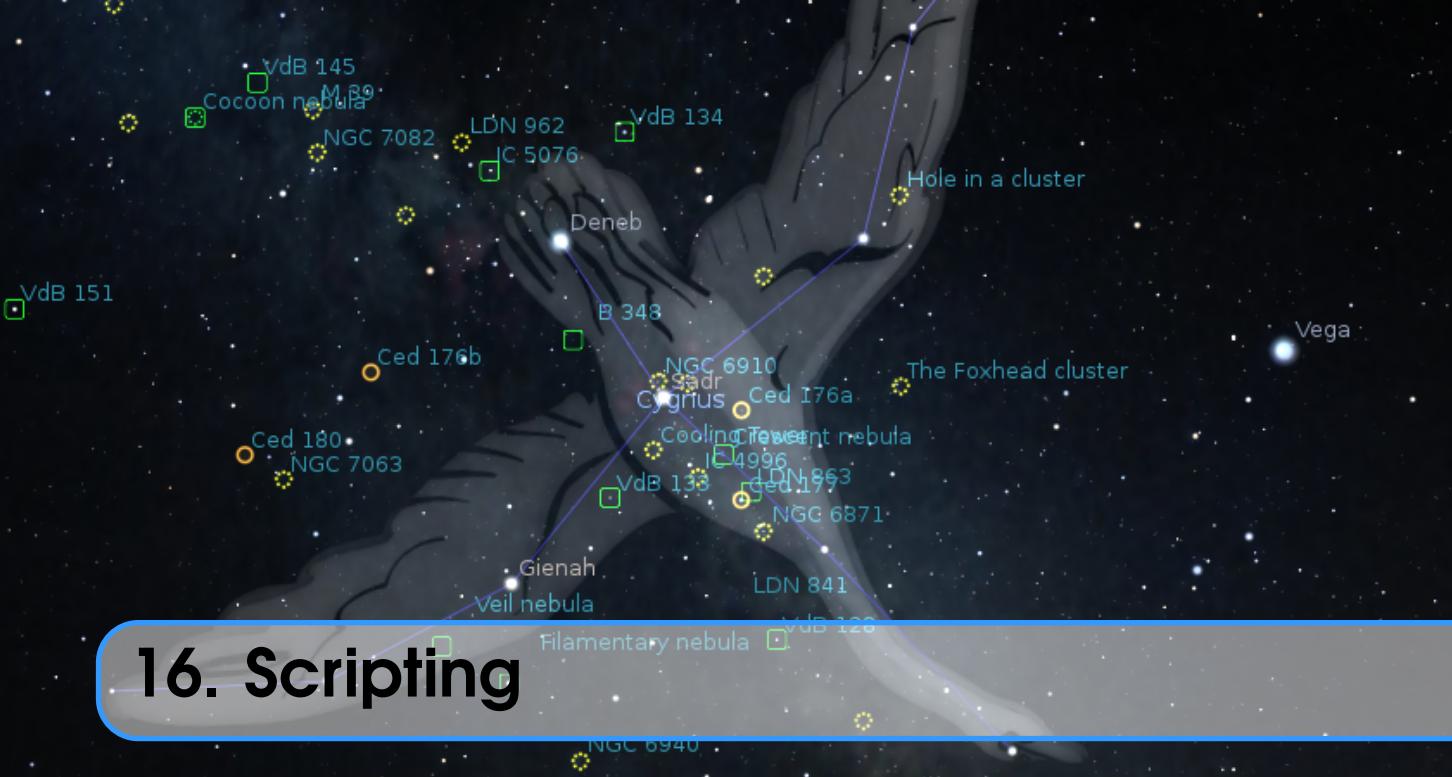
Note on Terminology

The (sparse) literature on terminology about computing these Heliacal, Acronychal or Cosmic events seems to disagree on which end of the night is to be computed. While all agree about Heliacal rises taking place in the morning, Acronychal and Cosmic are sometimes applied in reverse order from those described here. In case you use these data, make sure you keep this definition as well.

Author

This plugin has been contributed by Ivan Marti-Vidal (Onsala Space Observatory)[17] with some advice by Alexander Wolf and Georg Zotti.

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[17]`mailto:i.martividal@gmail.com`

16. Scripting

ALEXANDER WOLF, WITH ADDITIONS BY WOLFGANG LAUN

16.1 Introduction

The development of a powerful scripting system has been continuing for a number of years now and can now be called operational. The use of a script was recognised as a perfect way of arranging a display of a sequence of astronomical events from the earliest versions of Stellarium and a simple system called *Stratoscript* was implemented. The scripting facility is Stellarium's version of a *Presentation*, a feature that may be used to run an astronomical or other presentation for instruction or entertainment from within the Stellarium program. The original *Stratoscript* was quite limited in what it could do so a new Stellarium Scripting System has been developed.

Since version 0.10.1, Stellarium has included a scripting feature based on the Qt Scripting Engine[1]. This makes it possible to write small programs within Stellarium to produce automatic presentations, set up custom configurations, and to automate repetitive tasks.

As of version 0.14.0 a new scripting engine has reached a level where it has all required features for usage, however new commands may be added from time to time. Since version 0.14.0 support of scripts for the *Stratoscript* engine has been discontinued.

The programming language ECMAscript[2] (also known as JavaScript) gives users access to all basic ECMAScript language features such as flow control, variables, string manipulation and so on.

Interaction with Stellarium-specific features is done via a collection of objects which represent components of Stellarium itself. The various modules of Stellarium, and also activated plugins, can be called in scripts to calculate, move the scene, switch on and off display of objects, etc. You can write text output into text files with the `output()` command. You can call all public slots which are documented in the scripting API documentation[3].

---

[1]`http://doc.qt.io/qt-5/qtscript-index.html`
[2]`https://en.wikipedia.org/wiki/ECMAScript`
[3]`http://www.stellarium.org/doc/0.20/scripting.html`

16.2   The Script Console

It is possible to load, edit, run and save scripts using the script console window. To toggle the script console, press `F12`.

16.2.1   The Tabs in the Console

The three tabs "Script", "Log" and "Output" each provide a text field. In the "Script" text field you can edit a script, which can be loaded from and saved to a file, and executed. The "Log" text field receives all errors and other messages resulting from the script's execution; the "Output" text field will show the results of `core.output()` function calls.

16.2.2   The Menu Bar

The menu bar contains buttons for loading and saving a script. A file dialog is shown for selecting the file. The "clear" button lets you clear the contents of the text field in the currently selected tab. The drop-down menu "Execute:" offers a selection of menu entries, mainly intended to let you restore the sky to a clean state. The entry "selected text as script" executes selected text in the "Script" text field. Entries "remove screen text", "remove screen images" and "remove screen markers" remove labels, images and markers, respectively, that may have been shown on the screen. Each of the "clear map" entries results in a call to `core.clear()`, using one of the arguments "natural", "starchart", "deepspace", "galactic" or "supergalactic". These calls reset Stellarium's state, resulting in a basic state of the display and providing a clean starting point for another run of your script.

The button SSC runs the Stellarium Script Preprocessor with the script in the text field as input and produces an output by recursively inserting all included scripts into the text. *This output replaces the contents of the Script text field.*

16.2.3   German Keyboards

There is a glitch in the keyboard module of the underlying system that is responsible for keyboard handling. It affects users of Windows and Linux systems with a German, and probably also other international keyboards: The key combinations `AltGr`+`8` and `AltGr`+`9` cannot be used for typing [and]. You need to work around by copy-pasting these two characters.

16.3   Includes

Stellarium provides a mechanism for splitting scripts into different files. Typical functions or lists of variables can be stored in separate `.inc` files and used within other scripts through the **include()** command:

```
include("common_objects.inc");
```

16.4   Minimal Scripts

This script prints "Hello Universe" in the Script Console log window and into `log.txt`:

```
core.debug("Hello Universe");
```

This script prints "Hello Universe" in the Script Console output window and into the file `output.txt` which you will also find in the user data directory. The absolute path to the file will also be given in `log.txt`.

```
core.output("Hello Universe");
```

Figure 16.1: Retrograde motion of Mars in 2005. (Credit & Copyright: Tunc Tezel — APOD: 2006 April 22 – Z is for Mars.)

The file `output.txt` will be rewritten on each run of Stellarium. In case you need to save a copy of the current output file to another file, call

```
core.saveOutputAs("myImportantData.txt");
core.resetOutput();
```

This script uses the LabelMgr module to display "Hello Universe" in red, fontsize 20, on the screen for 3 seconds.

```
var label=LabelMgr.labelScreen("Hello Universe", 200, 200,
                                true, 20, "#ff0000");
core.wait(3);
LabelMgr.deleteLabel(label);
```

16.5 Example: Retrograde motion of Mars

A good way begin writing of scripts: set yourself a specific goal and try to achieve it with the help of few simple steps. Any complex script can be split into simple parts or tasks, which may solve any newbie problems in scripting.

Let me explain it with examples.

Imagine that you have set a goal to make a demonstration of a very beautiful, but longish phenomenon — the retrograde motion of the planet Mars (Fig. 16.1).

16.5.1 Script header

Any "complex" script should contain a few lines in the first part of the file, which contains important data for humans — the name of the script and its description — and some rules for Stellarium.

You can even assign default shortcuts in the script header, but make sure you assign a key not used elsewhere! The description may cover several lines (until the end of the commented header) and should therefore be the last entry of the header.

```
//
// Name: Retrograde motion of Mars
// Author: John Doe
// License: Public Domain
// Version: 1.0
// Shortcut: Ctrl+M
// Description: A demo of retrograde motion of Mars.
//
```

16.5.2 A body of script

At the first stage of writing of the script for a demo of retrograde motion of Mars we should set some limits for our demo. For example we want to see motion of Mars every day during 250 days since October 1st, 2009. Choosing a value of field of view and of the coordinates of the center of the screen should be done at the this stage also.

Let's add few lines of code into the script after the header and run it:

```
core.setDate("2009-10-01T10:00:00");
core.moveToRaDec("08h44m41s", "+18d09m13s",1);
StelMovementMgr.zoomTo(40, 1);
for (i=0; i<250; i++)
{
    core.setDate("+ 1 days");
    core.wait(0.2);
}
```

OK, Stellarium is doing something, but what exactly is it doing? The ground and atmosphere is enabled and any motion of Mars is invisible. Let's add an another few lines into the script (hiding the landscape and atmosphere) after setting date and time:

```
LandscapeMgr.setFlagLandscape(false);
LandscapeMgr.setFlagAtmosphere(false);
```

The whole sky is moving now — let's lock it! Add this line after previous lines:

```
StelMovementMgr.setFlagLockEquPos(true);
```

It looks better now, but what about cardinal points, elements of GUI and some "glitch of movement"? Let's change the script:

```
core.setDate("2009-10-01T10:00:00");
LandscapeMgr.setFlagCardinalsPoints(false);
LandscapeMgr.setFlagLandscape(false);
LandscapeMgr.setFlagAtmosphere(false);
core.setGuiVisible(false);
core.moveToRaDec("08h44m41s", "+18d09m13s",1);
StelMovementMgr.setFlagLockEquPos(true);
StelMovementMgr.zoomTo(40, 1);
core.wait(2);
for (i=0; i<250; i++)
```

```
{
        core.setDate("+ 1 days");
        core.wait(0.2);
}
core.setGuiVisible(true);
```

It's better, but let's draw the "path" of Mars! Add those line before the loop:

```
core.selectObjectByName("Mars", false);
SolarSystem.setFlagIsolatedTrails(true);
SolarSystem.setFlagTrails(true);
```

Hmm... let's add a few strings with info for users (insert those lines after the header):

```
var color = "#ff9900";
var info = LabelMgr.labelScreen("A motion of Mars", 20, 20,
            false, 24, color);
var apx = LabelMgr.labelScreen("Setup best viewing angle, FOV
            and date/time.", 20, 50, false, 18, color);
LabelMgr.setLabelShow(info, true);
LabelMgr.setLabelShow(apx, true);
core.wait(2);
LabelMgr.setLabelShow(apx, false);
```

Let's add some improvements to display info for users — change in the loop:

```
var label = LabelMgr.labelObject("  Normal motion, West to
            East", "Mars", true, 16, color, "SE");
for (i=0; i<250; i++)
{
        core.setDate("+ 1 days");
        if ((i % 10) == 0)
        {
                var strDate = "Day " + i;
                LabelMgr.setLabelShow(apx, false);
                var apx = LabelMgr.labelScreen(strDate, 20,
                                50, false, 16, color);
                LabelMgr.setLabelShow(apx, true);
        }
        if (i == 75)
        {
                LabelMgr.deleteLabel(label);
                label = LabelMgr.labelObject("  Retrograde or
                        opposite motion begins", "Mars",
                        true, 16, color, "SE");
                core.wait(2);
                LabelMgr.deleteLabel(label);
                label = LabelMgr.labelObject("  Retrograde
                        motion", "Mars", true, 16, color,
                        "SE");
        }
        if (i == 160)
        {
```

```
                LabelMgr.deleteLabel(label);
                label = LabelMgr.labelObject("  Normal motion
                        returns", "Mars", true, 16, color,
                        "SE");
                core.wait(2);
                LabelMgr.deleteLabel(label);
                label = LabelMgr.labelObject("  Normal motion",
                        "Mars", true, 16, color, "SE");
        }
        core.wait(0.2);
}
```
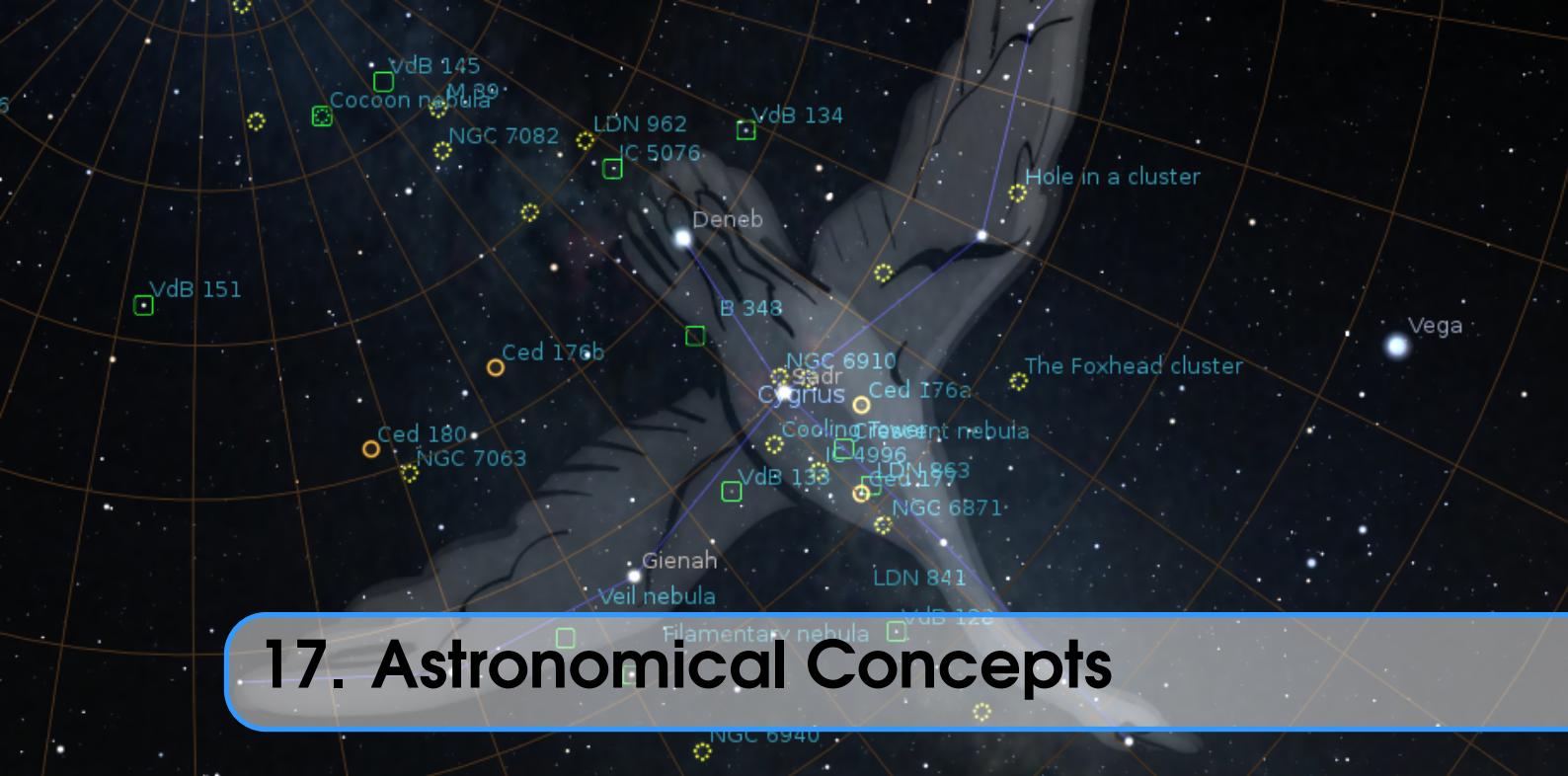
16.6 More Examples

The best source of examples is the `scripts` sub-directory of the main Stellarium source tree. This directory contains a sub-directory called `tests` which are not installed with Stellarium, but are nonetheless useful sources of example code for various scripting features.

IV

Practical Astronomy

17. Astronomical Concepts

Barry Gerdes, with additions by Georg Zotti

This section includes some general notes on astronomy in an effort to outline some concepts that are helpful to understand features of Stellarium. Material here is only an overview, and the reader is encouraged to get hold of a couple of good books on the subject. A good place to start is a compact guide and ephemeris such as the *National Audubon Society Field Guide to the Night Sky*[1]. Also recommended is a more complete textbook such as *Universe*. There are also some nice resources on the net, like the *Wikibooks Astronomy book*[2].

17.1 The Celestial Sphere

The *Celestial Sphere* is a concept which helps us think about the positions of objects in the sky. Looking up at the sky, you might imagine that it is a huge dome or top half of a sphere, and the stars are points of light on that sphere. Visualising the sky in such a manner, it appears that the sphere moves, taking all the stars with it — it seems to rotate. Watching the movement of the stars we can see that they seem to rotate around a static point about once a day. Stellarium is the perfect tool to demonstrate this!

1. Open the location dialog (F6). Set the location to be somewhere in mid-Northern latitudes. (Just click on the map to select a location, or fine-tune with the settings.) The United Kingdom is an ideal location for this demonstration.
2. Turn off atmospheric rendering A and ensure cardinal points are turned on (Q). This will keep the sky dark so the Sun doesn't prevent us from seeing the motion of the stars when it is above the horizon.
3. Pan round to point North, and make sure the field of view is about 90°.
4. Pan up so the 'N' cardinal point on the horizon is at the bottom of the screen.

---

[1] http://www.amazon.com/National-Audubon-Society-Field-Series/dp/0679408525
[2] http://en.wikibooks.org/wiki/Subject:Astronomy

5. Now increase the time rate. Press $\boxed{\text{K}}$, $\boxed{\text{L}}$, $\boxed{\text{L}}$, $\boxed{\text{L}}$, $\boxed{\text{L}}$ – this should set the time rate so the stars can be seen to rotate around a point in the sky about once every ten seconds. If you watch Stellarium's clock you'll see this is the time it takes for one day to pass at this accelerated rate.

The point which the stars appear to move around is one of the *Celestial Poles*.

The apparent movement of the stars is due to the rotation of the Earth. Our location as the observer on the surface of the Earth affects how we perceive the motion of the stars. To an observer standing at Earth's North Pole, the stars all seem to rotate around the *zenith* (the point directly upward). As the observer moves South towards the *equator*, the location of the celestial pole moves down towards the horizon. At the Earth's equator, the North celestial pole appears to be on the Northern horizon.

Similarly, observers in the Southern hemisphere see the Southern celestial pole at the zenith when they are at the South pole, and it moves to the horizon as the observer travels towards the equator.

1. Leave time moving on nice and fast, and open the configuration window. Go to the location tab and click on the map right at the top – i.e., set your location to the North pole. See how the stars rotate parallel to the horizon, around a point right at the top of the screen. With the field of view set to 90° and the horizon at the bottom of the screen, the top of the screen is the zenith.
2. Now click on the map again, this time a little further South. You should see the positions of the stars jump, and the centre of rotation has moved a little further down the screen.
3. Click on the map even further towards and equator. You should see the centre of rotation having moved down again.

To help with the visualisation of the celestial sphere, turn on the equatorial grid by clicking the button on the main tool-bar or pressing the $\boxed{\text{E}}$ key. Now you can see grid lines drawn on the sky. These lines are like lines of longitude and latitude on the Earth, but drawn for the celestial sphere.

The *Celestial Equator* is the line around the celestial sphere that is half way between the celestial poles – just as the Earth's equator is the line half way between the Earth's poles.

17.2 Coordinate Systems

17.2.1 Altitude/Azimuth Coordinates

The *Horizontal Coordinate System* (also called Altitude/Azimuth coordinate system) can be used to describe a direction of view (the *azimuth* angle) and an angular height in the sky (the *altitude* angle). The azimuth angle is measured clockwise round from due North[3]. Hence North itself is 0°, East 90°, Southwest is 225° and so on. The altitude angle is measured up from the *mathematical horizon*, which is just halfway between "straight up" and "straight down", without regard to the landscape. Looking directly up (at the *zenith*) would be 90°, half way between the zenith and the horizon is 45° and so on. The point opposite the zenith is called the *nadir*.

The Altitude/Azimuth coordinate system is attractive in that it is intuitive – most people are familiar with azimuth angles from bearings in the context of navigation, and the altitude angle is something most people can visualise pretty easily.

However, the altitude/azimuth coordinate system is not suitable for describing the general position of stars and other objects in the sky – the altitude and azimuth values for a celestial object change with time and the location of the observer.

---

[3]In some textbooks azimuth is counted from south. There is no global authority to decide upon this issue, just be aware of this when you compare numbers with other sources.
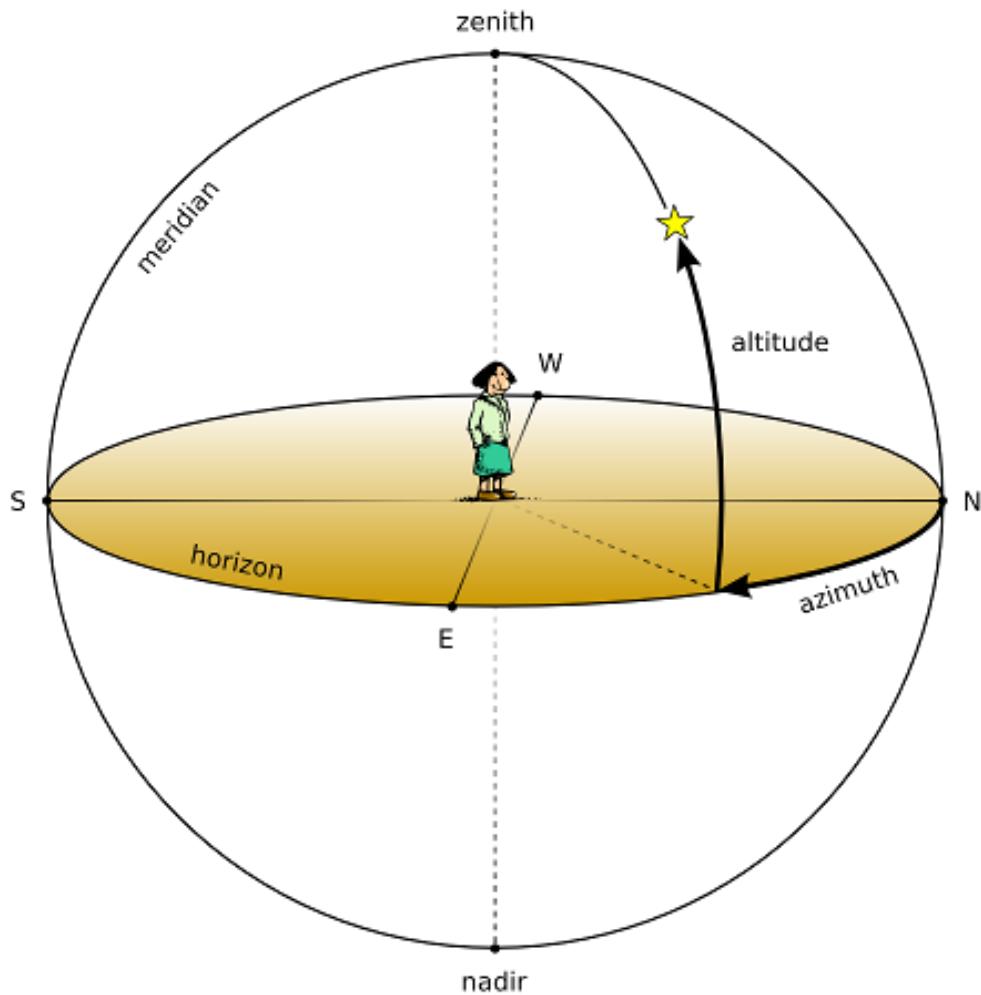
Figure 17.1: Altitude/Azimuth (Horizontal) Coordinate System

Stellarium can draw grid lines for altitude/azimuth coordinates. Use the ⊕ button on the main tool-bar to activate this grid, or press the ⎡Z⎤ key.

In addition, the *cardinal points* can be highlighted using the ✛ button or ⎡Q⎤ key.

There are a few great circles with special names which Stellarium can draw (see section 4.4.4).

Meridian This is the vertical line which runs from the North point towards the zenith and further to the South point.

(Mathematical) Horizon This is the line exactly 90° away from the zenith.

First Vertical This is the vertical line which runs from the East point towards the zenith and further to the West point.

17.2.2 Right Ascension/Declination Coordinates

Like the Altitude/Azimuth system, the *Right Ascension/Declination* (RA/Dec) Coordinate System (or *Equatorial Coordinate System*) uses two angles to describe positions in the sky. These angles are measured from standard points on the celestial sphere. *Right ascension* α and *declination* δ are
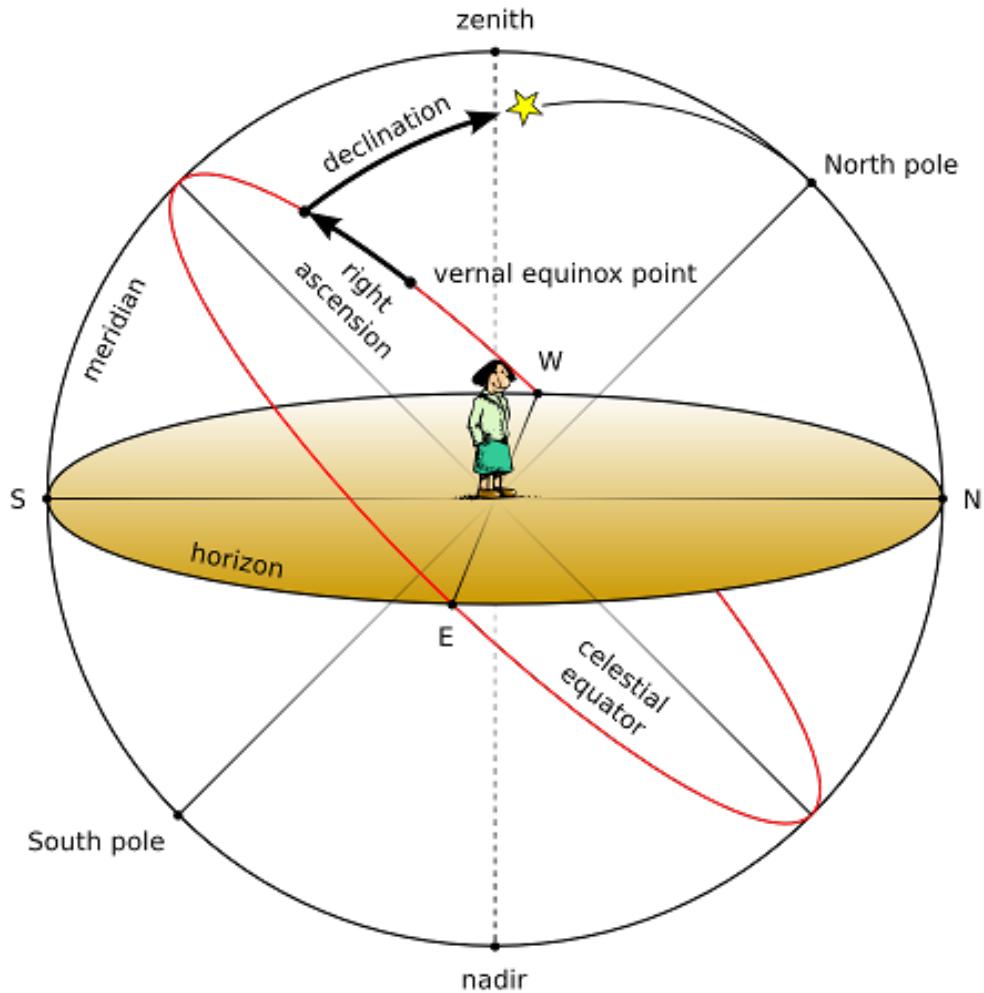
Figure 17.2: Equatorial Coordinates

to the celestial sphere what longitude and latitude are to terrestrial map makers.

The Northern celestial pole has a declination of $\delta = 90°$, the celestial equator has a declination of $\delta = 0°$, and the Southern celestial pole has a declination of $\delta = -90°$.

Right ascension is measured as an angle round from a point in the sky known as the *First Point of Aries*, in the same way that longitude is measured around the Earth from Greenwich. Figure 17.2 illustrates RA/Dec coordinates. The angle α is usually expressed as time with minute and seconds, with $15°$ equalling one hour.

Unlike Altitude/Azimuth coordinates, RA/Dec coordinates of a star do not change if the observer changes latitude, and do not change noticeably over the course of the day due to the rotation of the Earth. RA/Dec coordinates are generally used nowadays in star catalogues such as the Hipparcos catalogue.

However, the story is complicated a little by *precession* (section 17.8) and *parallax* (section 17.9). Precession causes a slow drift of the coordinates almost parallel to the *ecliptic*, and therefore star catalogues always have to specify their *equinox* of validity. Current catalogs and

atlases use coordinates for J2000.0.

Stellarium can draw grid lines for Equatorial coordinates. Use the button ⊕ on the main tool-bar to activate this grid, or press the ⎡E⎤ key to draw the equatorial grid for the simulation time. The Markings dialog (4.4.4) allows you to set also the grid for J2000.0 standard coordinates.

In case you are observing from another celestial object, the equatorial coordinates use a system similar to the one referring to the earth-based coordinates, but parallel to the planet's rotational axis.

There are again a few great circles with special names which Stellarium can draw in addition, both for simulation time and for J2000.0 (see section 4.4.4).

Celestial Equator the line directly above the earth's (or more generally, the observer's planet's) equator.

Colures These are lines similar to meridian and first vertical in the azimuthal system. The *Equinoctial Colure* runs from the North Celestial Pole NCP through the First Point of Aries ♈, South Celstial Pole SCP and First Point of Libra ♎ while the *Solstitial Colure* runs from the NCP through *First Point of Cancer* ♋, SCP and *First Point of Capricorn* ♑.

17.2.3 Ecliptical Coordinates

The earth's orbit around the sun, i.e., the *ecliptic*, defines the "equatorial line" of this coordinate system, which is traditionally used when computing the coordinates for planets.

The zero point of *ecliptical longitude* λ is the same as for equatorial coordinates, and the *ecliptical latitude* β is counted positive towards the *Northern Ecliptical Pole* NEP in the constellation of Draco.

Moon and sun (and to a much lesser extent, the other planets) pull on the equatorial bulge and try to put Earth's axis normal to its orbital plane. Earth acts like a spinning top and evades this pull in a sideways motion, so that earth's axis seems to describe a small circle over a period of almost 26.000 years (see section 17.8).

In addition, ecliptic obliquity against the equatorial coordinates, which mirrors the earth's axial tilt, slowly changes.

Therefore, also for ecliptical coordinates is is required to specify which date the coordinates refer to. Stellarium can draw two grids for Ecliptical coordinates. Use the ⎡,⎤ key to draw the *ecliptic* for the simulation time. The Markings dialog (4.4.4) allows you to show also a line for epoch J2000.0 and grids for the ecliptical coordinates for current epoch and epoch J2000.0. You can assign your own shortcut keys (section 4.8) if you frequently operate with these coordinates.

Since version 0.14.0 Stellarium can very accurately show the motions between the coordinate systems (Vondrák, Capitaine, and Wallace, 2011; Vondrák, Capitaine, and Wallace, 2012), and it is quite interesting to follow these motions for several millennia. To support such demonstrations, Stellarium can also draw the *precession circles* between celestial and ecliptical poles (activate them in the Markings dialog (4.4.4). If you observe long enough, you will see that these circles vary in size, reflecting the changes in ecliptic *obliquity*.

Many of the minor bodies are best observed around the times of their opposition. Stellarium can display a great circle in the ecliptical coordinates which runs through the ecliptic poles and through the sun, thereby allowing to estimate opposition and conjunction. Activate display of this *Opposition/Conjunction Line* in the Markings dialog (Labeled "O./C. longitude"; 4.4.4).

It is interesting to note that star catalogs before TYCHO BRAHE's (1546–1601), most notably the one in PTOLEMY's *Almagest*, used Ecliptical coordinates. The reason is simple: It was known since HIPPARCHUS that stellar coordinates slowly move along the ecliptic through *precession*, and the correction to coordinates of a date of interest was a simple addition of a linear correction to the ecliptical longitude in the catalog. Changes of ecliptic obliquity was discovered much later.

17.2.4 Galactic Coordinates

The Milky Way appears to run along a great circle over the sky, mirroring the fact that the sun is a star in it. Coordinates for non-stellar objects which belong to the Milky Way like *pulsars* or *planetary nebulae* are often mapped in *Galactic Coordinates*, where *galactic longitude l* and *galactic latitude b* are usually given in decimal degrees. Here, the zero point of galactic longitudes lies in the Galactic Center.

Stellarium can also draw a galactic grid and the galactic equator by activating the respective options in the Markings dialog (see section 4.4.4). You can assign a keyboard shortcut if you frequently use these coordinates (see 4.8).

17.3 Distance

As DOUGLAS ADAMS (1952–2001) pointed out in *The Hitchhiker's Guide to the Galaxy* (Adams, 1981),

> Space [...] is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space.[p.76]

Astronomers use a variety of units for distance that make sense in the context of the mind-boggling vastness of space.

Astronomical Unit (AU) This is the mean Earth-Sun distance. Roughly 150 million kilometres (1.49598×10^8 km). The AU is used mainly when discussing the solar system – for example the distance of various planets from the Sun.

Light year (LY) A light year is not, as some people believe, a measure of time. It is the distance that light travels in a year. The speed of light being approximately 300,000 kilometres per second means a light year is a very large distance indeed, working out at about 9.5 trillion kilometres (9.46073×10^{12} km). Light years are most frequently used when describing the distance of stars and galaxies or the sizes of large-scale objects like galaxies, nebulae etc.

Parsec (pc) A parsec is defined as the distance of an object that has an annual parallax of 1 second of arc. This equates to 3.26156 light years (3.08568×10^{13} km). Parsecs (and derivatives: kiloparsec kpc, megaparsec Mpc) are most frequently used when describing the distance of stars or the sizes of large-scale objects like galaxies, nebulae etc.

17.4 Time

The length of a day is defined as the amount of time that it takes for the Sun to travel from the highest point in the sky at mid-day to the next high-point on the next day. In astronomy this is called a *solar day*. The apparent motion of the Sun is caused by the rotation of the Earth. However, in this time, the Earth not only spins, it also moves slightly round its orbit. Thus in one solar day the Earth does not spin exactly 360° on its axis. Another way to measure day length is to consider how long it takes for the Earth to rotate exactly 360°. This is known as one *sidereal day*.

Figure 17.3 illustrates the motion of the Earth as seen looking down on the Earth orbiting the Sun. The red triangle on the Earth represents the location of an observer. The figure shows the Earth at four times:

1. The Sun is directly overhead - it is mid-day.
2. Twelve hours have passed since 1. The Earth has rotated round and the observer is on the opposite side of the Earth from the Sun. It is mid-night. The Earth has also moved round in its orbit a little.
3. The Earth has rotated exactly 360°. Exactly one sidereal day has passed since 1.
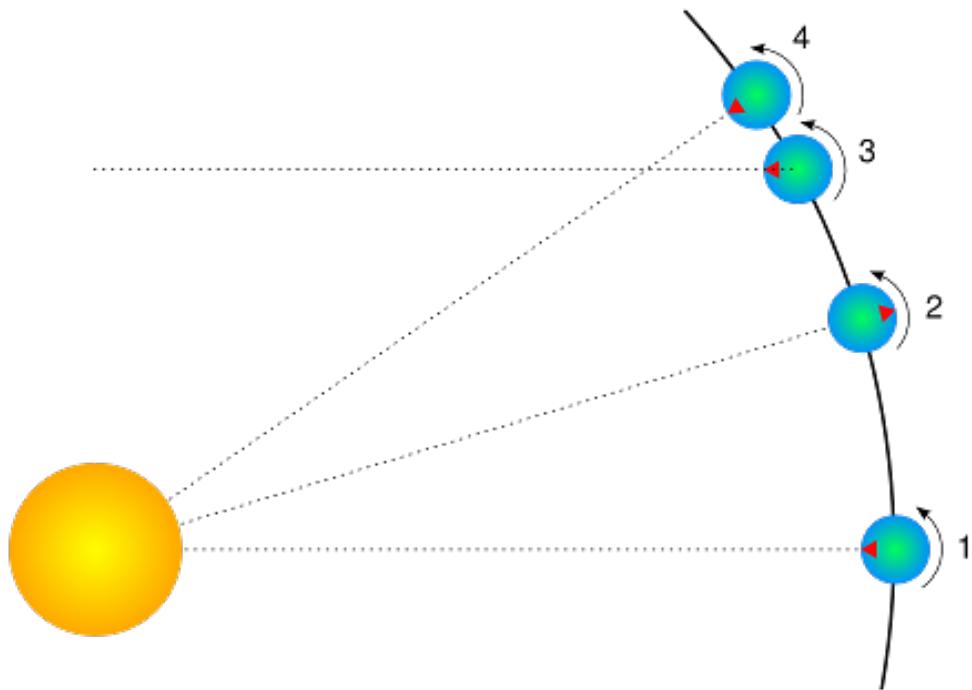
Figure 17.3: Sidereal day

4. It is mid-day again – exactly one solar day since 1. Note that the Earth has rotated more than 360° since 1.

It should be noted that in figure 17.3 the sizes of the Sun and Earth and not to scale. More importantly, the distance the Earth moves around its orbit is much exaggerated. The Earth takes a year to travel round the Sun – $365\frac{1}{4}$ solar days. The length of a sidereal day is about 23 hours, 56 minutes and 4 seconds.

17.4.1 Sidereal Time

It takes exactly one sidereal day for the celestial sphere to make one revolution in the sky. Astronomers find *sidereal time* useful when observing. This is the Right Ascension which is currently passing the meridian line. When visiting observatories, look out for doctored alarm clocks that have been set to run in sidereal time!

17.4.2 Julian Day Number

In the 19th century, astronomer JOHN HERSCHEL (1792–1871) introduced the use of *Julian Day* numbers (invented around the time of the Gregorian calendar reform). This is a simple continuous day count starting on January 1, -4712 (4713 BC). There are no years, months etc., and the integral day number switches at noon, so during a single night of observation (in Europe) the date never changes.

The fractional part of the number is just the fraction of day that has elapsed since last noon. Given that a day has 86400 seconds, we should give a JD with 5 decimal places to capture the nearest second.

This causes a problem for modern computers: even a "double precision float" can keep

only about 13 decimal places. More than 2.4 million days have passed, so that e.g. January 1, 2000, 12:00UT is 2451545.0, which is an accurately storable number with 7 decimal places, but 12:34:56UT is computed as 2451545.02426. A more accurate result would yield 2451545.024259259259... So, for a field where sub-second accuracy became crucial like spacecraft operations, the *Modified Julian Day* (MJD) has been introduced. It is simply

$$MJD = JD - 2400000.5. \tag{17.1}$$

This means, days start at midnight, and the (constant, in our era) decimal places of the "big numbers" at the begin of the number have been traded in for more decimal places at the end.

Don't put your expectations too high when you see MJD displayed (section 4.1): Stellarium uses a double-precision floating point number for JD for internal timekeeping, and Stellarium's display of MJD is simply computed from it. So you cannot set temporal increments smaller than a second, and it hardly would make sense to expect more accuracy from the simulation algorithms.

17.4.3 Delta T

Until around 1900, the earth's rotation was regarded as perfect standard of time. There were 86400 seconds per mean solar day, and the accuracy of reproducing time with mechanical clocks only in this time started to become as good as the earth's rotation itself.

Astronomers who computed solar eclipses reported in texts from antiquity wondered about a required time shift which they originally attributed to a yet-unknown "secular acceleration of the lunar motion". However, it turned out that indeed the gravitational effect of the moon which causes the tides also has effects on earth's rotation: the tides slowly break earth's rotational speed. The energy is also transferred to the moon, and the acceleration leads to the moon slowly moving away from the earth[4].

This led to the introduction of a time named Ephemeris Time (ET) with progresses in the speed of the second in the year 1900, to be used for positional computation in our solar system, in addition to Greenwich Mean Time (GMT), from which all zone times and "civil" clock times were derived.

The introduction of Atomic Clocks in the middle of the 20th century led to a redefinition of the (temporal) second, which has been de-coupled from earth's rotation. This time, the International Atomic Time TAI, is the basis for Terrestrial Time TT which can be considered as constantly progressing at constant speed[5], and is used for computation of the planetary positions.

Still, people living on earth prefer to have the mean solar noon governing the run of day and night. Therefore all forms of civil time are linked to Coordinated Universal Time UTC. Seconds in UTC and TAI are of equal length. The slow and irregular divergence between TAI and UTC is observed by a few standardisation institutes. When necessary, a leap second can be introduced to the UTC to bring the earth's rotation back in sync so that the Mean Sun again culminates at noon.

The difference $\Delta T = TT - UT$ (or "Delta T") describes the temporal offset which amounts already to more than a minute in the 21st century. There have been many attempts to properly model ΔT, and Stellarium offers several models you can choose from in the configuration dialog (see section 4.3.4). The default, "Espenak and Meeus (2006)", is a widely accepted standard. But if you are a researcher and want to experiment with alternative models, you will hopefully like this feature. you can even specify your own data for a, b, c, y and the secular term for lunar acceleration n

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[4]No need to worry, the moon recedes from the earth only a few centimeters per year as measured with the laser reflectors left by the Apollo astronauts in the 1970s. In a very far future, however, there will only be annular solar eclipses as a consequence!

[5]We don't discuss relativity here. The advanced reader is referred to the presentation in the Wikipedia, `https://en.wikipedia.org/wiki/Delta_T`.

(actually $\dot{n} = dn/dt$ in units of arcseconds/century^2) if you can model ΔT according to the formula

$$\Delta T = a + b \cdot u + c \cdot u^2 \text{ where} \tag{17.2}$$

$$u = \frac{\text{year} - y}{100} \tag{17.3}$$

List of ΔT models in Stellarium

The following list describes sources and a few details about the models for ΔT implemented in Stellarium.

Without correction. Correction is disabled. Use only if you know what you are doing!

Schoch (1931). This historical formula was obtained by Schoch (1931) and was also used in "A New Test of Einstein's Theory of Relativity by Ancient Solar Eclipses" (Henriksson, 2009). See for more in Peters (2010). $\dot{n} = -29.68''/\text{cy}^2$.

Clemence (1948). This empirical equation was published in "On the system of astronomical constants" (Clemence, 1948). Valid range of usage: between years 1681 and 1900. $\dot{n} = -22.44''/\text{cy}^2$.

IAU (1952). This formula is based on a study of post-1650 observations of the Sun, the Moon and the planets (Spencer Jones, 1939) and reproduced in *Astronomical Formulae for Calculators* (Meeus, 1988). It was also adopted in the PC program **SunTracker Pro**. Valid range of usage: between years 1681 and 1936. $\dot{n} = -22.44''/\text{cy}^2$.

Astronomical Ephemeris (1960). This is a slightly modified version of the IAU 1952 (Spencer Jones, 1939) formula which was adopted in the "Astronomical Ephemeris" (Wilkins, 1961) and in the *Canon of Solar Eclipses -2003 to +2526* (Mucke and Meeus, 1983). Valid range of usage: between years -500 and 2000. $\dot{n} = -22.44''/\text{cy}^2$.

Tuckerman (1962, 1964) & Goldstine (1973). The famous tables (Tuckerman, 1962; Tuckerman, 1964) list the positions of the Sun, the Moon and the planets at 5- and 10-day intervals from 601 BCE to 1649 CE. The same relation was also implicitly adopted in the syzygy tables of Goldstine (1973). Valid range of usage: between years -600 and 1649.

Muller & Stephenson (1975). This equation was published in "The accelerations of the earth and moon from early astronomical observations" (Muller and F. R. Stephenson, 1975). Valid range of usage: between years -1375 and 1975. $\dot{n} = -37.5''/\text{cy}^2$.

Stephenson (1978). This equation was published in "Pre-Telescopic Astronomical Observations" (F. R. Stephenson, 1978). $\dot{n} = -30.0''/\text{cy}^2$.

Schmadel & Zech (1979). This 12th-order polynomial equation (outdated and superseded by Schmadel and Zech (1988)) was published in "Polynomial approximations for the correction delta T E.T.-U.T. in the period 1800-1975" (Schmadel and Zech, 1979) as fit through data published by Brouwer (1952). Valid range of usage: between years 1800 and 1975, with meaningless values outside this range. $\dot{n} = -23.8946''/\text{cy}^2$.

Morrison & Stephenson (1982). This algorithm Morrison and F. R. Stephenson, 1982 was adopted in *Planetary Programs and Tables from –4000 to +2800* (Pierre Bretagnon and Simon, 1986) and in the PC planetarium program **RedShift**. Valid range of usage: between years -4000 and 2800. $\dot{n} = -26.0''/\text{cy}^2$.

Stephenson & Morrison (1984). This formula was published in "Long-term changes in the rotation of the earth - 700 B.C. to A.D. 1980" (F. R. Stephenson and Morrison, 1984). Valid range of usage: between years -391 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

Stephenson & Houlden (1986). This algorithm (Houlden and F. Stephenson, 1986) is used in the PC planetarium program **Guide 7**. Valid range of usage: between years -600 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

Espenak (1987, 1989). This algorithm was given in *Fifty Year Canon of Solar Eclipses: 1986 – 2035* (Espenak, 1987) and in *Fifty Year Canon of Lunar Eclipses: 1986 – 2035* (Espenak, 1989). Valid range of usage: between years 1950 and 2100.

Borkowski (1988). This formula was obtained by Borkowski (1988) from an analysis of 31 solar eclipse records dating between 2137 BCE and 1715 CE. Valid range of usage: between years -2136 and 1715. $\dot{n} = -23.895''/\text{cy}^2$.

Schmadel & Zech (1988). This 12th-order polynomial equation was published in "Empirical Transformations from U.T. to E.T. for the Period 1800-1988" (Schmadel and Zech, 1988) as data fit through values given by F. R. Stephenson and Morrison (1984). Valid range of usage: between years 1800 and 1988, with a mean error of less than one second, max. error 1.9s, and meaningless values outside this range. $\dot{n} = -26.0''/\text{cy}^2$.

Chapront-Touze & Chapront (1991). This formula was adopted by M. Chapront-Touze & J. Chapront in the shortened version of the ELP 2000-85 lunar theory in their *Lunar Tables and Programs from 4000 B.C. to A.D. 8000* (Chapront-Touzé and Chapront, 1991). The relations are based on those of F. R. Stephenson and Morrison (1984), but slightly modified to make them compatible with the tidal acceleration parameter of $\dot{n} = -23.8946''/\text{cy}^2$ adopted in the ELP 2000-85 lunar theory (Chapront-Touzé and Chapront, 1988a).

Stephenson & Morrison (1995). This equation was published in "Long-Term Fluctuations in the Earth's Rotation: 700 BC to AD 1990" (F. R. Stephenson and Morrison, 1995). Valid range of usage: between years -700 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

Stephenson (1997). F. R. Stephenson published this formula in his book *Historical Eclipses and Earth's Rotation* (F. Richard Stephenson, 1997). Valid range of usage: between years -500 and 1600. $\dot{n} = -26.0''/\text{cy}^2$.

Meeus (1998) (with Chapront, Chapront-Touze & Francou (1997)). From *Astronomical Algorithms* (Meeus, 1998), and widely used. Table for 1620..2000, and includes a variant of Chapront, Chapront-Touze & Francou (1997) for dates outside 1620..2000. Valid range of usage: between years -400 and 2150. $\dot{n} = -25.7376''/\text{cy}^2$.

JPL Horizons. The JPL Solar System Dynamics Group of the NASA Jet Propulsion Laboratory use this formula in their interactive website JPL Horizons[6]. Valid range of usage: between years -2999 and 1620, with zero values outside this range. $\dot{n} = -25.7376''/\text{cy}^2$.

Meeus & Simons (2000). This polynome was published in "Polynomial approximations to Delta T, 1620-2000 AD" (Meeus and Simons, 2000). Valid range of usage: between years 1620 and 2000, with zero values outside this range. $\dot{n} = -25.7376''/\text{cy}^2$.

Montenbruck & Pfleger (2000). The fourth edition of *Astronomy on the Personal Computer* (Montenbruck and Pfleger, 2000) provides simple 3rd-order polynomial data fits for the recent past. Valid range of usage: between years 1825 and 2005, with a typical 1-second accuracy and zero values outside this range.

Reingold & Dershowitz (2002, 2007, 2018). E. M. Reingold & N. Dershowitz present this polynomial data fit in *Calendrical Calculations: The Ultimate Edition* (Reingold and Dershowitz, 2018) and in their *Calendrical Calculations* (Reingold and Dershowitz, 2007), *Calendrical Tabulations 1900-2200* (Reingold and Dershowitz, 2002). It is based on *Astronomical Algorithms* (Meeus, 1991).

Morrison & Stephenson (2004, 2005). This important solution was published in "Historical values of the Earth's clock error ΔT and the calculation of eclipses" (Morrison and F. R. Stephenson, 2004) with addendum (Morrison and F. R. Stephenson, 2005). Valid range of usage: between years -1000 and 2000. $\dot{n} = -26.0''/\text{cy}^2$.

Stephenson, Morrison & Hohenkerk (2016). This important new solution was published in "Measurement of the Earth's rotation: 720 BC to AD 2015" (F. R. Stephenson, Morrison, and Hohenkerk, 2016). The solution combines a spline fit to observations (used between the given limits) with a parabolic fit (used as fallback outside the range, but without smooth transitions at the limits, i.e., values for 2016 and later deviate notably from current estimates,

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[6]http://ssd.jpl.nasa.gov/?horizons

and should not be used for dates after 2015). Recommended range of usage: between years
-720.0 and 2016.0 $\dot{n} = -25.82''/\text{cy}^2$.

Espenak & Meeus (2006). This solution[7] by F. Espenak and J. Meeus, based on Morrison and
F. R. Stephenson (2004) and a polynomial fit through tabulated values for 1600-2000, is
used for the NASA Eclipse Web Site[8] and in their *Five Millennium Canon of Solar Eclipses:
-1900 to +3000* (Espenak and Meeus, 2006). This formula is also used in the solar, lunar and
planetary ephemeris program **SOLEX**. Valid range of usage: between years -1999 and 3000.
$\dot{n} = -25.858''/\text{cy}^2$.

Reijs (2006). From the Length of Day (LOD; as determined by Morrison and F. R. Stephenson
(2004)), Victor Reijs derived a ΔT formula by using a Simplex optimisation with a cosine
and square function[9]. This is based on a possible periodicy described by Morrison and F. R.
Stephenson (2004). Valid range of usage: between years -1500 and 1100. $\dot{n} = -26.0''/\text{cy}^2$.

Banjevic (2006). This solution is based on F. R. Stephenson and Morrison (1984) and was
published in "Ancient eclipses and dating the fall of Babylon" (Banjevic, 2006). Valid
range of usage: between years -2020 and 1620, with zero values outside this range. $\dot{n} = -26.0''/\text{cy}^2$.

Islam, Sadiq & Qureshi (2008, 2013). This solution by S. Islam, M. Sadiq and M. S. Qureshi,
based on Meeus and Simons (2000), was published in "Error Minimization of Polynomial
Approximation of Delta T" (Islam, Sadiq, and Qureshi, 2008) and revisited by Sana Islam
in 2013. Valid range of usage: between years 1620 and 2007, with zero values outside this
range.

Khalid, Sultana & Zaidi (2014). This polynomial approximation with 0.6 seconds of accuracy
was published in "Delta T: Polynomial Approximation of Time Period 1620–2013" (Khalid,
Sultana, and Zaidi, 2014). Valid range of usage: between years 1620 and 2013, with zero
values outside this range.

Henriksson (2017). A solution which combines Schoch's 1931 solution (parabolic fit) with a
discussion of and correction for relativistic effects. The author claims an accurate fit for
Solar eclipses probably depicted in artefacts going back to the mid-fourth millennium
BC. Also with this setting, the exact times from his paper (Henriksson, 2017) cannot be
reproduced probably because the author used a different ephemeris, but the phenomena are
plausibly reproduced. Recommended range of usage: between years -4000.0 and 2000.0
$\dot{n} = -30.128''/\text{cy}^2$.

Custom equation of ΔT. This is the quadratic formula 17.2 for calculation of ΔT with coefficients
defined by the user.

17.5 Angles

Astronomers typically use degrees to measure angles. Since many observations require very precise
measurement, the degree is subdivided into sixty *minutes of arc* also known as *arc-minutes*. Each
minute of arc is further subdivided into sixty *seconds of arc*, or *arc-seconds*. Thus one degree is
equal to 3600 seconds of arc. Finer grades of precision are usually expressed using the SI prefixes
with arc-seconds, e.g. *milli arc-seconds* (one milli arc-second is one thousandth of an arc-second).

17.5.1 Notation

Degrees are denoted using the $°$ symbol after a number. Minutes of arc are denoted with a $'$, and
seconds of arc are denoted using $''$. Angles are frequently given in two formats:

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[7]This solution is used by default.
[8]http://eclipse.gsfc.nasa.gov/eclipse.html
[9]http://www.iol.ie/~geniet/eng/DeltaTeval.htm

1. DMS format — degrees, minutes and seconds. For example $90°15'12''$. When more precision is required, the seconds component may include a decimal part, for example $90°15'12.432''$.
2. Decimal degrees, for example $90.2533°$

17.5.2 Handy Angles

Being able to estimate angular distance can be very useful when trying to find objects from star maps in the sky. One way to do this with a device called a *crossbow*.

Crossbows are a nice way get an idea of angular distances, but carrying one about is a little cumbersome. A more convenient alternative is to hold up an object such as a pencil at arm's length. If you know the length of the pencil, d, and the distance of it from your eye, D, you can calculate its angular size, θ using this formula:

$$\theta = 2 \cdot \arctan\left(\frac{d}{2 \cdot D}\right) \tag{17.4}$$

Another, more handy (ahem!) method is to use the size of your hand at arm's length:

Tip of little finger About $1°$
Middle three fingers About $4°$
Across the knuckles of the fist About $10°$
Open hand About $18°$

Using you hand in this way is not very precise, but it's close enough to give you some way to translate an idea like "Mars will be $45°$ above the Southeastern horizon at 21:30". Of course, there is variation from person to person, but the variation is compensated for somewhat by the fact that people with long arms tend to have larger hands. In exercise 20.2 you will work out your own "handy angles".

17.6 The Magnitude Scale

When astronomers talk about magnitude, they are referring to the brightness of an object. How bright an object appears to be depends on how much light it is giving out and how far it is from the observer. Astronomers separate these factors by using two measures: *absolute magnitude* (Mag or *M*) which is a measure of how much light is being given out by an object, and *apparent magnitude* (mag or *m*) which is how bright something appears to be in the sky.

For example, consider two 100 watt lamps, one which is a few meters away, and one which is a kilometre away. Both give out the same amount of light – they have the same absolute magnitude. However the nearby lamp seems much brighter – it has a much greater apparent magnitude. When astronomers talk about magnitude without specifying whether they mean apparent or absolute magnitude, they are usually referring to apparent magnitude.

The magnitude scale has its roots in antiquity. The Greek astronomer HIPPARCHUS defined the brightest stars in the sky to be *first magnitude*, and the dimmest visible to the naked eye to be *sixth magnitude*. In the 19th century British astronomer NORMAN POGSON (1829–1891) quantified the scale more precisely, defining it as a logarithmic scale where a magnitude 1 object is 100 times as bright as a magnitude 6 object (a difference of five magnitudes). The zero-point of the modern scale was originally defined as the brightness of the star Vega, however this was re-defined more formally in 1982 (Aller et al., 1989). Objects brighter than Vega are given negative magnitudes.

The absolute magnitude of a star is defined as the magnitude a star would appear if it were 10 parsecs from the observer.

Table 17.1 lists several objects that may be seen in the sky, their apparent magnitude and their absolute magnitude where applicable (only stars have an absolute magnitude value. The planets and the Moon don't give out light like a star does – they reflect the light from the Sun).

Object	m	M
The Sun	-27	4.8
Vega	0.05	0.6
Betelgeuse	0.47	-7.2
Sirius (the brightest star)	-1.5	1.4
Venus (at brightest)	-4.4	—
Full Moon (at brightest)	-12.6	—

Table 17.1: Magnitudes of a few objects

17.7 Luminosity

Luminosity is an expression of the total energy radiated by a star. It may be measured in watts, however, astronomers tend to use another expression — *solar luminosities* where an object with twice the Sun's luminosity is considered to have two solar luminosities and so on. Luminosity is related to absolute magnitude.

17.8 Precession
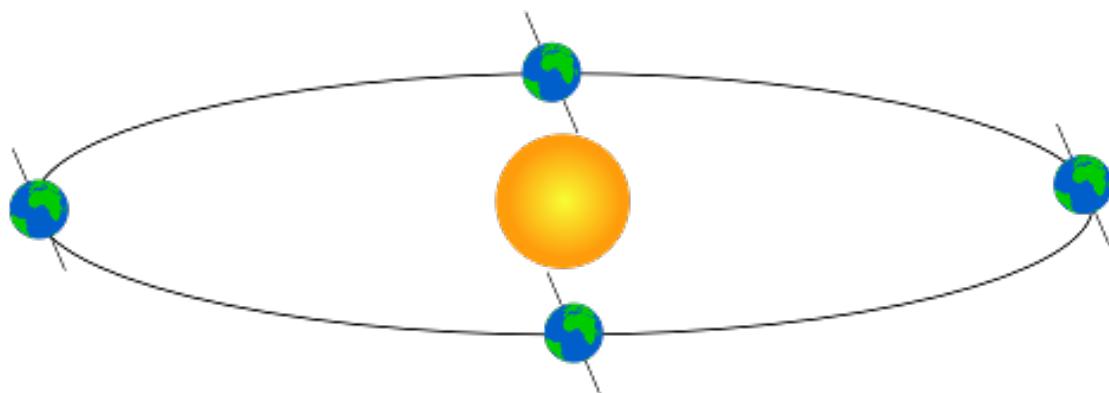
Figure 17.4: Ecliptic obliquity

As the Earth orbits the Sun throughout the year, the axis of rotation (the line running through the rotational poles of the Earth) seems to point towards the same position on the celestial sphere, as can be seen in figure 17.4. The angle between the axis of rotation and the perpendicular of the orbital plane is called the *obliquity of the ecliptic*. It is currently about $23°27'$ and is the angle between equatorial coordinates (17.2.2) and ecliptical coordinates (17.2.3).

Observed over very long periods of time the direction the axis of rotation points to does actually change. The angle between the axis of rotation and the orbital plane stays fairly constant, but the direction the axis points — the position of the celestial pole — transcribes a figure similar to a circle on the stars in the celestial sphere. The motion is similar to the way in which a gyroscope slowly twists, as figure 17.5 illustrates. This process is called *precession*. The circles can be shown in Stellarium: From the View menu (F4), tab "Markings", switch on "Precession Circles" (4.4.4).

Precession is a slow process. The axis of rotation twists through a full $360°$ about once every 26,000 years. However, over these long times other gravitational perturbations ("planetary precession") play a role, and what may be thought of as rigid "precession circle" can actually only show the instantaneous (current) state. Over millennia the circle slightly varies.
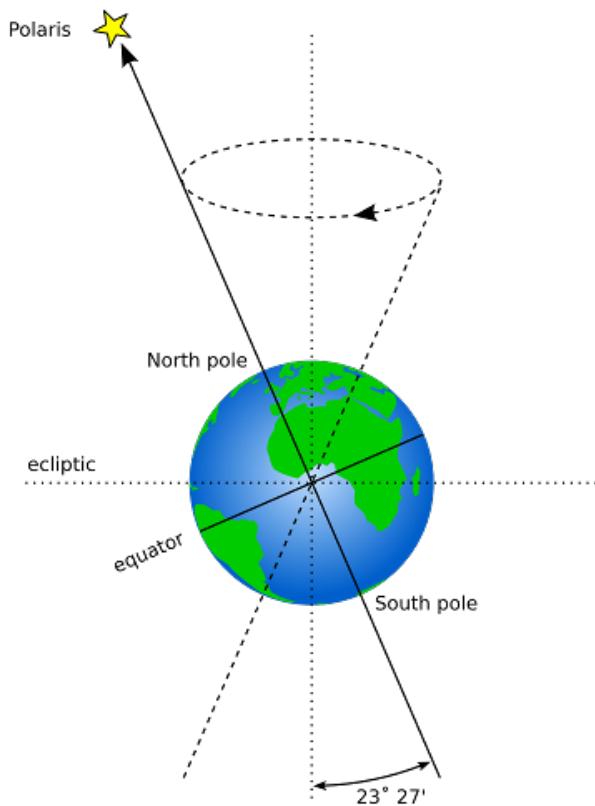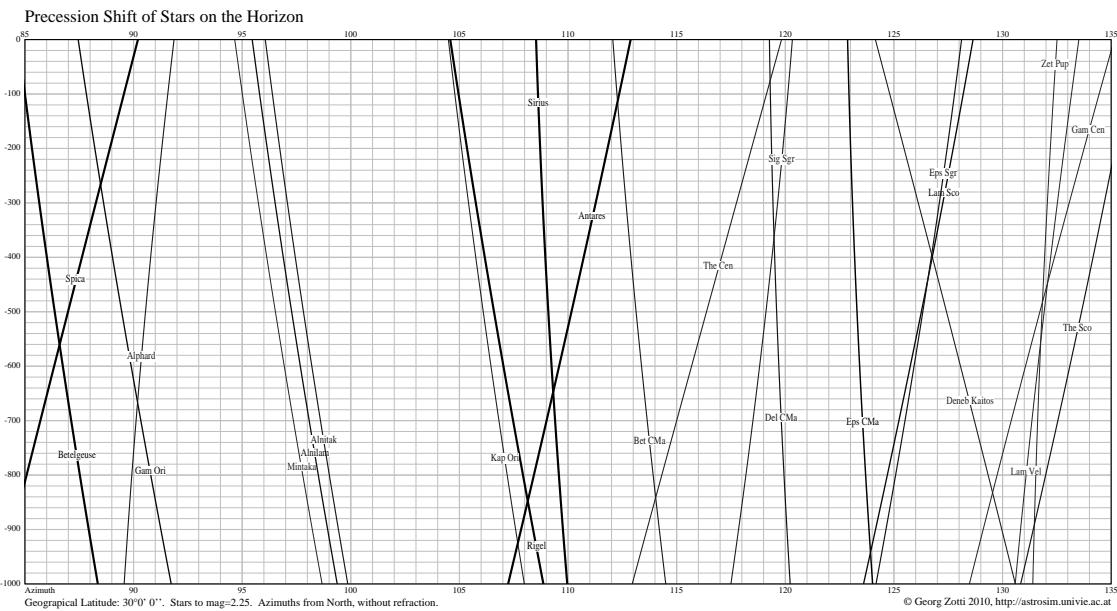
Figure 17.5: Precession

Figure 17.6: Precession: Change of rising positions of the stars along the eastern horizon from azimuths 85 to 135 degrees, between years 1000 BC and 0, for latitude $\varphi = 30°$.

Precession has some important implications:

1. RA/Dec coordinates change over time, albeit slowly. Measurements of the positions of stars recorded using RA/Dec coordinates must also include a date ("equinox") for those coordinates. Therefore the current star catalogues list their objects for the epoch and equinox J2000.0.

2. Polaris, the pole star, won't stay a good indicator of the location of the Northern celestial pole. In 14,000 years time Polaris will be nearly 47° away from the celestial pole!

3. The change in declination causes a shift in the rising and setting positions of the stars along the horizon. Figure 17.6 shows part of the horizon for latitude $\varphi = 30°$ North. For a given year (left vertical labels), make a horizontal line to find rising azimuth of the bright stars indicated by the twisting lines. Depending on where on the celestial sphere a star is located, it may appear to move north or south, or be almost stationary for several centuries.

17.9 Parallax

Parallax is the change of angular position of two stationary points relative to each other as seen by an observer, due to the motion of said observer. Or more simply put, it is the apparent shift of an object against a background due to a change in observer position.

This can be demonstrated by holding ones thumb up at arm's length. Closing one eye, note the position of the thumb against the background. After swapping which eye is open (without moving), the thumb appears to be in a different position against the background.

17.9.1 Geocentric and Topocentric Observations

When computing planetary positions was done manually by adding numbers tabulated in yearly almanacs, computing the Earth's position and, say, position of a minor planet was usually good enough to find the object in the sky. In both cases, the exact numbers refer to the gravitational centres of the respective bodies. However, we are sitting on Earth's surface, so the observed planet will be seen in a slightly shifted location. The amount for objects in the inner solar system is usually just a few arcseconds and is mostly negligible when we just want to find an object. But it makes a difference when it comes to observations of stellar occultations by planets or asteroids. Such a body may measure only a few tens of kilometres, and the shadow track which it leaves on Earth's surface is of approximately the same size.[10]

A much closer and bigger object is the Moon, which can also occult stars. It can even occult the one big star we call the Sun: this is a Solar Eclipse. And here it makes a huge difference where on the planet you are located.

If you are interested in astronomical computing, you may still be interested in geocentric numerical results. From the Settings panel (F2), tab "Tools", there is a checkbox for "Topocentric Coordinates". Switch it off to put yourself into the center of the planet you are located.

17.9.2 Stellar Parallax

A similar thing happens due to the Earth's motion around the Sun. Nearby stars appear to move against more distant background stars, as illustrated in figure 17.7. The movement of nearby stars against the background is called *stellar parallax*, or *annual parallax*.

Since we know the distance the radius of the Earth's orbit around the Sun from other methods, we can use simple geometry to calculate the distance of the nearby star if we measure annual parallax.

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[10]Unfortunately Stellarium (as of v0.15.0) is not accurate enough to reliably compute such occultations. Even a deviation of 0.5 arcseconds is too much here.
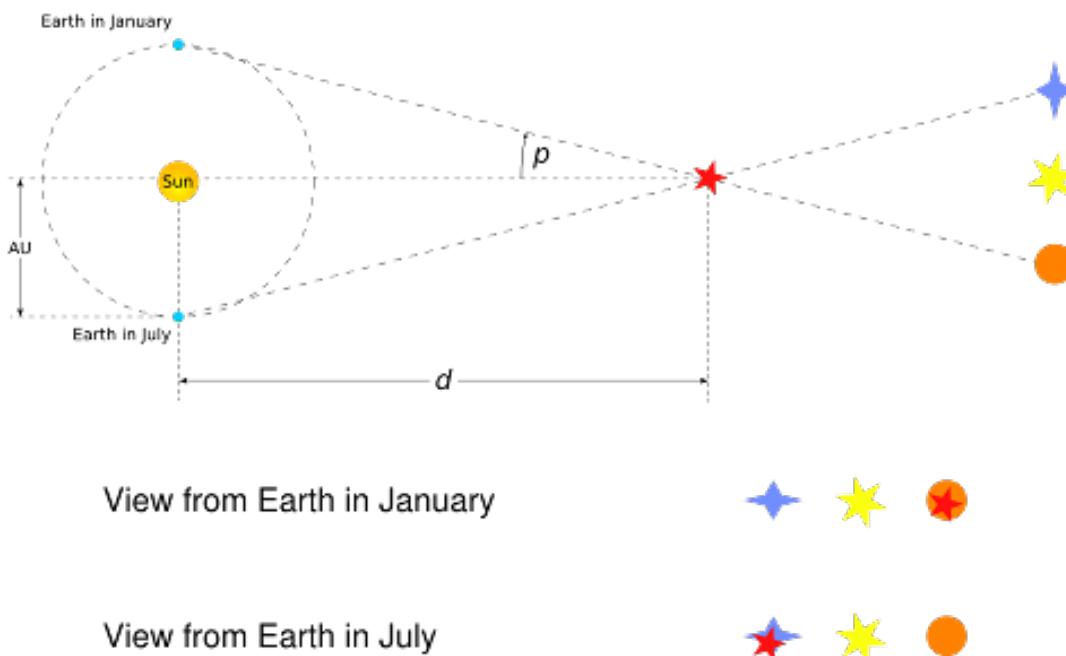
Figure 17.7: Stellar Parallax

As can be seen from figure 17.7, the annual parallax p is half the angular distance between the apparent positions of the nearby star. The distance of the nearby object is d. Astronomers use a unit of distance called the parsec (pc) which is defined as the distance at which a nearby star has $p = 1''$.

Even the nearest stars exhibit very small movement due to parallax. The closest star to the Earth other than the Sun is Proxima Centauri. It has an annual parallax of $0.77199''$, corresponding to a distance of 1.295 pc (4.22 light years).

Even with the most sensitive instruments for measuring the positions of the stars it is only possible to use parallax to determine the distance of stars up to about 1,600 light years from the Earth, after which the annual parallax is so small it cannot be measured accurately enough.

In Stellarium, the annual parallax can be listed in the object information for stars when available. It is not used for the positional calculations.

17.10 Proper Motion
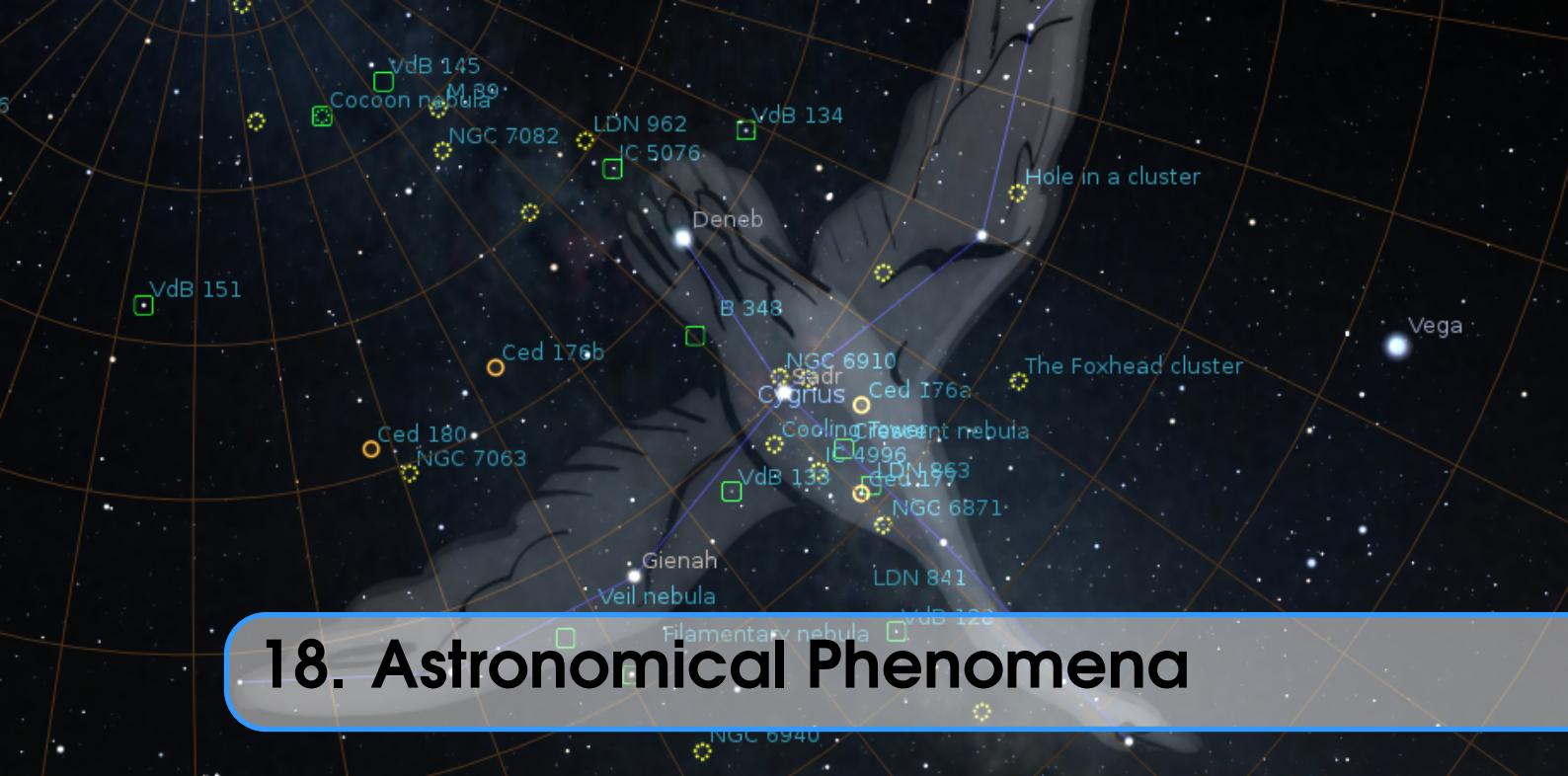
Proper motion is the change in the position of a star over time as a result of its motion through space relative to the Sun. It does not include the apparent shift in position of star due to annular parallax. The star exhibiting the greatest proper motion is *Barnard's Star* which moves more than ten seconds of arc per year.

If you want to simulate the effect of proper motion with Stellarium, put the map into equatorial view mode, switch off ground and cardinal marks, and set some high time lapse speed. You will see a few stars change their locations quite soon, those are usually stars in our galactic neighbourhood (see section 20.12).

Note however some limitations:

1. Stellarium will stop at ±100.000 years. This limit may be still suitable for most stellar locations. The planetary locations are not trustworthy outside of a much narrower temporal window (see section F). You cannot simulate the sky over the dinosaurs or such things.
2. Proper motion is only modelled by the linear components. True 3D motion in space requires

more computation, which would slow down the program.

3. Double stars are listed in catalogs as two individual stars with their current proper motion which consists of spatial motion and the orbital motion around their center of gravity. They may be seen flying apart, which is of course not realistic.

18. Astronomical Phenomena

BARRY GERDES, WITH ADDITIONS BY GEORG ZOTTI

This chapter focuses on the observational side of astronomy — what we see when we look at the sky.

18.1 The Sun

Without a doubt, the most prominent object in the sky is the Sun. The Sun is so bright that when it is in the sky, its light is scattered by the atmosphere to such an extent that almost all other objects in the sky are rendered invisible.

The Sun is a star like many others but it is much closer to the Earth at approximately 150 million kilometres (a distance also called 1 Astronomical Unit). The next nearest star, Proxima Centauri is approximately 260,000 times further away from us than the Sun! The Sun is also known by its Latin name, *Sol*.

Over the course of a year, the Sun appears to move round the celestial sphere in a great circle known as the *ecliptic*. Stellarium can draw the ecliptic on the sky. To toggle drawing of the ecliptic, press the , key.

WARNING: Looking at the Sun with even the smallest telescope or binoculars can permanently damage the eye. Never look at the Sun without using the proper filters attached to the front end (objective lens) of your instrument! Never use screw-in ocular filters, they may break in the heat and expose your eye to damaging amounts of energy. By far the safest way to observe the Sun is to look at it on a computer screen, courtesy of Stellarium!

18.2 Stars

The Sun is just one of billions of stars. Even though many stars have a much greater absolute magnitude than the Sun (they give out more light), they have an enormously smaller apparent magnitude due to their large distance. Stars have a variety of forms — different sizes, brightnesses,

temperatures, and colours. Measuring the position, distance and attributes of the stars is known as *astrometry*, and is a major part of observational astronomy.

18.2.1 Multiple Star Systems

Many stars have stellar companions. As many as six stars can be found orbiting one-another in close associations known as *multiple star systems — binary systems* being the most common with two stars. Multiple star systems are more common than solitary stars, putting our Sun in the minority group.

Sometimes multiple stars orbit each other in a way that means one will periodically eclipse the other. These are *eclipsing binaries* or *Algol variables*.

Optical Doubles & Optical Multiples

Sometimes two or more stars appear to be very close to one another in the sky, but in fact have great separation, being aligned from the point of view of the observer but of different distances. Such pairings are known as *optical doubles* and *optical multiples*.

18.2.2 Constellations

The constellations are groupings of stars that are visually close to one another in the sky. The actual groupings are fairly arbitrary — different cultures have grouped stars together into different constellations. In many cultures, the various constellations have been associated with mythological entities. As such people have often projected pictures into the skies as can be seen in figure 18.1 which shows the constellation of Ursa Major. On the left is a picture with the image of the mythical Great Bear, on the right only a line-art version (or *stick figure*) is shown. The seven bright stars of Ursa Major are widely recognised, known variously as "the plough", the "pan-handle", and the "big dipper". This sub-grouping is known as an *asterism* — a distinct grouping of stars. On the right, the picture of the bear has been removed and only a constellation diagram remains.
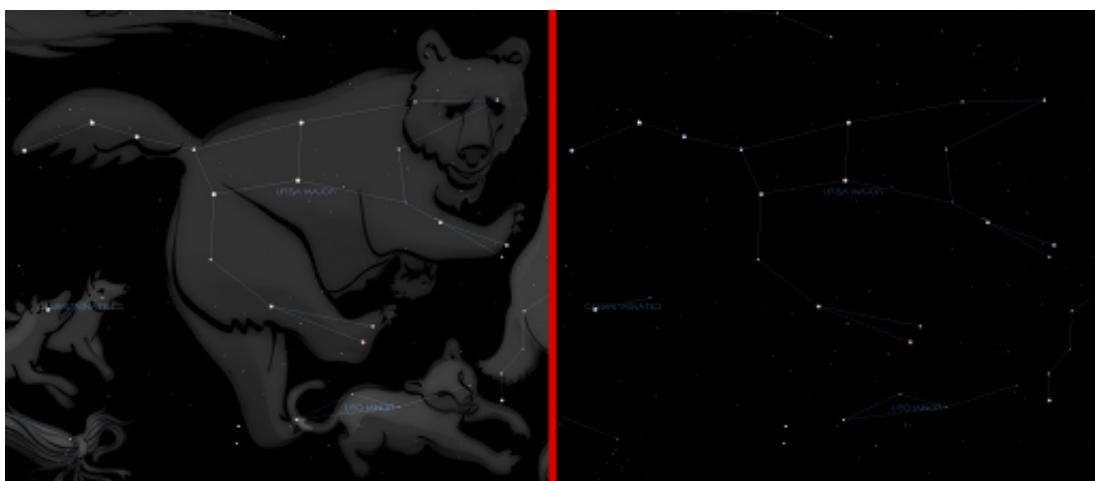
Figure 18.1: Ursa Major

Stellarium can draw both constellation diagrams and artistic representations of the constellations. Multiple sky cultures are supported: Western, Polynesian, Egyptian, Chinese, and several other sky cultures are available, although at time of writing the non-Western constellations are not complete, and as yet there are no artistic representations of these sky-cultures.

Aside from historical and mythological value, to the modern astronomer the constellations provide a way to segment the sky for the purposes of describing locations of objects, indeed one of

the first tasks for an amateur observer is *learning the constellations* — the process of becoming familiar with the relative positions of the constellations, at what time of year a constellation is visible, and in which constellations observationally interesting objects reside. The International Astronomical Union has adopted 88 "Western" constellations as a common system for segmenting the sky (Table 18.1). They are based on Greek/Roman mythology, but with several additions from Renaissance and later centuries. As such some formalisation has been adopted, each constellation having a *proper name*, which is in Latin, and a three letter abbreviation of that name. For example, Ursa Major has the abbreviation UMa. Also, the "Western" constellation have clearly defined boundaries (Delporte, 1930), which you can draw in Stellarium when you press the $\boxed{\text{B}}$ key[1]. The IAU constellation a selected object is placed in is also available in the object information data (Roman, 1987), regardless of the currently active skyculture. On the other hand, the shapes of mythological figures, and also stick figures, have not been canonized, so you will find deviations between Stellarium and printed atlases.

18.2.3 Star Names

The brighter stars often have one or more *common names* relating to mythical characters from the various traditions. For example the brightest star in the sky, Sirius is also known as The Dog Star (the name Canis Major — the constellation Sirius is found in — is Latin for "The Great Dog").

Most bright names have been given names in antiquity. PTOLEMY's most influential book, the *Syntaxis*, was translated to the Arab language in the age of early Muslim scientists. When, centuries later, the translation, called *Almagest*, was re-introduced to the re-awakening European science, those names, which often only designated the position of the star within the figure, were taken from the books, often misspelled, and used henceforth as proper names.

A few more proper names have been added later, sometimes dedicatory names added by court astronomers into their maps. There are also 3 stars named after the victims of the Apollo 1 disaster in 1967. Today, the International Astronomical Union (IAU) is the only scientifically accepted authority which can give proper names to stars. Some companies offer a paid name service for commemoration or dedication of a star for deceased relatives or such, but all you get here is a piece of paper with coordinates of (usually) an unremarkably dim star only visible in a telescope, and a name to remember, stored (at best) in the company's database.

There are several more formal naming conventions that are in common use.

Bayer Designation

The German astronomer JOHANN BAYER (1572–1625) devised one such system for his atlas, the *Uranographia*, first published in 1603. His scheme names the stars according to the constellation in which they lie prefixed by a lower case Greek letter (see Tab. 18.2), starting at α for (usually) the brightest star in the constellation and proceeding with $\beta, \gamma, \ldots$ in descending order of apparent magnitude. For example, such a *Bayer Designation* for Sirius is "α Canis Majoris" (note that the genitive form of the constellation name is used, refer to Table 18.1; today also the short form α CMa is in use). There are some exceptions to the descending magnitude ordering, and some multiple stars (both real and optical) are named with a numerical superscript after the Greek letter, e.g. $\pi^1 \ldots \pi^6$ Orionis.

Flamsteed Designation

English astronomer JOHN FLAMSTEED (1646–1719) numbered stars in each constellation in order of increasing right ascension followed by the genitive form of the constellation name, for example "61 Cygni" (or short: "61 Cyg").

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[1]These boundaries or borders have been drawn using star maps from 1875. Due to the effect of *precession*, these borders are no longer parallel to today's coordinates.

Abbr.	Name	Genitive	Abbr.	Name	Genitive
And	Andromeda	Andromedae	Lac	Lacerta	Lacertae
Ant	Antlia	Antliae	Leo	Leo	Leonis
Aps	Apus	Apodis	LMi	Leo Minor	Leonis Minoris
Aqr	Aquarius	Aquarii	Lep	Lepus	Leporis
Aql	Aquila	Aquilae	Lib	Libra	Librae
Ara	Ara	Arae	Lup	Lupus	Lupi
Ari	Aries	Arietis	Lyn	Lynx	Lyncis
Aur	Auriga	Aurigae	Lyr	Lyra	Lyrae
Boo	Bootes	Bootis	Men	Mensa	Mensae
Cae	Caelum	Caeli	Mic	Microscopium	Microscopii
Cam	Camelopardalis	Camelopardalis	Mon	Monoceros	Monocerotis
Cnc	Cancer	Cancri	Mus	Musca	Muscae
Cvn	Canes Venatici	Canum Venaticorum	Nor	Norma	Normae
CMa	Canis Maior	Canis Maioris	Oct	Octans	Octantis
CMi	Canis Minor	Canis Minoris	Oph	Ophiuchus	Ophiuchi
Cap	Capricornus	Capricorni	Ori	Orion	Orionis
Car	Carina	Carinae	Pav	Pavo	Pavonis
Cas	Cassiopeia	Cassiopeiae	Peg	Pegasus	Pegasi
Cen	Centaurus	Centauri	Per	Perseus	Persei
Cep	Cepheus	Cephei	Phe	Phoenix	Phoenicis
Cet	Cetus	Ceti	Pic	Pictor	Pictoris
Cha	Chamaeleon	Chamaeleonis	Psc	Pisces	Piscium
Cir	Circinus	Circini	PsA	Piscis Austrinus	Piscis Austrini
Col	Columba	Columbae	Pup	Puppis	Puppis
Com	Coma Berenices	Comae Berenicis	Pyx	Pyxis	Pyxidis
CrA	Corona Australis	Coronae Australis	Ret	Reticulum	Reticuli
CrB	Corona Borealis	Coronae Borealis	Sge	Sagitta	Sagittae
Crt	Crater	Crateris	Sgr	Sagittarius	Sagittarii
Crv	Corvus	Corvi	Sco	Scorpius	Scorpii
Cru	Crux	Crucis	Scl	Sculptor	Sculptoris
Cyg	Cygnus	Cygni	Sct	Scutum	Scuti
Del	Delphinus	Delphini	Ser	Serpens	Serpentis
Dor	Dorado	Doradus	Sex	Sextans	Sextantis
Dra	Draco	Draconis	Tau	Taurus	Tauri
Equ	Equuleus	Equulei	Tel	Telescopium	Telescopii
Eri	Eridanus	Eridani	Tri	Triangulum	Trianguli
For	Fornax	Fornacis	TrA	Triangulum Australe	Trianguli Australis
Gem	Gemini	Geminorum	Tuc	Tucana	Tucanae
Gru	Grus	Gruis	UMa	Ursa Major	Ursae Majoris
Her	Hercules	Herculis	UMi	Ursa Minor	Ursae Minoris
Hor	Horologium	Horologii	Vel	Vela	Velae
Hya	Hydra	Hydrae	Vir	Virgo	Virginis
Hyi	Hydrus	Hydri	Vol	Volans	Volantis
Ind	Indus	Indi	Vul	Vulpecula	Vulpeculae

Table 18.1: The official 88 IAU constellation names and abbreviations

α	alpha	η	eta	ν	nu	τ	tau
β	beta	θ	theta	ξ	xi	υ	upsilon
γ	gamma	ι	iota	o	omicron	φ	phi
δ	delta	κ	kappa	π	pi	χ	chi
ε	epsilon	λ	lambda	ρ	rho	ψ	psi
ζ	zeta	μ	mu	σ	sigma	ω	omega

Table 18.2: The Greek alphabet used by Bayer

Hipparcos

Hipparcos (for High Precision Parallax Collecting Satellite) was an astrometry mission of the European Space Agency (ESA) dedicated to the measurement of stellar parallax and the proper motions of stars. The project was named in honour of the Greek astronomer HIPPARCHUS.

Ideas for such a mission dated from 1967, with the mission accepted by ESA in 1980. The satellite was launched by an Ariane 4 on 8 August 1989. The original goal was to place the satellite in a geostationary orbit above the earth, however a booster rocket failure resulted in a highly elliptical orbit from 315 to 22,300 miles altitude. Despite this difficulty, all of the scientific goals were accomplished. Communications were terminated on 15 August 1993.

The program was divided in two parts: the *Hipparcos experiment* whose goal was to measure the five astrometric parameters of some 120,000 stars to a precision of some 2 to 4 milli arc-seconds and the *Tycho experiment*, whose goal was the measurement of the astrometric and two-colour photometric properties of some 400,000 additional stars to a somewhat lower precision.

The final Hipparcos Catalogue (120,000 stars with 1 milli arc-second level astrometry) and the final Tycho Catalogue (more than one million stars with 20-30 milli arc-second astrometry and two-colour photometry) were completed in August 1996. The catalogues were published by ESA in June 1997. The Hipparcos and Tycho data have been used to create the Millennium Star Atlas: an all-sky atlas of one million stars to visual magnitude 11, from the Hipparcos and Tycho Catalogues and 10,000 non-stellar objects included to complement the catalogue data.

Figure 18.2: Star Names and Data

There were questions over whether Hipparcos has a systematic error of about 1 milli arc-second

Spectral Type	Surface Temperature (K)	Star Colour
O	28,000—50,000	Blue
B	10,000—28,000	Blue-white
A	7,500—10,000	White-blue
F	6,000—7,500	Yellow-white
G	4,900—6,000	Yellow
K	3,500—4,900	Orange
M	2,000—3,500	Red

Table 18.3: Spectral Types

in at least some parts of the sky. The value determined by Hipparcos for the distance to the Pleiades is about 10% less than the value obtained by some other methods. By early 2004, the controversy remained unresolved.

Stellarium uses the Hipparcos Catalogue for star data, as well as having traditional names for many of the brighter stars. The stars tab of the search window allows for searching based on a Hipparcos Catalogue number (as well as traditional names), e.g. the star Sadalmelik in the constellation of Aquarius can be found by searching for the name, or its Hipparcos number, 109074.

Figure 18.2 shows the information Stellarium displays when a star is selected. At the top, the common name, Bayer/Flamsteed designations and Hipparcos number are shown, followed by the RA/Dec coordinates, apparent magnitude, distance and other data.

18.2.4 Spectral Type & Luminosity Class

Stars have many different colours. Seen with the naked eye most appear to be white, but this is due to the response of the eye — at low light levels the eye is not sensitive to colour. Typically the unaided eye can start to see differences in colour only for stars that have apparent magnitude brighter than 1. Betelgeuse, for example has a distinctly red tinge to it, and Sirius appears to be blue, while Vega is the prototype "white" star.

By splitting the light from a star using a prism attached to a telescope and measuring the relative intensities of the colours of light the star emits — the *spectrum* — a great deal of interesting information can be discovered about a star including its surface temperature, and the presence of various elements in its atmosphere.

Astronomers groups stars with similar spectra into *spectral types*, denoted by one of the following letters: O, B, A, F, G, K and M.[2] Type O stars have a high surface temperature (up to around 50,000 K) while the at other end of the scale, the M stars are red and have a much cooler surface temperature, typically 3000 K. The Sun is a type G star with a surface temperature of around 5,500 K. Spectral types may be further sub-divided using a numerical suffix ranging from 0-9 where 0 is the hottest and 9 is the coolest. Table 18.3 shows the details of the various spectral types.

For about 90% of stars, the absolute magnitude increases as the spectral type tends to the O (hot) end of the scale. Thus the whiter, hotter stars tend to have a greater luminosity. These stars are called *main sequence* stars. There are however a number of stars that have spectral type at the M end of the scale, and yet they have a high absolute magnitude. These stars are close to the ends of their lives and have a very large size, and consequently are known as *giants*, the largest of these known as *super-giants*.

There are also stars whose absolute magnitude is very low regardless of the spectral class.

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[2]The classic mnemonic for students of astrophysics says: "Oh, Be A Fine Girl, Kiss Me".

Luminosity class	Description
Ia, Ib	Super-giants
II	Bright giants
III	Normal giants
IV	Sub-giants
V	Main sequence
VI	Sub-dwarfs
VII	White-dwarfs

Table 18.4: Luminosity Classification

These are known as *dwarf stars*, among them *white dwarfs* (dying stars) and *brown dwarfs* ("failed stars").

The *luminosity class* is an indication of the type of star — whether it is main sequence, a giant or a dwarf. Luminosity classes are denoted by a number in roman numerals, as described in table 18.4.

Plotting the luminosity of stars against their spectral type/surface temperature gives a diagram called a Hertzsprung-Russell diagram (after the two astronomers EJNAR HERTZSPRUNG (1873–1967) and HENRY NORRIS RUSSELL (1877–1957) who devised it). A slight variation of this is shown in figure 18.3 (which is technically a colour/magnitude in figure 18.3 (which is technically a colour/magnitude plot).

18.2.5 Variable Stars

Most stars are of nearly constant luminosity. The Sun is a good example of one which goes through relatively little variation in brightness (usually about 0.1% over an 11 year solar cycle). Many stars, however, undergo significant variations in luminosity, and these are known as *variable stars*. There are many types of variable stars falling into two categories, *intrinsic* and *extrinsic*.

Intrinsic variables are stars which have intrinsic variations in brightness, that is, the star itself gets brighter and dimmer. There are several types of intrinsic variables, probably the best-known and most important of which is the Cepheid variable whose luminosity is related to the period with which its brightness varies. Since the luminosity (and therefore absolute magnitude) can be calculated, Cepheid variables may be used to determine the distance of the star when the annual parallax is too small to be a reliable guide. This is especially welcome because they are giant stars, and so they are even visible in neighboring galaxies.

Extrinsic variables are stars of constant brightness that show changes in brightness as seen from the Earth. These include rotating variables, stars whose apparent brightness change due to rotation, and eclipsing binaries.

Stellarium's catalogs include many kinds variable stars. See section C.3 for more details.

18.3 Our Moon

The Moon is the large satellite which orbits the Earth approximately every 28 days. It is seen as a large bright disc in the early night sky that rises later each day and changes shape into a crescent until it disappears near the Sun. After this it rises during the day then gets larger until it again becomes a large bright disc again.
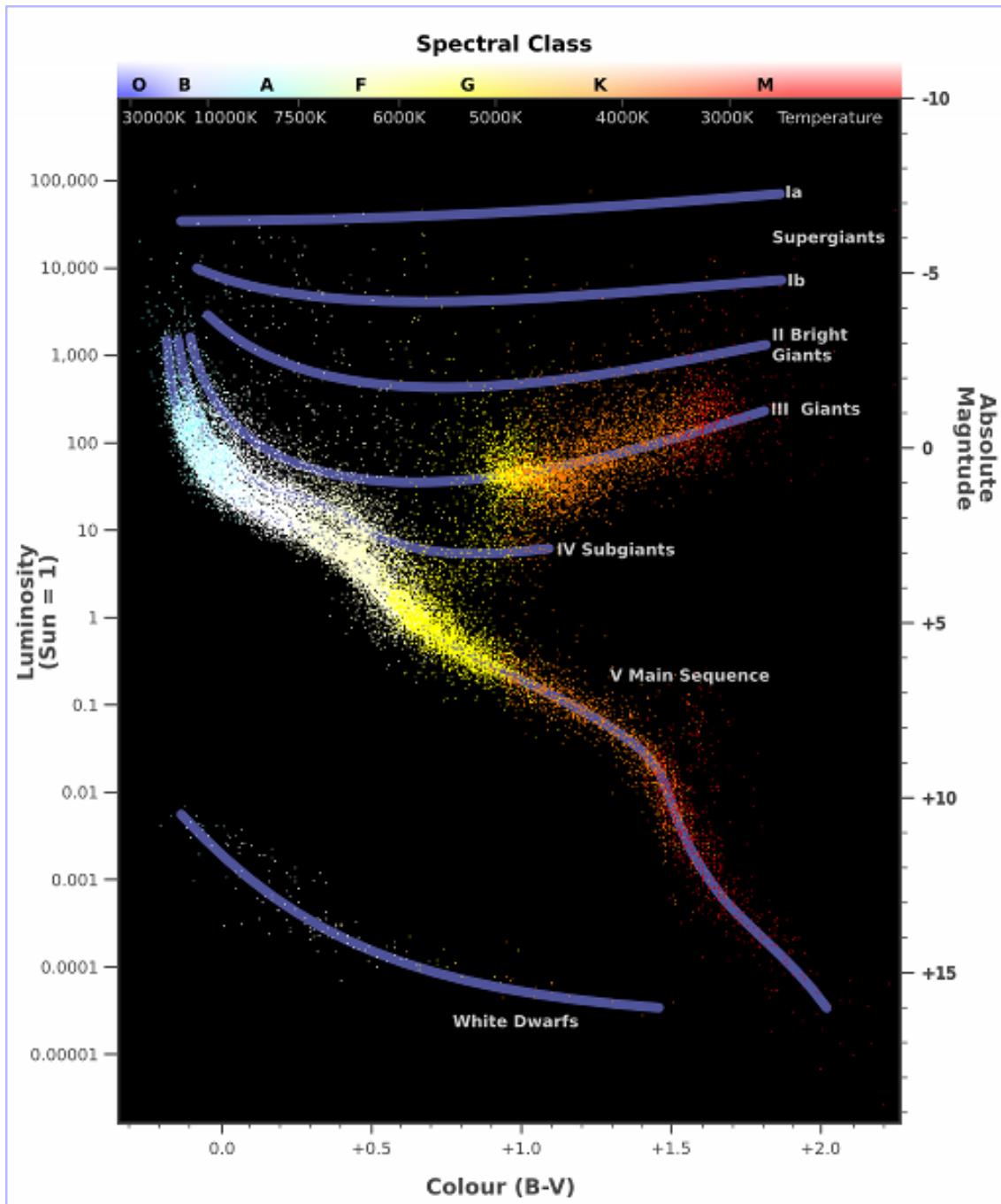
Figure 18.3: Hertzsprung-Russell Diagram

18.3.1 Phases of the Moon

As the moon moves round its orbit, the amount that is illuminated by the sun as seen from a vantage point on Earth changes. The result of this is that approximately once per orbit, the moon's face gradually changes from being totally in shadow to being fully illuminated and back to being in shadow again. This process is divided up into various phases as described in table 18.5.

18.4 The Major Planets

Unlike the stars whose relative positions remain more or less constant, the planets seem to move across the sky over time (the word "planet" comes from the Greek for "wanderer"). The planets are siblings of the Earth, massive bodies that are in orbit around the Sun. Until 2006 there was no formal definition of a planet, leading to some confusion about the classification for some bodies traditionally regarded as being planets, but which didn't seem to fit with the others.

In 2006 the International Astronomical Union (IAU) defined a planet as a celestial body that, within the Solar System:

1. is in orbit around the Sun
2. has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape; and
3. has cleared the neighbourhood around its orbit

or within another system:

1. is in orbit around a star or stellar remnants
2. has a mass below the limiting mass for thermonuclear fusion of deuterium; and
3. is above the minimum mass/size requirement for planetary status in the Solar System.

Moving from the Sun outwards, the 8 major planets are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Since the formal definition of a planet in 2006 Pluto has been relegated to having the status of *dwarf planet*, along with bodies such as Ceres and Eris. See figure 18.4.

18.4.1 Terrestrial Planets

The planets closest to the sun are called collectively the *terrestrial planets*. The terrestrial planets are: Mercury, Venus, Earth and Mars.

The terrestrial planets are relatively small, comparatively dense, and have solid rocky surface. Most of their mass is made from solid matter, which is mostly rocky and/or metallic in nature.

New Moon	The moon's disc is fully in shadow, or there is just a slither of illuminated surface on the edge.
Waxing Crescent	Less than half the disc is illuminated, but more is illuminated each night.
First Quarter	Approximately half the disc is illuminated, and increasing each night.
Waxing Gibbous	More than half of the disc is illuminated, and still increasing each night.
Full Moon	The whole disc of the moon is illuminated.
Waning Gibbous	More than half of the disc is illuminated, but the amount gets smaller each night.
Last Quarter	Approximately half the disc is illuminated, but this gets less each night.
Waning Crescent	Less than half the disc of the moon is illuminated, and this gets less each night.

Table 18.5: Lunar Phases
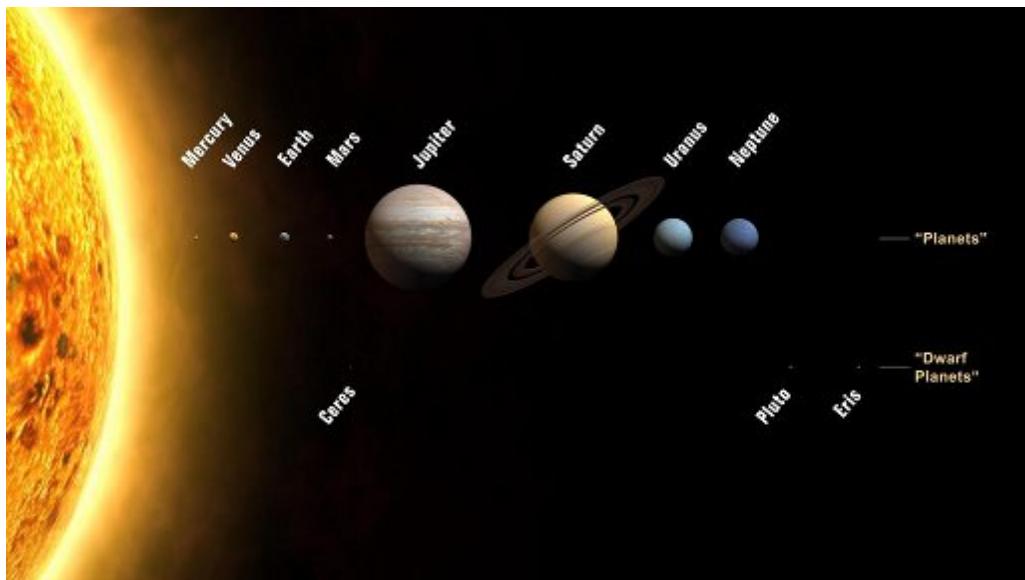
Figure 18.4: The Planets

18.4.2 Jovian Planets

Jupiter, Saturn, Uranus and Neptune make up the *Jovian planets*, also called *gas giants*. They are much more massive than the terrestrial planets, and do not have a solid surface. Jupiter is the largest of all the planets with a diameter of about 12, and mass over 300 times that of the Earth!

The Jovian planets do not have a solid surface – the vast majority of their mass being in gaseous form (although they may have rocky or metallic cores). Because of this, they have an average density which is much less than the terrestrial planets. Saturn's mean density is only about $0.7\,\mathrm{g/cm^3}$ – it would float in water!

18.5 The Minor Bodies

As well as the Major Planets, the solar system also contains innumerable smaller bodies in orbit around the Sun. These are generally the *dwarf planets* (Ceres, Pluto, Eris), the other *minor planets*, also known as *planetoids* or *asteroids*, and comets.

18.5.1 Asteroids

Asteroids are celestial bodies orbiting the Sun in more or less regular orbits mostly between Mars and Jupiter. They are generally rocky bodies like the inner (terrestrial) planets, but of much smaller size. They are countless in number ranging in size from about ten meters to hundreds of kilometres.

18.5.2 Comets

A comet is a small body in the solar system that orbits the Sun and (at least occasionally) exhibits a coma (or atmosphere) and/or a tail.

Most comets have a very eccentric orbit (featuring a highly flattened ellipse, or even a parabolic track), and as such spend most of their time a very long way from the Sun. Comets are composed of rock, dust and ices. When they come close to the Sun, the heat evaporates the ices, causing a gaseous release. This gas and loose material which comes away from the body of the comet is swept away from the Sun by the Solar wind, forming the tail.

Most larger comets exhibit two kinds of tail: a straight gas tail (often blue-green in photographs), and a wider, occasionally curved dust tail (reflecting whitish sunlight).

Comets whose orbit brings them close to the Sun more frequently than every 200 years are considered to be *short period* comets, the most famous of which is probably Comet Halley, named after the British astronomer EDMUND HALLEY (1656–1741/42[3]), which has an orbital period of roughly 76 years.

18.6 Meteoroids

These objects are small pieces of space debris left over from the early days of the solar system or which crumbled off a comet when it came close to the sun. These particles orbit the Sun and come in a variety of shapes, sizes an compositions, ranging from microscopic dust particles up to about ten meters across.

Sometimes these objects collide with the Earth. The closing speed of these collisions is generally extremely high (tens of kilometres per second). When such an object ploughs through the Earth's atmosphere, a large amount of kinetic energy is converted into heat and light, and a visible flash or streak can often be seen with the naked eye. Even the smallest particles can cause these events which are commonly known as *shooting stars*.

While smaller objects tend to burn up in the atmosphere, larger, denser objects can penetrate the atmosphere and strike the surface of the planet, sometimes leaving meteor craters.

Sometimes the angle of the collision means that larger objects pass through the atmosphere but do not strike the Earth. When this happens, spectacular fireballs are sometimes seen.

To clarify some terminology:

Meteoroids are the objects when they are floating in space.

Meteor is the name given to the visible atmospheric phenomenon.

Shooting Star colloquial term for a small meteor

Fireball, Bolide term for a very bright meteor. These illuminate the landscape, sometimes for several seconds, and occasionally even cause sounds. These are also candidates for

Meteorites , the objects that penetrate the atmosphere and land (or *impact*) on the surface.

In some nights over the year you can observe increased meteorite activity. Those meteors seem to come from a certain point in the sky, the *Radiant*. But what we see is similar to driving through a mosquito swarm which all seem to come head-on. Earth itself moves through space, and sweeps up a dense cloud of particles which originates from a comet's tail. Stellarium's Meteor Shower plugin (see section 13.6) can help you planning your next meteor observing night.

18.7 Zodiacal Light and *Gegenschein*

In very clear nights on the best observing sites, far away from the light pollution of our cities, you can observe a feeble glow also known as "false twilight" after evening twilight in the west, or before dawn in the east. The glow looks like a wedge of light along the ecliptic. Exactly opposite the sun, there is another dim glow that can be observed with dark-adapted eyes in perfect skies: the *Gegenschein* (counterglow).

This is sunlight reflected off the same dust and meteoroids in the plane of our solar system which is the source of meteors. Stellarium's sky can show the Zodiacal light (Kwon, Hong, and Weinberg, 2004), but observe how quickly light pollution kills its visibility!

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[3]Halley lived in a time when Great Britain still used the Julian calendar and started the years in March. He died January 14th, 1741 (Julian), which was called January 25th 1742 (Gregorian) in most other European countries.

18.8 The Milky Way

There is a band of very dense stars running right round the sky in huge irregular stripe. Most of these stars are very dim, but the overall effect is that on very dark clear nights we can see a large, beautiful area of diffuse light in the sky. It is this for which we name our galaxy the *Milky Way*.

The reason for this effect is that our galaxy is somewhat like a disc, and we are off to one side. Thus when we look towards the centre of the disc, we see more a great concentration of stars (there are more star in that direction). As we look out away from the centre of the disc we see fewer stars - we are staring out into the void between galaxies!

It's a little hard to work out what our galaxy would look like from far away, because when we look up at the night sky, we are seeing it from the inside. All the stars we can see are part of the Milky Way, and we can see them in every direction. However, there is some structure. There is a higher density of stars in particular places.

18.9 Nebulae

Seen with the naked eye, binoculars or a small telescope, a *nebula* (plural *nebulae*) is a fuzzy patch on the sky. Historically, the term referred to any extended object, but the modern definition excludes some types of object such as galaxies.

Observationally, nebulae are popular objects for amateur astronomers – they exhibit complex structure, spectacular colours (in most cases only visible in color photography) and a wide variety of forms. Many nebulae are bright enough to be seen using good binoculars or small to medium sized telescopes, and are a very photogenic subject for astro-photographers.

Nebulae are associated with a variety of phenomena, some being clouds of interstellar dust and gas in the process of collapsing under gravity, some being envelopes of gas thrown off during a supernova event (so called *supernova remnants*), yet others being the remnants of dumped outer layers around dying stars (*planetary nebulae*).

Examples of nebulae for which Stellarium has images include the Crab Nebula (M1), which is a supernova remnant, and the Dumbbell Nebula (M27) and the Ring Nebula (M57) which are planetary nebulae.

18.9.1 The Messier Objects

The *Messier* objects are a set of astronomical objects catalogued by CHARLES MESSIER (1730–1817) in his catalogue of *Nebulae and Star Clusters* first published in 1774. The original motivation behind the catalogue was that Messier was a comet hunter, and he was frustrated by objects which resembled but were not comets. He therefore compiled a list of these annoying objects.

The first edition covered 45 objects numbered M1 to M45. The total list consists of 110 objects, ranging from M1 to M110. The final catalogue was published in 1781 and printed in the *Connaissance des Temps* in 1784. Many of these objects are still known by their Messier number.

Because the Messier list was compiled by astronomers in the Northern Hemisphere, it contains only objects from the north celestial pole to a celestial latitude of about $-35°$. Many impressive Southern objects, such as the Large and Small Magellanic Clouds are excluded from the list. Because all of the Messier objects are visible with binoculars or small telescopes (under favourable conditions), they are popular viewing objects for amateur astronomers. In early spring, astronomers sometimes gather for "Messier Marathons", when all of the objects can be viewed over a single night.

Stellarium includes images of many Messier objects.

18.9.2 The Caldwell catalogue

The *Caldwell* catalogue is an astronomical catalogue of 109 star clusters, nebulae, and galaxies for observation by amateur astronomers. The list was compiled by PATRICK MOORE (1923–2012) as a complement to the Messier catalogue (O'Meara, 2003).

While the Messier catalogue is used by amateur astronomers as a list of deep-sky objects for observation, Moore noted that Messier's list was not compiled for that purpose and excluded many of the sky's brightest deep-sky objects (O'Meara, 2003), such as the Hyades, the Double Cluster (NGC 869 and NGC 884), and the Sculptor Galaxy (NGC 253). The Messier catalogue was actually compiled as a list of known objects that might be confused with comets. Moore also observed that since Messier compiled his list from observations in Paris, it did not include bright deep-sky objects visible in the Southern Hemisphere, such as Omega Centauri, Centaurus A, the Jewel Box, and 47 Tucanae (O'Meara, 2003). Moore compiled a list of 109 objects to match the commonly accepted number of Messier objects (he excluded M110 (Moore, 1995)), and the list was published in *Sky & Telescope* in December 1995 (Moore, 1995).

Moore used his other surname – Caldwell – to name the list, since the initial of "Moore" is already used for the Messier catalogue (O'Meara, 2003). Entries in the catalogue are designated with a "C" and the catalogue number (1 to 109).

Unlike objects in the Messier catalogue, which are listed roughly in the order of discovery by Messier and his colleagues, the Caldwell catalogue is ordered by declination, with C1 being the most northerly and C109 being the most southerly (O'Meara, 2003), although two objects (C 26=NGC 4244 and C 41, the Hyades) are listed out of sequence (O'Meara, 2003). Other errors in the original list have since been corrected: it incorrectly identified the S Norma Cluster (C 89=NGC 6087) as NGC 6067 and incorrectly labelled the Lambda Centauri Cluster (C 100=IC 2944) as the Gamma Centauri Cluster (O'Meara, 2003).

18.10 Galaxies

Stars, it seems, are gregarious – they like to live together in groups. These groups are called galaxies. The number of stars in a typical galaxy is literally astronomical – many *billions* – sometimes over *hundreds of billions* of stars!

Our own star, the sun, is part of a galaxy. When we look up at the night sky, all the stars we can see are in the same galaxy. We call our own galaxy the Milky Way (or sometimes simply "the Galaxy"[4]).

Other galaxies appear in the sky as dim fuzzy blobs. Only four are normally visible to the naked eye. The Andromeda galaxy (M31) visible in the Northern hemisphere, the two Magellanic clouds, visible in the Southern hemisphere, and the home galaxy Milky Way, visible in parts from north and south under dark skies.

There are thought to be billions of galaxies in the universe comprised of an unimaginably large number of stars.

The vast majority of galaxies are so far away that they are very dim, and cannot be seen without large telescopes, but there are dozens of galaxies which may be observed in medium to large sized amateur instruments. Stellarium includes images of many galaxies, including the Andromeda galaxy (M31), the Pinwheel Galaxy (M101), the Sombrero Galaxy (M104) and many others.

Astronomers classify galaxies according to their appearance. Some classifications include *spiral galaxies*, *elliptical galaxies*, *lenticular galaxies* and *irregular galaxies*.

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[4]Which means closely the same thing, the word deriving from Greek *gala*=milk.

18.11   Eclipses

Eclipses occur when an apparently large celestial body (planet, moon etc.) moves between the observer (that's you!) and a more distant object – the more distant object being eclipsed by the nearer one.

18.11.1   Solar Eclipses

Solar eclipses occur when our Moon moves between the Earth and the Sun. This happens when the inclined orbit of the Moon causes its path to cross our line of sight to the Sun. In essence it is the observer falling under the shadow of the moon.

There are three types of solar eclipses:

Partial The Moon only covers part of the Sun's surface.

Total The Moon completely obscures the Sun's surface.

Annular The Moon is at apogee (furthest from Earth in its elliptic orbit) and its disc is too small to completely cover the Sun. In this case most of the Sun's disc is obscured – all except a thin ring around the edge.

18.11.2   Lunar Eclipses

Lunar eclipses occur when the Earth moves between the Sun and the Moon, and the Moon is in the Earth's shadow. They occur under the same basic conditions as the solar eclipse but can occur more often because the Earth's shadow is so much larger than the Moon's.

Total lunar eclipses are more noticeable than partial eclipses because the Moon moves fully into the Earth's shadow and there is very noticeable darkening. However, the Earth's atmosphere refracts light (bends it) in such a way that some sunlight can still fall on the Moon's surface even during total eclipses. The blue parts of sunlight are scattered and filtered away, so that there is a marked reddening of the light as it passes through the atmosphere, and this makes the Moon appear in a deep red colour. The darkness and colors are notably influenced by atmospheric clarity and clouds. After big volcanic eruptions eclipses are often reported darker.

18.12   Observing Hints

When stargazing, there's a few little things which make a lot of difference, and are worth taking into account.

Dark skies For many people getting away from light pollution isn't an easy thing. At best it means a drive away from the towns, and for many the only chance to see a sky without significant glow from street lighting is on vacation. If you can't get away from the cities easily, make the most of it when you are away.

Wrap up warm The best observing conditions are the same conditions that make for cold nights, even in the summer time. Observing is not a strenuous physical activity, so you will feel the cold a lot more than if you were walking around. Wear a lot of warm clothing, don't sit/lie on the floor (at least use a camping mat, consider taking a deck-chair), and take a flask of hot drink.

Dark adaptation The true majesty of the night sky only becomes apparent when the eye has had time to become accustomed to the dark. This process, known as dark adaptation, can take up to half an hour, and as soon as the observer sees a bright light they must start the process over. Red light doesn't compromise dark adaptation as much as white light, so use a red torch if possible (and one that is as dim as you can manage with). A dim single red LED light is ideal, also to have enough light to take notes.

The Moon Unless you're particularly interested in observing the Moon on a given night, it can be a nuisance—it can be so bright as to make observation of dimmer objects such as nebulae

Airmass, Absorption and Extinction Angle (m_z=6.5; apparent altitudes)
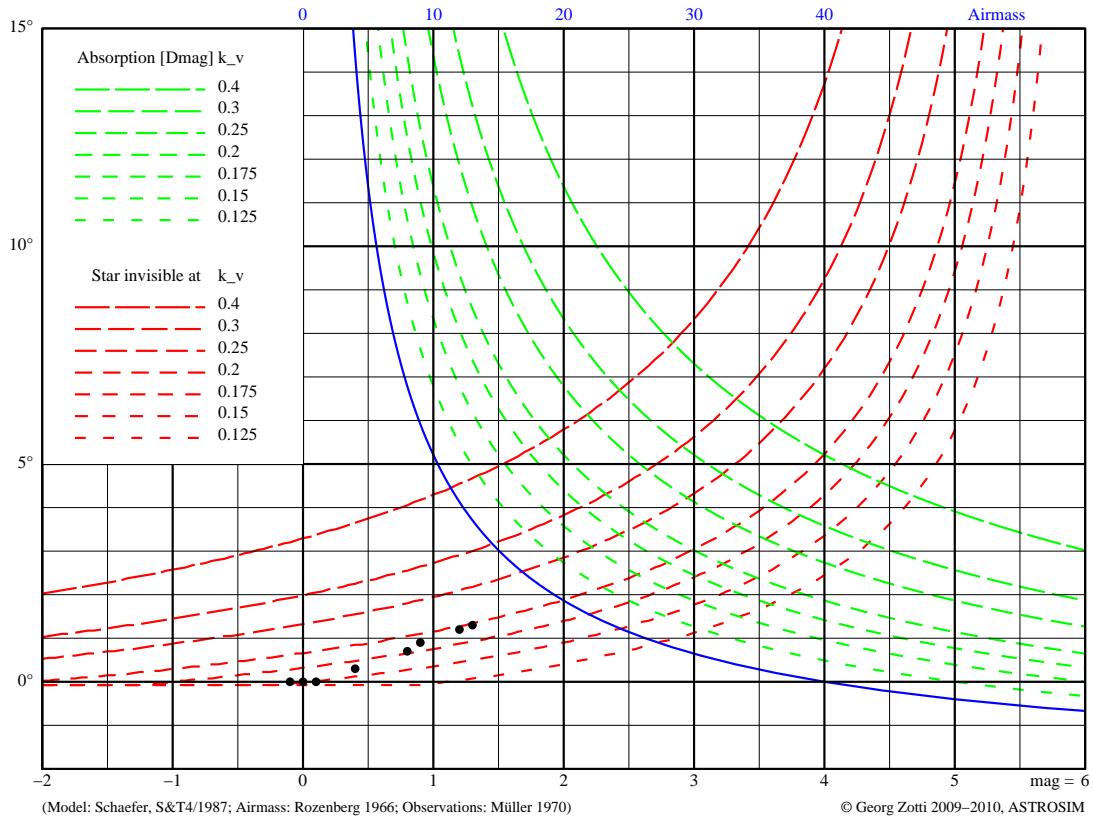
Figure 18.5: Airmass and Extinction. The figure shows Airmass (blue) along the line of sight in the altitude labeled on the left side. The green curves show how many magnitudes an object is dimmed down, depending on extinction factor k (called k_v in the figure). The red curves indicate at which altitude a star of given magnitude can be seen with good eyesight, again depending on k. The black dots are observed values found in the literature.

impossible. When planning what you want to observe, take the phase and position of the Moon into account. Of course Stellarium is the ideal tool for finding this out!

Averted vision A curious fact about the eye is that it is more sensitive to dim light towards the edge of the field of view. If an object is slightly too dim to see directly, looking slightly off to the side but concentrating on the object's location can often reveal it.

Angular distance Learn how to estimate angular distances. Learn the angular distances described in section 17.5.2. If you have a pair of binoculars, find out the angular distance across the field of view and use this as a standard measure.

18.13 Atmospheric effects

18.13.1 Atmospheric Extinction

Atmospheric Extinction is the attenuation of light of a celestial body by Earth's atmosphere. In the last split-second of its travel into our eyes or detectors, light from outer space has to pass our atmosphere, through layers of mixed gas, water vapour and dust. If a star is in the zenith, its light must pass one *air mass* and is reduced by whatever amount of water and dust is above you. When the star is on the horizon, it has to pass about 40 times longer through the atmosphere: 40 air masses

(Fig. 18.5). The number of air masses increases fast in low altitudes, this is why we see so few stars along the horizon. Usually blue light is extinguished more, this is why the sun and moon (and brigher stars) appear reddish on the horizon.

Stellarium can simulate extinction, and you can set the opacity of your atmosphere with a global factor k, the *magnitude loss per airmass* (see section 4.4.2). The best mountaintop sites may have $k = 0.15$, while $k = 0.25$ seems a value usable for good locations in lower altitudes.

18.13.2 Atmospheric Refraction

Atmospheric Refraction is a lifting effect of our atmosphere which can be observed by the fact that objects close to the horizon appear higher than they should be if computed only with spherical trigonometry. Stellarium simulates refraction for terrestrial locations when the atmosphere is switched on. Refraction depends on air pressure and temperature. Figure 18.6 has been created from the same formulae that are employed in Stellarium. You can see how fast refraction grows very close to the mathematical horizon.

Note that these models can only give approximate conditions. There are many weird effects in the real atmosphere, when temperature inversion layers can create light ducts, double sunsets etc.

Also note that the models give meaningful results only for altitudes above approximately $-2°$. Below that, in nature, there is always ground which blocks our view. In Stellarium you can switch off the ground, and you can observe a sunset with a strange egg-shaped sun below the horizon. This is of course nonsense. Stellarium is also not able to properly recreate the atmospheric distortions as seen from a stratosphere balloon, where the height of earth's surface is several degrees below the mathematical horizon.

Scintillation

Scintillation is the scientific name of the twinkling which stars show in turbulent atmosphere. The twinkling is caused by moving pockets of air with different temperature. Observe a star low on the horizon with a telescope, and you will note it does not stand still but dances around a bit, often also changing color to show red or blue hues. While the twinkling of stars may look fine and comforting to the naked eye on a nice warm summer evening, telescopic observers and astrophotographers don't like it at all. They rather complain about "bad seeing", because it deteriorates the optical resolution of their instruments and photographs.

Just like extinction and refraction are stronger along the horizon, stars in low altitude in general show more twinkling than stars higher up in the sky.

Note that planets seem to be affected less by scintillation: they are not point sources, but little disks, and so the effect of the turbulent pockets of air distorting different parts of the disks cancels out a bit when observing with the naked eye: planets appear to be more stable. Of course, the view in a telescope will still be deteriorated by the turbulent atmosphere.

While bad seeing was one key motivation of sending telescopes into earth orbit since the 1970s, the latest generation of ground-based giant telescopes is able to compensate for the turbulent motion by rapidly deforming their secondary mirror.

18.13.3 Light Pollution

An ugly side effect of civilisation is a steady increase in outdoor illumination. Many people think it increases safety, but while this statement can be questioned, one definite result, aside from environmental issues like dangers for the nocturnal fauna, are ever worsening conditions for astronomical observations or just enjoyment of the night sky.

Stellarium can simulate the effect of light pollution on the visibility of celestial objects. This is controlled from the light pollution section of the *Sky* tab of the *View* window (see section 4.10). Light pollution levels are set using a numerical value between 1 and 9 which corresponds to the
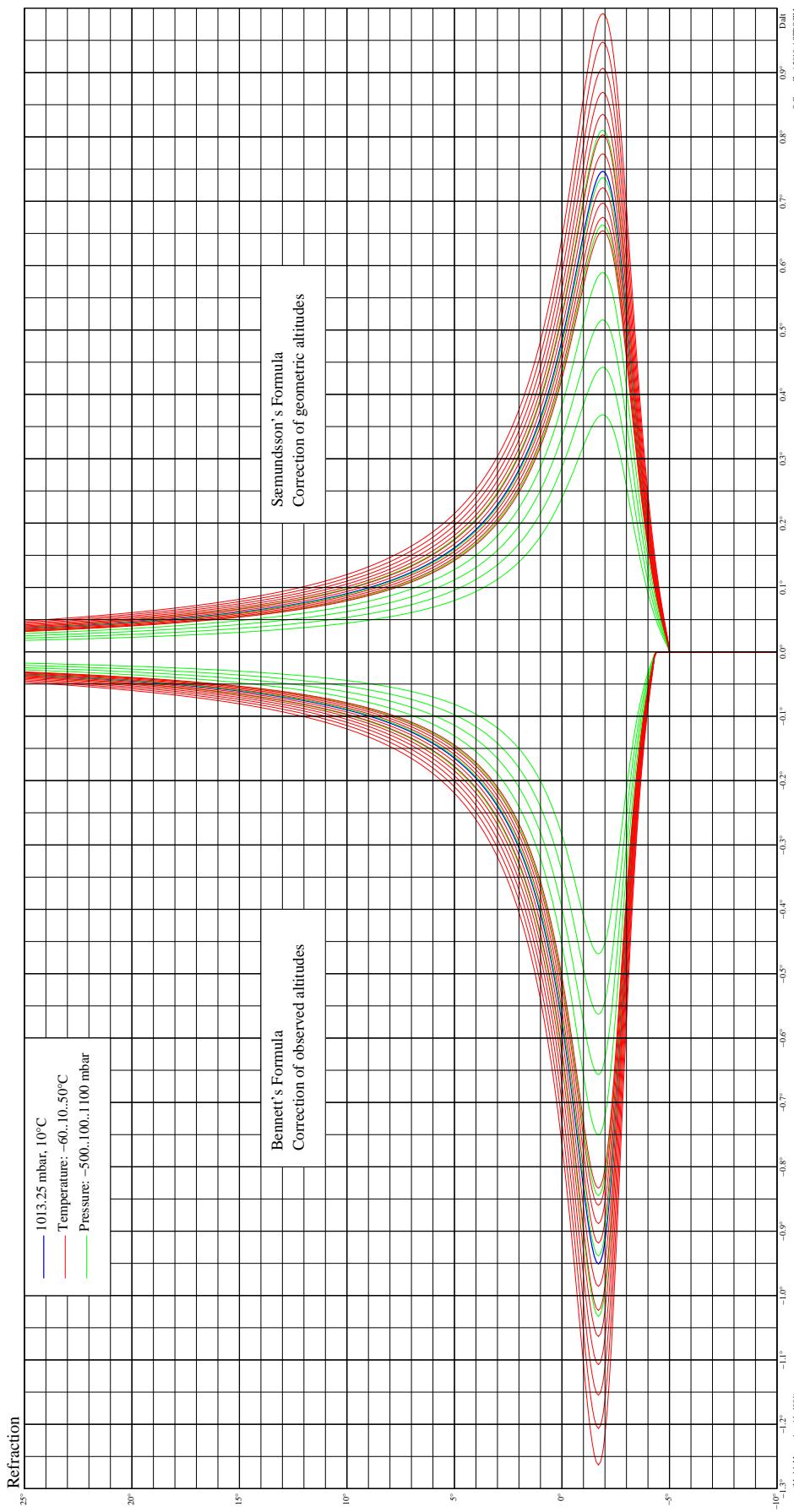
Figure 18.6: Refraction. The figure shows corrective values (degrees) which are subtracted from observed altitudes (left side) to reach geometric altitudes, or values to be added to computed values (right side). The models used are not directly inverse operations.

Bortle Dark Sky Scale (see Appendix B). Given that public lighting became bright enough to cause adverse effects on observability only during the 19th century, Stellarium presents an unpolluted sky for dates before 1825. Note that of course light pollution was not switched on over night, but became gradually noticeable over decades, but you have to estimate the appropriate level.

In addition, local variations of the amount of light pollution can be included in a light pollution layer in the landscapes, see section 7 for details. This foreground layer may include all kinds of light, e.g. campfires, so this is also available for earlier dates.

19. A Little Sky Guide

PAUL ROBINSON, WITH ADDITIONS BY ALEXANDER WOLF

This chapter lists some astronomical objects that can be located using Stellarium. All of them can be seen with the naked eye or binoculars. Since many astronomical objects have more than one name (often having a "proper name", a "common name" and various catalogue numbers), the chapter lists the name as it appears in Stellarium — use this name when using Stellarium's search function — and any other commonly used names.

The Location Guide entry gives brief instructions for finding each object using nearby bright stars or groups of stars when looking at the real sky — a little time spent learning the major constellations visible from your latitude will pay dividends when it comes to locating fainter (and more interesting!) objects. When trying to locate these objects in the night sky, keep in mind that Stellarium displays many stars that are too faint to be visible without optical aid, and even bright stars can be dimmed by poor atmospheric conditions and light pollution.

19.1 Dubhe and Merak, The Pointers

Type: Stars
Magnitude: 1.83, 2.36
Location Guide: *The two "rightmost" of the seven stars that form the main shape of "The Plough" (or "Big Dipper", part of Ursa Major).*

Northern hemisphere observers are very fortunate to have two stars that point towards Polaris which lie very close to the northern celestial pole. Whatever the time of night or season of the year they are always an immediate clue to the location of Polaris, the Pole Star.

19.2 M31, Messier 31, The Andromeda Galaxy

Type: Spiral Galaxy
Magnitude: 3.4

Location Guide: *Find the three bright stars that constitute the main part of the constellation of Andromeda. From the middle of these look toward the constellation of Cassiopeia.*

M31 is the most distant object visible to the naked eye, and among the few nebulae that can be seen without a telescope or powerful binoculars. Under good conditions it appears as a large fuzzy patch of light. It is a galaxy containing billions of stars whose distance is roughly 2.5 million light years from Earth.

19.3 The Garnet Star, μ Cephei

Type: Variable Star
Magnitude: 4.25 (Avg.)
Location Guide: *Cephius lies "above" the W-shape of Cassiopeia. The Garnet Star lies slightly to one side of a point halfway between 5 Cephei and 21 Cephei.*

A "supergiant" (1035 Solar radii) of spectral class M with a strong red colour. Given its name by Sir William Herschel in the 18th century, the colour is striking in comparison to its blue-white neighbours.

19.4 4 and 5 Lyrae, ε Lyrae

Type: Double Star
Magnitude: 4.7
Location Guide: *Close to Vega (α Lyrae), one of the brightest stars in the sky.*

In binoculars ε Lyrae is resolved into two separate stars. Remarkably, each of these is also a double star (although this will only be seen with a telescope) and all four stars form a physical system.

19.5 M13, Hercules Cluster

Type: Globular Cluster
Magnitude: 5.8
Location Guide: *Located approximately 1/3 of the way along a line from 44 (η) to 40 (ζ) Herculis.*

This cluster of hundreds of thousands of mature stars appears as a circular "cloud" using the naked eye or binoculars (a large telescope is required to resolve individual stars). Oddly the cluster appears to contain one young star and several areas that are almost devoid of stars.

19.6 M45, The Pleiades, The Seven Sisters

Type: Open Cluster
Magnitude: 1.2 (Avg.)
Location Guide: *Lies on the Bull's back, about 1/3 between Aldebaran in Taurus and Almaak in Andromeda.*

Depending upon conditions, six to 9 of the blueish stars in this famous cluster will be visible to someone with average eyesight, and in binoculars it is a glorious sight. The cluster has more than 500 members in total, many of which are shown to be surrounded by nebulous material in long exposure photographs.

19.7 C41, The Hyades

Type: Open Cluster
Magnitude: 0.5 (Avg.)
Location Guide: *Lies near Aldebaran in Taurus.*

The Hyades span about 6° of sky because they are one of the nearest open clusters, being about 153 light years away. The age of the Hyades is estimated to be about 625 million years. The five brightest member stars of the Hyades have consumed their hydrogen fuel in their cores and are now evolving into giant stars. Four of these stars, with Bayer designations γ, δ^1, ε, and θ Tauri, form an asterism that is traditionally identified as the head of Taurus, the Bull.

19.8 Algol, The Demon Star, β Persei

Type: Variable Star
Magnitude: 3.0 (Avg.)
Location Guide: *Halfway between Aldebaran in Taurus and the middle star of the "W" of Cassiopeia.*

Once every three days or so, Algol's brightness changes from 2.1 to 3.4 and back within a matter of hours. The reason for this change is that Algol has a dimmer giant companion star, with an orbital period of about 2.8 days, that causes a regular partial eclipse. Although Algol's fluctuations in magnitude have been known since at least the 17th century, it was the first to be proved to be due to an eclipsing companion — it is therefore the prototype Eclipsing Variable.

19.9 Sirius, α Canis Majoris

Type: Star
Magnitude: -1.47
Location Guide: *Sirius is easily found by following the line of three stars in Orion's belt southwards.*

Sirius is a white dwarf star at a comparatively close 8.6 light years. This proximity and its high innate luminance makes it the brightest star in our sky. Sirius is a double star; its companion is a White Dwarf, much dimmer but very hot, and is believed to be smaller than the earth.

19.10 M44, The Beehive, Praesepe

Type: Open Cluster
Magnitude: 3.7
Location Guide: *Cancer lies about halfway between the twins (Castor & Pollux) in Gemini and Regulus, the brightest star in Leo. The Beehive can be found between Asellus Borealis and Asellus Australis.*

There are probably 350 or so stars in this cluster, although it appears to the naked eye simply as a misty patch. It contains a mixture of stars from red giants to white dwarf and is estimated to be some 700 million years old.

19.11 27 Cephei, δ Cephei

Type: Variable Star
Magnitude: 4.0 (Avg.)
Location Guide: *Locate the four stars that form the square of Cepheus. One corner of the square*

has two other bright stars nearby forming a distinctive triangle — δ is at the head of this triangle in the direction of Cassiopeia.

δ Cephei gives its name to a whole class of variables, all of which are pulsating high-mass stars in the later stages of their evolution. δ Cephei is also a double star with a companion of magnitude 6.3 visible in binoculars.

19.12   Betelgeuse, α Orionis, 58 Orionis

Type: Star
Magnitude: 0.45
Location Guide: *The distinctly reddish star in the constellation of Orion – one of the shoulders of Orion.*

Betelgeuse is a distinctly reddish, semiregular variable star whose apparent magnitude varies between 0.0 and 1.3. It is classified as a red supergiant of spectral type M1-2, and is one of the largest stars visible to the naked eye. If Betelgeuse were at the center of the Solar System, its surface would extend past the asteroid belt, completely engulfing the orbits of Mercury, Venus, Earth, Mars, and possibly Jupiter.

In 1920, Betelgeuse became the first extrasolar star to have the angular size of its photosphere measured. Subsequent studies have reported an angular diameter (apparent size) ranging from 0.042 to 0.056 arcseconds, with the differences ascribed to the non-sphericity, limb darkening, pulsations, and varying appearance at different wavelengths. It is also surrounded by a complex, asymmetric envelope roughly 250 times the size of the star, caused by mass loss from the star itself.

19.13   M42, The Great Orion Nebula

Type: Nebula
Magnitude: 4.0
Location Guide: *Almost in the middle of the area bounded by Orion's belt and lower stars, Saiph and Rigel.*

The Great Orion Nebula is the brightest nebula visible in the night sky and lies at about 1.500 light years from earth. It is a truly gigantic gas and dust cloud that extends for several hundred light years, reaching almost halfway across the constellation of Orion. The nebula contains a cluster of hot young stars known as the Trapezium, and more stars are believed to be forming within the cloud.

19.14   La Superba, Y Canum Venaticorum, HIP 62223

Type: Star
Magnitude: 5.4 (Avg.)
Location Guide: *Almost the center of the arch of stars of Ursa Major's tail. Forms a neat triangle with Phekda (γ) and Alkaid (η, tail tip) in Ursa Major towards Canes Venatici.*

La Superba (215 Solar radii) is a "Carbon Star" — a group of relatively cool gigantic (usually variable) stars that have an outer shell containing high levels of carbon. This shell is very efficient at absorbing the short wavelengths of blue light, giving carbon stars a distinctive red or orange tint. It is one of the coolest and reddest known stars.

19.15 52 and 53 Bootis, ν^1 and ν^2 Bootis

Type: Double Star
Magnitude: 5.0, 5.0
Location Guide: *Follow a line from Seginus (γ Boo, left shoulder) to Nekkar (β Boo, the head) and then continue for the same distance again to arrive at this double star.*

    This optical double star consists of a pair of different spectral types. 52 Bootis, at approximately 800 light years, is twice as far away as 53 Boo.

19.16 Almach, γ Andromedae

Type: Multiple Star
Magnitude: 2.15 (Avg.)
Location Guide: *The bright star located in the "legs" of Andromeda.*

    In 1778, JOHANN TOBIAS MAYER discovered that γ Andromedae was a double star. When examined in a small telescope, it appears to be a bright, golden-yellow star (γ^1 Andromedae) next to a dimmer, indigo-blue star (γ^2 Andromedae), separated by approximately $10''$. It is often considered by stargazers to be a beautiful double star with a striking contrast of color. It was later discovered that γ^2 Andromedae is itself a triple star system. What appears as a single star to the naked eye is thus a quadruple star system.

19.17 Algieba, γ Leonis, 41 Leonis

Type: Double Star
Magnitude: 2.20 (Avg.)
Location Guide: *The third brightest star in the constellation Leo – located on the "neck" of Leo.*

    The bright binary system in Leo with orange-red and yellow or greenish-yellow components is visible through a modest telescope under good atmospheric conditions. To the naked eye, the Algieba system shines at mid-second magnitude, but a telescope easily splits the pair. On November 6, 2009, the discovery of a planetary companion around primary star γ^1 Leonis (γ Leonis A) was announced.

19.18 Castor, α Geminorum

Type: Multiple Star
Magnitude: 1.9 (Avg.)
Location Guide: *Castor is the second-brightest object in the constellation of Gemini.*

    Castor is a multiple star system made up of six individual stars; there are three visual components, all of which are spectroscopic binaries. Appearing to the naked eye as a single star, Castor was first recorded as a double star in 1718 by JAMES POUND, but it may have been resolved into at least two sources of light by Cassini as early as 1678. The separation between Castor A and Castor B has increased from about $2''$ (2 arcseconds) in 1970 to about $6''$ in 2017. These two binary pairs have magnitudes of 1.9 and 3.0.

    Both components have much fainter companions, Castor Aa and Ba, and both have orbits of a few days.

    Castor C, or YY Geminorum, was discovered to vary in brightness with a regular period. It is an eclipsing binary with additional variations due to areas of different brightness on the surface of one or both stars, as well as irregular flares. The Castor C components orbit each other in less than a day. Castor C is believed to be in orbit around Castor AB, but with an extremely long period of several thousand years. It is $73''$ distant from the bright components.

19.19   PZ Cas, HIP 117078

Type: Variable Star
Magnitude: 8.2 (Avg.)
Location Guide: *Lies about 1/3 between Caph (β Cas, the top right star of "W") in Cassiopeia and ι Cephei (32 Cep, top left star in "rectangle" of Cepheus).*

This faint red star is one of the biggest known stars — its average size parameter is 1565 Solar radii (the true value is from 1340 to 1940 Solar radii). PZ Cas is a pulsating variable star located in a region with heavy dust extinction.

19.20   VV Cephei, HIP 108317

Type: Variable Star, Double Star
Magnitude: 5.1 (Avg.)
Location Guide: *Lies near the center of the "rectangle" of Cepheus).*

This is an interesting eclipsing binary system — VV Cep A (1457 Solar radii) is a highly distorted star in a binary system, losing mass to its B-type companion VV Cephei B (10 Solar radii) for at least part of its orbit.

19.21   AH Scorpii, HIP 84071

Type: Variable Star
Magnitude: 7.1 (Avg.)
Location Guide: *Lies in Scorpius, about $1\frac{1}{4}$ of a continuation of the Scorpion's "tail".*

AH Sco (1411 Solar radii) is variable by nearly 3 magnitudes in the visual range, and an estimated 20% in total luminosity. The variation in diameter is not clear because the temperature also varies.

19.22   Albireo, β Cygni

Type: Double Star
Magnitude: 3.4, 5.1
Location Guide: *The "head" of Cygni.*

When viewed with the naked eye, it appears to be a single star. However, in a telescope it readily resolves into a double star, consisting of Albireo A (amber), and Albireo B (blue-green). Separated by $35''$, the two components provide one of the best contrasting double stars in the sky due to their different colors.

19.23   31 and 32 Cygni, o^1 and o^2 Cygni

Type: Multiple Star
Magnitude: 3.8, 4.0
Location Guide: *The two bright stars about 1/2 between Deneb (α Cygni, "tail" of Cygnus) and Rukh (δ Cygni, middle of the left "wing" of Cygnus).*

The wide binary o^1 Cygni and o^2 Cygni is separated $61'$ (NNE), and this star is an easy naked-eye double. o^1 Cygni with 30 Cyg and HD 192579 (HIP 99676) is a moderately difficult triple system. And surprise — each of o^1 Cyg and o^2 Cyg are also Algol-type eclipsing binaries!

Figure 19.1: Albireo: A Bright and Beautiful Double. *Credit & Copyright: Richard Yandrick.*

19.24 The Coathanger, Brocchi's Cluster, Cr 399

Type: Asterism

Location Guide: *It is best found by slowly sweeping across the Milky Way along an imaginary line from the bright star Altair toward the even brighter star Vega (around 1/3 between Altair and Vega).*

The asterism is made up of 10 stars ranging from 5th to 7th magnitude which form the conspicuous "coathanger", a straight line of 6 stars with a "hook" of 4 stars on the south side. Under a dark sky, Collinder 399 can be seen with the naked eye as an unresolved patch of light; binoculars or a telescope at very low power are usually needed in order to view the "coathanger" asterism.

19.25 Kemble's Cascade

Type: Asterism

Location Guide: *The asterism lies in the constellation Camelopardalis, about 1/3 between CS Cam and α Cam — HIP 18505 has magnitude 5 and can be found in the center of the chain.*

Kemble's Cascade is a chain of stars which are visible in binocular even in light-polluted skies.

19.26 The Double Cluster, χ and h Persei, NGC 884 and NGC 869

Type: Open Clusters

Location Guide: *The two open clusters near stars χ and h in the constellation Perseus.*

The Double Cluster (also known as Caldwell 14 or C14) is the common name for the naked-eye open clusters NGC 869 and NGC 884 (often designated h Persei and χ Persei, respectively). The Double Cluster is approximately the radiant of the Perseid meteor shower, which peaks annually around August 12 or 13. Although easy to locate in the northern sky, observing the Double Cluster in its two parts requires optical aid. They are described as being an "awe-inspiring" and "breathtaking" sight, and are often cited as targets in astronomical observers' guides.

19.27   Large Magellanic Cloud, PGC 17223

Type: Dwarf Spiral Galaxy

Magnitude: 0.9

Location Guide: *It is visible as a faint "cloud" in the night sky of the southern hemisphere straddling the border between the constellations of Dorado and Mensa, and it appears from Earth more than 20 times the width of the full moon.*

The *Large Magellanic Cloud* (LMC) is a satellite galaxy of the Milky Way. The Large Magellanic Cloud is usually considered an irregular galaxy. However, it shows signs of a bar structure, and has more recently been reclassified as a Magellanic-type dwarf spiral galaxy. At a distance of 50 kiloparsecs, the LMC is the third closest galaxy to the Milky Way, after the Sagittarius Dwarf Spheroidal (~16 kiloparsecs) and the putative Canis Major Dwarf Galaxy (~12.9 kiloparsecs, though its status as a galaxy is under dispute) lying closer to the center of the Milky Way. The LMC has a diameter of about 14,000 light-years (~4.3 kpc) and a mass of approximately 10 billion (10^{10}) solar masses, making it roughly 1/100 as massive as the Milky Way. The LMC has a wide range of galactic objects and phenomena — surveys of the galaxy have found roughly 60 globular clusters, 400 planetary nebulae, and 700 open clusters, along with hundreds of thousands of giant and supergiant stars.

Figure 19.2: Small and Large Magellanic Clouds over Paranal Observatory. *Credit: ESO/J. Colosimo.*

19.28   Tarantula Nebula, C 103, NGC 2070

Type: Nebula

Magnitude: 7.3

Location Guide: *Part of Large Magellanic Cloud.*

The Tarantula Nebula (also known as 30 Doradus) is an H II region in the Large Magellanic Cloud (LMC). 30 Doradus has at its centre the star cluster NGC 2070 which includes the compact concentration of stars known as R136 that produces most of the energy that makes the nebula visible. The estimated mass of the cluster is 450,000 solar masses, suggesting it will likely become

a globular cluster in the future (Bosch, E. Terlevich, and R. Terlevich, 2009). The closest supernova observed since the invention of the telescope, Supernova 1987A, occurred in the outskirts of the Tarantula Nebula.

19.29 Small Magellanic Cloud, NGC 292, PGC 3085

Type: Dwarf Irregular Galaxy
Magnitude: 2.2
Location Guide: *It is located mostly in the constellation of Tucana and appears as a hazy, light patch in the night sky about 3° across, looking like a detached piece of the Milky Way. Since it has a very low surface brightness, it is best viewed from a dark site away from city lights.*

The *Small Magellanic Cloud* (SMC) is a dwarf galaxy near the Milky Way. It is classified as a dwarf irregular galaxy. It has a diameter of about 7,000 light-years and has a total mass of approximately 7 billion times the mass of the Sun. The SMC contains a central bar structure and it is speculated that it was once a barred spiral galaxy that was disrupted by the Milky Way to become somewhat irregular. At a distance of about 200,000 light-years, it is one of the Milky Way's nearest neighbors. It is also one of the most distant objects that can be seen with the naked eye.

19.30 ω Centauri cluster, C 80, NGC 5139

Type: Globular Cluster
Magnitude: 5.3
Location Guide: *It is located around 1/3 between ζ and γ Centauri.*

Omega Centauri (ω Cen), or NGC 5139, is a globular cluster in the constellation of Centaurus that was first identified as a non-stellar object by Edmond Halley in 1677. Located at a distance of 15,800 light-years (4,850 pc), it is the largest globular cluster in the Milky Way at a diameter of roughly 150 light-years. It is estimated to contain approximately 10 million stars and a total mass equivalent to 4 million solar masses. Omega Centauri is so distinctive from the other galactic globular clusters that it is thought to have an alternate origin as the core remnant of a disrupted dwarf galaxy (Noyola, Gebhardt, and Bergmann, 2008).

19.31 47 Tucanae, C 106, NGC 104

Type: Globular Cluster
Magnitude: 4.1
Location Guide: *It can be seen with the naked eye near Small Magellanic Cloud.*

It is the one of brightest globular cluster in the sky, and is noted for having a very bright and dense core. It is also one of the most massive globular clusters in the Milky Way Galaxy, containing millions of stars. The cluster appears roughly the size of the full moon in the sky under ideal conditions.

19.32 The Coalsack Nebula, C 99

Type: Dark Nebula
Location Guide: *Dark region between α and β Crux.*

The Coalsack Nebula is the most prominent dark nebula in the skies, easily visible to the naked eye as a dark patch silhouetted against the southern Milky Way. It is located at a distance of approximately 600 light years away from Earth. The Coalsack is important in Australian Aboriginal astronomy, and forms the head of the Emu in the sky in several Aboriginal cultures.

Figure 19.3: The Coalsack Nebula taken by the Wide Field Imager on the MPG/ESO 2.2-metre telescope. *Credit: ESO*.

19.33 Mira, o Ceti, 68 Cet

Type: Variable Star
Magnitude: 2.0–10.1
Location Guide: *It is located around 1/3 between δ and θ Ceti.*

Mira (o Ceti) is a star estimated 200–400 light years away in the constellation Cetus. Mira is a binary star system that consists of a red giant (Mira A) undergoing mass loss and a high temperature white dwarf companion (Mira B) that is accreting mass from the primary. Such an arrangement of stars is known as a symbiotic system, and this is the closest such symbiotic pair to the Sun. Mira is the brightest periodic variable in the sky that is not visible to the naked eye for part of its cycle. Its distance is uncertain. Mira A is a well-known example of a category of long-period variable stars known as Mira variables, which are named after it.

19.34 α Persei Cluster, Cr 39, Mel 20

Type: Open Cluster
Magnitude: 1.2
Location Guide: *Around the white-yellow supergiant Mirfak, also known as α Persei in direction to δ Persei.*

The Alpha Persei Cluster, also known as Melotte 20 or Collinder 39, is an open cluster in the constellation of Perseus. To the naked eye, the cluster consists of several blue (spectral class B) stars.

19.35 M7, The Ptolemy Cluster

Type: Open Cluster
Magnitude: 3.3
Location Guide: *The cluster is easily detectable with the naked eye, close to the "sting" of Scorpius — near the center of the line between Shaula (λ Scorpii) and Kaus Media (δ Sagittarii).*

M7 has been known since antiquity — it was first recorded by the 2nd-century Greek-Roman astronomer Ptolemy, who described it as a nebula in 130 AD. Telescopic observations of the cluster reveal about 80 stars within a field of view of 1.3° across. At the cluster's estimated distance of 980 light years this corresponds to an actual diameter of 25 light years.

19.36 M22, NGC 6656, The Great Sagittarius Cluster

Type: Globular Cluster
Magnitude: 5.1
Location Guide: *Located just south of the Ecliptic, and northwest of λ Sagittarii (Kaus Borealis), the northernmost star of the "Teapot" asterism.*

M22 is an elliptical globular cluster of stars in the constellation Sagittarius, near the Galactic bulge region. It is one of the brightest and nearest globular clusters that is visible in the night sky. M22 is very unusual in that it is one of only four globulars that are known to contain a planetary nebula. In 2012 two black holes of between 10 and 20 solar masses each have been discovered in this globular cluster, initially with the Very Large Array radio telescope in New Mexico, and corroborated by the Chandra X-ray telescope. The angular size of M22 is over 0.5°.

19.37 M24, The Sagittarius Star Cloud

Type: Star Cloud
Magnitude: 4.6
Location Guide: *In the Milky Way region near Polis (μ Sagittarii).*

The Sagittarius Star Cloud is a star cloud in the constellation of Sagittarius, approximately 600 light years wide. The stars, clusters and other objects comprising M24 are part of the Sagittarius or Sagittarius-Carina arms of the Milky Way galaxy. Messier described M24 as a "large nebulosity containing many stars" and gave its dimensions as being some 1.5° across.

19.38 IC 4665, The Summer Beehive Cluster

Type: Open Cluster
Magnitude: 4.2
Location Guide: *Visible to the naked eye near Cebalrai (β Ophiuchi).*

IC 4665 is an open cluster in the constellation Ophiuchus which is easily visible in the smallest of telescopes and also with binoculars. From a sufficiently dark place it is also visible to the naked eye.

19.39 The E Nebula, Barnard 142 and 143

Type: Dark Nebula
Location Guide: *A well-defined dark area on a background of Milky Way near Tarazed (γ Aquilae).*

The "E" or "Barnard's E" Nebula (officially designated as B142 and B143) is a pair of dark nebulae in the constellation Aquila. It is a well-defined dark area on a background of the Milky

Way. The size of the nebula is roughly $0.5°$, and its distance from earth is estimated at about 2000 light years.

20. Exercises

PAUL ROBINSON, WITH ADDITIONS BY ALEXANDER WOLF

20.1 Find M31 in Binoculars

M31 – the *Andromeda Galaxy* – is the most distant object visible to the naked eye. Finding it in binoculars is a rewarding experience for new-comers to observing.

20.1.1 Simulation

1. Set the location to a mid-Northern latitude if necessary (M31 isn't always visible for Southern hemisphere observers). The UK is ideal.
2. Find M31 and set the time so that the sky is dark enough to see it. The best time of year for this at Northern latitudes is Autumn/Winter, although there should be a chance to see it at some time of night throughout the year.
3. Set the field of view to 6° (or the field of view of your binoculars if they're different. 6° is typical for 7x50 binoculars).
4. Practise finding M31 from the bright stars in Cassiopeia and the constellation of Andromeda. Learn the chain of stars that extends from Andromeda's central star perpendicular to her body.

20.1.2 For Real

This part is not going to be possible for many people. First, you need a good night and a dark sky. In urban areas with a lot of light pollution it's going to be very hard to see Andromeda.

20.2 Handy Angles

As described in section 17.5.2, your hand at arm's length provides a few useful estimates for angular size. It's useful to know whether your handy angles are typical, and if not, what they are.

The method here below is just one way to do it – feel free to use another method of your own construction!

Hold your hand at arm's length with your hand open – the tips of your thumb and little finger as far apart as you can comfortably hold them. Get a friend to measure the distance between your thumb and your eye, we'll call this D. There is a tendency to over-stretch the arm when someone is measuring it – try to keep the thumb-eye distance as it would be if you were looking at some distant object.

Without changing the shape of your hand, measure the distance between the tips of your thumb and little finger. It's probably easiest to mark their positions on a piece of paper and measure the distance between the marks, we'll call this d. Using some simple trigonometry, we can estimate the angular distance θ using equation (17.4).

Repeat the process for the distance across a closed fist, three fingers and the tip of the little finger.

For example, for one author $D = 72$ cm, $d = 21$ cm, so:

$$\theta = 2 \cdot \arctan\left(\frac{21}{144}\right) \approx 16\frac{1}{2}^\circ \tag{20.1}$$

Remember that handy angles are not very precise – depending on your posture at a given time the values may vary by a fair bit.

20.3 Find a Lunar Eclipse

Stellarium comes with two scripts for finding lunar eclipses, but can you find one on a different date?

20.4 Find a Solar Eclipse

Find a Solar Eclipse using Stellarium and take a screenshot of it. Use the location panel and see how the eclipse look on different locations at the same time. Don't forget to have "Topocentric coordinates" enabled in the settings (see section 17.9.1).

20.5 Find a retrograde motion of Mars

Find Mars using Stellarium and take a series of screenshots of its position at different times. Use the date and time panel and see how the motion of Mars changes over the time. Find periods of direct and retrograde motion of Mars (see also section 16.5).

20.6 Analemma

Set a time around noon and set time rate to pause, turn on the azimuthal grid. Find the Sun and check its horizontal coordinates. Use the date and time panel and see how the horizontal coordinates of the Sun change over time (please use one time step for simulation — look at the position of the Sun every 7 days for example). Use the location panel and see how the positions of the Sun look from different location at the same times. Check the change of positions of the Sun on Mars at the same times.

20.7 Transit of Venus

Set date to 6th of June, 2012, find Venus near the Sun and change scale of the view (zoom in). Find time of all four contacts and maximum of transit for your location. Because the Sun appears to rotate as it crosses the sky, Venus will appear to move on some curve — for example it will be an inverted "U" shape for eastern states of Australia. Check difference of path shape of Venus for equatorial and azimuthal mounts. Find a few dates and times for transit of Venus in past and in future. Notice how they usually come in pairs 8 years apart, with gaps of over 100 years between pairs.

20.8 Transit of Mercury

Set date to 9th of May, 2016, find Mercury near the Sun and change scale of the view (zoom in). Find time of all four contacts and maximum of transit for your location. Because the Sun appears to rotate as it crosses the sky, Mercury will appear to move on some curve — for example it will be an inverted "U" shape for observers from Europe. Check difference of path shape of Mercury for equatorial and azimuthal mounts. Find few dates and times for transit of Mercury in past and in future.

20.9 Triple shadows on Jupiter

Set date to 24th of January, 2015, find Jupiter and change scale of the view (zoom in). Find the time when three shadows will be visible on the disk of Jupiter. Which moons cast those shadows? Check which moons cause triple shadows on Jupiter at 3 June 2014. Details for this phenomenon you can find in the book *Mathematical astronomy morsels* (Meeus, 1997).

20.10 Jupiter without satellites

Set date to 9th November, 2019, find Jupiter and change scale of the view (zoom in). Find time limits for the disappearance of the moons. Which moons are on the back of the planet, and which — in front of it? Please give answer on the same questions for 3 September 2009. Details for this phenomenon you can find in the book *Mathematical astronomy morsels* (Meeus, 1997)

20.11 Mutual occultations of planets

Set date to 13th October, 1590, find Venus and change scale of the view (zoom in). Find time of minimal separation of Venus and Mars on this date. Set typical scale of view for visual observation and check Venus and Mars again. What would the typical observer of that time had said? Find the minimal separation between Venus and Saturn near end of August 1771. What would the typical observer on Earth had said? Find the minimal separation between Mars and Mercury in first half of August 2079.

Find mutual occultation of Earth and Mercury as seen from Mars near the end of November 2022. Find mutual occultation of Saturn and Mercury as seen from Venus near the middle of May 1967.

Details for this phenomenon you can find in the books *More mathematical astronomy morsels* (Meeus, 2002) and *Mathematical astronomy morsels III* (Meeus, 2004)

20.12   The proper motion of stars

Turn off ground and atmosphere, set time rate on pause, find the star HIP 87937 and change the scale of the view to better see *Barnard's Star*. Use the date and time panel and see how the location of the star is changing in time (please try use one time step for simulation — look at the position of the star every year for example). When will Barnard's star cross the border of constellation? When has Barnard's star crossed the border of constellation in the past?

Please check the proper motions of Sirius (HIP 32349), Procyon (HIP 37279), 61 Cyg (HIP 104214) and τ Cet (HIP 8102). Which star has the fastest proper motion? Which star has the slowest rate of proper motion?

When will observers see Arcturus and HIP 68706 as close optical binary? Find the minimal angular separation between θ and ε Ind in the past.

How will the appearance of following constellations change over a wide range of time (-100000..100000 years for example): Ursa Major, Orion, Bootes?

A note of caution, however: the proper motions are only modelled by extrapolating their current shift rates in right ascension and declination, but don't take radial velocity into account. The results in very far times should be seen only as approximations.

V

Appendices

A. Default Hotkeys

The currently configured hotkeys are visible in the Help dialog (F1). Here is the default list for reference.

A.1 Mouse actions with combination of the keyboard keys

Actions	Description
Arrow keys & left mouse drag	Pan view around the sky
Page Up/Down & Ctrl + Page Up/Down	Zoom in/out
Ctrl & left mouse drag	Time dragging
Ctrl & mouse wheel	Time scrolling: minutes
Ctrl + Shift & mouse wheel	Time scrolling: hours
Ctrl + Alt & mouse wheel	Time scrolling: days
Ctrl + Alt + Shift & mouse wheel	Time scrolling: years
Left click	Select object
Right click	Clear selection
Shift & left click	Add custom marker
Shift & right click	Delete the one closest marker to mouse cursor
Alt + Shift & right click	Delete all custom markers

A.2   Display Options

Shortcut key	Description
P	Planets
Alt + P	Planet labels
Ctrl + P	Planet markers
O	Planet orbits
Shift + T	Planet trails
Ctrl + Shift + P	Planet selection marker
Alt + N	Nomenclature labels
S	Stars
Alt + S	Star labels
D	Deep-sky objects (symbols)
I	Deep-sky objects background images
Ctrl + I	Reload the deep-sky objects background images
Ctrl + Alt + D	Toggle Hierarchical Progressive Surveys (experimental)
M	Milky Way
Ctrl + Shift + Z	Zodiacal Light
G	Ground
F	Fog
Shift + G	Landscape Illumination
Ctrl + Shift + G	Landscape Labels
A	Atmosphere
Q	Cardinal points
,	Ecliptic line
.	Equator line
E	Equatorial grid
Z	Azimuthal grid
H	Horizon line
;	Meridian line
C	Constellation lines
V	Constellation labels
R	Constellation art
B	Constellation boundaries
Ctrl + Alt + Shift + V	Select single constellation
Tab	Remove selection of constellations
Ctrl + Shift + N	Native planet names (from starlore)
Alt + V	Asterism labels
Alt + A	Asterism lines
Alt + R	Ray helpers
Ctrl + Alt + I	Reload the sky culture
W	Remove selection of constellations
Alt + W	Select all constellations
F11	Full-screen mode
Ctrl + N	Night mode
Ctrl + Shift + H	Flip scene horizontally

`Ctrl`+`Shift`+`V`	Flip scene vertically

A.3 Miscellaneous

Shortcut key	Description
`Ctrl`+`C`	Copy selected object information to clipboard
`Ctrl`+`Q`	Quit
`Ctrl`+`S`	Save screenshot
`Ctrl`+`M`	Switch between equatorial and azimuthal mount
`Ctrl`+`T`	Toggle visibility of GUI
`Ctrl`+`R`, `P`	Reload shaders (for development)

A.4 Movement and Selection

Shortcut key	Description
	Center on selected object
`Ctrl`+`H`	Go to home
`Ctrl`+`G`	Set home planet to selected planet ("go there")
`Shift`+`E`	Look towards East
`Shift`+`N`	Look towards North
`Shift`+`S`	Look towards South
`Shift`+`W`	Look towards West
`Shift`+`Z`	Look towards Zenith
`Alt`+`Shift`+`N`	Look towards North Celestial pole
`Alt`+`Shift`+`S`	Look towards South Celestial pole
`T`	Track object
`/`	Zoom in on selected object
`\`	Zoom out
`Ctrl`+`Alt`+`1`	Set FOV to 180°
`Ctrl`+`Alt`+`2`	Set FOV to 90°
`Ctrl`+`Alt`+`3`	Set FOV to 60°
`Ctrl`+`Alt`+`4`	Set FOV to 45°
`Ctrl`+`Alt`+`5`	Set FOV to 20°
`Ctrl`+`Alt`+`6`	Set FOV to 10°
`Ctrl`+`Alt`+`7`	Set FOV to 5°
`Ctrl`+`Alt`+`8`	Set FOV to 2°
`Ctrl`+`Alt`+`9`	Set FOV to 1°
`Ctrl`+`Alt`+`0`	Set FOV to 0.5°

A.5   Date and Time

Shortcut key	Description
`=`	Add 1 solar day
`-`	Subtract 1 solar day
`Ctrl` + `=`	Add 1 solar hour
`Ctrl` + `-`	Subtract 1 solar hour
`Alt` + `=`	Add 1 sidereal day
`Alt` + `-`	Subtract 1 sidereal day
`)`	Add 7 solar days
`(`	Subtract 7 solar days
`Ctrl` + `Alt` + `Shift` + `)`	Add 1 sidereal year
`Ctrl` + `Alt` + `Shift` + `(`	Subtract 1 sidereal year
`J`	Decrease time speed
`Shift` + `J`	Decrease time speed (a little)
`K`	Set normal time rate
`L`	Increase time speed
`Shift` + `L`	Increase time speed (a little)
`7`	Set time rate to zero
`8`	Set time to now
`0`	Set reverse time direction
`Ctrl` + `D` , `P`	Pause script execution
`Ctrl` + `D` , `R`	Resume script execution
`Ctrl` + `D` , `S`	Stop script execution

A.6   Scripts

Shortcut key	Description
`Ctrl` + `D` , `0`	Run script "Solar System Screensaver"
`Ctrl` + `D` , `1`	Run script "Western Constellations Tour"
`Ctrl` + `D` , `2`	Run script "Sky Culture Tour"
`Ctrl` + `D` , `3`	Run script "Screensaver"
`Ctrl` + `D` , `B`	Run script "Skybox Tiles"
`Ctrl` + `D` , `M` , `1`	Run script "Jupiter and triple shadow phenomena"
`Ctrl` + `D` , `M` , `2`	Run script "Jupiter without Galilean satellites"
`Ctrl` + `D` , `M` , `3`	Run script "Occultations of bright stars by planets"
`Ctrl` + `D` , `M` , `4`	Run script "Mutual occultations of planets"

A.7 Windows

Shortcut key	Description
F1	Toggle Help window
F2	Toggle Configuration window
F3	Toggle Search window
F4	Toggle Sky and viewing options window
F5	Toggle Date/time window
F6	Toggle Location window
F7	Toggle Shortcuts window
F10	Toggle Astronomical calculations window
F12	Toggle Script Console window
Alt + B	Toggle Bookmarks window

A.8 Plugins

A.8.1 Angle Measure

Shortcut key	Description
Ctrl + A	Toggle angle measurement

A.8.2 ArchaeoLines

Shortcut key	Description
Ctrl + U	Toggle archaeolines
Ctrl + Shift + U	Toggle archaeolines dialog

A.8.3 Equation of Time

Shortcut key	Description
Ctrl + Alt + T	Show solution for Equation of Time

A.8.4 Exoplanets

Shortcut key	Description
Ctrl + Alt + E	Show exoplanets
Alt + E	Toggle Exoplanets configuration window

A.8.5 Meteor Showers

Shortcut key	Description
Ctrl + Shift + M	Toggle meteor showers
Shift + M	Toggle radiant labels
Ctrl + Alt + M	Show search dialog
Ctrl + Alt + Shift + M	Show settings dialog

A.8.6 Oculars

Shortcut key	Description
`Ctrl`+`O`	Ocular view
`Alt`+`O`	Oculars popup menu
`Alt`+`C`	Show crosshairs
`Ctrl`+`B`	Telrad sight

A.8.7 Pulsars

Shortcut key	Description
`Ctrl`+`Alt`+`P`	Show pulsars

A.8.8 Quasars

Shortcut key	Description
`Ctrl`+`Alt`+`Q`	Show quasars

A.8.9 Satellites

Shortcut key	Description
`Ctrl`+`Z`	Toggle satellite hints
`Alt`+`Shift`+`Z`	Toggle satellite labels
`Alt`+`Z`	Toggle Satellites configuration window

A.8.10 Scenery3d: 3D landscapes

Shortcut key	Description
`Ctrl`+`W`	Toggle 3D landscape
`Ctrl`+`Shift`+`W`	Show settings dialog
`Ctrl`+`Alt`+`W`	Show viewpoint dialog
`Ctrl`+`R`, `T`	Toggle location text
`Ctrl`+`R`, `S`	Toggle shadows
`Ctrl`+`R`, `L`	Toggle torchlight
`Ctrl`+`R`, `D`	Toggle debug information
`Ctrl`+`R`, `P`	Reload shaders

A.8.11 Solar System Editor

Shortcut key	Description
`Ctrl`+`Alt`+`S`	Import orbital elements in MPC format...
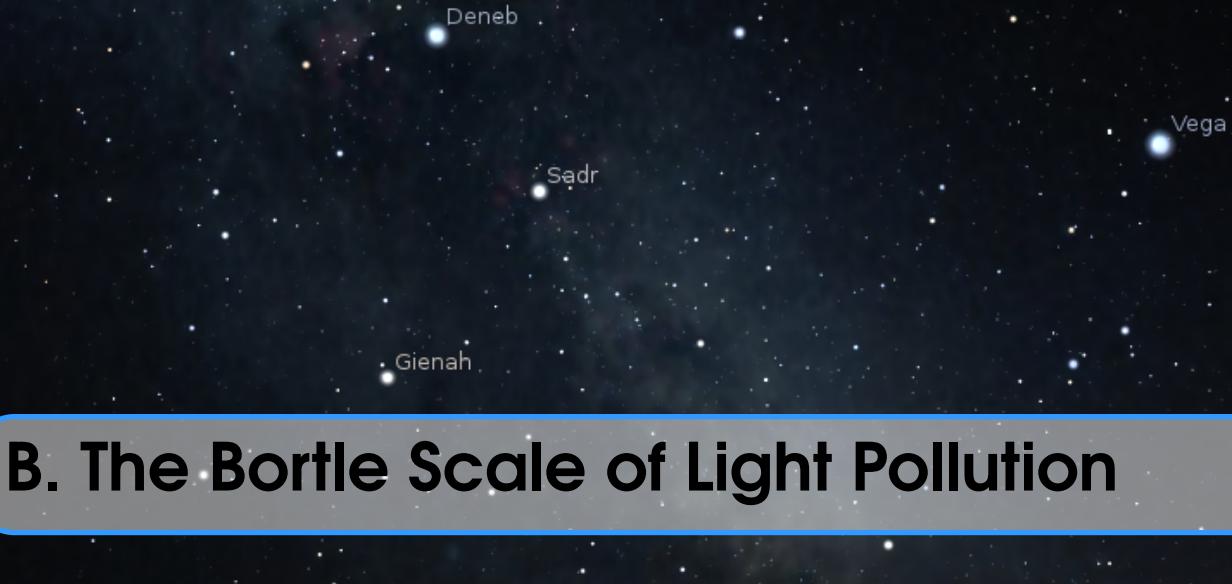
A.8.12 Telescope Control

Shortcut key	Description
`Ctrl`+`0`	Move a telescope to a given set of coordinates (shows dialog)
`Ctrl`+`1`	Move telescope #1 to selected object

Shortcut	Description
Ctrl + 2	Move telescope #2 to selected object
Ctrl + 3	Move telescope #3 to selected object
Ctrl + 4	Move telescope #4 to selected object
Ctrl + 5	Move telescope #5 to selected object
Ctrl + 6	Move telescope #6 to selected object
Ctrl + 7	Move telescope #7 to selected object
Ctrl + 8	Move telescope #8 to selected object
Ctrl + 9	Move telescope #9 to selected object
Alt + 1	Move telescope #1 to the point currently in the center of the screen
Alt + 2	Move telescope #2 to the point currently in the center of the screen
Alt + 3	Move telescope #3 to the point currently in the center of the screen
Alt + 4	Move telescope #4 to the point currently in the center of the screen
Alt + 5	Move telescope #5 to the point currently in the center of the screen
Alt + 6	Move telescope #6 to the point currently in the center of the screen
Alt + 7	Move telescope #7 to the point currently in the center of the screen
Alt + 8	Move telescope #8 to the point currently in the center of the screen
Alt + 9	Move telescope #9 to the point currently in the center of the screen
Ctrl + shift + 0	Move a telescope to a given set of coordinates (shows dialog)
Ctrl + shift + 1	Sync telescope #1 to selected object
Ctrl + shift + 2	Sync telescope #2 to selected object
Ctrl + shift + 3	Sync telescope #3 to selected object
Ctrl + shift + 4	Sync telescope #4 to selected object
Ctrl + shift + 5	Sync telescope #5 to selected object
Ctrl + shift + 6	Sync telescope #6 to selected object
Ctrl + shift + 7	Sync telescope #7 to selected object
Ctrl + shift + 8	Sync telescope #8 to selected object
Ctrl + shift + 9	Sync telescope #9 to selected object
Ctrl + shift + alt + 1	Abort last slew command of telescope #1
Ctrl + shift + alt + 2	Abort last slew command of telescope #2
Ctrl + shift + alt + 3	Abort last slew command of telescope #3
Ctrl + shift + alt + 4	Abort last slew command of telescope #4
Ctrl + shift + alt + 5	Abort last slew command of telescope #5
Ctrl + shift + alt + 6	Abort last slew command of telescope #6
Ctrl + shift + alt + 7	Abort last slew command of telescope #7
Ctrl + shift + alt + 8	Abort last slew command of telescope #8
Ctrl + shift + alt + 9	Abort last slew command of telescope #9

A.8.13 Text User Interface (TUI)

Shortcut key	Description
Alt + T	Activate TUI

B. The Bortle Scale of Light Pollution

The Bortle scale is a nine-level numeric scale that measures the night sky's brightness of a particular location. It quantifies the astronomical observability of celestial objects and the interference caused by light pollution. JOHN E. BORTLE created the scale and published it in *Sky & Telescope* magazine (Bortle, 2001) to help amateur astronomers evaluate the darkness of an observing site, and secondarily, to compare the darkness of observing sites. The scale ranges from Class 1, the darkest skies available on Earth, through Class 9, inner-city skies. It gives several criteria for each level beyond *naked-eye limiting magnitude* (NELM). The accuracy and utility of the scale have been questioned in recent research (Crumey, 2014).

B.1 Excellent dark sky site

Level: 1
Naked-eye limiting magnitude: 7.6 – 8.0
Approx. SQM mag/arcsec^2: 21.7 – 22.0[1]

Zodiacal light, gegenschein, zodiacal band visible; M33 direct vision naked-eye object; Scorpius and Sagittarius regions of the Milky Way cast obvious shadows on the ground; Airglow is readily visible; Jupiter and Venus affect dark adaptation; surroundings basically invisible.

B.2 Typical truly dark site

Level: 2
Naked-eye limiting magnitude: 7.1 – 7.5
Approx. SQM mag/arcsec^2: 21.5 – 21.7

Airglow weakly visible near horizon; M33 easily seen with naked eye; highly structured Summer Milky Way; distinctly yellowish zodiacal light bright enough to cast shadows at dusk and dawn; clouds only visible as dark holes; surroundings still only barely visible silhouetted against the sky; many Messier globular clusters still distinct naked-eye objects.

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[1]Dark Skies Awareness – `http://www.darkskiesawareness.org/nomogram.php`
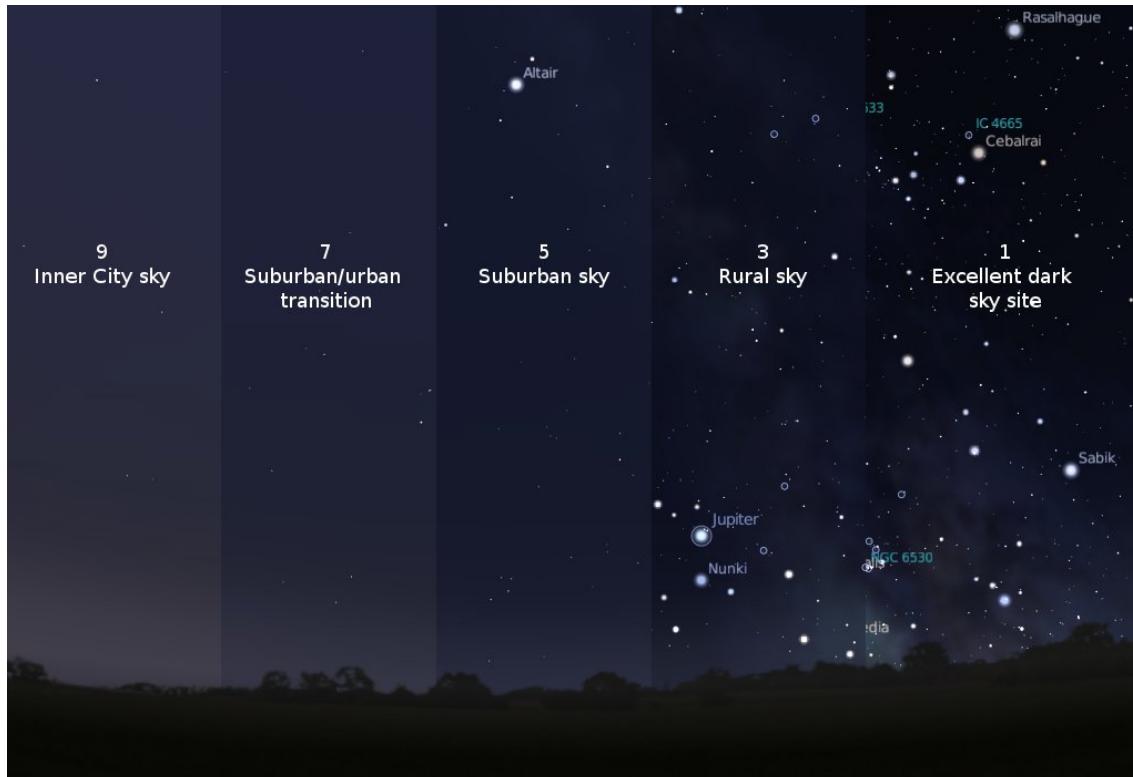
Figure B.1: Light Pollution Simulation / Bortle Scale

B.3   Rural sky

Level: 3
Naked-eye limiting magnitude: 6.6 – 7.0
Approx. SQM mag/arcsec^2: 21.3 – 21.5

   Some light pollution evident at the horizon; clouds illuminated near horizon, dark overhead; Milky Way still appears complex; M15, M4, M5, M22 distinct naked-eye objects; M33 easily visible with averted vision; zodiacal light striking in spring and autumn, color still visible; nearer surroundings vaguely visible.

B.4   Rural/suburban transition

Level: 4
Naked-eye limiting magnitude: 6.1 – 6.5
Approx. SQM mag/arcsec^2: 20.4 – 21.3

   Light pollution domes visible in various directions over the horizon; zodiacal light is still visible, but not even halfway extending to the zenith at dusk or dawn; Milky Way above the horizon still impressive, but lacks most of the finer details; M33 a difficult averted vision object, only visible when higher than 55°; clouds illuminated in the directions of the light sources, but still dark overhead; surroundings clearly visible, even at a distance.

B.5 Suburban sky

Level: 5
Naked-eye limiting magnitude: 5.6 – 6.0
Approx. SQM mag/arcsec^2: 19.1 – 20.4

Only hints of zodiacal light are seen on the best nights in autumn and spring; Milky Way is very weak or invisible near the horizon and looks washed out overhead; light sources visible in most, if not all, directions; clouds are noticeably brighter than the sky.

B.6 Bright suburban sky

Level: 6
Naked-eye limiting magnitude: 5.1 – 5.5
Approx. SQM mag/arcsec^2: 18.0 – 19.1

Zodiacal light is invisible; Milky Way only visible near the zenith; sky within 35° from the horizon glows grayish white; clouds anywhere in the sky appear fairly bright; surroundings easily visible; M33 is impossible to see without at least binoculars, M31 is modestly apparent to the unaided eye.

B.7 Suburban/urban transition

Level: 7
Naked-eye limiting magnitude: 4.6 – 5.0
Approx. SQM mag/arcsec^2: 18.0 – 19.1

Entire sky has a grayish-white hue; strong light sources evident in all directions; Milky Way invisible; M31 and M44 may be glimpsed with the naked eye, but are very indistinct; clouds are brightly lit; even in moderate-sized telescopes the brightest Messier objects are only ghosts of their true selves.

B.8 City sky

Level: 8
Naked-eye limiting magnitude: 4.1 – 4.5
Approx. SQM mag/arcsec^2: <18.0

Sky glows white or orange — you can easily read; M31 and M44 are barely glimpsed by an experienced observer on good nights; even with telescope, only bright Messier objects can be detected; stars forming familiar constellation patterns may be weak or completely invisible.
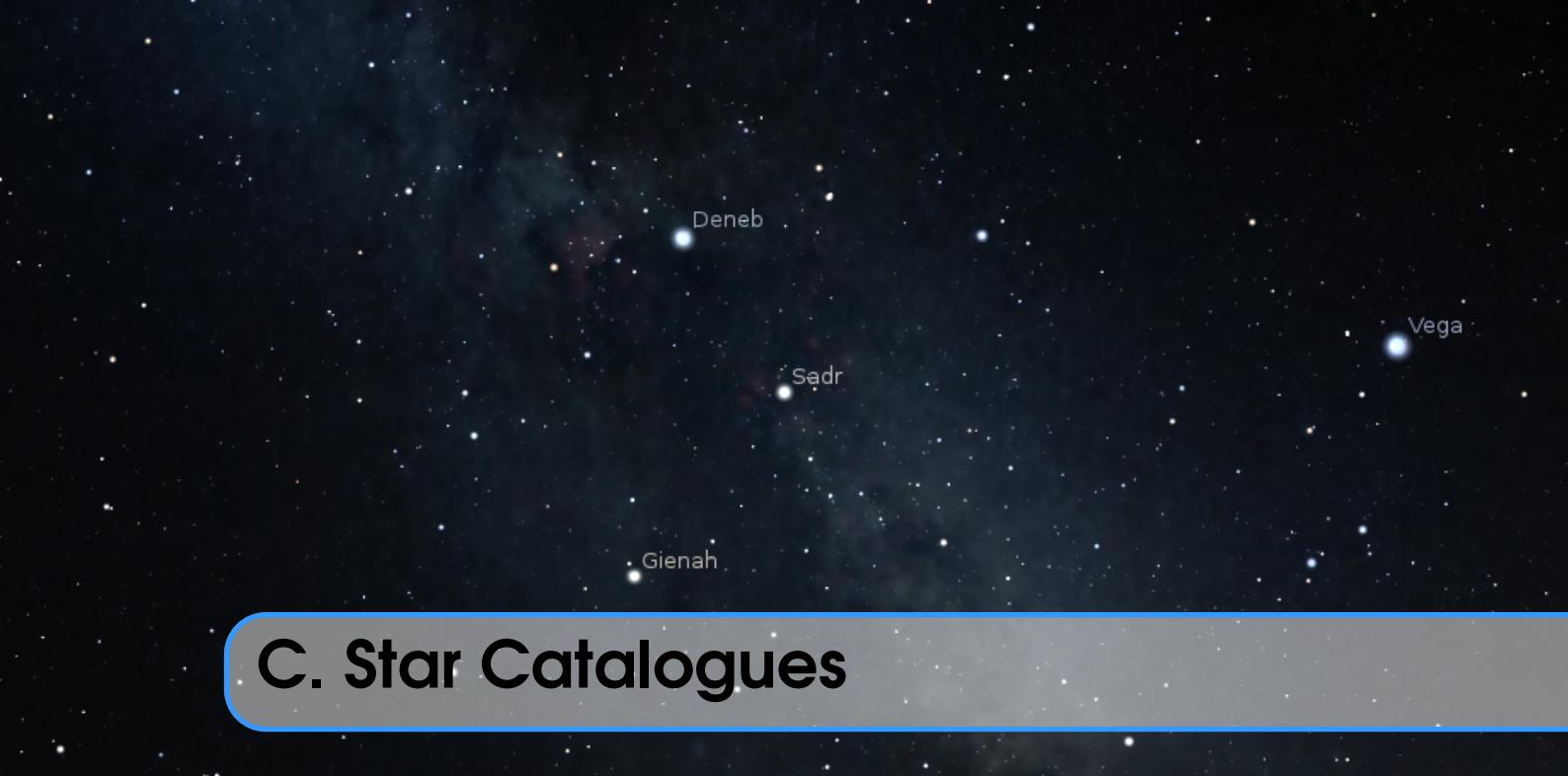
B.9 Inner-city sky

Level: 9
Naked-eye limiting magnitude: 4.0 at best
Approx. SQM mag/arcsec^2: <18.0

Sky is brilliantly lit with many stars forming constellations invisible and many weaker constellations invisible; aside from Pleiades, no Messier object is visible to the naked eye; only objects to provide fairly pleasant views are the Moon, the Planets and a few of the brightest star clusters.

C. Star Catalogues

This chapter provides technical descriptions on how Stellarium records its star catalogues, and the related file formats.

C.1 Stellarium's Sky Model

C.1.1 Zones

The celestial sphere is split into zones, which correspond to the triangular faces of a geodesic sphere. The number of zones (faces) depends on the level of sub-division of this sphere. The lowest level, 0, is an icosahedron (20 faces), subsequent levels L of sub-division give the number of zones n as:

$$n = 20 \cdot 4^L \tag{C.1}$$

Stellarium uses levels 0 to 7 in the existing star catalogues. Star Data Records contain the position of a star as an offset from the central position of the zone in which that star is located, thus it is necessary to determine the vector from the observer to the centre of a zone, and add the star's offsets to find the absolute position of the star on the celestial sphere.

This position for a star is expressed as a 3-dimensional vector which points from the observer (at the centre of the geodesic sphere) to the position of the star as observed on the celestial sphere.

C.2 Star Catalogue File Format

C.2.1 General Description

Stellarium's star catalogue data is kept in the `stars/default` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

The main catalogue data is split into several files:

`stars_0_0v0_8.cat`
`stars_1_0v0_8.cat`

```
stars_2_0v0_8.cat
stars_3_1v0_4.cat
stars_4_1v0_2.cat
stars_5_2v0_1.cat
stars_6_2v0_1.cat
stars_7_2v0_1.cat
stars_8_2v0_1.cat
```

There also exist some control and reference files:

```
stars_hip_cids_0v0_0.cat
stars_hip_sp_0v0_3.cat
gcvs_hip_part.dat
wds_hip_part.dat
cross-id.dat
hip_plx_err.dat
stars.ini
name.fab
```

When Stellarium starts, it reads the `stars.ini` file, from which it determines the names of the other files, which it then loads.

The files `stars_hip_cids_0v0_0.cat` and `stars_hip_sp_0v0_2.cat` contain reference data for the main catalogue files. The file `gcvs_hip_part.dat` contains data about variables stars (see section C.3) and file `wds_hip_part.dat` contains data about double stars (see section C.4) which again contains references into the main catalogue files.

The file `cross-id.dat` (see section C.5) contains cross-identification data between HIP, SAO, HD and HR designations.

The file `hip_plx_err.dat` contains parallax errors data for HIP stars.

A given catalogue file models stars for one and only one level (i.e. for a fixed number of zones), which is recorded in the header of the file. Individual star records do not contain full positional coordinates, instead they contain coordinates relative to the central position of the zone they occupy. Thus, when parsing star catalogues, it is necessary to know about the zone model to be able to extract positional data.

File	Data Type	Data Record Size	Geodesic Level	#Records	Notes
`stars_0_0v0_8.cat`	0	28 bytes	0	4,979	Hipparcos
`stars_1_0v0_8.cat`	0	28 bytes	1	21,806	Hipparcos
`stars_2_0v0_8.cat`	0	28 bytes	2	150,824	Hipparcos
`stars_3_1v0_4.cat`	1	10 bytes	3	425,807	Tycho 2
`stars_4_1v0_2.cat`	1	10 bytes	4	1,692,779	Tycho 2
`stars_5_2v0_1.cat`	2	8 bytes	5	7,083,058	NOMAD
`stars_6_2v0_1.cat`	2	8 bytes	6	24,670,782	NOMAD
`stars_7_2v0_1.cat`	2	8 bytes	7	50,733,321	NOMAD
`stars_8_2v0_1.cat`	2	8 bytes	7	92,304,337	NOMAD

For a given catalogue file, there may be one of three formats for the actual star data. The variation comes from the source of the data – the larger catalogues of fainter stars providing less data per star than the brighter star catalogues. See tables *Stellarium's star catalogue* and for details.

Stellarium's star catalogues are based on Hipparcos (Anderson and Francis, 2012; ESA, 1997), Tycho 2 (Høg et al., 2000) and NOMAD (Zacharias et al., 2004) catalogues.

C.2.2 File Sections

The catalogue files are split into three main sections as described in table C.1.

Section	Offset	Description
File Header Record	0	Contains magic number, geodesic subdivision level, and magnitude range
Zone Records	32	A list of how many records there are for each zone. The length of the zones section depends on the level value from the header
Star Data Records	32+4*n*	This section of the file contains fixed-size star records, as described below. Records do not contain zone information, which must be inferred by counting how many records have been read so far and switching zones when enough have been read to fill the number of stars for the zone, as specified in the zones section above. The value of *n* used in the offset description is the number of zones, as described above.

Table C.1: File sections

C.2.3 Record Types

File Header Record

The File Header Record describes file-wide settings. It also contains a magic number which servers as a file type identifier. See table C.2.

Zone Records

The *Zone Records* section of the file lists the number of star records there are per zone. The number of zones is determined from the level value in the File Header Record, as described in section C.1.1. The Zones section is simply a list of integer values which describe the number of stars for each zone. The total length of the Zones section depends on the number of zones. See table C.3.

Star Data Records

After the Zones section, the actual star data starts. The star data records themselves do not contain the zone in which the star belongs. Instead, the zone is inferred from the position of the record in the file. For example, if the Zone Records section of the file says that the first 100 records are for zone 0, the next 80 for zone 1 and so on, it is possible to infer the zone for a given record by counting how many records have been read so far.

The actual record structure depends on the value of the Data Type, as found in the File Header Record. See tables C.4, C.5 and C.6 for record structure details.

It should be noted that although the positional data loses accuracy as one progresses though the Star Record Types, this is compensated for by the face that the number of zones is much higher for the files where the smaller precision position fields are used, so the actual resolution on the sky isn't significantly worse for the type 1 and 2 records in practice.

Name	Offset	Type	Size	Description
Magic	0	int	4	magic number which identifies the file as a star catalogue. `0xde0955a3`
Data Type	4	int	4	type of the file, which defines the size and structure of the Star Data record for the file.
Major Version	8	int	4	file format major version number
Minor Version	12	int	4	file format minor version number
Level	16	int	4	sets the level of sub-division of the geodesic sphere used to create the zones. 0 means an icosahedron (20 triangular faces), subsequent levels of sub-division lead to numbers of zones as described in section C.2.3
Magnitude Minimum	20	int	4	low bound of the magnitude scale for values in this file. Note that this is still an integer in Stellarium's own internal representation
Magnitude Range	24	int	4	range of magnitudes expressed in this file
Magnitude Steps	28	int	4	number of steps used to describes values in the range

Table C.2: Header Record

Name	Offset	Type	Size	Description
num stars in zone 0	0	int	4	number of records in this file which are in zone 0
num stars in zone 1	4	int	4	number of records is this file which are in zone 1
. . .				
num stars in zone n	$4n$	int	4	number of records is this file which are in zone n

Table C.3: Zones section

Name	Offset	Type	Size	Description
hip	0	int	3	Hipparcos catalogue number
component_ids	3	unsigned char	1	index to an array of catalogue number suffixes. The list is read from the `stars_hip_component_ids.cat` file. The value of this field turns out to be the line number in the file - 1
x0	4	int	4	position of the star relative to the central point in the star's zone, in axis 1
x1	8	int	4	position of the star relative to the central point in the star's zone, in axis 2
b_v	9	unsigned char	1	magnitude level in B-V colour. This value refers to one of 256 discrete steps in the magnitude range for the file
mag	10	unsigned char	1	magnitude level in the V-I colour. This value refers to one of 256 discrete steps in the magnitude range for the file
sp_int	11	unsigned short int	2	index into an array of spectral type descriptions which is taken from the file `stars_hip_sp.cat`, the index corresponds to the line number in the file - 1
dx0	13	int	4	proper motion of the star in axis 1
dx1	17	int	4	proper motion of the star in axis 2
plx	21	int	4	parallax of the star. To get the actual value, divide by 10000.

Table C.4: Star Data Record Type 0

Name	Offset	Type	Size	Description
x0	0	int	20 bits	position of the star relative to the central point in the star's zone, in axis 1
x1	20 bits	int	20 bits	position of the star relative to the central point in the star's zone, in axis 2
dx0	40 bits	int	14 bits	proper motion of the star in axis 1
dx1	54 bits	int	14 bits	proper motion of the star in axis 2
b_v	68 bits	unsigned int	7 bits	magnitude level in B-V colour. This value refers to one of 128 discrete steps in the magnitude range for the file
mag	75 bits	unsigned int	5 bits	magnitude level in the V-I colour. This value refers to one of 32 discrete steps in the magnitude range for the file

Table C.5: Star Data Record Type 1

Name	Offset	Type	Size	Description
x0	0	int	18 bits	position of the star relative to the central point in the star's zone, in axis 1
x1	18 bits	int	18 bits	position of the star relative to the central point in the star's zone, in axis 2
b_v	36 bits	unsigned int	7 bits	magnitude level in B-V colour. This value refers to one of 128 discrete steps in the magnitude range for the file
mag	43 bits	unsigned int	5 bits	magnitude level in the V-I colour. This value refers to one of 32 discrete steps in the magnitude range for the file

Table C.6: Star Data Record Type 2

Name	Type	Description
HIP	int	This is the HIP identificator for the star. Used for reference to the main star catalogue.
GCVS	string	This is the GCVS designation for the variable star.
Type	string	Type of variability.
Max	float	Magnitude at maximum brightness.
MFlag	int	Magnitude flag code (0=No flag; 1="(" if max. magnitude is an amplitude; 2="<" if max. magnitude is a bright limit; 3=">" is max. magnitude is a faint limit).
Min I	float	First minimum magnitude or amplitude.
Min II	float	Second minimum magnitude.
V	char	The photometric system for magnitudes.
Epoch	float	Epoch for maximum or minimum light (in Julian days).
Period	float	Period for the variable star (in days).
M-m	float	Rising time or duration of the eclipse (in percent).
Spectrum	string	Spectral class of the variable star.

Table C.7: Variable Star Catalog File Format

C.3 Variable Stars

Since version 0.12.2 Stellarium supports the subset of variable stars from GCVS[1] which have HIP identificators (i.e., stars from the Hipparcos catalog). Stellarium's Catalog of Variable Stars is based on the "General catalogue of variable stars: Version GCVS 5.1" (Samus' et al., 2017).

C.3.1 Variable Star Catalog File Format
General Description

Stellarium's Variable Stars catalog data is kept in the `stars/default` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

File Format

The `gcvs_hip_part.dat` file contains data about 6862 Variable Stars (see section 18.2.5) which have HIP identificators and are stored in a plain text format with tab delimiter (Table C.7).

C.3.2 GCVS Variability Types

An improved system of variability classification is used in the fourth edition of the GCVS, based on recent developments in classification principles and taking into account the suggestions of a number of specialists. Variability types are grouped according to the major astrophysical reasons for variability.

All of these classes include objects of a dissimilar nature that belong to different types of light variability. On the other hand, an object may be variable because of almost all of the possible reasons or because of any combination of them. If a variable belongs to several types of variability, the types are joined in the data field by a "+" sign, e.g., E+UG, UV+BY.

Despite considerable success in understanding stellar variability processes, the classification adopted in the Catalogue is far from perfect. This is especially the case for explosive, symbiotic and novalike variables; X-ray sources; and peculiar objects.

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[1]`http://www.sai.msu.su/gcvs/gcvs/`

The new variability types (ZZO, AM, R, BE, BLBOO, EP, SRS, LPB) have been added in the Name-Lists 67-77 and in the GCVS vol.V.

You can read about latest different types of variability at SAI GCVS page[2].

Eruptive Variable Stars

Eruptive variables are stars varying in brightness because of violent processes and flares occurring in their chromospheres and coronae. The light changes are usually accompanied by shell events or mass outflow in the form of stellar winds of variable intensity and/or by interaction with the surrounding interstellar medium. This class includes the following types:

BE It becomes more and more clear that, although the majority of Be stars are photometrically variable, not all of them could be properly called GCAS variables. Quite a number of them show small-scale variations not necessarily related to shell events; in some cases the variations are quasi-periodic. By now we are not able to present an elaborated system of classification for Be variables, but we adopt a decision that in the cases when a Be variable cannot be readily described as a GCAS star we give simply BE for the type of variability.

FU Orion variables of the FU Orionis type. Characterized by gradual increases in brightness by about 6 mag in several months, followed by either almost complete constancy at maximum that is sustained for long periods of time or slow decline by 1-2 mag. Spectral types at maximum are in the range Ae(alpha) - Gpe(alpha). After an outburst, a gradual development of an emission spectrum is observed and the spectral type becomes later. These variables probably mark one of the evolutionary stages of T Tauri-type Orion variables (INT), as evidenced by an outburst of one member, V1057 Cyg, but its decline (2.5 mag in 11 years) commenced immediately after maximum brightness was attained. All presently known FU Ori variables are coupled with reflecting cometary nebulae.

GCAS Eruptive irregular variables of the Gamma Cas type. These are rapidly rotating B III-IVe stars with mass outflow from their equatorial zones. The formation of equatorial rings or disks is often accompanied by temporary fading. Light amplitudes may reach 1.5 mag in V.

I Poorly studied irregular variables with unknown features of light variations and spectral types. This is a very inhomogeneous group of objects.

 IA Poorly studied irregular variables of early (O-A) spectral type.

 IB Poorly studied irregular variables of intermediate (F-G) to late (K-M) spectral type.

 IN Orion variables. Irregular, eruptive variables connected with bright or dark diffuse nebulae or observed in the regions of these nebulae. Some of them may show cyclic light variations caused by axial rotation. In the Spectrum-Luminosity diagram, they are found in the area of the main sequence and subgiants. They are probably young objects that, during the course of further evolution, will become light-constant stars on the zero-age main sequence (ZAMS). The range of brightness variations may reach several magnitudes. In the case of rapid light variations having been observed (up to 1 mag in 1-10 days), the letter "S" is added to the symbol for the type (INS). This type may be divided into the following subtypes:

  INA Orion variables of early spectral types (B-A or Ae). They are often characterized by occasional abrupt Algol-like fadings (T Ori);

  INB Orion variables of intermediate and late spectral types, F-M or Fe-Me (BH Cep, AH Ori). F-type stars may show Algol-like fadings similar to those of many INA stars; K-M stars may produce flares along with irregular light variations;

  INT,IT Orion variables of the T Tauri type. Stars are assigned to this type on the basis of the following (purely spectroscopic) criteria: spectral types are in the range Fe-Me. The spectra of most typical stars resemble the spectrum of the solar

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[2]`http://www.sai.msu.su/gcvs/gcvs/vartype.htm`

chromosphere. The feature specific to the type is the presence of the flourescent emission lines Fe II 4046, 4132 A (anomalously intense in the spectra of these stars), emission lines [Si II] and [O I], as well as the absorption line Li I 6707 A. These variables are usually observed only in diffuse nebulae. If it is not apparent that the star is associated with a nebula, the letter "N" in the symbol for the type may be omitted, e.g., IT (RW AUR);

IN(YY) Some Orion variables (YY Ori) show the presence of absorption components on the redward sides of emission lines, indicating the infall of matter toward the stars' surfaces. In such cases, the symbol for the type may be accompanied by the symbol "YY".

IS Rapid irregular variables having no apparent connection with diffuse nebulae and showing light changes of about 0.5 - 1.0 mag within several hours or days. There is no strict boundary between rapid irregular and Orion variables. If a rapid irregular star is observed in the region of a diffuse nebula, it is considered an Orion variable and designated by the symbol INS. To attribute a variable to the IS type, it is necessary to take much care to be certain that its light changes are really not periodic. Quite a number of the stars assigned to this type in the third edition of the GCVS turned out to be eclipsing binary systems, RR Lyrae variables, and even extragalactic BL Lac objects.

ISA Rapid irregular variables of the early spectral types, B-A or Ae;

ISB Rapid irregular variables of the intermediate and late spectral types, F-M and Fe-Me.

RCB Variables of the R Coronae Borealis type. These are hydrogen-poor, carbon- and helium-rich, high-luminosity stars belonging to the spectral types Bpe-R, which are simultaneously eruptive and pulsating variables. They show slow nonperiodic fadings by 1-9 mag in V lasting from a month or more to several hundred days. These changes are superposed on cyclic pulsations with amplitudes up to several tenths of a magnitude and periods in the range 30-100 days.

RS Eruptive variables of the RS Canum Venaticorum type. This type is ascribed to close binary systems with spectra showing Ca II H and K in emission, their components having enhanced chromospheric activity that causes quasi-periodic light variability. The period of variation is close to the orbital one, and the variability amplitude is usually as great as 0.2 mag in V (UX Ari). They are X-ray sources and rotating variables. RS CVn itself is also an eclipsing system (see below).

SDOR Variables of the S Doradus type. These are eruptive, high-luminosity Bpec-Fpec stars showing irregular (sometimes cyclic) light changes with amplitudes in the range 1-7 mag in V. They belong to the brightest blue stars of their parent galaxies. As a rule, these stars are connected with diffuse nebulae and surrounded by expanding envelopes (P Cyg, Eta Car).

UV Eruptive variables of the UV Ceti type, these are K Ve-M Ve stars sometimes displaying flare activity with amplitudes from several tenths of a magnitude up to 6 mag in V. The amplitude is considerably greater in the ultraviolet spectral region. Maximum light is attained in several seconds or dozens of seconds after the beginning of a flare; the star returns to its normal brightness in several minutes or dozens of minutes.

UVN Flaring Orion variables of spectral types Ke-Me. These are phenomenologically almost identical to UV Cet variables observed in the solar neighborhood. In addition to being related to nebulae, they are normally characterized by being of earlier spectral type and greater luminosity, with slower development of flares (V389 Ori). They are possibly a specific subgroup of INB variables with irregular variations superimposed by flares.

WR Eruptive Wolf-Rayet variables. Stars with broad emission features of He I and He II as well as

C II-C IV, O II-O IV, and N III-N V. They display irregular light changes with amplitudes up to 0.1 mag in V, which are probably caused by physical processes, in particular, by nonstable mass outflow from their atmospheres.

Pulsating Variable Stars

Pulsating variables are stars showing periodic expansion and contraction of their surface layers. The pulsations may be radial or nonradial. A radially pulsating star remains spherical in shape, while in the case of nonradial pulsations the star's shape periodically deviates from a sphere, and even neighboring zones of its surface may have opposite pulsation phases.

Depending on the period value, on the mass and evolutionary status of the star, and on the scale of pulsational phenomena, the following types of pulsating variables may be distinguished:

ACYG Variables of the Alpha Cygni type, which are nonradially pulsating supergiants of Bep-AepIa spectral types. The light changes with amplitudes of the order of 0.1 mag often seem irregular, being caused by the superposition of many oscillations with close periods. Cycles from several days to several weeks are observed.

BCEP Variables of the Beta Cephei type (Beta Cep, Beta CMa), which are pulsating O8-B6 I-V stars with periods of light and radial-velocity variations in the range of 0.1 - 0.6 days and light amplitudes from 0.01 to 0.3 mag in V. The light curves are similar in shape to average radial-velocity curves but lag in phase by a quarter of the period, so that maximum brightness corresponds to maximum contraction, i.e., to minimum stellar radius. The majority of these stars probably show radial pulsations, but some (V469 Per) display nonradial pulsations; multiperiodicity is characteristic of many of these stars.

> **BCEPS** A short-period group of Beta Cep variables. The spectral types are B2-B3 IV-V; periods and light amplitudes are in the ranges 0.02 - 0.04 days and 0.015 - 0.025 days, respectively, i.e., an order of magnitude smaller than the normally observed ones.

BLBOO The so-called "anomalous Cepheids", i.e. stars with periods characteristic of comparatively long-period RRAB variables, but considerably brighter by luminosity (BL Boo = NGC 5466 V19).

CEP Cepheids. Radially pulsating, high luminosity (classes Ib-II) variables with periods in the range of 1-135 days and amplitudes from several hundredths to 2 mag in V (in the B band, the amplitudes are greater). Spectral type at maximum light is F; at minimum, the types are G-K. The longer the period of light variation, the later is the spectral type. The maximum of the surface-layer expansion velocity almost coinciding with maximum light.

> **CEP(B)** Cepheids (TU Cas, V 367 Sct) displaying the presence of two or more simultaneously operating pulsation modes (usually the fundamental tone with the period P0 and the first overtone P1). The periods P0 are in the range from 2 to 7 days, with the ratio P1/P0 approx. 0.71.

CW Variables of the W Virginis type. These are pulsating variables of the galactic spherical component (old disk) population with periods of approximately 0.8 to 35 days and amplitudes from 0.3 to 1.2 mag in V. They obey a period-luminosity relation different from that for Delta Cep variables (see DCEP). For an equal period value, the W Vir variables are fainter than the Delta Cep stars by 0.7 - 2 mag. The light curves of W Vir variables for some period intervals differ from those of Delta Cep variables for corresponding periods either by amplitudes or by the presence of humps on their descending branches, sometimes turning into broad flat maxima. W Vir variables are present in globular clusters and at high galactic latitudes. They may be separated into the following subtypes:

> **CWA** W Vir variables with periods longer than 8 days (W Vir);

> **CWB** W Vir variables with periods shorter than 8 days (BL Her).

DCEP These are the classical cepheids, or Delta Cep-type variables. Comparatively young objects

that have left the main sequence and evolved into the instability strip of the Hertzsprung-Russell (H-R) diagram, they obey the well-known Cepheid period-luminosity relation and belong to the young disk population. DCEP stars are present in open clusters. They display a certain relation between the shapes of their light curves and their periods.

DCEPS These are Delta Cep variables having light amplitudes <0.5 mag in V (<0.7 mag in B) and almost symmetrical light curves (M-m approx. 0.4 - 0.5 periods); as a rule, their periods do not exceed 7 days. They are probably first-overtone pulsators and/or are in the first transition across the instability strip after leaving the main sequence (SU Cas).

Traditionally, both Delta Cep and W Vir stars are quite often called Cepheids because it is often impossible to discriminate between them on the basis of the light curves for periods in the range 3 - 10 days. However, these are distinct groups of entirely different objects in different evolutionary stages. One of the significant spectral differences between W Vir stars and Cepheids is the presence, during a certain phase interval, of hydrogen-line emission in the former and of Ca II H and K emission in the latter.

DSCT Variables of the Delta Scuti type. These are pulsating variables of spectral types A0-F5 III-V displaying light amplitudes from 0.003 to 0.9 mag in V (usually several hundredths of a magnitude) and periods from 0.01 to 0.2 days. The shapes of the light curves, periods, and amplitudes usually vary greatly. Radial as well as nonradial pulsations are observed. The variability of some members of this type appears sporadically and sometimes completely ceases, this being a consequence of strong amplitude modulation with the lower value of the amplitude not exceeding 0.001 mag in some cases. The maximum of the surface layer expansion does not lag behind the maximum light for more than 0.1 periods. DSCT stars are representatives of the galactic disk (flat component) and are phenomenologically close to the SX Phe variables.

DSCTC Low amplitude group of Delta Sct variables (light amplitude <0.1 mag in V). The majority of this type's representatives are stars of luminosity class V; objects of this subtype generally are representative of the Delta Sct variables in open clusters.

GDOR Gamma Doradus stars. Early type F dwarfs showing (multiple) periods from several tenths of a day to slightly in excess of one day. Amplitudes usually do not exceed 0.1 mag. Presumably low degree g-mode non-radial pulsators. Prototype: gamma Dor.

L Slow irregular variables. The light variations of these stars show no evidence of periodicity, or any periodicity present is very poorly defined and appears only occasionally. Like for the type I, stars are often attributed to this type because of being insufficiently studied. Many type L variables are really semiregulars or belong to other types.

LB Slow irregular variables of late spectral types (K, M, C, S); as a rule, they are giants (CO Cyg). This type is also ascribed, in the GCVS, to slow red irregular variables in the case of unknown spectral types and luminosities.

LC Irregular variable supergiants of late spectral types having amplitudes of about 1 mag in V (TZ Cas).

LPB The comparatively long-period pulsating B stars (periods exceeding (LBV) one day).

M Mira (Omicron) Ceti-type variables. These are long-period variable giants with characteristic late-type emission spectra (Me, Ce, Se) and light amplitudes from 2.5 to 11 mag in V. Their periodicity is well pronounced, and the periods lie in the range between 80 and 1000 days. Infrared amplitudes are usually less than in the visible and may be <2.5 mag. For example, in the K band they usually do not exceed 0.9 mag. If the amplitudes exceed 1 - 1.5 mag , but it is not certain that the true light amplitude exceeds 2.5 mag, the symbol "M" is followed by a colon, or the star is attributed to the semiregular class with a colon following the symbol for that type (SR).

PVTEL Variables of the PV Telescopii type. These are helium supergiant Bp stars with weak hydrogen lines and enhanced lines of He and C. They pulsate with periods of approximately 0.1 to 1 days, or vary in brightness with an amplitude of 0.1 mag in V during a time interval of about a year.

RPHS Very rapidly pulsating hot (subdwarf B) stars. Typical periods are hundreds of seconds, amplitudes are within several hundredths of a magnitude. Prototype: V361 Hya = EC 14026-2647.

RR Variables of the RR Lyrae type, which are radially-pulsating giant A-F stars having amplitudes from 0.2 to 2 mag in V. Cases of variable light-curve shapes as well as variable periods are known. If these changes are periodic, they are called the *Blazhko effect*.

Traditionally, RR Lyrae stars are sometimes called short-period Cepheids or cluster-type variables. The majority of these stars belong to the spherical component of the Galaxy; they are present, sometimes in large numbers, in some globular clusters, where they are known as pulsating horizontal-branch stars. Like Cepheids, maximum expansion velocities of surface layers for these stars practically coincide with maximum light.

    RR(B) RR Lyrae variables showing two simultaneously operating pulsation modes, the fundamental tone with the period P0 and the first overtone, P1 (AQ Leo). The ratio P1/P0 is approximately 0.745;

    RRAB RR Lyrae variables with asymmetric light curves (steep ascending branches), periods from 0.3 to 1.2 days, and amplitudes from 0.5 to 2 mag in V;

    RRC RR Lyrae variables with nearly symmetric, sometimes sinusoidal, light curves, periods from 0.2 to 0.5 days, and amplitudes not greater than 0.8 mag in V (SX UMa).

RV Variables of the RV Tauri type. These are radially pulsating supergiants having spectral types F-G at maximum light and K-M at minimum. The light curves are characterized by the presence of double waves with alternating primary and secondary minima that can vary in depth so that primary minima may become secondary and vice versa. The complete light amplitude may reach 3-4 mag in V. Periods between two adjacent primary minima (usually called formal periods) lie in the range 30-150 days (these are the periods appearing in the Catalogue). Two subtypes, RVA and RVB, are recognized:

    RVA RV Tauri variables that do not vary in mean magnitude (AC Her);

    RVB RV Tauri variables that periodically (with periods from 600 to 1500 days and amplitudes up to 2 mag in V) vary in mean magnitude (DF Cyg, RV Tau).

SR Semiregular variables, which are giants or supergiants of intermediate and late spectral types showing noticeable periodicity in their light changes, accompanied or sometimes interrupted by various irregularities. Periods lie in the range from 20 to >2000 days, while the shapes of the light curves are rather different and variable, and the amplitudes may be from several hundredths to several magnitudes (usually 1-2 mag in V).

    SRA Semiregular late-type (M, C, S or Me, Ce, Se) giants displaying persistent periodicity and usually small (<2.5 mag in V) light amplitudes (Z Aqr). Amplitudes and light-curve shapes generally vary and periods are in the range of 35-1200 days. Many of these stars differ from Miras only by showing smaller light amplitudes;

    SRB Semiregular late-type (M, C, S or Me, Ce, Se) giants with poorly defined periodicity (mean cycles in the range of 20 to 2300 days) or with alternating intervals of periodic and slow irregular changes, and even with light constancy intervals (RR CrB, AF Cyg). Every star of this type may usually be assigned a certain mean period (cycle), which is the value given in the Catalogue. In a number of cases, the simultaneous presence of two or more periods of light variation is observed;

    SRC Semiregular late-type (M, C, S or Me, Ce, Se) supergiants (Mu Cep) with amplitudes of about 1 mag and periods of light variation from 30 days to several thousand days;

SRD Semiregular variable giants and supergiants of F, G, or K spectral types, sometimes with emission lines in their spectra. Amplitudes of light variation are in the range from 0.1 to 4 mag, and the range of periods is from 30 to 1100 days (SX Her, SV UMa).

SRS Semiregular pulsating red giants with short period (several days to a month), probably high-overtone pulsators. Prototype: AU Ari.

SXPHE Phenomenologically, these resemble DSCT (Delta Sct) variables and are pulsating subdwarfs of the spherical component, or old disk galactic population, with spectral types in the range A2-F5. They may show several simultaneous periods of oscillation, generally in the range 0.04-0.08 days, with variable-amplitude light changes that may reach 0.7 mag in V. These stars are present in globular clusters.

ZZ ZZ Ceti variables. These are nonradially pulsating white dwarfs that change their brightnesses with periods from 30 s to 25 min and amplitudes from 0.001 to 0.2 mag in V. They usually show several close period values. Flares of 1 mag are sometimes observed; however, these may be explained by the presence of close UV Ceti companions.

These variables are divided into the following subtypes:

ZZA ZZ Cet-type variables of DA spectral type (ZZ Cet) having only hydrogen absorption lines in their spectra;

ZZB ZZ Cet-type variables of DB spectral type having only helium absorption lines in their spectra.

ZZO ZZ Cet-type variables of the DO spectral type showing HeII and and CIV absorpion lines in their spectra.

Rotating Variable Stars

Variable stars with nonuniform surface brightness and/or ellipsoidal shapes, whose variability is caused by axial rotation with respect to the observer. The nonuniformity of surface brightness distributions may be caused by the presence of spots or by some thermal or chemical inhomogeneity of the atmosphere caused by a magnetic field whose axis is not coincident with the rotation axis. These stars are subdivided into the following types:

ACV Alpha2 Canum Venaticorum variables. These are main-sequence stars with spectral types B8p-A7p and displaying strong magnetic fields. Spectra show abnormally strong lines of Si, Sr, Cr, and rare earths whose intensities vary with rotation. They exhibit magnetic field and brightness changes (periods of 0.5-160 days or more). The amplitudes of the brightness changes are usually within 0.01-0.1 mag in V.

ACVO Rapidly oscillating Alpha2 CVn variables. These are nonradially pulsating, rotating magnetic variables of Ap spectral type (DO Eri). Pulsation periods are in the range of 6-12 mmag (0.004-0.01 days), while amplitudes of light variation caused by the pulsation are about 0.01 mag in V. The pulsational variations are superposed on those caused by rotation.

BY BY Draconis-type variables, which are emission-line dwarfs of dKe-dMe spectral type showing quasiperiodic light changes with periods from a fraction of a day to 120 days and amplitudes from several hundredths to 0.5 mag in V. The light variability is caused by axial rotation of a star with a variable degree of nonuniformity of the surface brightness (spots) and chromospheric activity. Some of these stars also show flares similar to those of UV Cet stars, and in those cases they also belong to the latter type and are simultaneously considered eruptive variables.

ELL Rotating ellipsoidal variables (b Per, Alpha Vir). These are close binary systems with ellipsoidal components, which change combined brightnesses with periods equal to those of orbital motion because of changes in emitting areas toward an observer, but showing no eclipses. Light amplitudes do not exceed 0.1 mag in V.

FKCOM FK Comae Berenices-type variables. These are rapidly rotating giants with nonuniform surface brightnesses, which have G-K spectral types with broad H and K Ca II emission and sometimes Halpha. They may also be spectroscopic binary systems. Periods of light variation (up to several days) are equal to rotational periods, and amplitudes are several tenths of a magnitude. It is not excluded that these objects are the product of further evolution of EW (W UMa) close binary systems (see below).

PSR Optically variable pulsars (CM Tau), which are rapidly rotating neutron stars with strong magnetic fields, radiating in the radio, optical, and X-ray regions. Pulsars emit narrow beams of radiation, and periods of their light changes coincide with rotational periods (from 0.004 to 4 s), while amplitudes of the light pulses reach 0.8 mag.

R Close binary systems characterized by the presence of strong reflection (re-radiation) of the light of the hot star illuminating the surface of the cooler companion. Light curves are sinusoidal with the period equal to Porb, maximum brightness coinciding with the passage of the hot star in front of the companion. The eclipse may be absent. The range of light variation is about 0.5-1.0mag V (KV Vel).

SXARI SX Arietis-type variables. These are main-sequence B0p-B9p stars with variable-intensity He I and Si III lines and magnetic fields. They are sometimes called helium variables. Periods of light and magnetic field changes (about 1 day) coincide with rotational periods, while amplitudes are approximately 0.1 mag in V. These stars are high-temperature analogs of the ACV variables.

Cataclysmic (Explosive and Novalike) Variables

These are variable stars showing outbursts caused by thermonuclear burst processes in their surface layers (novae) or deep in their interiors (supernovae). We use the term "novalike" for variables that show novalike outbursts caused by rapid energy release in the surrounding space (UG-type stars - see below) and also for objects not displaying outbursts but resembling explosive variables at minimum light by their spectral (or other) characteristics. The majority of explosive and novalike variables are close binary systems, their components having strong mutual influence on the evolution of each star. It is often observed that the hot dwarf component of the system is surrounded by an accretion disk formed by matter lost by the other, cooler, and more extended component. This category is subdivided into the following types:

N Novae. Close binary systems with orbital periods from 0.05 to 230 days. One of the components of these systems is a hot dwarf star that suddenly, during a time interval from one to several dozen or several hundred days, increases its brightness by 7-19 mag in V, then returns gradually to its former brightness over several months, years, or decades. Small changes at minimum light may be present. Cool components may be giants, subgiants, or dwarfs of K-M type. The spectra of novae near maximum light resemble A-F absorption spectra of luminous stars at first. Then broad emission lines (bands) of hydrogen, helium, and other elements with absorption components indicating the presence of a rapidly expanding envelope appear in the spectrum. As the light decreases, the composite spectrum begins to show forbidden lines characteristic of the spectra of gas nebulae excited by hot stars. At minimum light, the spectra of novae are generally continuous or resemble the spectra of Wolf-Rayet stars. Only spectra of the most massive systems show traces of cool components. Some novae reveal pulsations of hot components with periods of approximately 100 s and amplitudes of about 0.05 mag in V after an outburst. Some novae eventually turn out to be eclipsing systems. According to the features of their light variations, novae are subdivided into fast (NA), slow (NB), very slow (NC), and recurrent (NR) categories.

NA Fast novae displaying rapid light increases and then, having achieved maximum light, fading by 3 mag in 100 or fewer days (GK Per);

NB Slow novae that fade after maximum light by 3 mag in >= 150 days (RR Pic). Here the presence of the well-known "dip" in the light curves of novae similar to T Aur and DQ Her is not taken into account: The rate of fading is estimated on the basis of a smooth curve, its parts before and after the "dip" being a direct continuation of one another;

NC Novae with a very slow development and remaining at maximum light for more than a decade, then fading very slowly. Before an outburst these objects may show long-period light changes with amplitudes of 1-2 mag in V (RR Tel); cool components of these systems are probably giants or supergiants, sometimes semiregular variables, and even Mira variables. Outburst amplitudes may reach 10 mag. High excitation emission spectra resemble those of planetary nebulae, Wolf-Rayet stars, and symbiotic variables. The possibility that these objects are planetary nebulae in the process of formation is not excluded;

NL Novalike variables, which are insufficiently studied objects resembling novae by the characteristics of their light changes or by spectral features. This type includes, in addition to variables showing novalike outbursts, objects with no bursts ever observed; the spectra of novalike variables resemble those of old novae, and small light changes resemble those typical for old novae at minimum light. However, quite often a detailed investigation makes it possible to reclassify some representatives of this highly inhomogeneous group of objects into other types;

NR Recurrent novae, which differ from typical novae by the fact that two or more outbursts (instead of a single one) separated by 10-80 years have been observed (T CrB).

SN Supernovae (B Cas, CM Tau). Stars that increase, as a result of an outburst, their brightnesses by 20 mag and more, then fade slowly. The spectrum during an outburst is characterized by the presence of very broad emission bands, their widths being several times greater than those of the bright bands observed in the spectra of novae. The expansion velocities of SN envelopes are in the thousands of km/s. The structure of a star after outburst alters completely. An expanding emission nebula results and a (not always observable) pulsar remains at the position of the original star. According to the light curve shape and the spectral features, supernovae are subdivided into types I and II.

SNI Type I supernovae. Absorption lines of Ca II, Si, etc., but no hydrogen lines are present in the spectra. The expanding envelope almost lacks hydrogen. During 20-30 days following maximum light, the brightness decreases by approximately 0.1 mag per day, then the rate of fading slows and reaches a constant value of 0.014/day;

SNII Type II supernovae. Lines of hydrogen and other elements are apparent in their spectra. The expanding envelope consists mainly of H and He. Light curves show greater diversity than those of type I supernovae. Usually after 40-100 days since maximum light, the rate of fading is 0.1 mag per day.

UG U Geminorum-type variables, quite often called dwarf novae. They are close binary systems consisting of a dwarf or subgiant K-M star that fills the volume of its inner Roche lobe and a white dwarf surrounded by an accretion disk. Orbital periods are in the range 0.05-0.5 days. Usually only small, in some cases rapid, light fluctuations are observed, but from time to time the brightness of a system increases rapidly by several magnitudes and, after an interval of from several days to a month or more, returns to the original state. Intervals between two consecutive outbursts for a given star may vary greatly, but every star is characterized by a certain mean value of these intervals, i.e., a mean cycle that corresponds to the mean light amplitude. The longer the cycle, the greater the amplitude. These systems are frequently sources of X-ray emission. The spectrum of a system at minimum is continuous, with broad H and He emission lines. At maximum these lines almost disappear or become shallow absorption lines. Some of these systems are eclipsing, possibly indicating that the primary

minimum is caused by the eclipse of a hot spot that originates in the accretion disk from the infall of a gaseous stream from the K-M star. According to the characteristics of the light changes, U Gem variables may be subdivided into three types: SS Cyg, SU UMa, and Z Cam.

UGSS SS Cygni-type variables (SS Cyg, U Gem). They increase in brightness by 2-6 mag in V in 1-2 days and in several subsequent days return to their original brightnesses. The values of the cycle are in the range 10 days to several thousand;

UGSU SU Ursae Majoris-type variables. These are characterized by the presence of two types of outbursts called "normal" and "supermaxima". Normal, short outbursts are similar to those of UGSS stars, while supermaxima are brighter by 2 mag, are more than five times longer (wider), and occur several times less frequently. During supermaxima the light curves show superposed periodic oscillations (superhumps), their periods being close to the orbital ones and amplitudes being about 0.2-0.3 mag in V. Orbital periods are shorter than 0.1 days; companions are of dM spectral type;

UGZ Z Camelopardalis-type stars. These also show cyclic outbursts, differing from UGSS variables by the fact that sometimes after an outburst they do not return to the original brightness, but during several cycles retain a magnitude between maximum and minimum. The values of cycles are from 10 to 40 days, while light amplitudes are from 2 to 5 mag in V.

ZAND Symbiotic variables of the Z Andromedae type. They are close binaries consisting of a hot star, a star of late type, and an extended envelope excited by the hot star's radiation. The combined brightness displays irregular variations with amplitudes up to 4 mag in V. A very inhomogeneous group of objects.

Close Binary Eclipsing Systems

We adopt a triple system of classifying eclipsing binary systems: according to the shape of the combined light curve, as well as to physical and evolutionary characteristics of their components. The classification based on light curves is simple, traditional, and suits the observers; the second and third classification methods take into account positions of the binary-system components in the (MV ,B-V) diagram and the degree of inner Roche lobe filling. Estimates are made by applying the simple criteria proposed by Svechnikov and Istomin (1979). The symbols for the types of eclipsing binary systems that we use are given below.

Classification based on the shape of the light curve

E Eclipsing binary systems. These are binary systems with orbital planes so close to the observer's line of sight (the inclination i of the orbital plane to the plane orthogonal to the line of sight is close to 90 deg) that the components periodically eclipse each other. Consequently, the observer finds changes of the apparent combined brightness of the system with the period coincident with that of the components' orbital motion.

EA Algol (Beta Persei)-type eclipsing systems. Binaries with spherical or slightly ellipsoidal components. It is possible to specify, for their light curves, the moments of the beginning and end of the eclipses. Between eclipses the light remains almost constant or varies insignificantly because of reflection effects, slight ellipsoidality of components, or physical variations. Secondary minima may be absent. An extremely wide range of periods is observed, from 0.2 to >= 10000 days. Light amplitudes are also quite different and may reach several magnitudes.

EB Beta Lyrae-type eclipsing systems. These are eclipsing systems having ellipsoidal components and light curves for which it is impossible to specify the exact times of onset and end of eclipses because of a continuous change of a system's apparent combined brightness between eclipses; secondary minimum is observed in all cases,

its depth usually being considerably smaller than that of the primary minimum; periods are mainly longer than 1 day. The components generally belong to early spectral types (B-A). Light amplitudes are usually <2 mag in V.

EP Stars showing eclipses by their planets. Prototype: V0376 Peg.

EW W Ursae Majoris-type eclipsing variables. These are eclipsers with periods shorter than 1 days, consisting of ellipsoidal components almost in contact and having light curves for which it is impossible to specify the exact times of onset and end of eclipses. The depths of the primary and secondary minima are almost equal or differ insignificantly. Light amplitudes are usually <0.8 mag in V. The components generally belong to spectral types F-G and later.

Classification according to the components' physical characteristics

GS Systems with one or both giant and supergiant components; one of the components may be a main sequence star.

PN Systems having, among their components, nuclei of planetary nebulae (UU Sge).

RS RS Canum Venaticorum-type systems. A significant property of these systems is the presence in their spectra of strong Ca II H and K emission lines of variable intensity, indicating increased chromospheric activity of the solar type. These systems are also characterized by the presence of radio and X-ray emission. Some have light curves that exhibit quasi sine waves outside eclipses, with amplitudes and positions changing slowly with time. The presence of this wave (often called a distortion wave) is explained by differential rotation of the star, its surface being covered with groups of spots; the period of the rotation of a spot group is usually close to the period of orbital motion (period of eclipses) but still differs from it, which is the reason for the slow change (migration) of the phases of the distortion wave minimum and maximum in the mean light curve. The variability of the wave's amplitude (which may be up to 0.2 mag in V) is explained by the existence of a long-period stellar activity cycle similar to the 11-year solar activity cycle, during which the number and total area of spots on the star's surface vary.

WD Systems with white-dwarf components.

WR Systems having Wolf-Rayet stars among their components (V444 Cyg).

Classification based on the degree of filling of inner Roche lobes

AR Detached systems of the AR Lacertae type. Both components are subgiants not filling their inner equipotential surfaces.

D Detached systems, with components not filling their inner Roche lobes.

DM Detached main-sequence systems. Both components are main-sequence stars and do not fill their inner Roche lobes.

DS Detached systems with a subgiant. The subgiant also does not fill its inner critical surface.

DW Systems similar to W UMa systems in physical properties (KW, see below), but not in contact.

K Contact systems, both components filling their inner critical surfaces.

KE Contact systems of early (O-A) spectral type, both components being close in size to their inner critical surfaces.

KW Contact systems of the W UMa type, with ellipsoidal components of F0-K spectral type. Primary components are main-sequence stars and secondaries lie below and to the left of the main sequence in the (MV,B-V) diagram.

SD Semidetached systems in which the surface of the less massive component is close to its inner Roche lobe.

The combination of the above three classification systems for eclipsers results in the assignment

of multiple classifications for object types. These are separated by a solidus ("/") in the data field. Examples are: E/DM, EA/DS/RS, EB/WR, EW/KW, etc.

Optically Variable Close Binary Sources of Strong, Variable X-ray Radiation (X-ray Sources)

AM AM Her type variables; close binary systems consisting of a dK-dM type dwarf and of a compact object with strong magnetic field, characterized by variable linear and circular polarization of light. The total range of light variations may reach 4-5 mag V.

X Close binary systems that are sources of strong, variable X-ray emission and which do not belong to or are not yet attributed to any of the above types of variable stars. One of the components of the system is a hot compact object (white dwarf, neutron star, or possibly a black hole). X-ray emission originates from the infall of matter onto the compact object or onto an accretion disk surrounding the compact object. In turn, the X-ray emission is incident upon the atmosphere of the cooler companion of the compact object and is reradiated in the form of optical high-temperature radiation (reflection effect), thus making that area of the cooler companion's surface an earlier spectral type. These effects lead to quite a peculiar complex character of optical variability in such systems. These objects may be subdivided into the following types:

    XB X-ray bursters. Close binary systems showing X-ray and optical bursts, their duration being from several seconds to ten minutes, with amplitudes of about 0.1 mag in V (V 801 Ara, V 926 Sco);

    XF Fluctuating X-ray systems showing rapid variations of X-ray (Cygnus X-1 = V1357 Cyg) and optical (V821 Ara) radiation on time scalesof dozens of milliseconds;

    XI X-ray irregulars. Close binary systems consisting of a hot compact object surrounded by an accretion disk and a dA - dM-type dwarf. These display irregular light changes on time scales of minutes and hours, and amplitudes of about 1 mag in V. Superposition of a periodic variation because of orbital motion is possible (V818 Sco);

    XJ X-ray binaries characterized by the presence of relativistic jets evident at X-ray and radio wavelengths, as well as in the optical spectrum in the form of emission components showing periodic displacements with relativistic velocities (V1343 Aql);

    XND X-ray, novalike (transient) systems containing, along with a hot compact object, a dwarf or subgiant of G-M spectral type. These systems occasionally rapidly increase in brightness by 4-9 mag in V, in the visible simultaneously with the X-ray range, with no envelope ejected. The duration of the outburst may be up to several months (V616 Mon);

    XNG X-ray, novalike (transient) systems with an early-type supergiant or giant primary component and a hot compact object as a companion. Following the main component's outburst, the material ejected by it falls onto the compact object and causes, with a significant delay, the appearance of X rays. The amplitudes are about 1-2 mag in V (V725 Tau);

    XP X-ray pulsar systems. The primary component is usually an ellipsoidal early-type supergiant. The reflection effect is very small and light variability is mainly caused by the ellipsoidal primary component's rotation. Periods of light changes are between 1 and 10 days; the period of the pulsar in the system is from 1 s to 100 min. Light amplitudes usually do not exceed several tenths of a magnitude (Vela X-1 = GP Vel);

    XPR X-ray pulsar systems featuring the presence of the reflection effect. They consist of a dB-dF-type primary and an X-ray pulsar, which may also be an optical pulsar. The mean light of the system is brightest when the primary component is irradiated by X rays; it is faintest during a low state of the X-ray source. The total light amplitude may

reach 2-3 mag in V (HZ Her);

XPRM,XM X-ray systems consisting of a late-type dwarf (dK-dM) and a pulsar with a strong magnetic field. Matter accretion on the compact object's magnetic poles is accompanied by the appearance of variable linear and circular polarization; hence, these systems are sometimes known as "polars". The amplitudes of the light changes are usually about 1 mag in V but, provided that the primary component is irradiated by X rays, the mean brightness of a system may increase by 3 mag in V. The total light amplitude may reach 4-5 mag in V (AM Her, AN UMa).

If the beam of X-ray emission originating at the magnetic poles of the rotating hot compact object does not pass through the observer's position and the system is not observed as a pulsar, the letter "P" in the above symbols for X-ray-system types is not used. If an X-ray system is also an eclipsing or an ellipsoidal variable, the X-ray symbol is preceded by "E" or "ELL" joined with the X-ray symbol by a "+" sign (e.g., E+X, ELL+X).

Other Symbols

In addition to the variable-star types described above, certain other symbols that need to be explained will be found in the Type data field:

BLLAC Extragalactic BL Lacertae-type objects. These are compact quasistellar objects showing almost continuous spectra with weak emission and absorption lines and relatively rapid irregular light changes with amplitudes up to 3 mag in V or more. Sources of strong X-ray radiation and radio waves, their emission displays strong and variable linear polarization in the visible and infrared spectral regions. Some objects of this type, considered erroneously to be variable stars and designated in the GCVS system, will probably sometimes be included in the main table of the Catalogue in the future, too.

CST Nonvariable stars, formerly suspected to be variable and hastily designated. Further observations have not confirmed their variability.

GAL Optically variable quasistellar extragalactic objects (active galactic nuclei [AGNs]) considered to be variable stars by mistake.

L: Unstudied variable stars with slow light changes.

QSO Optically variable quasistellar extragalactic sources (quasars) that earlier were erroneously considered to be variable stars.

S Unstudied variable stars with rapid light changes.

* Unique variable stars outside the range of the classifications described above. These probably represent either short stages of transition from one variability type to another or the earliest and latest evolutionary stages of these types, or they are insufficiently studied members of future new types of variables.

+ If a variable star belongs to several types of light variability simultaneously, the types are joined in the Type field by a "+" sign (e.g., E+UG, UV+BY).

: Uncertainty flag on Type of Variability

C.4 Double Stars

Since version 0.15.0 Stellarium supports the subset of double stars from WDS[3] which have HIP identificators (i.e., stars from the Hipparcos catalog). Stellarium's Catalog of Double Stars is based on the "The 2001 US Naval Observatory Double Star CD-ROM. I. The Washington Double Star Catalog" (Mason et al., 2001). Cross reference data for WDS and HIP designations is based on the XHIP catalog (Anderson and Francis, 2012) through the astronomical database SIMBAD (Wenger et al., 2000).

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[3]`http://ad.usno.navy.mil/wds/`

C.4.1 Double Star Catalog File Format

Stellarium's Double Stars catalog data is kept in the `stars/default` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

File Format

The `wds_hip_part.dat` file contains data about 16411 *double stars* which have HIP identificators and stored in plain text format with tab delimiters.

Name	Type	Description
HIP	int	HIP identificator for the star. Used for reference to the main star catalogue.
WDS	string	WDS designation for the double star.
Observation	int	Date of last satisfactory observation (in years).
Position Angle	float	Position Angle at date of last satisfactory observation (in decimal degrees).
Separation	float	Separation at date of last satisfactory observation (in arcsec).

Table C.8: Format of `wds_hip_part.dat`

C.5 Cross-Identification Data

Since version 0.14.0 Stellarium supports cross-identification between stars from Hipparcos (HIP) (Anderson and Francis, 2012), Smithsonian Astrophysical Observatory (SAO) Star Catalog J2000.0, Henry Draper Catalogue and Extension (HD) (Cannon and Pickering, 1993) and *Catalogue of bright stars* (Hoffleit, 1964) (BSC5 or HR) catalogues.

C.5.1 Cross-Identification Catalog File Format
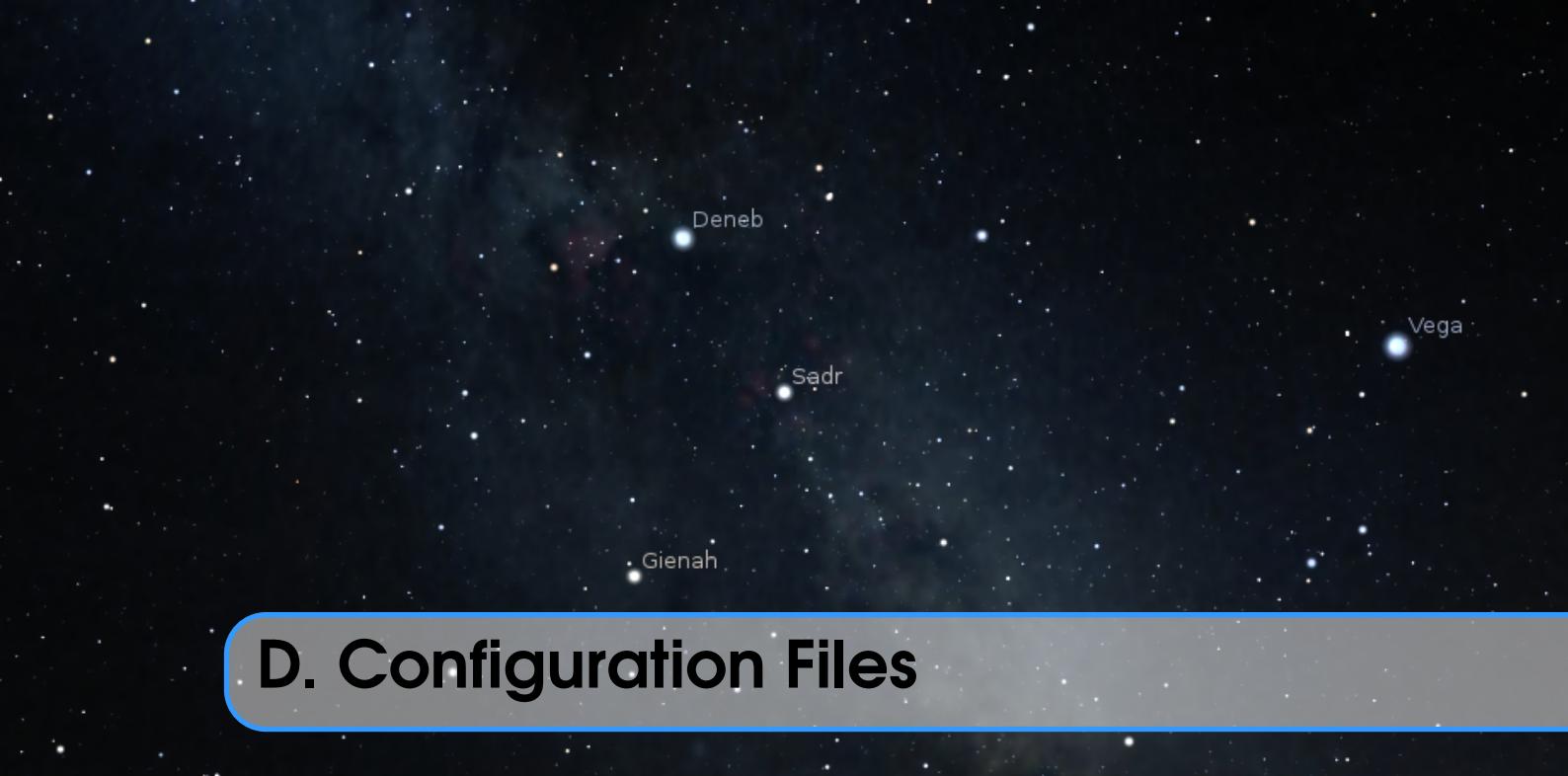
Stellarium's Cross-Identification catalog data is kept in the `stars/default` sub-directory of the Installation Directory and/or User Directory (see section 5.1).

File Format

The file `cross-id.dat` contains cross reference data for catalogues HIP, SAO, HD and HR, which stored in the plain text format with tab delimiter.

Name	Type	Description
HIP	int	HIP identificator for the star. Used for reference to the main star catalogue.
SAO	int	SAO identificator for the star.
HD	int	HD identificator for the star.
HR	int	HR identificator for the star.

Table C.9: Format of `cross-id.dat`

D. Configuration Files

D.1 Program Configuration

First, see 5.4 (The Main Configuration File) for information about the file `config.ini`, including its default installed location, and command line options that can affect how it is processed.

The file `config.ini` (or a file which you can load instead with the `--config <file>` option) is structured into the following parts. In addition, plugins can add a section named like the plugin (Exception: The Text User Interface plugin's section is named `[tui]` for historical reasons).

D.1.1 [astro]

This section includes settings for the commonly displayed objects.

ID	Type	Default	Description
apparent_magnitude_algorithm	string	ExpSup2013	Set algorithm for computation of apparent magnitude of the planets. Possible values: *ExpSup2013*, *ExpSup1992*, *AstrAlm1984*, *Mueller1893* and *Generic*.
nebula_magnitude_limit	float	8.5	Value of limiting magnitude for the deep-sky objects.
star_magnitude_limit	float	6.5	Value of limiting magnitude for the stars. Sometimes you don't want to display more stars when zooming in.
planet_magnitude_limit	float	6.5	Value of limiting magnitude for the planets. Sometimes you don't want to display more planets when zooming in.
planets_orbits_color_style	string	one_color	Set the style of orbits color. Possible values: *one_color*, *groups* and *max*.

flag_nebula_magnitude_limit	bool	false	Set to *true* to activate limit for showing deep-sky objects.
flag_star_magnitude_limit	bool	false	Set to *true* to activate limit for showing stars
flag_planet_magnitude_limit	bool	false	Set to *true* to activate limit for showing planets.
extinction_mode_below_horizon	string	zero	Set extinction mode for atmosphere below horizon. Possible values: *zero*, *mirror* and *major_planets*.
flag_stars	bool	true	Set to *false* to hide the stars on start-up
flag_star_name	bool	true	Set to *false* to hide the star labels on start-up
flag_star_additional_names	bool	true	Set *true* to use additional names (also known as) for stars.
flag_planets	bool	true	Set to *false* to hide the planet labels on start-up
flag_planets_hints	bool	true	Set to *false* to hide the planet hints on startup (names and circular highlights)
flag_planets_orbits	bool	false	Set to *true* to show the planet orbits on startup
flag_permanent_orbits	bool	false	Set to *true* to show the orbit of planet, when planet is out of the viewport also.
flag_planets_pointers	bool	false	Set to *true* to show the planet pointer markers on startup
flag_planets_nomenclature	bool	false	Set to *true* to show the planetary nomenclature markers and labels
flag_hide_local_nomenclature	bool	true	Set to *true* to hide the planetary nomenclature items on the observer's celestial body
flag_light_travel_time	bool	true	Should be *true* to improve accuracy in the movement of the planets by compensating for the time it takes for light to travel. This has a slight impact on performance, but is essential e.g. for Jupiter's moons.
flag_object_trails	bool	false	Turns on and off drawing of object trails (which show the movement of the planets over time).
flag_nebula	bool	true	Set to *false* to hide the nebulae on start-up.
flag_nebula_name	bool	false	Set to *true* to show the nebula labels on start-up.
flag_nebula_display_no_texture	bool	false	Set to *true* to suppress displaying of nebula textures.
nebula_hints_amount	float	3.0	Sets the amount of hints [0...10].

nebula_labels_amount	float	3.0	Sets the amount of labels [0...10].
flag_milky_way	bool	true	Set to *false* to hide the Milky Way.
milky_way_intensity	float	1.0	Sets the relative brightness with which the milky way is drawn. Typical [1...3].
flag_zodiacal_light	bool	true	Set to *false* to hide the zodiacal light
zodiacal_light_intensity	float	1.0	Sets the relative brightness with which the zodiacal light is drawn.
max_mag_nebula_name	float	8.0	Sets the magnitude of the nebulae whose name is shown.
flag_nebula_hints_proportional	bool	false	Enables/disables proportional markers for deep-sky objects.
flag_surface_brightness_usage	bool	false	Enables/disables usage surface brightness for markers for deep-sky objects.
flag_size_limits_usage	bool	false	Enables/disables usage angular size filter for markers for deep-sky objects.
size_limit_min	int	1	Minimal angular size of visible deep-sky objects in arcminutes.
size_limit_max	int	600	Maximum angular size of visible deep-sky objects in arcminutes.
flag_use_type_filter	bool	false	Enables/disables usage of the type filters for deep-sky objects.
flag_nutation	bool	true	Enables/disables usage nutation.
flag_topocentric_coordinates	bool	true	Enables/disables usage topocentric coordinates.
flag_dso_designation_usage	bool	false	If *true*, use designations of deep-sky objects on the sky instead of their common names.
flag_dso_outlines_usage	bool	false	If *true*, use outlines for big deep-sky objects on the sky instead of their hints.
flag_dso_additional_names	bool	true	Set *true* to use additional names (also known as) for deep-sky objects.
flag_grs_custom	bool	false	Turns on and off to using custom settings for calculation of position of Great Red Spot on Jupiter.
grs_longitude	int	216	Longitude (System II) of Great Red Spot on Jupiter in degrees.
grs_drift	float	15.0	Annual drift of Great Red Spot on Jupiter in degrees.
grs_jd	float	2456901.5	Initial JD for calculation of position of Great Red Spot on Jupiter.

grs_measurements_url	string		URL of recent measurements of GRS' position[1].
meteor_zhr	int	10	ZHR for sporadic meteors.
de430_path	string		Path to JPL DE430 ephemerides file.
flag_use_de430	bool	false	Enables/disables usage JPL DE430 ephemerides (if available).
de431_path	string		Path to JPL DE431 ephemerides file.
flag_use_de431	bool	false	Enables/disables usage JPL DE431 ephemerides (if available).
flag_toast_survey	bool	false	Enables/disables Digitized Sky Survey in TOAST format.
toast_survey_host	string		Host of Digitized Sky Survey storage data.
toast_survey_directory	string	results	Directory name of Digitized Sky Survey storage data.
toast_survey_levels	int	11	Count of levels for Digitized Sky Survey storage data.

D.1.2 [**astrocalc**]

This section includes settings for the Astronomical Calculations feature.

ID	Type	Default	Description
flag_ephemeris_markers	bool	true	Set to *true* to show the calculated ephemeris markers for Solar system bodies.
flag_ephemeris_line	bool	false	Set to *true* to show the connecting line between the ephemeris markers.
flag_ephemeris_dates	bool	false	Set to *true* to show the dates of calculated ephemeris for Solar system bodies.
flag_ephemeris_magnitudes	bool	false	Set to *true* to show the magnitude of Solar system body for the calculated ephemeride.
flag_ephemeris_horizontal	bool	false	Set to *true* to use horizontal coordinates for ephemerides.
flag_ephemeris_skip_data	bool	false	Set to *true* to skip the showing data near ephemeris markers.
flag_ephemeris_smart_dates	bool	true	Set to *true* to use smart format for dates, who showing near ephemeris markers.
flag_ephemeris_scale_markers	bool	false	Set to *true* to use small ephemeris markers, when line is enabled.
ephemeris_celestial_body	string	Moon	Default celestial body for computation of ephemerides.
ephemeris_time_step	int	6	Identificator for time step category.
ephemeris_data_step	int	0	Value of skipping step when skipping option is enabled (lable each N steps, where N is step).

---

[1]Default value is `http://jupos.privat.t-online.de/rGrs.htm`

celestial_magnitude_limit	float	6.0	Value of limiting magnitude for the celestial objects in computation of their positions.
celestial_category	int	200	Identificator for default category of celestial bodies.
flag_horizontal_coordinates	bool	false	Set to *true* to use horizontal coordinates for compute of positions for the celestial objects.
flag_phenomena_opposition	bool	false	Set to *true* to compute of opposition phenomenon between the Solar system bodies.
flag_phenomena_perihelion	bool	false	Set to *true* to compute perihelion and aphelion for Solar system bodies (except moons).
phenomena_angular_separation	float	1.0	Allowed angular separation between celestial bodies for computation of phenomena.
phenomena_celestial_body	string	Venus	Default celestial body for computation of phenomena.
phenomena_celestial_group	int	0	Identificator for group of celestial bodies for computation of phenomenae.
wut_magnitude_limit	float	10.0	Value of limiting magnitude for calculations within What's Up Tonight feature.
wut_time_interval	int	0	Identificator for time interval within What's Up Tonight feature computations.
wut_angular_limit_flag	bool	false	Set to *true* to use the angular size filter.
wut_angular_limit_min	float	1.0	Minimal allowed angular size, arcminutes.
wut_angular_limit_max	float	600.0	Maximal allowed angular size, arcminutes.
graphs_celestial_body	string	Moon	Default celestial body for draw of graphs.
graphs_duration	int	1	How much years account into calculation of graphs.
graphs_first_id	int	1	Identificator for left graph (blue line).
graphs_second_id	int	2	Identificator for right graph (yellow line).

D.1.3 [**color**]

This section defines the RGB colors for the various objects, lines, grids, labels etc. Values are given in float from 0 to 1. e.g. *1.0,1.0,1.0* for white, or *1,0,0* for red. Leave no whitespace between the numbers!

ID	*Default*		*Colour of the. . .*
default_color	0.5,0.5,0.7		default colour.
daylight_text_color	0.0,0.0,0.0		info text at daylight.
info_text_color	1.0,1.0,1.0		info text color when overwrite mode for text color is enabled.
sky_background_color	0.0,0.0,0.0		sky background (non-black is useful for artists only).
ecliptical_J2000_color	0.4,0.1,0.1		ecliptical grid (J2000.0 frame).
ecliptic_J2000_color	0.7,0.2,0.2		ecliptic line (J2000.0 frame).

equinox_J2000_points_color	0.7,0.2,0.2		equinox points (J2000.0 frame).
solstice_J2000_points_color	0.7,0.2,0.2		solstice points (J2000.0 frame).
ecliptic_J2000_poles_color	0.7,0.2,0.2		ecliptic poles (J2000.0 frame).
ecliptical_color	0.6,0.3,0.1		ecliptical grid (of date).
ecliptic_color	0.9,0.6,0.2		ecliptic line (of date).
equinox_points_color	0.9,0.6,0.2		equinox points (of date).
solstice_points_color	0.9,0.6,0.2		solstice points (of date).
ecliptic_poles_color	0.9,0.6,0.2		ecliptic poles (of date).
precession_circles_color	0.9,0.6,0.2		precession circles.
equator_J2000_color	0.2,0.2,0.6		equator line (J2000.0 frame).
equatorial_J2000_color	0.1,0.1,0.5		equatorial grid (J2000.0 frame).
celestial_J2000_poles_color	0.2,0.2,0.6		celestial poles (J2000.0 frame).
equator_color	0.3,0.5,1.0		equator line (of date).
equatorial_color	0.2,0.3,0.8		equatorial grid (of date).
celestial_poles_color	0.3,0.5,1.0		celestial poles (of date).
circumpolar_circles_color	0.3,0.5,1.0		circumpolar circles.
galactic_color	0.3,0.2,0.1		galactic grid.
galactic_equator_color	0.5,0.3,0.1		galactic equator line.
galactic_poles_color	0.5,0.3,0.1		galactic poles.
supergalactic_color	0.2,0.2,0.2		supergalactic grid.
supergalactic_equator_color	0.4,0.4,0.4		supergalactic equator line.
supergalactic_poles_color	0.4,0.4,0.4		supergalactic poles.
azimuthal_color	0.0,0.3,0.2		azimuthal grid.
horizon_color	0.2,0.6,0.2		horizon line.
meridian_color	0.2,0.6,0.2		meridian line.
prime_vertical_color	0.2,0.5,0.2		prime vertical.
zenith_nadir_color	0.2,0.6,0.2		zenith and nadir.
cardinal_color	0.8,0.2,0.1		cardinal points.
colures_color	0.5,0.0,0.5		colures.
antisolar_point_color	0.9,0.3,0.5		antisolar point.
apex_points_color	0.8,0.2,0.3		apex points.
oc_longitude_color	0.6,0.2,0.4		opposition/conjunction longitude.
asterism_lines_color	0.4,0.4,0.8		asterism lines.
asterism_names_color	0.4,0.4,0.8		asterism names.
rayhelper_lines_color	1.0,1.0,0.0		the ray helper lines.
const_lines_color	0.2,0.2,0.6		constellation lines.
const_names_color	0.4,0.6,0.9		constellation names.
const_boundary_color	0.3,0.1,0.1		constellation boundaries.
dso_label_color	0.2,0.6,0.7		deep-sky objects labels.

dso_circle_color	1.0,0.7,0.2		deep-sky objects symbols, if not of the types below.
dso_galaxy_color	1.0,0.2,0.2		galaxies symbols.
dso_radio_galaxy_color	0.3,0.3,0.3		radio galaxies symbols.
dso_active_galaxy_color	1.0,0.5,0.2		active galaxies symbols.
dso_interacting_galaxy_color	0.2,0.8,1.0		clusters of galaxies symbols.
dso_galaxy_cluster_color	0.2,0.5,1.0		interacting galaxies symbols.
dso_quasar_color	1.0,0.2,0.2		quasars symbols.
dso_possible_quasar_color	1.0,0.2,0.2		possible quasars symbols.
dso_bl_lac_color	1.0,0.2,0.2		BL Lac objects symbols.
dso_blazar_color	1.0,0.2,0.2		blazars symbols.
dso_nebula_color	0.1,1.0,0.1		nebulae symbols.
dso_planetary_nebula_color	0.1,1.0,0.1		planetary nebulae symbols.
dso_reflection_nebula_color	0.1,1.0,0.1		reflection nebulae symbols.
dso_bipolar_nebula_color	0.1,1.0,0.1		bipolar nebulae symbols.
dso_emission_nebula_color	0.1,1.0,0.1		emission nebulae symbols.
dso_dark_nebula_color	0.3,0.3,0.3		dark nebulae symbols.
dso_hydrogen_region_color	0.1,1.0,0.1		hydrogen regions symbols.
dso_supernova_remnant_color	0.1,1.0,0.1		supernovae remnants symbols.
dso_supernova_candidate_color	0.1,1.0,0.1		supernova candidates symbols.
dso_supernova_remnant_cand_color	0.1,1.0,0.1		supernova remnant candidates symbols.
dso_interstellar_matter_color	0.1,1.0,0.1		interstellar matter symbols.
dso_cluster_with_nebulosity_color	0.1,1.0,0.1		clusters associated with nebulosity symbols.
dso_molecular_cloud_color	0.1,1.0,0.1		molecular clouds symbols.
dso_possible_planetary_nebula_color	0.1,1.0,0.1		possible planetary nebulae symbols.
dso_protoplanetary_nebula_color	0.1,1.0,0.1		protoplanetary nebulae symbols.
dso_cluster_color	1.0,1.0,0.1		star clusters symbols.
dso_open_cluster_color	1.0,1.0,0.1		open star clusters symbols.
dso_globular_cluster_color	1.0,1.0,0.1		globular star clusters symbols.
dso_stellar_association_color	1.0,1.0,0.1		stellar associations symbols.
dso_star_cloud_color	1.0,1.0,0.1		star clouds symbols.
dso_star_color	1.0,0.7,0.2		star symbols.
dso_symbiotic_star_color	1.0,0.7,0.2		symbiotic star symbols.
dso_emission_star_color	1.0,0.7,0.2		emission-line star symbols.
dso_emission_object_color	1.0,0.7,0.2		emission objects symbols.
dso_young_stellar_object_color	1.0,0.7,0.2		young stellar objects symbols.
star_label_color	0.4,0.3,0.5		star labels.
planet_names_color	0.5,0.5,0.7		planet names.
planet_pointers_color	1.0,0.3,0.3		planet pointers.
planet_nomenclature_color	0.1,1.0,0.1		planetary nomenclature hints and labels.
sso_orbits_color	0.7,0.2,0.2		default orbits.

major_planet_orbits_color	0.7,0.2,0.2		major planet orbits.
minor_planet_orbits_color	0.7,0.5,0.5		minor planet orbits.
dwarf_planet_orbits_color	0.7,0.5,0.5		dwarf planet orbits.
moon_orbits_color	0.7,0.2,0.2		moon of planet orbits.
cubewano_orbits_color	0.7,0.5,0.5		cubewano orbits.
plutino_orbits_color	0.7,0.5,0.5		plutino orbits.
sdo_orbits_color	0.7,0.5,0.5		scattered disk object orbits.
oco_orbits_color	0.7,0.5,0.5		Oort cloud object orbits.
sednoid_orbits_color	0.7,0.5,0.5		Sednoid object orbits.
interstellar_orbits_color	1.0,0.6,1.0		Interstellar object "orbits" (trajectories).
comet_orbits_color	0.7,0.8,0.8		comet orbits.
mercury_orbit_color	0.5,0.5,0.5		orbit of Mercury.
venus_orbit_color	0.9,0.9,0.7		orbit of Venus.
earth_orbit_color	0.0,0.0,1.0		orbit of Earth.
mars_orbit_color	0.8,0.4,0.1		orbit of Mars.
jupiter_orbit_color	1.0,0.6,0.0		orbit of Jupiter.
saturn_orbit_color	1.0,0.8,0.0		orbit of Saturn.
uranus_orbit_color	0.0,0.7,1.0		orbit of Uranus.
neptune_orbit_color	0.0,0.3,1.0		orbit of Neptune.
object_trails_color	1.0,0.7,0.0		planet trails.
custom_marker_color	0.1,1.0,0.1		custom marker.
script_console_keyword_color	1.0,0.0,1.0		syntax highlight for keywords in the script console.
script_console_module_color	0.0,1.0,1.0		syntax highlight for modules in the script console.
script_console_comment_color	1.0,1.0,0.0		syntax highlight for comments in the script console.
script_console_function_color	0.0,1.0,0.0		syntax highlight for functions in the script console.
script_console_constant_color	1.0,0.5,0.5		syntax highlight for constants in the script console.

D.1.4 [custom_selected_info]

You can fine-tune the bits of information to display for the selected object in this section. Set the entry to *true* to display it.

ID	Type	Description
flag_show_absolutemagnitude	bool	absolute magnitude for objects.
flag_show_altaz	bool	horizontal coordinates for objects.
flag_show_catalognumber	bool	catalog designations for objects.
flag_show_distance	bool	distance to object.
flag_show_extra	bool	extra info for object.
flag_show_hourangle	bool	hour angle for object.

flag_show_magnitude	bool	magnitude for object.
flag_show_name	bool	common name for object.
flag_show_radecj2000	bool	equatorial coordinates (J2000.0 frame) of object.
flag_show_radecofdate	bool	equatorial coordinates (of date) of object.
flag_show_galcoord	bool	galactic coordinates (System II) of object.
flag_show_supergalcoord	bool	supergalactic coordinates of object.
flag_show_eclcoordj2000	bool	ecliptic coordinates (J2000.0 frame) of object.
flag_show_eclcoordofdate	bool	ecliptic coordinates (of date) of object.
flag_show_type	bool	type of object.
flag_show_size	bool	size of object.
flag_show_sidereal_time	bool	sidereal time.
flag_show_rts_time	bool	rise, transit and set times.
flag_show_velocity	bool	velocity of object.
flag_show_constellation	bool	show 3-letter IAU constellation label.

D.1.5 [custom_time_correction]

Stellarium allows experiments with ΔT. See 17.4.3 for details.

ID	Type	Description
coefficients	[float,float,float]	Coefficients a, b, c for custom equation of ΔT
ndot	float	n-dot value for custom equation of ΔT
year	int	Year for custom equation of ΔT

D.1.6 [devel]

This section is for developers only.

ID	Type	Description
convert_dso_catalog	bool	Set to *true* to convert file `catalog.txt` into file `catalog.dat`. Default value: *false*.
convert_dso_decimal_coord	bool	Set to *true* to use decimal values for coordinates in source catalog. Default value: *true*.

D.1.7 [dso_catalog_filters]

In this section you can fine-tune which of the deep-sky catalogs should be selected on startup.

ID	Type	Default	Description
flag_show_ngc	bool	true	New General Catalogue (NGC).
flag_show_ic	bool	true	Index Catalogue (IC).
flag_show_m	bool	true	Messier Catalog (M).
flag_show_c	bool	false	Caldwell Catalogue (C).
flag_show_b	bool	false	Barnard Catalogue (B).
flag_show_sh2	bool	false	Sharpless Catalogue (Sh-II).
flag_show_vdb	bool	false	Van den Bergh Catalogue of reflection nebulae (VdB).
flag_show_rcw	bool	false	The RCW catalogue of Hα-emission regions in the southern Milky Way.
flag_show_lbn	bool	false	Lynds' Catalogue of Bright Nebulae (LBN).
flag_show_ldn	bool	false	Lynds' Catalogue of Dark Nebulae (LDN).
flag_show_cr	bool	false	Collinder Catalogue (Cr).

flag_show_mel	bool	false	Melotte Catalogue of Deep Sky Objects (Mel).
flag_show_pgc	bool	false	HYPERLEDA. I. Catalog of galaxies (PGC).
flag_show_ced	bool	false	Cederblad Catalog of bright diffuse Galactic nebulae (Ced).
flag_show_ugc	bool	false	The Uppsala General Catalogue of Galaxies (UGC).
flag_show_arp	bool	false	Atlas of Peculiar Galaxies (Arp).
flag_show_vv	bool	false	The Catalogue of Interacting Galaxies (VV).
flag_show_pk	bool	false	The Catalogue of Galactic Planetary Nebulae (PK).
flag_show_png	bool	false	The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (PN G).
flag_show_snrg	bool	false	A catalogue of Galactic supernova remnants (SNR G).
flag_show_aco	bool	false	A Catalog of Rich Clusters of Galaxies (ACO).
flag_show_hcg	bool	false	A Hickson Compact Group (HCG).
flag_show_abell	bool	false	Abell Catalog of Planetary Nebulae (Abell).
flag_show_eso	bool	false	ESO/Uppsala Survey of the ESO(B) Atlas (ESO).

D.1.8 [dso_type_filters]

In this section you can fine-tune which types of the deep-sky objects should be selected on startup.

ID	Type	Default	Description
flag_show_galaxies	bool	true	display galaxies.
flag_show_active_galaxies	bool	true	display active galaxies.
flag_show_interacting_galaxies	bool	true	display interacting galaxies.
flag_show_open_clusters	bool	true	display open star clusters.
flag_show_globular_clusters	bool	true	display globular star clusters.
flag_show_bright_nebulae	bool	true	display bright nebulae.
flag_show_dark_nebulae	bool	true	display dark nebulae.
flag_show_planetary_nebulae	bool	true	display planetary nebulae.
flag_show_hydrogen_regions	bool	true	display hydrogen regions.
flag_show_supernova_remnants	bool	true	display supernovae remnants.
flag_show_galaxy_clusters	bool	true	display clusters of galaxies.
flag_show_other	bool	true	display other deep-sky objects.

D.1.9 [gui]

This section includes settings for the graphical user interface. See sections 4.3.3–4.3.5 for most of these keys.

ID	Type	Default	Description
flag_show_gui	bool	true	If *true*, display GUI.
screen_font_size	int	13	Sets the font size for screen texts. Typical value: *13..15*
gui_font_size	int	13	Sets the dialog font size. Typical value: *10..20*
base_font_name	string	Verdana (Windows) DejaVu Sans (others)	Selects the name for base font
base_font_file	string		Selects the name for font file, e.g. *DejaVuSans.ttf*

flag_font_selection	bool	false	Show GUI elements for font selection.
flag_mouse_cursor_timeout	bool	true	Set to *false* if you want to have cursor visible at all times.
mouse_cursor_timeout	float	10	Set to *0* if you want to keep the mouse cursor visible at all times. non-0 values mean the cursor will be hidden after that many seconds of inactivity
flag_show_boundaries_button	bool	false	Show a button to toggle constellation boundaries
flag_show_asterism_lines_button	bool	false	Show a button to toggle asterism lines
flag_show_asterism_labels_button	bool	false	Show a button to toggle asterism labels
flag_show_ecliptic_grid_button	bool	false	Show a button to toggle ecliptic grid
flag_show_icrs_grid_button	bool	false	Show a button to toggle ICRS (equatorial J2000.0) grid
flag_show_galactic_grid_button	bool	false	Show a button to toggle galactic grid
flag_show_goto_selected_button	bool	true	Show a button to center to selected object
flag_show_nightmode_button	bool	true	Show a button to toggle night mode
flag_show_nebulae_ background_button	bool	false	Show a button to toggle images for deep-sky objects
flag_show_flip_buttons	bool	false	Show the image flipping buttons in the main toolbar
flag_show_dss_button	bool	false	Show a button to toggle Digitized Sky Survey (DSS)
flag_show_hips_button	bool	false	Show a button to toggle HiPS survey display
flag_show_bookmark_button	bool	false	Show a button to show and edit bookmarks
flag_show_fullscreen_button	bool	true	Show a button to toggle fullscreen view
flag_show_quit_button	bool	true	Show a button to quit via button press
flag_show_buttons_background	bool	true	If *true*, use background under buttons on bottom bar.
flag_overwrite_info_color	bool	false	Set *true* to use one color for test in info panel for all objects.
selected_object_info	string	all	Values: *all*, *short*, *none*, and *custom* (since V0.12.0; see 4.3.2).
custom_marker_size	float	5.0	Size of custom marker.
custom_marker_radius_limit	int	15	Limit the click radius for mouse cursor position in any direction for removing of closest custom marker.

auto_hide_horizontal_toolbar	bool	true	Set to *true* if you want auto hide the horizontal toolbar.
auto_hide_vertical_toolbar	bool	true	Set to *true* if you want auto hide the vertical toolbar.
flag_use_window_transparency	bool	false	If *false*, show menu bars opaque
flag_show_datetime	bool	true	display date and time in the bottom bar
flag_time_jd	bool	false	use JD format for time in the bottom bar
flag_show_tz	bool	false	show time zone info in the bottom bar
flag_show_location	bool	true	display location in the bottom bar
flag_show_fps	bool	true	show at how many frames per second Stellarium is rendering
flag_show_fov	bool	true	show how many degrees your vertical field of view is
flag_fov_dms	bool	false	use DMS format for FOV in the bottom bar
flag_show_decimal_degrees	bool	false	If *true*, use decimal degrees for coordinates
flag_use_azimuth_from_south	bool	false	If *true*, calculate azimuth from south towards west (as in some astronomical literature)
flag_surface_brightness_arcsec	bool	false	Toggle usage the measure unit $^{mag}/_{\square}{}'$ ($^{mag}/arcmin^2$) or $^{mag}/_{\square}{}''$ ($^{mag}/arcsec^2$) for the surface brightness of deep-sky objects.
flag_surface_brightness_short	bool	false	Toggle usage the short notation for the surface brightness of deep-sky objects.
flag_enable_kinetic_scrolling	bool	true	If *true*, use kinetic scrolling in the GUI[2].
pointer_animation_speed	float	1.0	Animation speed of pointers.
gpsd_hostname	string	localhost	hostname of server running **gpsd** (non-Windows only)
gpsd_port	int	2947	port number of **gpsd** (non-Windows only)
gps_interface	string	COM3	Port number of serial/USB GPS device. (May look like `ttyUSB0` on Linux, if you really don't run **gpsd**.)
gps_baudrate	int	4800	baudrate of serial/USB GPS device (for direct serial connection only)

---

[2]Scroll by dragging in the window directly, not a slider handle. Scrolling stops after a short time.

D.1.10 [init_location]

ID	Type	Description
landscape_name	string	Sets the landscape you see. Built-in options are *garching, geneva, grossmugl, guereins, hurricane, jupiter, mars, moon, neptune, ocean, saturn, trees, uranus, zero.*
location	string	Name of location on which to start stellarium.
last_location	string	Coordinates of last used location in stellarium.

D.1.11 [landscape]

ID	Type	Description
atmosphere_fade_duration	float	Sets the time (seconds) it takes for the atmosphere to fade when de-selected
flag_landscape	bool	Set to *false* if you don't want to see the landscape at all
flag_fog	bool	Set to *false* if you don't want to see fog on start-up
flag_atmosphere	bool	Set to *false* if you don't want to see atmosphere on start-up
flag_landscape_sets_location	bool	Set to *true* if you want Stellarium to modify the observer location when a new landscape is selected (changes planet and longitude/latitude/altitude if location data is available in the landscape.ini file)
minimal_brightness	float	Set minimal brightness for landscapes. [0...1] Typical value: *0.01*
atmospheybin	int	Set atmosphere binning coefficient for axis Y.
flag_minimal_brightness	bool	Set to *true* to use minimal brightness for landscape.
flag_landscape_sets_minimal_brightness	bool	Set to *true* to use value for minimal brightness for landscape from landscape settings.
flag_enable_illumination_layer	bool	Set to *true* to use illumination layer for landscape.
flag_enable_labels	bool	Set to *true* to use landscape labels from gazetteer layer.
atmospheric_extinction_coefficient	float	Set atmospheric extinction coefficient k [mag/airmass]
temperature_C	float	Set atmospheric temperature [Celsius]
pressure_mbar	float	Set atmospheric pressure [mbar]
cache_size_mb	int	Set the cache size for landscapes [megabytes]. Default: 100

D.1.12 [localization]

ID	Type	Description
sky_culture	string	Sets the sky culture to use. E.g. *western, polynesian, egyptian, chinese, lakota, navajo, inuit, korean, norse, tupi, maori, aztec, sami.*
sky_locale	string	Sets language used for names of objects in the sky (e.g. planets). The value is a short locale code, e.g. *en, de, en_GB*
app_locale	string	Sets language used for Stellarium's user interface. The value is a short locale code, e.g. *en, de, en_GB*.
time_zone	string	Sets the time zone. Valid values: *system_default*, or some region/location combination, e.g. *Pacific/Marquesas*
time_display_format	string	time display format: can be *system_default*, *24h* or *12h*.
date_display_format	string	date display format: can be *system_default, mmddyyyy, ddmmyyyy, yyyymmdd* (ISO8601), *wwmmddyyyy, wwddmmyyyy, wwyyyymmdd*.

D.1.13 [main]

ID	Type	Description
invert_screenshots_colors	bool	If *true*, Stellarium will saving the screenshorts with inverted colors.
screenshot_dir	string	Path for saving screenshots
screenshot_format	string	File format. One of `png|jpg|jpeg|tif|tiff| webp|pbm|pgm|ppm|xbm|xpm|ico`
screenshot_custom_size	bool	*true* if you want to specify particular dimensions next:
screenshot_custom_width	int	custom width of screenshots. Max. available size is hardware dependent!
screenshot_custom_height	int	custom height of screenshots. Max. available size is hardware dependent!
version	string	Version of Stellarium. This parameter may be used to detect necessary changes in config.ini file, do not edit.
use_separate_output_file	bool	Set to *true* if you want to create a new file for script output for each start of Stellarium
restore_defaults	bool	If *true*, Stellarium will restore default settings at startup. This is equivalent to calling Stellarium with the `-restore-defaults` option.
ignore_opengl_warning	bool	Set to *true* if you don't want to see OpenGL warnings for each start of Stellarium.
check_requirements	bool	Set to *false* if you want to disable and permanently ignore checking hardware requirements at startup. Expect problems if hardware is below requirements!
geoip_api_url	string	URL for JSON interface of GeoIP service.

D.1.14 [navigation]

This section controls much of the look&feel of Stellarium. Be careful if you change something here.

ID	Type	Description
preset_sky_time	float	Preset sky time used by the dome version. Unit is Julian Day. Typical value: *2451514.250011573*
startup_time_mode	string	Set the start-up time mode, can be *actual* (start with current real world time), or *Preset* (start at time defined by preset_sky_time)
flag_enable_zoom_keys	bool	Set to *false* if you want to disable the zoom
flag_manual_zoom	bool	Set to *false* for normal zoom behaviour as described in this guide. When set to true, the auto zoom feature only moves in a small amount and must be pressed many times
flag_enable_move_keys	bool	Set to *false* if you want to disable the arrow keys
flag_enable_mouse_navigation	bool	Set to *false* if you want to disable the mouse navigation.
init_fov	float	Initial field of view, in degrees, typical value: "60".
min_fov	float	Minimal field of view, in degrees, typical value: "0.001389" (5").
init_view_pos	floats	Initial viewing direction. This is a vector with x,y,z-coordinates. x being N-S (S +ve), y being E-W (E +ve), z being up-down (up +ve). Thus to look South at the horizon use *1,0,0*. To look Northwest and up at 45°, use *-1,-1,1* and so on.
auto_move_duration	float	Duration (seconds) for the program to move to point at an object when the space bar is pressed. Typical value: *1.4*
mouse_zoom	float	Sets the mouse zoom amount (mouse-wheel)
move_speed	float	Sets the speed of movement
zoom_speed	float	Sets the zoom speed
viewing_mode	string	If set to *horizon*, the viewing mode simulate an alt/azi mount, if set to *equator*, the viewing mode simulates an equatorial mount
flag_manual_zoom	bool	Set to *true* if you want to auto-zoom in incrementally.
auto_zoom_out_resets_direction	bool	Set to *true* if you want to auto-zoom restoring direction.
time_correction_algorithm	string	Algorithm of DeltaT correction.

D.1.15 [**plugins_load_at_startup**]

This section lists which plugins are loaded at startup (those with *true* values). Each plugin can add another section into this file with its own content, which is described in the respective plugin documentation, see 11. You activate loading of plugins in the F2 settings dialog, tab "Plugins". After selection of which plugins to load, you must restart Stellarium.

ID	Type	Description
AngleMeasure	bool	12.1 Angle Measure plugin
ArchaeoLines	bool	13.9 ArchaeoLines plugin
CompassMarks	bool	12.2 Compass Marks plugin

MeteorShowers	bool	13.6 Meteor Showers plugin
Exoplanets	bool	13.3 Exoplanets plugin
Observability	bool	15.8 Observability Analysis
Oculars	bool	15.1 Oculars plugin
Pulsars	bool	13.4 Pulsars plugin
Quasars	bool	13.5 Quasars plugin
RemoteControl	bool	12.6 Remote Control plugin
RemoteSync	bool	12.7 Remote Sync plugin
Satellites	bool	13.8 Satellites plugin
SolarSystemEditor	bool	12.8 Solar System Editor plugin
Supernovae	bool	13.2 Historical Supernovae plugin
TelescopeControl	bool	15.2 Telescope Control plugin
TextUserInterface	bool	12.5 Text User Interface plugin
Novae	bool	13.1 Bright Novae plugin
Scenery3dMgr	bool	14 Scenery 3D plugin

D.1.16 [projection]

This section contains the projection of your choice and several advanced settings important if you run Stellarium on a single screen, multi-projection, dome projection, or other setups.

ID	Type	Description
type	string	Sets projection mode. Values: *ProjectionPerspective, ProjectionEqualArea, ProjectionStereographic, ProjectionFisheye, ProjectionHammer, ProjectionCylinder, ProjectionMercator, ProjectionOrthographic, ProjectionMiller*, or *ProjectionSinusoidal*.
flip_horz	bool	
flip_vert	bool	
viewport	string	How the view-port looks. Values: *none* (regular rectangular screen), *disk* (circular screen, useful for planetarium setup).
viewportMask	string	How the view-port looks. Values: *none*.
viewport_fov_diameter	float	
viewport_x	float	Usually 0.
viewport_y	float	Usually 0.
viewport_width	float	
viewport_height	float	
viewport_center_x	float	Usually half of viewport_width.
viewport_center_y	float	Usually half of viewport_height.
viewport_center_offset_x	float	[-0.5...+0.5] Usually 0.
viewport_center_offset_y	float	[-0.5...+0.5] Use negative values to move the horizon lower.

D.1.17 [proxy]

This section has setting for connection to network through proxy server (proxy will be using when host of proxy is filled).

ID	Type	Description
host_name	string	Name of host for proxy. E.g. *proxy.org*
type	string	Type of proxy. E.g. *socks*
port	int	Port of proxy. E.g. *8080*
user	string	Username for proxy. E.g. *michael_knight*
password	string	Password for proxy. E.g. *xxxxx*

D.1.18 [scripts]

ID	Type	Default	Description
startup_script	string	startup.ssc	name of script executed on program start
flag_script_allow_write_absolute_path	bool	false	set true to let scripts store files to absolute pathnames. This may pose a security risk if you run scripts from other authors without checking what they are doing.

D.1.19 [search]

ID	Type	Description
flag_search_online	bool	If *true*, Stellarium will be use SIMBAD for search.
simbad_server_url	string	URL for SIMBAD mirror
flag_start_words	bool	If *false*, Stellarium will be search phrase only from start of words
coordinate_system	string	Specifies the coordinate system. *Possible values:* equatorialJ2000, equatorial, horizontal, galactic. *Default value:* equatorialJ2000.

D.1.20 [spheric_mirror]

Stellarium can be used in planetarium domes. You can use a projector with a hemispheric mirror with geometric properties given in this section. Note: These functions are only rarely used or tested, some may not work as expected.

ID	Type	Default	Description
flip_horz	bool	true	Flip the projection horizontally
flip_vert	bool	false	Flip the projection vertically
projector_alpha	float	0	This parameter controls the properties of the spheric mirror projection mode.
projector_gamma	float		This parameter controls the properties of the spheric mirror projection mode.
projector_delta	float	-1e100	This parameter controls the properties of the spheric mirror projection mode.
projector_phi	float	0	This parameter controls the properties of the spheric mirror projection mode.
projector_position_x	float	0	
projector_position_y	float	1	
projector_position_z	float	-0.2	

mirror_position_x	float	0	
mirror_position_y	float	2	
mirror_position_z	float	0	
image_distance_div_height	float	-1e100	
mirror_radius	float	0.25	
dome_radius	float	2.5	
custom_distortion_file	string		
texture_triangle_base_length	float		
zenith_y	float	0.125	deprecated
scaling_factor	float	0.8	deprecated
distorter_max_fov	float	175.0	Set the maximum field of view for the spheric mirror distorter in degrees. Typical value: *180*
viewportCenterWidth	float		projected image width, pixels
viewportCenterHeight	float		projected image height, pixels
viewportCenterX	float		projected image center X, pixels
viewportCenterY	float		projected image center Y, pixels

D.1.21 [**stars**]

This section controls how stars are rendered.

ID	*Type*	*Description*
relative_scale	float	relative size of bright and faint stars. Higher values mean that bright stars are comparitively larger when rendered. Typical value: *1.0*
absolute_scale	float	Changes how large stars are rendered. larger value lead to larger depiction. Typical value: *1.0*
star_twinkle_amount	float	amount of twinkling. Typical value: *0.3*
flag_star_twinkle	bool	*true* to allow twinkling (but only when atmosphere is active!).
flag_forced_twinkle	bool	*true* to allow twinkling stars even without atmosphere. This is obvious nonsense and contrary to nature, but some users seem to like it.
flag_star_halo	bool	*false* to not draw a halo around the brightest stars. This looks poor, but some users seem to prefer it.
mag_converter_max_fov	float	maximum field of view for which the magnitude conversion routine is used. Typical value: *90.0*.
mag_converter_min_fov	float	minimum field of view for which the magnitude conversion routine is used. Typical value: *0.001*.
labels_amount	float	amount of labels. Typical value: *3.0*
init_bortle_scale	int	initial value of light pollution on the Bortle scale. Typical value: *3*.

D.1.22 [**tui**]

The built-in text user interface (TUI) plugin (see chapter 12.5) is most useful for planetariums. You can even configure a system shutdown command. For historical reasons, the section is not called [TextUserInterface] but simply [tui].

ID	Type	Default	Description
tui_font_size	float	15	Font size for TUI.
tui_font_color	floatRGB	0.3,1,0.3	Font color for TUI.
flag_show_gravity_ui	bool	false	Set to *true* to enable gravity mode for UI (for dome projection)
flag_show_tui_datetime	bool	false	Set to *true* if you want to see a date and time label suited for dome projections
flag_show_tui_short_obj_info	bool	false	Set to *true* if you want to see object info suited for dome projections
tui_admin_shutdown_command	string		e.g. for Linux: `shutdown -poweroff +2`

D.1.23 [video]

ID	Type	Description
fullscreen	bool	If *true*, Stellarium will start up in full-screen mode, else windowed mode
screen_w	int	Display width when in windowed mode. Value in pixels, e.g. *1024*
screen_h	int	Display height when in windowed mode. Value in pixels, e.g. *768*
screen_x	int	Horizontal position of the top-left corner in windowed mode. Value in pixels, e.g. *0*
screen_y	int	Vertical position of the top-left corner in windowed mode. Value in pixels, e.g. *0*
viewport_effect	string	This is used when the spheric mirror display mode is activated. Values include *none* and *sphericMirrorDistorter*.
minimum_fps	int	Sets the minimum number of frames per second to display at (hardware performance permitting)
maximum_fps	int	Sets the maximum number of frames per second to display at. This is useful to reduce power consumption in laptops.

D.1.24 [viewing]

This section defines which objects, labels, lines, grids etc. you want to see on startup. Set those to *true*. Most items can be toggled with hotkeys or switched in the GUI.

ID	Type	Description
flag_asterism_drawing	bool	Display asterism line drawing
flag_asterism_name	bool	Display asterism names
flag_rayhelper_drawing	bool	Display the ray helper line drawing
flag_constellation_drawing	bool	Display constellation line drawing
flag_constellation_name	bool	Display constellation names
flag_constellation_art	bool	Display constellation art
flag_constellation_boundaries	bool	Display constellation boundaries
flag_constellation_isolate_selected	bool	If *true*, constellation lines, boundaries and art will be limited to the constellation of the selected star, if that star is "on" one of the constellation lines.

flag_constellation_pick	bool	Set to *true* if you only want to see the line drawing, art and name of the selected constellation star
flag_isolated_trails	bool	Set to *true* if you only want to see the trail line drawn for the selected planet (asteroid, comet, moon)
number_isolated_trails	int	Number of isolated trails for latest selected Solar system bodies [1..5].
max_trail_points	int	Limit maximum length of trails. Trails are drawn for 1 year or this number of computing steps. Default 5000, reduce if drawing trails slows down the program too much.
flag_isolated_orbits	bool	Set to *true* if you want to see orbits only for selected planet and their moons.
flag_azimutal_grid	bool	Display azimuthal grid
flag_equatorial_grid	bool	Display equatorial grid (of date)
flag_equatorial_J2000_grid	bool	Display equatorial grid (J2000)
flag_ecliptic_grid	bool	Display ecliptic grid (of date)
flag_ecliptic_J2000_grid	bool	Display ecliptic grid (J2000)
flag_galactic_grid	bool	Display galactic grid (System II)
flag_galactic_equator_line	bool	Display galactic equator line
flag_equator_line	bool	Display celestial equator line (of date)
flag_equator_J2000_line	bool	Display celestial equator line (J2000)
flag_ecliptic_line	bool	Display ecliptic line (of date)
flag_ecliptic_J2000_line	bool	Display ecliptic line (J2000)
flag_meridian_line	bool	Display meridian line
flag_prime_vertical_line	bool	Display Prime Vertical line (East-Zenith-West)
flag_colure_lines	bool	Display colure lines (Celestial Pole-♈/♋/♎/♑)
flag_cardinal_points	bool	Display cardinal points
line_thickness	int	Set the line thickness for grids and lines. Typical value: *1*
cardinal_font_size	int	Font size for cardinal points. Typical value: *24*
subcardinal_font_size	int	Font size for subcardinal points. Typical value: *18*
flag_gravity_labels	bool	Set to *true* if you want labels to undergo gravity (top side of text points toward zenith). Useful with dome projection.
flag_moon_scaled	bool	Keep it *false* if you want to see the real moon size
moon_scale	float	Sets the moon scale factor, sometimes useful to correlate to our perception of the moon's size. Typical value: *4*
flag_minorbodies_scaled	bool	Set to *true* if you want to see minor bodies enlarged
minorbodies_scale	float	Set scale factor for minor bodies, to see them in unnatural detail. Typical value: *10*
constellation_art_intensity	float	brightness [0...1] of the constellation art images. Typical value: *0.5*
constellation_art_fade_duration	float	time the constellation art takes to fade in or out, in seconds. Typical value: *1.5*
constellation_font_size	int	font size for constellation labels

constellation_line_thickness	int	thickness of constellation lines [1...5]. Typical value: *1*
asterism_font_size	int	font size for asterism labels
asterism_line_thickness	int	thickness of the asterism lines [1...5]. Typical value: *1*
rayhelper_line_thickness	int	thickness of the ray helper lines [1...5]. Typical value: *1*

flag_night	bool	Enable night mode (red-only mode) on startup
light_pollution_luminance	float	Sets the level of the light pollution simulation
use_luminance_adaptation	bool	Enable dynamic eye adaptation
sky_brightness_label_threshold	float	Sky brightness [cd/m^2] to show infotext in black

D.1.25 [**DialogPositions**]

By default, GUI panels appear centered in the screen. You can move them to your favorite location, and on next start they will appear on that location instead. The entries in this section define the upper left pixel coordinate where panels are stored.

Examples:

ID	*Type*	*Example*	*Description*
Help	int,int	58,39	Position of Help panel
DateTime	int,int	1338,944	Position of time panel

D.1.26 [**DialogSizes**]

v0.15.1

GUI panels can be resized by dragging on their lower corners or borders. Enlarged sizes are stored here, and on next start they will appear in this size. The entries in this section define the size.

Examples:

ID	*Type*	*Example*	*Description*
Help	int,int	895,497	Size of Help panel
AstroCalc	int,int	913,493	Size of AstroCalc panel

D.1.27 [**hips**]

v0.18.0

This section defines the source list of the HiPS surveys, as well as other HiPS related options.

ID	*Type*	*Description*
show	bool	show HiPS at startup?
sources/size	int	Number of HiPS survey sources
sources/n/url	string	uri of the *n*th source hipslist file ($n \in [1 \ldots$ `sources/size`$]$)
visible/url	bool	HiPS configured to be displayed. (Stores current setting on program exit)

D.2 Solar System Configuration Files

The files[3] `ssystem_major.ini` and `ssystem_minor.ini` (in the `data/` subdirectory of the program directory, contain orbital and rotational data from which Stellarium configures the Solar System objects.

The minor bodies can be modified by placing a privately modified copy of `ssystem_minor.ini` into your own `data/` directory (see Chapter 5). You can edit the file either manually, or with the Solar System Editor plugin (see Section 12.8).

Each object's data are described in its own section which is typically named after the object name. Some section names (e.g. those using diacriticals, spaces or other problematic characters) appear a bit mangled.

We list here examples for the major planets, larger moons with special coordinate functions, minor moons with generic orbital elements, minor planets and comets with elliptical and parabolic orbit elements.

All elements are stored in alphabetic order in the files, however it makes more sense to present the elements in another structure which better reflects the meaning. The actual order of the objects in the files, and order of entries inside an object section, is irrelevant.

D.2.1 File ssystem_major.ini

Planet section

Example:

```
[jupiter]
name=Jupiter
type=planet
coord_func=jupiter_special

albedo=0.51
atmosphere=1
color=1., 0.983, 0.934
tex_map=jupiter.png #texture courtesy of Bj\xf6rn J\xf3nsson
halo=true
oblateness=0.064874
orbit_visualization_period=4331.87
parent=Sun
radius=71492
rot_equator_ascending_node=-22.203
rot_obliquity=2.222461
rot_periode=9.92491
rot_pole_de=64.49
rot_pole_ra=268.05
rot_rotation_offset=-1 # use JupiterGRS patch
```

where

name English name of the planet. May appear translated.

type Mandatory for planets:

parent =Sun. The body which this object is running around. Default: Sun

coord_func The planet positions are all computed with a dedicated function (VSOP or DE43x).

---

[3]Before v0.16, there was a single file, `ssystem.ini`, with slightly different rules.

orbit_visualization_period number of (earth) days for how long the orbit should be made visible. Typically Stellarium shows one orbit line. The orbit slowly drifts, however.

atmosphere (0 or 1) flag to indicate whether observer locations should enable atmosphere drawing.

radius Equator radius, km.

oblateness Flattening of the polar diameter. (r_{pole}/r_{eq})

albedo total albedo (reflectivity) of the planet. Used for "generic" magnitude computation, but the major planets usually have dedicated magnitude formulas, so the value is not evaluated unless you are observing from a location outside Earth.

color Used to colorize halo. At least one of the components should be 1.

tex_halo File name of texture map for halo texture in `textures` folder. (Used when zoomed out far enough so that the actual sphere is not visible.)

tex_map File name of texture map in `textures` folder.

halo Should be true to draw a halo (simple light disk) when object too small to draw a sphere.

Elements for the Physical Ephemeris

rot_equator_ascending_node *deprecated*

rot_obliquity *deprecated*

rot_pole_ra constant of axis right ascension in ICRF, degrees

rot_pole_ra1 change per century of axis right ascension in ICRF, degrees

rot_pole_de constant of axis declination in ICRF, degrees

rot_pole_de1 change per century of axis declination in ICRF, degrees

rot_rotation_offset longitude of central meridian at J2000.0. The special value here indicates special treatment for the Great Red Spot.

rot_periode Duration of one sidereal rotation, in earth hours.

rot_equator_ascending_node and rot_obliquity are the generic values to specify the axis orientation with respect to the parent object's equator, or the VSOP87 inertial plane in case of planets. However, for planets the IAU has been using right ascension and declination of the pole in the ICRF for decades now. The elements to use for planets should therefore be the rot_pole_* values.

In many cases, the attitude/rotation formula is given like

$$\alpha_0 \;=\; \texttt{rot\_pole\_ra} + T * \texttt{rot\_pole\_ra1} \tag{D.1}$$

$$\delta_0 \;=\; \texttt{rot\_pole\_de} + T * \texttt{rot\_pole\_de1} \tag{D.2}$$

$$W \;=\; \texttt{rot\_rotation\_offset} + d * \texttt{rot\_periode} \tag{D.3}$$

These cases are covered by the data in `ssystem_major.ini`. Other cases are dealt with in a different way.

Moon section

All planet moons are defined only in `ssystem_major.ini`.

Moons are special in that they orbit another planet. Therefore, the rotational elements used to be specified relative to the equatorial plane of the parent planet, and `orbit_SemiMajorAxis` are specified in kilometers. However, current IAU reference material gives axis orientation with right ascension and declination values for the pole in ICRF coordinates, with some of them in motion. So again, if one of the `rot_pole_...` values exist, we assume the current standard. For more complicated motion, again some special functions are applied.

```
[amalthea]
name = Amalthea
type = moon
parent = Jupiter
iau_moon_number = JV
```

```
coord_func=ell_orbit
orbit_AscendingNode=141.5521520794674
orbit_Eccentricity=0.006175744402949701
orbit_Epoch=2454619.50000
orbit_Inclination=0.3864576103404582
orbit_LongOfPericenter=245.4222355150120000
orbit_MeanLongitude=224.7924893552550000
orbit_Period=0.5016370462116355
orbit_SemiMajorAxis=181994.8658358799
orbit_visualization_period=0.5016370462116355

radius=73
rot_equator_ascending_node=213.7
rot_obliquity=15.5
rot_periode=12.039289109079252
rot_rotation_offset=235.50

albedo=0.06
color=1., 0.627, 0.492
halo=true
tex_map=amalthea.png
model=j5amalthea_MLfix.obj
```

where

name English name of planet moon. No number, just the name. May be translated.

type moon

parent English name of planet or parent body.

iau_moon_number a short label (string) consisting of the planet's initial and the moon's Roman number in order of discovery.

coord_func Must be ell_orbit for moons with orbital elements given, or <name>_special for

orbit_AscendingNode Ω

orbit_Eccentricity e

orbit_Epoch

orbit_Inclination i [degrees]

orbit_LongOfPericenter

orbit_MeanLongitude

orbit_Period [days]

orbit_SemiMajorAxis a [km]

orbit_visualization_period [days] Defaults to orbit_Period to show orbit as closed line. This is in fact only useful in case of special functions for positioning where orbit_Period is not given.

radius Equator radius, km.

oblateness Flattening of the polar diameter. (r_{pole}/r_{eq})

rot_equator_ascending_node =213.7 TRY TO AVOID!

rot_obliquity =15.5 TRY TO AVOID!

rot_pole_ra constant of axis right ascension in ICRF, degrees

rot_pole_ra1 change per century of axis right ascension in ICRF, degrees

rot_pole_de constant of axis declination in ICRF, degrees

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rot_pole_de1 change per century of axis declination in ICRF, degrees

rot_rotation_offset longitude of central meridian at J2000.0.

rot_periode Duration of one sidereal rotation, in earth hours. For moons in bound rotation (which always show one face towards their parent planet), it is best to omit this value: it defaults to `orbit_Period * 24`.

albedo total reflectivity [0..1]

color for drawing halo (default: 1,1,1)

halo [=true|false] to draw a simple diffuse dot when zoomed out. Default: true

tex_map name of spherical texture map. Many moons have been mapped by visiting spacecraft!   v0.16.0

model (optional) name of a 3D model for a non-spherical body in the `model` subdirectory of the program directory.

Observers

Stellarium is great for excursions to the surface of any object with known orbital elements. Configuring a viewpoint away from a planet requires a special kind of location.

Solar System Observer

The Solar System Observer has been provided as a neutral view location high above the North pole of the Solar System. It has been configured like this:

```
[solar_system_observer]
name=Solar System Observer
parent=Sun
halo=false
hidden=true
coord_func=ell_orbit
orbit_Inclination=90
orbit_MeanLongitude=90
orbit_Period=70000000000
orbit_SemiMajorAxis=70000000000
rot_obliquity=90
type=observer
```

Note the inclination and mean longitude of 90 degrees, and that it is `hidden` and has no `halo`.

Planet Observers

There are other "observer" locations for all planets which have moons: Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. They have all been provided as neutral view locations above the Northern hemisphere of the respective planet. For example: v0.19.2

```
[earth_observer]
name=Earth Observer
parent=Earth
halo=false
hidden=true
coord_func=ell_orbit
orbit_Inclination=90
orbit_MeanLongitude=90
orbit_Period=100000000000
orbit_SemiMajorAxis=149600000
rot_obliquity=90
```

```
type = observer
```

The distance `orbit_semiMajorAxis` has been configured with a distance that resembles the semimajor axis of the respective planet: when you want to compare the views from Earth and from the observer, light time correction should be at least approximately equal.

D.2.2 File ssystem_minor.ini
Minor Planet section

```
[4vesta]
type = asteroid
minor_planet_number = 4
name = Vesta

coord_func = comet_orbit
parent = Sun
orbit_ArgOfPericenter = 151.19843
orbit_AscendingNode = 103.85141
orbit_Eccentricity = 0.0887401
orbit_Epoch = 2457000.5
orbit_Inclination = 7.14043
orbit_MeanAnomaly = 20.86389
orbit_MeanMotion = 0.27154465
orbit_SemiMajorAxis = 2.3617933
orbit_visualization_period = 1325.46

color = 1., 1., 1.
halo = true
oblateness = 0.0

albedo = 0.423
radius = 280
absolute_magnitude = 3.2
slope_parameter = 0.32
tex_map = vesta.png
model = 4vesta_21_MLfix.obj
```

`type` can be `asteroid`, `dwarf planet`, `cubewano`, `plutino`, `scattered disc object`, `Oort cloud object`. With the exception of Pluto (which is included in `ssystem_major.ini` and cannot be changed), all positions for minor bodies are computed with the orbiting elements given in this way.

Note that although all minor planets orbit the sun in an elliptical orbit, the `coord_func=comet_orbit`. However, it is more common for minor planets to specify epoch, mean anomaly and mean motion.

Visual magnitude is modelled from absolute magnitude *H* and slope parameter *G*.

Elements for rotational axis may be given just like for planets when they are known. It is recommended to use the modern specification (elements `rot_pole_...`).

v0.16.0   A few asteroids have been visited by spacecraft, and for many other asteroids visual observations of stellar occultations by asteroids and light curve measurements have enabled researchers to derive 3D shape models of asteroids. If a model is available in the `models` subdirectory of the program directory, this can be configured with a `model` entry.

Comet section

Comets are tiny, and their outgassing and close approaches to the major planets cause fast changes in their orbital elements, so that each apparition should be specified with a dedicated section in `ssystem_minor.ini`.

The coord_func is always specified as `comet_orbit`. Note the specification of a time (JDE) at pericenter which is typical for comets.

Comet brightness is evaluated from

$$\mathrm{mag} = \texttt{absolute\_magnitude} + 5\cdot\log\mathrm{distance} + 2.5\cdot\texttt{slope\_parameter}\cdot\log(\mathrm{CometSunDistance})$$

(D.4)

The term `slope_parameter` may be a misnomer in case of comets. From the literature (Meeus, 1998) (equation 33.13) we find

$$\mathrm{mag} = g + 5\log\Delta + \kappa\log r$$

(D.5)

from which $\kappa = 2\cdot\texttt{slope\_parameter}$. In any case, κ is typically $[5\ldots15]$ and specific for each comet.

`albedo` is used to set the brightness for rendering the body, if you are close enough.

A large number of elements for historical comets is provided in the file `ssystem_1000comets.ini` in the installation directory. You can copy&paste what you need into your `ssystem_minor.ini` or add all with the Solar System Editor plugin (section 12.8). Unfortunately it is not possible to specify several sets of orbital elements for different epochs of one apparition which would allow automatic changes.

Periodic Comet

```
[1phalley]
type = comet
name =1P/ Halley

coord_func = comet_orbit
parent = Sun [can be omitted]
orbit_ArgOfPericenter =111.7154
orbit_AscendingNode =58.8583
orbit_Eccentricity =0.968004
orbit_Inclination =162.2453
orbit_PericenterDistance =0.57136
orbit_TimeAtPericenter =2446463.12979167
orbit_good =780

color =1.0, 1.0, 1.0
dust_brightnessfactor =1.5
dust_lengthfactor =0.4
dust_widthfactor =1.5

albedo =0.1
radius =5
absolute_magnitude =5.5
slope_parameter =3.2
tex_map = nomap.png
```

```
model=1682q1halley_MLfix.obj [optional]
```

You may want to e.g. change the name in this entry to name=1P/Halley (1982i). Note a rather short duration of orbit_good, which means the comet is only displayed 780 days before and after perihel.

Some comets have been visited by spacecraft so that shape models of their cores may be available and can be configured with a model entry.

v0.16.0

Parabolic/Hyperbolic Comet

```
[c2013us10%28catalina%29]
type=comet
name=C/2013 US10 (Catalina)

coord_func=comet_orbit
parent=Sun
orbit_ArgOfPericenter=340.3533
orbit_AscendingNode=186.141
orbit_Eccentricity=1.000372
orbit_Inclination=148.8766
orbit_PericenterDistance=0.822958
orbit_TimeAtPericenter=2457342.20748843
orbit_good=1000

color=1.0, 1.0, 1.0
dust_brightnessfactor=1.5
dust_lengthfactor=0.4
dust_widthfactor=1.5

albedo=0.1
radius=5
absolute_magnitude=4.4
slope_parameter=4
tex_map=nomap.png
```

This has basically the same format. Note eccentricity is larger 1, this means the comet is running on a slightly hyperbolic orbit. Stellarium shows data for this comet for almost 3 years (orbit_good=1000 days) from perihel.

E. Planetary nomenclature

Planetary nomenclature, like terrestrial nomenclature, is a system of uniquely identifying features on the surface of a planet or natural satellite so that the features can be easily located, described, and discussed. Since the invention of the telescope, astronomers have given names to the surface features they have discerned, especially on the Moon and Mars. To standardize planetary nomenclature, the International Astronomical Union (IAU) was assigned in 1919 the task of selecting official names for features on solar system bodies[1].
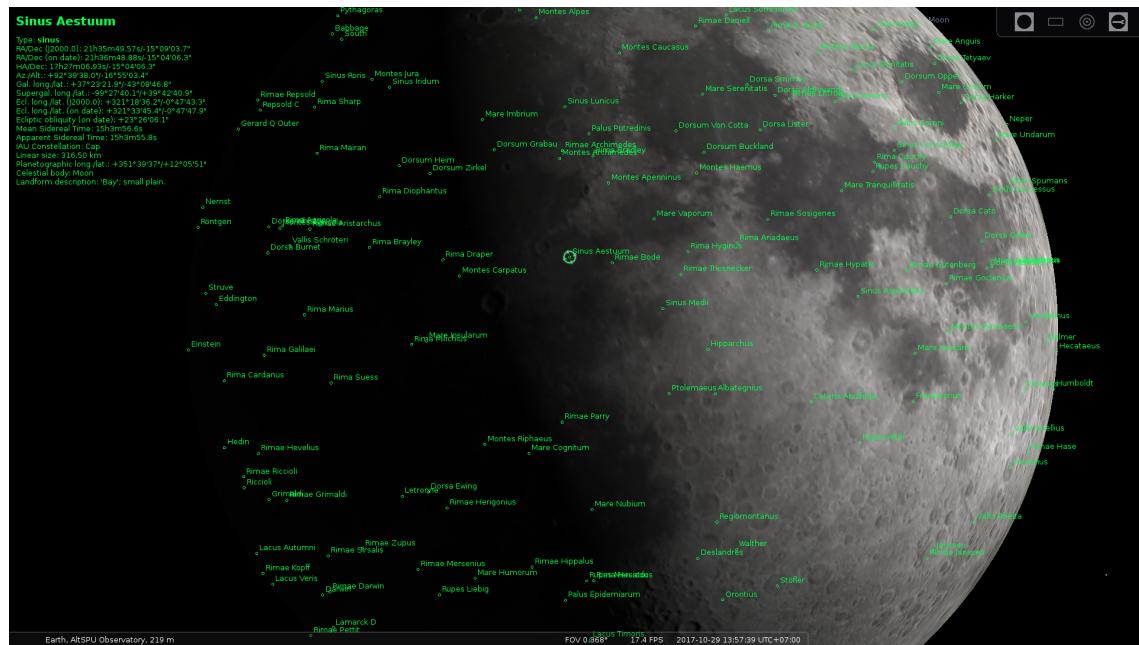
Figure E.1: Feature nomenclature of the Moon.

---

[1]History of Planetary Nomenclature – https://planetarynames.wr.usgs.gov/Page/History

Since version 0.17.0 Stellarium supports planetary nomenclature, which allows using the planetarium for educational and informative purposes on the one hand, and as tool for recognition and targeting of the planetary features for advanced amateurs on the other hand, avoiding the need for additional cartographic software in the field.

All planetary nomenclature items are stored in a dedicated internal format, and all names are translatable to provide better understanding of those names by average users and newbies – for example in schools or universities. Of course all nomenclature items are available for finding in the Search Tool after enabling the display of nomenclature (this feature is rather costly in terms of computing power and therefore is by default disabled in the GUI).

The information in sections E.2–E.5, included here for reference, has been taken from the "Gazetteer of Planetary Nomenclature" website by the International Astronomical Union (IAU) Working Group for Planetary System Nomenclature (WGPSN)[2].

E.1   Format of nomenclature data file

File `data/nomenclature.fab` is a plain text file in UTF-8 encoding and has a very simple data format:

  • One item per line;
  • Each item contains seven elements with white space ("space" or "tab" character) as delimiter.

Item	Type	Comment
planet name	string	English name of the planet, moon or minor body carrying the named feature
ID of planetary feature	integer	unique integer, equal to Feature ID obtained from Gazetteer of Planetary Nomenclature
translatable name of planetary feature	string	English name, containing context data for translators
type of planetary feature	string	2-char code (see *designation* column in table in section E.5)
center latitude of planetary feature	float	decimal degrees
center longitude of planetary feature	float	decimal degrees
size of planetary feature	float	kilometers

Example:

```
Vesta 15201 _("Caesonia","crater") AA 31.20117 249.93457 104.23
```

E.2   How names are approved by the IAU

When images are first obtained of the surface of a planet or satellite, a theme for naming features is chosen and a few important features are named, usually by members of the appropriate IAU task group (a commonly accepted planet-naming group). Later, as higher resolution images and maps become available, additional features are named at the request of investigators mapping or describing specific surfaces, features, or geologic formations. Anyone may suggest that a specific name be considered by a task group. If the members of the task group agree that the name is appropriate, it can be retained for use when there is a request from a member of the scientific community that a specific feature be named. Names successfully reviewed by a task group are

---

[2]`https://planetarynames.wr.usgs.gov`, visited on 2017-10-30

submitted to the IAU Working Group for Planetary System Nomenclature (WGPSN)[3]. Upon successful review by the members of the WGPSN, names are considered provisionally approved and can be used on maps and in publications as long as the provisional status is clearly stated. Provisional names are then presented for adoption to the IAU's General Assembly, which met triennially in the past, and which now adopts nomenclature for planetary surface features as required. A name is not considered to be official – that is, "adopted" – until the General Assembly has given its approval.

E.3 IAU rules and conventions

Names adopted by the IAU must follow various rules and conventions established and amended through the years by the Union. These include:

1. Nomenclature is a tool and the first consideration should be to make it simple, clear, and unambiguous.
2. In general, official names will not be given to features whose longest dimensions are less than 100 meters, although exceptions may be made for smaller features having exceptional scientific interest.
3. The number of names chosen for each body should be kept to a minimum. Features should be named only when they have special scientific interest, and when the naming of such features is useful to the scientific and cartographic communities at large.
4. Duplication of the same surface feature name on two or more bodies, and of the same name for satellites and minor planets, is discouraged. Duplications may be allowed when names are especially appropriate and the chances for confusion are very small.
5. Individual names chosen for each body should be expressed in the language of origin. Transliteration for various alphabets should be given, but there will be no translation from one language to another.
6. Where possible, the themes established in early solar system nomenclature should be used and expanded on.
7. Solar system nomenclature should be international in its choice of names. Recommendations submitted to the IAU national committees will be considered, but final selection of the names is the responsibility of the International Astronomical Union. Where appropriate, the WGPSN strongly supports an equitable selection of names from ethnic groups, countries, and gender on each map; however, a higher percentage of names from the country planning a landing is allowed on landing site maps.
8. No names having political, military or religious significance may be used, except for names of political figures prior to the 19th century.
9. Commemoration of persons on planetary bodies should not normally be a goal in itself, but may be employed in special circumstances and is reserved for persons of high and enduring international standing. Persons being so honored must have been deceased for at least three years, before a proposal may be submitted.
10. When more than one spelling of a name is extant, the spelling preferred by the person, or used in an authoritative reference, should be used. Diacritical marks are a necessary part of a name and will be used.
11. Ring and ring-gap nomenclature and names for newly discovered satellites are developed in joint deliberation between WGPSN and IAU Commission X2. Names will not be assigned to satellites until their orbital elements are reasonably well known or definite features have been identified on them.

---

[3]Working Group for Planetary System Nomenclature – `https://planetarynames.wr.usgs.gov/`

12. Accessible and authoritative sources, including Internet sources, are required for adopted names. Wikipedia is not sufficient as a source, but may be useful for identifying appropriate sources.

In addition to these general rules, each task group develops additional conventions as it formulates an interesting and meaningful nomenclature for individual planetary bodies. Most of these conventions are self evident from study of the appendixes that follow.

E.4   Naming conventions

Names for all planetary features include a descriptor term, with a few exceptions. For craters, the descriptor term is implicit. Some features named on Io and Triton do not carry a descriptor term because they are ephemeral.

In general, the naming convention for a feature type remains the same regardless of its size. Exceptions to this rule are channels (valles) on Mars and Venus, and craters on the Moon, Mars, and Venus; naming conventions for these features differ according to size. The categories for naming features on each planet or satellite (and the exceptions) are listed in Categories for Naming Features on Planets and Satellites[4]. One feature classification, regio, was originally used on early maps of the Moon and Mercury (drawn from telescopic observations) to describe vague albedo features. It is now also used to delineate a broad geographic region.

Named features on bodies so small that coordinates have not yet been determined are identified on drawings or images of the body that are included in the IAU Transactions volume of the year when the names were adopted. Satellite rings and gaps in the rings are named for scientists who have studied these features; drawings that show these names are also included in the pertinent Transactions volume. Names for atmospheric features are informal at present; a formal system will be chosen in the future.

The boundaries of many large features (such as terrae, regiones, planitiae, and plana) are not topographically or geomorphically distinct; the coordinates of these features are identified from an arbitrarily chosen center point. Boundaries (and thus coordinates) may be determined more accurately from geochemical and geophysical data obtained by future missions.

During active missions, small surface features are often given informal names. These may include landing sites, spacecraft impact sites, and small topographic features, such as craters, hills, and rocks. Such names will not be given official status by the IAU, except as provided for by Rule 2 above. As for the larger objects, official names for any such small features would have to conform to established IAU rules and categories.

When a satellite has been discovered through the efforts of a large scientific team, the list of individual team members may be too long to include all contributors. In such cases, credit for the discovery will go to the science team.

---

[4]Surface Feature Categories – `https://planetarynames.wr.usgs.gov/Page/Categories`

E.5   Descriptor terms (feature types)
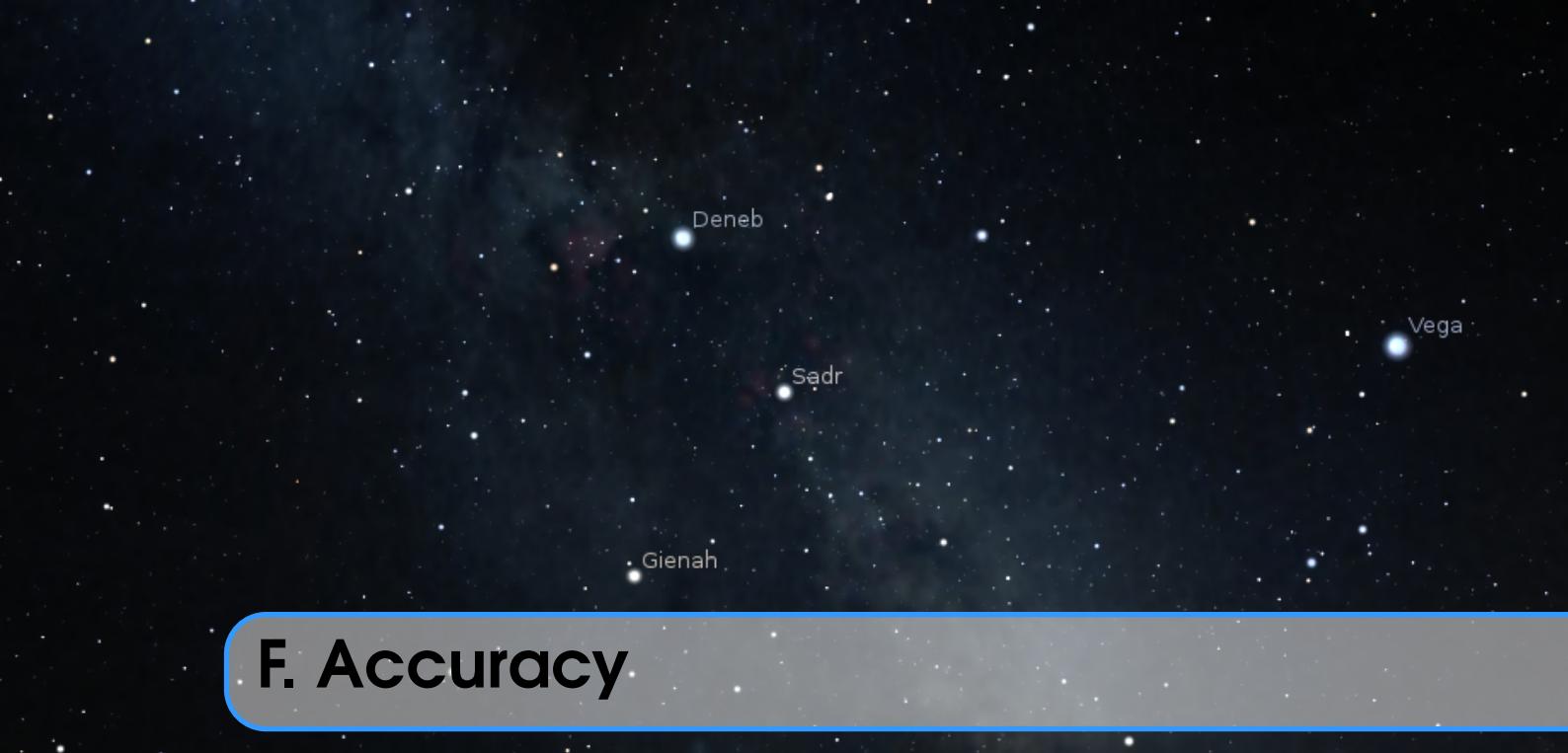
Descriptor terms are intended to represent morphological characteristics, not geological origin. The WGPSN does not endorse any specific scientific hypotheses when assigning descriptors.

Feature	Designation	Description
Albedo Feature	AL	Geographic area distinguished by amount of reflected light
Arcus, arcūs	AR	Arc-shaped feature
Astrum, astra	AS	Radial-patterned features on Venus
Catena, catenae	CA	Chain of craters
Cavus, cavi	CB	Hollows, irregular steep-sided depressions usually in arrays or clusters
Chaos, chaoses	CH	Distinctive area of broken terrain
Chasma, chasmata	CM	A deep, elongated, steep-sided depression
Collis, colles	CO	Small hills or knobs
Corona, coronae	CR	Ovoid-shaped feature
Crater, craters	AA	A circular depression
Dorsum, dorsa	DO	Ridge
Eruptive center	ER	Active volcanic centers on Io
Facula, faculae	FA	Bright spot
Farrum, farra	FR	Pancake-like structure, or a row of such structures
Flexus, flexūs	FE	A very low curvilinear ridge with a scalloped pattern
Fluctus, fluctūs	FL	Flow terrain
Flumen, flumina	FM	Channel on Titan that might carry liquid
Fossa, fossae	FO	Long, narrow depression
Fretum, freta	FT	Strait, a narrow passage of liquid connecting two larger areas of liquid
Insula, insulae	IN	Island (islands), an isolated land area (or group of such areas) surrounded by, or nearly surrounded by, a liquid area (sea or lake)
Labes, labēs	LA	Landslide
Labyrinthus, labyrinthi	LB	Complex of intersecting valleys or ridges
Lacuna, lacunae	LU	Irregularly shaped depression on Titan having the appearance of a dry lake bed
Lacus, lacūs	LC	"Lake" or small plain; on Titan, a "lake" or small, dark plain with discrete, sharp boundaries
Landing site name	LF	Lunar features at or near Apollo landing sites
Large ringed feature	LG	Cryptic ringed features
Lenticula, lenticulae	LE	Small dark spots on Europa
Linea, lineae	LI	A dark or bright elongate marking, may be curved or straight
Lingula, lingulae	LN	Extension of plateau having rounded lobate or tongue-like boundaries
Macula, maculae	MA	Dark spot, may be irregular

Mare, maria	ME	"Sea"; on the Moon, low albedo, relatively smooth plain, generally of large extent; on Mars, dark albedo areas of no known geological significance; on Titan, large expanses of dark materials thought to be liquid hydrocarbons
Mensa, mensae	MN	A flat-topped prominence with cliff-like edges
Mons, montes	MO	Mountain
Oceanus, oceani	OC	A very large dark area on the moon
Palus, paludes	PA	"Swamp"; small plain
Patera, paterae	PE	An irregular crater, or a complex one with scalloped edges
Planitia, planitiae	PL	Low plain
Planum, plana	PM	Plateau or high plain
Plume, plumes	PU	Cryo-volcanic features on Triton
Promontorium, promontoria	PR	"Cape"; headland promontoria
Regio, regiones	RE	A large area marked by reflectivity or color distinctions from adjacent areas, or a broad geographic region
Reticulum, reticula	RT	Reticular (netlike) pattern on Venus
Rima, rimae	RI	Fissure
Rupes, rupēs	RU	Scarp
Satellite Feature	SF	A feature that shares the name of an associated feature. For example, on the Moon the craters referred to as "Lettered Craters" are classified in the gazetteer as "Satellite Features"
Scopulus, scopuli	SC	Lobate or irregular scarp
Serpens, serpentes	SE	Sinuous feature with segments of positive and negative relief along its length
Sinus, sinūs	SI	"Bay"; small plain; on Titan, bays within seas or lakes of liquid hydrocarbons
Sulcus, sulci	SU	Subparallel furrows and ridges
Terra, terrae	TA	Extensive land mass
Tessera, tesserae	TE	Tile-like, polygonal terrain
Tholus, tholi	TH	Small domical mountain or hill
Unda, undae	UN	Dunes
Vallis, valles	VA	Valley
Vastitas, vastitates	VS	Extensive plain
Virga, virgae	VI	A streak or stripe of color

Author and Acknowledgement

F. Accuracy

Stellarium originally was developed to present a beautiful simulation of the night sky, mostly to understand what is visible in the sky when you leave your house, i.e., for present times. To save computation time, some concessions were made in astronomical accuracy by using simplified models which seemed acceptable at that time. However, many users started to overstress Stellarium's capabilities to simulate the historical sky of many centuries in the past, and found — or even worse: did not find, but simply published — the resulting inconsistencies and errors. Unfortunately, celestial motions are indeed more complicated than a simple clockwork, and the process of retrofitting detailed and accurate models which started around v0.11.0 is not completed yet. Therefore, when using Stellarium for scientific work like eclipse simulation to illustrate records found in Cuneiform tablets, always also use some other reference to compare, and of course specify the program version you used for your work. (The next version may be more accurate or at least provide different results!) You can of course contact us if you are willing and able to help improving Stellarium's accuracy!

F.1 Date Range

The calendar dates are limited to a very wide interval of years, -100.000…100.000. This is mostly useful to visualize the effect of stellar proper motions or the wobbling motion of Earth's axis known as precession. If you observe the other planets, this is way beyond what current models are able to show! Observe for example the Moon: you will find that it seems to run on a polar orbit around +78.000 and even retrograde on a highly elongated orbit a few millennia after that. This is obvious nonsense, caused by extrapolating mathematical models in inappropriate ways.

F.2 Stellar Proper Motion

Even though you can follow stellar proper motion for tens of thousands of years, please note that the computation only takes the linear components $\Delta\alpha$, $\Delta\delta$ into account. For times far from today, a true 3D computation would be required, so that also changes in distance (and thus, brighness)

Object(s)	Method	Notes
Mercury, Venus, Earth-Moon barycenter, Mars	VSOP87	Accuracy is 1 arc-second from 2000 B.C. – 6000 A.D.
Jupiter, Saturn	VSOP87	Accuracy is 1 arc-second from 0 A.D. – 4000 A.D.
Uranus, Neptune	VSOP87	Accuracy is 1 arc-second from 4000 B.C. – 8000 A.D.
Pluto	?	Pluto's position is valid only from 1885 A.D. – 2099 A.D.
Earth's Moon	ELP2000-82B	Fit against JPL DE200, which provides date range 1850–2050. Positions should be usable for some (unspecified) longer interval.
Galilean satellites	L2	Valid from 500 A.D. – 3500 A.D.

Table F.1: Orbit-centric accuracy of used algorithms

could be simulated. Still, the simulation here should give a good impression which close and/or fast stars will move over time, and thus how constellations become deformed.

Note that due to the way the stars are stored in catalogs, zooming in on fast stars like Arcturus may even cease to display such stars when their original area in the sky is no longer in view.

Also, binary stars seem to break apart because Stellarium does not store them as systems revolving about their combined center of gravity.

These known deficits were also identified in a recent study (De Lorenzis and Orofino, 2018), which emphasized errors with Arcturus, Dubhe, Sirius, Toliman and Vega which already deviate noticably from their correct locations around 2500BC. If you need accurate stellar positions for earlier prehistory from a free and open-source program, it seems only **Cartes du Ciel** currently can be recommended as on a par with the best available solutions.

F.3 Planetary Positions

Stellarium uses the VSOP87 theory (P. Bretagnon and Francou, 1988) to calculate the positions of the planets over time. This is an analytical ephemeris modeled to match the numerical integration run DE200 from NASA JPL, which by itself gives positions for 1850...2050. Its use is recommended for the years -4000...+8000. You can observe the sun leaving the "ecliptic of date" and running on the "ecliptic J2000" outside this date range. This is obviously a mathematical trick to keep continuity. Still, positions may be somewhat useful outside this range, but don't expect anything reliable 50,000 years in the past!

The optionally usable JPL DE431 delivers planet positions strictly for -13000...+17000 only, and nothing outside, but likely with higher accuracy. Outside of this range, positions from VSOP87 will be shown again.

As far as Stellarium is concerned, the user should bear in mind the limits of the VSOP87 and other models (Table F.1). Accuracy values for VSOP87 are heliocentric as given by P. Bretagnon and Francou (1988).

Note that Stellarium models light-time correction (if enabled), but does not yet model aberration of light. Therefore seasons' beginnings are off by a few minutes.

F.4 Minor Bodies

Positions for the Minor Bodies (Dwarf Planets, Asteroids, Comets) are computed with standard algorithms found in astronomical text books. The generally used method of orbital elements allows to compute the positions of the respective object on an undisturbed Kepler orbit around the sun. However, gravitational, and in the case of comets, non-gravitational (outgassing) disturbances slowly change these orbital elements. Therefore an *epoch* is given for such elements, and computation of positions for times far from this epoch will lead to positional errors. Therefore, when searching for asteroids or comets, always update your orbital elements (See section 12.8), and use elements with an epoch as close to your time of observation as possible! Stellarium does not simulate gravitational perturbances and orbital changes of minor bodies passing major planets.

F.5 Precession and Nutation

Since v0.14.0, Stellarium computes the orientation of earth's axis according to the IAU2006 Precession in a long-time variant developed by Vondrák, Capitaine, and Wallace (2011), and IAU2000B Nutation (McCarthy and Luzum, 2003). This also now allows proper depiction of the changes in ecliptic obliquity and display of "instantaneous precession circles" around the ecliptic poles. These circles are indeed varying according to ecliptical obliquity. Nutation is only computed for about 500 years around J2000.0. Nobody could have observed it before 1609, and it is unclear for how long this model is applicable.

F.6 Planet Axes

Orientation for the other planets is still simplified. Future versions should implement modern IAU-approved models.

F.7 Eclipses

The moon's motion is very complicated, and eclipse computations can be tricky. One aspect which every student of history, prehistory and archaeology should know but as it seems not every does, is at least a basic understanding of the irregular slow-down of earth's rotation known as ΔT (see section 17.4.3).

Eclipse records on cuneiform tablets go back to the 8th century BC, some Chinese records go back a bit further. Experts on Earth rotation have provided models for ΔT based on such observations. These are usually given as parabolic fit, with some recommended time span. Extrapolating parabolic fits to erratic curves too far into the past is dangerous, pointless and inevitably leads to errors or invalid results. Models differ by many hours (exceeding a whole day!) when applied too far in the past. This means, there was certainly an eclipse, and latitude will be OK, but you cannot say which longitude the eclipse was covering. The probability to have seen a total eclipse at a certain interesting location will be very small and should by itself not be used as positive argument for any reasonable statement. This is not a problem of Stellarium, but of current knowledge. To repeat, you may find a solar eclipse in the 6th millennium BC, but you cannot even be sure which side of Earth could observe it!

WANTED: A model for ΔT that works in the Mesolithic!

F.8 The Calendar
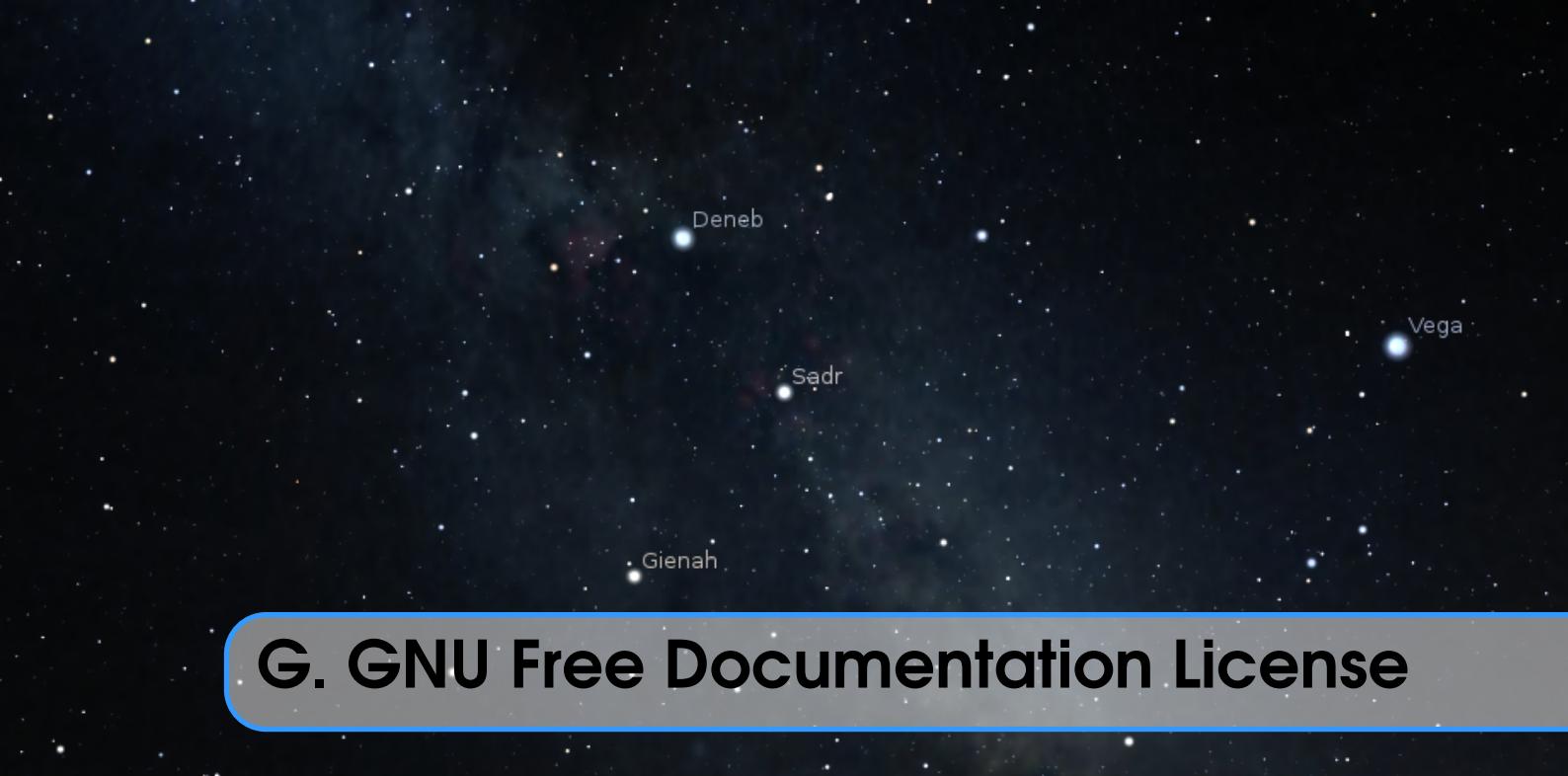
Stellarium follows the widely accepted convention that dates before the Gregorian calendar reform are given in the Julian calendar, introduced by JULIUS CAESAR in 46 BC. This calendar introduces

a leap day every fourth year, which is a bit too much. If you want to show summer solstice in the year -2500, you will notice it is not on June 21st. This is not an error of Stellarium – the Gregorian reform had a reason! In prehistoric times, it may be more useful to work with solar ecliptic longitudes. For example, summer solstice is at $\lambda = 90°$.

JULIUS CAESAR introduced a Solar calendar to the Roman empire in 46 BC but was assassinated in March 44 BC=-43 (see below). His simple 4-year leap rule was then misapplied by the high priests of Rome by adding a leap day every third year. AUGUSTUS fixed the calendar, and only 8 AD was the first correctly applied leap year as we know them (Ginzel, 1908, §186, §189). Be careful if you are working in Augustean and earlier times in the Roman world, maybe even related to named dates in the pre-Julian Roman calendar: Stellarium does not model these issues! Better find independent conversion methods to Julian Day Number (JD), and use that.

Some authors (esp. for Mesoamerican dates) give dates in the proleptic Gregorian calendar (which means, they apply the Gregorian leap year rules before 1582). This is a convention, they may of course do that, but you must do the conversion to the Julian calendar to visualize the sky with Stellarium. Hopefully they also give Julian Day numbers (JD), you can use them with Stellarium. JD numbers are independent from calendar systems.

Some have noted a difference of one between dates given as BC versus Stellarium's negative years. Note that historical chronology does not know a year Zero! (Try to write this date in Roman numbers!) Year 1 AD was preceded by year 1 BC. Astronomers want to simplify computations and therefore use a year 0 (equivalent to 1 BC). It is simple: 1 BC=0, 2 BC=-1, ... 100 BC=-99. Stellarium is an astronomy program. Just accept this.

G. GNU Free Documentation License

Version 1.3, 3 November 2008

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G.1 PREAMBLE

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When not listed as chapter authors, the following were the main contributors to the User Guide, mostly for versions before V0.15:

Matthew Gates	Primary author of the first User Guide (versions 0.9 to 0.12)
Paul Robinson	Sky guide; exercise ideas
Andras Mohari	Celestial sphere diagrams; numerous corrections
Rudy Gobits, Dirk Schwarzhans	Mac platform specifics
Barry Gerdes (†2014)	Windows platform specifics
	Customisation of .fab files
	Documentation Maintainer up to V0.12
Sigma	Japanese translation; many corrections
Richard Powell	Figure 18.3 (colour/magnitude diagram) is a modification of his diagram; he kindly granted permission for it to be distributed under the FDL
John Twin	Many spelling corrections
Georg Zotti	Lead author of the 0.15+ editions
Alexander Wolf	New layout, many contributions for the 0.15+ editions
The rest of the Stellarium developer team	You know who you are... :-)

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Stellarium on Github `https://github.com/Stellarium/`
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`Q`
Current issues (FAQ) `https://github.com/Stellarium/stellarium/wiki/Common-Pro`
`blems-for-the-current-version`
Google Group `https://groups.google.com/group/stellarium`
Feedback forum `https://sourceforge.net/p/stellarium/discussion/278769/`

H.3 Technical Articles

Stellarium would not look the same and work without these works from computer graphics and astronomy.

The tone reproductor class The class mainly performs a fast implementation of the algorithm from Tumblin and Rushmeier (1993), with more accurate values from Devlin et al. (2002). The blue shift formula is taken from Jensen et al. (2000) and combined with the Scotopic vision formula from Larson, Rushmeier, and Piatko (1997).

The skylight class The class governs sky colors and is a fast implementation of the algorithm by Preetham, Shirley, and Smits (1999).

The skybright class The class governs physical sky brightness values based on Bradley Schaefer's **VISLIMIT.BAS** basic source code (Schaefer, 1998). The basic sources are available on the Sky and Telescope web site (code "offered as-is and without support").

The ΔT calculations For implementation of calculation routines for ΔT we used the following sources:

1. ΔT webpage by Rob van Gent: `http://www.staff.science.uu.nl/~gent0113/`
   `deltat/deltat.htm`
2. *Five Millennium Canon of Solar Eclipses: -1900 to +3000* (Espenak and Meeus, 2006)
   (`http://eclipse.gsfc.nasa.gov/SEhelp/deltatpoly2004.html`)
3. "On the system of astronomical constants" (Clemence, 1948)
4. "The rotation of the earth, and the secular accelerations of the sun, moon and planets" (Spencer Jones, 1939)
5. "Polynomial approximations for the correction delta T E.T.-U.T. in the period 1800-1975" (Schmadel and Zech, 1979)
6. "ELP 2000-85 and the dynamic time-universal time relation" (Borkowski, 1988)
7. "Empirical Transformations from U.T. to E.T. for the Period 1800-1988" (Schmadel and Zech, 1988)
8. "Historical values of the Earth's clock error ΔT and the calculation of eclipses" (Morrison and F. R. Stephenson, 2004) with Addendum (Morrison and F. R. Stephenson, 2005)
9. "Polynomial approximations to Delta T, 1620-2000 AD" (Meeus and Simons, 2000)
10. *Canon of Solar Eclipses -2003 to +2526* (Mucke and Meeus, 1983)
11. "The accelerations of the earth and moon from early astronomical observations" (Muller and F. R. Stephenson, 1975)
12. "Pre-Telescopic Astronomical Observations" (F. R. Stephenson, 1978)
13. "Long-term changes in the rotation of the earth - 700 B.C. to A.D. 1980" (F. R. Stephenson and Morrison, 1984)
14. "Long-Term Fluctuations in the Earth's Rotation: 700 BC to AD 1990" (F. R. Stephenson and Morrison, 1995)
15. *Historical Eclipses and Earth's Rotation* (F. Richard Stephenson, 1997)
16. *Astronomical Algorithms* (Meeus, 1998)

17. *Astronomy on the Personal Computer* (Montenbruck and Pfleger, 2000)
18. *Calendrical Calculations (The Millennium Edition)* (Reingold and Dershowitz, 2001)
19. ΔT webpage by V. Reijs: `http://www.iol.ie/~geniet/eng/DeltaTeval.htm`

Precession: "New precession expressions, valid for long time intervals" (Vondrák, Capitaine, and Wallace, 2011) with correction (Vondrák, Capitaine, and Wallace, 2012)

Nutation: "An abridged model of the precession-nutation of the celestial pole" (McCarthy and Luzum, 2003) This model provides accuracy better than 1 milli-arcsecond in the time 1995-2050. It is applied for years 1500..2500 only.

H.4 Included Source Code

- Some computation of the sidereal time (`sidereal_time.h/c`) and Pluto orbit contains code from the libnova library (LGPL) by Liam Girdwood.
- The `orbit.cpp/h` and `solve.h` files were directly borrowed from **Celestia** (Chris Laurel; GPL license). They have now evolved a bit.
- Several implementations of IMCCE theories for planet and satellite movement by Johannes Gajdosik (MIT-style license, see the corresponding files for the license text)
- The tesselation algorithms were originally extracted from the glues library version 1.4 by Mike Gorchak <mike@malva.ua> (SGI FREE SOFTWARE LICENSE B).
- OBJ loader in the Scenery3D plugin based on glObjViewer (c) 2007 dhpoware
- Parts of the code to work with DE430 and DE431 data files have been taken from Project Pluto (GPL license).
- The `SpoutLibrary.dll` and header from the SpoutSDK version 2.005 available at `http://spout.zeal.co` (BSD license).

H.5 Data

1. The Hipparcos star catalog From ESA (European Space Agency) and the Hipparcos mission. ref. ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200 `http://cdsweb.u-strasbg.fr/ftp/cats/I/239`
2. The solar system data mainly comes from IMCCE and partly from Celestia.
3. Polynesian constellations are based on diagrams from the Polynesian Voyaging Society
4. Chinese constellations are based on diagrams from the Hong Kong Space Museum
5. Egyptian constellations are based on the work of Juan Antonio Belmonte, Instituto de Astrofisica de Canarias
6. The Tycho-2 Catalogue of the 2.5 Million Brightest Stars Hog E., Fabricius C., Makarov V.V., Urban S., Corbin T., Wycoff G., Bastian U., Schwekendiek P., Wicenec A. Astron. Astrophys. 355, L27 (2000) `http://cdsweb.u-strasbg.fr/ftp/cats/I/259`
7. Naval Observatory Merged Astrometric Dataset (NOMAD) version 1 (`http://www.nofs.navy.mil/nomad`) Norbert Zacharias writes:

> "There are no fees, both UCAC and NOMAD are freely available with the only requirement that the source of the data (U.S. Naval Observatory) and original product name need to be provided with any distribution, as well as a description about any changes made to the data, if at all."

The changes made to the data are:
- try to compute visual magnitude and color from the b,v,r values
- compute nr_of_measurements = the number of valid b, v, r values
- throw away or keep stars (depending on magnitude, nr_of_measurements, combination of flags, tycho2 number)

- add all stars from Hipparcos (incl. component solutions), and tycho2+1st supplement
- reorganize the stars in several brigthness levels and triangular zones according to position and magnitude

The programs that are used to generate the star files are called **MakeCombinedCatalogue**, **ParseHip**, **ParseNomad**, and can be found in the util subdirectory in source code. The position, magnitudes, and proper motions of the stars coming from NOMAD are unchanged, except for a possible loss of precision, especially in magnitude. When there is no V magnitude, it is estimated from R or B magnitude. When there is no B or V magnitude, the color B-V is estimated from the other magnitudes. Also proper motions of faint stars are neglected at all.

8. Stellarium's Catalog of Variable Stars based on General Catalog of Variable Stars (GCVS) version 2013Apr. `http://www.sai.msu.su/gcvs/gcvs/` Samus N.N., Durlevich O.V., Kazarovets E V., Kireeva N.N., Pastukhova E.N., Zharova A.V., et al., General Catalogue of Variable Stars (Samus+ 2007-2012) `http://cdsarc.u-strasbg.fr/viz-bin/Cat?cat=B%2Fgcvs&`

9. Consolidated DSO catalog was created from various data:

   (a) NGC/IC data taken from SIMBAD Astronomical Database `http://simbad.u-strasbg.fr`

   (b) Distance to NGC/IC data taken from NED (NASA/IPAC EXTRAGALACTIC DATABASE) `http://ned.ipac.caltech.edu`

   (c) Catalogue of HII Regions (Sharpless, 1959) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/20`)

   (d) H-α emission regions in the Southern Milky Way (Rodgers+, 1960) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/216`)

   (e) Catalogue of Reflection Nebulae (Van den Bergh, 1966) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/21`)

   (f) Lynds' Catalogue of Dark Nebulae (LDN) (Lynds, 1962) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/7A`)

   (g) Lynds' Catalogue of Bright Nebulae (Lynds, 1965) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/9`)

   (h) Catalog of bright diffuse Galactic nebulae (Cederblad, 1946) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/231`)

   (i) Barnard's Catalogue of 349 Dark Objects in the Sky (Barnard, 1927) (`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=VII/220A`)

   (j) A Catalogue of Star Clusters shown on Franklin-Adams Chart Plates (Melotte, 1915) from NASA ADS (`http://adsabs.harvard.edu/abs/1915MmRAS..60..175M`)

   (k) On Structural Properties of Open Galactic Clusters and their Spatial Distribution. Catalog of Open Galactic Clusters (Collinder, 1931) from NASA ADS (`http://adsabs.harvard.edu/abs/1931AnLun...2....1C`)

   (l) The Collinder Catalog of Open Star Clusters. An Observer's Checklist. Edited by Thomas Watson from CloudyNights (`http://www.cloudynights.com/page/articles/cat/articles/the-collinder-catalog-updated-r2467`)

10. Cross-identification of objects in consolidated DSO catalog was maked with:

   (a) SIMBAD Astronomical Database `http://simbad.u-strasbg.fr`

   (b) Merged catalogue of reflection nebulae (Magakian, 2003) `http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=J/A+A/399/141`

   (c) Messier Catalogue from Wikipedia (includes morphological classification and distances) `https://en.wikipedia.org/wiki/List_of_Messier_objects`

   (d) Caldwell Catalogue from Wikipedia (includes morphological classification and dis-

tances) `https://en.wikipedia.org/wiki/Caldwell_catalogue`
11. Morphological classification and magnitudes (partially) for Melotte catalogue from Deep-SkyPedia `http://deepskypedia.com/wiki/List:Melotte`

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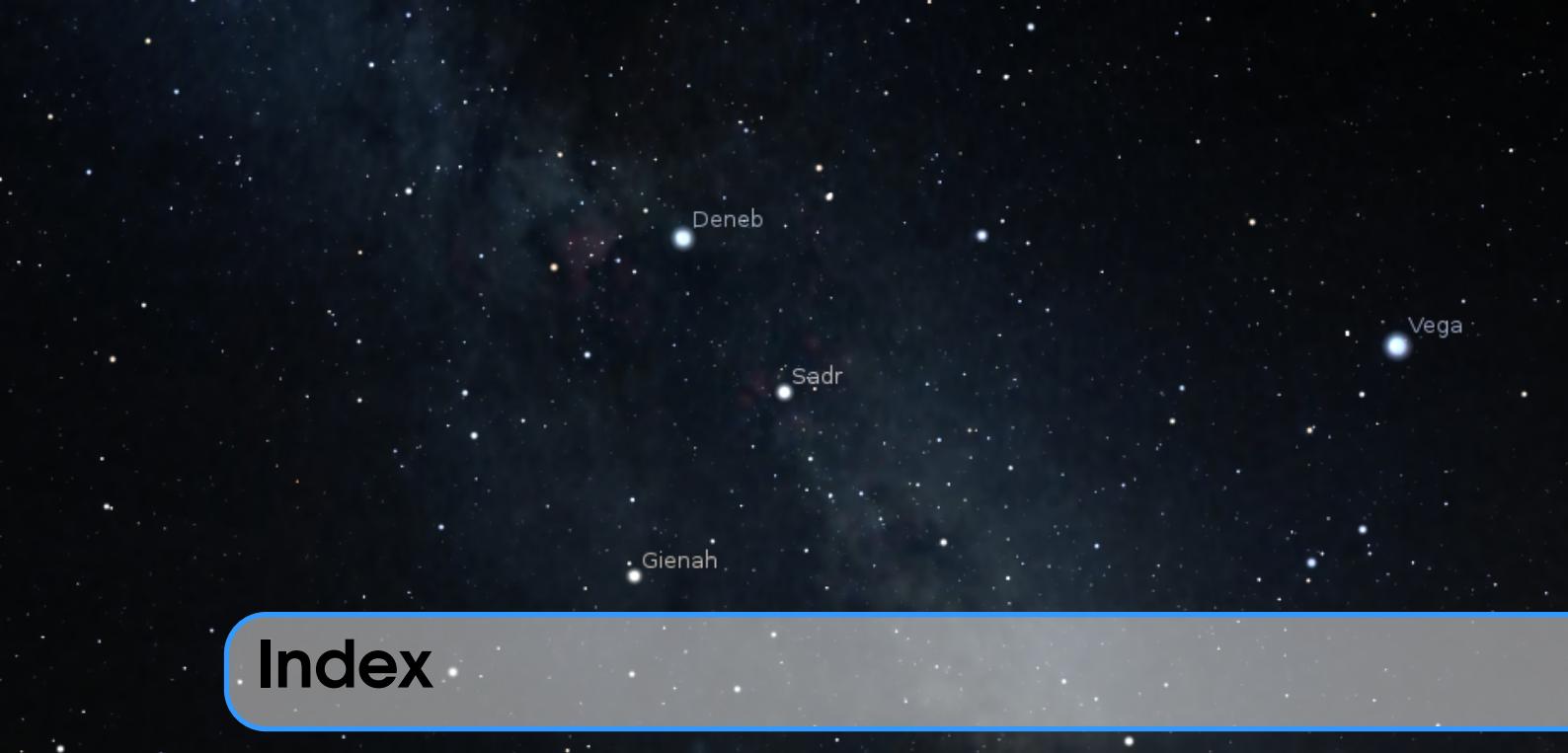
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