The KStars Handbook

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The KStars Handbook

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Abstract

KStars is free, open source, cross-platform Astronomy Software. It provides an accurate graphical simulation of the night sky, from any location on Earth, at any date and time. The display includes up to 100 million stars, 13,000 deep-sky objects,all 8 planets, the Sun and Moon, and thousands of comets, asteroids, supernovae, and satellites. For students and teachers, it supports adjustable simulation speeds in order to view phenomena that happen over long timescales, the KStars Astrocalculator to predict conjunctions, and many common astronomical calculations. For the amateur astronomer, it provides an observation planner, a sky calendar tool, and an FOV editor to calculate field of view of equipment and display them. Find out interesting objects in the 'What's up Tonight' tool, plot altitude vs. time graphs for any object, print high-quality sky charts, and gain access to lots of information and resources to help you explore the universe! HiPS all-sky progressive overlay provide stunning views from numerous surveys spanning the whole electromagnetic spectrum. Included with KStars is Ekos astrophotography suite, a complete astrophotography solution that can control all INDI devices including numerous telescopes, CCDs, DSLRs, focusers, filters, and a lot more. Ekos supports highly accurate tracking using online and offline astrometry solver, autofocus and autoguiding capabilities, and capture of single or multiple images using the powerful built in sequence manager.

Chapter 1

Introduction

KStars lets you explore the night sky from the comfort of your computer chair. It provides an accurate graphical representation of the night sky for any date, from any location on Earth. The display includes 126,000 stars to 9th magnitude (100 million with addon catalogs), 13,000 deep-sky objects (Messier, NGC, and IC catalogs), all planets, the Sun and Moon, hundreds of comets and asteroids, the Milky Way, 88 constellations, and guide lines such as the celestial equator, the horizon and the ecliptic.

However, KStars is more than a simple night-sky simulator. The display provides a compelling interface to a number of tools with which you can learn more about astronomy and the night sky. There is a context-sensitive popup menu attached to each displayed object, which displays object-specific information and actions. Hundreds of objects provide links in their popup menus to informative web pages and beautiful images taken by the Hubble Space Telescope and other observatories.

From an object's popup menu, you can open its Detailed Information Window, where you can examine positional data about the object, and query a huge treasury of online databases for professional-grade astronomical data and literature references about the object. You can even attach your own Internet links, images and text notes, making KStars a graphical front-end to your observing logs and your personal astronomical notebook.

Our Astrocalculator tool provides direct access to many of the algorithms the program uses behind the scenes, including coordinate converters and time calculators.

You can plan an observing session using our Altitude vs. Time tool, which will plot curves representing the Altitude as a function of time for any group of objects. If that is too much detail, we also provide a What's up Tonight? tool that summarizes the objects that you will be able to see from your location on any given night. You can add your favorite objects to your observing wish-list using the Observation Planner tool, which allows you to plan your observation sessions professionally. To see how object appears in the eyepiece under different telescopes and field of views, use the Simulate Eyepiece View tool to render a simulated view of what you see.

KStars also provides a Solar System Viewer, which shows the current configuration of the major planets in our solar system. There is also a Jupiter Moons Tool which shows the positions of Jupiter's four largest moons as a function of time.

Our primary goal is to make KStars an interactive educational tool for learning about astronomy and the night sky. To this end, the KStars Handbook includes the AstroInfo Project, a series of short, hyperlinked articles on astronomical topics that can be explored with KStars. In addition, KStars includes D-Bus functions that allow you to write complex scripts, making KStars a powerful 'demo engine' for classroom use or general illustration of astronomical topics. Furthermore, any 3rd party tool or language with support of D-Bus can be used to write powerful scripts using KStars D-Bus API.

Enable HiPS all-sky progressive overlay to fetch high-resolution images and display them directly in the sky map. You can select from numerous catalogs compiled from different earth and

space based missions. This features requires a fast internet connection in order to download the images. The images are cached locally to reduce bandwidth. You can optimize the caching options to best balance between disk space versus bandwidth.

However, KStars is not just for students. You can control telescopes and cameras with KStars, using the elegant and powerful INDI protocol. KStars supports several popular telescopes including Meade's LX200 family and Celestron GPS. Several popular CCD cameras, webcams, and computerized focusers are also supported. Simple slew/track commands are integrated directly into the main window's popup menu, and the INDI Control Panel provides full access to all of your telescope's functions. INDI's Client/Server architecture allows for seamless control of any number of local or remote telescopes using a single KStars session. For advanced users, KStars provides Ekos, a complete astrophotography suite for Linux. Ekos is based on a modular extensible framework to perform common astrophotography tasks. This includes highly accurate GO-TOs using astrometry solver, ability to measure and correct polar alignment errors , auto-focus and auto-guide capabilities, and capture of single or stack of images with filter wheel support.

We are very interested in your feedback; please report bugs or feature requests to the KStars development mailing list: kstars-devel AT kde.org. You can also use the automated bug reporting tool, accessible from the Help menu.

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Chapter 2

A Quick Tour of KStars

This chapter presents a guided tour of KStars, introducing many of its important features.
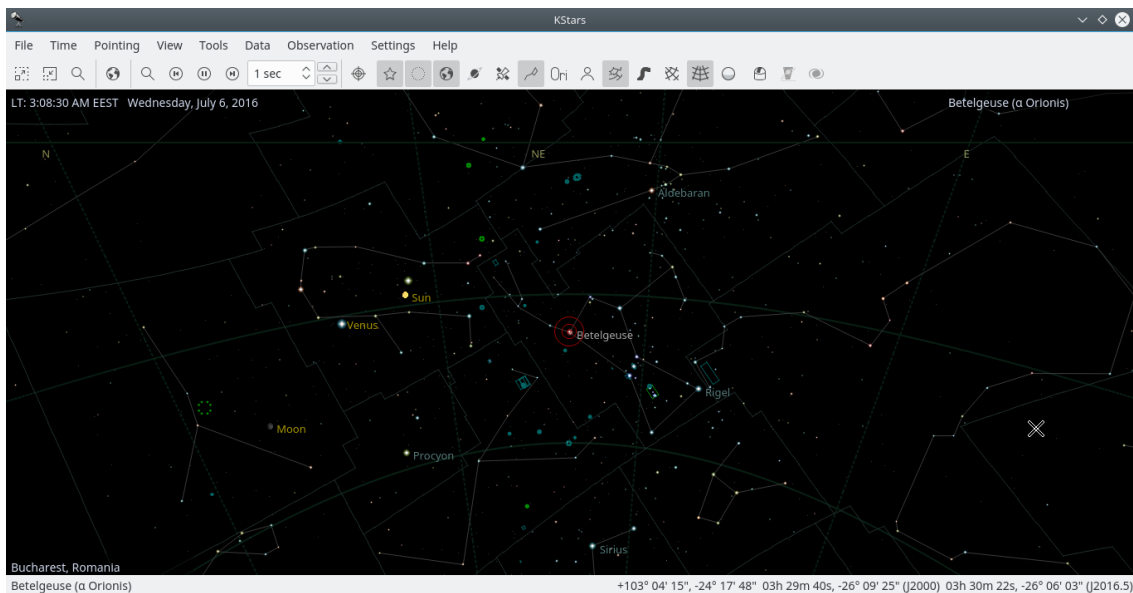
The above screenshot shows a typical view of the KStars program. You can see the sky display centered on Betelgeuse, the brightest star in the constellation Orion. Stars are displayed with realistic colors and relative brightnesses. In three corners of the sky display, there are on-screen text labels displaying data on the current time ('LT: 3:08:30 AM EEST Wednesday, July 6, 2016'), the current Geographic Location ('Bucharest, Romania'), and the current object in the center of the display ('Focused on: Betelgeuse (alpha Orionis)'). Above the sky display, there are two toolbars. The main toolbar contains shortcuts for menu functions, as well as a time-step widget which controls how fast the simulation clock runs. The view toolbar contains buttons that toggle the display of different kinds of objects in the sky. At the bottom of the window, there is a status bar which displays the name of any object you click on, and the sky coordinates (both Right Ascension/Declination and Azimuth/Altitude) of the mouse cursor.

2.1 The Setup Wizard

The first time you run KStars, you will be presented with a Setup Wizard, which allows you to easily set your geographic location and download some extra data files. You can press the **OK** button at any time to exit the Setup Wizard.

The second page of the Setup Wizard allows you to choose the starting geographic location, by selecting from the list of the 3400+ known locations on the right side of the window. The list of locations can be filtered to match the text you enter in the **City filter:**, **Province filter:**, and **Country filter:** edit boxes. If your desired location is not present in the list, you can select a nearby city instead for now. Later on, you can add your precise location manually using the Set Geographic Location tool. Once you have selected a starting location, press the **Next** button.

The last page of the Setup Wizard allows you to download extra data that are not included with the standard distribution of KStars. Simply press the **Download Extra Data...** button to open the **Get New Stuff** tool. When you are all done, press the **OK** button in the Setup Wizard to start exploring KStars.

2.2   Have a Look Around

Now that we have the time and location set, let us have a look around. You can pan the display using the arrow keys. If you hold down the **Shift** key before panning, the scrolling speed is increased. The display can also be panned by clicking and dragging with the mouse. Note that while the display is scrolling, not all objects are displayed. This is done to cut down on the CPU load of recomputing object positions, which makes the scrolling smoother (you can configure what gets hidden while scrolling in the Configure - KStars window). There are several ways to change the magnification (or *Zoom level*) of the display:

1. Use the **+** and **-** keys.

2. Press the **Zoom In**/**Zoom Out** buttons in the toolbar.

3. Select the **View** → **Zoom In / Zoom Out** menu item.

4. Select the **View** → **Zoom to Angular Size...** menu item. This allows you to specify the field-of-view angle for the display, in degrees.

5. Use the scroll wheel on your mouse.

6. Drag the mouse up and down with the middle mouse button pressed.

7. Hold down **Ctrl** while dragging the mouse. This will allow you to define a rectangle in the map. When you release the mouse button, the display will zoom to match the rectangle.

Notice that as you zoom in, you can see fainter stars than at lower zoom settings.

Zoom out until you can see a green curve; this represents your local horizon. If you have not adjusted the default KStars configuration, the display will be solid green below the horizon, representing the solid ground of the Earth. There is also a white curve, which represents the celestial equator, and a brown curve, which represents the Ecliptic, the path that the Sun appears to follow across the sky over the course of a year. The Sun is always found somewhere along the Ecliptic, and the planets are never far from it.

You can configure KStars to draw or not the celestial equator and Ecliptic curves on the Sky Map using the **Settings** → **Configure KStars...** menu item. Select the **Guides** page and check/uncheck the **Celestial equator** and **Ecliptic** check boxes. You can also configure which colors KStars uses for drawing these curves, using the **Colors** page.
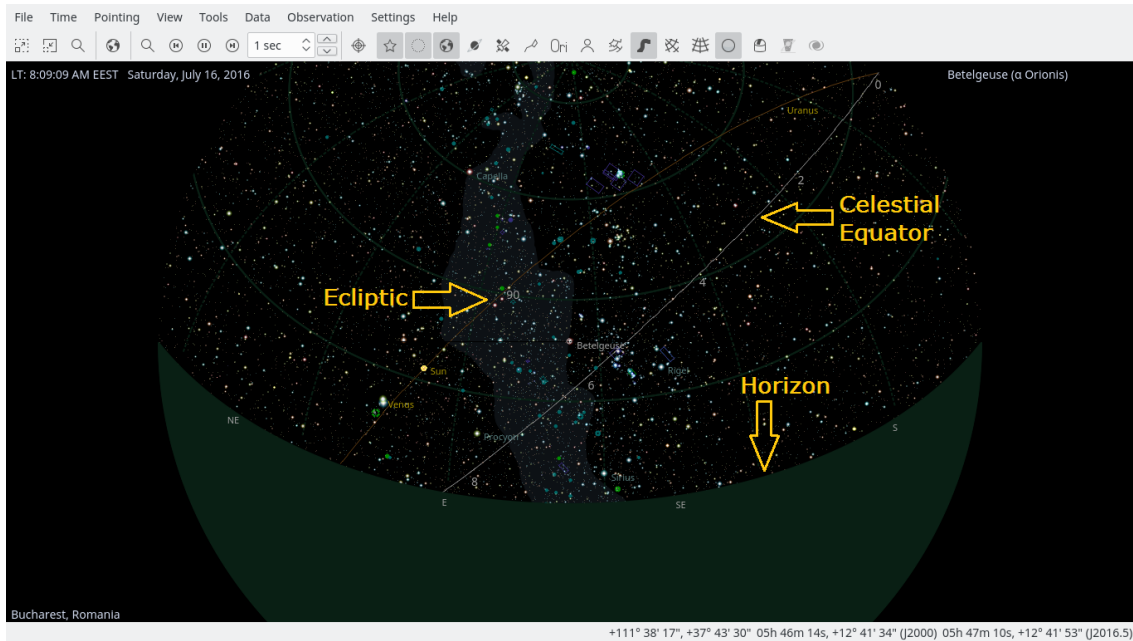
2.3 Objects in the Sky

KStars displays thousands of celestial objects: stars, planets, comets, asteroids, clusters, nebulae and galaxies. You can interact with displayed objects to perform actions on them or obtain more information about them. Clicking on an object will identify it in the status bar, and simply hovering the mouse cursor on an object will label it temporarily in the map. Double-clicking will recenter the display on the object and begin tracking it (so that it will remain centered as time passes). Right clicking an object opens the object's popup menu, which provides more options.

2.3.1 The Popup Menu

Here is an example of the right click popup menu, for the Uranus:
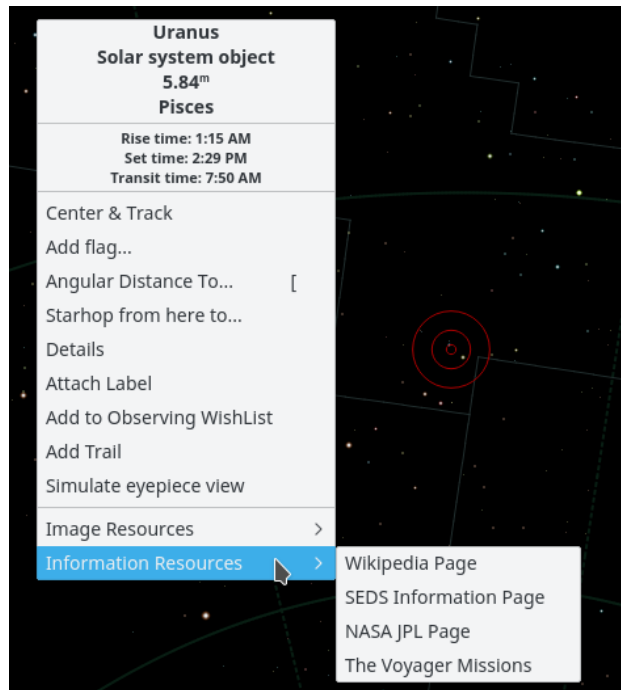
The appearance of the popup menu depends somewhat on the kind of object you right-click on, but the basic structure is listed below. You can get more detailed information about the popup menu.

The top section contains some lines of information which are not selectable: the object's names ("Uranus"), object type ("Solar system object"), and the constellation which contains the object ("Pisces"). The next three lines show the object's rise, set, and transit times. If the rise and set times say "circumpolar", it means that the object is always above the horizon for the present location.

The middle section contains actions which can be performed on the selected object, such as **Center & Track**, **Details**, and **Attach Label**. See the popup menu description for a full list and description of each action.

The bottom section contains links to images and/or informative webpages about the selected object. If you know of an additional URL with information or an image of the object, you can add a custom link to the object's popup menu. Use the **Details** item in the popup menu to open the **Object Details** dialog. On the **Links** tab use the **Add Link...** button.

2.3.2 Finding Objects

You can search for named objects using the **Find Object** tool, which can be opened by clicking on the **search** icon in the toolbar, by selecting **Pointing** → **Find Object...** menu item, or by pressing **Ctrl**+**F**. The **Find Object** window is shown below:
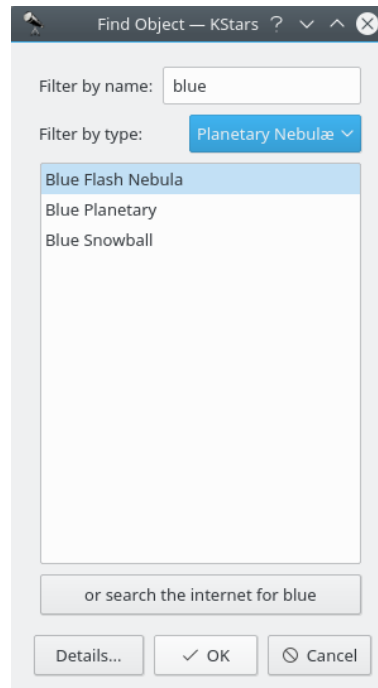
The window contains a list of (almost, see Section 3.4) all the named objects that KStars is aware of. Many of the objects only have a numeric catalog name (for example, NGC 3077), but some objects have a common name as well (for example, Whirlpool Galaxy). You can filter the list by name and by object type. To filter by name, enter a string in the edit box at the top of the window; the list will then only contain names which start with that string. To filter by type, select a type from the combo box at the bottom of the window.

KStars provides another method for resolving the objects that are missing from any of its prede-fined catalogues, by using an internet connection. Thus, if you want to find an object that KStars is not aware of, you can easily do this by querying several professional astronomical databases as: SIMBAD, NED or VizieR. This can be done by entering the object's name and then press the **or search the internet for *ObjectName*** button. After your object is found, you can use it exactly as any object that is already loaded into KStars (i.e. adding it to the Observing WishList). If the object was not found in the online databases, then a warning dialogue will pop-up. Once you resolve an object by using this method, it is stored in KStars database, so if you close KStars and open it again, your object will still be there.

You can choose to enable or disable this feature by checking or unchecking the **Resolve names not known to KStars using online services** check box from **Catalogs** page, inside of **Configure - KStars** dialog (select the **Settings → Configure KStars...** menu item). If this checkbox is checked, when an object name unknown to KStars is entered in the **Find Dialog**, KStars will contact online services to learn about the desired object and then add it directly to KStars database. The objects acquired in this manner are stored in a fake catalog, called '_Internet_Resolved'. Thus, you can enable or disable the display of these objects by checking or unchecking the '_Internet_Resolved' catalog from the catalogues list. Note that you can not delete this fake catalogue, as you can do with a custom catalogue. If this checkbox is unchecked, then the **Find Object** window will be exactly the same, excepting a minor change: the online searching button will no longer be visible.
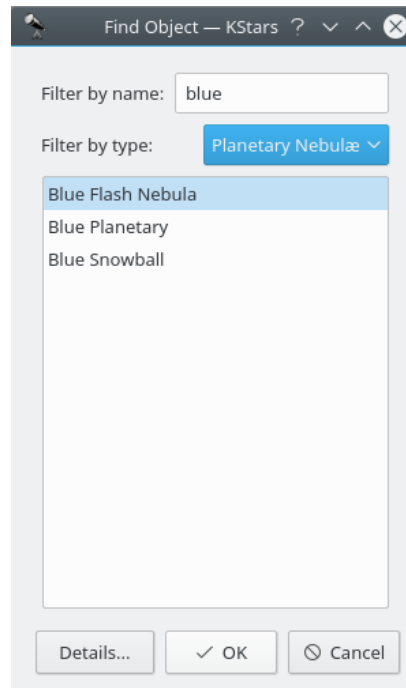
To center the display on an object, highlight the desired object in the list, and press **Ok**. Note that if the object is below the horizon, the program will warn you that you may not see anything except the ground (you can make the ground invisible in the **Guides** settings page, or by pressing the **Ground** button in the View toolbar).

2.3.3 Centering and Tracking

KStars will automatically begin tracking on an object whenever one is centered in the display, either by using the **Find Object** window, by double-clicking on it, or by selecting **Center & Track** from its right-click popup menu. You can disengage tracking by panning the display, pressing the **Stop Tracking** icon in the Main toolbar, or selecting **Pointing** → **Stop Tracking** menu item.

NOTE
When tracking on a Solar System body, KStars will automatically attach an 'orbit trail', showing the path of the body across the sky. You will likely need to change the clock's timestep to a large value (such as '1 day') to see the trail.

2.3.4 Keyboard Actions

When you click on an object in the map, it becomes the *selected object*, and its name is identified in the statusbar. There are a number of quick key commands available which act on the selected object:

C

Center and Track on the selected object.

D

Show the Details window for the selected object.

L

> Toggle a visible name label on the selected object.

O

> Add the selected object to the Observing wish-list.

T

> Toggle a visible curve on the sky, showing the path of the object across the sky (only applicable to Solar System bodies).

> NOTE
> By holding down the **Shift** key, you can perform these actions on the centered object, rather than the selected object.

2.4 End of the Tour

This concludes the tour of KStars, although we have only scratched the surface of the available features. KStars includes many useful astronomy tools, it can directly control your telescope, and it offers a wide variety of configuration and customization options. In addition, this Handbook includes the AstroInfo Project, a series of short, interlinked articles explaining some of the celestial and astrophysical concepts behind KStars.

Chapter 3

Configuring KStars

3.1 Setting the Geographic Location

Here is a screenshot of the **Set Geographic Location** window:
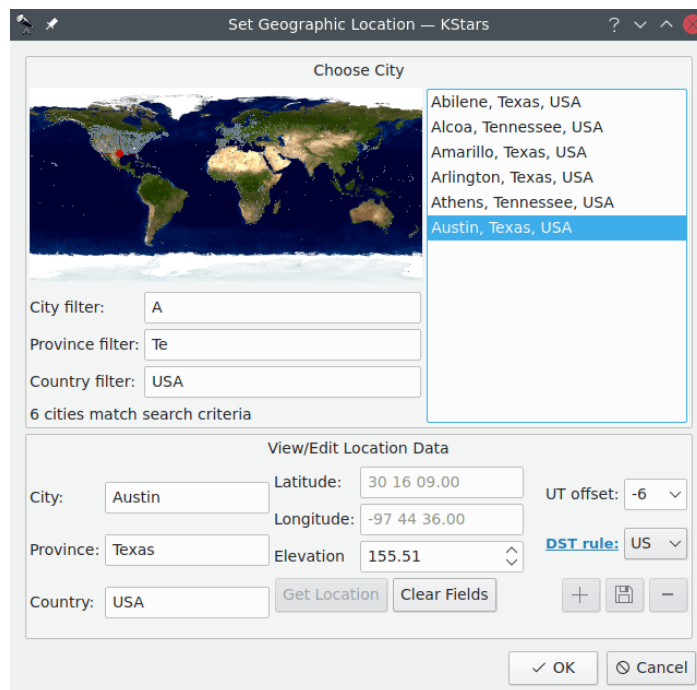
There is a list of over 3400 predefined cities available to choose from. You set your location by highlighting a city from this list. Each city is represented in the world map as a small dot, and when a city is highlighted in the list, a red crosshairs appears on its location in the map.

It is not practical to scroll through the full list of 3400 locations, looking for a specific city. To make searches easier, the list can be filtered by entering text in the boxes below the map. For example, in the screenshot, the text **A** appears in the **City filter:** box, while **Te** has been entered in the **Province filter:** box, and **USA** is in the **Country filter:** box. Note that all of the cities displayed in the list have city, province, and country names that begin with the entered filter strings, and that the message below the filter boxes indicates that 6 cities are matched by the filters. Also notice that the dots representing these six cities in the map have been colored white, while the unmatched cities remain gray.

The list can also be filtered by location in the map. Clicking anywhere in the world map will show only those cities within two degrees of the clicked location. At this time, you can search by name, or by location, but not both at once. In other words, when you click on the map, the name filters are ignored, and vice versa.

The longitude, latitude and time zone information for the currently-selected location are displayed in the boxes at the bottom of the window. If you feel that any of these values are inaccurate, you can modify them and press the **+** (Add City) button to record your custom version of the location. You can also define a completely new location by pressing the **Clear Fields** button, and entering the data for the new location. Note that all fields except the optional **Province:**/**Country:** must be filled before the new location can be added to the list. KStars will automatically load your custom locations for all future sessions. Please note, at this point, the only way to remove a custom location is to remove the appropriate line from the file `kstars/mycities.dat` in your folder **qtpaths --paths GenericDataLocation** .

If you add custom locations (or modify existing ones), please send us your `mycities.dat` file so that we can add your locations to the master list.

3.2   Setting the Time

When KStars starts up, the time is set to your computer's system clock, and the KStars clock is running to keep up with the real time. If you want to stop the clock, select the **Time** → **Stop Clock** menu item, or simply click on the **Stop Clock** icon in the toolbar. You can make the clock run slower or faster than normal, or even make it run backward, using the time-step spinbox in the toolbar. This spinbox has two sets of up/down buttons. The first one will step through all 83 available time steps, one by one. The second one will skip to the next higher (or lower) unit of time, which allows you to make large timestep changes more quickly.

You can set the time and date by selecting the **Time** → **Set Time...** menu item, or by pressing the **Time** icon in the toolbar. The **Set Time** window uses a standard KDE Date Picker widget, coupled with a spinbox for setting the hours and minutes. If you want to re-synchronize the simulation clock back to the current CPU time, just select the **Time** → **Set Time to Now** menu item.

NOTE

KStars can accept very remote dates beyond the usual limits imposed by QDate. Currently, you can set the date between the years -100000 and +100000. We may extend this range even further in future releases. However, please be aware that the accuracy of the simulation becomes more and more degraded as more remote dates are examined. This is especially true for the positions of solar system bodies.

3.3   The Configure KStars Window

The **Configure - KStars** window allows you to modify a wide range of display options. You can access the window with the **Configure** toolbar icon, or by selecting the **Settings** → **Configure KStars...** menu item. The window is depicted below:
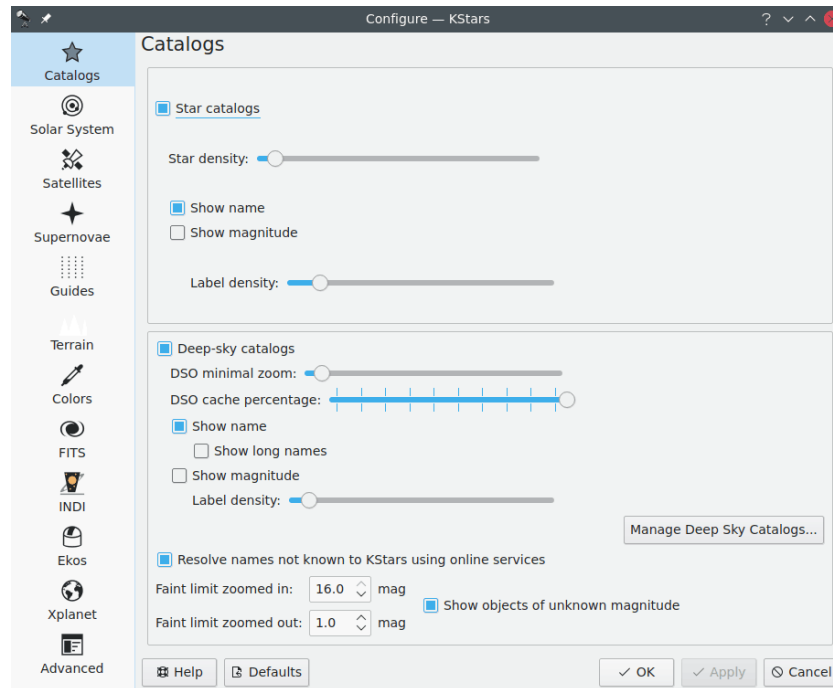
The **Configure - KStars** window is divided into twelve pages: **Catalogs**, **Solar System**, **Satellites**, **Supernovae**, **Guides**, **Terrain**, **Colors**, **FITS**, **INDI**, **Ekos**, **Xplanet** and **Advanced**.

In the **Catalogs** page, you determine several properties concerning the display of the star and deep sky object catalogs.

In the **Solar System** page, you can specify whether the Sun, Moon, planets, comets and asteroids are displayed.

The **Satellites** page allows you to set the satellites view options.

The **Supernovae** page allows you to manage how supernovae are displayed by KStars.

The **Guides** page lets you toggle whether non-objects are displayed (i.e., constellation lines, constellation names, the Milky Way contour).

> It is possible to choose a **Sky culture:** for the constellation lines and names on this page. The current version of KStars includes data for more than a dozen sky cultures.

The **Terrain** page allows you to set the terrain or landscape image and configure its speedup options.

The **Colors** page allows you to set the color scheme, and to define new custom color schemes.

For detailed explanation of the options on the **FITS** page see the Configure FITS section.

For detailed explanation of the options on the **INDI** page see the Configure INDI section.

For detailed explanation of **Ekos** astrophotography suite, see the Ekos section of this manual.

The **Xplanet** page provides fine-grained control over Solar system planet surface renderer Xplanet (should be installed separately).

The **Advanced** page provides fine-grained control over the more subtle behaviors of KStars.

3.4   Catalogs
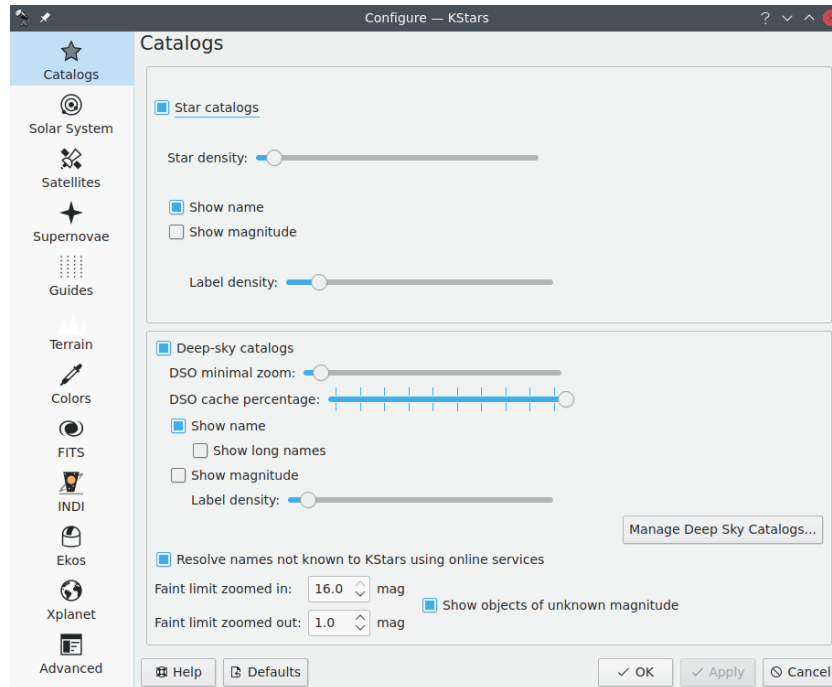
In the **Catalogs** page, you can configure which object catalogs are displayed by KStars, as well as how much information you would like to be included on the Sky Map. By default, KStars includes ∼300,000 named and unnamed stars up to magnitude 8. For Deep Sky Objects, the included catalog is the New General Catalog ('NGC') including the Index Catalog ('IC') and the Messier Catalog.

The New General Catalog of Nebulae and Clusters of Stars (abbreviated as NGC) is a catalog of ca 7,840 deep-sky objects.

The Index Catalog of Nebulae and Clusters of Stars (abbreviated as IC) serves as a supplement to the NGC, and contains an additional 5,386 objects, collectively known as the IC objects.

You can install new catalogs using KStars 'Add-On Installer'. You can open it via the **Data → Download New Data...** menu item. You can choose from a list of catalogs, including (but not limited to):

- Steinicke NGC/IC Catalog: is a more complete NGC/IC catalog.

- Abell Planetary Nebulae Catalog: is a catalog of 86 planetary nebulae. The maximum magnitude is represented by Abell 47's value of 19.5.

- Sharpless HII region Catalog: is the Sharpless (Sh2) catalog of HII regions (diffuse nebulae).

- Hickson Compact Groups: is a catalog consisting of 99 compact groups of galaxies.

- Tycho-2 Star Catalog: is a catalog of more than 2.5 million of the brightest stars. It contains stars with a magnitude value from 8.0 to 12.5.

- USNO NOMAD Catalog: is a catalog of about 100 million stars with magnitude from 12.5 to 16.5. Note that is requires Tycho-2 to be installed.

The following is a summary of catalogs in KStars:

Name	Abbreviation	Number of objects	Magnitude
Default Catalog	Default	~300,000	Up to 8 magnitude
Tycho-2	Tycho2	more than 2.5 million	8.0-12.5
Naval Observatory Merged Astronomic Dataset	USNO NOMAD	100 million	12.5-16.5

Table 3.1: Stars Catalogs

Name	Abbreviation	Number of objects	Magnitude
New General Catalog of Nebulae and Clusters of Stars (OpenNGC)	NGC	7,840	-
Steinicke NGC/IC	-	-	-
Abell Planetary Nebulae Catalog	-	86	Up to 19.5 magnitude
Sharpless HII region Catalog	Sh2	-	-
Hickson Compact Groups	-	99	-

Table 3.2: Deep-sky objects Catalogs

> NOTE
> A potentially more up-to-date listing can be found in the catalog repository documentation.

The **Stars** section allows you to manage how stars are displayed in KStars. You can choose to see the stars or not by checking the **Star catalogs** checkbox. If you check it, then multiple options will be enabled. Thus, you can set how many stars are drawn on the map using the **Star density:** slider. You can also customize KStars to toggle star name and magnitudes. Star names are drawn next to bright stars. To display labels of fainter stars, increase the **Label density:** slider.

Below the stars section, the **Deep-Sky Objects** section controls the display of several non-stellar object catalogs. You can toggle the display of Deep Sky Objects and control the display of their names and magnitudes. By default, the list of deep-sky objects includes the Messier, NGC and IC catalogs. Addons catalogs are available via the **Data → Download New Data...** menu item where you can download catalogs provided by KStars team and the community through the catalog packaging repository. The **DSO minimal zoom:** slider controls the minimal zoom level for which the DSOs are shown. Increasing the minimal zoom level can lead to performance improvements when panning the skymap zoomed-out. The **DSO cache percentage:** slider regulates how much of the DSO master catalog is being kept in memory. If you experience memory issues with large catalogs, try lowering the percentage. The **Label density:** slider controls the perceived density of labels for the DSOs. If labels start to overlap and the skymap begins to look too crowded, try tuning this option. The **Faint limit zoomed in/out:** regulates up to which magnitude objects are shown on the skymap (higher magnitude is fainter). If **Show objects of unknown magnitude** is ticked, objects of unknown magnitude are always shown.

The following sections will detail how DSO catalogs work in KStars and how they're managed.

3.4.1 The DSO Catalog Database

> NOTE
> This section aims at introducing the catalog database of KStars in simple but technical terms. It can be skipped without missing anything essential but helps understanding how to deal with and create (custom) catalogs.

DSO catalogs in KStars are just SQL (sqlite3) database tables. Each catalog is represented by its own table which contains all its objects and an entry in a catalog metadata table. Additionally, catalogs may be imported or exported from and into stand-alone database files.

Each object has the usual properties like name and coordinates but additionally features two IDs. The first ID is the unique identifier for the specific object and is calculated by hashing all the object fields along with the catalog id. Because objects can be contained in several catalogs each object has an additional object id (OID) that identifies the physical object and may be shared by several objects of different catalogs.

To speed up object lookup all enabled catalogs are merged into a master table. Each catalog has a priority number and if several objects with the same OID occur the one from the catalog with the highest priority is loaded. The objects from the master catalog are then drawn on the sky and generally available in KStars.

Currently, deduplication (the assignment of OIDs) is only supported by the tooling of the catalog packaging repository. The aim of this tool-chain is to reproducibly build catalogs in a homogeneous environment. Every catalog is implemented as a python module and provides standard methods to acquire data, parse it and find duplicates in other catalogs. All downloadable catalogs are implemented this way. If you'd like to make a catalog of your own available for KStars, it is recommended that you implement it as a package in the repository. The tooling provided there is so flexible, that it should work for you. For more information on how to do that see the catalog repository documentation. If you are not familiar with python programming you can request the addition of a catalog by opening a ticket in the repository or contacting the maintainers. KStars provides also provides means to create custom catalogs by manually entering data or importing CSV tables, but those are less flexible and offer no deduplication.

3.4.2 The Catalog Management GUI

The catalog management GUI is reached via the **Data → Manage DSO Catalogs...** menu item and is displayed below.
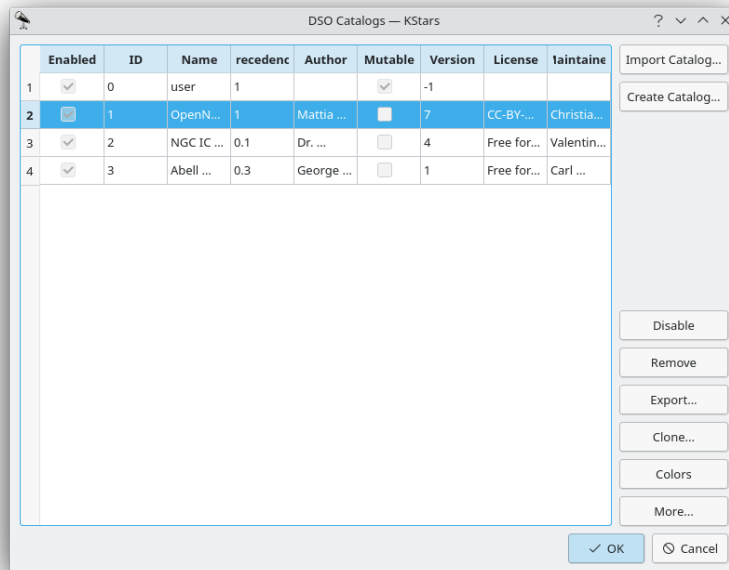
The DSO catalog management interface.

On the left, a list of catalogs is displayed. In this list, you can read off key catalog properties, including whether a catalog is enabled, what its ID is and what its name is. The **Mutable** column signifies whether the catalog can be edited or not. Catalogs which have been downloaded from the catalog repository via the **Data → Download New Data...** menu item are usually immutable whereas user-created catalogs aren't. You can always **Clone** a catalog to make it mutable.

The buttons in the upper right corner allow you to add catalogs to the database.

Import Catalog...

> Import a catalog in the .kscat format from a file.
>
> This is usually done to try out new versions of catalogs that haven't yet been picked up by the usual download server.

With the buttons in the lower right corner, you can add, remove, modify and explore catalogs. Their actions always refer to the currently selected catalog (the highlighted row on the left).

Create Catalog...

> Create a new catalog. See Section 3.4.3.

Enable / Disable

> Enable or disable a catalog.
>
> This is reflected in the skymap upon closing the catalog management GUI.

Remove

> Remove a catalog from the catalog database.
>
> This is reflected in the skymap upon closing the catalog management GUI.

Export...

> Export a catalog into a .kscat file.
>
> The resulting file can be imported with **Import Catalog...** button.

Clone...

Make an exact copy of the catalog and insert it into the database.

This is useful if you wish to make modifications to an immutable catalog.

> NOTE
> Note however that this is not the recommended way to alter catalogs that are provided by the catalog packaging repository i.e. the catalogs downloaded via the **Data → Download New Data...** menu item.

Colors

Open the catalog color editor (See Section 3.4.4.).
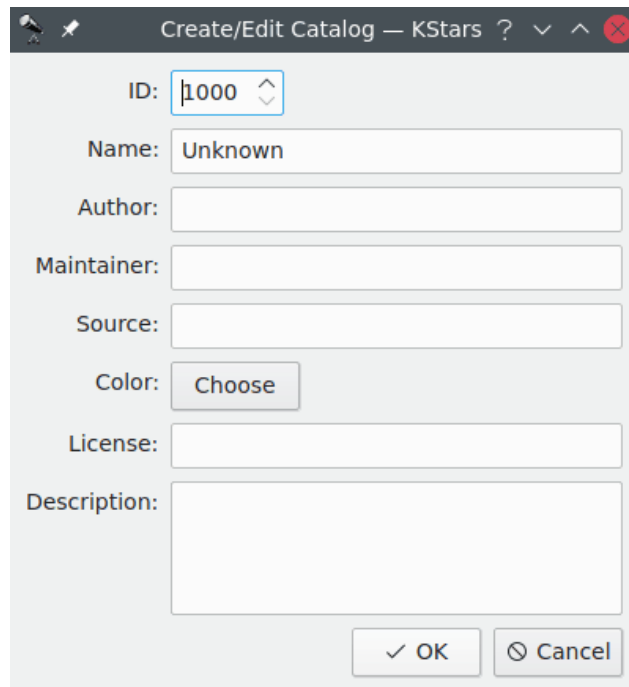
This will open a dialog which allows you to set the colors in which objects from the selected catalog will be displayed for each color scheme.

More...

Open the catalog details dialog. (See Section 3.4.5.)

In there, you can see the contents of the catalog, as well as some more meta information. Amongst other things, you can also edit its contents (if it is mutable).

3.4.3 Creating a new Catalog

This dialog reached through the catalog management GUI (see Section 3.4.2). The **ID:** field will be automatically chosen but can be changed. The **Color:** field configures in which color the objects of the catalog will be displayed. All the other values are optional or have sensible defaults. You can, of course, change these values at a later point.

Upon clicking **Ok** an empty catalog with the meta data entered into the dialog will be added to the database and can then be filled with objects. (See Section 3.4.5 and Section 3.4.5.2.)

3.4.4 Catalog Color Editor
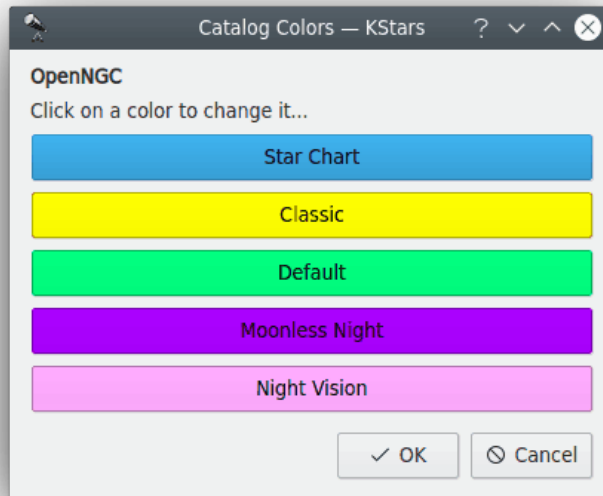
This dialog reached through the catalog management GUI (see Section 3.4.2). Each button represents the color that objects will be drawn in for a specific color scheme. Clicking on a button will allow you to choose a color with a color picker. The button colors are initialized with the default colors from the catalog specification. The color "default" is the color which will be chosen for the catalog if there is no color set for a color scheme.

3.4.5 Catalog Details Dialog
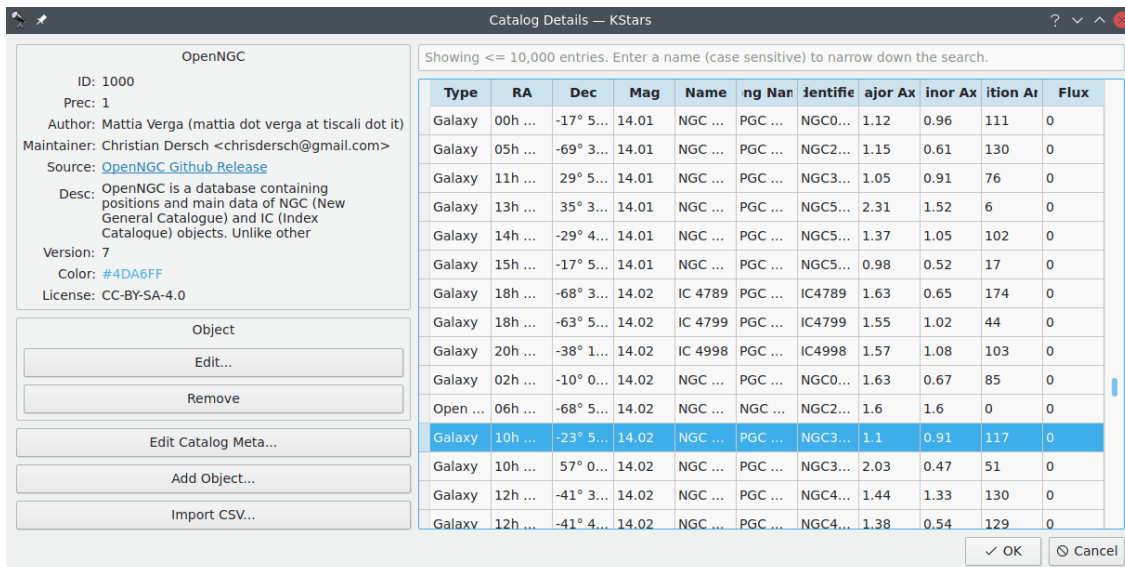
This dialog reached through the catalog management GUI (see Section 3.4.2). In the top left corner, the catalog metadata is being displayed. On the right, a table of all objects in the catalog

is being shown. The search line above the table filters objects by name. Double-clicking a row opens the object details dialog (see Section 5.1).

Selecting a row enables the **Object** menu on the left. Selecting multiple rows performs the single-object action for each selected object.

Edit...
>   Edit the catalog object. (See Section 3.4.5.1).

Remove
>   Removes the object from the catalog.

Below the **Object** section, the general catalog options are situated.

Edit Catalog Meta...
>   Edit the catalog metadata displayed in the top left. This opens the dialog described in Section 3.4.3.

Add Object...
>   Add an object to the catalog. (See Section 3.4.5.1.)

Import CSV...
>   Import objects from a tabular text format (csv, tsv, etc.) into the catalog. (See Section 3.4.5.2.)

3.4.5.1 Adding/Editing Objects
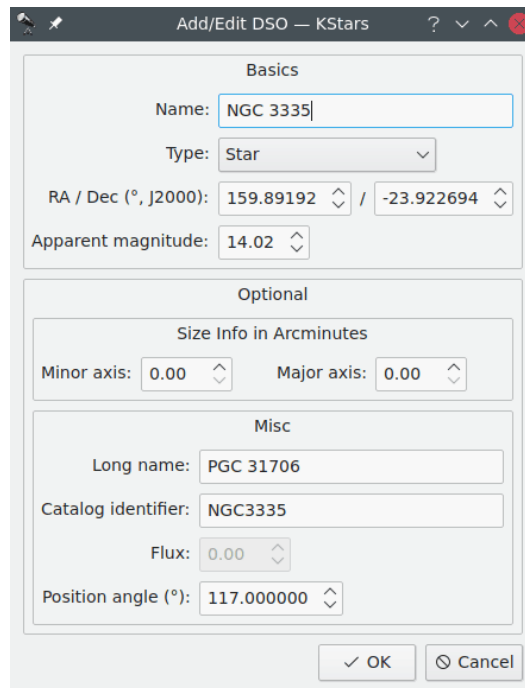
This dialog allows to create or edit a deep sky object (DSO). The **Basics** section contains fields that have to be filled in.

Name:
>   The name of the object which will be displayed in the sky.

Type:

The type of the object.

RA / Dec (, J2000):

The coordinates of the object in degrees and with respect to the J2000 epoch.

Apparent magnitude:

The apparent magnitude of the object.

The **Optional** section contains data fields that are optional, is divided into two subsections. They are set to and can be left at their defaults.

The **Size Info in Arcminutes** subsection. The object is modeled as an ellipse which is described by its major and minor axis.

The **Misc** subsection.

Long name:

A longer, more descriptive name.

Usually, the long name is something like 'Andromeda Galaxy' for the object M31. It can contain alternative designations and names in other catalogs as well.

Catalog identifier:

A catalog internal identifier.

For example the screenshot above, the object originates from the OpenNGC catalog where each row is identified by 'NGCXXXX'.

Flux:

The flux of the object. Only applies for radio sources.

Position angle ():

If the object is extended, it must have some orientation in the sky. The position angle is the angle between its major axis and a straight line to the north pole.

3.4.5.2 Importing CSV (and similar formats)

The screenshot above shows the CSV import dialog in its default state. In the **Input** section, you can configure the csv parser. The **Comment prefix:** is the character that signals commented-out lines in the input. The **Separator:** should be adjusted to fit your input. Usually, it is ',' or ';' but other separators can occur. Finally, you can choose to skip a number of lines at the beginning of the file. **Select/Read** button lets you choose a csv file to read with the above configuration. After that, the dialog will look as in the screenshot below.
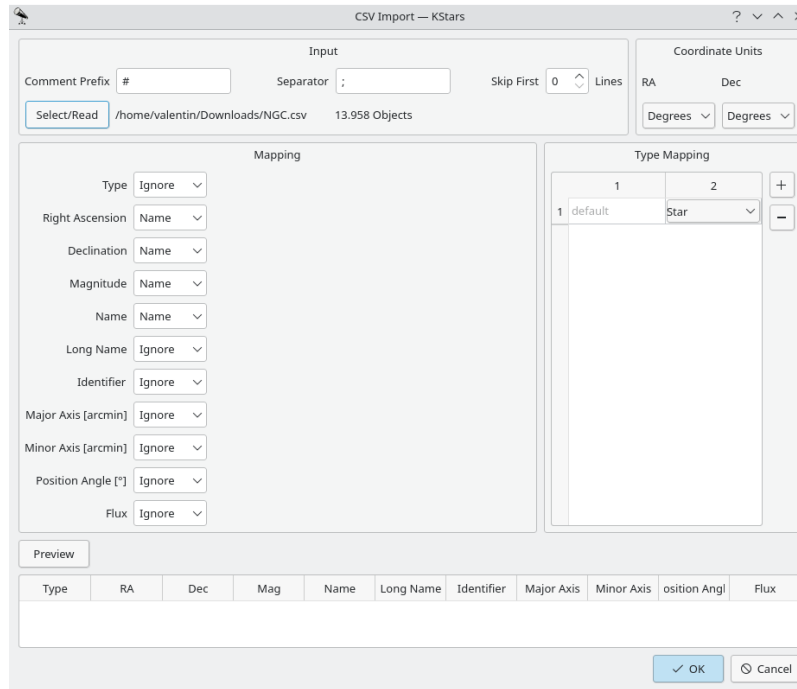
In the top right you can choose whether coordinates are being expressed in degrees or hours/minutes/seconds. The **Mapping** section lets you map columns in the CSV file to data fields in KStars. Selecting **Ignore** assigns the default value for this field. Entering your own text will use this as the value for every object being read. The **Type Mapping** section maps strings to object types. You can add and remove mappings by clicking **+** or **-**. When you're done mapping, you can test your settings by clicking **Preview** to read the first few objects from the csv. If you are satisfied you can click **OK** to import the whole catalog or adjust your settings and preview again. As a reference, a mapping for the OpenNGC catalog is shown in the below screenshot.
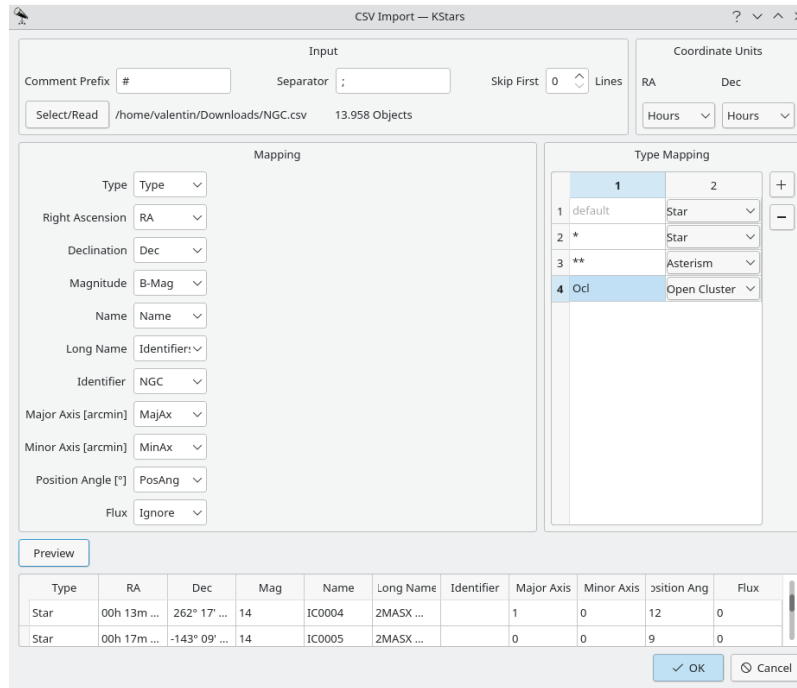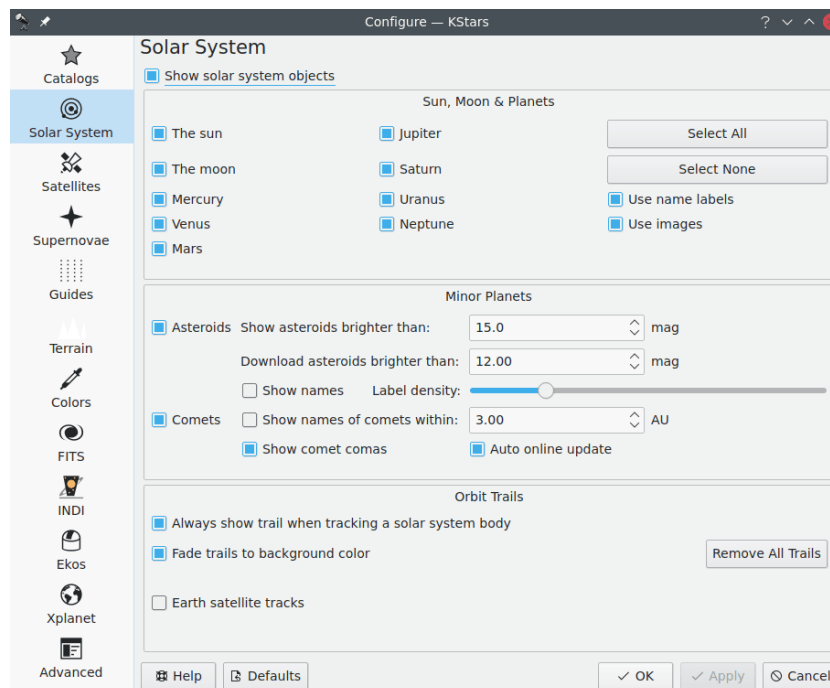
3.5 Solar System

In the **Solar System** page, you can specify whether the Sun, Moon, planets, comets and asteroids are displayed, and whether the major bodies are drawn as colored circles or actual images. You can also toggle whether solar system bodies have name labels attached, and control how many of the comets and asteroids get name labels. There is an option to automatically attach a temporary 'orbit trail' whenever a solar system body is tracked, and another to toggle whether the color of the orbit trail fades into the background sky color.

3.6 Satellites
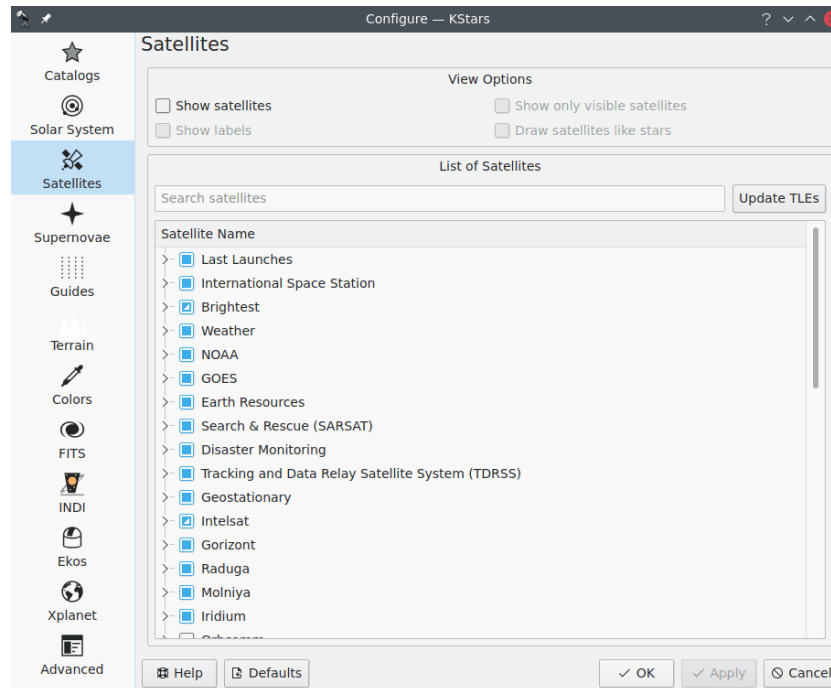
The **Satellites** page allows you to set the satellites view options. Firstly, you can see or hide the satellites on the skymap using **Show satellites** checkbox from the top **View Options** section. By default, satellites are drawn as small light red filled circles with an optional dark red name label next to them. You can enable or disable these labels by checking or not the **Show labels** checkbox. It is located below the **Show satellites** checkbox, within the **View Options** section.

The colors of the dots representing satellites and their name labels can be easily customized using the **Colors** page from the same **Configure - KStars** window. In addition, satellites can be drawn just like regular stars by checking the **Draw satellites like stars** checkbox. To display only the visible satellites from your current geographic location and time, select **Show only visible satellites**.

KStars can draw artificial satellites from many predefined groups. Thus, you can select to display a particular group, multiple groups or partially select subgroups. Under each group, a list of individual satellites is presented. To select all satellites from a group, you need to check the group checkbox. You can also select only the satellites of interest in each group. The satellites orbital elements can be updated via the internet by pressing the **Update TLEs** button. Another way for updating the satellites orbital elements is to use the **Data → Updates → Update Satellites Orbital Elements** menu item. If you know the name of a desired satellite then you can use the search satellites method that KStars provides. You need to enter the name of satellite in the **Search satellites** text box and the list will be reduced only to its best matches.

You can add new satellites to KStars default satellites set by editing the `kstars/data/satellite s.dat` file. As each line of this file is a group of satellites, you need to add a new entry for your desired satellites group. An entry should have the following format: **Group Name;local_fil ename;url**. For example: **Iridium;iridium.tle;https://celestrak.com/NORAD/el ements/iridium.txt**.

3.7 Supernovae
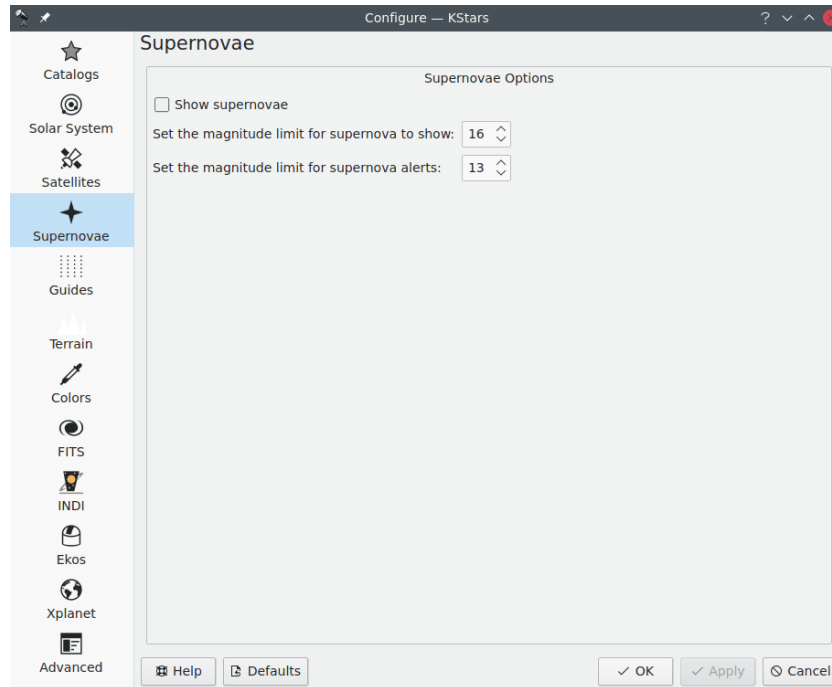
The **Supernovae** page allows you to decide if the supernovae are displayed or not by checking the **Show supernovae** checkbox. By default, supernovae are drawn as small light orange '+' mark. As for satellites, the color of supernovae can be easily customized using the **Colors** page.

You can set the magnitude limit for showing a supernova as well as magnitude limit for supernova alerts using the spin boxes control. The limiting magnitude is the faintest apparent magnitude of an skyobject that is visible with the naked-eye or a telescope.

The list of recent supernovae can be updated via the **Data** → **Updates** → **Update Recent Supernovae data** menu item.

3.8 Guides
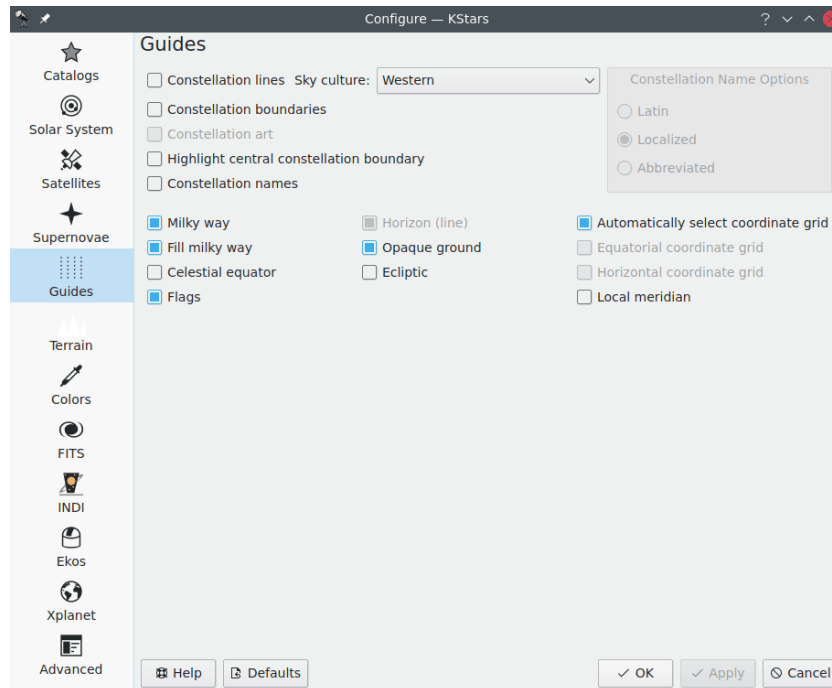
The **Guides** page lets you toggle whether non-objects are displayed (i.e., constellation lines, constellation names, the Milky Way contour, the celestial equator, the ecliptic, the horizon line, and the opaque ground). You can also choose a sky culture, whether you would like to see Latin constellation names, IAU-standard three-letter abbreviations, or constellation names using your local language.

3.9 Terrain
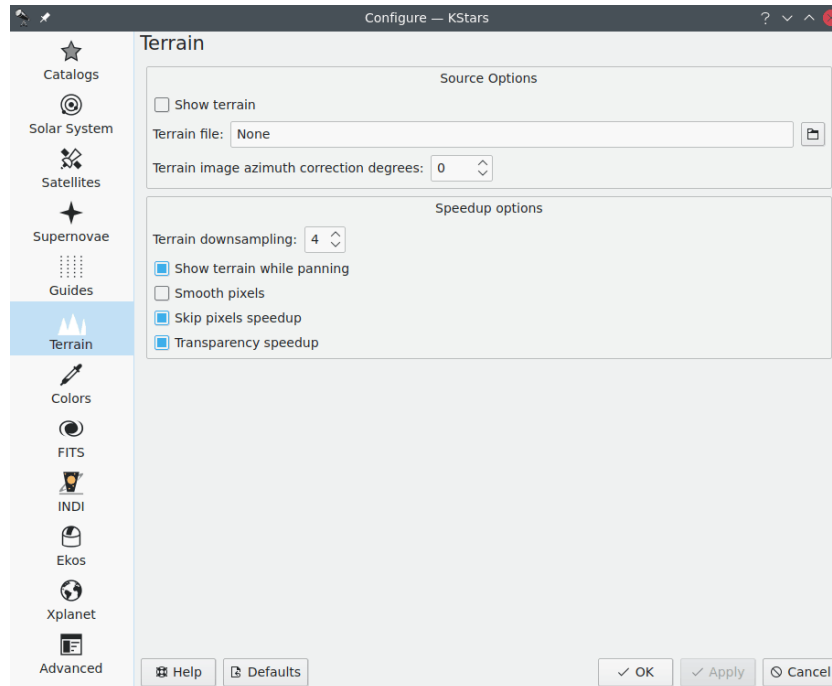
The **Terrain** page lets you configure whether the terrain (landscape) image will be shown on the skymap.

The user is responsible for creating a partially-transparent image, that is overlayed onto the sky map. This image should have transparent regions that the user creates to let the skymap show through, and opaque regions representing the trees, buildings, the landscape around the telescope. There is a particular format required, and this is a significant effort. There are many resources on the web that explain how this is done for Stellarium. The details of image creation are the same.

Initially, the user captures a full sphere equirectangular projection image from approximately the same point-of-view as his/her telescope. This kind of image can be captured with the Google Camera App, or the Google YouTube App on iPhone, or likely many other camera apps. The user then needs to edit the resulting image so that the sky is erased/transparent, and save it as a PNG. Finally, the user needs to determine where North is in the image, so it can eventually be aligned with the skymap. Once all that is done, the sky map can simulate the local sky view including the local terrain.

Once the image is created, it is possible to upload it via the **Terrain** page and configure the azimuth correction value (in degrees) that allows the user to rotate the view so north in the sky map is aligned with the north in the image.

Moreover, some speedup options can be configured to achieve the best user experience when rendering the terrain on the sky map.

> TIP
>
> You can toggle the terrain overlay on and off using a keyboard shortcut **Ctrl**-**Shift**-**T** and the **View** → **Show Terrain** menu item.

3.10 Colors
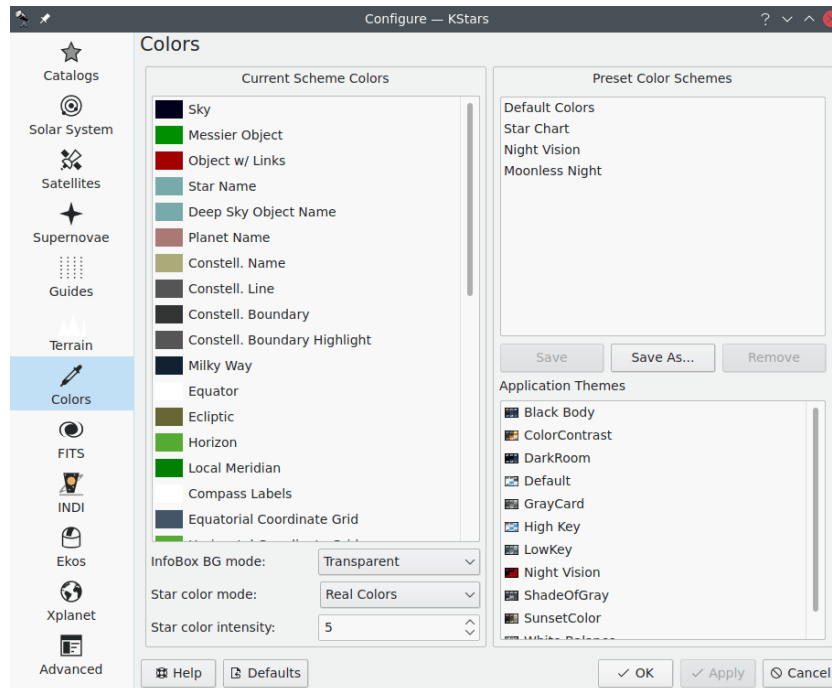
The **Colors** page allows you to set the color scheme, and to define custom color schemes. The tab is split into two panels:

The left panel shows a list of all display items with adjustable colors. Click on any item to bring up a color selection window to adjust its color. Below the list is the **Star color mode:** dropdown box. By default, KStars draws stars with a realistic color tint according to the spectral type of the star. However, you may also choose to draw the stars as solid white, black or red circles. If you are using the realistic star colors, you can set the saturation level of the star colors with the **Star color intensity:** spinbox.

The right panel lists the defined color schemes. There are four predefined schemes: the **Default Colors** scheme, **Star Chart**, which uses black stars on a white background, **Night Vision**, which uses only shades of red in order to protect dark-adapted vision, and **Moonless Night**, a more realistic, dark theme. Additionally, you can save the current color settings as a custom scheme by clicking the **Save As...** button. It will prompt you for a name for the new scheme, and then your scheme will appear in the list in all future KStars sessions. To remove a custom scheme, simply highlight it in the list, and press the **Remove** button.

3.11 FITS
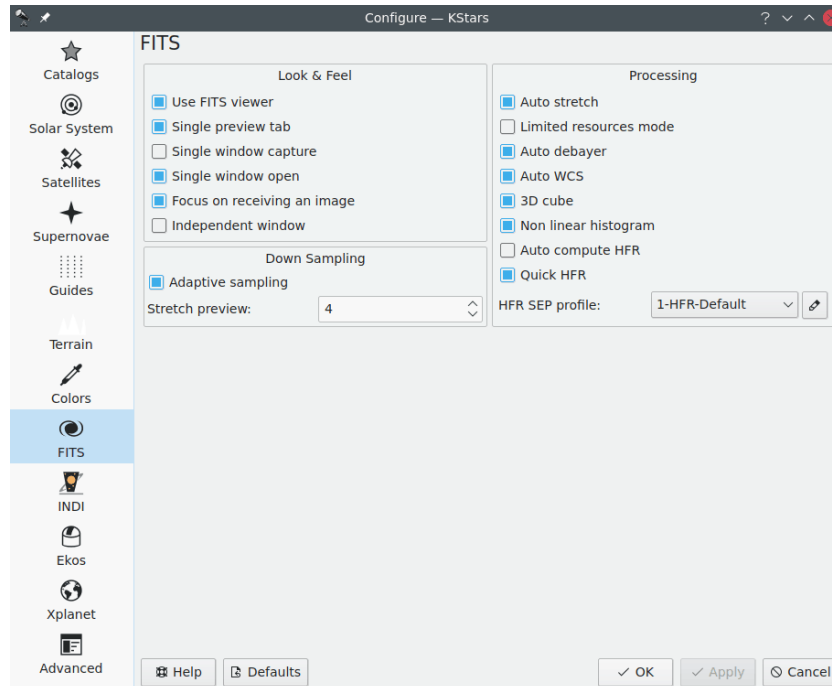
FITS (Flexible Image Transport System) is a popular open standard for storage, transmission and processing of digital data. For the details, one is referred to the corresponding Wikipedia article. This page allows you to configure presentation and processing of FITS data in KStars.

The left panel is for configuring FITS viewer itself.

Check the **Use FITS viewer** item if you want automatically display received images in the FITS Viewer.

The **Single preview tab** item is to display all captured FITS images in a single tab instead of multiple tabs per image. The **Single window capture** item is to display captured FITS images from all cameras in a single FITS Viewer window instead of a dedicated window to each camera. The **Single window open** item is to display opened FITS images in a single FITS Viewer window instead of a dedicated window to each file and the **Independent window** item is to make FITS Viewer window independent from KStars.

The right panel lists processing options. The **Auto stretch** item is to always apply auto stretch to images in FITS Viewer, **Limited resources mode** is to enable limited resource mode to turn off any resource-intensive operations, namely: **Auto debayer** (bayered images will not be debayered; only grayscale images are shown), **Auto WCS** (World Coordinate System data will not be processed; WCS maps sky coordinates to image coordinates; equatorial grid lines, object identification, and telescope slew within an image are disabled), and **3D cube** (RGB images will not be processed; only grayscale images are shown). You can switch off some of these resource-greedy operations separately as well.

3.12 INDI
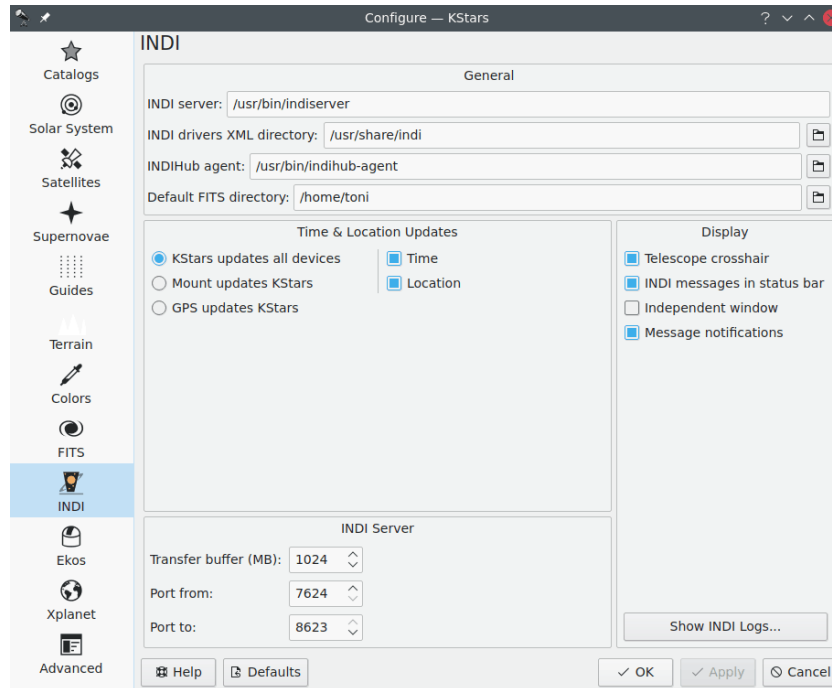
For detailed explanation of the options on the **INDI** page see the Configure INDI section.

3.13 Ekos
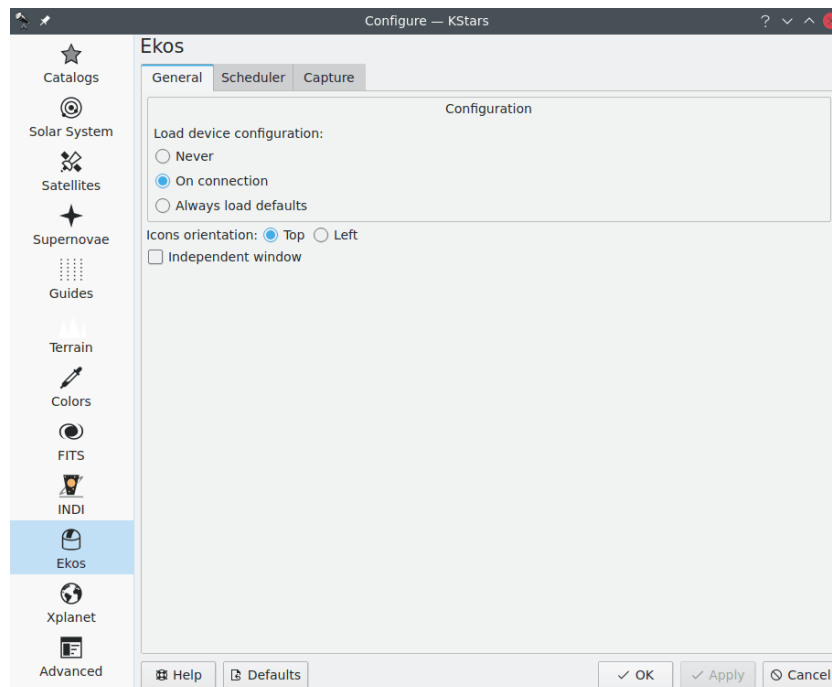
Ekos is an astrophotography suite, a complete astrophotography solution that can control all
INDI devices including numerous telescopes, CCDs, DSLRs, focusers, filters, and a lot more.

Ekos supports highly accurate tracking using online and offline astrometry solver, autofocus and autoguiding capabilities, and capture of single or multiple images using the powerful built in sequence manager. For detailed explanation of **Ekos**, see the Ekos section of this manual.

3.14 Xplanet
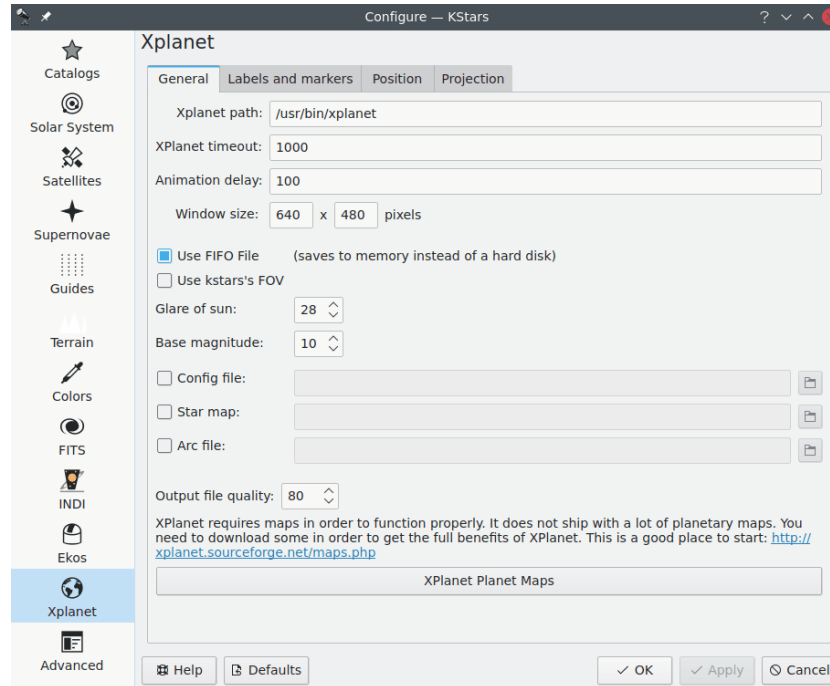
Xplanet (should be installed separately) is a solar system planet surface renderer. This page allows you to configure presentation and processing of Xplanet data in KStars.

3.15 Advanced
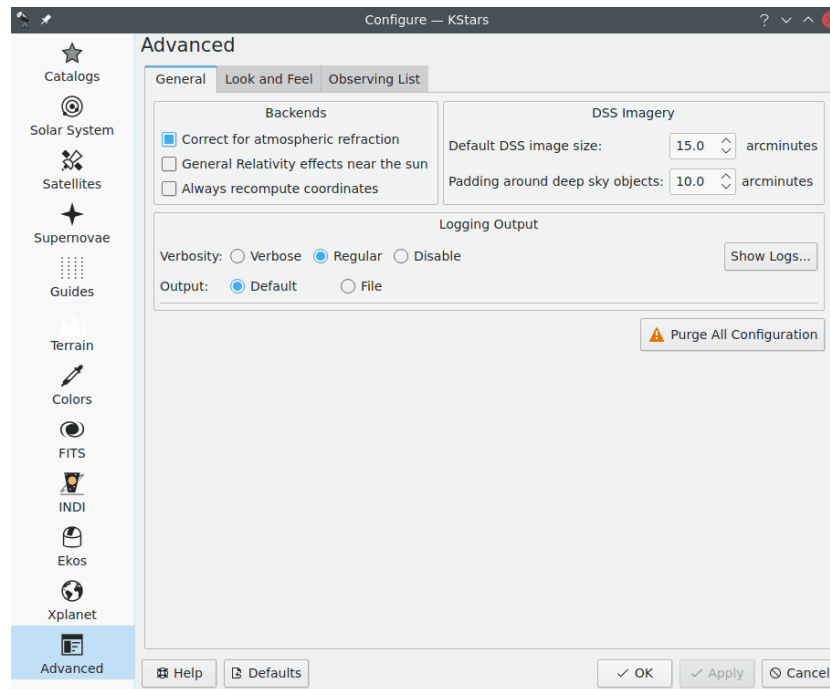
The **Advanced** page provides fine-grained control over the more subtle behaviors of KStars.

The **Correct for atmospheric refraction** checkbox controls whether the positions of objects are corrected for the effects of the atmosphere. Because the atmosphere is a spherical shell, light from outer space is 'bent' as it passes through the atmosphere to our telescopes or eyes on the Earth's surface. The effect is largest for objects near the horizon, and actually changes the predicted rise or set times of objects by a few minutes. In fact, when you 'see' a sunset, the Sun's actual position is already well below the horizon; atmospheric refraction makes it seem as if the Sun is still in the sky. Note that atmospheric refraction is never applied if you are using **Equatorial coordinates**.

The **Use animated slewing** checkbox controls how the display changes when a new focus position is selected in the map. By default, you will see the sky drift or 'slew' to the new position; if you uncheck this option, then the display will instead 'snap' immediately to the new focus position.

If the **Attach label to centered object** checkbox is selected, then a name label will automatically be attached to an object when it is being tracked by the program. The label will be removed when the object is no longer being tracked. Note that you can also manually attach a persistent name label to any object with its popup menu.

There are three situations when KStars must redraw the sky display very rapidly: when a new focus position is selected (and **Use animated slewing** is checked), when the sky is dragged with the mouse, and when the time step is large. In these situations, the positions of all objects must be recomputed as rapidly as possible, which can put a large load on the CPU. If the CPU cannot keep up with the demand, then the display will seem sluggish or jerky. To mitigate this, KStars will hide certain objects during these rapid-redraw situations, as long as the **Hide objects while moving** checkbox is selected. The timestep threshold above which objects will be hidden is determined by the **Also hide if time step larger than:** timestep-spinbox. You can specify the objects that should be hidden in the **Configure Hidden Objects** section.

3.16 Customizing the Display

There are several ways to modify the display to your liking.

- Toggle whether the Info Boxes are drawn in the **Settings** → **Info Boxes** submenu. In addition, you can manipulate the three Info Boxes with the mouse. Each box has additional lines of data that are hidden by default. You can toggle whether these additional lines are visible by double-clicking a box to 'shade' it. Also, you can reposition a box by dragging it with the mouse. When a box hits a window edge, it will 'stick' to the edge when the window is resized.

- Toggle whether the Toolbars are drawn in the **Settings** → **Toolbars Shown** submenu. Like most KDE toolbars, they can also be dragged around and anchored on any window edge, or even detached from the window completely if they are unlocked.

- Select a different color scheme in the **Settings** → **Color Schemes** submenu. There are four predefined color schemes, and you can define your own in the **Configure - KStars** window.

- Choose an 'FOV Symbol' using the **Settings** → **FOV Symbols** submenu. *FOV* is an acronym for 'field-of-view'. An FOV symbol is drawn at the center of the window to indicate where the display is pointing. Different symbols have different angular sizes; you can use a symbol to show what the view through a particular telescope would look like. For example, if you choose the '7x35 Binoculars' FOV symbol, then a circle is drawn on the display that is 9.2 degrees in diameter; this is the field-of-view for 7x35 binoculars.

  You can define your own FOV symbols (or modify the existing symbols) using the **Edit FOV Symbols...** menu item, which launches the FOV Editor:
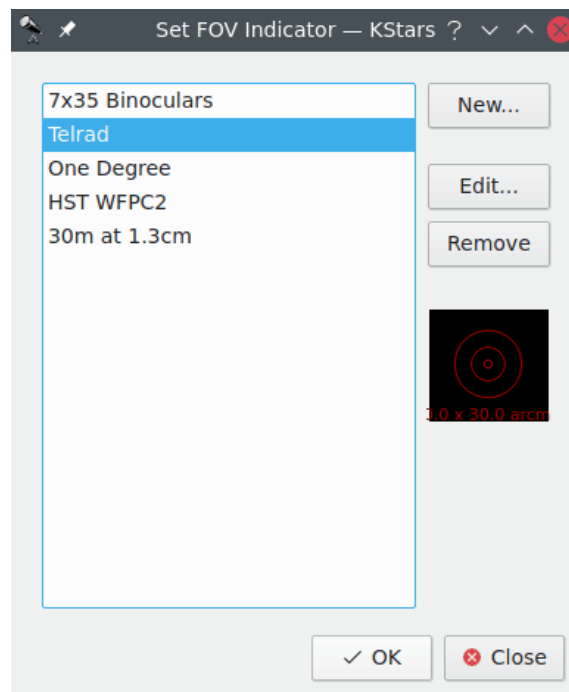
  The list of defined FOV symbols is displayed on the left. On the right are buttons for adding a new symbol, editing the highlighted symbol's properties, and removing the highlighted symbol from the list. Note that you can even modify or remove the four predefined symbols (if you remove all symbols, the four defaults will be restored the next time you start KStars). Below these three buttons is a graphical preview display showing the highlighted symbol from the list. When the **New...** or **Edit...** button is pressed, the **New FOV Indicator** window is opened:
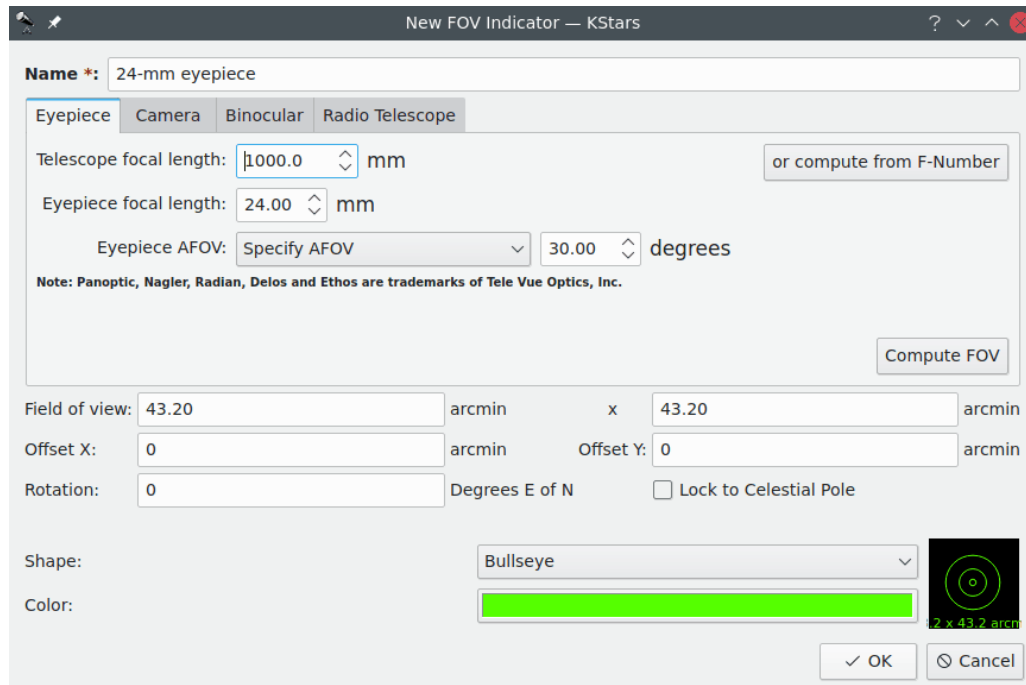
This window lets you modify the four properties that define a FOV symbol: name, size, shape, and color. The angular size for the symbol can either be entered directly in the **Field of View** edit box, or you can use the Eyepiece/Camera Tabs to calculate the field-of-view angle, given parameters of your telescope/eyepiece or telescope/camera setup. The five available shapes are: Square, Circle, Crosshairs, Bullseye and Semitransparent circle. Once you have specified all four parameters, press **Ok**, and the symbol will appear in the list of defined symbols. It will also be available from the **Settings** → **FOV Symbols** submenu.

3.17   HiPS Progressive Overlay

KStars provides support for HiPS: Hierarchical Progressive Surveys. HiPS provides multi-resolution progressive surveys to be overlayed directly in client applications. It provides an immersive experience as you can explore the night sky dynamically. With over 200+ surveys across the whole electromagnetic spectrum from radio, infrared, visual, to even gamma rays, the user can pan and zoom progressively deeper into the data visually.

It can be enabled from the **View** → **HiPS All Sky Overlay** submenu.

Under the submenu, a list of enabled surveys are listed. Click on the survey of interest to activate it. You can only activate one-overlay at a time. After activating the survey, KStars shall begin downloading the data in the background and progressively overlay the images unto the sky map as they become ready. Zooming in usually requires another patch of images that should trigger another download cycle.
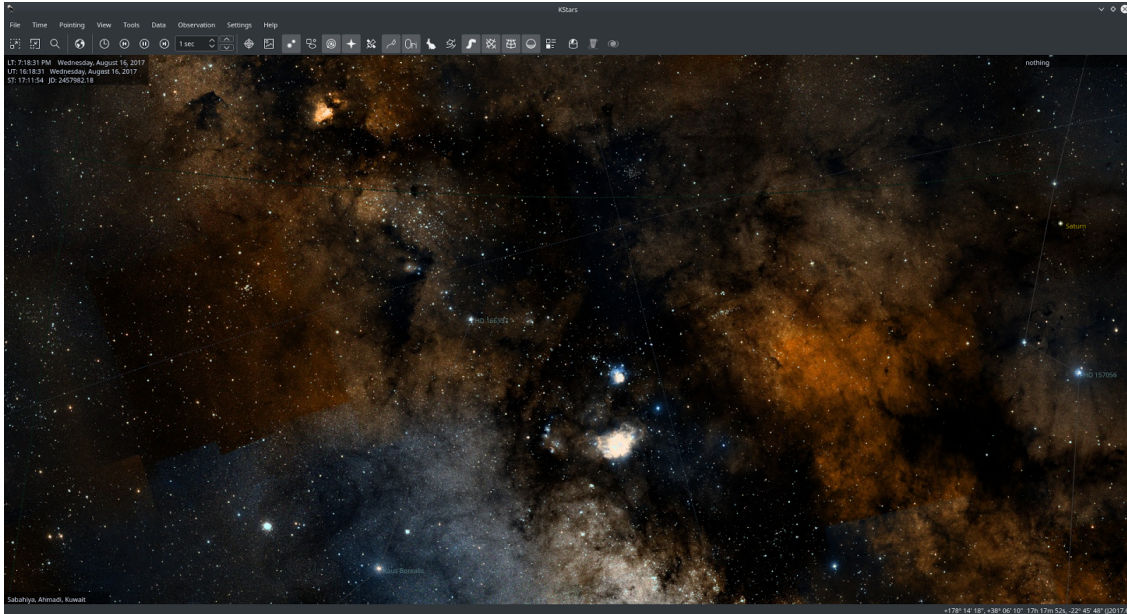
The above screenshot shows the DSS Color visual overlay in KStars.

HiPS Settings... menu item shows a dialog with the following pages:

- **Display**: Enable or disable **Show HiPS grid** and **Linear interpolation** checkboxes. The interpolation is enabled by default and should make the overlay appear smoother.

- **Cache**: Set the **Disk:** and **Memory:** cache size in MB. Increase cache size if you have abundant resources and want to reduce bandwidth required to download the images.

- **Sources**: Browse a list of HiPS sources and enable/disable them accordingly. When you select each source, a summary and a preview are downloaded that include information on the mission in additional to technical data on the survey.

Chapter 4

Command Reference

4.1 Menu Commands

4.1.1 File Menu

File → Open Image... (Ctrl+O)

Open a image in the FITS Viewer tool.

File → Save Sky Image...

Create image on disk from current display.

File → Run Script... (Ctrl+R)

Run the specified KStars script.

File → Printing Wizard...

Starts a wizard to configure capturing sky objects images using telescope and printing the results as a good looking printout for further use or catalogization.

File → Print... (Ctrl+P)

Send the current sky map to the printer (or to a PostScript®/PDF file).

File → Quit (Ctrl+Q)

Quit KStars.

4.1.2 Time Menu

Time → Set Time to Now (Ctrl+E)

Sync time to system clock.

Time → Set Time... (Ctrl+S)

Set time and date.

Time → Advance One Step Backward in Time (<)

Advance one step backward in time in the KStars simulation of the sky chart. The duration of the time step can be configured after pressing the little **>** button on the KStars toolbar.

Time → Stop Clock

    Toggle whether time passes.

Time → Advance One Step Forward in Time (>)

    Advance one step forward in time in the KStars simulation of the sky chart. The duration of the time step can be configured after pressing the little **>** button on the KStars toolbar.

4.1.3 Pointing Menu

Pointing → Zenith (Z)

    Center the display at the Zenith point (straight up).

Pointing → North (N)

    Center the display above the North point on the horizon.

Pointing → East (E)

    Center the display above the East point on the horizon.

Pointing → South (S)

    Center the display above the South point on the horizon.

Pointing → West (W)

    Center the display above the West point on the horizon.

Pointing → Set Coordinates Manually... (Ctrl+M)

    Center the display on specific sky coordinates.

Pointing → Find Object... (Ctrl+F)

    Locate an object by name using the Find Object Window.

Pointing → Engage/Stop Tracking (Ctrl+T)

    Toggle tracking on/off. While tracking, the display will remain centered on the current position or object.

4.1.4 View Menu

View → Zoom In (Ctrl++)
    Zooms view in.

View → Zoom Out (Ctrl+-)
    Zooms view out.

View → Default Zoom (Ctrl+Z)
    Restore the default Zoom setting.

View → Zoom to Angular Size... (Ctrl+Shift+Z)
    Zoom to specified field-of-view angle.

View → Full Screen Mode (Ctrl+Shift+F)
    Toggle full-screen mode.

View → Switch to Star Globe View / Switch to Horizontal View (Space)

> Toggle between the Horizontal and Equatorial Coordinate Systems.

View → Show Terrain (Ctrl+Shift+T)

> Toggle the terrain image visibility.

View → Projection

> A submenu that lists all projections.

> > **Lambert Azimuthal Equal-area (F5)**
> >
> > > Switch sky chart view to the Lambert azimuthal equal-area projection.
> >
> > **Azimuthal Equidistant (F6)**
> >
> > > Switch sky chart view to the azimuthal equidistant projection.
> >
> > **Orthographic (F7)**
> >
> > > Switch sky chart view to the orthographic projection.
> >
> > **Equirectangular (F8)**
> >
> > > Switch sky chart view to the equirectangular projection.
> >
> > **Stereographic (F9)**
> >
> > > Switch sky chart view to the stereographic projection.
> >
> > **Gnomonic (F10)**
> >
> > > Switch sky chart view to the gnomonic projection.

View → HiPS All Sky Overlay

> A submenu that lists the enabled surveys. Select the **HiPS Settings...** menu item for configure the HiPS sky overlays.

4.1.5 Tools Menu

Tools → Calculator (Ctrl+Shift+C)

> Opens the AstroCalculator Tool, which provides full access to many of the mathematical functions used by KStars.

Tools → Devices

> A submenu for control supported devices.

> > **List your Equipment... (Ctrl+0)**
> >
> > > Allows you to define your equipment characteristics for observation logs. The Configure Equipment window is divided into four tabs: **Telescope**, **Eyepiece**, **Lens** and **Filter**. You can add a new equipment by completing its characteristics and pressing **Add New...** button. You can also save or remove an equipment from the list.
> >
> > **Device Manager... (Ctrl+D)**
> >
> > > Opens up the device manager, which allows you to start/shutdown device drivers and connect to remote INDI servers.
> >
> > **Custom Drivers...**
> >
> > > A dialog to customize the drivers.
> >
> > **INDI Control Panel...**
> >
> > > Opens up INDI Control Panel, which allows you to control all the features supported by a device.

Tools → Sky Calendar

Opens the **Sky Calendar** Tool, which allows you to plan observations of Solar System planets by giving graphical data on sets and rises of these objects.

Tools → Altitude vs. Time (Ctrl+A)

Opens the Altitude vs. Time Tool, which can plot curves representing the altitude of any object as a function of time. This is useful for planning observing sessions.

Tools → What's up Tonight (Ctrl+U)

Opens the What's up Tonight Tool, which presents a summary of the objects which are observable from your location on a given date.

Tools → What's Interesting... (Ctrl+W)

Opens the **What's Interesting** Tool, which allows you to be informed about the most interesting observations that can be made from your current location using the given equipment.

Tools → XPlanet Solar System Simulator (Ctrl+X)

This menu item will appear only if you have installed the XPlanet optional package.

Tools → Script Builder (Ctrl+B)

Opens the Script Builder Tool, which provides a GUI interface for building KStars D-Bus scripts.

Tools → Solar System (Ctrl+Y)

Opens the Solar System Viewer, which displays an overhead view of the solar system on the current simulation date.

Tools → Ekos (Ctrl+K)

Opens Ekos, a complete and powerful tool for astrophotography. With Ekos, you can align and guide your telescope, focus your CCD, and capture images using an easy intuitive interface.

Tools → Jupiter's Moons (Ctrl+J)

Opens the Jupiter Moons Tool, which displays the positions of Jupiter's four brightest moons as a function of time.

Tools → Flags

Opens the **Flag manager** Tool, which can be used to assign color labels and icons to the given positions on the sky chart.

4.1.6 Data Menu

Data → Download New Data... (Ctrl+N)

Open the **Get Hot New Stuff** dialog to download additional data for KStars.

Data → Manage DSO Catalogs

Open the **DSO Catalogs** dialog for manage the catalog database of KStars.

Data → Updates

This submenu can be used to update various object data, namely asteroids, comets and satellites orbital elements as well as recent supernovae data from the Internet. The data will be downloaded for the current user account only. If you use KStars from different account you should download them for every account separately.

KStars tries to download recent supernovae list automatically by default. You can switch the download off using **Supernovae** page of KStars Settings window.

4.1.7 Observation Menu

Observation → Observation Planner (Ctrl+L)

Open the Observation Planner tool.

Observation → Execute the Session Plan... (Ctrl+2)

Opens session plan wizard or execute the planned session.

Observation → Polaris Hour Angle...

Opens the **Polaris Hour Angle** tool.

4.1.8 Settings Menu

Settings → Info Boxes

A submenu that lists the different info boxes.

Show Info Boxes

Toggle display of all three Info Boxes:

- **Time Box**
- **Focus Box**
- **Location Box**

Show Time Box

Toggle display of the Time Info Box. By default, the Time Info Box is located in the top left side of the screen. You can change the position of Time Info Box by holding the left-click mouse button and dragging it to the new position.

Show Focus Box

Toggle display of the Focus Info Box. By default, the Focus Info Box is located in the top right side of the screen. You can change the position of Focus Info Box by holding the left-click mouse button and dragging it to the new position.

Show Location Box

Toggle display of the Location Info Box. By default, the Location Info Box is located in the bottom left side of the screen. You can change the position of Location Info Box by holding the left-click mouse button and dragging it to the new position.

Settings → Toolbars Shown

A submenu that lists the different toolbars.

Main Toolbar

Toggle display of the Main Toolbar. By default, the Main Toolbar provides useful shortcuts for controlling the sky map view (i.e. Zoom in and Zoom out) and for controlling KStars clock as well. You can Start / Stop the clock, advance one step backward / forward in time and also you can easily set the time step used by KStars' clock. The time step is the rate at which time flows in the simulation. For setting the time step, you can use the spin box used for establishing the time step units and the spin box used for increasing / decreasing the time step value. Using the Main Toolbar you can quickly open the **Find Object**, **Set Time** or **Set Geographic Location** window. Main Toolbar can be configured using the **Settings → Configure Toolbars...** menu item.

View Toolbar

Toggle display of the View Toolbar. View Toolbar controls which sky objects are drawn on KStars Sky Map (stars, deep sky objects, Solar system objects, supernovae or satellites) as well as what constellation information is included (constellation lines, constellation names, constellation art or constellation boundaries). It also provides icon shortcuts for: showing milky way (drawn with dark grey color), showing equatorial/horizontal coordinate grid and for showing the green opaque ground. Note that when the horizon is switched off, refraction effects are temporarily disabled. View Toolbar can be configured using the **Settings** → **Configure Toolbars...** menu item.

INDI Toolbar

Toggle display of the INDI Toolbar. By default, INDI Toolbar contains five shortcut icons:

- **Toggle Ekos**

- **Toggle INDI Control Panel**

- **Toggle FITS Viewer**

- **Toggle Sensor FOV**

- **Toggle Lock Telescope Center**

INDI Toolbar can be configured using the **Settings** → **Configure Toolbars...** menu item.

Telescope Toolbar

Toggle display of the Telescope Toolbar. By default, Telescope Toolbar contains seven shortcut icons:

- **Toggle Mount Control Panel**
- **Toggle Telescope Tracking**
- **Slew telescope to the focused object**

- **Sync telescope to the focused object**

- **Park telescope**

- **Unpark telescope**

- **Abort telescope motions**

Telescope Toolbar can be configured using the **Settings** → **Configure Toolbars...** menu item.

Dome Toolbar

Toggle display of the Dome Toolbar. By default, Dome Toolbar contains two shortcut icons:

- **Park dome**

- **Unpark dome**
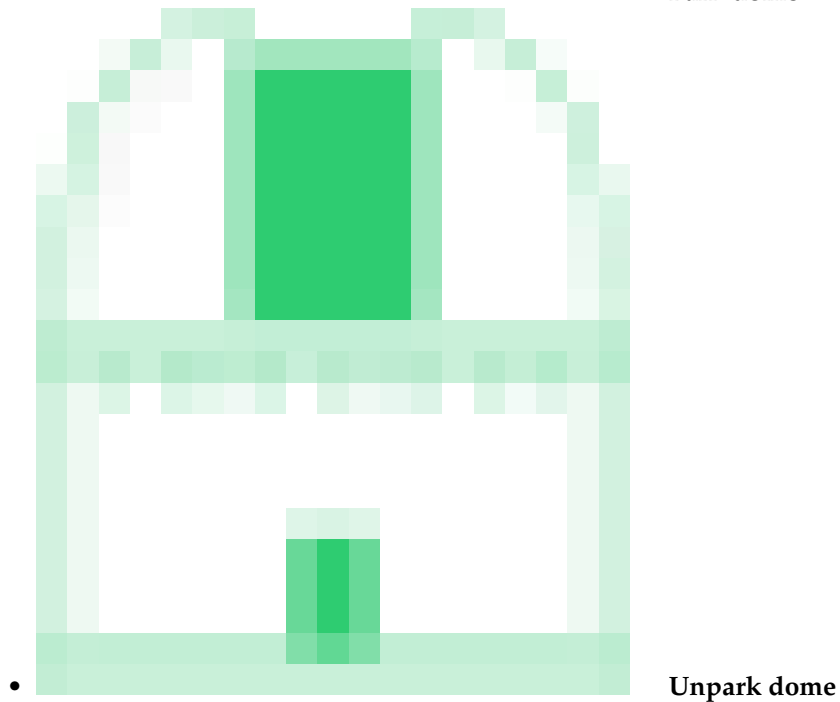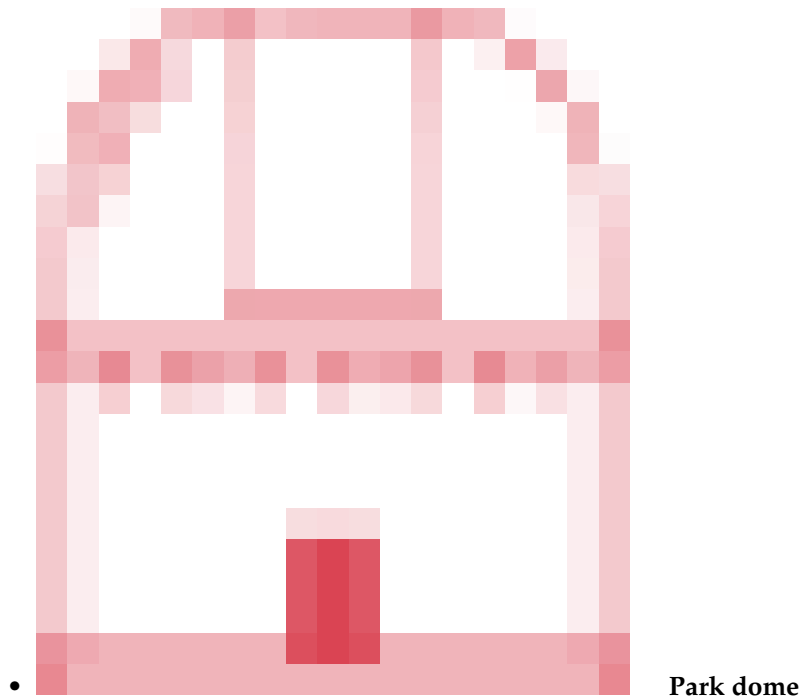
  Dome Toolbar can be configured using the **Settings** → **Configure Toolbars...** menu item.

Settings → **Statusbar**

A submenu that lists the different statusbars.

Show Statusbar

Toggle display of the Statusbar. It is located in the bottom of KStars window.

Show Az/Alt Field

Toggle display of the mouse cursor's horizontal coordinates in the statusbar.

Show RA/Dec Field

Toggle display of the mouse cursor's equatorial coordinates in the statusbar.

Show J2000.0 RA/Dec Field

Toggle display of the mouse cursor's equatorial J2000 coordinates in the statusbar.

Settings → Themes

Lists the available Theme items.

Settings → Color Schemes

This submenu contains all of the defined color schemes: Classic, Star Chart, Night Vision and Moonless Night. It can also include your custom color schemes. Select any item to set that color scheme.

Settings → FOV Symbols

This submenu lists the available field-of-view (FOV) Symbols. The FOV Symbol is drawn at the center of the display. You may choose one or more from the list of predefined symbols (7x35 Binoculars, Telrad, One Degree, HST WFPC2 or 30m at 1.3cm) by checking their specific checkbox, or you may use no symbol by unchecking all the items from the symbols list. You can also define your own symbols (or modify existing symbols) using the **Edit FOV Symbols...** menu item.

Settings → Artificial Horizon...

If you select this submenu, then Artificial Horizon Manager will be opened. Artificial Horizon Manager is used to define on the skymap one or more regions that are blocked from view from your current location (i.e. tall trees or building). The window is split in two sections: in the left side is the Regions section while in the right side is the Points section. You can add a new region by pressing the **+** (Add Region) button or you can remove a region by selecting it in the regions list and then pressing the **-** (Remove Region) button. In order to draw a region you need to define a list of points that encompasses the blocked area. You can add a new point by pressing the **+** (Add Point) button from the right Points section. You can also remove a highlighted point from the list of points or you can clear all the points. There are two ways to add a new point to a selected region: manually by entering the point's coordinates or by selecting the point from the skymap after clicking **Select Points** button. Note that each point is described by a set of horizontal coordinates: Az (Azimuth) and Alt (Altitude). If you want to modify a point's coordinates, just double click on its Az/Alt text box value and enter the new value. First and Last points must be on the horizon. Polygons must be closed to be considered valid regions. Artificial Horizon Manager provides a easy way to rename your regions. By default, regions are named as: 'Region ' plus an index (i.e. 'Region 1' or 'Region 2'). For renaming a region, just double click on its name and then you will be invited to complete a new region name. You can also control which regions are enabled or disabled for marking on the map by a simple click on the checkbox in front of each region. After you defined your desired regions you can apply them by pressing the **Apply** button. If you want to use these regions again, in further astronomy sessions, you can save them such that next time when you will open KStars they will be automatically marked on the skymap.

Settings → Manage Observer... (Ctrl+1)

Selecting this will open Manage Observers window that enables you to register a number of observers which are using KStars on this computer. You can add a new entry to observers list by completing the mandatory fields: **Name:** and **Surname:** and then pressing the **+** (Add observer) button. Note that **Contact:** field is optional, KStars allowing you to add a new observer even though **Contact:** text box is empty. You can also remove an observer from the list using **-** (Remove observer) button.

Settings → Geographic... (Ctrl+G)

Select a new geographic location.

Settings → Configure Keyboard Shortcuts...

Open the Configure Shortcuts window which allows you to modify KStars shortcuts. You can use KStars default shortcuts scheme or define your own shortcuts scheme. In order to add a new custom shortcut to an action, you need to click on action's name and then press the **Custom:** checkbox. Then click on the button next to **Custom:** checkbox and enter the shortcut you would like to use in KStars. You can also remove a shortcut by pressing the **Delete** button after you select an action from the list. KStars helps you to find an action by providing its search method; just enter the name of the action and the list will be reduced to its best matches. For example, I will give you a brief example on how to use KStars Configure Shortcuts feature:

- Firstly, open the Configure Shortcuts window from the **Settings** menu.
- Then select the action you would like to add a shortcut (i.e. Artificial Horizon). You can use the search method provided by KStars. Just type 'art' in the search text box and the list will be reduced to only four actions. The Artificial Horizon is the first action in the list.
- Now that you find your desired action, you can add a new shortcut by clicking on its name. After you click on the action name, press the **Custom** checkbox. There is a button next to **Custom** checkbox used for adding new shortcuts. By default, if an action has no custom shortcut, the 'None' tag will be assigned to this button. Press this button and then add your custom shortcut. For example, for Artificial Horizon, you can use **Ctrl**+H shortcut. Hold the **Ctrl** key and press H. Your shortcut be automatically saved, thus you can use it next time when you open KStars.

Settings → Configure KStars...

Modify configuration options.

Settings → Startup Wizard...

Shows the **Setup Wizard** dialog. It is the same window that you saw when you ran KStars for the very first time. KStars Setup Wizard will help you set up some basic options, such as your location on Earth. The first page of Setup Wizard is a welcome page and if you press **Next** button, you will get the **Choose Your Home Location** page. Here you can select your exact home location or a city near your home location if your accurate location is not present in KStars cities database. Browsing the entire list is not so efficient and thus, KStars provides you a easy-to-use method for selecting your desired city in a short time. You may filter the list of cities by the name of your city, province and country. By giving more details about your location, the list's size will reduced only to its best matches. When you high-light a city in the cities list, the **Longitude:** and **Latitude:** boxes will be updated, containing the accurate information of your selected location. When you hit the **Next** button, you will get the last page of KStars Setup Wizard: 'Download Extra Data Files' page. Here you may download optional data files via the Internet, in order to enhance KStars, such as Messier object images, or a more complete NGC/IC catalog. Press the **Download Extra Data...** button to proceed. After you pressed this button, the **Get Hot New Stuff** dialog will appear. It is KStars Add-On Installer, which will help you to manage what extra information you added to KStars. Firstly, you can choose how the add-ons list is displayed, by pressing the **Details view mode** or **Icons view mode** button. You may also order the list by various criteria like: newest, rating, most downloads or installed. This can be easily done by selecting an option using the radio button. You can also make searches using the **Search:** text box. Regarding the list of add-ons, you may perform several actions by selecting an add-on from the list: you can install or uninstall an add-on using the **Install** / **Uninstall** button, you can open the Details window using the **Details** button or you can rate an add-on by giving a number of gold stars, up to five stars. If you want to send an email to the author of an add-on, you are able to do that by clicking on his e-mail address. Then, your default e-mail application will guide you through the sending process. After you managed your KStars add-ons, then you can close the window by pressing the **Close** button. You can also use the Download Extra Data Files tool later, by selecting the **Data → Download New Data...** menu item.

Additionally KStars has the common KDE **Settings** menu items, for more information read the sections about the Settings Menu of the KDE Fundamentals.

4.1.9 Help Menu

KStars has the common KDE **Help** menu items, for more information read the section about the Help Menu of the KDE Fundamentals.

4.1.10 Popup Menu

The right click popup menu is context-sensitive, meaning its content varies depending on what kind of object you click on. We list all possible popup menu items here, with the relevant object type [in brackets].

[All]

Identification and quick info: The top several lines are devoted to the name(s) of the object, its type and the constellation in which it lies. The magnitude is shown with the superscript 'm' if it is available. For stars, the Spectral Type is also shown here. For deep-sky objects, the dimensions, if known, are shown in arcminutes (eg: 6′×3′) and the source catalog is also shown.

[All]

Rise, Transit, and Set times for the object on the current simulation date are shown on the next three lines.

[All]

Center & Track: Center the display on this location, and engage tracking. Equivalent to double-clicking.

[All]

Add flag...: Open KStars 'Flag manager' window. Here you can manage your flags and use some of KStars features. When 'Flag manager' window is open for a selected object, **Right ascension** and **Declination** text boxes will be automatically filled with the coordinate values of the selected object on the Sky Map. Besides these two text boxes, you can set the **Epoch**, add a **Label**, set the **Label color** or even add an **Icon**. To add custom icons, just add images in 'qtpaths --paths GenericDataLocation'/kstars/ . File names must begin with the 'flag' keyword. For example, the file 'flagSmall_red_cross.gif' will be shown as Small red cross in the combo box. After you set up the information of the new flag, you can add it to the flags list using the **Add** button. You may also change flags details (i.e. RA/Dec, label or icon) and then save the new ones by pressing the **Save changes** button. Using the Flag manager, you can easily center an object in Map or in Telescope, by pressing **Center in Map** or **Center in Telescope** button. In order to delete a value from the list, just select it in the list and then press **Delete** button. Your flags are saved after you close current session and thus you will be able to see them everytime you will use KStars again.

[All]

Angular Distance To...: Enter ″angular distance mode″. In this mode, a dotted line is drawn from the first target object to the current mouse position. When you click with the right mouse button on a second object, this will display the angular distance between the two objects near the second object. You can press the **Esc** key to exit angular distance mode without measuring an angle.

[All]

Starhop from here to: will enable you to find a path between two points in the sky. Star hopping is a technique that uses bright stars as a guide for finding fainter objects. So if

you have a bright star, you can use it as a reference to find a fainter object. Starting from your reference star, KStars will find a route to the destination, traversing a sequence of stars/patterns of stars. The object for which you called **Starhop from here to** tool will be your starting point. When your starting point is established, a dotted line will appear, allowing you to decide which will be your end point. You have to move the mouse cursor to your destination object position and right click on it. Then, a dialog box will pop up, requiring you to set the FOV used for star hopping. For selecting a FOV, you need to make a choice from the FOV combo box list of values. The values you can choose include default FOV values (7x35 Binoculars, Telrad, One Degree, HST WFPC2 and 30m at 1.3cm) plus your customized FOVs. After you selected the FOV, KStars will find a route for you. Thus, the dialog box will contain a list of object used in the starhop. If KStars did not manage to find a route, then an error dialog box will be displayed, giving you a helping hand. When the Star-Hopper algorithm ends, the dialog box will contain a list of objects used in starhop route. For every object from the list, you can perform a set of actions: you can ask for details using the **Details** button, center selected object in the map using **Center on map** button or you can go to next star by pressing the **Next** button. Note that when go to next star, it will be automatically centered on the map. Also, Star-Hopper tool provides directions to star hop for every object of the list.

[All]

> **Details**: Open the Object Details window for this object.

[All]

> **Attach Label**: Attach a permanent name label to the object. If the object already has a label attached, this item will read **Remove Label**.

[All]

> **Add to Observing WishList**: Add the selected object to **Observation Planner**'s Wish List. You can see the Wish List, by selecting the **Observation → Observation Planner** menu item. If the object is already in the Observing WishList, then this item will become **Remove Label**.

[Solar system objects]

> **Add Trail**: Add a trail to current Solar system object. A star trail is the continuous path created by the star in the night sky due to the rotation of the Earth. If the object already has a trail, this item will become **Remove Trail**.

[All]

> **Simulate eyepiece view**: Eyepiece View feature renders the view through the eyepiece of various telescope types. Firstly, an input dialog is shown, which asks you to select one of the visible FOVs to use as a FOV for the eyepiece view. The user also has the option of trying to determine it from the image (accurate if image has metadata, otherwise it will be random). After you set the FOV, the "Eyepiece Field View" window will pop up. You can easily rotate the view using the "Rotation" slider. You can also flip and invert the view to help match the view through a telescope/camera. "Eyepiece view" tool can help you locate many objects with ease, instead of trying to work with relative positions and relative orientations. This is an important advantage, especially when you are star hopping. Note that for getting best results, time must be synced with current time in KStars, and KStars must be in horizontal coordinates mode.

[Solar system objects]

> **Image Resources**: gives a list of image links for current Solar system object. The images are displayed in KStars Image Viewer tool. Image Viewer tool allows you to invert the colors and save the image in your computer.

[Solar system objects]

> **Information Resources**: gives a list of documentation links for current Solar system object. The links are opened in your default browser.

[All objects without Solar system objects]

> **Show SDSS Image**: download a SDSS (Sloan Digital Sky Survey) image of the object from the Internet, and display it in the Image Viewer tool.

[All objects without Solar system objects]

> **Show DSS Image**: download a DSS (Digitized Sky Survey) image of the object from the Internet, and display it in the Image Viewer tool.

4.2 Keyboard Commands

4.2.1 Navigation Keys

Arrow Keys

> Use the arrow keys to pan the display. Holding down the **Shift** key doubles the scrolling speed.

+ / -

> Zoom In/Out.

Ctrl+Z

> Restore the default Zoom setting.

Ctrl+Shift+Z

> Zoom to specified field-of-view angle.

0–9

> Center Display on a major Solar System body:
>
> - **0**: Sun
> - **1**: Mercury
> - **2**: Venus
> - **3**: Moon
> - **4**: Mars
> - **5**: Jupiter
> - **6**: Saturn
> - **7**: Uranus
> - **8**: Neptune
> - **9**: Pluto

Z

> Center the display at the Zenith Point (straight up).

N

> Center the display above the North point on the horizon.

E

> Center the display above the East point on the horizon.

S

> Center the display above the South point on the horizon.

W

> Center the display above the West point on the horizon.

Ctrl+T

Toggle tracking mode.

<

Advance the simulation clock backwards by one time step.

>

Advance the simulation clock forwards by one time step.

4.2.2 Menu Shortcuts

Ctrl+N

Download extra data.

Ctrl+O

Open a FITS image in the FITS Editor.

Ctrl+I

Export sky image to a file.

Ctrl+L

Run a KStars Observation Planner.

Ctrl+R

Run a KStars D-Bus script.

Ctrl+P

Print the current sky map.

Ctrl+Q

Quit KStars.

Ctrl+E

Sync the simulation clock with the current system time.

Ctrl+S

Set the simulation clock to a specified Time and Date.

Ctrl+Shift+F

Toggle full-screen mode.

Ctrl+0

Define equipment (telescope, eyepiece, lens and filter) characteristics for observation logs.

Ctrl+1

Add a new observer item for your observation logs.

Space

Toggle between the Horizontal and Equatorial Coordinate Systems.

F1

Open the KStars Handbook.

F5

Switch sky chart view to the Lambert azimuthal equal-area projection.

F6

Switch sky chart view to the azimuthal equidistant projection.

F7

Switch sky chart view to the orthographic projection.

F8

Switch sky chart view to the equirectangular projection.

F9

Switch sky chart view to the stereographic projection.

F10

Switch sky chart view to the gnomonic projection.

4.2.3 Actions for the Selected Object

Each of the following keystrokes performs an action on the *selected object*. The selected object is the last object which was clicked on (identified in the status bar). Alternatively, if you hold down the **Shift** key, then the action is performed on the centered object instead.

C

Center and Track on the selected object.

D

Open the Details window for the selected object.

L

Toggle a name label for the selected object.

O

Add the selected object to the observing list.

P

Open the selected object's popup menu.

T

Toggle a trail on the selected object (solar system bodies only).

4.2.4 Tools Shortcuts

Ctrl+F

Open the Find Object window, for specifying a sky object on which to center.

Ctrl+M

Open the **Set Coordinates Manually** tool, for specifying RA/Dec or Az/Alt coordinates on which to center. The tool defaults to J2000 epoch for the RA/Dec.

[

Start an Angular Distance measurement at the current mouse cursor position. The angular distance between start and end points is displayed at the endpoint.

Ctrl+G

Open the Set Geographic Location window.

Ctrl+C

Open the AstroCalculator.

Ctrl+A

> Open the Altitude vs. Time tool.

Ctrl+U

> Open the What's up Tonight? tool.

Ctrl+W

> Open the 'What's Interesting' tool.

Ctrl+B

> Open the Script Builder tool.

Ctrl+Y

> Open the Solar System Viewer.

Ctrl+J

> Open the Jupiter Moons tool.

4.3 Mouse Commands

Moving the mouse

> The sky coordinates (Az/Alt, RA/Dec and J2000.0 RA/Dec) of the mouse cursor are updated in the status bar. The status bar is located in the right bottom corner of the screen. The status bar can be customized by selecting **Settings** → **Statusbar** submenu. Here you may choose what coordinates systems KStars will display in the status bar. Furthermore, you can hide the status bar by unchecking the **Show Statusbar** checkbox.

"Hovering" the mouse

> A temporary name label is attached to the object nearest to the mouse cursor.

Left-clicking

> The object nearest the mouse click is identified in the status bar.

Double-clicking

> Center and track on the location or object nearest the mouse click. Double-clicking on an Info Box will 'shade' it to show/hide extra information.

Right-clicking

> Open the popup menu for the location or object nearest the mouse cursor.

Scrolling the mouse wheel

> Zoom the display in or out. If you do not have a mouse wheel, you can hold the middle mouse button and drag vertically.

Click-and-dragging

> **Dragging the sky map**
>
> > Pan the display, following the drag motion.
>
> **Ctrl+dragging the sky map**
>
> > Define a rectangle in the map. When the mouse button is released, the display is zoomed in to match the field-of-view to the bounds of the rectangle.
>
> **Dragging an Info Box**
>
> > The Info Box is repositioned in the map. Info Boxes will 'stick' to window edges, so that they remain on the edge when the window is resized.

Chapter 5

KStars Tools

KStars comes with a number of tools that allow you to explore some more advanced aspects of astronomy and the night sky.

- Object Details
- Astrocalculator
- Altitude vs. Time Plotter
- What's up Tonight?
- Simulate Eyepiece View
- Script Builder
- Solar System Viewer
- Ekos
- Jupiter Moons Tool
- Observation Planner
- FITS Viewer

5.1 Object Details Window

The Object Details Window presents advanced data available about a specific object in the sky. To access this tool, right-click on any object, and select the **Details...** item from the popup menu.

The window is divided into a number of tabs. In the **General** tab, we present basic data about the current object. This includes names and catalog designations, object type, and magnitude (brightness). On the **Position** tab are the object's Equatorial and Horizontal coordinates, as well as its rise, set and transit times.

In the **Links** tab, you can manage the internet links associated with this object. The Image and Information links associated with the object are listed. These are the links that appear in the popup menu when the object is right-clicked. You can add custom links to the object with the **Add Link...** button. This will open a window in which you fill in the URL and link text for the new link (you can also test the URL in the web browser from this window). Every time you add a custom URL to a certain object, you are able to choose the resource type using the **Resource Type** button. Keep in mind that the custom link can easily point to a file on your local disk, so you can use this feature to index your personal astronomical images or observing logs.

You can also modify or remove any link using the **Edit Link...** and **Remove Link...** buttons.

The **Advanced** tab (not available for all objects) allows you to query professional astronomical databases on the internet for information regarding the current object. To use these databases, double click on the desired database in the list to see the results of your query in a web browser window. The query is made using the primary name of the object you clicked on to open the Details Dialog. The following databases are available for querying:

- **Set of Identifications, Measurements, and Bibliography for Astronomical Data (SIMBAD)**: SIMBAD is similar to NED, except it provides data about all kinds of objects, not just galaxies.

- **SkyView**: Provides images from All-Sky surveys that have been performed in dozens of different parts of the spectrum, from Gamma Rays to the Radio. The KStars interface will retrieve an image from any of these surveys, centered on the selected object.

- **High Energy Astrophysical Archive (HEASARC)**: Here you can retrieve data about the current object from a number of 'High-energy' observatories, which covers the Ultraviolet, X-ray and Gamma Ray portions of the electromagnetic spectrum.

- **NASA/IPAC Extragalactic Database (NED)**: NED provides encapsulated data and bibliographic links about extragalactic objects. You should only use NED if your target is extragalactic; i.e. if it is itself a galaxy.

- **NASA Astrophysical Data System (ADS)**: This incredible bibliographic database encompass the entire body of literature published in international peer-review Journals about astronomy and astrophysics. The database is divided into four general subject areas (Astronomy and Astrophysics, Astrophysics Preprints, Instrumentation, and Physics and Geophysics). Each of these has three sub-nodes that query the database in different ways. 'Keyword search' will return articles which listed the object's name as a keyword. 'Title word search' will return articles which included the object name in their Title, and the 'Title & Keyword search' uses both options together.

- **Multimission Archive at Space Telescope (MAST)**: The Space Telescope Science Institute provides access to the entire collection of images and spectra taken with the Hubble Space Telescope, as well as several other space-based observatories.

Finally, in the **Log** tab, you can type in some text that will remain associated with this object's **Details** window. You could use this to attach personal observing notes, for example. Your notes will be saved, such that you can easily read or use them next time when you will use KStars.

5.2 The Astrocalculator

The KStars Astrocalculator provides several modules that give you direct access to algorithms used by the program. The modules are organized by subject:

TIME CALCULATORS

- Julian Day
- Sidereal Time
- Almanac
- Equinoxes and Solstices

COORDINATE CONVERTERS

- Equatorial/Galactic Coordinates
- Apparent Coordinates
- Horizontal Coordinates
- Ecliptic Coordinates
- Angular Distance
- Geodetic Coordinates

SOLAR SYSTEM

- Planets Coordinates

5.2.1 Julian Day module
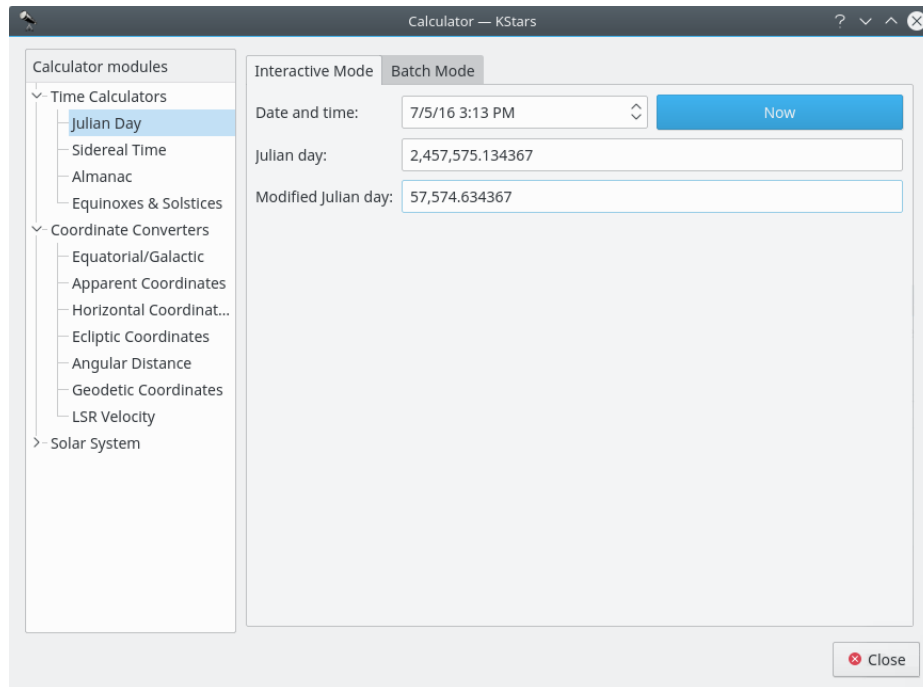
This module converts between the calendar **Date and time:**, the **Julian day:**, and the **Modified julian day:**. The Modified Julian Day is simply equal to the Julian Day - 2,400,000.5.

To use the module, enter one of the three dates and the corresponding values for the other two date systems will be displayed. You can also set the Date and time to now, by pressing the **Now** button.

There is a batch mode for this module. To use it, simply generate an input file whose lines each contain a number of values for the input parameter: 'Date and time', 'Julian day' or 'Modified Julian day'. Then specify the input and output filenames, and press the **Compute** button to generate the output file. The output file will contains values for the other two complementary parameters. For example, if your input file contains a set of **Date and time:** values, then each line of the output file will contain values for **Julian day:** and **Modified julian day:**. You can read the output directly in KStars by pressing the **View output...** button.

TIP
Exercise:
What calendar date does MJD = 0.0 correspond to?

5.2.2 Sidereal Time module
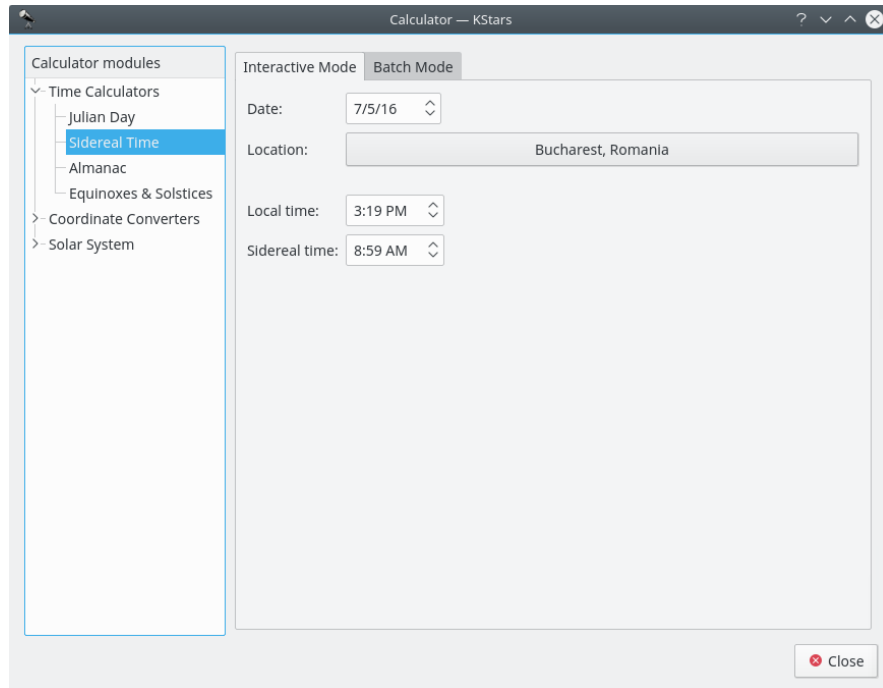
This module converts between Universal Time and Local Sidereal Time. First, select a geographic location and a date for the calculation. Then the corresponding value for the other Time will be displayed.

There is a batch mode for this module. To use it, simply generate an input file whose lines each contain values for the input parameter: **Compute sidereal time** or **Compute standard time** from to left dropdown box. You can choose to set the **Date:** and **Location:** in the current window, or you can tell KStars to read these values from the **Input file:**. Then specify the input and output filenames, and press the **Compute** button to generate the output file. The output file will contains values for the complementary parameter. For example, if your input file contains a set of 'standard time' values, then each line of the output file will contain values for 'sidereal time'. You can read the output directly in KStars by pressing the **View output...** button.

5.2.3 Day Duration module
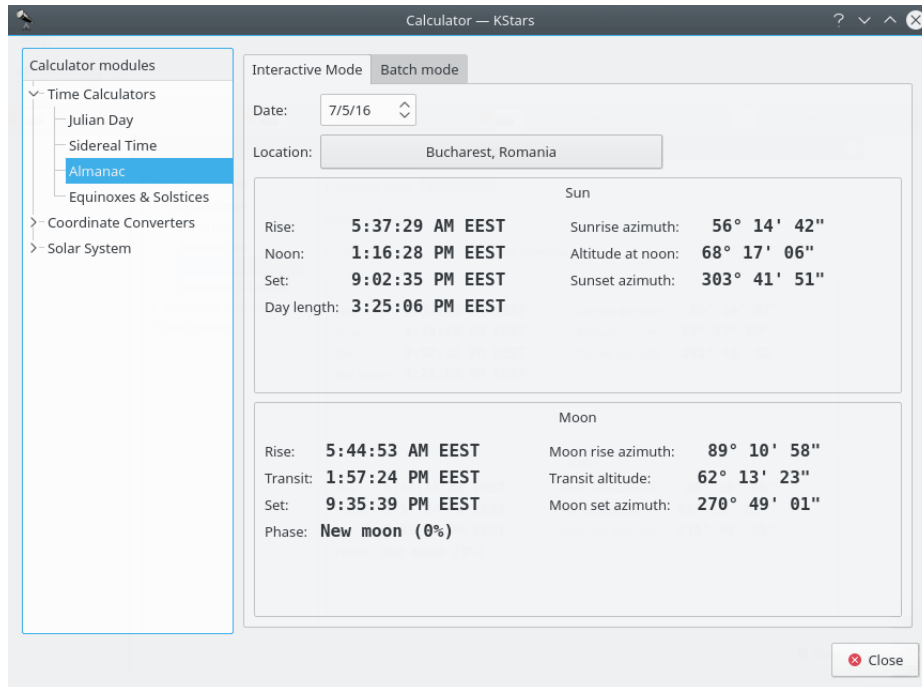
This module computes the length of day as well as sunrise, sun-transit (noon), and sunset times for any calendar date, for any location on Earth. First select the desired geographic coordinates and date, then the data is computed and displayed.

5.2.4 Equinoxes and Solstices module
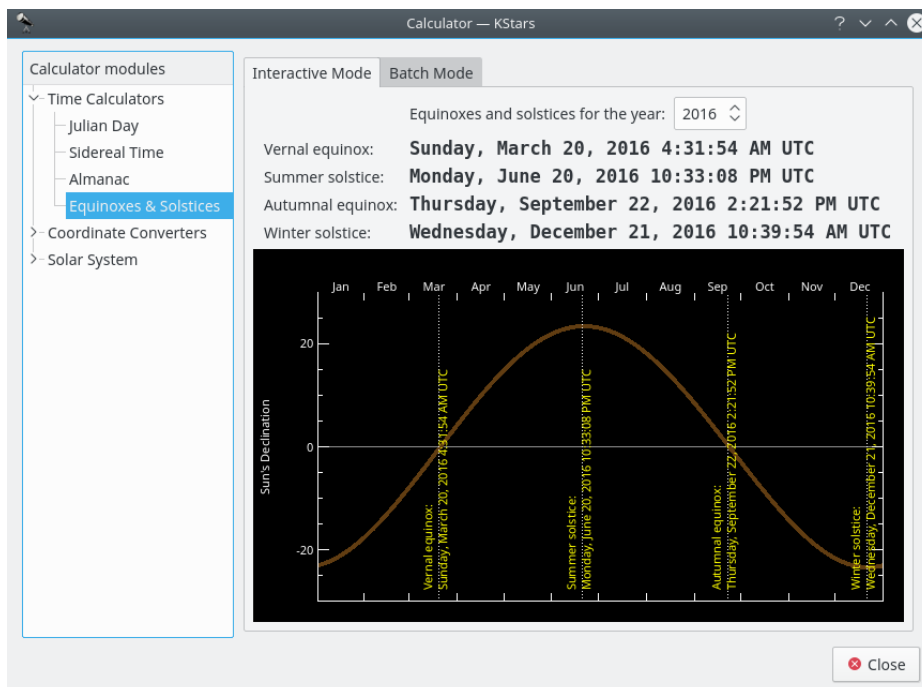
The Equinoxes and Solstices module calculates the date and time of an equinox or solstice for a

given year. You specify the year and the date and time of the events (Vernal Equinox, Summer Solstice, Autumnal Equinox, or Winter Solstice) are displayed.

There is a batch mode for this module. To use it, simply generate an input file whose lines each contain a year for which the Equinox and Solstice data will be computed. Then specify the input and output filenames, and press the **Compute** button to generate the output file. Each line in the output file contains the input year and the date of each event. You can also read the output directly in KStars by pressing the **View output...** button.

5.2.5 Equatorial/Galactic Coordinates module
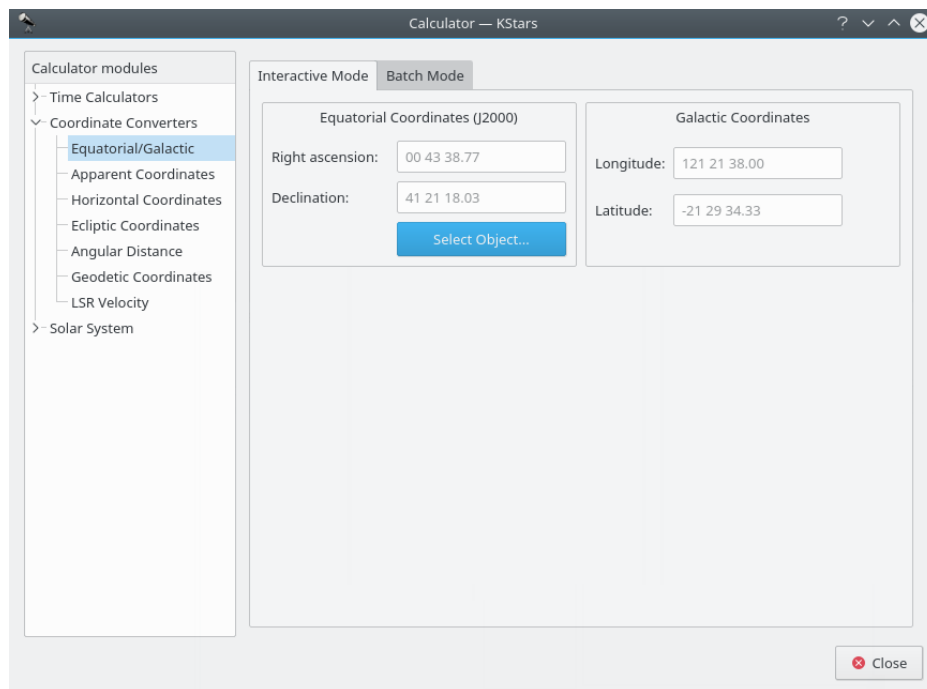
This module converts from Equatorial coordinates to Galactic coordinates, and vice versa. Fill in the coordinate values in either the **Galactic coordinates** or **Equatorial coordinates (J2000)** section. Alternatively set the equatorial coordinates by selecting an object using the **Find Object** dialog. Then the complementary coordinates will be filled in.

The module contains a batch mode for converting several coordinate pairs at once. You must construct an input file in which each line contains two values: the input coordinate pairs (either Equatorial or Galactic). Then specify which coordinates you are using as input, and identify the input and output filenames. Finally, press the **Run** button to generate the output file, which will contain the converted coordinates (Equatorial or Galactic; the complement of what you chose as the input values).

5.2.6 Apparent Coordinates module
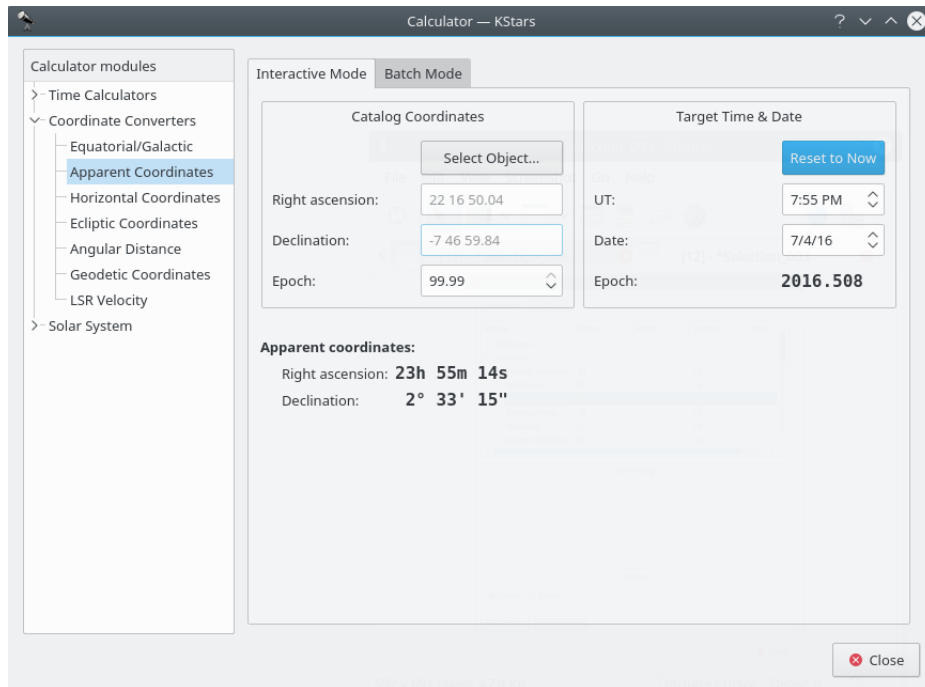
The Apparent Coordinates module converts the *catalog coordinates* of a point in the sky to its *apparent coordinates* for any date. The coordinates of objects in the sky are not fixed, because of precession, nutation and aberration. This module takes these effects into account.

To use the module, first enter the desired target date and time in the **Target Time & Date** section. Then, enter the catalog coordinates in the **Catalog Coordinates** section. Alternatively you can set the catalog coordinates by selecting an object using the **Find Object** dialog. You can also specify the catalog's epoch here (usually 2000.0 for modern object catalogs). Then the object's coordinates for the target date will be displayed in the **Apparent coordinates:** section.

5.2.7 Horizontal Coordinates module
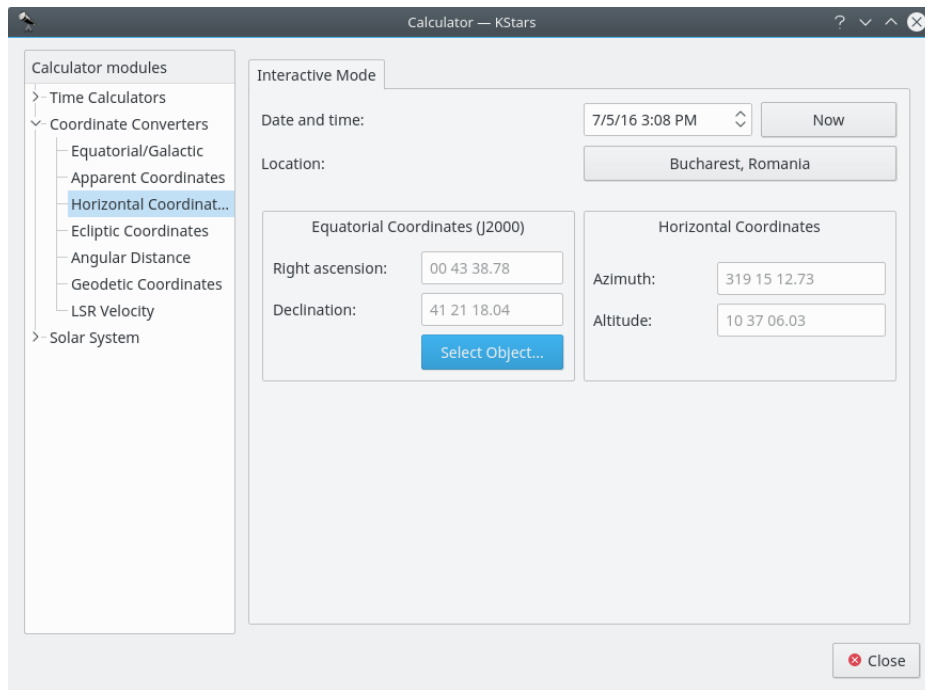
This module converts from Equatorial coordinates to Horizontal coordinates. First, select the date, time, and geographic coordinates for the calculation. Then, fill in the equatorial coordinates to be converted or use the **Find Object** dialog in the **Equatorial Coordinates (J2000)** section. The corresponding Horizontal coordinates will be presented in the **Horizontal Coordinates** section.

5.2.8 Ecliptic Coordinates module
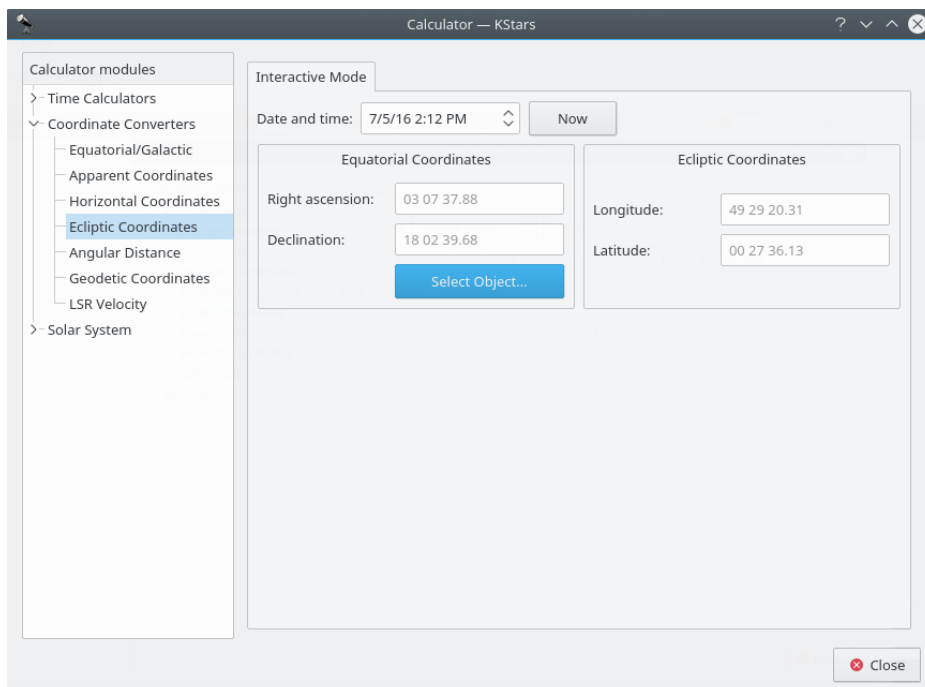
This module converts between Equatorial coordinates and Ecliptic coordinates. First, select **Date and time:**. Then, fill in the coordinate values in either the **Ecliptic Coordinates** or **Equatorial Coordinates** section. Alternatively set the equatorial coordinates by selecting an object using the **Find Object** dialog. Then the complementary coordinates will be filled in.

5.2.9 Angular Distance module
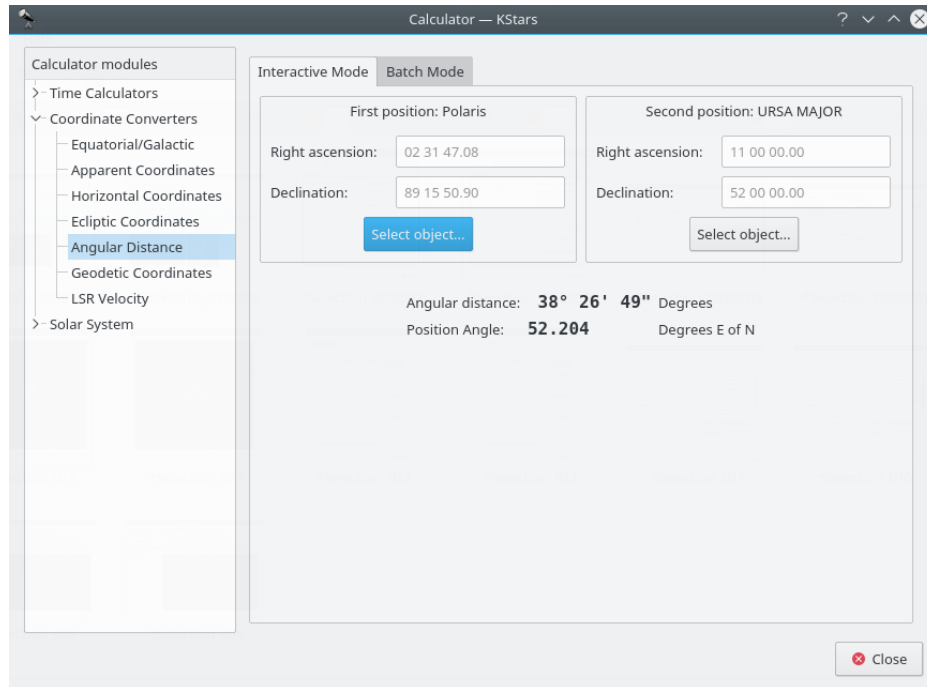
The Angular Distance tool is used to measure the angle between any two points on the sky. You simply specify the Equatorial coordinates of the desired pair of points, and then obtain the angle between the two points.

There is also a Batch mode for this module. In batch mode, you specify an input filename which contains a number of parameters (up to four) on each line: the initial right ascension (RA), initial declination (Dec), final right ascension and final declination. By default, each line should contain four numbers signifying the RA and Dec values for pairs of points. Alternatively, you can specify a single value for any of these four coordinates in the calculator panel (the corresponding values in the input file should be skipped if they are specified in the calculator).

Once you have specified the input filename and an output filename, simply press the **Run** button to generate the output file.

5.2.10 Geodetic Coordinates module
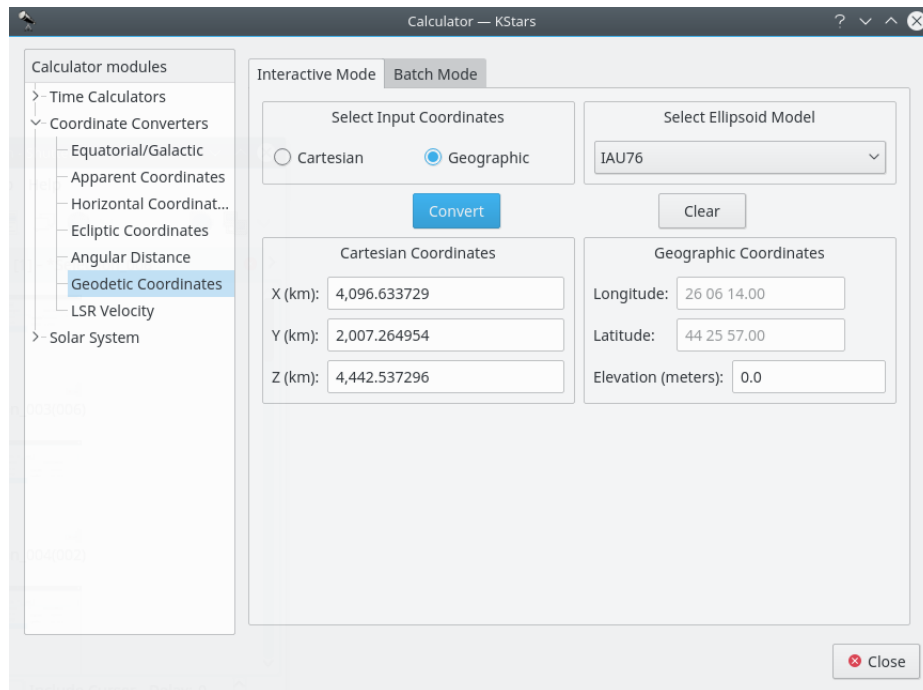
The normal geographic coordinate system assumes that the Earth is a perfect sphere. This is nearly true, so for most purposes geographic coordinates are fine. If very high precision is required, then we must take the true shape of the Earth into account. The Earth is an ellipsoid; the distance around the equator is about 0.3% longer than a Great Circle that passes through the poles. The *Geodetic Coordinate system* takes this ellipsoidal shape into account, and expresses the position on the Earth's surface in Cartesian coordinates (X, Y and Z) or in Geographic coordinates (Longitude, Latitude and Elevation).

To use the module, first select which coordinates you will use as input in the **Select Input Coordinates** section: **Cartesian** or **Geographic** radio buttons. Then select an ellipsoid model and fill in the input coordinates in either the **Cartesian Coordinates** section or the **Geographic Coordinates** section. When you press the **Convert** button, the corresponding coordinates will be filled in.

The module contains a batch mode for converting several coordinate values at once. You must construct an input file in which each line contains up to three numbers: the input coordinate values (either Cartesian or Geographic). Then specify which coordinates you are using as input, and identify the input and output filenames. Finally, press the **Run** button to generate the output file, which will contain the converted coordinates (Cartesian or Geographic; the complement of what you chose as the input values).

5.2.11 Planet Coordinates module
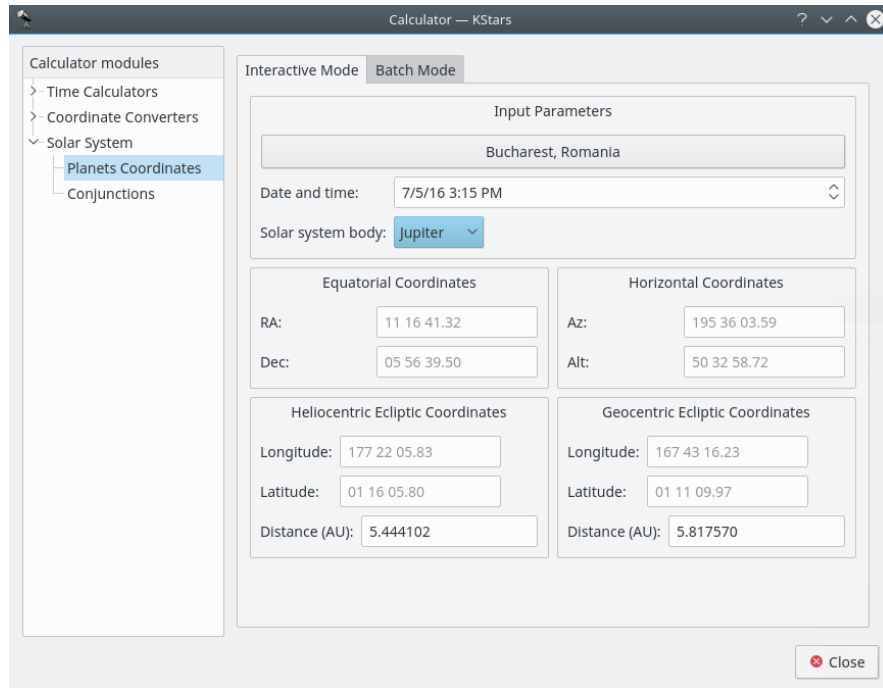
The Planet Coordinates module computes positional data for any major solar system body, for any time and date and any geographic location. Simply select from the **Solar system body:** dropdown list, and specify the desired date, time, and geographic coordinates (these values are preset to the current KStars settings). Then the Equatorial, Horizontal, and Ecliptic coordinates of the body are computed and displayed.

There is a batch mode for this module. You must construct an input file in which each line specifies values for the input parameters (solar system body, date, time, longitude, and latitude). You may choose to specify a constant value for some of the parameters in the calculator window (these parameters should be skipped in the input file). You may also specify which of the output parameters (Equatorial, Horizontal, Heliocentric ecliptic and Geocentric ecliptic coordinates) should be calculated. Finally, specify the input and output filenames, and press the **Run** button to generate the output file with the computed values.

5.3 Altitude vs. Time Tool
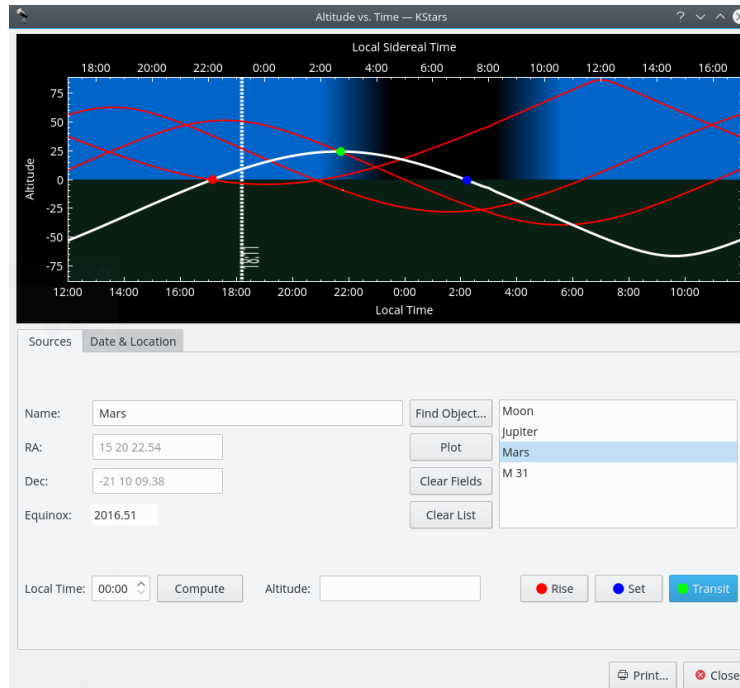
This tool plots the altitude of any objects as a function of time, for any date and location on Earth. The top section is a graphical plot of altitude angle on the vertical axis, and time on the horizontal axis. The time is shown both as standard local time along the bottom, and sidereal time along the top. The bottom half of the graph is shaded green to indicate that points in this region are below the horizon.

There are a few ways to add curves to the plot. The simplest way to add the curve of an existing object is to simply type its name in the **Name:** input field, and press Enter, or the **Plot** button. If the text you enter is found in the object database, the object's curve is added to the graph. You can also press the **Find Object...** button to open the Find Object Window to select an object from the list of known objects. If you want to add a point that does not exist in the object database, simply enter a name for the point, and then fill in the coordinates in the **RA:** and **Dec:** input fields. Then press the **Plot** button to add the curve for your custom object to the plot (note that you have to pick a name that does not already exist in the object database for this to work).

When you add an object to the plot, its altitude vs. time curve is plotted with a thick white line, and its name is added to the listbox at the lower right. Any objects that were already present are plotted with a thinner red curve. You can choose which object is plotted with the thick white curve by highlighting its name in the listbox.

These curves show the objects' Altitude (angle above the horizon) as a function of time. When a curve passes from the lower half to the upper half, the object has risen; when it falls back to the lower half, it has set. For example, in the screenshot, the minor planet *Quaoar* is setting at around 15:00 local time, and is rising at about 04:00 local time.

The plot can be easily zoomed and panned using the mouse. The zooming level can be adjusted using the mouse scroll wheel. When the plot is zoomed out, the zooming level will be automatically limited to a default minimum value, such as the axes' ranges are able to cover the entire plot (i.e. on vertical axis, the maximum altitude value should touch the top edge of the plot frame). The same principle is applied when the plot is panned using the mouse movement. For panning the plot, all you need to do is to click on the point of the plot you want to pan and then drag the mouse on your desired direction: left, right, up or down.

Another useful feature that Altvstime tool provides is its ability to compute and mark the Rise/Set/Transit times. This can be accomplished by a simple press of one of the **Rise**, **Set** or

Transit buttons. When one of these buttons is pressed, a filled colored circle will be marked on the curve. The color used for Rise, Set and Transit dots are: red for Rise, blue for Set and green for Transit time. For a more intuitive way of using these buttons, they are marked with the color of their specific dots. This way, the user can easily understand the plot and make the association between a certain color and its significance.

Altvstime tool provides an easy way to find out the altitude of a sky-object at a certain moment of time using the **Compute** button. After you select the object from the Objects list and set the moment of time, the altitude can be computed by pressing the **Compute** button. But this is not the only way you can find out the altitude. Another method is to hover with mouse above one curve and thus, a tooltip containing the Local Time, Local Sidereal Time and Altitude will come up. This way, you can read the information in real time.

The Altitude of an object depends on both where you are on Earth, and on the Date. By default, the Tool adopts the Location and Date from the current KStars settings. You can change these parameters in the **Date & Location** Tab. To change the Location, you can press the **Choose City...** button to open the Set Geographic Location Window, or enter Longitude and Latitude values manually in the input fields, and press the **Update** button. To change the Date, use the spin and combo boxes, then press **Update**. Note that any curves you had already plotted will be automatically updated when you change the Date and/or Location.

TIP
Exercise:
Plot the Sun's Altitude curve. Make sure the geographic location is not near the equator. Change the Date to some time in June, and then again to sometime in January. You can see easily why we have seasons; in the winter, the Sun is above the horizon for less time (the days are shorter), and its altitude is never very high.

5.4 Simulate Eyepiece View

On the left hand side is the sky map shot from KStars. On the right hand side is the POSS (DSS) image of the same region. The orientation in the above example has been adjusted to match the view through a Dobsonian telescope at the location and time of the simulation in KStars.

This tool simulates how an object looks through your eyepiece. In addition to rendering the eyepiece field, KStars can also fetch and overlay the DSS imagery. Additionally, if you are using a Dobsonian telescope, you can rotate the field of view to match the eyepiece view.

To use this feature, first define your eyepieces' fields of view using the FOV Symbol editor.

Then there are two ways to invoke the feature:

- In Sky Map, right click on the desired object and click **Simulate eyepiece view** in the popup menu.

- In observation planner, right click an object and click **Simulate eyepiece view** in the popup menu.

When the tool is first invoked, it will prompt a dialog to select the desired FOV to render the view. To compare the rendered view against a real sky image, click the **Fetch DSS image** button to download a DSS image. You can manually adjust the view to match your eyepiece using the rotation slider, the **Invert view** and **Flip view** check boxes. Alternatively, you can use a pre-calculated amount of rotation by using one item of the **Preset:** dropdown box that is tailored for different optical systems.
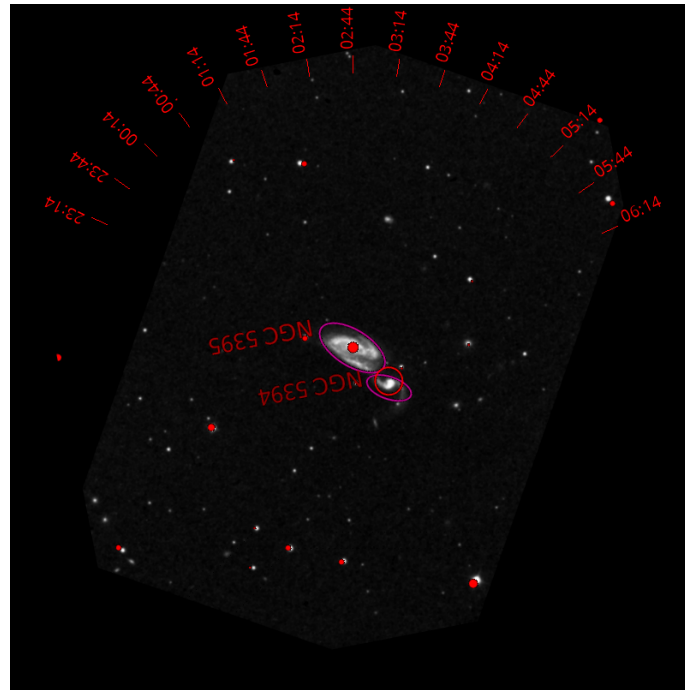
Arp84 eyepiece view with ticks enabled indicating how the chart must be oriented to match the eyepiece view through a Dobsonian at a given time (the generated data is for location McDonald Observatory Texas, and the date is 14th Dec 2016).

To export the view to a file, click **Export** button. Export enables adding ticks for printed charts as shown above and save the image.

5.5   What's up Tonight? Tool

The 'What's up Tonight?' (WUT) tool displays a list of objects that will be visible at night from any location, on any date. By default, the Date and Location are taken from the current settings in the main window, but you can change either value using the **Change Date...** and **Change Location...** buttons at the top of the WUT window.

The WUT tool also displays a short almanac of data for the selected date: the rise and set times for the Sun and moon, the duration of the night, and the Moon's illumination fraction.

Below the almanac is where the object information is displayed. 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 on the selected night are displayed (Mars, Jupiter and Saturn). When an object in the list is selected, its rise, set and transit times are displayed in the lower-right panel (i.e. Mars rises at 17:13, transits at 21:46 and sets at 02:16). In addition, you can press the **Object Details...** button to open the Object Details window for that object.

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'), or 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 magnitude by setting a minimum magnitude using the **Show objects brighter than magnitude:** spinbox. You may center the selected object in the Sky Map or add it to Wish List by pressing the **Center Object** or **Add to List** button.

5.6 The Script Builder Tool

KDE applications can be controlled externally from another program, from a console prompt, or from a shell script using the Inter-process communication protocol (D-Bus). KStars takes advantage of this feature to allow rather complex behaviors to be scripted and played back at any time. This can be used, for example, to create a classroom demo to illustrate an astronomical concept.

The problem with D-Bus scripts is, writing them is a bit like programming, and can seem a daunting task to those who do not have programming experience. The Script Builder Tool provides a GUI point-and-click interface for constructing KStars D-Bus scripts, making it very easy to create complex scripts.

5.6.1 Introduction to the Script Builder

Before explaining how to use the Script Builder, I provide a very brief introduction to all of the GUI components; for more infomation, use the ″What's This?″ function.
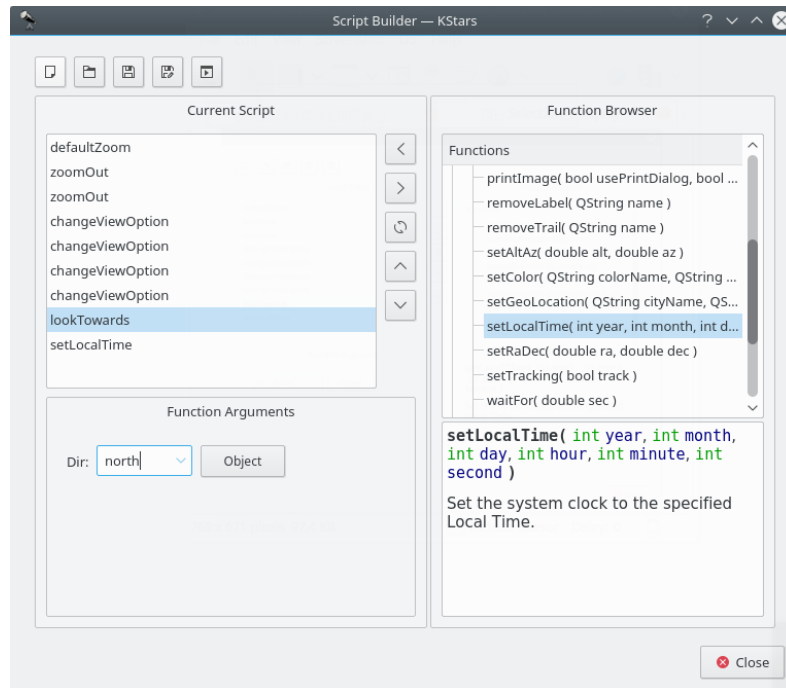
The Script Builder is shown in the above screenshot. The box on the left is the *Current Script box*; it shows the list of commands that comprise the current working script. The box on the right is the *Function Browser*; it displays the list of all available script functions. Below the Function Browser, there is a small panel which will display short documentation about the script function highlighted in the Function Browser. The panel below the Current Script box is the *Function Arguments panel*; when a function is highlighted in the Current Script box, this panel will contain items for specifying values for any arguments that the highlighted function requires.

Along the top of the window, there is a row of buttons which operate on the script as a whole. From left to right, they are: **New Script**, **Open Script...**, **Save Script**, **Save Script As...**, and **Test Script**. The function of these buttons should be obvious, except perhaps the last button. Pressing **Test Script** will attempt to run the current script in the main KStars window. You should move the Script Builder window out of the way before pressing this, so you can see the results.

In the center of the window, there is a column of buttons which operate on individual script functions. From top to bottom, they are: **Add Function**, **Remove Function**, **Copy Function**, **Move Up**, and **Move Down**. **Add Function** adds the currently-highlighted function in the Function Browser to the Current Script box (you can also add a function by double-clicking on it). The rest of the buttons operate on the function highlighted in the Current Script box, either removing it, duplicating it, or changing its position in the current script.

5.6.2 Using the Script Builder

In order to illustrate using the Script Builder, we present a small tutorial example where we make a script that tracks the Moon while the clock runs at an accelerated rate.

If we are going to track the Moon, we will need to point the display at it first. The *lookToward* function is used to do this. Highlight this function in the Function Browser, and note the documentation displayed in the panel below the Browser. Press the **Add Function** button to add this function to the Current Script box. The Function Arguments panel will now contain a combobox labeled 'Dir', short for direction. This is the direction in which the display should be pointed. The combobox contains only the cardinal compass points, not the Moon or any other objects. You can either enter 'Moon' in the box manually, or press the **Object...** button to use the **Find Object...** window to select the Moon from the list of named objects. Note that, as usual, centering on

an object automatically engages object-tracking mode, so there is no need to add the *setTracking* function after lookToward.

Now that we have taken care of pointing at the Moon, we next want to make time pass at an accelerated rate. Use the *setClockScale* function for this. Add it to the script by double-clicking on it in the Function Browser. The Function Arguments panel contains a timestep spinbox for setting the desired time step for the simulation clock. Change the timestep to 3 hours.

OK, we have pointed at the Moon and accelerated the clock. Now we just want the script to wait for several seconds while the display tracks on the Moon. Add the *waitFor* function to the script, and use the Function Arguments panel to specify that it should wait for 20 seconds before continuing.

To finish up, let us reset the clock's timestep to the normal value of 1 second. Add another instance of setClockScale, and set its value to 1 sec.

Actually, we are not quite done yet. We should probably make sure that the display is using Equatorial coordinates before the script tracks the Moon with an accelerated time step. Otherwise, if the display is using Horizontal coordinates, it will rotate very quickly through large angles as the Moon rises and sets. This can be very confusing, and is avoided by setting the View Option *UseAltAz* to 'false'. To change any View Option, use the *changeViewOption* function. Add this function to the script, and examine the Function Arguments panel. There is a combobox which contains the list of all options which can be adjusted by changeViewOption. Since we know we want the UseAltAz option, we could simply select it from the combobox. However, the list is quite long, and there is no explanation of what each item is for. It therefore may be easier to press the **Browse Tree...** button, which will open a window containing a tree view of the available options, organized by topic. In addition, each item has a short explanation of what the option does, and the data type of the option's value. We find UseAltAz under the **Skymap Options** category. Just highlight this item and press **OK**, and it will be selected in the combobox of the Function Arguments panel. Finally, make its value 'false' or '0'.

One more step: changing UseAltAz at the end of the script does us no good; we need this to be changed before anything else happens. So, make sure this function is highlighted in the Current Script box, and press the **Move Up** button until it is the first function.

Now that we have finished the script, we should save it to disk. Press the **Save Script** button. This will first open a window in which you can provide a name for the script, and fill in your name as the author. Enter 'Tracking the Moon' for a name, and your name as the author, and press **OK**. Next, you will see the standard KDE Save File dialog. Specify a filename for the script and press **OK** to save the script. Note that if your filename does not end with '.kstars', this suffix will be automatically attached. If you are curious, you can examine the script file with any text editor.

Now that we have a completed script, we can run it in a couple of ways. From a console prompt, you can simply execute the script as long as an instance of KStars is currently running. Alternatively, you can execute the script from within KStars using the **File → Run Script...** menu item.

5.7 Solar System Viewer
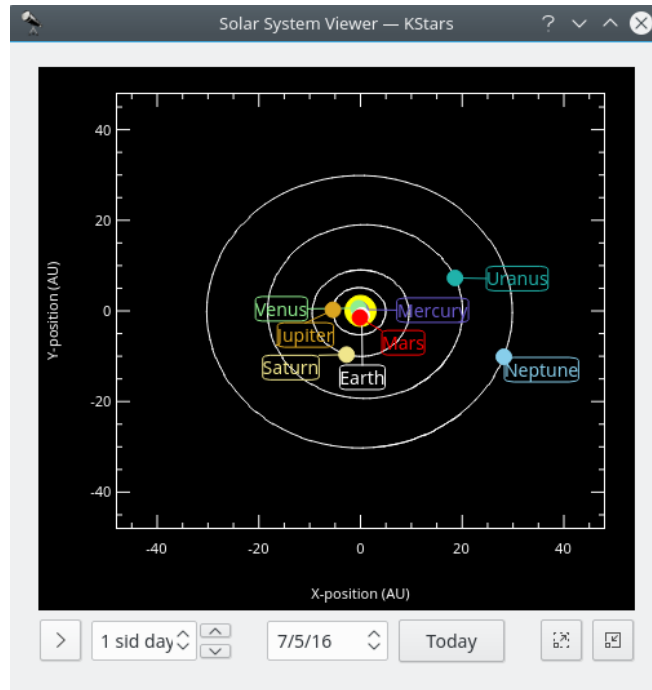
This tool displays a model of our solar system as seen from above. The Sun is drawn as a yellow dot in the center of the plot, and the orbits of the planets are drawn as ellipses with the correct shapes and orientations. The current position of each planet along its orbit is drawn as a colored dot, along with a name label. The display can be zoomed in and out with the **+** and **-** keys, and the display can be recentered with the arrow keys, or by double-clicking anywhere in the window with the mouse. You can also center on a planet with the **0–9** keys (**0** is the Sun; **9** is Pluto). If you center on a planet, it will be tracked as time passes in the tool.

The Solar System Viewer has its own clock, independent of the clock in the main KStars window. There is a timestep control widget here, similar to the one in the main window's toolbar. However, this control defaults to a timestep of 1 day (so that the motions of the planets can be seen), and it starts out with the clock paused when the tool is opened. You may set the date to now by pressing the **Today** button.

> NOTE
> The current model used for Pluto's orbit is only good for dates within about 100 years of the present date. If you let the Solar System clock advance beyond this range, you will see Pluto behave very strangely! We are aware of this issue, and will try to improve Pluto's orbit model soon.

5.8 Ekos

Ekos is an advanced cross-platform (Windows®, Mac® OS, Linux®) observatory control and automation tool with a particular focus on Astrophotography. It is based on a modular extensible framework to perform common astrophotography tasks. This includes highly accurate GOTOs using astrometry solver, ability to measure *and* correct polar alignment errors, auto-focus & auto-guide capabilities, and capture of single or stack of images with filter wheel support. Ekos is shipped with KStars.

https://www.youtube.com/embed/un2KVJY3Yis

Ekos introductory video

Features:

- Control your telescope, Camera (& DSLRs), filter wheel, focuser, guider, adaptive optics unit, and any INDI-compatible auxiliary device from Ekos.

- *Built-in* native autoguiding with support for automatic dithering between exposures and support for Adaptive Optics devices in addition to traditional guiders.

- Extremely accurate GOTOs using astrometry.net solver (both Online and Offline solvers supported).

- Load & Slew: Load a FITS image, slew to solved coordinates, and center the mount on the exact image coordinates in order to get the same desired frame.

- Measure & Correct Polar Alignment errors using astromety.net solver.

- Easy to use Polar Alignment Assistant tool. A very quick and reliable tool to polar align your German Equatorial Mount!

- Capture and record video streams in SER format.

- Completely automated scheduler to control all your observatory equipment, select the best targets for imaging given current conditions and constraints, monitor weather conditions, and capture your data while you are away!

- *Smart* Dark Library: All your dark frames with different binning/temperature/frame settings are saved for future use. Ekos re-uses dark frames intelligently without taking unnecessary captures. You can configure how long you want to reuse all the dark frames.

- Define multiple driver profiles for local and remote setups. Switch among them easily.

- Auto and manual focus modes using Half-Flux-Radius (HFR) method.

- Automated unattended meridian flip. Ekos performs post meridian flip alignment, calibration, focusing, and guiding to resume the capture session.

- Automatic focus between exposures when a user-configurable HFR limit is exceeded.

- Powerful sequence queue for batch capture of images with optional prefixes, timestamps, filter wheel selection, and much more!

- Export and import sequence queue sets as Ekos Sequence Queue (`.esq`) files.

- Center the telescope anywhere in a captured FITS image or any FITS with World Coordinate System (WCS) header.

- Automatic flat field capture, just set the desired ADU and let Ekos does the rest!

- Automatic abort and resumption of exposure tasks if guiding errors exceed a user-configurable value.

- Support for dome slaving.

- Complete integration with KStars Observation Planner and SkyMap.

- Fully scriptable via D-Bus.

- Integrate with all INDI native devices.

5.8.1 Ekos Setup
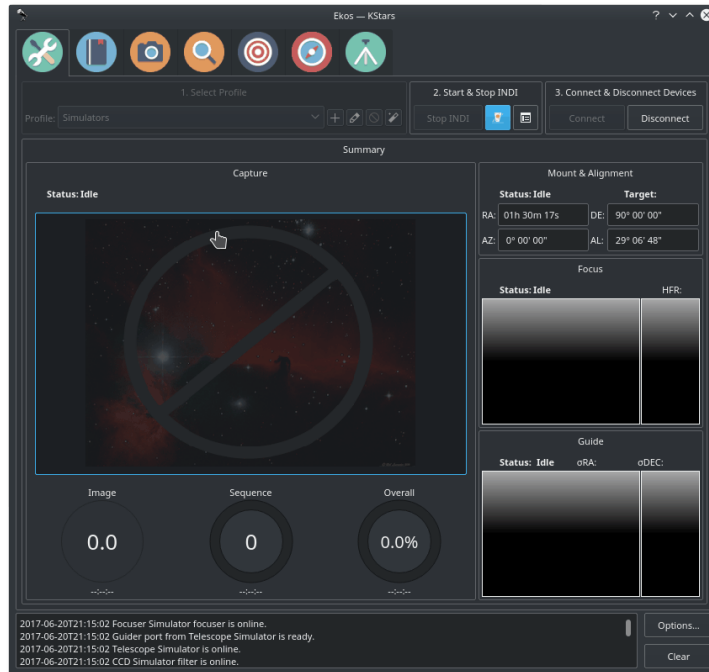
Ekos is a part of KStars. KStars/Ekos is already included with your StellarMate gadget. It is also available for Linux, Mac OS, and Windows if you want to install on your primary machine. After you run KStars on your PC or on StellarMate (Either directly via HDMI or via VNC), Ekos can be accessed from the **Tools** menu or via the **Ekos** on the main toolbar, or by a keyboard shortcut (**Ctrl-K**). In addition to the Ekos window, KStars provides a more detailed INDI Control Panel where you can directly set and control the device parameters.

When running Ekos, it is *not* necessary to start INDI Server via StellarMate Web Manager as Ekos manages that transparently.
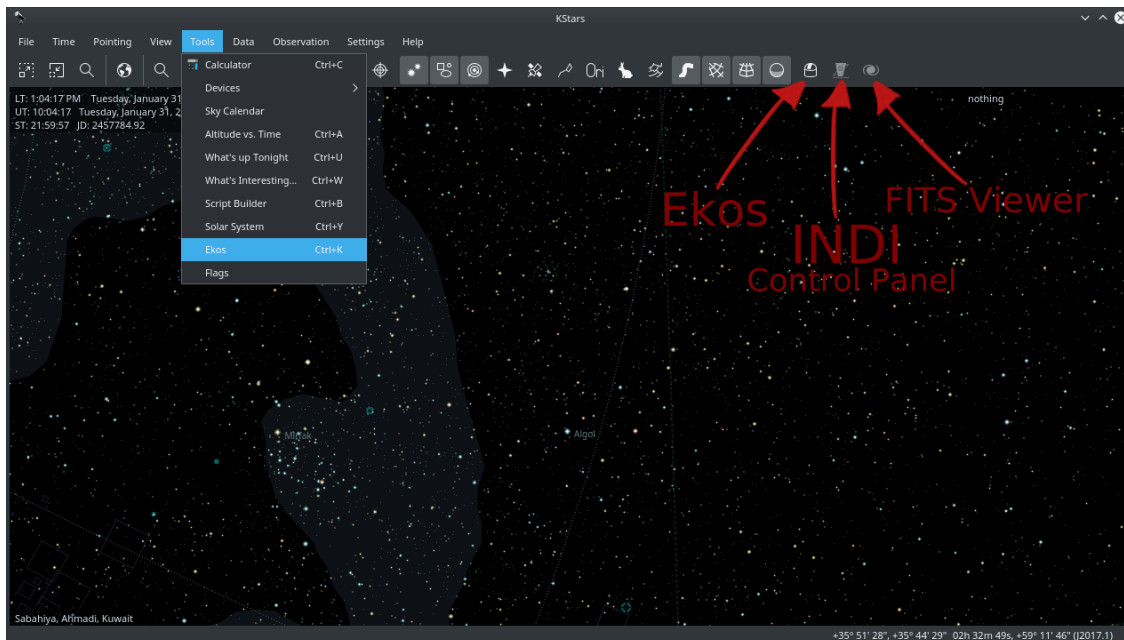
5.8.2 User Interface

Ekos Astrophotography Tool is organized into several *Modules*. A module is a set of functions and tasks for a particular step in astrophotography and/or data acquisition. Currently, the following modules are included with Ekos:

- Setup & Summary Module

- Scheduler Module

- Capture Module

- Focus Module

- Alignment Module

- Guide Module

- Mount Module

Each module has its own tab and icon in the graphical user interface as illustrated in the screenshot below:
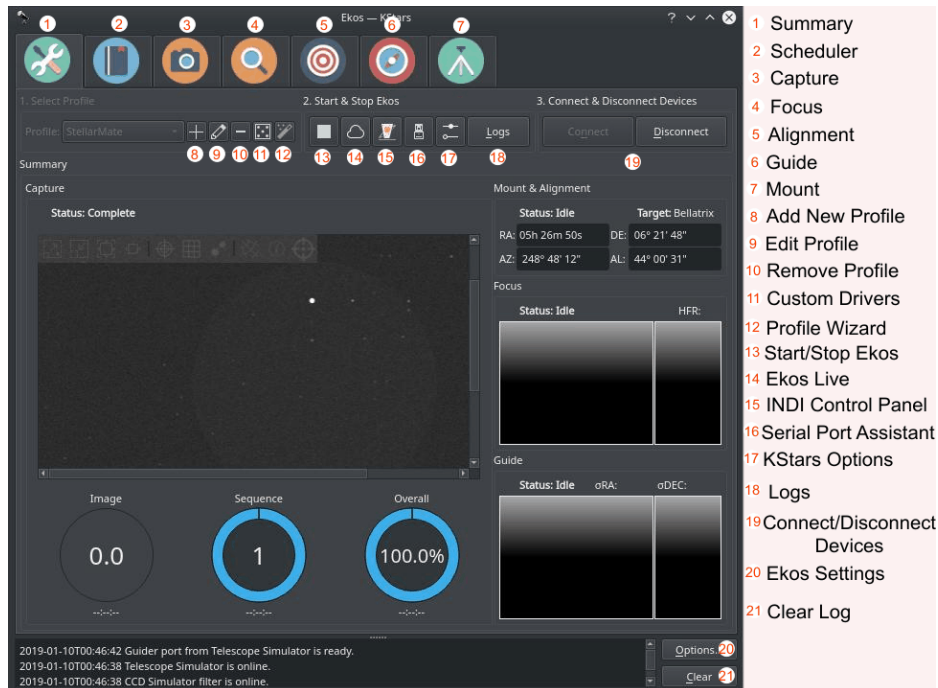
Summary & Setup Module

As its name suggests, this is where you will create and manage your equipment profile, and connect to your devices. It also provides a summary view where the capture progress along with the focus & guide operations is displayed in a compact format to convey the most important information relevant to the user.

Scheduler Module

After mastering Ekos, users are encouraged to learn how to use the Scheduler module since it facilitates the complete observation process greatly. It enables you to select multiple targets, specify which conditions and requirements to be met, and what frames are required for capture. Afterwards the scheduler intelligently calculates the best observation time for each object and then proceed to control the complete observatory from startup to shutdown.

Capture Module

This is the primary module for camera & filter wheel control. Create imaging sequences, capture previews, and watch video streams. It supports rotator control and can automatically capture flat frames in a number of scenarios.

Focus Module

Measure the sharpness of your images in the focus module by calculating Half-Flux-Radius. The lower the HFR, the sharper the image becomes. You can run the focus module with or without a focuser. With an electronic focuser, you can run an autofocus operation where Ekos iterates and calculates the optical focus position.

Guide Module

To achieve long exposure astrophotography, guiding is necessary to ensure the image is locked and stabilized for the complete duration of the exposure duration. Deviations from the frame with time can lead to blurry images and star trails. In the guide module, it can automatically select a suitable guide star and then lock the mount to always keep that star in its position. If the guide module detects any deviation from this locked position, it sends correction pulses to the mount to bring it back to the original position.

Mount Module

Mount control can be either done via the Sky Map interactively or via the Mount Control Panel in the mount module. Configure telescope properties (focal length & aperture) for both your primary imaging telescope and guide scope. However, it is recommended to select the telescopes in the equipment profile and not change the values directly in the mount module.

5.8.3 Profile Wizard

The Profile Wizard is a handy tool to setup your equipment for the first time. It should popup automatically the first time you run KStars. Follow the guided instructions to setup your first equipment profile.

Greeting Page
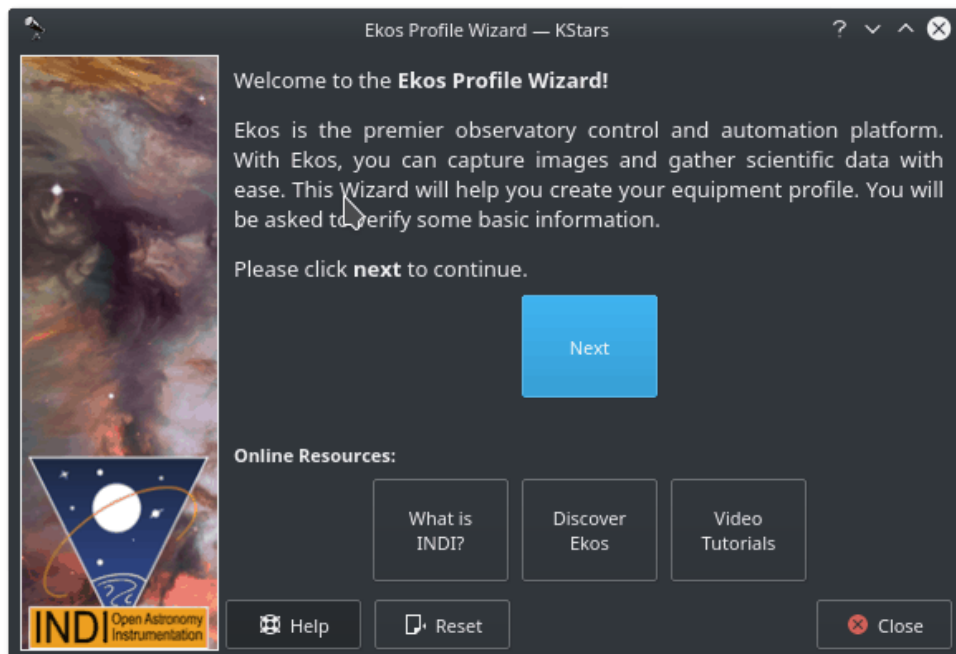
The first greeting screen contains some links to learn more about Ekos & INDI. Click **Next** to continue.

Equipment Location Page

Next, you will be presented with the equipment location page. Your selection depends on where your equipment is connected to:

- **Equipment is attached to this device**: Select this option if Ekos is running on your StellarMate (via HDMI or VNC), device (Windows®/Linux®) or Mac® OS.

- **Equipment is attached to a remote device**: Select this option if Ekos is running on your device (Windows®/Linux®) or Mac® OS, and your equipment is connected to a remote computer.

- **Equipment is attached to StellarMate**: Select this option if Ekos is running on your device (Windows®/Linux®) or Mac® OS, and your equipment is connected to StellarMate.
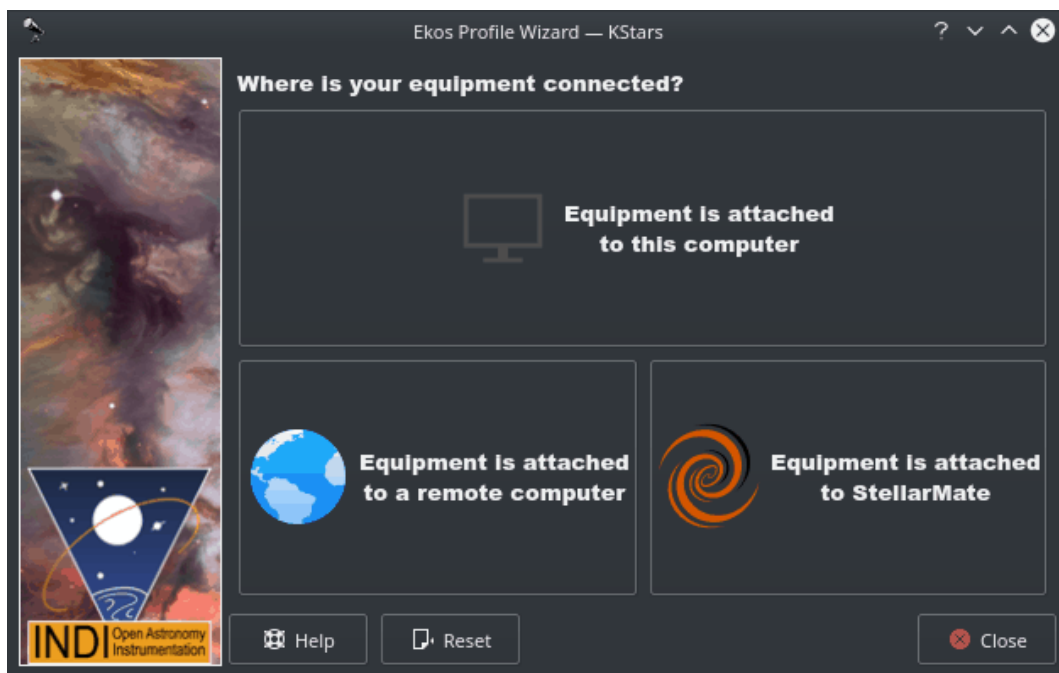
Click **Next** to continue.

Remote Connection Page

In case selected the 2nd option in the last step, you shall be presented with the Remote Connect Page, here you will enter the hostname or IP address of the StellarMate unit. You can get the hostname from the StellarMate mobile App. Alternatively, you can construct the hostname from StellarMate HotSpot SSID. You should see the SSID when you search for WiFi networks nearby. For example, suppose the SSID is `stellarmate`. The hostname should be *stellarmate.local*. That is, if you remove the underscore, and append *.local*, then you will get the unit hostname. You can always use the StellarMate App to change the unit default hostname to the name of your choice.
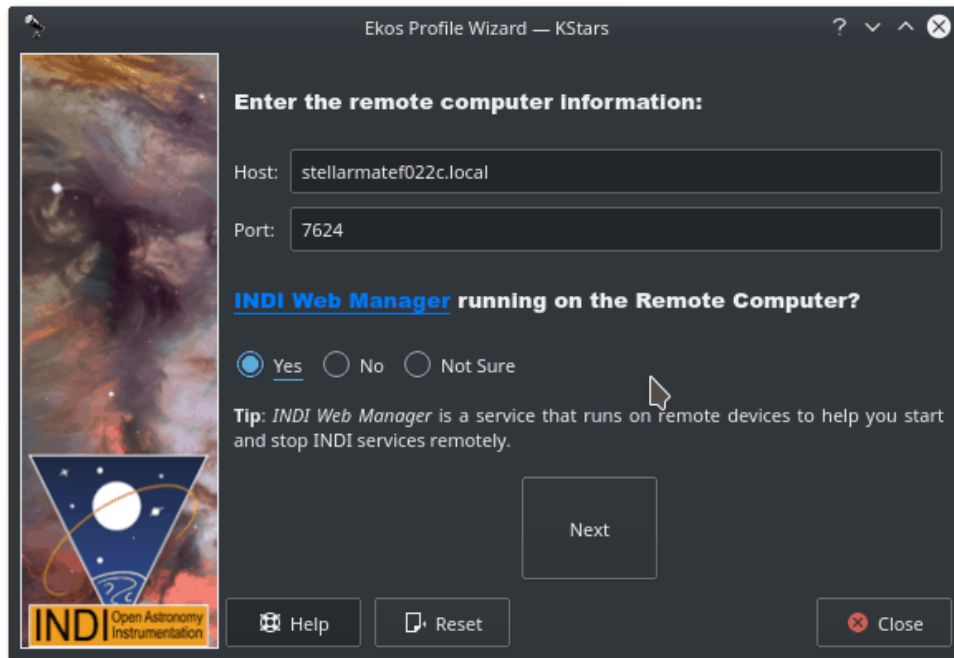
For the INDI Manager question, always select **Yes** since StellarMate Web Manager is running by default on the unit. Click **Next** to continue.

Profile Creation Page

Now you get to name your equipment profile. Afterwards select which guider application to use. The **Internal Guider** is the only officially supported selection in StellarMate. You may opt to select **PHD2/LinGuider** but the details are out of the scope of this documentation. If additional services are desired, check the ones you want to run.
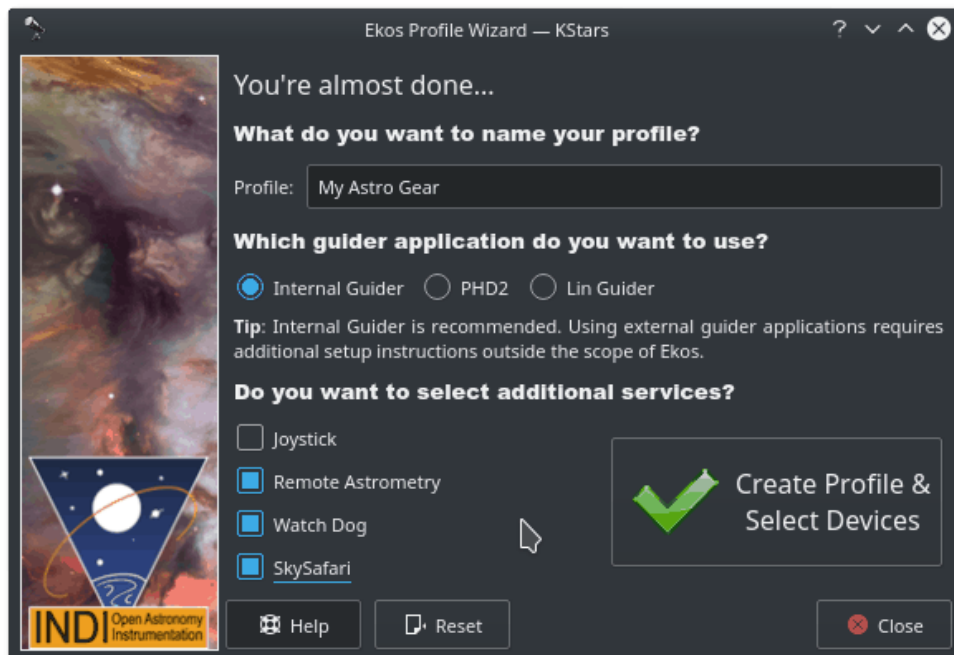
In the example above, we select Remote Astrometry, WatchDog, and SkySafari drivers. The detailed explanations for each is provided in the tooltip when you over them. Once done, click

Create Profile button. You should now be presented with the Profile Editor.

5.8.4 Profile Editor
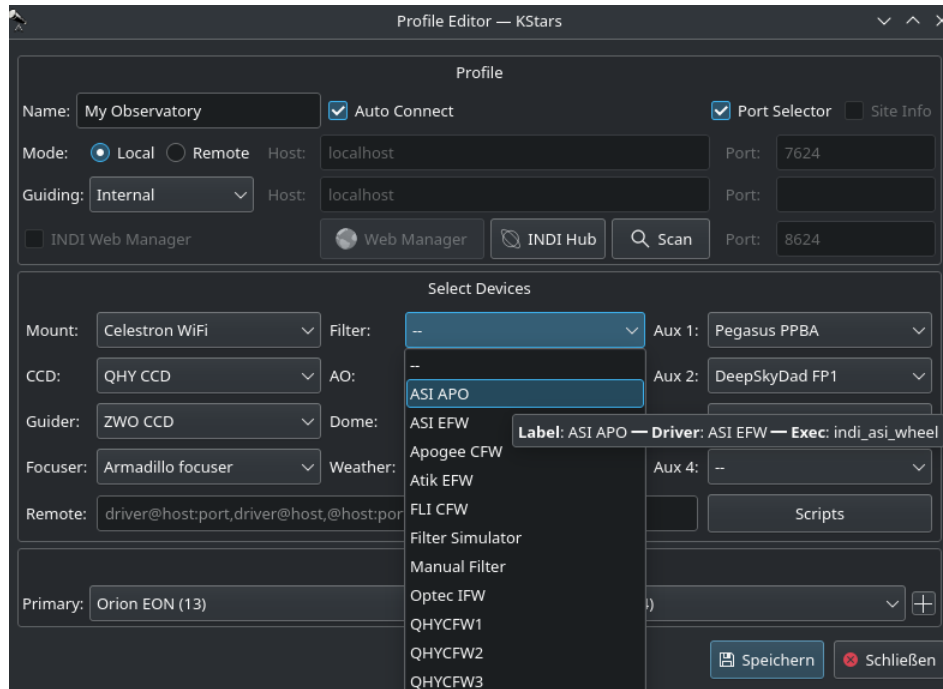
Profiles

You can define profiles for your equipment and their connection mode using the **Profile Editor**. Ekos comes pre-installed with the **Simulators** profile which can be used to start simulator devices for demonstration purposes:

- **Connection Mode**: Ekos can be started either locally or remotely. Local mode is when Ekos is running in the same machine as INDI server, i.e. all the devices are connected directly to the machine. If you run INDI server on a remote machine (for example, on a Raspberry PI), you need to set the INDI server host and port.

- **Auto Connect**: Check this option to enable automatic connection to all your devices after INDI server is started. If unchecked, INDI devices are created but not automatically connected. This is useful when you want to make changes to the driver (e.g. change baud rate or IP address or any other settings) *before* you connect to it.

- **Port Selector**: Check this option to enable Port Selector. When creating a new profile, it is checked by default. Port Selector is used to select initial serial and network communication parameters for the devices in the equipment profile. After connecting to equipment for the first time, the Port Selector popup is displayed where the communication parameters can be set before establishing connection. Once connected, the Port Selector option is turned off. It can be toggled to checked in the profile editor to enable it back.

- **Site Info**: Optionally, you can check the **Site Info** checkbox and Ekos will load the **current** city and timezone whenever is Ekos is started with this profile. This can be useful when connecting to the remote geographic site so that Ekos is in sync location and time wise.

- **Guiding**: Select which Guide application you want to use for guiding. By default, the Ekos internal Guide Module is utilized. External guiders include PHD2 and LinGuider.

- **INDI Web Manager**: StellarMate Web Manager is a web-based tool to start and stop INDI drivers. You should always check this option when connecting remotely to a StellarMate unit.
- **Device Selection**: Select your devices from each category. Please note that if you have a CCD with a guide head, you can leave the guider drop-down menu *blank* as Ekos will auto-detect the guide head from the CCD camera. Similarly, if your CCD includes embedded filter wheel support, then you do *not* need to specify the filter wheel device in the filter drop-down menu.
- **Scripts**: Adjust pre-driver and post-driver delays and scripts for each driver. A rule can be defined for each driver in case there is a need to introduce delays before and/or after starting a particular driver. The fields before the driver selection dropdown are to be executed *before* the driver is started, whereas the fields after the driver selection dropdown are to be executed *after* the driver started. The script field, if specified, should include the full path to an executable script with the appropriate permissions. All drivers configured in the scripts editor would be started first and in order before the rest of the equipment profile drivers.
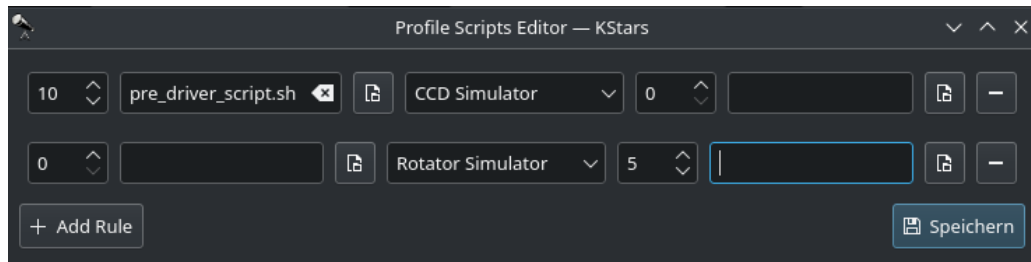
Start & Stop INDI

Start and Stop INDI services. Once INDI server is established, INDI Control Panel will be displayed. Here you can change some driver options such as which port the device is connected to etc.

Connect & Disconnect Devices

Connect to INDI server. Based on the devices connected, Ekos modules (CCD, Focus, Guide, etc.) will be established and available to use.

Once you are ready, click **Start INDI** to establish INDI server and connection to your equipment. Ekos shall create the various module icons (Mount, Capture, Focus, etc.) as the connection is established with the device.

5.8.5 Logs

Logging is a very important tool in order to diagnose any issues with either INDI drivers or Ekos. Before submitting any support request, the log must be attached in order to help diagnose the exact issue. Depending on the exact problem, you may need to enable logging for the feature or drivers that exhibit issues. Enabling logging for everything is not recommended as it will produce too much data that would be useful to diagnose the issue and could result in missing the root cause all other. So only enable the necessary logs.

The following short video explains how to use the Logging feature to submit logs.

https://www.stellarmate.com/images/videos/indi_logs_guide.mp4

Logging feature

5.8.6   Capture
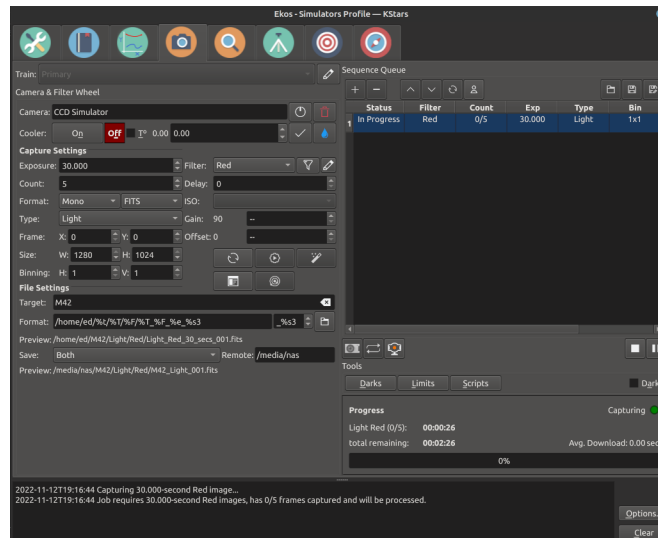
The Capture Module is your primary image and video acquisition module in Ekos. It enables you to capture single (Preview), multiple images (Sequence Queue), or record SER videos along with a selection of filter wheel and rotator, if available.

5.8.6.1   CCD & Filter Wheel Group

Select the desired CCD/DSLR and Filter Wheel (if available) for capture. Set CCD temperature and filter settings.

- **CCD**: Select the active CCD camera. If your camera has a guide head, you can select it from here as well.

- **FW**: Select the active Filter Wheel device. If your camera has a built-in filter wheel, the device would be the same as the camera.

- **Cooler**: Toggle Cooler On/Off. Set the desired temperature, if your camera is equipped with a cooler. Check the option to force temperature setting before any capture. Capture process is only started after the measured temperature is within requested temperature tolerance. The *default* tolerance is 0.1 degrees Celsius but can be adjusted in **Capture** options under Ekos configuration.

5.8.6.2 Capture Settings
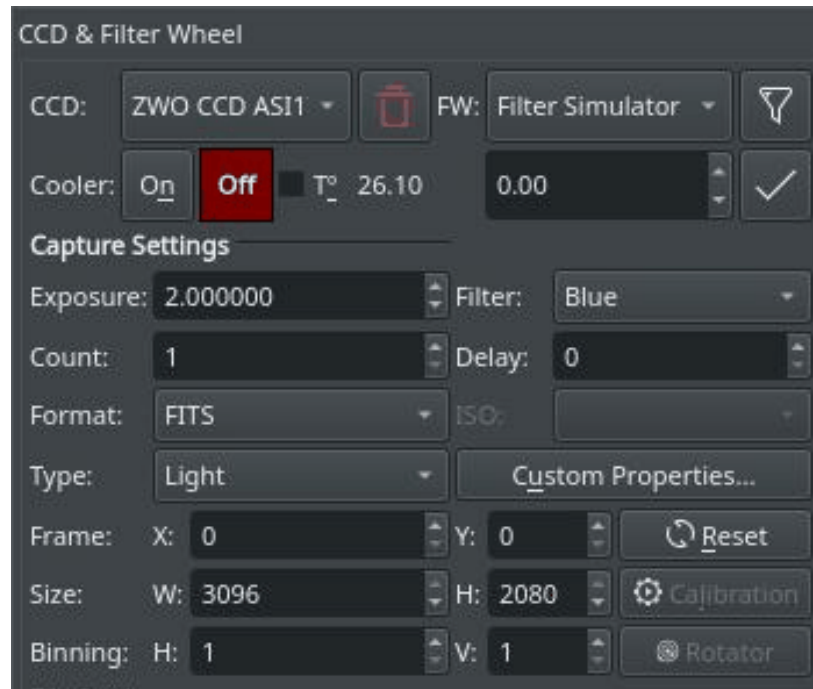
Set all capture parameters as detailed below. Once set, you can capture a preview by click on **Preview** or add a job to the sequence queue.

- **Exposure**: Specify exposure duration in seconds.

- **Filter**: Specify the desired filter.

- **Count**: Number of images to capture

- **Delay**: Delay in seconds between image captures.

- **Type**: Specify the type of desired CCD frame. Options are **Light**, **Dark**, **Bias**, and **Flat** frames.

- **ISO**: For DSLR cameras, specify the ISO value.

- **Format**: Specify capture save format. For all CCDs, only **FITS** option is available. For DSLR cameras, you can an additional option to save in **Native** format (e.g. RAW or JPEG).

- **Custom Properties**: Set extended properties available in the camera to the job settings.

- **Calibration**: For Dark &s; Flat frames, you can set additional options explained in the Calibration Frames section below.

- **Frame**: Specify the left (X), top (Y), width (W), and height (H) of the desired CCD frame. If you changed the frame dimensions, you can reset it to default values by clicking on the reset button.

- **Binning**: Specify horizontal (X) and vertical (Y) binning.

5.8.6.2.1 Custom Properties

Many cameras offer additional properties that cannot be directly set in the capture settings using the common control. The capture controls described above represent the most common settings shared among different cameras, but each camera is unique and may offer its own extended

properties. While you can use INDI Control Panel to set any property in the driver; it is important to be able to set such property for each job in the sequence. When you click **Custom Properties**, a dialog is shown divided into **Available Properties** and **Job Properties**. When you move an **Available Properties** to the **Job Property** list, its current value can be recorded once you click **Apply**. When you add a job to the **Sequence Queue**, the properties values selected in the **Job Properties** list shall be recorded and saved.

The following video explains this concept is more detail with a live example:

https://www.stellarmate.com/images/fss/videos/custom_properties.mp4

Custom Properties feature

5.8.6.3 File Settings
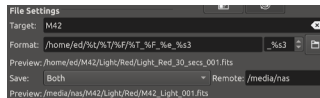
Settings for specifying where captured images are saved to, and how to generate unique file names in addition to upload mode settings.

- **Target**: The name of the celestial target to be captured e.g. M42. Can be preloaded by the Scheduler Module and by selection with KStars.

- **Format**: The Format string defines the path and filename of the captured images by the use of placeholder tags that are filled in with the selected item of data at save time.

  A tag is identified by the % character. All tags have a single letter short form, and a self descriptive long form.

  Arbitrary text may also be included within the Format string, **except the % and \ characters.** The / path character can be used to define arbitrary directories.

  Note: Tags are case sensitive in both their short and long forms.

  Available placeholder tags:

  – **%f** or **%filename**: The name of the sequence .esq file, without extension.
  – **%D** or **%Datetime**: The current time and date **when the file is saved. Only use this tag in the filename portion of the format, not in the path portion.**
  – **%T** or **%Type**: The frame type e.g. 'Light', 'Bias', 'Dark', 'Flat'...
  – **%e** or **%exposure**: The exposure duration in seconds.
  – **%F** or **%Filter**: The active filter name.
  – **%t** or **%target**: The Target name.
  – **%s*** or **%sequence***: The image sequence identifier where * is the number of digits used (1-9). **This tag is mandatory and must be the last element in the format.**

- **Directory Browse Button**: Opens a browse dialog to allow selection of the directory location used in the Format string. Use when first defining a Capture job.

- **Preview**: Shows a preview of the resulting filename according to the Format string and other job settings.

  Placeholder tags that are specified by the sequence .seq file can only be displayed once the sequence file has been saved.

  The Datetime tag is previewed with the current system time and will be replaced by the time at point of image save.

  The sequence tag is always previewed as image 1 in the sequence and will be automatically incremented when the job is in progress.

- **Upload**: Select how captured images are uploaded:

    1. **Client**: Captured images are only uploaded to Ekos and saved to the local directory specified above.
    2. **Local**: Captured images are only saved locally on the remote computer.
    3. **Both**: Captured images are saved on the remote device **and** uploaded to Ekos.

    When selecting **Local** or **Both**, you must specify the remote directory where the remote images are saved to. By default, all captured images are uploaded to Ekos.

- **Remote**: When selecting either **Local** or **Both** modes above, you must specify the remote directory where remote images are saved to.

- **Preview**: Shows a preview of the resulting filename according the provided path job settings. The file name format for saving remotely is pre-defined, placeholder tags may not be used. The file sequence number is always previewed as image 1 in the sequence and will be automatically incremented when the job is in progress.

5.8.6.4 Limit Settings
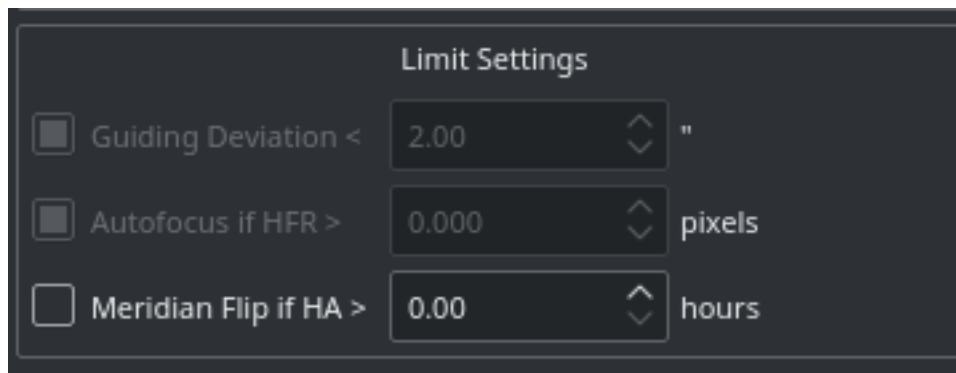
Limit settings are applicable to all the images in the sequence queue. When a limit is exceeded, Ekos shall command the appropriate action to remedy the situation as explained below.

- **Guiding Deviation**: If checked, it enforces a limit of maximum allowable guiding deviation for the exposure, if autoguiding is used. If the guiding deviation exceeds this limit in arcseconds, it aborts the exposure sequence. It will automatically resume the exposure sequence again once the guiding deviation goes below this limit.

- **Autofocus if HFR >**: If autofocus is enabled in the focus module and at least one autofocus operation was completed successfully, you can set the maximum acceptable HFR value. If this option is enabled then between consecutive exposures, the HFR value is recalculated, and if found to exceed the maximum acceptable HFR value, then an autofocus operation is automatically triggered. If the autofocus operation is completed successfully, the sequence queue resumes, otherwise, the job is aborted.

- **Meridian Flip**: If supported by the mount, set the hour angle limit (in hours) before a meridian flip is commanded. For example, if you set the meridian flip duration to 0.1 hours, Ekos shall wait until the mount passes the meridian by 0.1 hours (6 minutes), then it commands the mount to perform a meridian flip. After the meridian flip is complete, Ekos re-aligns using astrometry.net (if the alignment was used) and resumes guiding (if it was started before) and then resumes the capture process automatically.

5.8.6.5 Sequence Queue

Sequence Queue is the primary hub of the Ekos Capture Module. This is where you can plan and execute jobs using the sequence queue built-in powerful editor. To add a job, simply select all the parameters from the capture and file settings as indicated above. Once you selected your desired parameters, click on the add button ✛ in the sequence queue to add it to the queue.
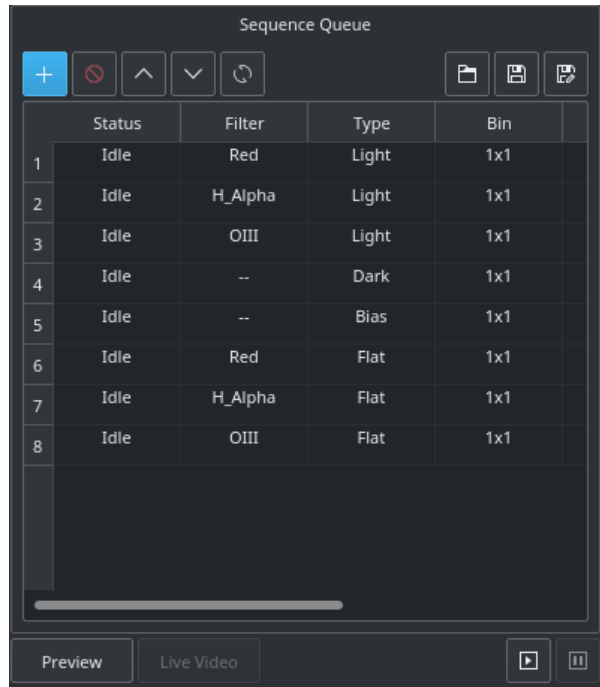
You can add as many jobs as desired. While it is not strictly necessary, it is preferable to add the dark and flat jobs after the light frames. Once you are done adding jobs, simply click **Start Sequence** ⊙ to begin executing the jobs. A job state changes from **Idle** to **In Progress** and finally to **Complete** once it is done. The Sequence Queue automatically starts the next job. If a job is aborted, it may be resumed again. To pause a sequence, click the pause button ⏸ and the sequence will be stopped after the current capture is complete. To reset the status of all the jobs, simply click the reset button ↻ . Please beware that all image progress counts are reset as well. To preview an image in KStars FITS Viewer, click the **Preview** button.

Sequence queues can be saved as an XML file with extension `.esq` (Ekos Sequence Queue). To load a sequence queue, click the open document button 🗀 . Please note that it will replace any current sequence queues in Ekos.

IMPORTANT

Job Progress: Ekos is designed to execute and resume the sequence over multiple nights if required. Therefore, if **Remember Job Progress** option is enabled in Ekos Options, Ekos shall scan the file system to count how many images are already completed and will resume the sequence from where it was left off. If this default behavior is not desired, simply turn off **Remember Job Progress** under options.

To edit a job, double click it. You will notice the add button ✛ now changed to check mark

button [✓] . Make your changes on the left-hand side of the CCD module and once done, click on the check mark button. To cancel a job edit, click anywhere on the empty space within the sequence queue table.

If your camera supports live video feed, then you can click the **Live Video** button to start streaming. The video stream window enables recording and subframing of the video stream. For more information, check the video below:

https://www.youtube.com/embed/qRsAqTL4ZZI

Recording feature

5.8.6.6 Filter Settings
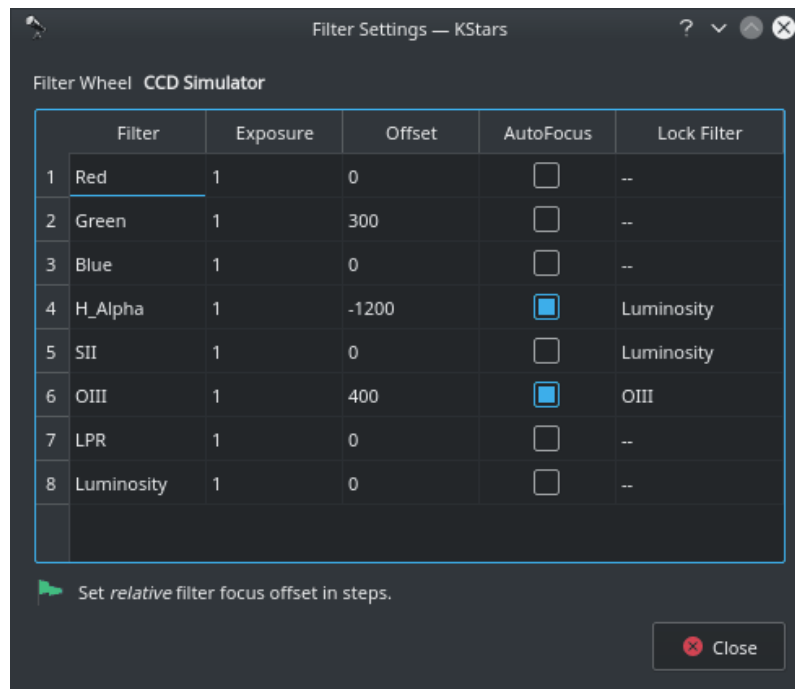
Click the filter icon [▽] next to the filter wheel selection box to open the filter settings dialog. If you are using filters that are not parafocal with each other and require a specific amount of focus offsets in order to get them into proper then set all the relative focus offsets in the dialog.

Configure settings for each filter individually:

1. **Filter**: Filter Name.

2. **Exposure**: Set exposure time used when performing focus under this filter. By default, it is set to 1 second.

3. **Offset**: Set relative offsets. Ekos will command a focus offset change if there is a difference between the current and target filter offsets. For example, given the values in the example image, if the current filter is set to *Red* and next filter is *Green*, then Ekos shall command the focuser to Focus In by +300 ticks. Relative positive focus offsets denote Focus Out while negative values denote Focus In.

4. **Auto Focus**: Check this option to initial AutoFocus process whenever the filter is changed to this filter.

5. **Lock Filter**: Set which filter should be set and *locked* when performing autofocus for this filter.

Let's take an example. Suppose the capture sequence is running and the current filter is **Green**, so the relative offset is already set to +300. The next image in the sequence uses Hydrogen Alpha (H_Alpha) so before Ekos captures the next frame, the following actions take place:

- Since Luminosity is specified as the locked filter and auto-focus is checked, the filter is changed to Luminosity.

- A focus offset is -300 is applied since the prior filter **Green** was moved +300 previously.

- Auto Focus process is initiated.

- Once Auto Focus is complete, the filter is changed to H_Alpha.

- A focus offset of -1200 is applied.

- Capture sequence is resumed.

5.8.6.7 FITS Viewer

Captured images are displayed in KStars FITS Viewer tool, and also in the summary screen. Set options related to how the images are displayed in the viewer.

- **Auto Dark**: You can capture an image and auto dark subtract it by checking this option. Note that this option is only applicable when using **Preview**, you cannot use it in batch mode sequence queue.

- **Effects**: Image enhancement filter to be applied to the image after capture.

5.8.6.8 Rotator Settings
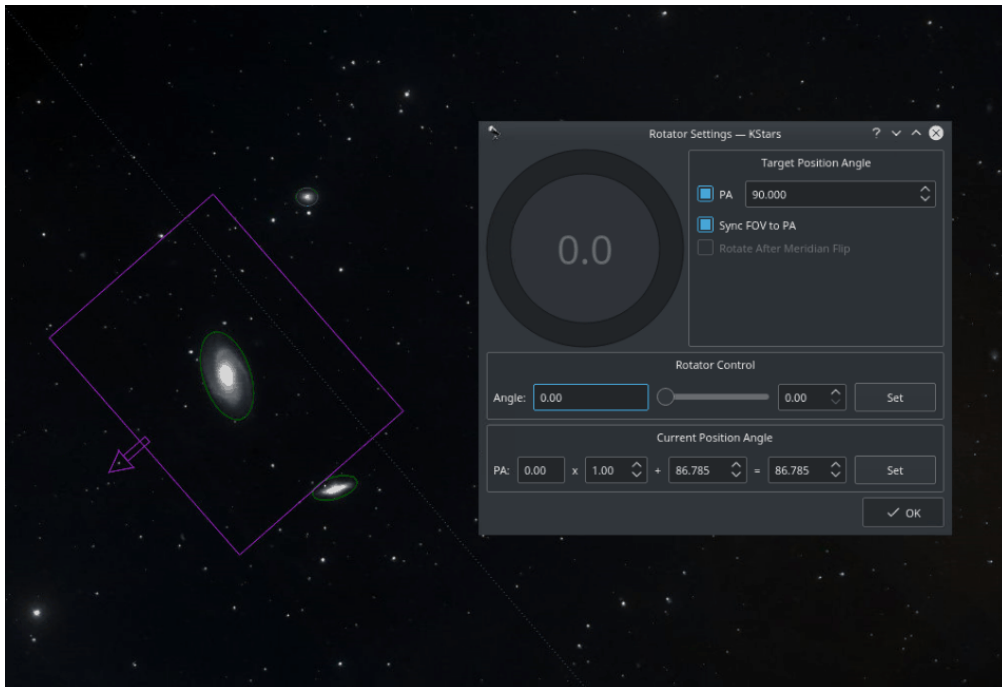
Field Rotators are supported in INDI & Ekos. The rotator angle is the raw angle reported by the rotator and is not necessary the Position Angle. A Position Angle of *zero* indicates that the frame top (indicated by small arrow) is pointing *directly* at the pole. The position angle is expressed as

E of N (East of North), so 90 degrees PA indicates the frame *top* points 90 degrees away (counterclockwise) from the pole. Check examples for various PAs.

To calibrate the Position Angle (PA), capture and solve an image in the Ekos Align module. An *offset* and a *multiplier* are applied to the raw angle to produce the position angle. The Ekos Rotator dialog permits direct control of the raw angle and also the PA. The offset and multiplier can be changed manually to synchronize the rotator's raw angle with the actual PA. Check **Sync FOV to PA** to rotate the current Field of View (FOV) indicator on the Sky Map with the PA value as you change it in the dialog.

https://www.youtube.com/embed/V_hRPMlPjmA

Rotator settings

Each capture job may be assigned different rotator angles, but be aware that this would cause guiding to abort as it would lose track of the guide star when rotating. Therefore, for most sequences, the rotator angle is kept the same for all capture jobs.

5.8.6.9 Calibration Frames
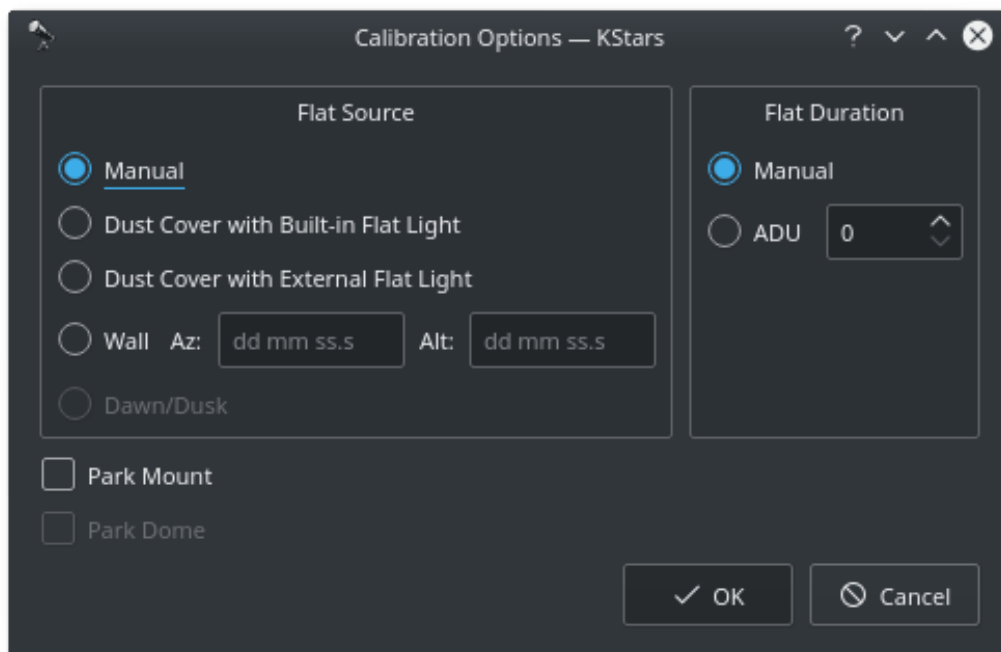
For Flat Field frames, you can set calibration options in order to automate the process. The calibration options are designed to facilitate automatic unattended flat field frame capture. It can also be used for dark and bias frames if desired. If your camera is equipped with a mechanical shutter, then it is not necessary to set calibration settings unless you want to close the dust cover to ensure no light at all passes through the optical tube. For flat fields, you must specify the flat field light source, and then specify the duration of the flat field frame. The duration can be either manual or based on ADU calculations.

1. Flat Field Source

   - **Manual**: The flat light source is manual.
   - **Dust Cover with Built-In Flat Light**: If using a dust cover with builtin light source (e.g. FlipFlat). For dark and bias frames, close the dust cap before proceeding. For flat frames, close the dust cap and turn on the light source.

- **Dust Cover with External Flat Light**: If using a dust cover with an external flat light source. For dark and bias frames, close the dust cap before proceeding. For flat frames, open the dust cap and turn on the light source. The external flat light source location is presumed to be the parking location.
- **Wall**: Light source is a panel on the observatory wall. Specify the Azimuth and Altitude coordinates of the panel and the mount shall slew there before capturing the flat field frames. If the light panel is controllable from INDI, Ekos shall turn it on/off as required.
- **Dawn/Dusk**: Currently unsupported.

2. Flat Field Duration
   - **Manual**: Duration is as specified in the Sequence Queue.
   - **ADU**: Duration is variable until specified ADU is met.

Before the calibration capture process is started, you can request Ekos to park the mount and/or dome. Depending on your flat source selection above, Ekos will use the appropriate flat light source before starting flat frames capture. If ADU is specified, Ekos begins by capturing a couple of preview images to establish the curve required to achieve the desired ADU count. Once an appropriate value is calculated, another capture is taken and ADU is recounted until a satisfactory value is achieved.

5.8.6.10 Video Tutorials

https://www.youtube.com/embed/Gz07j7VPnpc

Capture

https://www.youtube.com/embed/yfz9_UJIvLY

Filter Wheels

5.8.7 Focus

5.8.7.1 Theory Of Operation
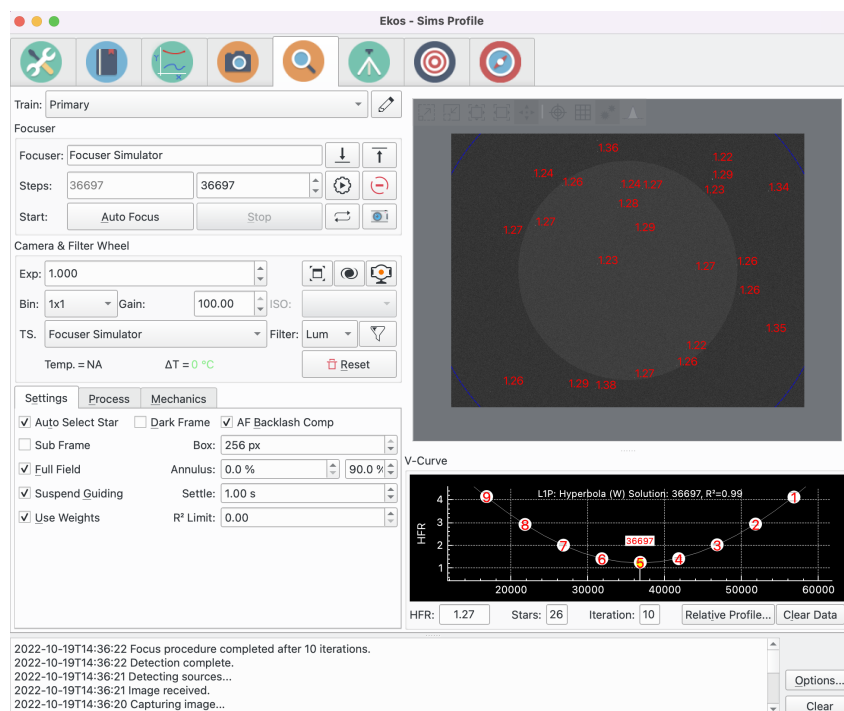
In order to focus an image, Ekos needs to establish a numerical method for gauging how *good* your focus is. It's easy when you look at an image and can see it as *unfocused*, as the human eye is very good at detecting that, but *how* can Ekos possibly know that?

There are multiple methods. One is to calculate the Full Width at Half Maximum (FHWM) of a star profile within an image, and then adjust the focus until an optimal (narrower) FWHM is reached. The problem with FWHM is that it assumes the initial focus position to be close to the critical focus. Additionally, FWHM does not perform very well under low-intensity fluxes. An Alternative method is Half-Flux-Radius (HFR), which is a measure of the width in pixels counting from the center of the star until the accumulated intensity is half of the total flux of the star. HFR proved to be much more stable in conditions where you might have unfavorable sky conditions, when the brightness profile of the stars is low, and when the starting position of the focus is far from the optimal focus.

After Ekos processes an image, it selects either a single star and starts measuring its HFR, or it selects a set of stars matching the criteria that have been set and calculates an average HFR. It can automatically select stars, or you can select a single star manually. It is recommended to allow Ekos to select a set of stars.

Ekos supports 4 different focus algorithms: Iterative, Polynominal, Linear and Linear 1 Pass.

- **Iterative**: In the Iterative algorithm, Ekos operates iteratively by moving in discrete steps, decided initially by the user-configurable step size and later by the slope of the V-Curve, to get closer to the optimal focus position where it then changes gears and performs smaller, finer moves to reach the optimal focus. The focus process stops when the measured HFR is within the configurable tolerance of the minimum recorded HFR in the process. In other words, whenever the process starts searching for a solution within a narrowly limited range, it checks if the current HFR is within % difference compared to the minimum HFR recorded, and if this condition is met then the Autofocus process is considered successful. The default value is set to 1% and is sufficient for most situations. The Step options specify the number of initial ticks the focuser has to move. If the image is severely out of focus, we set the step size high (i.e. greater than 250). On the other hand, if the focus is close to optimal focus, we set the step size to a more reasonable range (less than 50). It takes trial and error to find the best starting tick, but Ekos only uses that for the first focus motion, as all subsequent motions depend on the V-Curve slope calculations. Key features include:

  - The algorithm relies on the focuser having well controlled backlash.

  - The algorithm can be fast using a minimum number of steps.

  - The algorithm works on a "good enough" paradigm whereby it stops when the HFR is within % Tolerance of the perceived minimum.

- **Polynomial**: In the Polynomial algorithm, the process starts off in Iterative mode, but once we cross to the other side of the V-Curve (once HFR values start increasing again after decreasing for a while), then Ekos performs quadratic curve fitting to find a solution that predicts the minimum possible HFR position. Key features include:

  - The algorithm relies on the focuser having well controlled backlash.

  - The algorithm can be fast using a minimum number of steps.

  - The algorithm uses curve fitting to pinpoint the optimum focus position.

- **Linear**: In the Linear algorithm, Ekos steps outward from its starting point then moves inward taking regular datapoints through the point of optimum focus and then further inward, to draw a V-Curve. It then fits a quadratic curve to the datapoints and calculates the point of optimum focus. It then moves out again past the point of optimum focus, halves the stepsize and moves in again for a second pass. It looks to follow the curve from the first pass and find the minimum HFR. Due to randomness in the HFR measurements it uses the % tolerance to help decide when it has found a solution. Key features include:

  - The algorithm compensates for focuser backlash and can deal with both consistent and inconsistent backlash.

- The algorithm is slow, taking 2 passes to identify optimum focus.

- The algorithm uses curve fitting to pinpoint the optimum focus position in pass 1, but then uses % Tolerance to try to stop as close as possible to this HFR on pass 2.

- The algorithm is highly configurable with user control over many parameters like step size and number of steps.

- **Linear 1 Pass**: In the Linear 1 Pass algorithm, Ekos initially performs like the Linear algorithm in establishing the first pass V-Curve and fitting a curve to it to find the solution. Then, however, it moves directly to the calculated minimum. Key features include:

  - The algorithm compensates for focuser backlash, providing that backlash is consistent.

  - The algorithm is fast, taking 1 pass to identify optimum focus.

  - The algorithm uses more sophisticated curve fitting to pinpoint the optimum focus position.

  - The algorithm is highly configurable with user control over many parameters like step size and number of steps.

5.8.7.2 Optical Train Group
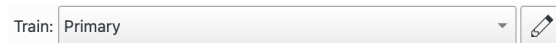
Train: Primary

The Optical Train group displays the currently selected Optical Train. By default this will be the primary imaging train, but other trains can be selected. The group consists of:

- **Train**: The Optical Train currently in use by the Focus tab. Hover the mouse over this field for a more detailed description of the selected train.

- **Edit Button**: Brings up the Optical Train dialog to view and potentially change the optical trains.

5.8.7.3 Focuser Group

Focuser

Focuser: Focuser Simulator

Steps: 36701   36701

Start: Auto Focus   Stop
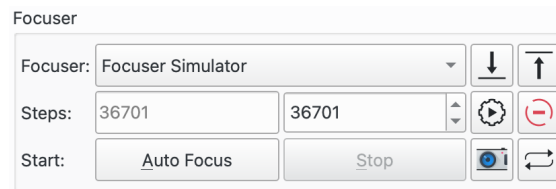
All INDI-compatible focusers are supported. It is recommended to use **absolute** focusers for the best results since their absolute position is known on power up. In INDI, the focuser *zero* position is when the drawtube is **fully retracted**. When focusing *outwards*, the focuser position increases, while it decreases when focusing *inwards*. The following focuser types are supported:

- **Absolute**: Absolute Position Focusers such as RoboFocus, MoonLite, ASI ZWO

- **Relative**: Relative Position Focusers.

- **Time Based**: Time based focusers with no position feedback that adjust focus position by moving for a certain amount of time.

Start off by selecting the Focuser from the dropdown.

For absolute focusers, you can set the ticks count in the Initial Steps Size field in the Mechanics tab. For absolute and relative focusers, the step size is in units of *ticks* and for simple, or time based, focusers, the step size is in *milliseconds*. The **In** and **Out** buttons can then be used to move the focuser by this number of ticks.

The Steps fields will initially contain the starting point in ticks for the focuser. As the focuser moves, the left field will update to reflect the focuser's current position. The right field will initially contain the starting position of the focuser but will update each time a successful Autofocus run completes, to keep a last good focus position. In addition you can set the right field to whatever value you like, and use the **Goto** button to move the focuser to this position.

The **Goto Focus Position** button moves the focuser to the position in the righthand Steps field.

The **Stop Focuser Motion** button stops the in-progress focuser motion.

The **Auto Focus** button starts an Autofocus run. The **Stop** button is used to stop the run.

The **Capture Image** button will take a frame based on the current settings in the **CCD and Filter Wheel** group. The **Start Framing** button will start repeatedly capturing frames until the **Stop** button is pressed.

Some of the focus algorithms will attempt to cope with being started away from the point of optimum focus, but for predictable results, it is best to start from a position of being approximately in focus. For first time setup, **Start Framing** can be used along with the **In** and **Out** buttons to adjust the focus position to roughly minimize the HFR of the stars in the captured images. When Framing is used in this way, the V-Curve graph changes to show a time series of frames and their associated HFRs. This makes the framing process much easier to perform.

If you are completely new to astronomy, it is always a good idea to get familiar with your equipment in daylight. This includes getting the approximate focus position on a distant object. This will provide a good starting position for focusing on stars when nighttime comes.

5.8.7.4 Camera & Filter Wheel Group
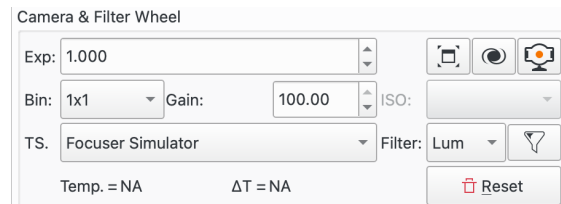
This section of parameters deals with the Camera and Filter settings to use when focusing.

The top row of controls allows CCD parameters to be set.

- **Exp**: The exposure time in seconds.

- The **Toggle Full Screen** button pops the window displaying the focus frame out to a separate window. Pressing it again returns it within the focus window.

- The **Show in FITS Viewer** button pops-up a separate FITS Viewer window to display the focus frame, in addition to the focus frame displayed within the focus window.

- The **Live Video** button brings up the associated popup.

The next row of controls allows Camera parameters to be set. Choose a value from the binning dropdown and then set either the camera gain or ISO.

- **Binning**: Increasing the binning will change the image scale as well as resulting in brighter pixels. A good place to start would be 1x1 and then see whether better results can be obtained by binning at higher levels such as 2x2 or 4x4.

- **Gain**: Set the Gain for the Camera being used to focus. The value needs to be high enough to give a clear star pattern but not so high as to create too much noise to interfere with the focus operation. Some experimentation will be required to find an optimum value. If you are unsure where to start try unity gain for your camera and adjust from there.

- **ISO**: Set the ISO for the Camera being used to focus. Some experimentation will be required to find an optimum value.

The third row of controls deals with the Temperature Source and Filter, if there is one:

- **TS**: Select the temperature source from the dropdown. Underneath are displayed the current temperature from the selected temperature source and the change in temperature between when the last successful Autofocus run completed and the current temperature. It is common practice to redo focus after significant temperature changes that alter the telescope's focus point.

- **Filter**: Select the filter to use.
  To start focusing it will probably be easier to select the filter that allows the most light through, for example the Lum filter. The **Filter Settings** button brings up the Filter Settings popup. This allows a number of parameters to be set per filter to be used during an Autofocus run which could be unattended so a user would not be available to set parameters at run time. Broadly these allow two types of focus runs:

  - **Per Filter**: When another module, for example, the Capture module requires a filter change, it is possible to automatically refocus for the new filter. The exposure to use for each filter is taken from the Filter Settings popup. This is very useful where, for example, narrowband filter require longer exposure times than broadband filters.

  - **Lock Filter**: It is possible to specify a Lock filter to use when it is required to focus another filter. For example, if a Red filter is used and an Autofocus run required, it is possible to run the Autofocus using the Lum filter and then, when complete, adjust the focus position by an Offset value corresponding to the predetermined focus difference between the Lum and Red filters. This is useful when, for example, it is difficult to focus some filters directly without excessively long exposure times. Note that this locked filter approach may also be used in the Alignment Module whenever it performs a capture for astrometry.

- **Reset** button will reset the focusing subframe to full frame.

5.8.7.5 Focus Settings

Next are 3 tabbed panes of parameters. These parameters are retained between sessions. First up is the Settings pane.

- **Auto Select Star**: Allow Ekos to select the focus star(s) from the image. If not selected then the user will have to manually select a star.

- **Dark Frame**: Check this option to perform dark-frame subtraction. This option can be useful in noisy images, where a pretaken dark is subtracted from the focus image before further processing.
  Dark frames are used by Focus, Alignment and Guiding. See the Dark Library feature within the Capture Module for more details on how to setup Dark Frames.

- **AF Backlash Comp**: Check this option to have the Autofocus algorithm perform backlash compensation. This option is available when using the Linear and Linear 1 Pass algorithms. This field should be set together with the **Backlash** field. See the Focus Mechanics section for more details.

Backlash in the focuser setup is likely to a combination of backlash in the electronic focuser itself (e.g. in the gearing mechanism), in the binding of the electronic focuser to the telescope drawtube, and in the telescope drawtube's mechanism. Thus, each setup will have its own backlash characteristic.

There are several things to consider when working out how to deal with backlash:

- **No Backlash**: If you are fortunate enough to have a setup with no backlash then it would make sense to set AF Backlash Comp off. It should work fine if AF Backlash Comp is on, but the AutoFocus routine will make unnecessary movements.

- **Backlash Managed by Focuser**: If your focuser had the ability to manage backlash itself then you can use this facility and turn off AF Backlash Comp. Alternatively, if it's possible, you could turn off the focuser's backlash facility and set AF Backlash Comp on.

- **Backlash Managed by Device Driver**: If your device driver had the ability to manage backlash itself then you can use this facility and turn off AF Backlash Comp. Alternatively, if it's possible, you could turn off the device driver's backlash facility and set AF Backlash Comp on.

It is important to have backlash managed in one place to avoid conflicts.

- **Sub Frame**: Either use the Full Field of the camera or select a Subframe around the focus star during the Autofocus procedure. This is only relevant if a single star is used for focusing. Enabling subframing can speed up the focus process.

- **Box**: Sets the box size used to enclose the focus star when using **Sub Frame**. Increase if you have very large stars. For Bahtinov focus the box size can be increased even more to better enclose the Bahtinov diffraction pattern.

- **Full Field**: Either use the full field of the camera or select a Sub Frame around the focus star during the Autofocus procedure. If using multiple stars then this option must be selected.

- **Annulus**: Used in conjunction with Full Field, Annulus provides two input fields that together define a doughnut over the FOV of the camera. Stars falling outside of the doughnut are discounted from processing. Setting an inner value above 0% causes stars in the centre of the FOV to be discarded. This could be useful to avoid using stars in the target of the image (for example a galaxy) for focusing purposes. Setting an outer value below 100% causes stars in the edges of the FOV to be discarded during focusing. This could be useful if you do not have a flat field out to the edges of your FOV.

- **Suspend Guiding**: Set this option to suspend guiding during an Autofocus run. An additional check is made to only suspend guiding if it is being carried out via the primary scope, for example when using an Off Axis Guider. The purpose of this is to prevent guiding from having problems with defocused stars during the focus process.

- **Settle**: This option is used in conjunction with **Suspend Guiding**. It allows any vibrations in the optical train to settle by waiting this many seconds after the Autofocus process has completed, before restarting guiding.

- **Use Weights**: This is an experimental option only available with the Linear 1 Pass focus algorithm and Curve Types of Hyperbola and Parabola. It requires Full Field to be selected. The option calculates the standard deviation of star HFRs and uses the square of this (mathematically the variance) as a weighting in the curve fitting process. The advantage of this is that datapoints with less reliable data and therefore larger HFR standard deviations will be given less weight than more reliable datapoints. If this option is unchecked, and for all other curve fitting where the option is not allowed, all datapoints are given equal weight in the curve fitting process.

    See the Levenberg-Marquardt Solver for more details.

- **R² Limit**: This is an experimental option only available with the Linear 1 Pass focus algorithm and Curve Types of Hyperbola and Parabola. As part of the Linear 1 Pass algorithm, the degree to which the curve fits the datapoints, or Coefficient of Determination, R^2, is calculated. This option allows a minimum acceptable value of R^2 to be defined that is compared to the value

obtained from the curve fitting process. If the minimum value has not been achieved then Autofocus will rerun. Only one rerun will be performed and even if the minimum R^2 has not been met the second time, the Autofocus run will still be deemed successful.

Experiment to find an appropriate value but a good starting point would be 0.8 or 0.9

5.8.7.6 Focus Process

This is the Focus Process parameters pane.

- **Detection**: Select star detection algorithm. Each algorithm has its strengths and weaknesses. It is recommended to keep the default value, SEP, unless it fails to properly detect stars. The following are available:

    - **SEP**: Source Extraction and Photometry built in library. This is the default value.
    - **Centroid**: An extraction method based on estimating star mass around signal peaks.
    - **Gradient**: A single source extraction model based on the Sobel filter.
    - **Threshold**: A single source detection algorithm based on pixel values.
    - **Bahtinov**: This detection method can be used when using a Bahtinov mask for focusing. First take an image, then select the star to focus on. A new image will be taken and the diffraction pattern will be analysed. Three lines will be displayed on the diffraction pattern showing how well the pattern is recognized and how good the image is in focus. When the pattern is not well recognized, the *Num. of rows* parameter can be adjusted to improve recognition. The line with the circles at each end is a magnified indicator for the focus. The shorter the line, the better the image is in focus.

- **SEP Profile**: If the star detection algorithm is set to *SEP*, then choose a parameter profile to use with the algorithm. It is recommended to use the default 1-Focus-Default profile as a starting point.

- **Threshold**: Threshold percentage value is used for star detection using the *Threshold* detection algorithm. Increase to restrict the centroid to bright cores. Decrease to enclose fuzzy stars.

- **Algorithm**: Select the Autofocus process algorithm:

    - **Iterative**: Moves focuser by discreet steps initially decided by the step size. Once a curve slope is calculated, further step sizes are calculated to reach an optimal solution. The algorithm stops when the measured HFR is within **Tolerance** of the minimum HFR recorded in the procedure.
    - **Polynomial**: Starts with the iterative method. Upon crossing to the other side of the V-Curve, polynomial fitting coefficients along with possible minimum solution are calculated. This algorithm can be faster than a purely iterative approach given a good data set.
    - **Linear**: This algorithm builds a V-Curve with approximately **Out step Multiple** steps on each side of the minimum. Having built the V-Curve it then fits a quadratic equation to the curve (parabolic shape) and uses this to calculate the focuser position giving the minimum HFR. Having identified the minimum it then performs a 2nd pass halving the step size, recreating the curve from the 1st pass. It attempts to stop within **Tolerance** of the minimum HFR calculated during the 1st pass.

- **Linear 1 Pass**: This algorithm starts in the same way as **Linear** building a V-Curve. Having built the V-Curve it then fits the **Curve Fit** type to the datapoints and then calculates the focuser position giving the minimum HFR. Having identified the minimum it then moves directly to that point in a way designed to neutralise backlash.

    This algorithm supports the older style Quadratic curve type as well as the newer Levenberg-Marquardt Solver for Hyperbolic and Parabolic curves. It will also weight the datapoints in the curve fitting process if Use Weights is checked.

- **Effect**: You may select an **Effect** filter to enhance the image for preview purposes. It is highly advisable to turn off any effects during the focusing process as it may interfere with HFR calculations. For DSLR cameras, you can change the ISO settings.

- **Tolerance**: The tolerance percentage value is used to help decide when the Autofocus process stops in the **Iterative** and **Linear** algorithms. During the Autofocus process, HFR values are recorded, and once the focuser is close to an optimal position, it starts measuring HFRs against the minimum recorded HFR in the sessions and stops whenever a measured HFR value is within % difference of the minimum recorded HFR. Decrease the value to narrow the optimal focus point solution radius. Increase to expand solution radius.

> **WARNING**
> Setting the value too low might result in a repetitive loop and would most likely result in a failed Autofocus process.

- **Kernel Size**: The kernel size of the gaussian blur applied to the image before applying Bahtinov edge detection. Used when **Detection** is Bahtinov.

- **Average over**: Number of frames to capture at each datapoint. It is usually sensible to start with 1 but increasing this will result in an averaging process over the star HFRs.

- **Sigma**: The sigma of the gaussian blur applied to the image before applying Bahtinov edge detection. Used when **Detection** is Bahtinov.

- **Num. of rows**: The number of lines displayed on screen when using a Bahtinov mask. Used when **Detection** is Bahtinov.

- **Curve Fit**: The type of curve to fit to the datapoints.

    - **Quadratic**: Uses a quadratic equation using a linear style least squares algorithm supplied by GSL (GNU Science Library). This is, in effect, a parabolic curve.
    - **Hyperbola**: Fits a Hyperbola using a non-linear least squares algorithm supplied by GSL (GNU Science Library). See Levenberg-Marquardt Solver for more details.
    - **Parabola**: Fits a Parabola using a non-linear least squares algorithm supplied by GSL (GNU Science Library). See Levenberg-Marquardt Solver for more details.

5.8.7.7 Focus Mechanics

Settings	Process	Mechanics		
Initial Step size:	5000	Max Travel:	60000	
Max Step size:	100000	Backlash:	300	
Settle:	2.000 s	Out Step Multiple:	4.00	
Capture Timeout:	12	Motion Timeout:	10	

This is the Focus Mechanics parameters pane.

- **Initial Step size**: This sets the step size to be used by various focus algorithms. For absolute and relative focusers this is the number of ticks; for timer based focusers this is the number of milliseconds.

- **Max Travel**: Puts bounds on the amount of travel from the current focuser position that is permitted by the Autofocus algorithms. The purpose is to protect the focuser from travelling too far and potentially damaging itself. On the other hand, the value needs to be big enough to allow sufficient focuser motion to permit the auto focus runs to complete.

- **Max Step size**: Used by the Iterative focus algorithm to limit the maximum step size that can be used.

- **Backlash**: All mechanical devices with gears suffer from backlash. In a typical focuser there will be a dead zone where changing direction (e.g. from "in" to "out") results in movement of the focuser by a few ticks, but no actual movement of the optical train.

  The Linear 1 Pass algorithm (like the Linear algorithm) provides backlash compensation in the 2 places during an auto focus run when the focuser moves outwards:

  – The initial outward movement of Initial Step Size * Out Step Multiple at the start of the run.
  – When the inward pass is complete and Ekos has determined the best focus position and moves outward to it.

  Linear 1 Pass will extend (by x ticks) the outward movement, and then, as a separate movement it will move inward by x ticks. So it always approaches the desired position in an inward direction.
  There are 2 schemes that can be used:

  – Set Backlash to 0. Ekos will use a value of 5 * Initial Step Size.
  – Set Backlash > 0. EKOS will use this value in its backlash calculations. There will probably be instructions with your focuser for determining the value of Backlash. It is not necessary to set an exact value for either Linear or Linear 1 Pass to work correctly; all that is required is that the value set in Backlash is >= the actual backlash value. For example, if you measure backlash and get a value around 100, any value >=100 will work equally well. For example, set Backlash = 200.

- **Settle**: The number of seconds to wait, after moving the focuser, before starting the next capture. The purpose is to stop any vibrations in the optical train from affecting the next frame.

- **Out Step Multiple**: Used by the Linear and Linear 1 Pass focus algorithms, this parameter specifies the initial number of outward steps the focuser takes at the start of a Autofocus run.

- **Capture Timeout**: The amount of time in seconds to wait for a captured image to be received before declaring a timeout.

- **Motion Timeout**: The amount of time in seconds to wait for the focuser to move to the requested position before declaring a timeout.

5.8.7.8 Focus Display
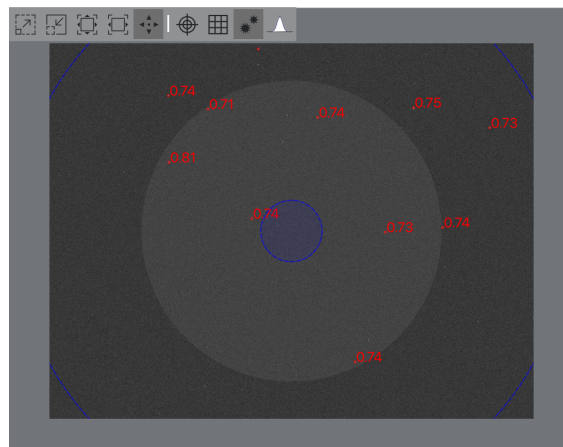
The focus display, displays a FITS viewer window onto the frame taken during the focus process. It displays the **Annulus** values superimposed on the image. All the stars detected by Ekos based on the selected parameters, have their HFR value displayed next to the associated star.

The window supports the following FITS viewer options (at the top of the window):

- **Zoom In** and **Zoom Out**.
- **Default Zoom** and **Zoom to Fit**.
- **Toggle Stretch**: Toggle screen stretch on or off.
- **Toggle Crosshairs**: Toggle crosshairs on or off.
- **Toggle Gridlines**: Toggle pixel gridlines on or off.
- **Toggle Stars**: Toggle star detection on or off.

5.8.7.9   V-Curve
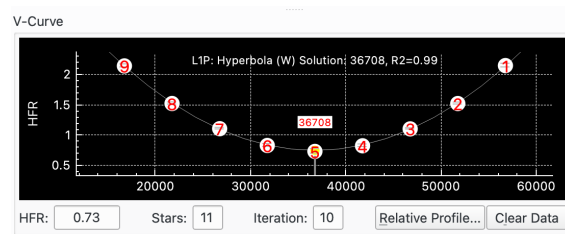
The V-Curve displays focuser position (x-axis) versus Half-Flux-Radius (HFR) (y-axis). Each datapoint is drawn on the graph and represented by a circle with a number representing the datapoint. How many datapoints are taken and how the focuser moves is determined by the parameters chosen.

For certain algorithms, Ekos will also draw a curve of best fit through the datapoints. If **Use Weights** is selected then error bars are indicated on each datapoint that correspond to the standard deviation in measured HFR value.

Under the V-Curve a number of parameters are displayed:

- **HFR**: Displays the star HFR for the most recent datapoint.
- **Stars**: The number of stars used for the most recent datapoint.
- **Iteration**: The number of datapoints taken so far.
- **HFR**: Invokes the Relative Profile popup.
- **Clear Data**: Resets the V-Curve graph by clearing the displayed data.

When framing, the graph format changes to that of a "time series" where horizontal axis denotes the frame number. This is to aid you in the framing process as you can see how HFR changes between frames.
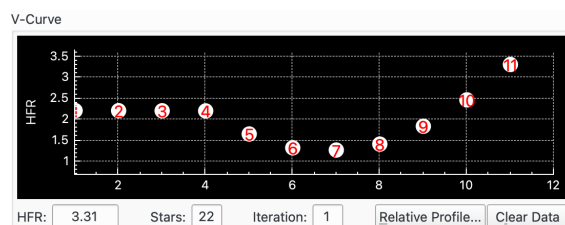
5.8.7.10 Relative Profile
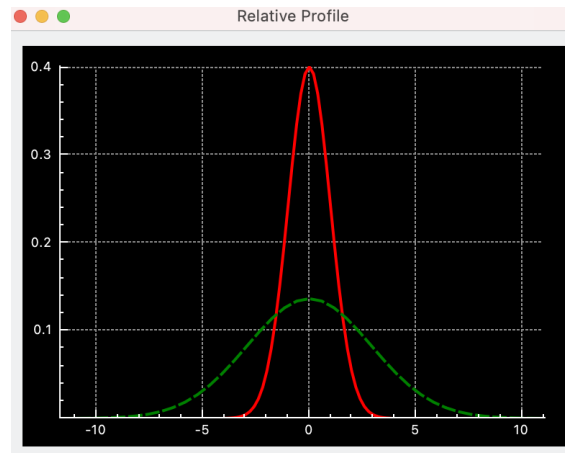
The relative profile is a graph that displays the relative HFR values plotted against each other. Lower HFR values correspond to narrower shapes and vice-versa. The solid red curve is the profile of the current HFR value, while the dotted green curve is for the previous HFR value. Finally, the magenta curve denotes the first measured HFR. This enables you to judge how well the Autofocus process improved the relative focus quality.

5.8.7.11 How to Setup for an Autofocus Run

The exact settings that work best for a given astronomical setup need to be worked out by the user using trial and error, but this section gives some pointers. It uses the Linear 1 Pass algorithm:

- Start near to focus by manually finding focus. Use the **Start Framing** option and manually adjust focus to get to approximate focus.

- Select Linear 1 Pass and your curve of choice, say Hyperbola. Select Use Weights.

- Make sure you are finding enough stars.

  - Start with the SEP star detection method and the 1-Focus-Default profile unless you have reason to use a different setup.

  - On the Settings tab, use Full Field (rather than Sub Frame) which will use many stars rather than just one. Select Auto Select Star to let the system select the stars to use.

  - Make sure Annulus is set to use a large amount of frame to make use of as many stars as possible. Note that there may be other factors that prevent you using all of the field such as issues with an un-flat field in the corners of the sensor, but don't overdo the restriction.

  - Set the camera settings such as exposure, gain and binning such that you are getting a good number of stars. Its impossible to be prescriptive here but try for between 20 and 100 (obviously if your focal length and target can't find that many then the process should still work but may be less optimal from a curve fitting perspective). As a suggestion start with 2 sec exposures, unity gain for your camera and 1x1 binning.

  - Upping the exposure usually finds more stars (but makes the focus process longer). You can also try taking multiple frames at the same point by setting the Average Over field > 1 frame.

- Setup the Mechanics tab.

  - Setup Backlash. See the Backlash section for more details but if you do not know the value for your equipment then set to 0.

- Setup Max Travel. This should be appropriate for your focuser to prevent overextending it. It needs to be big enough to support the values set in Initial Step Size and Out Step Multiple. It will need a minimum of just over Initial Step Size * Out Step Multiple. If you can, set it to, say, double this.
- Settle. If your focuser causes vibration in the optical train then you need to set this value so that after moving, the system waits for Settle seconds before taking the next frame. Try moving the focuser then taking a few frames at the same position. If the first frame after movement has bigger HFRs than subsequent frames, then you probably need to up the value in Settle.
- Out Step Multiple. Start with 4 or 5. This will give you 9-10 or 11-12 datapoints which is a good place to start. You need enough datapoints to form a curve, but the more you have the longer the process will take to complete.
- Initial Step Size. The following shows a "good curve". There is significant movement in the HFR axis to clearly demonstrate the curve, in this case max HFR is about 2.2 whilst min is 0.75 which gives a max / min of about 3.
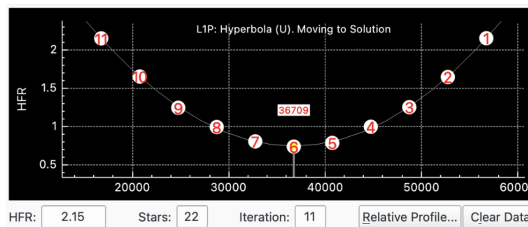
- In contrast, the next picture shows an Initial Step Size that has been set too low. The HFR varies from about 0.78 to 0.72. Which gives a max / min just over 1. The other clue that this is a poor setup is that the Error Bar range is very large compared to HFR movement which means that the curve solver is drawing a curve through a lot of noise, which means the results will not be very accurate.
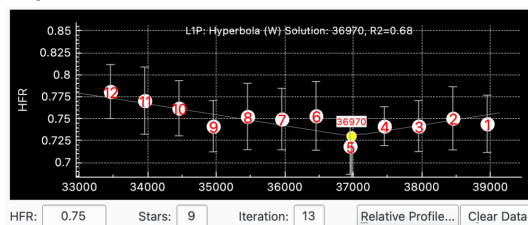
5.8.7.12 Coefficient of Determination, R²

The Coefficient of Determination, or R^2, is calculated in order to give a measure of how well the fitted curve matches the datapoints. More information is available here. This is an experimental feature that is available for the Linear 1 Pass focus algorithm. In essence, R^2 gives a value between 0 and 1, with 1 meaning a perfect fit where all datapoints sit on the curve, and 0 meaning that there is no correlation between the datapoints and the curve. The user should experiment with their equipment to see what values they can obtain, but as a guide, a value above, say 0.8 would be a good fit.

There is an option to set an "R^2 Limit" in the Settings tab of the Focus window that is compared to the calculated R^2 after the auto focus run has completed. If the limit value has not been achieved, then the auto focus is rerun.

Setting an R^2 Limit could be useful for unattended observation if the focus run produces a bad result for a 1-off reason. Obviously if the reason is not transitory then rerunning will not improve anything.

If the R^2 Limit is not achieved and the focus process is rerun, and again fails to achieve the R^2 Limit, then the focus run is marked as successful to avoid the process getting stuck rerunning auto focus forever.

This feature is turned off by setting the R^2 Limit to 0.

5.8.7.13 Levenberg–Marquardt Solver

The Levenberg-Marquardt (LM) algorithm is used to solve non-linear least squares problems. The GNU Science Library provides an implementation of the solver. These resources provide more details:

- https://en.wikipedia.org/wiki/Levenberg–Marquardt_algorithm

- https://www.gnu.org/software/gsl/doc/html/nls.html

The Levenberg-Marquardt algorithm is a new feature added for the Linear 1 Pass focus algorithm. It is a non-linear least-squares solver and thus suitable for many different equations. The basic idea is to adjust the equation y = f(x,P) so that the computed y values are as close as possible to the y values of the datapoints provided, so that the resultant curve fits the data as best as it can. P is a set of parameters that are varied by the solver in order to find the best fit. The solver measures how far away the curve is at each data point, squares the result and adds them all up. This is the number to be minimized, let's call it S. The solver is supplied with an initial guess for the parameters, P. It calculates S, makes an adjustment to P and calculates a new S1. Provided S1 < S then we are moving in the right direction. It iterates through the procedure until:

- the delta in S is less than a supplied limit (convergence has been reached), or

- the maximum number of iterations has been reached, or

- the solver encountered an error.

The solver is capable of solving either an unweighted or weighted set of datapoints. In essence, an unweighted set of data gives equal weight to each datapoint when trying to fit a curve. An alternative is to weight each datapoint with a measure that corresponds to how accurate the measurement of the datapoint actually is. In our case this is the variance of star HFRs associated with the datapoint. The variance is the standard deviation squared.

Currently the solver is used to fit either a parabolic or a hyperbolic curve.

5.8.8 Guide
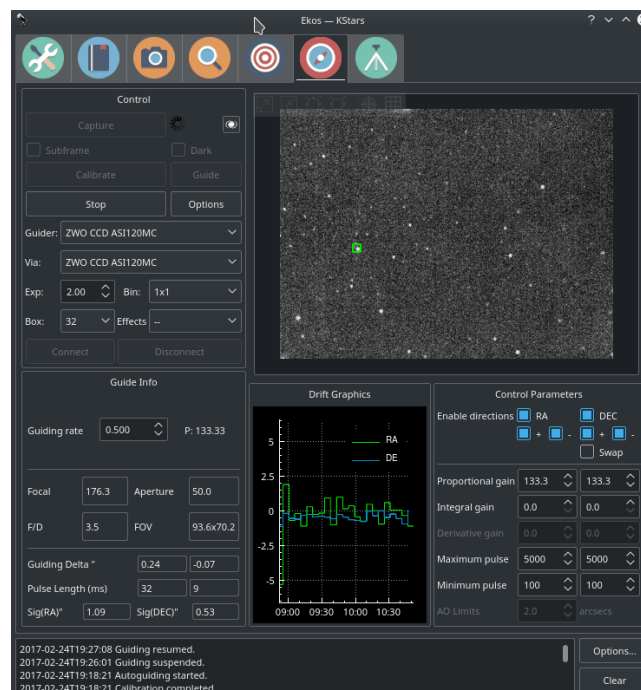
5.8.8.1   Introduction

Ekos Guide Module enables autoguiding capability using either the powerful built-in guider, or at your option, external guiding via PHD2 or lin_guider. Using the internal guiding, guider CCD frames are captured and sent to Ekos for analysis. Depending on the deviations of the guide star from its lock position, guiding pulses corrections are sent to your mount **Via** any device that supports ST4 ports. Alternatively, you may send the corrections to your mount *directly*, if supported by the mount driver. Most of the GUI options in the Guide Module are well documented so just hover your mouse over an item and a tooltip will popup with helpful information.

To perform guiding, you need to select a Guider CCD in Ekos Profile Setup. The telescope aperture and focal length must be set in the telescope driver. If the Guider CCD is attached to a separate Guide Scope, you must also set the Guide Scope's **Focal Length** and **Aperture**. You can set these values under the **Options** tab of the telescope driver or from the Mount module. Autoguiding is a two-step process: Calibration & Guiding.

https://www.youtube.com/embed/aza2fGIF7YE

Guiding introduction

During the two processes, you must set the following:

- **Guider**: Select the Guider CCD.

- **Via**: Selects which device receives the autoguiding correction pulses from Ekos. Usually, guider CCDs have an ST4 port. If you are using the guider's ST4 to autoguide your telescope, set the guider driver in the **Via** combo box. The guider CCD will receive the correction pulses from Ekos and will relay them to the mount via the ST4 port. Alternatively, some telescopes support pulse commands and you can select the telescope to be a receiver of the Ekos correction pulses.

- **Exposure**: CCD Exposure in seconds.

- **Binning**: CCD Binning.

- **Box**: Size of the box enclosing the guide star. Select a suitable size that is neither too large or too small for the selected star.

- **Effects**: Specify filter to be applied to the image to enhance it.

5.8.8.2   Dark Frames

Dark frames are *immensely* helpful in reducing noises in your guide frames. It is highly recommended to take dark frames before you begin and calibration or guiding procedure. To take a dark frame, check the **Dark** checkbox and then click **Capture**. For the first time this is performed, Ekos will ask you about your camera shutter. If your camera does not have a shutter, then Ekos will warn you anytime you take a dark frame to cover your camera/telescope before proceeding with the capture. On the other hand, if the camera already includes a shutter, then Ekos will directly proceed with taking the dark frame. All dark frames are automatically saved to Ekos Dark Frame Library. By default, the Dark Library keeps reusing dark frames for 30 days after which it will capture new dark frames. This value is configurable and can be adjusted in Ekos settings in the KStars settings dialog.
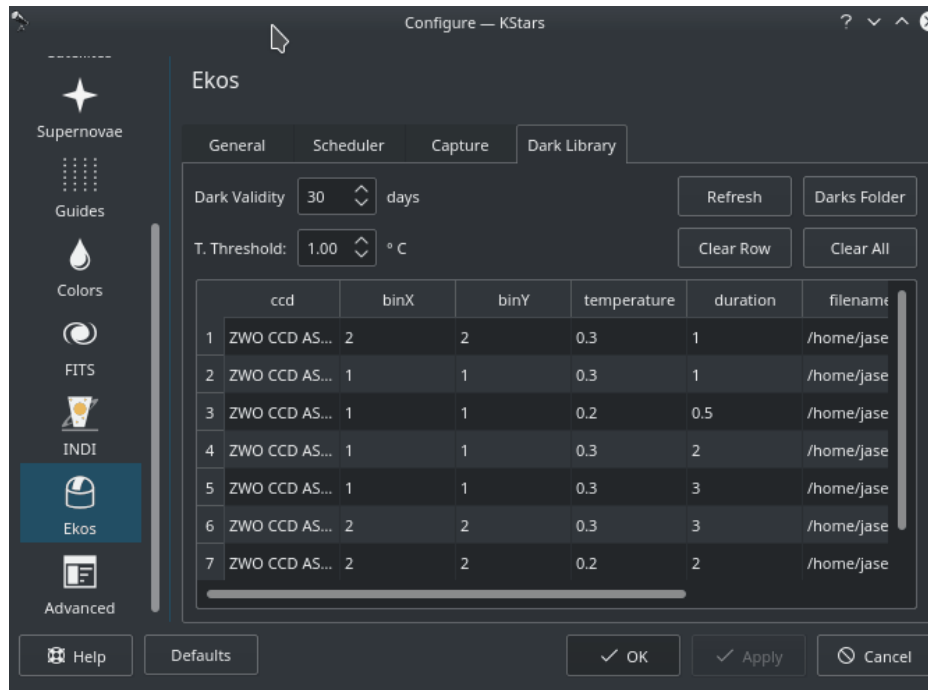
It is recommended to take dark frames covering several binning and exposure values so that they may be reused transparently by Ekos whenever needed.

5.8.8.3 Calibration
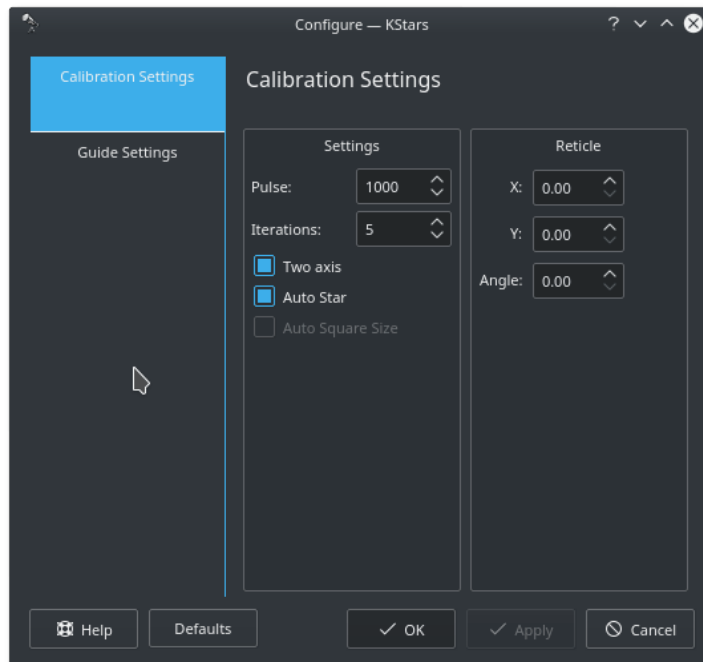
In the calibration phase, you need to capture an image, select a guide star, and click **Guide** to begin the calibration process. If calibration was already completed successfully before, then the autoguiding process shall begin immediately, otherwise, it would start the calibration process. If **Auto Star** is checked, then you are only required to click **Capture** and Ekos will automatically select the best-fit guide star in the image and continues the calibration process automatically. If

Auto Star is disabled, Ekos will try to automatically highlight the best guide star in the field. You need to confirm or change the selection before you can start the calibration process. The calibration options are:

- **Pulse**: The duration of pulses in milliseconds to be sent to the mount. This value should be large enough to cause a noticeable movement in the guide star. If you increase the value and you do not notice any movement of the guide star, then this suggests possible mount issues such as jamming or connection issues via the ST4 cable.

- **Two axis**: Check if you want the calibration process makes calibration in both RA & DEC. If unchecked, the calibration is only performed in RA.

- **Auto Star**: If checked, Ekos will attempt to select the best guide star in the frame and begins the calibration process automatically.

The reticle position is the guide star position selected by you (or by the auto selection) in the captured guider image. You should select a star that is not close to the edge. If the image is not clear, you may select different **Effects** to enhance it.

Ekos begins the calibration process by sending pulses to move the mount in RA and DEC. If the calibration process fails due to short drift, try increasing the pulse duration. To clear calibration, click the trash bin icon next to the **Guide** button.

> WARNING
> Calibration can fail for a variety of reasons. To improve the chances of success, try the tips below.

- **Better Polar Alignment**: This is critical to the success of any astrophotography session. Perform a quick polar alignment with a polar scope (if available) or by using Ekos Polar Alignment procedure in the **Align** module.

- **Set binning to 2x2**: Binning improves SNR and is often very important to the success of the calibration and guiding procedures.

- Prefer to use ST4 cable between guide-camera and mount over using mount pulse commands.

- Select different filter (e.g. High contrast) and see if that makes a difference to bring down the noise.

- Smaller Square Size.

- Take dark frames to reduce noise.

- Play with DEC Proportional Gain or disable DEC control completely and see the difference.

- Leave algorithm to the default value (**Smart**).

5.8.8.4 Guiding
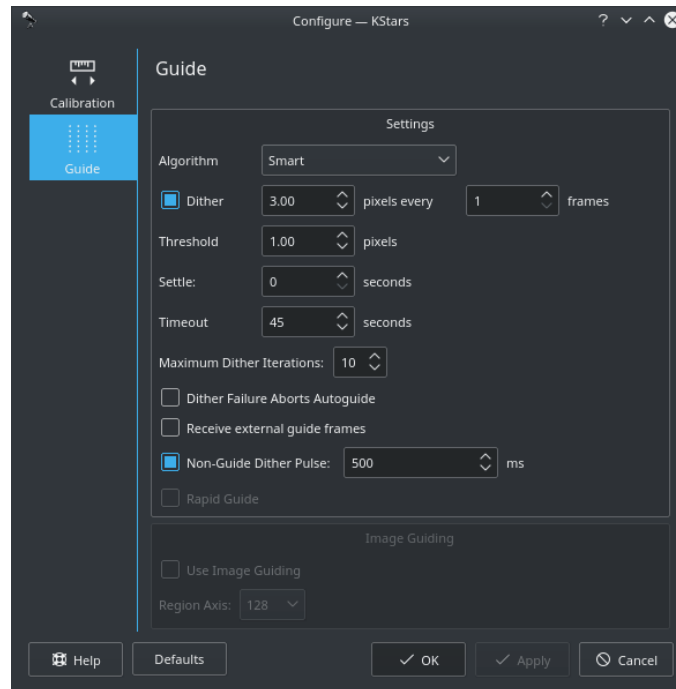
Once the calibration process is completed successfully, the guiding shall begin automatically hereafter. The guiding performance is displayed in the **Drift Graphics** region where **Green** reflects deviations in RA and **Blue** deviations in DEC. The colors of the RA/DE lines can be changed in KStars color scheme in KStars settings dialog. The vertical axis denotes the deviation in arcsecs from the guide star central position and the horizontal axis denotes time. You can hover over the line to get the exact deviation at this particular point in time. Furthermore, you can also zoom and drag/pan the graph to inspect a specific region of the graph.

Ekos can utilize multiple algorithms to determine the center of mass of the guide star. By default, the *smart* algorithm is suited best for most situation. The *fast* algorithm is based on HFR calculations. You can try switching guiding algorithms if Ekos cannot keep of the guide star within the guiding square properly.

The info region displays information on the telescope & FOV, in addition to the deviations from the guide star along with the correction pulses sent to the mount. The RMS value for each axis is displayed along with the total RMS value in arcsecs. The internal guider employs PID controller to correct the mount tracking. Currently, the *only* the proportional and integral gains are utilized within the algorithm, so adjusting it should affect the length of the generated pulses sent to the mount in milliseconds.

To enable automatic dithering between frames, make sure to check the **Dither** checkbox. By default, Ekos should dither (i.e. move) the guiding box by up to 3 pixels after each frame captured in Ekos Capture Module. The motion duration and direction are randomized. Since the guiding performance can oscillate immediately after dithering, you can set the appropriate **Settle** duration to wait after dither is complete before resuming the capture process. In rare cases where the dithering process can get stuck in an endless loop, set the appropriate **Timeout** to abort the process. But even if dithering fails, you can select whether this failure should terminate the autoguiding process or not. Toggle **Abort Autoguide on failure** to select the desired behavior.

Non-guide dithering is also supported. This is useful when no guide camera is available or when performing short exposures. In this case, the mount can be commanded to dither in a random direction for up to the pulse specified in the **Non-Guide Dither Pulse** option.

Ekos supports multiple guiding methods: Internal, PHD2, and LinGuider. You need to select the desired guider in your Ekos equipment profile:

- **Internal Guider**: Use Ekos internal guider. This is the default and recommended option.

- **PHD2**: Use PHD2 as the external guider. If selected, specify the host and port of the PHD2. Leave to default values if Ekos and PHD2 are running on the same machine.

- **LinGuider**: Use LinGuider as the external guider. If selected, specify the host and port of the LinGuider. Leave to default values if Ekos and LinGuider are running on the same machine.

5.8.8.5 Guiding Direction Control
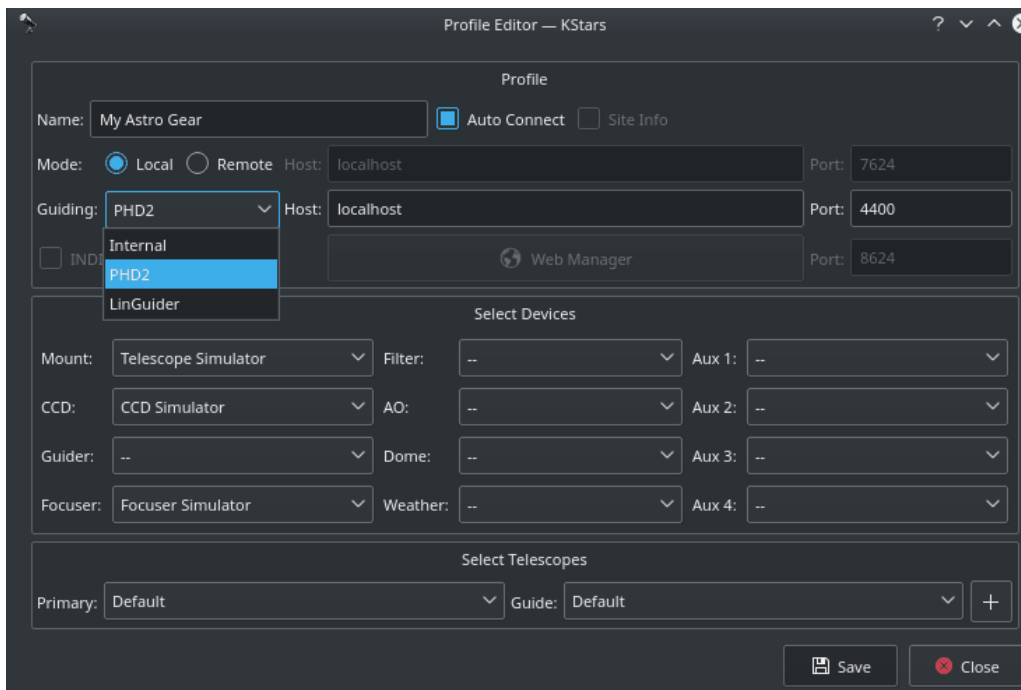
You can fine-tune the guiding performance in the Control Section. The autoguide process works like a PID controller when sending correction commands to the mount. You can alter the Proportional and Integral gains to improve the guiding performance if necessary. By default, guiding corrective pulses are sent to both mount axis in all directions: positive and negative. You can fine-tune control by selecting which axis shall receive corrective guiding pulses and within each axis, you can indicate which direction **(Positive) +** or **Negative (-)** receives the guiding pulses. For example, for the Declination axis, the **+** direction is North and **-** is South.

5.8.8.6 Guiding Rate

Each mount has a particular guiding rate in (x15″/sec) and usually ranges from 0.1x, to 1.0x with 0.5x being a common value used by many mounts. The default guiding rate is 0.5x sidereal, which is equivalent to a proportional gain of 133.33. Therefore, set the guiding rate value to whatever value used by your mount, and Ekos shall display the *recommended* proportional gain value that you may set in the proportional gain field under the **Control Parameters**. Setting this value *does not* change your mount guiding rate! You must change your mount guiding rate either via the INDI driver, if supported, or via the hand controller.

5.8.8.7 Drift Graphics
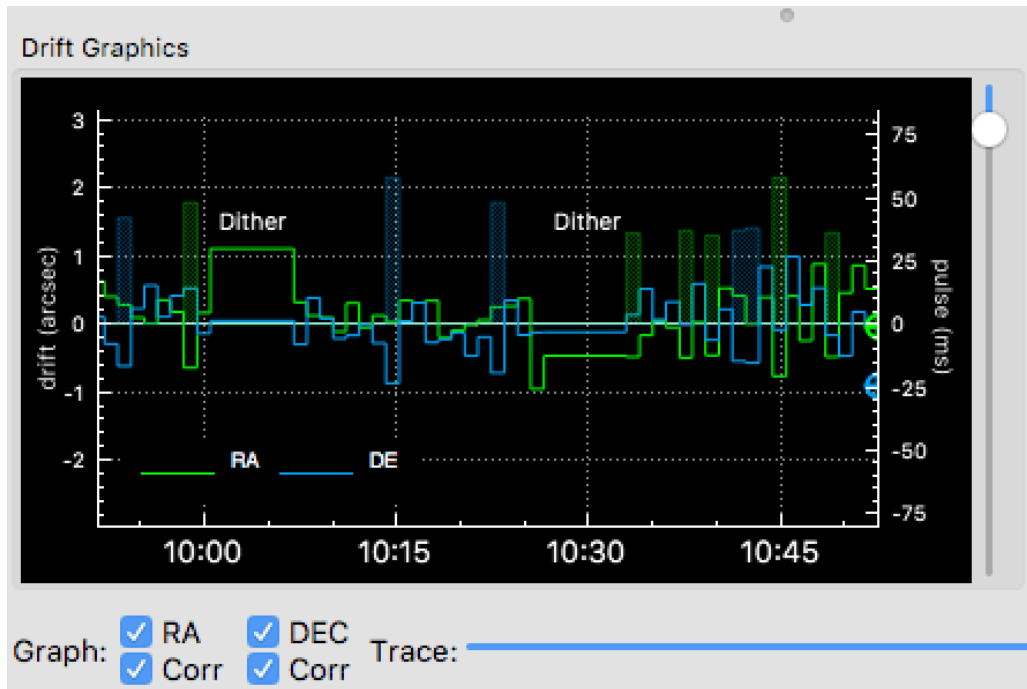
The drift graphics is a very useful tool to monitor the guiding performance. It is a 2D plot of guiding *deviations* and *corrections*. By default, only the guiding deviations in RA and DE are displayed. The horizontal axis is the time in seconds since the autoguiding process was started while the vertical axis plots the guiding drift/deviation in arcsecs for each axis. Guiding corrections (pulses) can also be plotted in the same graph and you can enable them by checking the **Corr** checkbox below each Axis. The corrections are plotted as shaded areas in the background with the same color as that of the axis.

You can pan and zoom the plot, and when hovering the mouse over the graph, a tooltip is displayed containing information about this specific point in time. It contains the guiding drift and any corrections made, in addition to the local time, this event was recorded. A vertical slider to the right of the image can be used to adjust the height of the secondary Y-axis for pulses corrections.

The **Trace** horizontal slider at the bottom can be used to scroll through the guide history. Alternatively, you can click the **Max** checkbox to lock the graph onto the latest point so that the drift graphics autoscrolls. The buttons to the right of the slider are used for autoscaling the graphs, exporting the guide data to a CSV file, clearing all the guide data, and for scaling the target in the **Drift Plot**. Furthermore, the guide graph includes a label to indicate when a dither occurred so the user knows guiding was not bad at those points.

The colors of each axis can be customized in KStars Settings color scheme.

5.8.8.8 Drift Plot

A bulls-eye scatter plot can be used to gauge the *accuracy* of the overall guiding performance. It is composed of three concentric rings of varying radii with the central green ring having a

default radius of 2 arcsecs. The last RMS value is plotted as   with its color reflecting which concentric ring it falls within. You can change the radius of the innermost green circle by adjusting the drift plot accuracy.

5.8.8.9 Guiding with GPG

The internal guider can use predictive and adaptive guiding by enabling GPG guiding. This adaptively models the periodic error of the mount, and adds its predicted contribution to each guide pulse. Optionally, by enabling Dark Guiding, it can output the predicted corrections much faster than the guide camera exposure rate, effectively performing periodic error correction and allowing longer guide camera exposures.

5.8.8.10 PHD2 Support

You can opt to select external PHD2 application to perform guiding instead of the built-in guider.
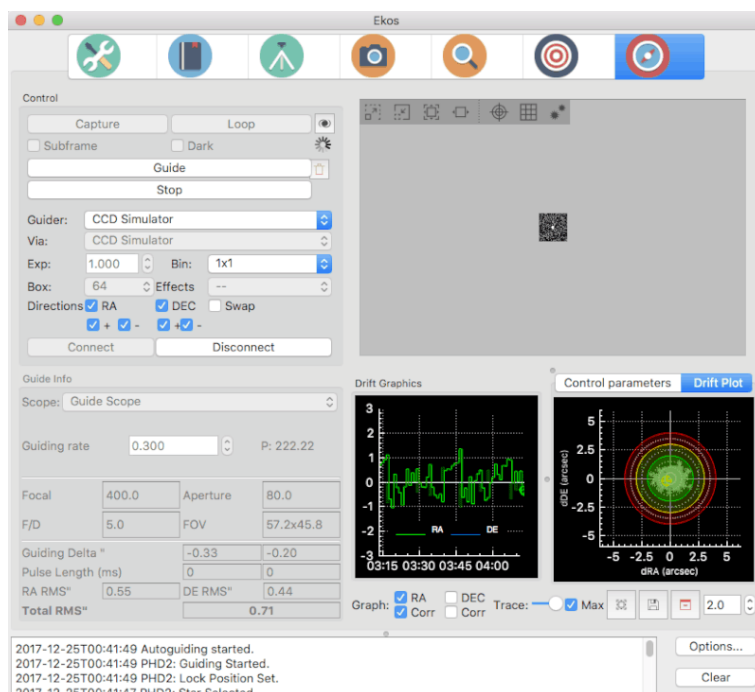
If PHD2 is selected, the **Connect** and **Disconnect** buttons are enabled to allow you to establish a connection with the PHD2 server. You can control PHD2 exposure and DEC guide settings. When clicking **Guide**, PHD2 should perform all the required actions to start the guiding process. PHD2 **must** be started and configured *before* Ekos.

After launching PHD2, select your INDI equipment and set their options. From Ekos, connect to PHD2 by clicking the **Connect** button. On startup, Ekos will attempt to automatically connect to PHD2. Once the connection is established, you may begin the guiding immediately by click on the **Guide** button. PHD2 shall perform calibration if necessary. If dithering is selected, PHD2 shall be commanded to dither given the offset pixels indicated and once guiding is settled and stable, the capture process in Ekos shall resume.

> NOTE
> Ekos saves a CSV guide log data that can be useful for analysis of the mount's performance under `~/.local/share/kstars/guide_log.txt`. This log is only available when using the built-in guider.

5.8.9 Align

5.8.9.1 Introduction
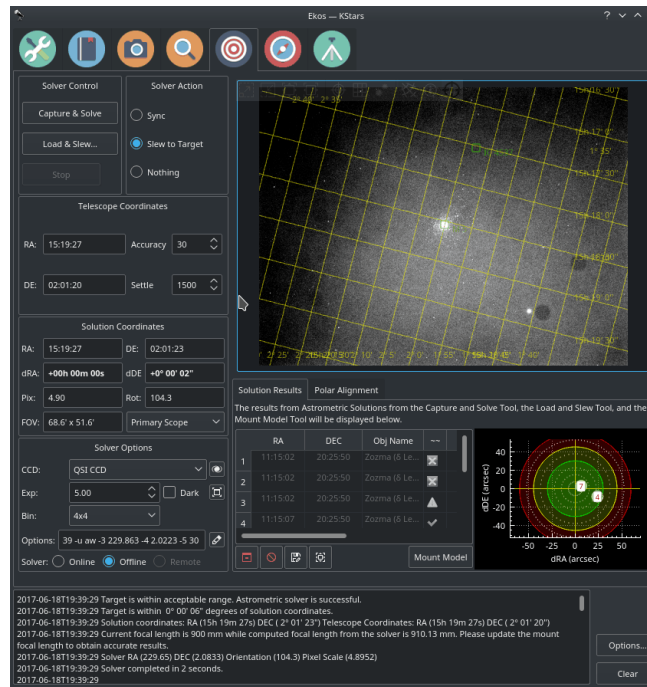
Ekos Alignment Module enables highly accurate GOTOs to within sub-arcseconds accuracy and can measure and correct polar alignment errors. This is possible thanks to the astrometry.net solver. Ekos begins by capturing an image of a star field, feeding that image to astrometry.net solver, and getting the central coordinates (RA, DEC) of the image. The solver essentially performs a pattern recognition against a catalog of millions of stars. Once the coordinates are determined, the true pointing of the telescope is known.

Often, there is a discrepancy between where the telescope thinks it is looking at and where it is truly pointing. The magnitude of this discrepancy can range from a few arcminutes to a couple of degrees. Ekos can then correct the discrepancy by either syncing to the new coordinates, or by slewing the mount to the desired target originally requested.

Furthermore, Ekos provides a Polar Alignment Assistant Tool to correct polar alignment errors. It takes three images, slewing between the images, and calculates the offset between the mount axis and polar axis. It feeds back to the user the altitude and azimuth adjustments needed to align these axes. These images are typically taken near the celestial pole (Close to Polaris for Northern Hemisphere) but can work well taken from anywhere, usually starting near the meridian and slewing either East or West.

At a minimum, you need a CCD/Webcam and a telescope that supports Slew & Sync commands. Most popular commercial telescope nowadays support such commands.

For the Ekos Alignment Module to work, you have an option of either utilizing the *online* astrometry.net solver, *offline*, or *remote* solver:

- **Online Solver**: The online solver requires no configuration, and depending on your Internet bandwidth, it might take a while to upload and solve the image.

- **Offline Solver**: The offline solver can be faster and requires no Internet connection. In order to use the offline solver, you must install astrometry.net in addition to the necessary index files.

- **Remote Solver**: The remote solver is an offline solver the resides on a different machine (for example, you can use Astrometry solver on StellarMate). Captured images are solved on the remote machine.

5.8.9.2 Get astrometry.net

If you are planning to use *Offline* astrometry then you need to download astrometry.net application.

> **NOTE**
> Astrometry.net is already shipped with StellarMate so there is no need to install it. Index files from 16 arcminutes and above (4206 to 4019) are included with StellarMate. For any additional index files, you need to install them as necessary. To use Astrometry in StellarMate from a remote Ekos on Linux®/Windows®/Mac® OS, make sure to select **Remote** option in Ekos Alignment Module. Furthermore, make sure that the **Astrometry** driver is selected in your equipment profile.
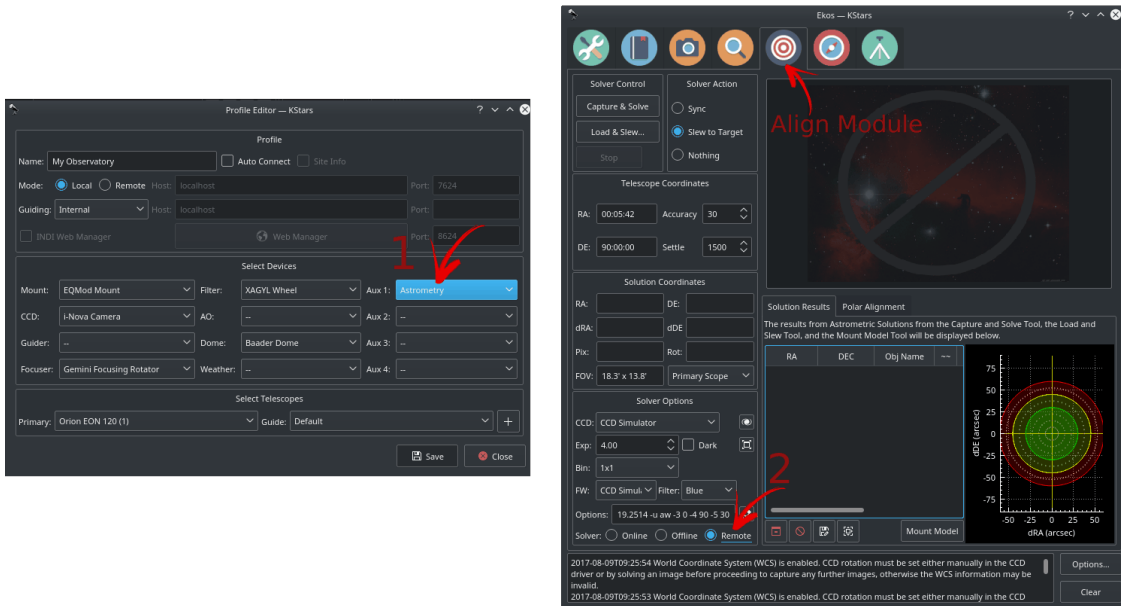
Windows®

To use astrometry.net under Windows®, you need to download and install the ANSVR Local Astrometry.net solver. The ANSVR mimics the astrometry.net online server on your local computer; thus the internet not required for any astrometry queries.

After installing the ANSVR server and downloading the appropriate index files for your setup, make sure ANSVR server is up and running and then go to Ekos Alignment options where you can simply change the **API URL** to use the ANSVR server as illustrated below:
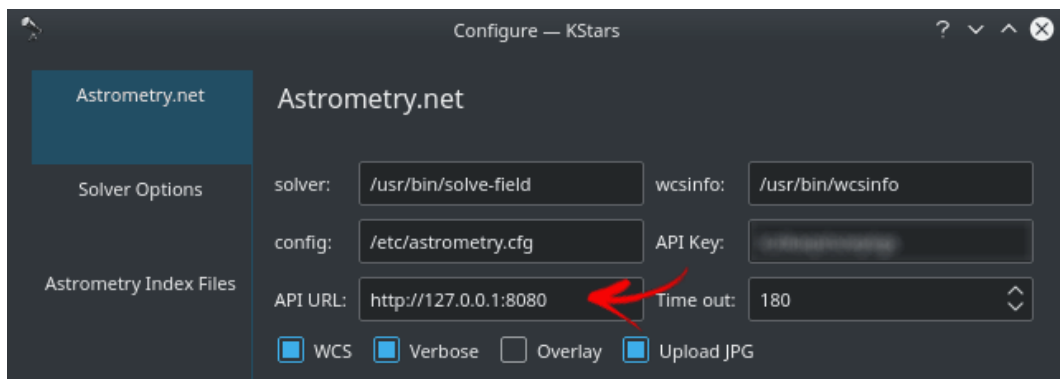
In Ekos Align module, you must set the solver type to **Online** so that it uses the local ANSVR server for all astrometry queries. Then you can use the align module as you would normally do.

Remember as indicated above that StellarMate *already* includes astrometry.net. Therefore, if you would like to use StellarMate remotely to solve your images, simply change solver type to **Remote** and ensure that your equipment profile includes **Astrometry** driver which can be selected under the **Auxiliary** dropdown. This is applicable to all operating systems and not just Windows®.

Mac® OS

Astrometry.net is already included with KStars for Mac® OS, so no need to install it.

Linux®

Astrometry.net is already included with KStars bleeding version. But if astrometry is not installed, then you can install it by running the following command under Ubuntu™:

sudo apt-get install astrometry.net

5.8.9.3 Download Index Files

For offline (and remote) solvers, index files are necessary for the solver to work. The complete collection of index files is huge (over 30 GB), but you only need to download what is necessary for your equipment setup. Index files are sorted by the Field-Of-View (FOV) range they cover. There are two methods to fetch the necessary index files: The new download support in Align module, and the old manual way.

5.8.9.3.1 Automatic Download
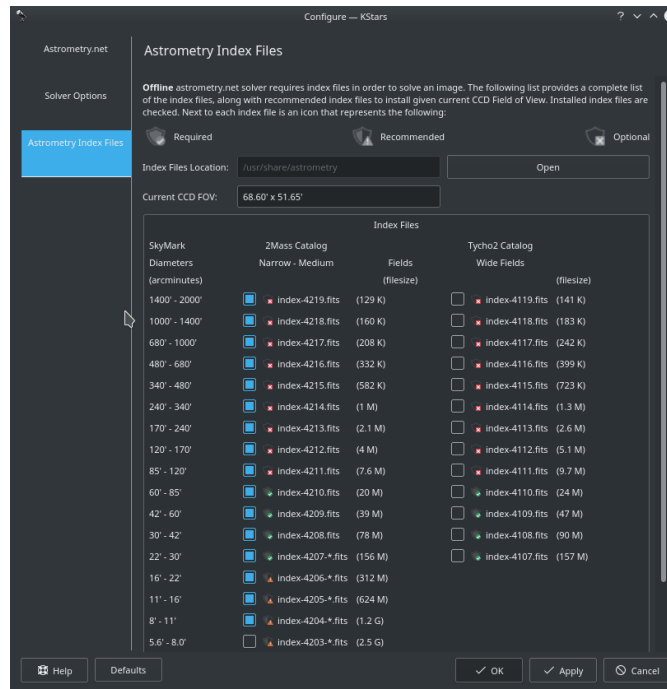
Automatic download is only available for Ekos users on Linux® & Mac® OS. For Windows® users, please download ANSVR solver.

To access the download page, click the **Options** button in the [Align module](#) and then select **Astrometry Index Files** tab. The page displays the current FOV of your current setup and below

it a list of available and installed index files. Three icons are used to designate the importance of index files given your current setup as follows:

- ⬤ **Required**

- ⬤ **Recommended**

- ⬤ **Optional**

You must download all the required files, and if you have plenty of hard drive space left, you can also download the recommended indexes. If an index file is installed, the checkmark shall be checked, otherwise check it to download the relevant index file. Please only download one file at a time, especially for larger files. You might be prompted to enter the administrator password (default in StellarMate is **smate**) to install the files. Once you installed all the required files, you can begin using the offline astrometry.net solver immediately.

5.8.9.3.2 Manual Download

You need to download and install the necessary index files suitable for your telescope+CCD field of view (FOV). You need to install index files covering 100% to 10% of your FOV. For example, if your FOV is 60 arcminutes, you need to install index files covering skymarks from 6 arcminutes (10%) to 60 arcminutes (100%). There are many online tools to calculate FOVs, such as Starizona Field of View Calculator.

Index Filename	FOV (arcminutes)	Debian Package
index-4219.fits	1400 - 2000	astrometry-data-4208-4219
index-4218.fits	1000 - 1400	
index-4217.fits	680 - 1000	
index-4216.fits	480 - 680	
index-4215.fits	340 - 480	
index-4214.fits	240 - 340	
index-4213.fits	170 - 240	
index-4212.fits	120 - 170	
index-4211.fits	85 - 120	
index-4210.fits	60 - 85	
index-4209.fits	42 - 60	
index-4208.fits	30 - 42	
index-4207-*.fits	22 - 30	astrometry-data-4207
index-4206-*.fits	16 - 22	astrometry-data-4206
index-4205-*.fits	11 - 16	astrometry-data-4205
index-4204-*.fits	8 - 11	astrometry-data-4204
index-4203-*.fits	5.6 - 8.0	astrometry-data-4203
index-4202-*.fits	4.0 - 5.6	astrometry-data-4202
index-4201-*.fits	2.8 - 4.0	astrometry-data-4201-1astrometry-data-4201-2astrometry-data-4201-3astrometry-data-4201-4
index-4200-*.fits	2.0 - 2.8	astrometry-data-4200-1astrometry-data-4200-2astrometry-data-4200-3astrometry-data-4200-4

Table 5.1: Index Files

The Debian packages are suitable for any Debian-based distribution (Ubuntu, Mint, etc.). If you downloaded the Debian Packages above for your FOV range, you can install them from your favorite package manager, or via the following command:

sudo dpkg -i astrometry-data-*.deb

On the other hand, if you downloaded the FITS index files directly, copy them to `/usr/share/as trometry` directory.

> NOTE
> It is recommended to use a download manager as such DownThemAll! for Firefox to download the Debian packages as browsers' built-in download manager may have problems with download large packages.

5.8.9.4 How to Use?

Ekos Align Module offers multiple functions to aid you in achieving accurate GOTOs. Start with your mount in home position with the telescope tube looking directly at the celestial pole. For users in Northern Hemisphere, point the telescope as close as possible to Polaris. It is not necessary to perform 2 or 3 star alignments, but it can be useful for some mount types. Make sure your camera is focused and stars are resolved.

- **Capture & Solve**: Capture an image and determine what region in the sky the telescope is exactly looking at. The astrometry results include the equatorial coordinates (RA & DEC) of the center of the captured image in addition to pixel scale and field rotation. Depending on the Solver Action settings, the results can be used to Sync the mount or Sync and then Slew to the target location. For example, suppose you slewed the mount to Vega then used *Capture & Solve*. If the actual telescope location is different from Vega, it will be first synced to the solved coordinate and then Ekos shall command the mount to slew to Vega. After slew is complete, the Alignment module will repeat Capture & Solve process again until the error between reported and actual position falls below the accuracy thresholds (30 arcseconds by default).

- **Load & Slew**: Load a FITS or JPEG file, solve it, and then slew to it.

- **Polar Alignment Assistant**: A simple tool to aid in polar alignment of German Equatorial Mounts.

> WARNING
> **Never** solve an image at or near the celestial pole (unless Ekos Polar Alignment Assistant Tool is used). Slew at least 20 degrees away from the celestial pole before solving the first image. Solving very close to the poles will make your mount pointing worse so avoid it.

5.8.9.5 Alignment Settings
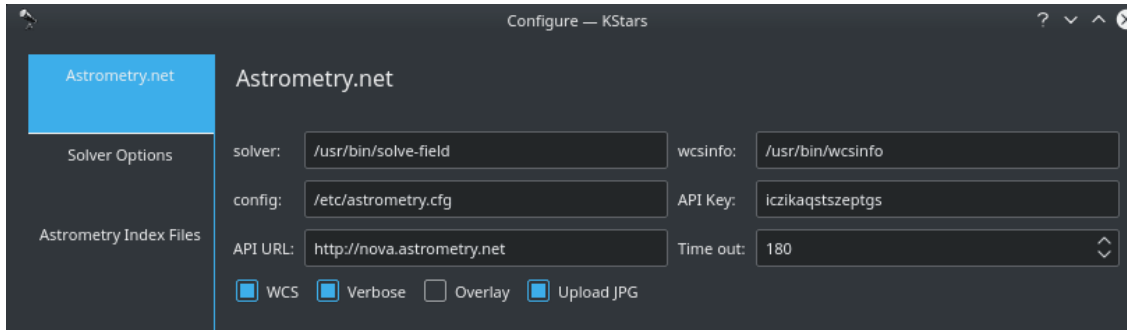
Before you begin the alignment process, select the desired CCD & Telescope. You can explore astrometry.net options that are passed to the astrometry.net solver each time an image is captured:

- **CCD**: Select CCD to capture from.

- **Exposure**: Exposure duration in seconds.

- **Accuracy**: Acceptable difference between reported telescope coordinate and actually solved coordinate.

- **Bin X**: Set horizontal binning of the CCD.

- **Bin Y**: Set vertical binning of the CCD.

- **Scope**: Set the active telescope in case you have different Primary and Guide scopes. FOV is re-calculated when selecting a different telescope.

- **Options**: Options that are passed to the astrometry.net solver. Click the edit button ✎ to explore the options in detail.

- **Solver**: Select solver type (Online, Offline, Remote). The remote solver is only available when connecting to a remote device.

By default, the solver will search all over the sky to determine the coordinates of the captured image. This can *take a lot of time*; therefore, in order to speed up the solver, you can restrict it to only search within a specified area in the sky designated by the **RA**, **DEC**, and **Radius** options above.

5.8.9.6 Astrometry.net Options

Options for offline and online solvers.
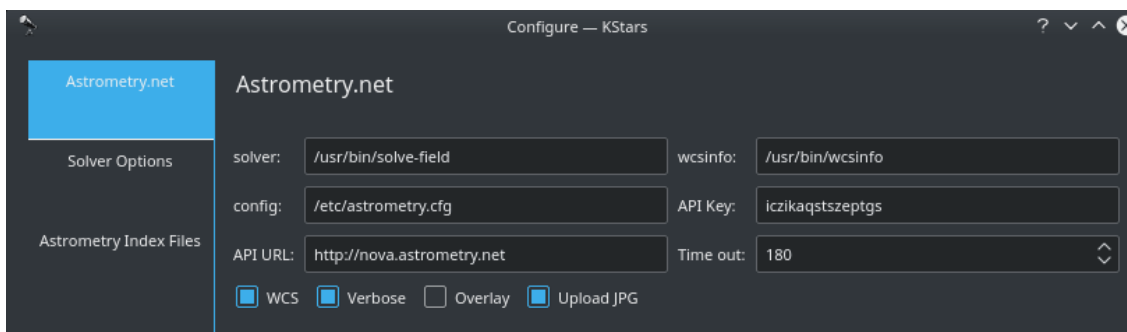
Most of the options are sufficient by default. If you have astrometry.net installed in a non-standard location, you can change the paths as necessary.

- **WCS**: World-Coordinate-System is a system for embedding equatorial coordinate information within the image. Therefore, when you view the image, you can hover it and view the coordinate for each pixel. You can also click anywhere in the image and command to the telescope to slew there. It is highly recommended to keep this option on.

- **Verbose**: If the solver repeatedly fails to solve, check this option to enable *verbose* output of the solver to help you identify any problems.

- **Overlay**: Overlay captured images unto the sky map of KStars.

- **Upload JPG**: When using online astrometry.net, upload all images are JPEGs to save bandwidth as FITS images can be large.

5.8.9.7 Solver Options

Ekos selects and updates the optimal options by default to accelerate the performance of the solver. You may opt to change the options that are passed to the solver in case the default options are not sufficient.
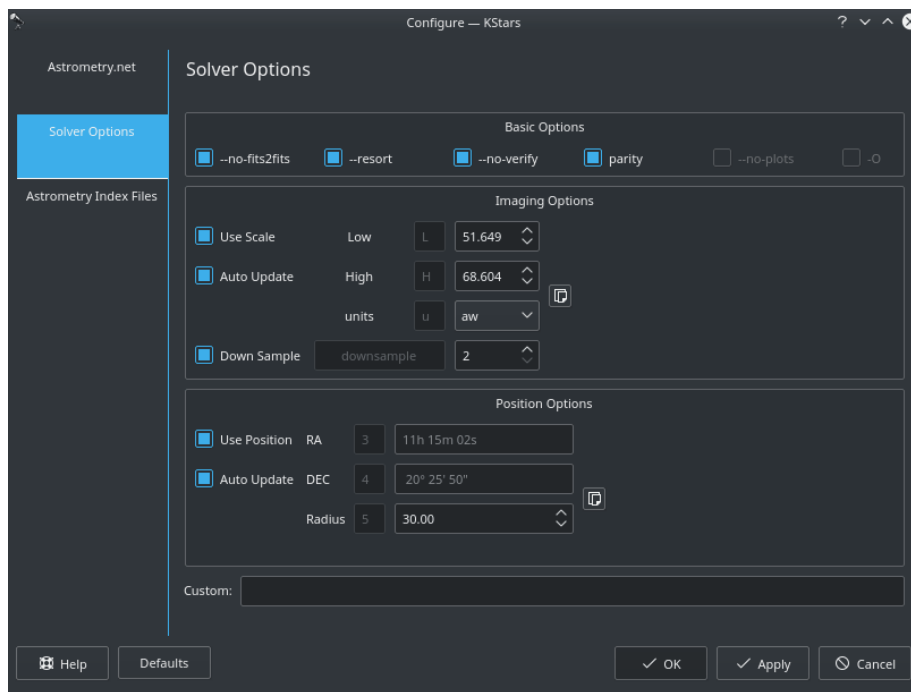
5.8.9.8 Capture & Solve

Using Ekos Alignment Module, aligning your mount using the controller's 1, 2, or 3 star alignment is *not* strictly necessary, though for some mounts it is recommended to perform a rough 1 or 2 star alignment before using Ekos alignment module. If you are using EQMod, you can start using Ekos alignment module right away. A typical workflow for GOTO alignment involves the following steps:

1. Set your mount to its home position (usually the NCP for equatorial mounts).

2. Select **Slew to Target** in the **Solver Action**.

3. Slew to a nearby bright star.

4. After slew is complete, click **Capture & Solve**.

If the solver is successful, Ekos will sync and then slew to the star. The results are displayed in the **Solution Results** tab along with a bullseye diagram that shows the offset the reported telescope coordinates (i.e. where the telescope *thinks* it is looking at) vs. its actual position in the sky as determined by the solver.

Each time the solver is executed and returns successful results, Ekos can run on the following actions:

- **Sync**: Syncs the telescope coordinates to the solution coordinates.

- **Slew to Target**: Syncs the telescope coordinates to the solution coordinates and then slew to the target.

- **Nothing**: Just solve the image and display the solution coordinates.

5.8.9.9 Polar Alignment

When setting up a German Equatorial Mount (GEM) for imaging, a critical aspect of capturing long-exposure images is to ensure proper polar alignment. A GEM mount has two axis: Right Ascension (RA) axis and Declination (DE) axis. Ideally, the RA axis should be aligned with the celestial sphere polar axis. A mount's job is to track the star's motion around the sky, from the moment they rise at the eastern horizon, all the way up across the median, and westward until they set.

https://www.stellarmate.com/images/videos/polar_align.webm

Polar Alignment Assistant

In long exposure imaging, a camera is attached to the telescope where the image sensor captures incoming photons from a particular area in the sky. The incident photons have to strike the same photo-site over and over again if we are to gather a clear and crisp image. Of course, actual photons do not behave in this way: optics, atmosphere, seeing quality all scatter and refract photons in one way or another. Furthermore, photons do not arrive uniformly but follow a Poisson distribution. For point-like sources like stars, a point spread function describes how photons are spatially distributed across the pixels. Nevertheless, the *overall* idea we want to keep the source photons hitting the same pixels. Otherwise, we might end up with an image plagued with various trail artifacts.
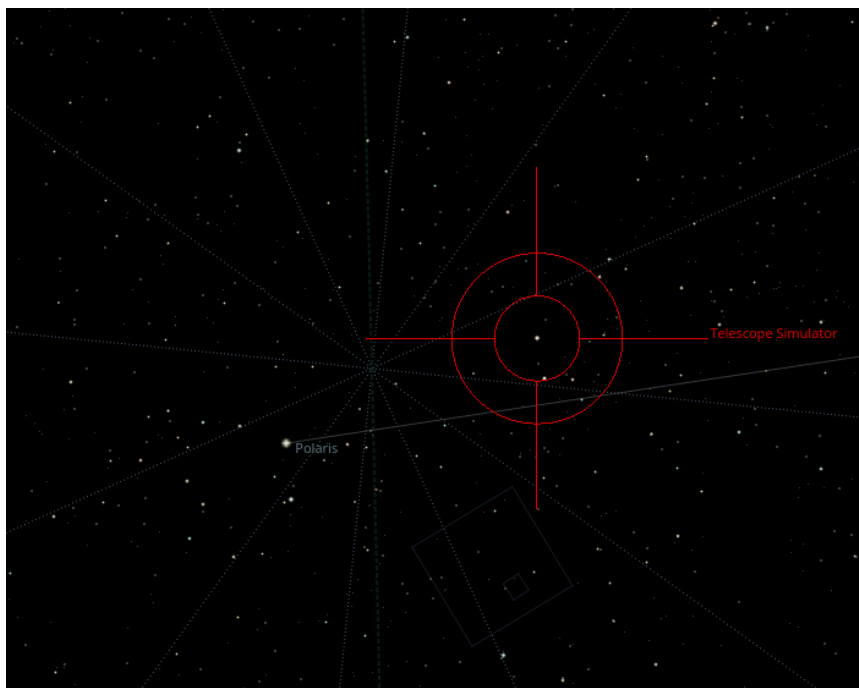
Since mounts are not perfect, they cannot perfectly keep track of object as it transits across the sky. This can stem from many factors, one of which is the misalignment of the mount's Right Ascension axis with respect to the celestial pole axis. Polar alignment removes one of the biggest sources of tracking errors in the mount, but other sources of error still play a factor. If properly aligned, some mounts can track an object for a few minutes with the only deviation of 1-2 arcsec RMS.

However, unless you have a top of the line mount, then you'd probably want to use an autoguider to keep the same star locked in the same position over time. Despite all of this, if the axis of the mount is not properly aligned with the celestial pole, then even a mechanically-perfect mount would lose tracking with time. Tracking errors are proportional to the magnitude of the misalignment. It is therefore very important for long exposure imaging to get the mount polar aligned to reduce any residual errors as it spans across the sky.

Before starting the process, point the mount as close as possible to the celestial pole with the counterweights down. If you are living in the Northern Hemisphere, point it as close as possible to Polaris. If Polaris is not visible (e.g. blocked by trees or buildings) you may point elsewhere, preferably near the Meridian. Make sure there is at least 30-60 degrees of sky viewable in an arc East or West of the Meridian from the position you choose. Select the direction of free sky, the number of degrees for each of two slews, the mount slew speed, and whether the mount will be slewing automatically (recommended) or manually.

The tool works by capturing and solving three images. After capturing each, the mount rotates by the fixed amount you entered and another image is captured and solved. If you chose manual, you will need to slew the mount by roughly the angle chosen.
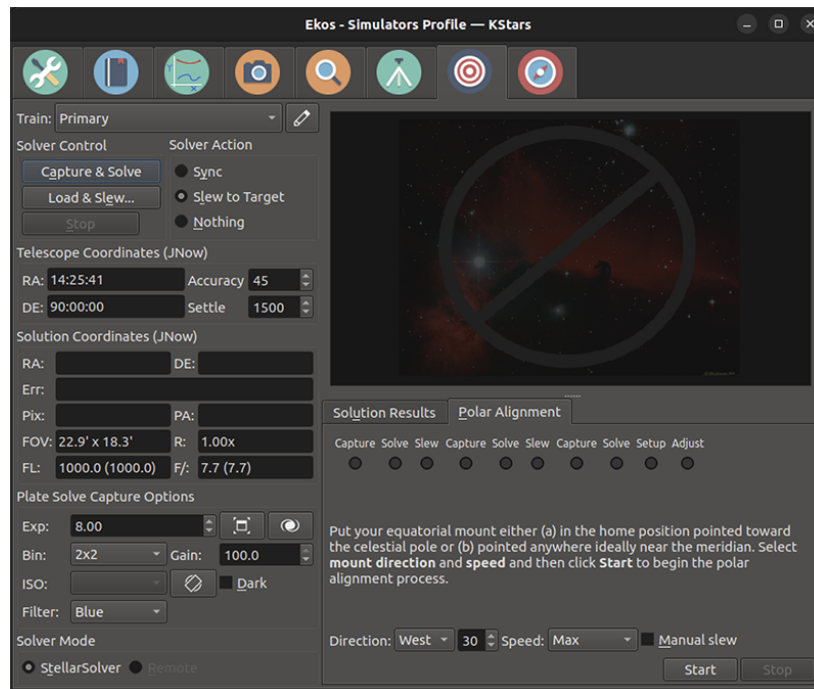
5.8.9.9.1 Plate Solve Correction Scheme

The images below show the workflow when the *Plate Solve* correction technique is used. The image below shows a display after the 3 measurement images are captured and solved. It shows an error of almost 18′ in altitude and that the mount's axis needs to be moved up. Similarly it shows an azimuth error of almost 15′ and that the axis needs to be moved to the right (as viewed from behind the telescope).
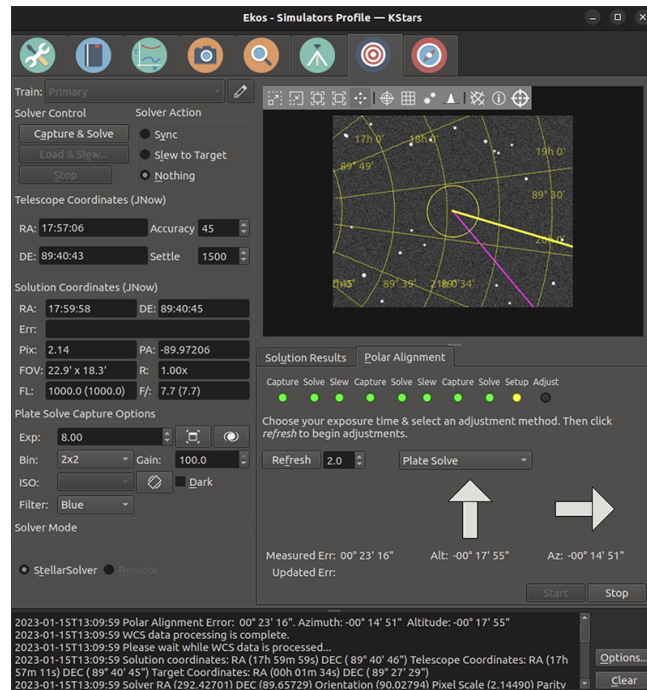
If your error is low enough (e.g. less than an arc-minute) then you don't need to make any adjustments. Simply press stop and you're done.

If you will be making corrections to your mount's axis, you should select the adjustment approach (we're using Plate Solve in this example), and how often the system should recapture images to re-measure the polar alignment error. The refresh interval should be frequent, but it doesn't make sense to make it faster that your CPU can capture and plate-solve the images. We're using 2s in this example. Then press the **Refresh** button to begin the correction process.

The system will capture images, and re-estimate the polar alignment error after each image. You can try to reduce the error by adjusting the Altitude and Azimuth correction knobs on your mount. The image below shows the screen after the altitude error has been almost zeroed. See the difference between the *Measured Error* row, which shows the originally measured error after the original 3 captures, and the *Updated Error* row which shows the current error estimate.
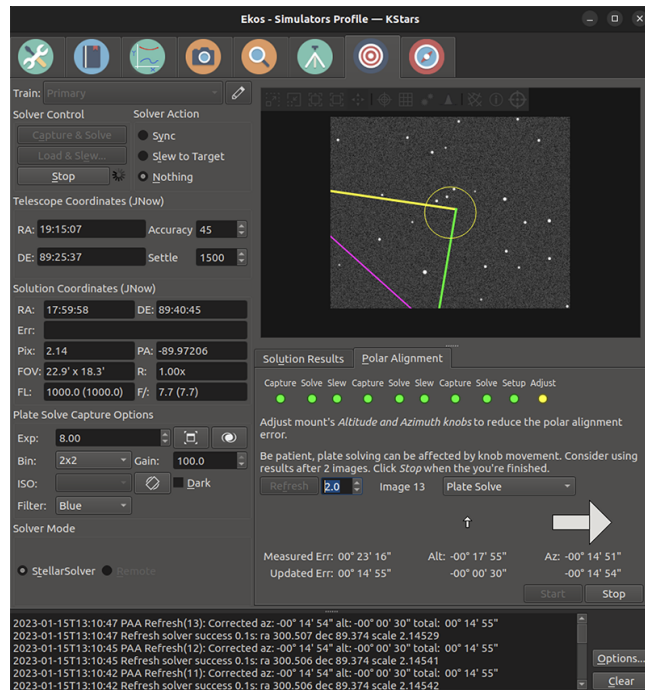
Below the user has also adjust Azimuth to reduce the error further. Now the error is very low and the process is done. The user should press the stop button.
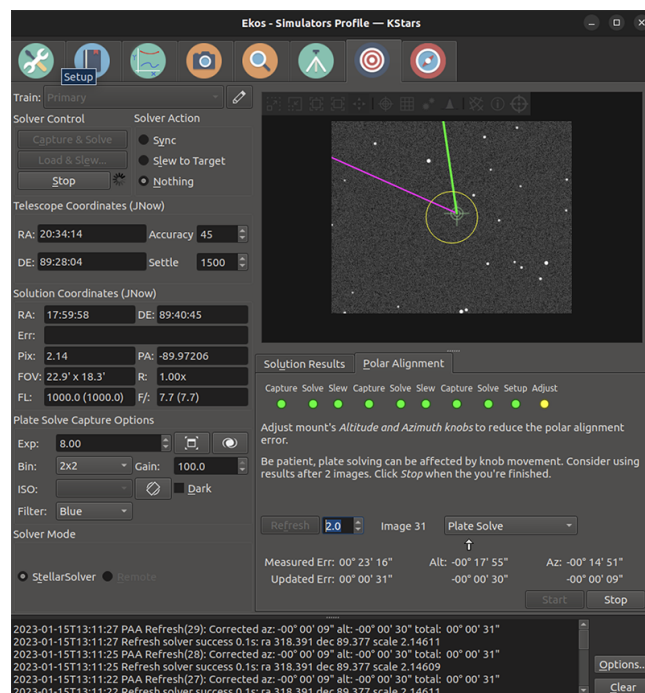
5.8.9.9.2 Move Star Correction Scheme

We also have an alternative schemes for correcting polar alignment. Two variations are *Move Star & Calc Error* and *Move Star*. When you select this scheme, the system place a yellow/green/violet triangle on the screen. The triangle can be moved by clicking near a star, and the yellow/violet corner is moved to that star. In this scheme the user corrects polar alignment by first adjusting the mount's azimuth knob so that the selected star moves along the yellow side of the triangle.

Once the star is near the next vertex, the azimuth knob should be adjusted so that the star moves along the green side of the triangle. Once the star is moved to the green/violet vertex, the mount is polar aligned, and the user can click *stop*.

The difference between *Move Star & Calc Error* and *Move Star* is that in the former, the system attempts to track the star the user has selected, and places a circle around that star. In that scheme it also attempts to update the *Updated Err* row. If the star tracking isn't reliable, simply ignore it or use the *Move Star* scheme and move the star by-eye until it's close to the final target. An example of using this technique is shown in this video: https://www.youtube.com/watch?v=iOp7hrxw0oU
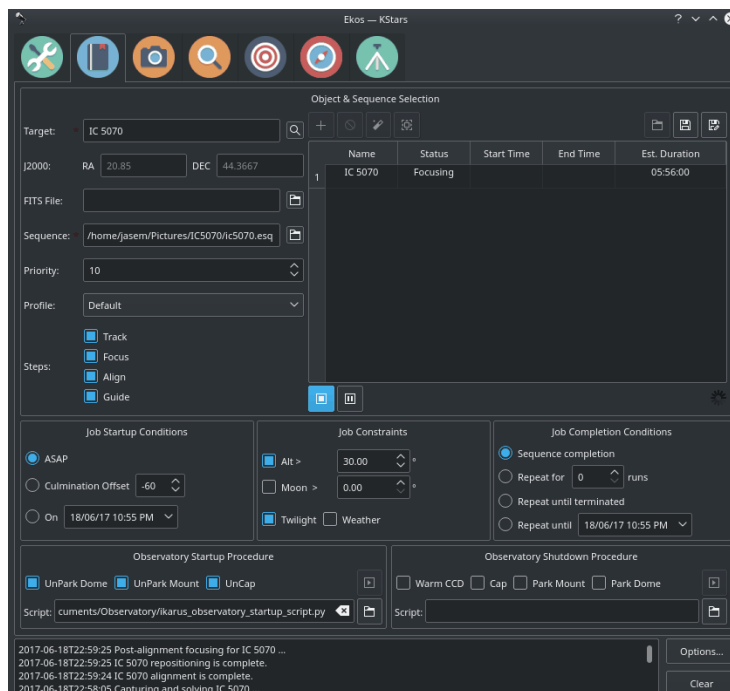
5.8.10 Scheduler

5.8.10.1 Introduction

Ekos Scheduler is an indispensable arsenal in building your robotic observatory. A Robotic observatory is an observatory composed of several subsystems that are orchestrated together to achieve a set of scientific objectives without human intervention. It is the only Ekos module that does not require Ekos to be started as it is utilized to *start* and *stop* Ekos. It is designed to be straightforward and intuitive. However, the scheduler should only be used after you mastered Ekos and knows all the quirks of your equipment. Since the complete process is automated, including focus, guiding, and meridian flip, all equipment should be thoroughly used with Ekos and all their parameters and settings adjusted to achieve the best result.

With Ekos, the user can utilize the powerful sequence queue to image batches of images for a particular target. In simple setups, the user is expected to focus the CCD, align the mount, frame the target, and start guiding before initiating the capture process. For more complex observatory environments, there are usually predefined custom procedures to be executed to prepare the observatory for imaging, and another set of procedures on shutdown. The user may plan to image one or more targets during the night and expects data to be ready by morning. In KStars, tools such as the Observation Planner and What's up Tonight help the user in selecting candidates for imaging. After selecting the desired candidates, the user can add them to the Ekos Scheduler list for evaluation. The user may also add the targets directly in Ekos scheduler or select a FITS file of a previous image.

5.8.10.2 Settings

Ekos Scheduler provides a simple interface to aid the user in setting the conditions and constraints required for an observation job. Each observation job is composed of the following:

- **Target name and coordinates**: Select target from the Find Dialog or **Add** it from Observation Planner. You can also enter a custom name.

- Optional **FITS File**: If a FITS file is specified, the astrometry solver shall solve the file and use the central RA/DEC as the target coordinates.

- **Sequence** file: The sequence file is constructed in the Ekos Capture Module. It contains the number of images to capture, filters, temperature settings, prefixes, download directory, etc.

- **Priority**: Set job priority in the range of 1 to 20 where 1 designates the highest priority and 20 the lowest priority. Priority is applied in calculating the weight used to select the next target to image.

- **Profile**: Select which equipment profile to utilize when starting Ekos. If Ekos & INDI are already started and online, this selection is ignored.

- **Steps**: The user selects which Ekos modules should be utilized in the observation job execution workflow.

- **Startup Conditions**: Conditions that must be met **before** the observation job is started. Currently, the user may select to start as soon as possible, **ASAP**, or when the target is near or past culmination, or at a specific time.

- **Constraints**: Constraints are conditions that must be met **at all times** during the observation job execution process. These include minimum target altitude, minimum moon separation, twilight observation, artificial horizon altitude constraints, and weather monitoring.

- **Completion Conditions**: Conditions that trigger completion of the observation job. The default selection is to simply mark the observation job as complete once the sequence process is complete. Additional conditions enable the user to repeat the sequence process indefinitely or up until a specific time.

You must select the **Target** and **Sequence** before you can add a job to the Scheduler. When the scheduler starts, it evaluates all jobs in accord to the conditions and constraints specified and attempts to select the best job to execute. Selection of the job depends on a simple heuristic algorithm that scores each job given the conditions and constraints, each of which is weighted accordingly. If two targets have identical conditions and constraints, usually the higher priority target followed by higher altitude target is selected for execution. If no candidates are available at the current time, the scheduler goes into sleep mode and wakes up when the next job is ready for execution.
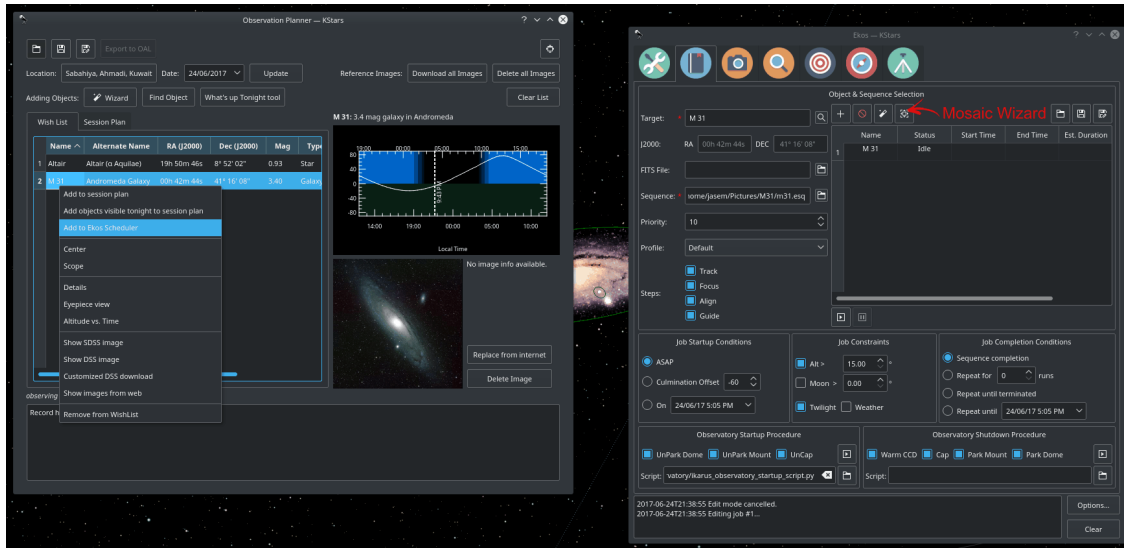
The description above only tackles the **Data Acquisition** stage of the observatory workflow. The overall procedure typically utilized in an observatory can be summarized in three primary stages:

1. Startup

2. Data Acquisition (including preprocessing and storage)

3. Shutdown

5.8.10.3 Startup Procedure

Startup procedure is unique to each observatory but may include:

- Turning on power to equipment

- Running safety/sanity checks

- Checking weather conditions

- Turning off light

- Fan/Light control

- Unparking dome

- Unparking mount

- etc.

Ekos Scheduler only initiates the startup procedure once the startup time for the first observation job is close (default *lead* time is 5 minutes before *startup* time). Once the startup procedure is completed successfully, the scheduler picks the observation job target and starts the sequence process. If a startup script is specified, it shall be executed first.

5.8.10.4 Data Acquisition

Depending the on the user selection, the typical workflow proceeds as follows:

- Slew mount to target. If a FITS file was specified, it first solves the files and slew to the file coordinates.

- Auto-focus target. The autofocus process automatically selects the best star in the frame and runs the autofocus algorithm against it.

- Perform plate solving, sync mount, and slew to target coordinates.

- Perform post-alignment focusing since the frame might have moved during the plate solving process.

- Perform calibration and start auto-guiding: The calibration process automatically selects the best guide star, performs calibration, and starts the autoguide process.

- Load the sequence file in the Capture module and start the imaging process.

5.8.10.5 Shutdown

Once the observation job is completed successfully, the scheduler selects the next target. If the next target scheduled time is not due yet, the mount is parked until the target is ready. Furthermore, if the next scheduled target is not due for a user-configurable time limit, the scheduler performs a *preemptive* shutdown to preserve resources and performs the startup procedure again when the target is due.

If an unrecoverable error occurs, the observatory initiates shutdown procedure. If there is a shutdown script, it will be executed last.

The following video demonstrates an earlier version of the scheduler, but the basic principles still apply today:

https://www.youtube.com/embed/v8vIXD1kois

Ekos Scheduler

5.8.10.6 Weather Monitoring

Another critical feature of any remotely operated robotic observatory is weather monitoring. For weather updates, Ekos relies on the selected INDI weather driver to continuously monitor the weather conditions. For simplicity sake, the weather conditions can be summed in three states:

1. **Ok**: Weather conditions are clear and optimal for imaging.

2. **Warning**: Weather conditions are not clear, seeing is subpar, or partially obstructed and not suitable for imaging. Any further imaging process is suspended until the weather improves. Warning weather status does not pose any danger to the observatory equipment so the observatory is kept operational. The exact behavior to take under Warning status can be configured.

3. **Alert**: Weather conditions are detrimental to the observatory safety and shutdown must be initiated as soon as possible.

5.8.10.7 Startup & Shutdown Scripts

Due to the uniqueness of each observatory, Ekos enables the user to select startup and shutdown scripts. The scripts take care of any necessary procedures that must take place on startup and shutdown stages. On startup, Ekos executes the startup scripts and only proceeds to the remainder of the startup procedure (unpark dome/unpark mount) if the script completes successfully. Conversely, the shutdown procedure begins with parking the mount & dome before executing the shutdown script as the final procedure.

Startup and shutdown scripts can be written any language that can be executed on the local machine. It must return 0 to report success, any other exist value is considered an error indicator. The script's standard output is also directed to Ekos logger window. The following is an sample demo startup script in Python:

```python
#!/usr/bin/env python
# -*- coding: utf-8 -*-

import os
import time
import sys

print "Turning on observatory equipment..."
sys.stdout.flush()

time.sleep(5)

print "Checking safety switches..."
sys.stdout.flush()

time.sleep(5)

print "All systems are GO"
sys.stdout.flush()

exit(0)
```

The startup and shutdown scripts must be *executable* in order for Ekos to invoke them (e.g. use **chmod +x startup_script.py** to mark the script as executable). Ekos Scheduler enables truly simple robotic operation without the need of any human intervention in any step of the process. Without human presence, it becomes increasingly critical to gracefully recover from failures in any stage of the observation run. Using Plasma notifications, the user can configure audible alarms and email notifications for the various events in the scheduler.

5.8.10.8 Mosaic Planner
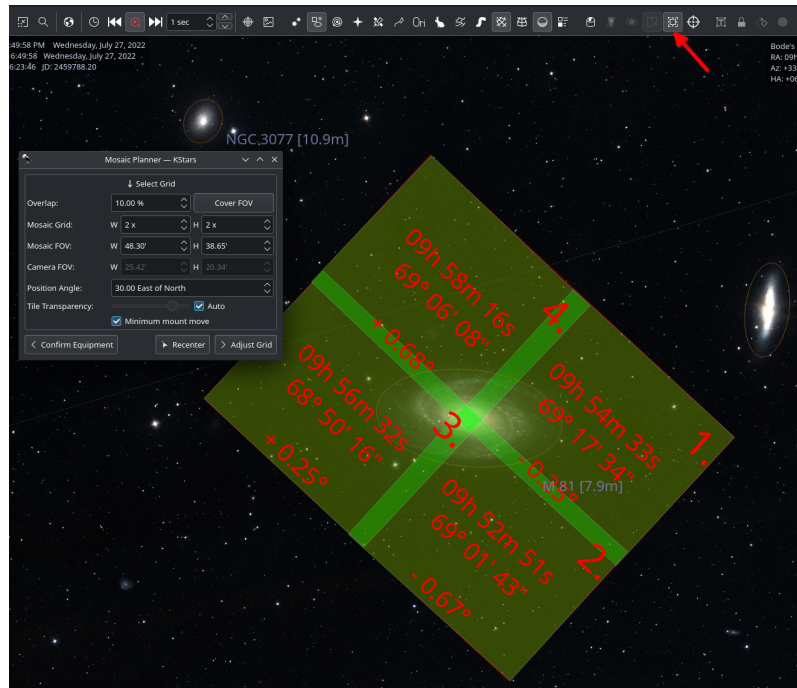
Hubble-like super wide field images of galaxies and nebulae are truly awe-inspiring, and while it takes great skills to obtain such images and process them; many notable names in the field of astrophotography employ gear that is not *vastly* different from yours or mine. I emphasize *vastly* because some do indeed have impressive equipment and dedicated observatories worth tens of the thousands of dollars. Nevertheless, many amateurs can obtain stellar wide-field images by combining smaller images into a single grand mosaic.

We are often limited by our camera+telescope Field of View (FOV). By increasing FOV by means of a focal reducer or a shorter tube, we gain a larger sky coverage at the expense of spatial resolution. At the same time, many attractive wide-field targets span multiple FOVs across the sky. Without any changes to your astrophotography gear, it is possible to create a super mosaic image *stitched* together from several smaller images. There are two major steps to accomplish a super mosaic image:

1. Capture multiple images spanning the target with some overlap between images. The overlap is necessary to enable the processing software from aligning and joining the sub-images.

2. Process the images and *stitch* them into a super mosaic image.

The 2nd step is handled by image processing applications such as PixInsight, among others, and will not be the topic of discussion here. The first step can be accomplished in Ekos Scheduler where it creates a mosaic suitable for your equipment and in accordance with the desired field of view. Not only Ekos creates the mosaic panels for your target, but it also constructs the corresponding observatory jobs required to capture all the images. This greatly facilitates the logistics of capturing many images with different filters and calibration frames across a wide area of the sky.

The **Mosaic Planner** in the Ekos Scheduler will create multiple Scheduler jobs based on a central target. To toggle the planner, click on the **Mosaic Planner** button in Ekos Scheduler or KStars INDI toolbar as illustrated in the screenshot. The planner draws the Mosaic Panel directly unto the sky map. It is recommended to enable HiPS overlay for the best experience. The planner is composed of four stages:

1. **Confirm Equipment**: Ekos attempts to load equipment settings from INDI. If unsuccessful, you need to enter your equipment settings including your telescope focal length in addition to camera's width, height, and pixel dimensions. The settings are saved for future sessions.
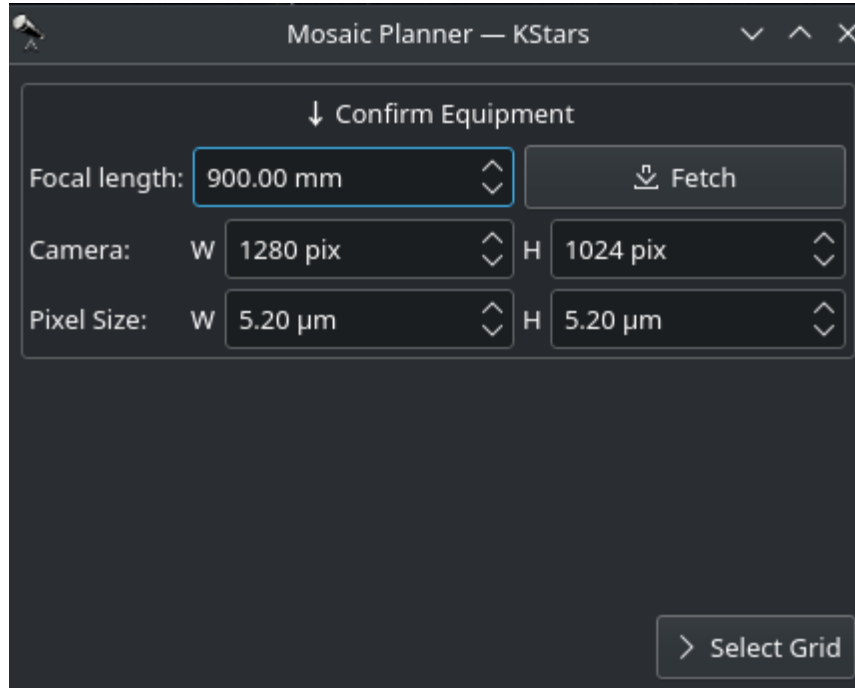
2. **Adjust Grid**: Select the mosaic panel dimension and overlap percentage. The Mosaic Panel is updated accordingly on the sky map. Adjust the Position Angle to match the desired mosaic orientation in the sky. If the Position Angle is different from your camera's usual orientation, you may need to rotate the camera either manually or via a mechanized rotator when the scheduler jobs are executed. Tile transparency is automatically calculated by default but may be turned off and adjusted manually. To compute the mosaic field from the number of tiles, click the **Cover FOV** button. The mosaic panel can be centered in the sky map by clicking on the **Recenter** button.
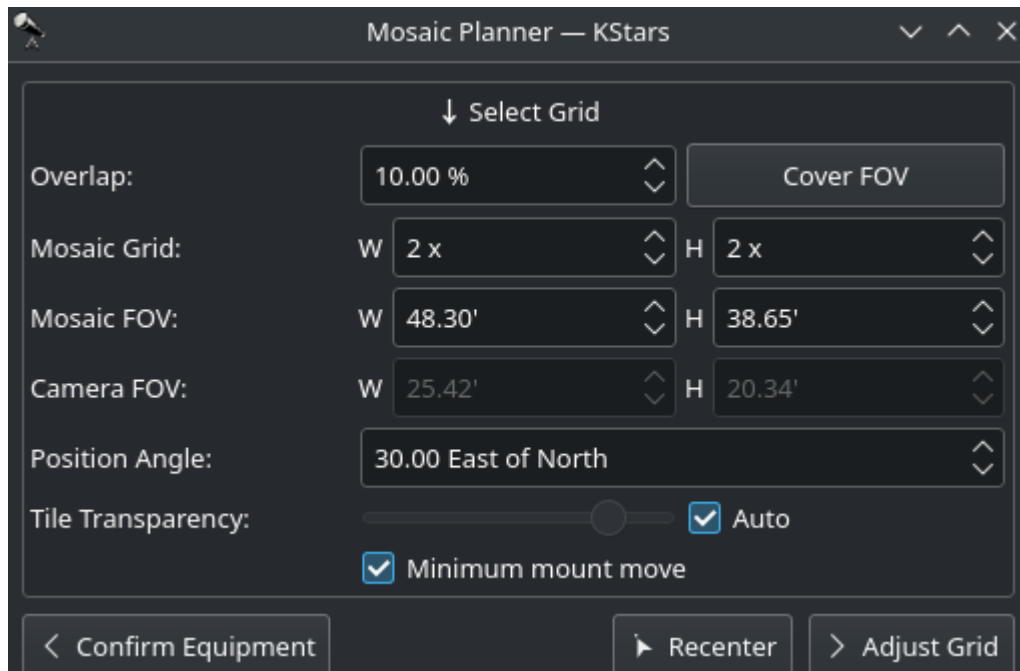
A large overlap will make frame stitching easier during post-processing, but it requires more panes to cover the desired extent. However, if you already know the minimal amount of sub-frames your rejection algorithm will use during post-processing, you may want to increase the overlap to attain that amount on the areas covered by multiple panes. For instance, a 4x4 mosaic grid with 75% overlap has 16 sub-frames covering the central intersection, which is enough for Winsorized Sigma rejection. Although the resulting stack does not have the same height on all parts of the final frame, this method gives you control on signal-to-noise ratio and allows you to provide context to your target while exposing a relatively low number of captures.

The large number drawn in the corner of each grid pane represents the order in which panes will be captured. The default S-shaped choice (west-east then alternating high-low/low-high moves), ensures minimal movement of the mount during observation. Uncheck **Minimum mount move** to revert to west-east/high-low movement only. The coordinates of each pane are rendered in their center as degrees, minutes and seconds. Finally, the angle each pane rotates from the center of the mosaic is displayed at the bottom. If your field of view is large, or if your mosaic is located close to a celestial pole, you may observe that rendered panes start rotating visibly due their horizontal position or high declination. Use the **overlap** to ensure panes cover the desired frame extents properly.
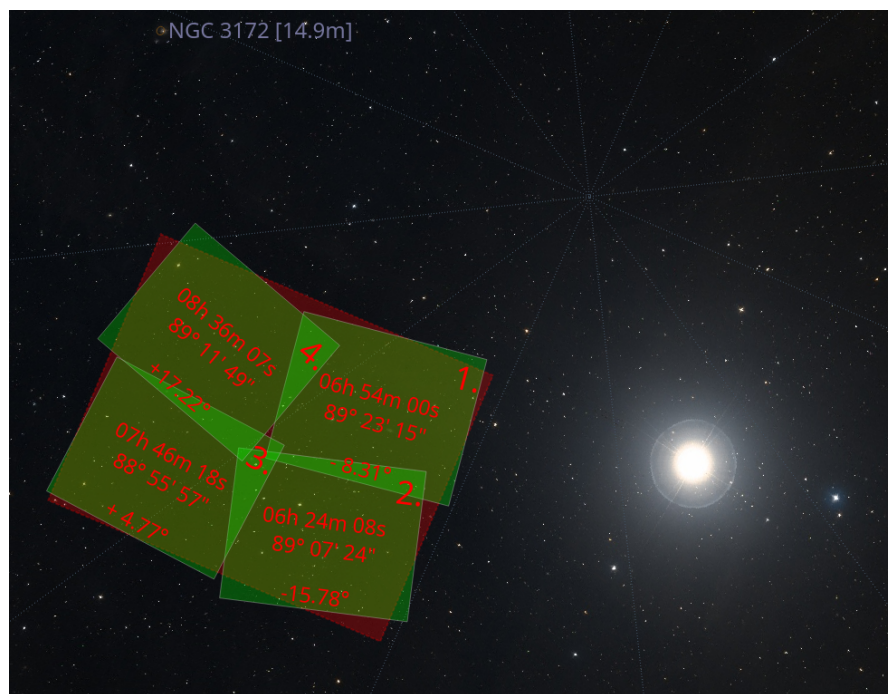
3. **Adjust Grid**: Adjust Grid center by manually entering the J2000 center or by dragging the center of the mosaic on the sky map.

4. **Create Jobs**: The final step is to select the sequence file and directory to store the images. Target field is automatically filled but may be changed as desired. Select the steps each scheduler job should execute in sequence (Track -> Focus -> Align -> Guide -> Capture), and adjust the frequency of automatic alignment and focus routines that must be executed during the mosaic operation. For example, if **Align Every** is set to 2 Scheduler Jobs, then the first job will run the astrometry alignment, while the second job will skip it. When the third job is executed, alignment is performed again and so forth.
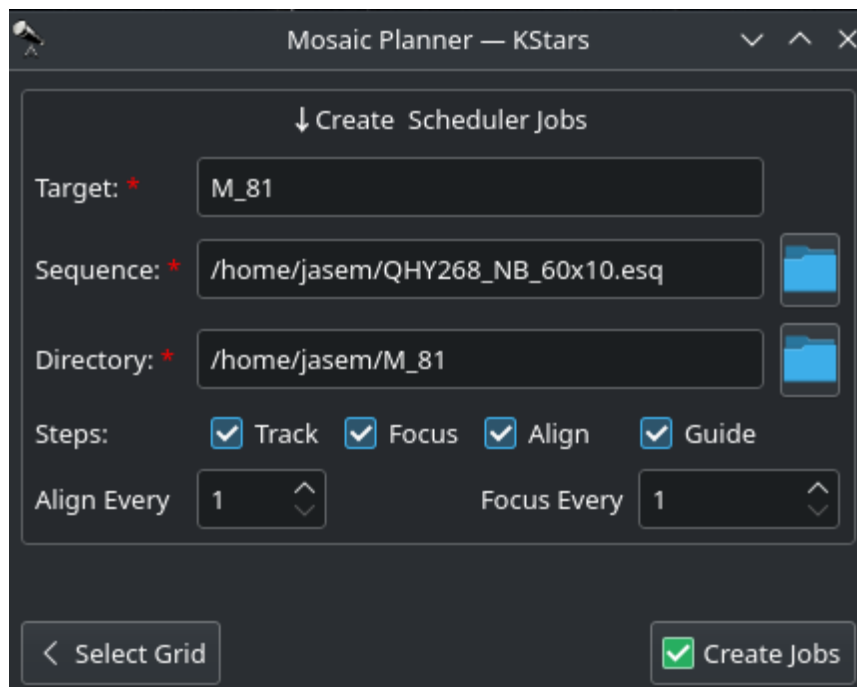
Click **Create Jobs** to generate mosaic scheduler jobs and add them to the schedule queue.

5.8.11 Analyze
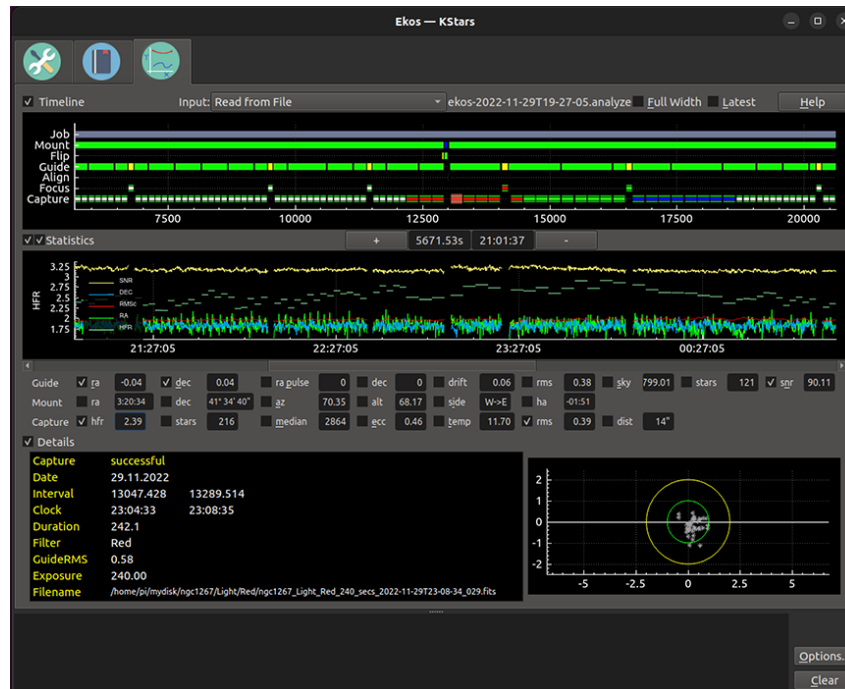
5.8.11.1 Introduction

The Analyze Module records and displays what happened in an imaging session. That is, it does not control any if your imaging, but rather reviews what occurred. Sessions are stored in an `analyze` folder, a sister folder to the main logging folder. The `.analyze` files written there can be loaded into the **Analyze** tab to be viewed. **Analyze** also can display data from the current imaging session.

There are two main graphs, **Timeline** and **Stats**. They are coordinated—they always display the same time interval from the Ekos session, though the x-axis of the **Timeline** shows seconds elapsed from the start of the log, and **Stats** shows clock time. The x-axis can be zoomed in and out with the **+/-** buttons, as well as with standard keyboard shortcuts (e.g. zoom-in == **Ctrl-+**) The x-axis can be panned with the scroll bar as well as with the left and right arrow keys. You can view your current imaging session, or review old sessions by loading `.analyze` files using the **Input** dropdown. Checking **Full Width** displays all the data, and **Latest** displays the most recent data (you can control the width by zooming).

The three main displays can be hidden to make more room for the other displays. There are checkboxes to the left of the section titles (Timeline, Statistics, and Details) that enable and hide the displays.

5.8.11.2 Timeline

Timeline shows the major Ekos processes, and when they were active. For instance, the **Capture** line shows when images were taken (wither green for RGB or color-coded by the filter) and when imaging was aborted (shown as red sections). Clicking on a capture section gives information about that image, and double clicking on one brings up the image taken then in a fitsviewer, if it is available.

> NOTE
> If you have moved your captured images, you can set **alternate directory** in the input menu to a directory which is the base of part of the original file path.

Clicking on a **Focus** segment shows focus session information and displays up the position vs HFR measurements from that session. Clicking on a **Guider** segment shows a drift plot from that session, (if it's guiding) and the session's RMS statistics. Other timelines show status information when clicked.

5.8.11.3 Statistics

A variety of statistics can be displayed on the **Statistics** graph. There are too many for all to be shown in a readable way, so select among them with the checkboxes. A reasonable way to start might be to use **rms**, **snr** (using the internal guider with SEP Multistar), and **hfr** (if you have auto-compute HFR in the FITS options). Experiment with others.

The left axis shown is initially appropriate only for RA/DEC error, drift, RMS error, RA/DEC pulses, and HFR, plotted in arc-seconds and defaulting to a range of -2 to 5 arc-seconds. However, clicking on one of boxes below the Statistics graph (that shows a statistic's value) will set that statistic's range as the range shown on the left-axis. Double clicking on that box will bring up a menu allowing you to adjust the statistic's plotted y-range (e.g. setting it to auto, explicitly typing in the range, setting it back to its default value, and also changing the color of that statistic's plot).

The statistic shown on the left axis can also be scaled (awkwardly) using the mouse wheel. It can be panned by dragging the mouse up or down over the left axis' numbers. Clicking anywhere inside the Statistics graph fills in the values of the displayed statistics. Checking the latest box causes the most recent values (from a live session) to be the statistics displayed. This graph is zoomed and panned horizontally in coordination with the timeline.

5.8.12 Ekos Tutorials

5.8.12.1 Viewer

StellarMate is shipped with a VNC Server. This enables you to access the whole StellarMate desktop remotely. To connect to VNC, you can either use a Desktop/Mobile VNC Client, or simply via any browser.

The VNC address is: **https:// stellarmate_hostname:6080/vnc.html**

Where `stellarmate_hostname` is the actual hostname (or IP address) of your unit and 6080 is the port. If you do not know the unit hostname, you can find the hostname in your StellarMate App.

You can use Real VNC which is available on all platforms to access stellarmate.

Once you access StellarMate, you can use it like any full-fledged computer. The default username is **stellarmate** and the default password is **smate**.

5.9 Jupiter Moons Tool
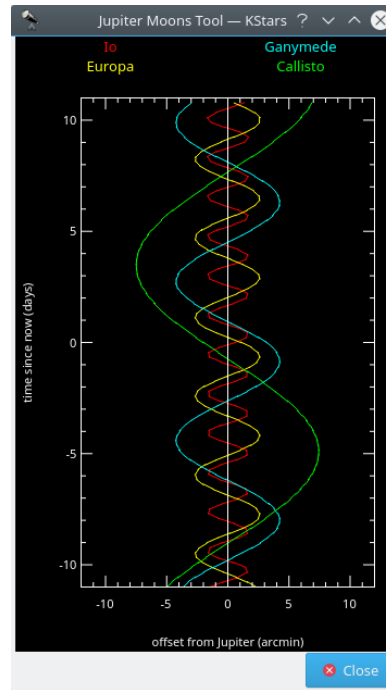
This tool displays the positions of Jupiter's four largest moons (Io, Europa, Ganymede, and Callisto) relative to Jupiter, as a function of time. Time is plotted vertically; the units are days and 'time=0.0' corresponds to the current simulation time. The horizontal axis displays the angular offset from Jupiter's position, in arcminutes. The offset is measured along the direction of Jupiter's equator. Each moon's position as a function of time traces a sinusoidal path in the plot, as the moon orbits around Jupiter. Each track is assigned a different color to distinguish it from the others; the name labels at the top of the window indicate the color used by each moon (i.e. red for Io, yellow for Europa, green for Callisto and blue for Ganymede).

The plot can be manipulated with the keyboard. The time axis can be expanded or compressed using the **+** and **-** keys. The time displayed at the center of the window can be changed with the **[** and **]** keys.

5.10 Observation Planner

Since KDE SC 4.4, Prakash Mohan's GSoC work has been released in KStars. KStars now has an awesome observation planner to plan your observation sessions. The execute session option allows you to log information about objects as you observe them. Alternately, you may also write a short log in the session planner itself. We wish you a lot of fun planning your observations with KStars!

You can even add some pictures to the objects. The image list is a Google image search list. To add image to an object just press **Find Image** button on the right and then find an image that you like. If you do not have an Internet connection you can open an image from your hard drive. Note that images that will be used are going to be cropped to 600x600 pixels.

The first way of doing this is by pressing **Ctrl+2** or **Ctrl+L** to open the Observation List, then press the **Add Object** button.

The **Download all Images** button does a search for the SDSS images and displays the DSS image if the requested RA/Dec is out of the SDSS footprint.

This is an SDSS image of a galaxy

This is an DSS image of the same galaxy

The **Delete all Images** button does the opposite. It deletes all downloaded images.

The image for the galaxy is now deleted

You can add more objects by pressing the **Find Object** button. It will open the **Find Object** tool which provides two accurate methods for sorting out the items, depending on what criteria you want to use. You can filter the list by objects type: Any, Stars, Solar System, Clusters (Globular and Open), Nebulae (Gaseous and Planetary), Galaxies, Comets, Asteroids, Constellations, Supernovae or Satellites. You can also filter the objects list by name. Enter the name of desired

object in the **Filter by name** text box.

Inside Observation Planner window you can see the 'Altitude vs Time' widget (AltvsTime), which shows you how the altitude of a selected object varies over time.

Below the AltvsTime widget, there is a text box in that you can add observing notes for current sky object.

Note that the Wish List is not the Session Plan. In the Wish List you can add objects that you wish to observe at some point. From there you can add them to the Session Plan.

You can see the pop-up window that comes after right-clicking on an object.
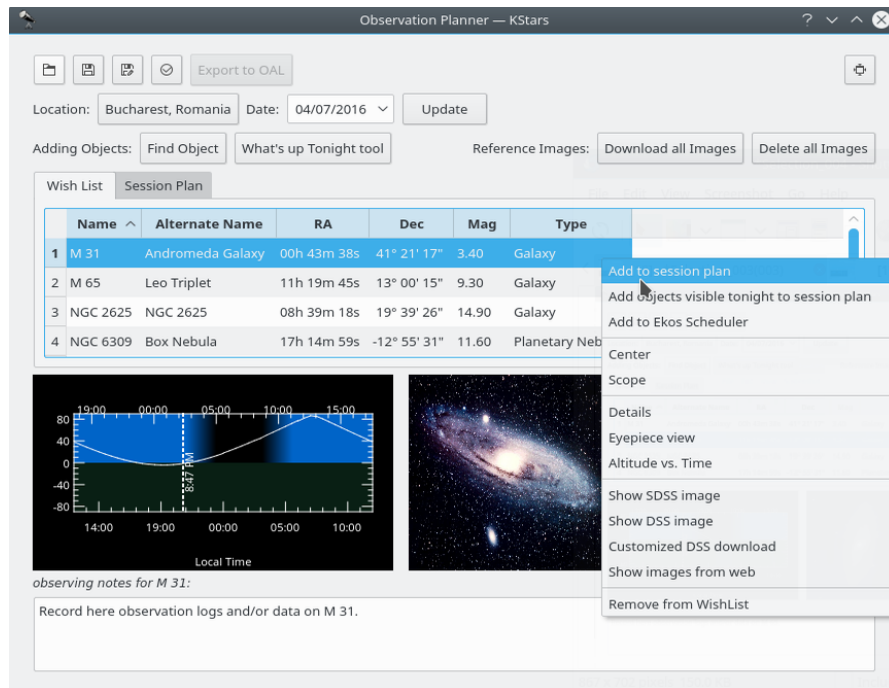
Add objects to Session Plan window

Here is the second way of adding objects in your Observation Plan, using the Observing List Wizard. You just need to press the fourth button on the top-left corner of the Observation Planner window.

Despite looking differently this way is basically the same as the first one. Although that it could be a bit more detailed. Here you can see the same categories of objects.

You can choose where these objects to be on the sky. There are four options available for you: All over the sky (which is the default option), by constellation and in a region (rectangular or circular).
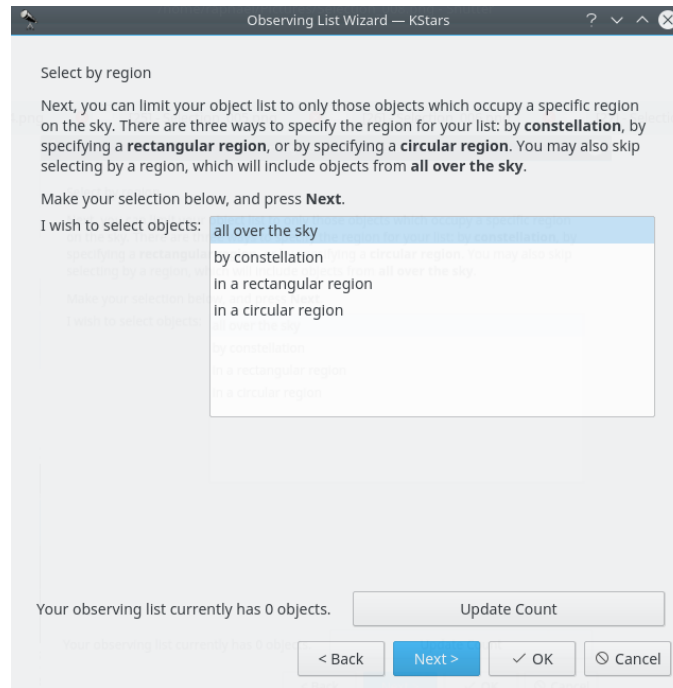
You can choose the date for the observation and the place you are going to observe from.
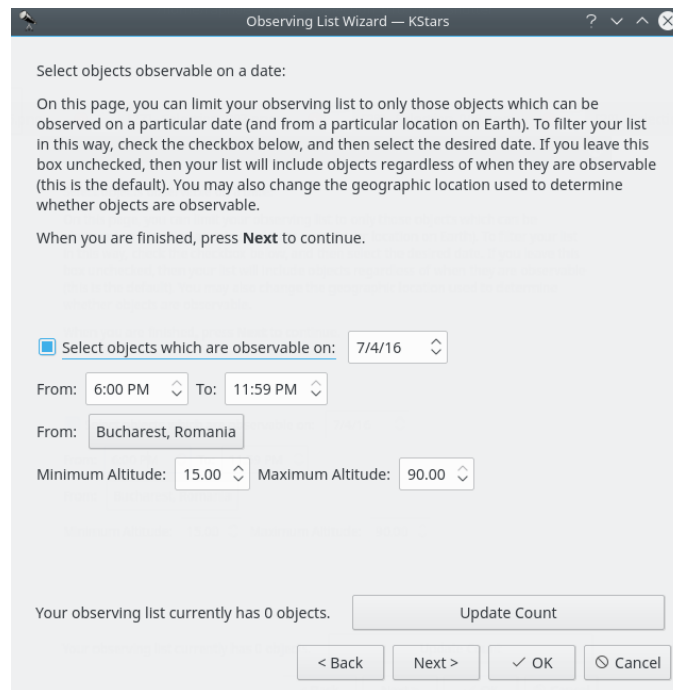
You can choose the treshold of magnitude for the objects to be shown. In astronomy, absolute magnitude (also known as absolute visual magnitude when measured in the standard V photometric band) measures a celestial object's intrinsic brightness.
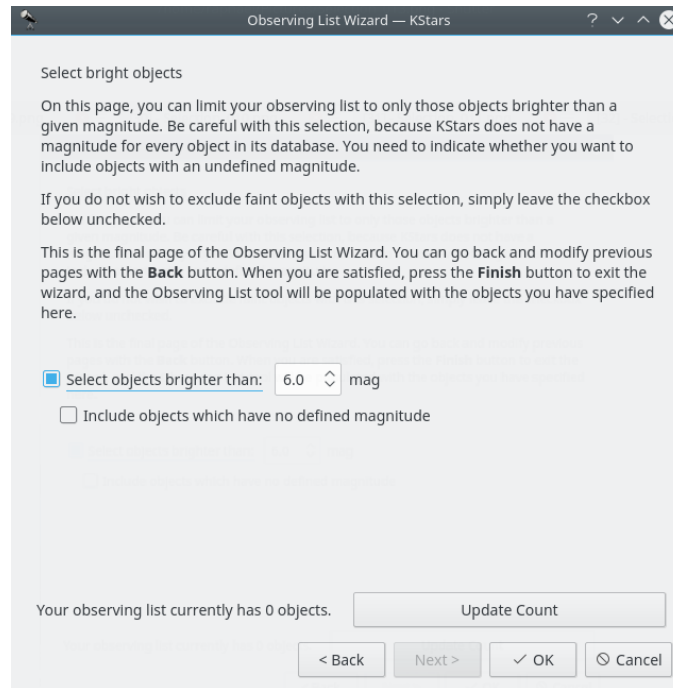
You can save your observation plan. And it will save it with a `.obslist` extension.
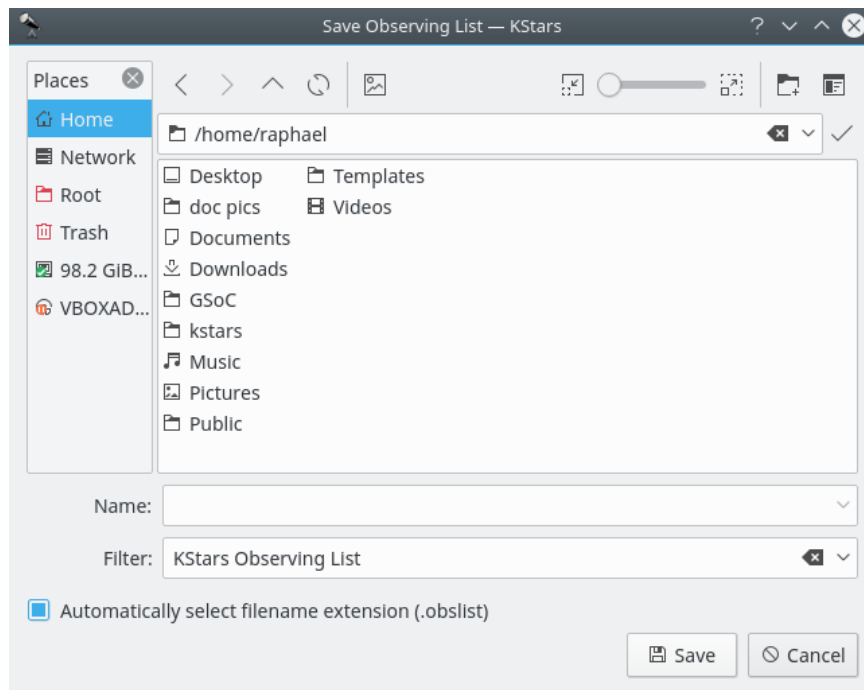
You can also access the **WUT** (What's up tonight), which could be of a great assistance to you. It can give you ideas what to observe on a date, time and place that you specify using the configuration buttons int the top-right corner of the **What's up tonight** window.
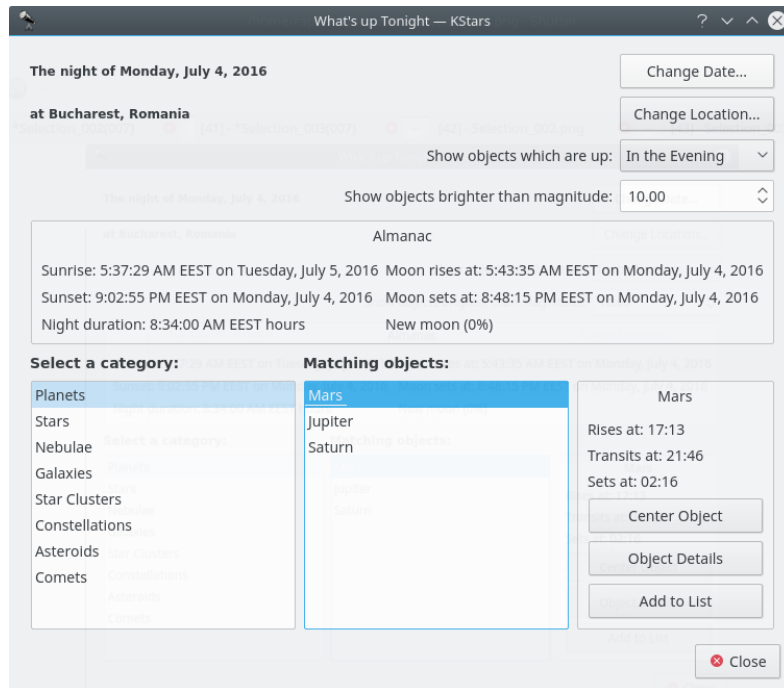
Another way of adding objects to your observation plan is using the newly introduced **Batch Add** will open up a text box where you can type many objects to add in one shot to the observation planner. Any objects not in the KStars database already will be resolved using SIMBAD Astronomical Database (provided this has been enabled in the Settings) and added to the database. The entire process of adding objects is slow and may take a while, and you can watch the progress in the Status Bar. Any objects that could not be found are then listed in an error message, so you can identify and fix the errors. Usually this may be because SIMBAD expects a different way of specifying the object (e.g. Sim 147 instead of Simeis 147). This new feature allows you to easily scrape data from observing lists on the web etc. and add them to your workflow in KStars.

This is how the **Execution Session** Window look. It can be opened by pressing **Ctrl**+**2**. In it you can also see some information about the selected object and you are able to add observing notes.
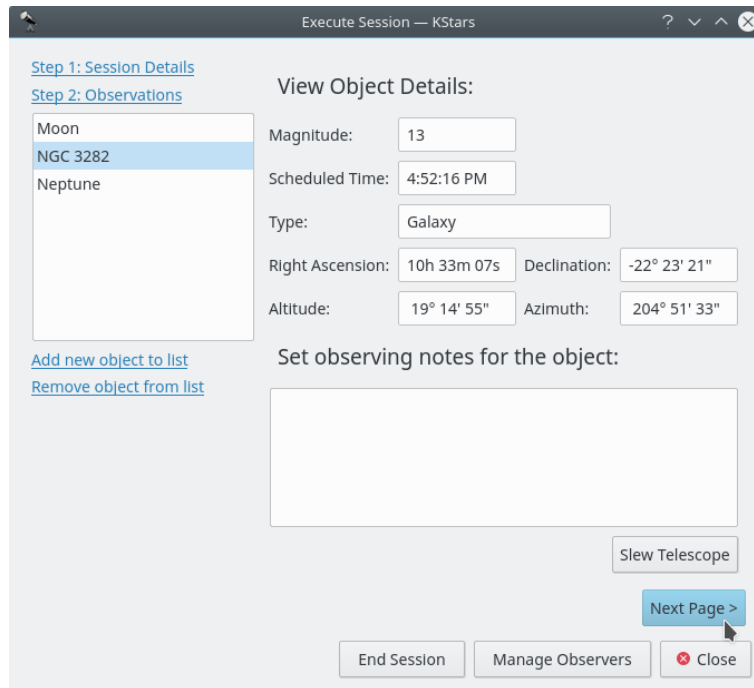
First Execute Session window

By pressing the **Next Page** button you will access the second page of Session Plan. Here you are able to see information not about your object, but about your equipment.
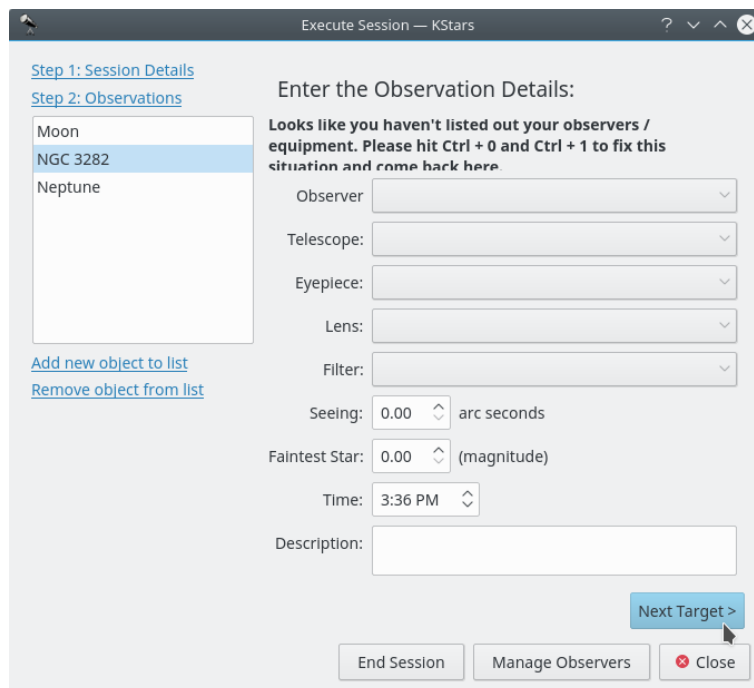
Second Execute Session window

Pressing the **Next Target** button will cause the Execute Session to open the first window about the next object.

5.11 FITS Viewer Tool

The Flexible Image Transport System (FITS) is the standard format for representing images and data in Astronomy.

The KStars FITS Viewer tool is automatically invoked when new images are received from the camera. It is primarily used to view and examine FITS data. It is not designed for editing of FITS Images. To open a FITS file, select the **File** → **Open Image...** menu item, or press **Ctrl+O**.
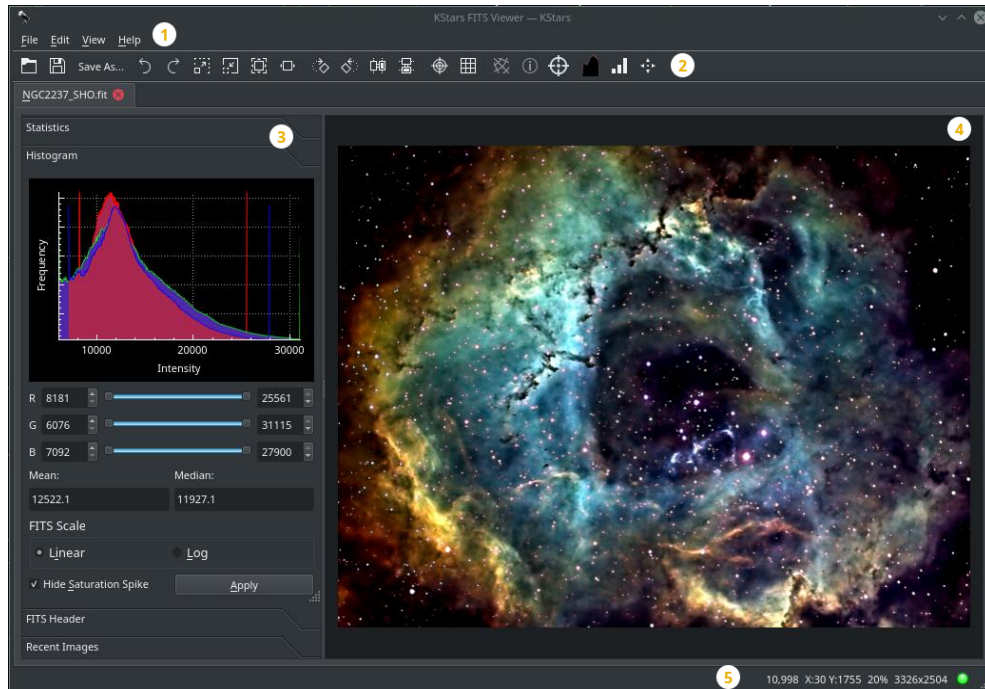
The above diagram illustrates the FITS Viewer work area and window. The tool provides basic functions for image display. FITS data depth is preserved throughout all processing, open, and save functions. While the tool adhere to the FITS standard, it does not support all possible FITS features:

- Support for only *one* image per file.

- Support for only 2D and 3D data. 1D data are discarded.

The FITS Viewer window is divided into the following regions:

1. Main Menu
   - File
     - Standard Open, Save, and Save As actions.
     - FITS Header: Display FITS header table data.
     - Debayer: Covert RAW image to RGB.
   - Edit
     - Undo: Undo last action.
     - Redo: Redo last action.
     - Copy: Copy image to clipboard.
   - View
     - Zoom Controls: Zoom in, Zoom out, standard Zoom.
     - Filters: Auto Stretch, Contrast, High Pass, Rotate, Flip.
     - Mark Stars: Detect and mark stars in the image.

2. Main Toolbar

- Open File.
- Save File: Save FITS data. Any filters applied to the image will be saved.
- Save File As.
- Undo last action.
- Redo last action.
- Zoom In: Zoom in up to a maximum of 400%. For large images this operation can be very memory intensive. Turn on Limited Resource Mode to save memory.
- Zoom Out.
- View in Actual Size.
- Zoom to fit.
- Rotate Right.
- Rotate Left.
- Flip Horizontal.
- Flip Vertical.
- Show Cross Hairs: Toggles crosshairs in the center of the image.
- Show Pixel Gridlines: Toggles pixel grid.
- Show Equatorial Gridlines: Toggles Equatorial Grid if FITS contains a valid WCS header.
- Show Objects in Image: Identifies objects such as stars, galaxies, and nebulae within the image.
- Center Telescope: Toggle Center Telescope mode. When active and if the image contains a valid WCS header, clicking anywhere in the image triggers the telescope slewing to the clicked point.
- Histogram: Toggle histogram view in the side panel.
- Statistics: Toggle FITS Statistic view in the side panel.
- Auto Stretch: Apply Auto Stretch filter to the image.
- Toggle Selection Rectangle: Toggle selection rectangle for statistics of a region of interest.

3. Side Panel: The side panel can be opened by dragging the separator to the right. When dragged to the left, the side panel can also be closed.

- Statistics: Displays image statistics including Minimum, Maximum, Average, and Median values.
- Histogram: Displays image histogram with controls to adjust the minimum and maximum values for each channel. Both linear and logarithmic scalings are available to apply to the image.
- FITS Header: Displays a table for FITS header keywords, values, and comments.
- Recent Images: Displays recently opened images. Clicking on any image will load it.

4. Image Display Area. Hovering over the image will update the status bar values accordingly.

5. Status Bar: From right to left, the following status indicators are available:

- Loading Indicator: The LED becomes yellow when an image is getting loaded and turns green after loading is successfully done. If there are problems with loading the image, it turns red.
- Resolution: Image resolution in pixels.
- Cartesian Coordinates: Displays and updates the current mouse position as you hover over the image. It include the X and Y position in addition to the current value.
- Equatorial Coordinates: If the image contains a valid WCS header, the J2000 Right Ascension (RA) and declination (DE) values are displayed.

In addition to image display, the viewer can process World-Coordinate-System (WCS) header if present within the FITS file and provides useful information regarding the objects found within the image, equatorial grid overlay, popup menu, and the ability to slew the mount (if connected) to any point within the image.

Several filters can be applied to enhance the image include auto stretch and high contrast. Depending on the image size, these operations can take a few seconds to complete. The bottom status bar displays the current pixel value and current X & Y coordinates of the mouse pointer within the image. Furthermore, it includes the current zoom level and the image resolution.

When loading a bayered image, the viewer can automatically debayer the image if *Auto Debayer* is checked in the FITS Settings. The debayering operation fetches the bayer pattern (e.g. RGGB) from the FITS header. If none exists, you can alter the debayering algorithm and pattern from the **File** menu or by using the **Ctrl-D** shortcut.

Since operations such as auto debayering and auto WCS are computationally expensive and stress the processor on low-powered embedded devices, you can toggle their behavior in KStars Settings FITS page.
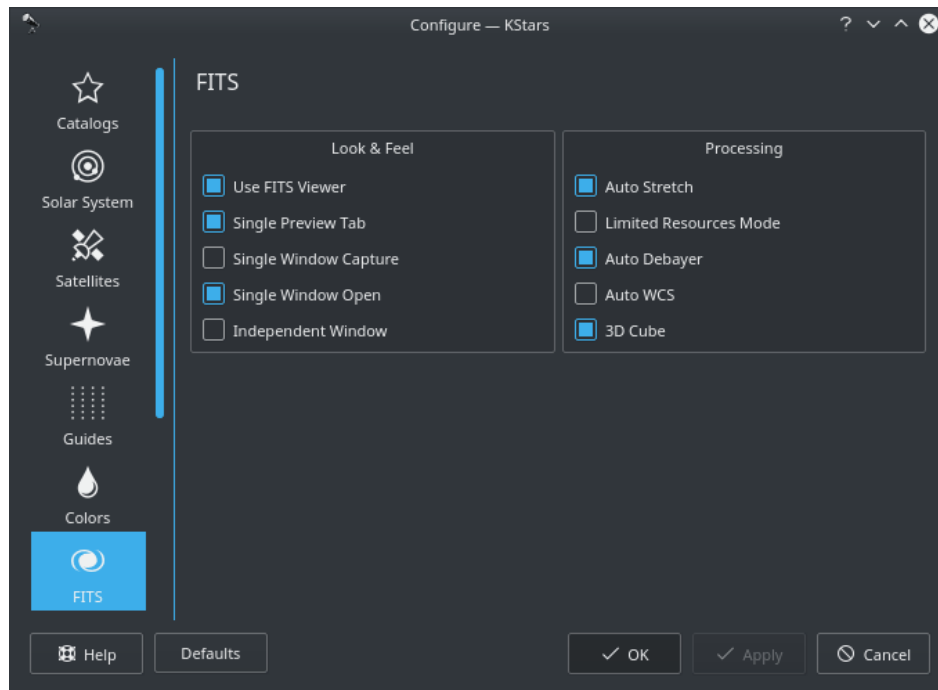
Hovering over any option shall display a detailed tooltip that explains its function.

5.11.1 Features

- Support for 8, 16, 32, IEEE-32, and IEEE-64 bits formats.
- Support Color FITS images (3D Cubes) and Bayered FITS images.
- Histogram with linear, logarithmic, and square-root scales.
- Brightness/Contrast controls.
- Pan and Zoom.
- Auto levels.
- Statistics.
- Statistics for a region of interest(Rectangle).

- Rectangular and Equatorial Grids (if WCS info is present).

- Detection and highlight of stars.

- FITS header query.

- Undo/Redo.

Histogram
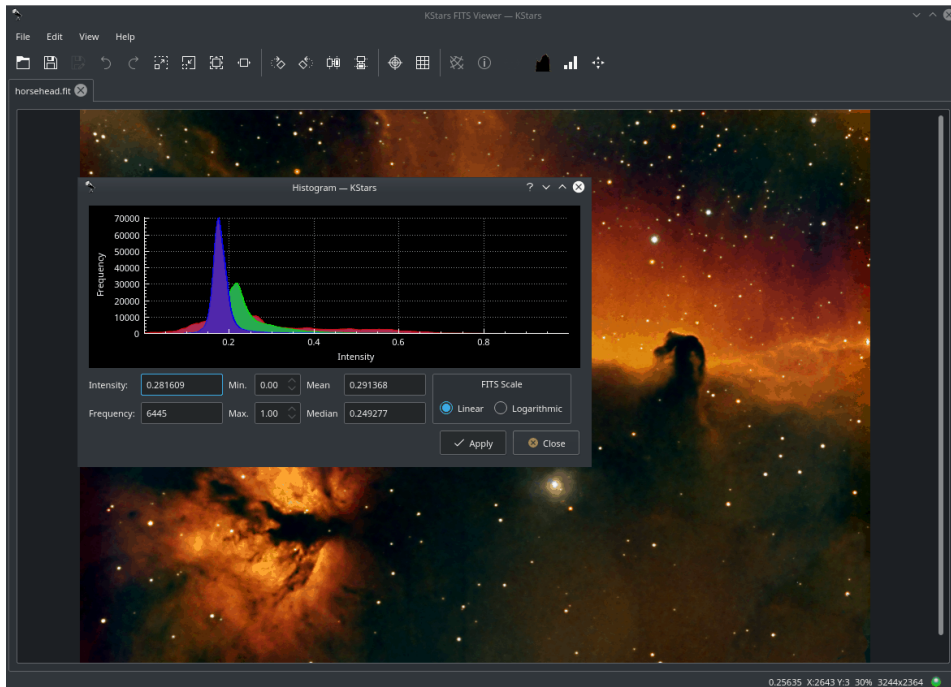
Displays multi-channel FITS histogram. The user can rescale the image by optionally defining an upper and lower limit for the cutoff region. The rescaling operation (linear, logarithmic, or square-root) may then be applied to the region enclosed by the upper and lower limits.

FITS Header

Displays a read-only table listing FITS header keywords and values.

Statistics

Provides simple statistics for minimum and maximum pixel values and their respective locations. FITS depth, dimension, mean, and standard deviation.

Statistics of region of interest
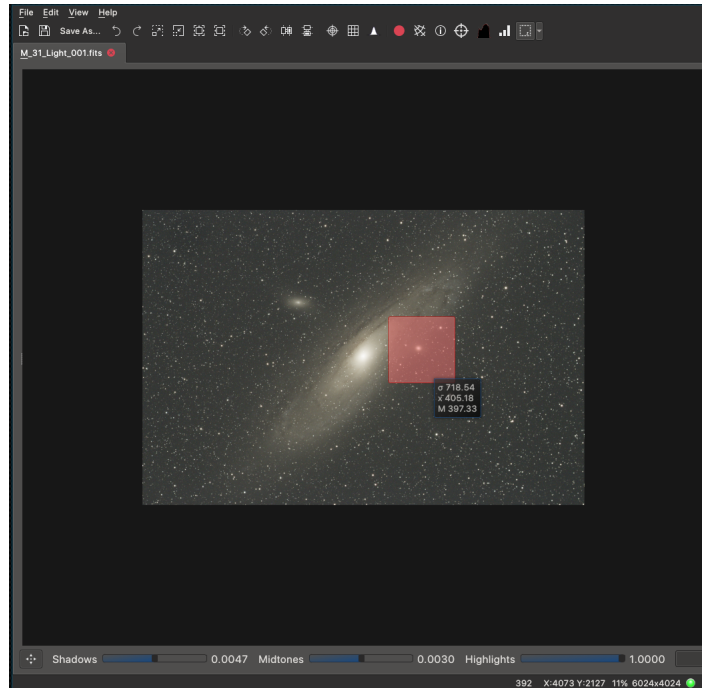
Provides simple statistics average mean, average standard deviation and average median of the selected region by the user in a tooltip.

The user can either set the selection region by **Shift-Left Click** dragging or by choosing an entry from the drop down menu of the Toggle Selection Rectangle button. In addition to this, the user can translate the region by simple **Left Click** drag of the mouse. The statistics of the region are shown as a tooltip once the cursor is brought over the selection region. For smaller images, the statistics are updated instantly, and for larger images, the statistics are updated once the user releases the **Left Click** button after modification of the region.

5.11.2 Embedded FITS Viewer
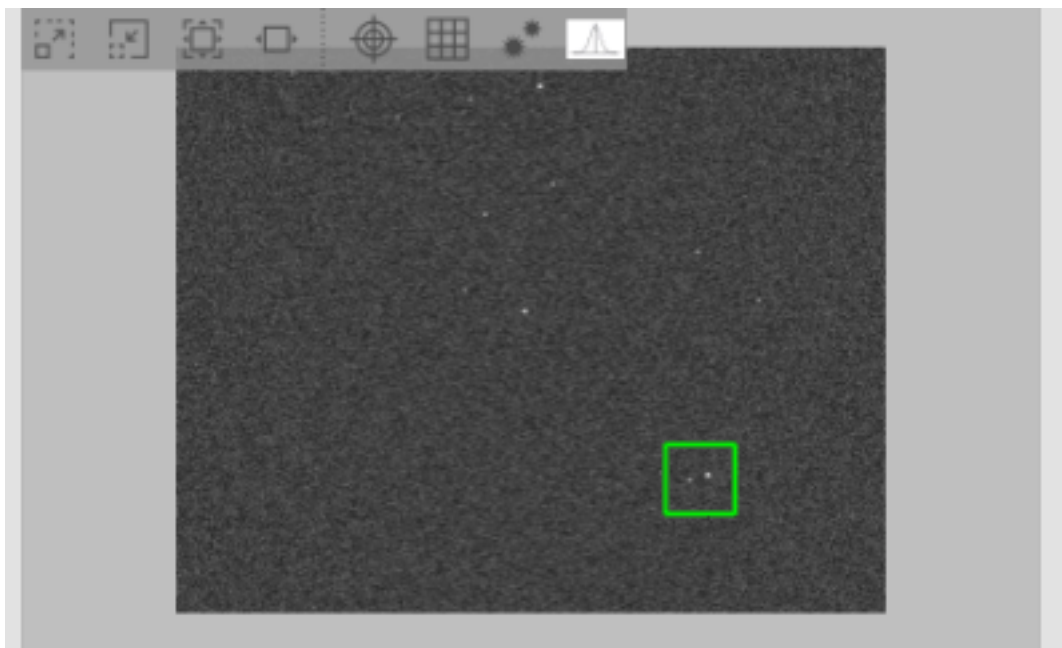
In Ekos Focus, Guide, and Align modules, captured images are displayed in the embedded FITS Viewer. The embedded viewer includes a *floating bar* that can be used to perform several functions:

- Zoom Out
- Zoom In
- Default Zoom
- Zoom To Fit
- Toggle Cross Hairs
- Toggle Pixel Gridlines
- Toggle Detected Stars: Highlight detected stars with red circles.
- Star Profile: View detailed 3D star profile.

The floating bar is automatically hidden once the mouse leaves the embedded viewer area. You can use the mouse to pan and zoom just like the standalone FITS Viewer tool. The green tracking box can be used to select a specific star or region within the image, for example, to select a guide star.

5.11.3 3D Star Profile & Data Visualization Tool
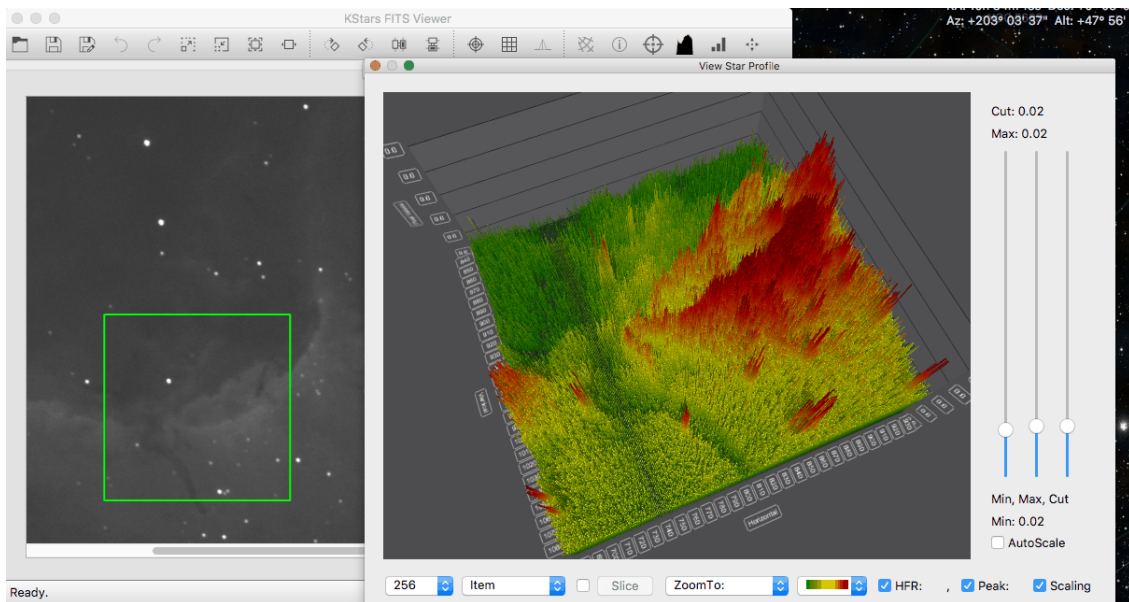
The 3D data visualization tool can plot 3D graphs of the selected region of the image. This is particularly useful for astrophotographers who want to visualize the profile of a star they are considering focusing or guiding on. For scientists, it enables them to examine a cross-section of the data to understand the relative brightness of different objects in the image. Additionally, it empowers imagers who want to visually see what is going on in their data collection in a new way.

To use the new feature, the user needs to select the **View Star Profile** icon in one of the Ekos Module Views, or in the FITS Viewer. Then, the region selected in the green tracking box will show up in the 3D graph as shown above. The user will then have one of the following toolbars at the bottom.
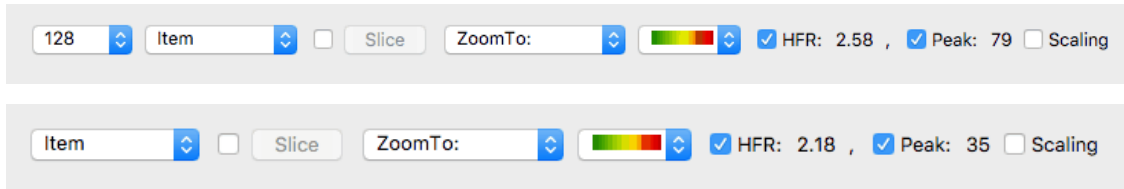
At the far left, the sample size combo box will let the user select the size of the image crop shown in the graph. This option is only available in the **Summary Screen**, the Align Module, and the FITS Viewer. The second combo box lets the user control whether they are selecting an individual item, or a row, or a column of pixels. The slice button will be enabled if the user selects **Row** or **Column**. It will put the graph in slice mode so that the user can see a cross-section view of the image. Third, is a checkbox that will open up two sliders that will let the user drag the slider to change the selection. This is extremely useful in the slide mode to change the selected point and to move the cross section around the graph. It is also useful in the normal view when in **Explore Mode** so that the user can zoom around the image examining the pixels.

Then the user has the **Zoom To** combo box, which the user can use to zoom the graph to different preset locations. Next is the combo box that lets the user select the color scheme of the graph. Then are the HFR and the Peak checkboxes, which will both turn on the HFR and Peak labels on each found star in the image, but will also display one of them at the bottom of the screen. And finally comes the Scaling checkbox, which enables the **Scaling** Side Panel. There are three sliders in that panel, one to control the minimum value displayed on the graph or 'black point', one to control the maximum value displayed in the graph or the 'white point', and a third that is disabled by default that lets the user control the cutoff value for data displayed on the graph.
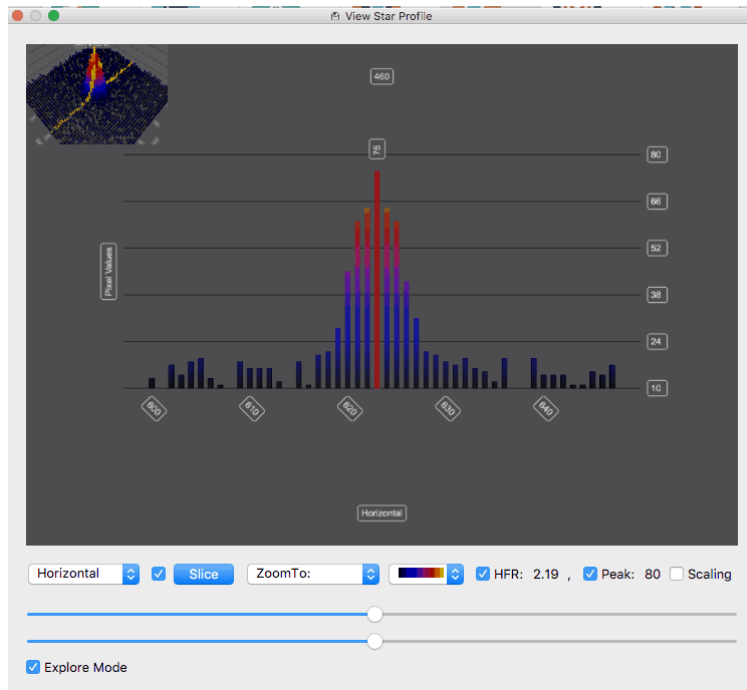
This third slider is very useful to get really big peaks out of the way so you can study the finer details in the image. There is a checkbox at the top to enable/disable the cutoff slider. And finally at the bottom of the sliders is the **Auto scale** button. This will auto scale the sliders as you sample different areas in the image. It will not only optimize the display of the data but will also affect the minimum and maximum points of the slider. If you disable auto scale, then as you sample different parts of the image, they will be displayed at the same scale. A particularly useful way to use this is to select an area of your image using auto scale, tweak the min, max, and cutoff sliders to your liking, and then turn off the auto scale feature to explore other areas of the graph.
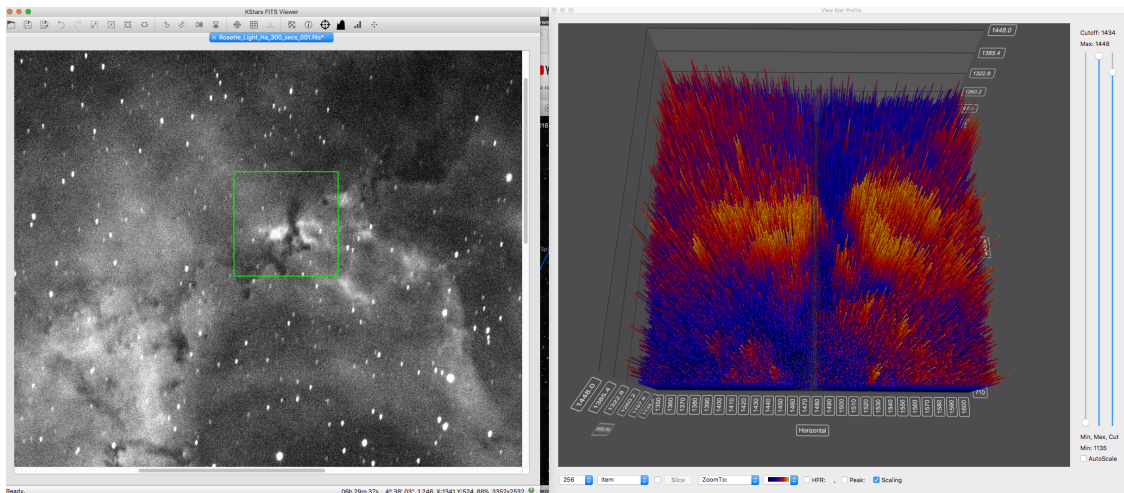
Chapter 6

Command-Line mode for Image Generation

You can use KStars to generate an image of the sky without actually launching the GUI portion of the program. To use this feature, start KStars from a command prompt using arguments to specify the filename for the image, as well as the desired image dimensions:

kstars --dump [--filename *kstars.png*] [--height *640*] [--width *480*] [--script *myscript.kstars*] [--date *˜4 July 1976 12:30:00˜*]

If no filename is specified, it generates a file named kstars.png. It will attempt to generate an image that matches the extension of your filename. The following extensions are recognized: 'png', 'jpg', 'jpeg', 'gif', 'pnm', and 'bmp'. If the filename extension is not recognized, it defaults to the PNG image type.

Likewise, if the image width and height are not specified, they default to 640 and 480, respectively.

By default, KStars will read in the options values stored in your $KDEHOME/share/config/ksta rsrc file to determine where the image will be centered, and how it is rendered. This means you need to run KStars in normal GUI mode, and exit the program when it is set up with the desired options for the generated images. This is not very flexible, so we also provide the ability to execute a KStars D-Bus script to set the scene before generating the image. The filename you specify as the script argument should be a valid KStars D-Bus script, such as one created with the Script Builder Tool. The script can be used to set where the image is pointing, set the geographic location, set the time and date, change the Zoom level, and adjust other view options. Some of the D-Bus functions make no sense in non-GUI mode (such as waitForKey()); if these functions are encountered while parsing the script, they are simply ignored.

By default, KStars will use the system CPU time and date for generating the image. Alternatively, you may specify a time and date with the '--date' argument. You can also use this argument for specifying the startup date in normal GUI mode.

Chapter 7

Astronomical Device Control with INDI

KStars provides an interface to configure and control astronomical instruments via the INDI protocol.

The INDI protocol supports a variety of astronomical instruments such as CCD cameras and focusers. For an up to date list of supported devices, please visit INDI supported devices page.

7.1 INDI Setup

KStars can control local and remote devices seamlessly via the INDI server/client architecture. INDI devices may be run in three different modes:

1. **Local**: The local mode is the most common and is used to control local device (i.e. a device attached to your machine).

2. **Server**: The server mode establishes an INDI server for a particular device and waits for connections from remote clients. You cannot operate server devices, you can only start and shut them down.

3. **Client**: The client mode is used to connect to remote INDI servers running INDI devices. You can control remote devices seamlessly like local devices.

You can run local device, establish INDI servers, and connect to remote clients from the **Tools** → **Devices** → **Device Manager...** menu item.

Here is a screenshot of the **Device Manager** window:
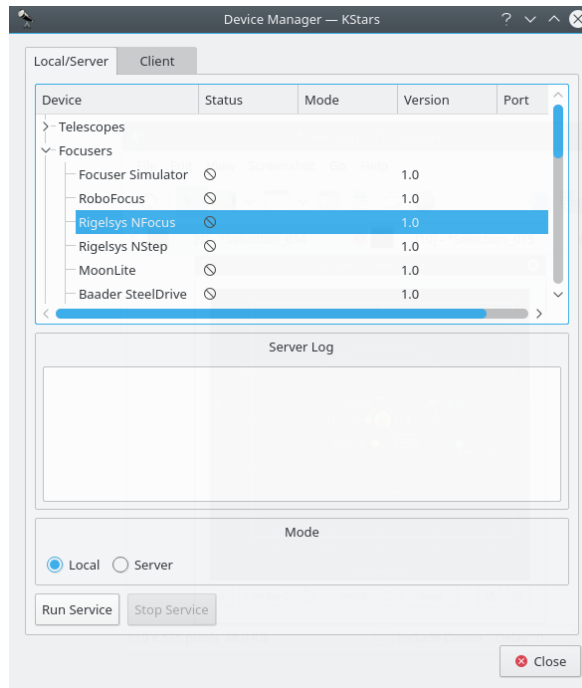
You can run devices by browsing the device tree, selecting a specific device, and then clicking on the **Run Service** button. You can select the operation mode, either local or server as defined above. The port number is randomly generated between the range from 7624 to 10,000. To specify a port, click on the port column next to the desired driver. KStars allows multiple drivers to run under one INDI server, and hence one port. Select multiple drivers then press **Run Service** button.

To control remote devices, refer to the remote device control section.

7.2 Telescope Setup

Most telescopes are equipped with RS232 interface for remote control. Connect the RS232 jack in your telescope to your computer's Serial/USB port. Traditionally, the RS232 connects to the serial port of your computer, but since many new laptops abandoned the serial port in favor of USB/FireWire ports, you might need to obtain a Serial to USB adaptor to use with new laptops.

After connecting your telescope to the Serial/USB port, turn your telescope on. It is *highly* recommended that you download and install the latest firmware for your telescope controller.

The telescope needs to be aligned before it can be used properly. Align your telescope (one or two stars alignment) as illustrated in your telescope manual.

KStars needs to verify time and location settings before connecting to the telescope. This insures proper tracking and synchronization between the telescope and KStars. The following steps will enable you to connect to a device that is connected to your computer. To connect and control remote devices, please refer to remote device control section.

You can use the Telescope Setup Wizard and it will verify all the required information in the process. It can automatically scan ports for attached telescopes. You can run the wizard by selecting the **Devices** → **Telescope Wizard** menu item.

Alternatively, you can connect to a local telescope by performing the following steps:

1. Set your geographical location. Open the **Set Geographic Location** window by selecting the **Settings** → **Geographic...** menu item, or by pressing the **Globe** icon in the toolbar, or by pressing **Ctrl**+**G**.

2. Set your local time and date. You can change to any time or date by selecting **Time** → **Set Time...** menu item, or by pressing the **Time** icon in the toolbar. The **Set Time** window uses a standard KDE Date Picker widget. If you ever need to reset the clock back to the current time, just select the **Time** → **Set Time to Now** menu item.

3. Click on the **Tools** → **Devices** → **Device Manager...** menu item.

4. Under the **Device** column, select your telescope model.

5. Click on the **Run Service** button.

6. Click **Close** to leave the Device Manager Dialog.

> FREQUENT SETTINGS
> You do not need to set the geographic location and time every time you connect to a telescope. Only adjust the settings as needed.

You are now ready to use the device features, KStars conveniently provides two interchangeable GUI interfaces for controlling telescopes:

CONTROLLING YOUR TELESCOPE

1. **Sky map Control**: For each device you run in the **Device Manager**, a corresponding entry will show up in popup menu that allows you to control the properties of the device. You can issue commands like **Slew**, **Sync**, and **Track** directly from the sky map.

   Here is a screenshot of the popup menu with an active LX200 Classic device:
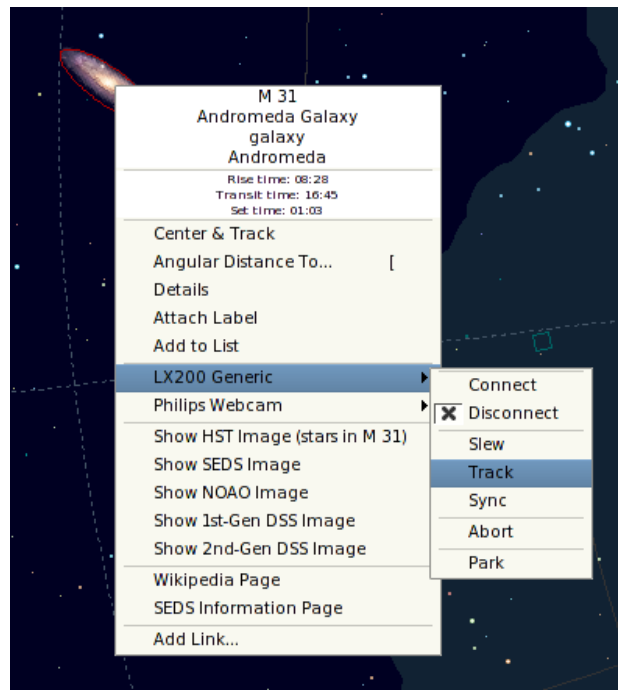
2. **INDI Control Panel**: The panel offers the user with all the features supported by a device.

   The panel is divided into three main sections:

   • **Device tabs**: Each additional active device occupies a tab in the INDI panel. Multiple devices can run simultaneously without affecting the operation of other devices.

- Property views on the **Main Control** and **Options** tabs: Properties are the key element in INDI architecture. Each device defines a set of properties to communicate with the client. The current position of the telescope is an example of a property. Semantically similar properties are usually contained in logical blocks or groupings.

- **Log viewer**: Devices report their status and acknowledge commands by sending INDI messages. Each device has its own log view. A device usually sends messages to its device driver only, but a device is permitted to send a generic message when appropriate.
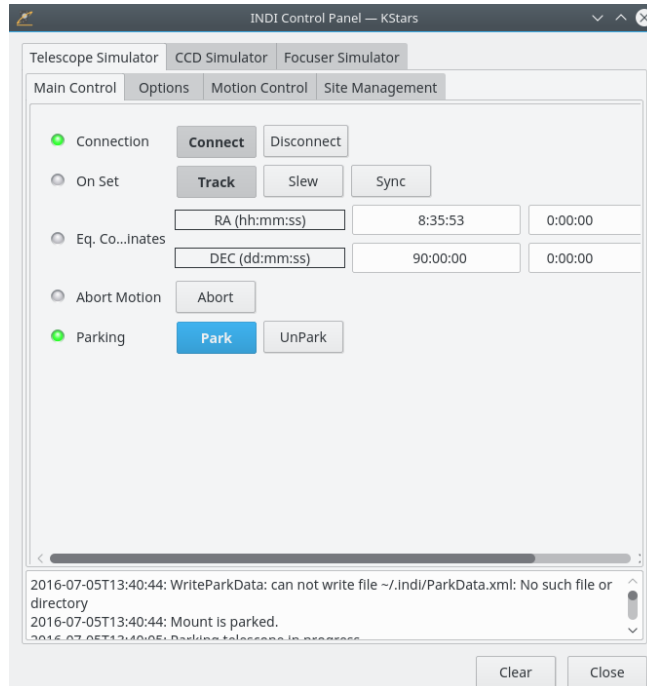
You are not restricted on using one interface over another as they can be both used simultaneously. Actions from the **Sky map** are automatically reflected in the **INDI Control Panel** and vice versa.

To connect to your telescope, you can either select **Connect** from your device popup menu or alternatively, you can press **Connect** under your device tab in the **INDI Control Panel**.

> IMPORTANT
> By default, KStars will try to connect to the `/dev/ttyS0` port. To change the connection port, select the **Tools** → **Devices** → **INDI Control Panel...** menu item and change the port under your device tab.

KStars automatically updates the telescope's longitude, latitude, and time based on current settings in KStars. You can enable/disable these using the **INDI** page from the **Settings** → **Configure KStars...** menu item. Using the **INDI** page you can configure KStars to display or not INDI status messages in the status bar. By default INDI server port numbers have values between the range from 7624 to 9000, but you can easily change the range using the **From:** and **To:** text boxes from the **Server Port** section.

If KStars communicates successfully with the telescope, it will retrieve the current RA and DEC from the telescope and will display a crosshair on the sky map indicating the telescope position. You can hide the crosshair that marks telescope position using **INDI** page from the **Settings** → **Configure KStars...** menu item.

> SYNCHRONIZING YOUR TELESCOPE
>
> If you aligned your telescope and the last alignment star was, for example, Vega, then the crosshair should be centered around Vega. If the crosshair was off target, then you can right-click Vega from the sky map and select **Sync** from your telescope menu. This action will instruct the telescope to synchronize its internal coordinates to match those of Vega, and the telescope's crosshair should now be centered around Vega.

This is it: your telescope is ready to explore the heavens!

> WARNING
>
> Never use the telescope to look at the sun. Looking at the sun might cause irreversible damage to your eyes and your equipment.

7.3 CCD and Video-Capture Setup

You can run CCD and Video Capture devices from the **Tools** → **Devices** → **Device Manager...** menu item. Like all INDI devices, some of the device controls will be accessible from the skymap. The device can be controlled fully from the **INDI Control Panel...** item.

The standard format for image capture is FITS. Once an image is captured and downloaded, it will be automatically displayed in the KStars FITS Viewer.

7.4 Configure INDI

The **INDI** page allows you to modify *Client side* INDI specific options. To access it, select the **INDI** page from **Settings** → **Configure KStars...** menu item. The window is divided into several main categories: General, Device Updates, Display and Server Port:

- **General**
  - **INDI server:** Specify the binary of installed INDI server in your system. By default, KStars uses '/usr/bin/indiserver' binary.
  - **INDI drivers XML directory:** Specify the XML directory where INDI drivers are located in your system. By default, KStars uses '/usr/share/indi' directory.
  - **Default FITS directory:** Specify the directory where all captured FITS images will be saved to. If no directory is specified, images will be stored in $HOME.

- **Time & Location Updates**
  - **KStars updates all devices**: KStars is the master source for time and location settings. All INDI devices time and locations settings are synchronized to KStars settings.
  - **Mount updates KStars**: Mount handset is the master source of time and location settings. KStars time and location settings are synchronized with controller settings.
  - **GPS updates KStars**: GPS driver is the master source of time and location settings. KStars time and location settings are synchronized with GPS settings.
  - **Time**: Synchronize KStars date and time automatically from the update source.
  - **Location**: Synchronize KStars location settings from the update source.

- **Display**

- **Telescope crosshair**: When checked, KStars displays the telescope's target crosshair on the sky map. The crosshair is displayed upon a successful connection to the telescope and its location is updated periodically. The telescope's name is displayed next to the crosshair. KStars displays one crosshair per each connected telescope. To change the color of the telescope's crosshair, open the Configure - KStars window. Select the **Colors** page, and then change the color of the **Target Indicator** item to the desired color.

- **Independent window**: Make **FITS Viewer** window independent.

- **Message notifications**: Show INDI messages as desktop notifications instead of dialogs.

- **Server Port**

  - Specify range of ports that INDI Server will bind to when starting new drivers.

7.5 INDI Concepts

The main key concept in INDI is that devices have the ability to describe themselves. This is accomplished by using XML to describe a generic hierarchy that can represent both canonical and non-canonical devices. In INDI, all *devices* may contain one or more *properties*. Any *property* may contain one or more *elements*. There are four types of INDI properties:

- Text property.

- Number property.

- Switch property (Represented in GUI by buttons and checkboxes).

- Light property (Represented in GUI by colored LEDs).

For example, all INDI devices share the CONNECTION standard switch *property*. The CONNECTION property has two elements: CONNECT and DISCONNECT switches. KStars parses the generic XML description of properties and builds a GUI representation suitable for direct human interaction.

The INDI control panel offers many device properties not accessible from the sky map. The properties offered differ from one device to another. Nevertheless, all properties share common features that constrains how they are displayed and used:

- Permission: All properties can either be read-only, write-only, or read and write enabled. An example of a read-write property is the telescope's Right Ascension. You can enter a new Right Ascension and the telescope, based on current settings, will either slew or sync to the new input. Furthermore, when the telescope slews, its Right Ascension gets updated and sent back to the client.

- State: Prefixed to each property is a state indicator (round LED). Each property has a state and an associated color code:

State	Color	Description
Idle	Gray	Device is performing no action with respect to this property
Ok	Green	Last operation performed on this property was successful and active
Busy	Yellow	The property is performing an action
Alert	Red	The property is in critical condition and needs immediate attention

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Table 7.1: INDI State color code

The device driver updates the property state in real-time when necessary. For example, if the telescope is in the process of slewing to a target, then the RA/DEC properties will be signaled as **Busy**. When the slew process is completed successfully, the properties will be signaled as **Ok**.

- Context: Numerical properties can accept and process numbers in two formats: decimal and sexagesimal. The sexagesimal format is convenient when expressing time or equatorial/geographical coordinates. You can use any format at your convenience. For example, all the following numbers are equal:

  - -156.40
  - -156:24:00
  - -156:24

- Time: The standard time for all INDI-related communications is Universal Time UTC specified as YYYY-MM-DDTHH:MM:SS in accord with ISO 8601. KStars communicates the correct UTC time with device drivers automatically. You can enable/disable automatic time updates from the **INDI** page in the settings dialog.

7.6 Remote Device Control

KStars provides a simple yet powerful layer for remote device control. A detailed description of the layer is described in the INDI white paper.

You need to configure both the server and client machines for remote control:

1. **Server**: To prepare a device for remote control, follow the same steps in the local/server setup. When you start a device service in the **Device Manager**, a port number is displayed under the **Port** column. In addition to the port number, you also need the hostname or IP address of your server.

2. **Client**: Select the **Tools** → **Devices** → **Device Manager...** menu item and you can add, modify, or delete hosts into **Client** tab. Add a host by clicking on the **Add** button. Enter the hostname/IP address of the server in the **Host:** field, and enter the port number obtained from the *server* machine in step 1.
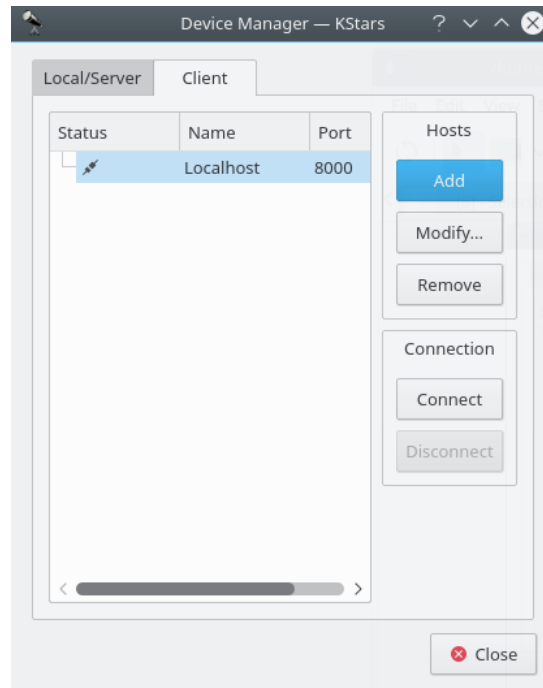
After you add a host, right click on the host to **Connect** or **Disconnect**. If a connection is established, you can control the telescope from the **Sky map** or **INDI Control Panel** exactly as described in the local/server section. It is as easy at that.

7.6.1 Running an INDI server from the command line

While KStars allows you to easily deploy an INDI server; you can launch an INDI server from the command line.

Since INDI is an independent backend component, you can run an INDI server on a host without KStars. INDI can be compiled separately to run on remote hosts. Furthermore, device drivers log messages to `stderr` and that can be helpful in a debugging situation. The syntax for INDI server is as following:

$ **indiserver** [options] driver [`driver ...`]

```
Options:
 -l d    : Log driver messages to <d>/YYYY-MM-DD.islog
 -m m    : Kill client if gets more than this many MB behind, default 128.
 -d m    : Drop streaming blobs if client gets more than this many MB  ←
    behind, default 5. 0 to disable.
 -p p    : Alternate IP port, default 7624.
 -r r    : Maximum driver restarts on error, default 10.
 -f path : Path to fifo for dynamic startup and shutdown of drivers.
 -v      : Show key events, no traffic.
 -vv     : -v + key message content.
 -vvv    : -vv + complete xml.
 driver  : Executable or [device]@host[:port]
```

For example, if you want to start an INDI server running an LX200 GPS driver and listening to connections on port 8000, you would run the following command:

$ **indiserver** -p 8000 `lx200gps`

7.6.2 Secure Remote Operation

Suppose we want to run an indiserver with INDI drivers on a remote host, `remote_host`, and connect them to KStars running on the local machine.

From the local machine log onto the remote host, `remote_host`, by typing:

$ **ssh** -L `local_port:remote_host:remote_port`

This binds the `local_port` on the local machine to the `remote_port` on the `remote_host`. After logging in, run indiserver on the remote host:

$ **indiserver** -p `remote_port` [`driver`...]

Back on the local machine, start KStars then open the **Device Manager** and add a host under the **Client** tab. The host should be the local host (usually 127.0.0.1) and the port number should be the `local_port` used in the steps above. Right-click on the host and select **Connect** from the popup menu. KStars will connect to the remote INDI server securely. The host information will be saved for future sessions.

7.7 INDI Frequently Asked Questions

Q: *What is INDI?*

A: INDI is the Instrument-Neutral-Distributed-Interface control protocol developed by Elwood C. Downey of ClearSky Institute. KStars employs device drivers that are compatible with the INDI protocol. INDI has many advantages including loose coupling between hardware devices and software drivers. Clients that use the device drivers (like KStars) are completely unaware of the device capabilities. In run time, KStars communicates with the device drivers and builds a completely dynamical GUI based on services provided by the device. Therefore, new device drivers can be written or updated and KStars can take full advantage of them without any changes on the client side.

Q: *Do you plan to support more devices?*

A: Yes. We plan to support major CCD cameras and focusers and extend support for more telescopes. If you would like INDI to support a particular device, please send an email to indi-devel@lists.sourceforge.net

Q: *What operations does KStars provide to control the telescope?*

A: It depends on the particular telescope you're running, but the minimum three operations are **Slew**, **Track**, and **Sync**, which you can issue directly from the sky map. Your telescope must be aligned for those operations to perform correctly. Some telescopes offer you more operations like site management, slew modes, focusing, parking, and more. You can access the telescopes extended features from the **Tools** → **Devices** → **INDI Control Panel...** menu item.

Q: *What's the difference between **Slew**, **Track**, and **Sync** exactly?*

A: The command **Slew** orders the telescope to move to a particular target, and once the telescope reaches its target, the telescope keeps tracking that target at a *sidereal* rate (i.e., the rate at which stars move across the sky). This works well for stars, Messier objects, and about everything outside our solar system. But solar system objects travel differently across the sky and so the telescope must **Track** the objects as they move.

Therefore, you need to issue a track command if you want to track an object with non-sidereal motion. On the other hand, **Sync** is used to synchronize the telescope's internal coordinates with that of an object you select.

Q: *Can I control my telescope remotely?*

A: Yes. You can start an INDI server on the machine connected to your telescope and the server will listen to requests from KStars clients. Once you're connected, you can control your telescope

directly from the sky map. This procedure is described in detail in the Remote device control section.

Q: *When I try to* **Connect***, KStars reports that the telescope is not connected to the serial/USB port. What can I do?*

A: This message is triggered when KStars cannot communicate with the telescope. Here are few things you can do:

1. Check that you have both reading and writing permission for the port you are trying to connect to.

2. Check the connection cable, make sure it is in good condition and test it with other applications.

3. Check your telescope power, make sure the power is on and that the telescope is getting enough power.

4. Select the **Tools** → **Devices** → **INDI Control Panel...** menu item and set the correct port in the **INDI Control Panel** dialog. The default device is `/dev/ttyS0`

5. Restart KStars and retry again.

Q: *KStars reports that the telescope is online and ready, but I cannot find the telescope's crosshair, where is it?*

A: KStars retrieves the telescopes RA and DEC coordinates upon connection. If your alignment was performed correctly, then you should see the crosshair around your target in the Sky Map. However, the RA and DEC coordinates provided by the telescope may be incorrect (even below the horizon) and you need to Sync your telescope to your current target. You can use the right-click menu to center and track the telescope crosshair in the sky map.

Q: *The telescope is moving erratically or not moving at all. What can I do?*

A: This behavior is mostly due to incorrect settings, please verify the following check list:

1. Is the telescope aligned?

2. Is the telescope alignment mode correct? Use **INDI Control Panel** to check and change these settings (`Alt/Az,Polar, Land`).

3. Are the telescope's time and date settings correct?

4. Are the telescope's longitude and latitude settings correct?

5. Is the telescope's UTC offset correct?

6. Are the telescope's RA and DEC axis locked firmly?

7. Is the telescope's N/S switch (when applicable) setup correctly for your hemisphere?

8. Is the cable between the telescope and computer in good condition?

If you think all settings are correct but the telescope still moves erratically or not at all, then please send a report to indi-devel@lists.sourceforge.net.

Chapter 8

Questions and Answers

1. *What do the different symbols for deep-sky objects mean?*

   The symbol indicates the object type:

   - dotted circle: Open Cluster
   - cross-in-circle: Globular Cluster
   - box: Gaseous Nebula
   - diamond: Supernova Remnant
   - circle with outer lines: Planetary Nebula
   - ellipse: Galaxy

2. *What do the different colors of Deep-sky objects mean?*

   Generally, the different colors indicate to which catalog the object belongs (Messier, NGC or IC). However, some objects have a different color which indicates that there are extra images available in the popup menu (the default 'extras' color is red).

3. *Why are there so many more U.S. cities than in other countries?*

   When we started KStars, we were unable to find a longitude/latitude database that covered the globe equitably. However, the KStars community is rapidly overcoming this problem! We have already received city lists from many users around the world. If you can contribute to this effort, please send us your list of cities and coordinates.

4. *How can I add a new custom location to KStars?*

   If you would like to use a location that is not on the list, enter the relevant information (longitude, latitude, city name, province name, and country name), then press **Add City** button. All fields must be filled, except the optional province field. You can also modify the values for an existing city, by simply changing the values in the window, and adding it to the list.

5. *I have added a custom location to KStars that I no longer want. How do I remove it from the program?*

   You can easily remove a custom location from KStars by selecting it in the cities list and pressing the **Remove City** button. Note that you can not remove a KStars default city.

6. *Why do some objects disappear when I am scrolling the display?*

   When the display is in motion, KStars must recompute the screen coordinates of every object in its database, which involves some pretty heavy trigonometry. When scrolling the display (either with the arrow keys or by dragging with the mouse), the display may become slow and jerky, because the computer is having trouble keeping up. By excluding many of the objects, the computational load is greatly reduced, which allows for smoother scrolling. You can turn off this feature in the **Configure - KStars** window, and you can also configure which objects get hidden.

7. *I do not understand all the terms used in KStars. Where can I learn more about the astronomy behind the program?*

   The KStars Handbook includes the AstroInfo Project; a series of short, hyperlinked articles about astronomical topics that can be explored and illustrated with KStars. AstroInfo is a community effort, like GNUpedia or Everything2. If you'd like to contribute to AstroInfo, please join our mailing list: kstars-devel AT kde.org.

8. *I want KStars to start up with a time and date different from my system CPU clock. Is this possible?*

   Yes; to start KStars with a different time/date, use the `--date` argument, followed by a date string like '4 July 1976 12:30:00'

9. *I want KStars to start up with the simulation clock paused. Is this possible?*

   Yes; to start KStars with the clock paused, simply add the `--paused` argument to the command line.

10. *How accurate/precise is KStars?*

    KStars is pretty accurate, but it is not (yet) as precise as it can possibly be. The problem with high-precision calculations is that you start having to deal with a large number of complicating factors. If you are not a professional astronomer, you will probably never have a problem with its accuracy or precision.

    Here is a list of some of the complicating factors which limit the program's precision:

    - Planet positions are only accurate for dates within 4000 years or so of the current epoch. The planet positions are predicted using a Fourier-like analysis of their orbits, as observed over the past few centuries. We learnt in school that planets follow simple elliptical orbits around the Sun, but this is not strictly true. It would be true only if there was only one planet in the Solar system, and if the Sun and the planet were both point masses. As it is, the planets are constantly tugging on each other, perturbing the orbits slightly, and tidal effects also induce precessional wobbling. In fact, recent analysis suggests that the planets' orbits may not even be stable in the long term (i.e., millions or billions of years). As a rule of thumb, you can expect the position of a planet to be accurate to a few arcseconds between the dates -2000 and 6000.
    Pluto is the exception to this; its position is perhaps ten times less precise than the positions of the other planets. Still, for dates near the present epoch, its position can be trusted to about an arcsecond.
    The moon's position is the most difficult to predict to high precision. This is because its motion is quite perturbed by the Earth. Also, since it is so nearby, even minute effects that would be undetectable in more distant bodies are easily apparent in the moon.

    - The objects with the worst long-term precision in the program are the comets and asteroids. We use a very simplistic orbital model for the minor planets that does not include third-body perturbations. Therefore, their positions can only be trusted for dates near the present epoch. Even for the present epoch, one can expect positional errors among the minor planets of order 10 arcseconds or more.

11. *Why do I have to download an improved NGC/IC catalog and Messier object images? Why not just include them as part of the KStars distribution?*

    The author of the downloadable NGC/IC catalog has released it with the restriction that it may not be used commercially. For most KStars users, this is not a problem. However, it is technically against the KStars license (the GPL) to restrict usage in this way. We removed the Messier object images from the standard distribution for two reasons: to simply reduce the size of KStars, and also because of similar licensing concerns with a couple of the images. The inline images are significantly compressed to a very low quality from their original form, so I doubt there is a real copyright concern, but I did obtain explicit permission from the images' authors to use the few images for which there was any question about it (see `README.images`). Still, just to be absolutely safe, I removed them from the standard distribution, and marked the download archive as being 'free for non-commercial use'.

12. *I am really enjoying the beautiful images I have downloaded through KStars! I would like to share them with the world; can I publish a calendar featuring these images (or are there any usage restrictions on the images)?*

    It depends on the image, but many of the images restrict against commercial usage. The Image Viewer's statusbar will usually contain information about the image's copyright holder, and what usage restrictions apply. As a rule of thumb: anything published by NASA is in the public domain (including all HST images). For everything else, you can pretty safely assume that the images may not be used commercially without permission. When in doubt, contact the image's copyright holder directly.

13. *Can I help contribute to future versions of KStars?*

    Yes, definitely! Introduce yourself on our mailing list: kstars-devel AT kde.org. If you want to help with the coding, download the latest KStars Git version of the code and dive right in. There are several README files in the distribution that explain some of the code's subsystems. If you need ideas of what to work on, see the TODO file. You can submit patches to kstars-devel mailing list, and feel free to post any questions you have about the code there as well.

    If you are not into coding, we can still use your help with i18n, docs, AstroInfo articles, URL links, bug reports, and feature requests.

Chapter 9

The AstroInfo Project

Here you can find a collection of short articles that explain various astronomical concepts used in KStars. From coordinate systems to celestial mechanics, you can find answers to your questions here.

The articles sometimes also contain exercises that you can perform with KStars to illustrate the concept behind the article.

9.1 AstroInfo: Table of Contents

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9.2 Celestial Coordinate Systems

A basic requirement for studying the heavens is determining where in the sky things are. To specify sky positions, astronomers have developed several *coordinate systems*. Each uses a coordinate grid projected on the Celestial Sphere, in analogy to the Geographic coordinate system used on the surface of the Earth. The coordinate systems differ only in their choice of the *fundamental plane*, which divides the sky into two equal hemispheres along a great circle. (the fundamental plane of the geographic system is the Earth's equator). Each coordinate system is named for its choice of fundamental plane.

9.2.1 The Equatorial Coordinate System

The *Equatorial coordinate system* is probably the most widely used celestial coordinate system. It is also the most closely related to the Geographic coordinate system, because they use the same fundamental plane, and the same poles. The projection of the Earth's equator onto the celestial sphere is called the Celestial Equator. Similarly, projecting the geographic Poles onto the celestial sphere defines the North and South Celestial Poles.

However, there is an important difference between the equatorial and geographic coordinate systems: the geographic system is fixed to the Earth; it rotates as the Earth does. The Equatorial

system is fixed to the stars[1], so it appears to rotate across the sky with the stars, but of course it is really the Earth rotating under the fixed sky.

The *latitudinal* (latitude-like) angle of the Equatorial system is called *Declination* (Dec for short). It measures the angle of an object above or below the Celestial Equator. The *longitudinal* angle is called the *Right Ascension* (RA for short). It measures the angle of an object East of the Vernal Equinox. Unlike longitude, Right Ascension is usually measured in hours instead of degrees, because the apparent rotation of the Equatorial coordinate system is closely related to Sidereal Time and Hour Angle. Since a full rotation of the sky takes 24 hours to complete, there are (360 degrees / 24 hours) = 15 degrees in one Hour of Right Ascension.

The equatorial coordinates for deep-sky objects and stars do not vary appreciably over short durations of time, since they are not affected by the *diurnal motion* (the daily apparent rotation of the sky around the earth. However, note that this takes 1 sidereal day, as against 1 solar day). They are suitable coordinates for making catalogs of stars and deep-sky objects (note that *Galactic Coordinates* also work well, but are cumbersome to use from an earth point-of-view). However, there are effects that cause the RA and Dec of objects to vary over time, namely Precession and *nutation*, and *proper motion*, the latter being even less important. Equatorial coordinates are thus generally specified with an appropriate epoch, to account for precession. Popular epochs include J2000.0 (Julian Year 2000) and B1950.0 (*Besselian Year* 1950).

9.2.2 The Horizontal Coordinate System

The Horizontal coordinate system uses the observer's local horizon as the Fundamental Plane. This conveniently divides the sky into the upper hemisphere that you can see, and the lower hemisphere that you can't (because the Earth is in the way). The pole of the upper hemisphere is called the Zenith. The pole of the lower hemisphere is called the *nadir*. The angle of an object above or below the horizon is called the *Altitude* (Alt for short). The angle of an object around the horizon (measured from the North point, toward the East) is called the *Azimuth*. The Horizontal Coordinate System is sometimes also called the Alt/Az Coordinate System.

The Horizontal Coordinate System is fixed to the Earth, not the Stars. Therefore, the Altitude and Azimuth of an object changes with time, as the object appears to drift across the sky. In addition, because the Horizontal system is defined by your local horizon, the same object viewed from different locations on Earth at the same time will have different values of Altitude and Azimuth.

Horizontal coordinates are very useful for determining the Rise and Set times of an object in the sky. When an object has Altitude=0 degrees, it is either Rising (if its Azimuth is < 180 degrees) or Setting (if its Azimuth is > 180 degrees).

9.2.3 The Ecliptic Coordinate System

The Ecliptic coordinate system uses the Ecliptic for its Fundamental Plane. The Ecliptic is the path that the Sun appears to follow across the sky over the course of a year. It is also the projection of the Earth's orbital plane onto the Celestial Sphere. The latitudinal angle is called the *Ecliptic Latitude*, and the longitudinal angle is called the *Ecliptic Longitude*. Like Right Ascension in the Equatorial system, the zeropoint of the Ecliptic Longitude is the Vernal Equinox.

What do you think such a coordinate system would be useful for? If you guessed charting solar system objects, you are right! Each of the planets (except Pluto) orbits the Sun in roughly the same plane, so they always appear to be somewhere near the Ecliptic (i.e., they always have small ecliptic latitudes).

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[1] Actually, the equatorial coordinates are not quite fixed to the stars. See precession. Also, if Hour Angle is used in place of Right Ascension, then the Equatorial system is fixed to the Earth, not to the stars.

9.2.4 The Galactic Coordinate System

The Galactic coordinate system uses the *Milky Way* as its Fundamental Plane. The latitudinal angle is called the *Galactic Latitude*, and the longitudinal angle is called the *Galactic Longitude*. This coordinate system is useful for studying the Galaxy itself. For example, you might want to know how the density of stars changes as a function of Galactic Latitude, to how much the disk of the Milky Way is flattened.

9.3 The Celestial Equator

The *Celestial Equator* is an imaginary great circle on the celestial sphere. The celestial equator is the fundamental plane of the Equatorial Coordinate System, so it is defined as the locus of points with Declination of zero degrees. It is also the projection of the Earth's equator onto the sky.

The Celestial Equator and the Ecliptic are set at an angle of 23.5 degrees in the sky. The points where they intersect are the Vernal and Autumnal Equinoxes.

9.4 The Celestial Poles

The sky appears to drift overhead from east to west, completing a full circuit around the sky in 24 (Sidereal) hours. This phenomenon is due to the spinning of the Earth on its axis. The Earth's spin axis intersects the Celestial Sphere at two points. These points are the *Celestial Poles*. As the Earth spins; they remain fixed in the sky, and all other points seem to rotate around them. The celestial poles are also the poles of the Equatorial Coordinate System, meaning they have *Declinations* of +90 degrees and -90 degrees (for the North and South celestial poles, respectively).

The North Celestial Pole currently has nearly the same coordinates as the bright star *Polaris* (which is Latin for 'Pole Star'). This makes Polaris useful for navigation: not only is it always above the North point of the horizon, but its Altitude angle is always (nearly) equal to the observer's Geographic Latitude (however, Polaris can only be seen from locations in the Northern hemisphere).

The fact that Polaris is near the pole is purely a coincidence. In fact, because of Precession, Polaris is only near the pole for a small fraction of the time.

TIP
Exercises:
Use the **Find Object** window (**Ctrl**+**F**) to locate Polaris. Notice that its Declination is almost (but not exactly) +90 degrees. Compare the Altitude reading when focused on Polaris to your location's geographic latitude. They are always within one degree of each other. They are not exactly the same because Polaris isn't exactly at the Pole. (you can point exactly at the pole by switching to Equatorial coordinates, and pressing the up-arrow key until the sky stops scrolling).
Use the **Time Step** spinbox in the toolbar to accelerate time to a step of 100 seconds. You can see the entire sky appears to rotate around Polaris, while Polaris itself remains nearly stationary.
We said that the celestial pole is the pole of the Equatorial coordinate system. What do you think is the pole of the horizontal (Altitude/Azimuth) coordinate system? (The Zenith).

9.5 The Celestial Sphere

The celestial sphere is an imaginary sphere of gigantic radius, centered on the Earth. All objects which can be seen in the sky can be thought of as lying on the surface of this sphere.

Of course, we know that the objects in the sky are not on the surface of a sphere centered on the Earth, so why bother with such a construct? Everything we see in the sky is so very far away, that their distances are impossible to gauge just by looking at them. Since their distances are indeterminate, you only need to know the *direction* toward the object to locate it in the sky. In this sense, the celestial sphere model is a very practical model for mapping the sky.

The directions toward various objects in the sky can be quantified by constructing a Celestial Coordinate System.

9.6 The Ecliptic

The ecliptic is an imaginary Great Circle on the Celestial Sphere along which the Sun appears to move over the course of a year. Of course, it is really the Earth's orbit around the Sun causing the change in the Sun's apparent direction. The ecliptic is inclined from the Celestial Equator by 23.5 degrees. The two points where the Ecliptic crosses the Celestial Equator are known as the Equinoxes.

Since our solar system is relatively flat, the orbits of the planets are also close to the plane of the ecliptic. In addition, the constellations of the zodiac are located along the ecliptic. This makes the ecliptic a very useful line of reference to anyone attempting to locate the planets or the constellations of the zodiac, since they all literally 'follow the Sun'.

Because of the 23.5-degree tilt of the Ecliptic, the *Altitude* of the Sun at noon changes over the course of the year, as it follows the path of the Ecliptic across the sky. This causes the seasons. In the Summer, the Sun is high in the sky at noon, and it remains above the Horizon for more than twelve hours. Whereas, in the winter, the Sun is low in the sky at noon, and remains above the Horizon for less than twelve hours. In addition, sunlight is received at the Earth's surface at a more direct angle in the Summer, which means that a given area at the surface receives more energy per second in the Summer than in Winter. The differences in day duration and in energy received per unit area lead to the differences in temperature we experience in Summer and Winter.

TIP

Exercises:

Make sure your location is set to somewhere that is not very near the equator for these experiments. Open the **Configure - KStars** window, and switch to Horizontal coordinates, with the Opaque Ground shown. Open the **Set Time** window (**Ctrl**+**S**),and change the Date to sometime in the middle of Summer, and the Time to 12:00 Noon. Back in the Main Window, point toward the Southern Horizon (press **S**). Note the height of the Sun above the Horizon at Noon in the Summer. Now, change the Date to something in the middle of Winter (but keep the Time at 12:00 Noon). The Sun is now much lower in the Sky. You will also notice that the day durations are different if you open the **What's up Tonight?** tool for each date.

9.7 The Equinoxes

Most people know the Vernal and Autumnal Equinoxes as calendar dates, signifying the beginning of the Northern hemisphere's Spring and Autumn, respectively. Did you know that the equinoxes are also positions in the sky?

The Celestial Equator and the Ecliptic are two Great Circles on the Celestial Sphere, set at an angle of 23.5 degrees. The two points where they intersect are called the *Equinoxes*. The *Vernal Equinox* has coordinates RA=0.0 hours, Dec=0.0 degrees. The *Autumnal Equinox* has coordinates RA=12.0 hours, Dec=0.0 degrees.

The Equinoxes are important for marking the seasons. Because they are on the Ecliptic, the Sun passes through each equinox every year. When the Sun passes through the Vernal Equinox (usually on March 21st), it crosses the Celestial Equator from South to North, signifying the end of Winter for the Northern hemisphere. Similarly, when the Sun passes through the Autumnal Equinox (usually on September 21st), it crosses the Celestial Equator from North to South, signifying the end of Winter for the Southern hemisphere.

9.8 Geographic Coordinates

Locations on Earth can be specified using a spherical coordinate system. The geographic ('earth-mapping') coordinate system is aligned with the spin axis of the Earth. It defines two angles measured from the center of the Earth. One angle, called the *Latitude*, measures the angle between any point and the Equator. The other angle, called the *Longitude*, measures the angle *along* the Equator from an arbitrary point on the Earth (Greenwich, England is the accepted zero-longitude point in most modern societies).

By combining these two angles, any location on Earth can be specified. For example, Baltimore, Maryland (USA) has a latitude of 39.3 degrees North, and a longitude of 76.6 degrees West. So, a vector drawn from the center of the Earth to a point 39.3 degrees above the Equator and 76.6 degrees west of Greenwich, England will pass through Baltimore.

The Equator is obviously an important part of this coordinate system; it represents the *zeropoint* of the latitude angle, and the halfway point between the poles. The Equator is the *Fundamental Plane* of the geographic coordinate system. All Spherical Coordinate Systems define such a Fundamental Plane.

Lines of constant Latitude are called *Parallels*. They trace circles on the surface of the Earth, but the only parallel that is a Great Circle is the Equator (Latitude=0 degrees). Lines of constant Longitude are called *Meridians*. The Meridian passing through Greenwich is the *Prime Meridian* (longitude=0 degrees). Unlike Parallels, all Meridians are great circles, and Meridians are not parallel: they intersect at the north and south poles.

> TIP
> Exercise:
> What is the longitude of the North Pole? Its latitude is 90 degrees North.
> This is a trick question. The Longitude is meaningless at the north pole (and the south pole too). It has all longitudes at the same time.

9.9 Great Circles

Consider a sphere, such as the Earth, or the Celestial Sphere. The intersection of any plane with the sphere will result in a circle on the surface of the sphere. If the plane happens to contain the center of the sphere, the intersection circle is a *Great Circle*. Great circles are the largest circles that can be drawn on a sphere. Also, the shortest path between any two points on a sphere is always along a great circle.

Some examples of great circles on the celestial sphere include: the Horizon, the Celestial Equator, and the Ecliptic.

9.10 The Horizon

The *Horizon* is the line that separates Earth from Sky. More precisely, it is the line that divides all of the directions you can possibly look into two categories: those which intersect the Earth, and

those which do not. At many locations, the Horizon is obscured by trees, buildings, mountains, etc. However, if you are on a ship at sea, the Horizon is strikingly apparent.

The horizon is the *Fundamental Plane* of the Horizontal Coordinate System. In other words, it is the locus of points which have an *Altitude* of zero degrees.

9.11 Hour Angle

As explained in the Sidereal Time article, the *Right Ascension* of an object indicates the Sidereal Time at which it will transit across your Local Meridian. An object's *Hour Angle* is defined as the difference between the current Local Sidereal Time and the Right Ascension of the object:

HA_{obj} = LST - RA_{obj}

Thus, the object's Hour Angle indicates how much Sidereal Time has passed since the object was on the Local Meridian. It is also the angular distance between the object and the meridian, measured in hours (1 hour = 15 degrees). For example, if an object has an hour angle of 2.5 hours, it transited across the Local Meridian 2.5 hours ago, and is currently 37.5 degrees West of the Meridian. Negative Hour Angles indicate the time until the *next* transit across the Local Meridian. Of course, an Hour Angle of zero means the object is currently on the Local Meridian.

9.12 The Local Meridian

The Local Meridian is an imaginary Great Circle on the Celestial Sphere that is perpendicular to the local Horizon. It passes through the North point on the Horizon, through the Celestial Pole, up to the Zenith, and through the South point on the Horizon.

Because it is fixed to the local Horizon, stars will appear to drift past the Local Meridian as the Earth spins. You can use an object's Right Ascension and the Local Sidereal Time to determine when it will cross your Local Meridian (see Hour Angle).

9.13 Precession

Precession is the gradual change in the direction of the Earth's spin axis. The spin axis traces a cone, completing a full circuit in 26,000 years. If you have ever spun a top or a dreidel, the 'wobbling' rotation of the top as it spins is precession.

Because the direction of the Earth's spin axis changes, so does the location of the Celestial Poles.

The reason for the Earth's precession is complicated. The Earth is not a perfect sphere, it is a bit flattened, meaning the Great Circle of the equator is longer than a 'meridonal' great circle that passes through the poles. Also, the Moon and Sun lie outside the Earth's Equatorial plane. As a result, the gravitational pull of the Moon and Sun on the oblate Earth induces a slight *torque* in addition to a linear force. This torque on the spinning body of the Earth leads to the precessional motion.

> **TIP**
> Exercise:
> Precession is easiest to see by observing the Celestial Pole. To find the pole, first switch to Equatorial Coordinates in the **Configure - KStars** window, and then hold down the **Up** arrow key until the display stops scrolling. The declination displayed in the center of the **Info Panel** should be +90 degrees, and the bright star Polaris should be nearly at the center of the screen. Try slewing with the left and right arrow keys. Notice that the sky appears to rotate around the Pole.
> We will now demonstrate Precession by changing the Date to a very remote year, and observing that the location of the Celestial Pole is no longer near Polaris. Open the **Set Time** window (**Ctrl**+**S**), and set the date to the year 8000 (currently, KStars cannot handle dates much more remote than this, but this date is sufficient for our purposes). Notice that the sky display is now centered at a point between the constellations Cygnus and Cepheus. Verify that this is actually the pole by slewing left and right: the sky rotates about this point; in the year 8000, the North celestial pole will no longer be near Polaris.

9.14 The Zenith

The Zenith is the point in the sky where you are looking when you look 'straight up' from the ground. More precisely, it is the point on the sky with an *Altitude* of +90 Degrees; it is the Pole of the Horizontal Coordinate System. Geometrically, it is the point on the Celestial Sphere intersected by a line drawn from the center of the Earth through your location on the Earth's surface.

The Zenith is, by definition, a point along the Local Meridian.

> **TIP**
> Exercise:
> You can point to the Zenith by pressing **Z** or by selecting the **Pointing** → **Zenith** menu item.

9.15 Epoch

An epoch is a certain instant of time (usually past) used as a reference for time measurement in astronomy. In order to make calculations easier, astronomers usually use the number of days that have passed since a certain moment in time as a way of representing time in astronomical calculations. This arbitrarily chosen "starting point" reference for time is called an epoch.

An epoch is usually cited along with equatorial coordinates in astronomical catalogs, since the equatorial coordinates of sky objects change (although slowly) with time. Printed star charts / atlases are usually marked as being valid for a certain epoch.

The most popular epoch used currently is J2000.0, (the Julian year 2000.0), which (almost exactly) corresponds to 1st January 2000, 12:00 noon UTC. Other epochs include B1900 and B1950.

KStars supports catalogs based on J2000.0 and B1950.0 epochs.

9.16 Julian Day

Julian Days are a way of reckoning the current date by a simple count of the number of days that have passed since some remote, arbitrary date. This number of days is called the *Julian Day*, abbreviated as JD. The starting point, JD=0, is January 1, 4713 BC (or -4712 January 1, since there was no year '0'). Julian Days are very useful because they make it easy to determine the number of days between two events by simply subtracting their Julian Day numbers. Such a calculation

is difficult for the standard (Gregorian) calendar, because days are grouped into months, which contain a variable number of days, and there is the added complication of Leap Years.

Converting from the standard (Gregorian) calendar to Julian Days and vice versa is best left to a special program written to do this, such as the KStars Astrocalculator. However, for those interested, here is a simple example of a Gregorian to Julian day converter:

JD = D - 32075 + 1461*(Y + 4800 + (M - 14) / 12) / 4 + 367*(M - 2 - (M - 14) / 12 * 12) / 12 - 3*((Y + 4900 + (M - 14) / 12) / 100) / 4

where D is the day (1-31), M is the Month (1-12), and Y is the year (1801-2099). Note that this formula only works for dates between 1801 and 2099. More remote dates require a more complicated transformation.

An example Julian Day is: JD 2440588, which corresponds to 1 Jan, 1970.

Julian Days can also be used to tell time; the time of day is expressed as a fraction of a full day, with 12:00 noon (not midnight) as the zero point. So, 3:00 pm on 1 Jan 1970 is JD 2440588.125 (since 3:00 pm is 3 hours since noon, and 3/24 = 0.125 day). Note that the Julian Day is always determined from Universal Time, not Local Time.

Astronomers use certain Julian Day values as important reference points, called Epochs. One widely-used epoch is called J2000; it is the Julian Day for 1 Jan, 2000 at 12:00 noon = JD 2451545.0.

Much more information on Julian Days is available on the internet. A good starting point is the U.S. Naval Observatory. If that site is not available when you read this, try searching for 'Julian Day' with your favorite search engine.

9.17 Leap Years

The Earth has two major components of motion. First, it spins on its rotational axis; a full spin rotation takes one *Day* to complete. Second, it orbits around the Sun; a full orbital rotation takes one *Year* to complete.

There are normally 365 days in one *calendar* year, but it turns out that a *true* year (i.e., a full orbit of the Earth around the Sun; also called a *tropical year*) is a little bit longer than 365 days. In other words, in the time it takes the Earth to complete one orbital circuit, it completes 365.24219 spin rotations. Do not be too surprised by this; there is no reason to expect the spin and orbital motions of the Earth to be synchronized in any way. However, it does make marking calendar time a bit awkward...

What would happen if we simply ignored the extra 0.24219 rotation at the end of the year, and simply defined a calendar year to always be 365.0 days long? The calendar is basically a charting of the Earth's progress around the Sun. If we ignore the extra bit at the end of each year, then with every passing year, the calendar date lags a little more behind the true position of Earth around the Sun. In just a few decades, the dates of the solstices and equinoxes will have drifted noticeably.

In fact, it used to be that all years *were* defined to have 365.0 days, and the calendar 'drifted' away from the true seasons as a result. In the year 46 BCE, Julius Caeser established the *Julian Calendar*, which implemented the world's first *leap years*: He decreed that every 4th year would be 366 days long, so that a year was 365.25 days long, on average. This basically solved the calendar drift problem.

However, the problem wasn't completely solved by the Julian calendar, because a tropical year isn't 365.25 days long; it's 365.24219 days long. You still have a calendar drift problem, it just takes many centuries to become noticeable. And so, in 1582, Pope Gregory XIII instituted the *Gregorian calendar*, which was largely the same as the Julian Calendar, with one more trick added for leap years: even Century years (those ending with the digits '00') are only leap years if they are divisible by 400. So, the years 1700, 1800, and 1900 were not leap years (though they would have been under the Julian Calendar), whereas the year 2000 *was* a leap year. This change makes the average length of a year 365.2425 days. So, there is still a tiny calendar drift, but it amounts to

an error of only 3 days in 10,000 years. The Gregorian calendar is still used as a standard calendar throughout most of the world.

> NOTE
> Fun Trivia: When Pope Gregory instituted the Gregorian Calendar, the Julian Calendar had been followed for over 1500 years, and so the calendar date had already drifted by over a week. Pope Gregory re-synchronized the calendar by simply *eliminating* 10 days: in 1582, the day after October 4th was October 15th!

9.18 Sidereal Time

Sidereal Time literally means 'star time'. The time we are used to using in our everyday lives is Solar Time. The fundamental unit of Solar Time is a *Day*: the time it takes the Sun to travel 360 degrees around the sky, due to the rotation of the Earth. Smaller units of Solar Time are just divisions of a Day:

- 1/24 Day = 1 Hour

- 1/60 Hour = 1 Minute

- 1/60 Minute = 1 Second

However, there is a problem with Solar Time. The Earth does not actually spin around 360 degrees in one Solar Day. The Earth is in orbit around the Sun, and over the course of one day, it moves about one Degree along its orbit (360 degrees/365.25 Days for a full orbit = about one Degree per Day). So, in 24 hours, the direction toward the Sun changes by about a Degree. Therefore, the Earth has to spin 361 degrees to make the Sun look like it has traveled 360 degrees around the Sky.

In astronomy, we are concerned with how long it takes the Earth to spin with respect to the 'fixed' stars, not the Sun. So, we would like a timescale that removes the complication of Earth's orbit around the Sun, and just focuses on how long it takes the Earth to spin 360 degrees with respect to the stars. This rotational period is called a *Sidereal Day*. On average, it is 4 minutes shorter than a Solar Day, because of the extra 1 degree the Earth spins in a Solar Day. Rather than defining a Sidereal Day to be 23 hours, 56 minutes, we define Sidereal Hours, Minutes and Seconds that are the same fraction of a Day as their Solar counterparts. Therefore, one Solar Second = 1.00278 Sidereal Seconds.

The Sidereal Time is useful for determining where the stars are at any given time. Sidereal Time divides one full spin of the Earth into 24 Sidereal Hours; similarly, the map of the sky is divided into 24 Hours of *Right Ascension*. This is no coincidence; Local Sidereal Time (LST) indicates the Right Ascension on the sky that is currently crossing the Local Meridian. So, if a star has a Right Ascension of 05h 32m 24s, it will be on your meridian at LST=05:32:24. More generally, the difference between an object's RA and the Local Sidereal Time tells you how far from the Meridian the object is. For example, the same object at LST=06:32:24 (one Sidereal Hour later), will be one Hour of Right Ascension west of your meridian, which is 15 degrees. This angular distance from the meridian is called the object's Hour Angle.

> TIP
> The Local Sidereal Time is displayed by KStars in the **Time Info Box**, with the label 'ST' (you have to 'unshade' the box by double-clicking it in order to see the sidereal time). Note that the changing sidereal seconds are not synchronized with the changing Local Time and Universal Time seconds. In fact, if you watch the clocks for a while, you will notice that the Sidereal seconds really are slightly shorter than the LT and UT seconds.
> Point to the Zenith (press **Z** or select the **Pointing → Zenith** menu item). The Zenith is the point on the sky where you are looking 'straight up' from the ground, and it is a point on your Local Meridian. Note the Right Ascension of the Zenith: it is exactly the same as your Local Sidereal Time.

9.19 Time Zones

The Earth is round, and it is always half-illuminated by the Sun. However, because the Earth is spinning, the half that is illuminated is always changing. We experience this as the passing of days wherever we are on the Earth's surface. At any given instant, there are places on the Earth passing from the dark half into the illuminated half (which is seen as *dawn* on the surface). At the same instant, on the opposite side of the Earth, points are passing from the illuminated half into darkness (which is seen as *dusk* at those locations). So, at any given time, different places on Earth are experiencing different parts of the day. Thus, Solar time is defined locally, so that the clock time at any location describes the part of the day consistently.

This localization of time is accomplished by dividing the globe into 24 vertical slices called *Time Zones*. The Local Time is the same within any given zone, but the time in each zone is one Hour *earlier* than the time in the neighboring Zone to the East. Actually, this is a idealized simplification; real Time Zone boundaries are not straight vertical lines, because they often follow national boundaries and other political considerations.

Note that because the Local Time always increases by an hour when moving between Zones to the East, by the time you move through all 24 Time Zones, you are a full day ahead of where you started. We deal with this paradox by defining the *International Date Line*, which is a Time Zone boundary in the Pacific Ocean, between Asia and North America. Points just to the East of this line are 24 hours behind the points just to the West of the line. This leads to some interesting phenomena. A direct flight from Australia to California arrives before it departs. Also, the islands of Fiji straddle the International Date Line, so if you have a bad day on the West side of Fiji, you can go over to the East side of Fiji and have a chance to live the same day all over again.

9.20 Universal Time

The time on our clocks is essentially a measurement of the current position of the Sun in the sky, which is different for places at different Longitudes because the Earth is round (see Time Zones).

However, it is sometimes necessary to define a global time, one that is the same for all places on Earth. One way to do this is to pick a place on the Earth, and adopt the Local Time at that place as the *Universal Time*, abbreviated UT. (The name is a bit of a misnomer, since Universal Time has little to do with the Universe. It would perhaps be better to think of it as *global time*).

The geographic location chosen to represent Universal Time is Greenwich, England. The choice is arbitrary and historical. Universal Time became an important concept when European ships began to sail the wide open seas, far from any known landmarks. A navigator could reckon the ship's longitude by comparing the Local Time (as measured from the Sun's position) to the time back at the home port (as kept by an accurate clock on board the ship). Greenwich was home to England's Royal Observatory, which was charged with keeping time very accurately, so that ships in port could re-calibrate their clocks before setting sail.

> TIP
> Exercise:
> Set the geographic location to 'Greenwich, England' using the **Set Location** window (**Ctrl**+**G**). Note that the Local Time (LT) and the Universal Time (UT) are now the same.
> Further Reading: The history behind the construction of the first clock that was accurate and stable enough to be used on ships to keep Universal Time is a fascinating tale, and one told expertly in the book 'Longitude', by Dava Sobel.

9.21 Telescopes

Invented in Holland at the beginning of the 17th century, telescopes are the tools used by astronomers and astrophysicists for their observations. With the development of modern science,

telescopes are nowadays used for observing in all ranges of the electromagnetic spectrum, inside and outside Earth's atmosphere. Telescopes work by collecting light with a large surface aerie called objective that makes the incoming light to converge. The final image will be viewed by using an eyepiece.

9.21.1 Aperture and Focal Ratio

Telescopes are used in order to collect light from celestial objects and to converge it to a point, named the focal point. They are described by two parameters, *aperture* and *Focal Ratio*. The diameter of the light collecting surface is called the *aperture* of the telescope – the bigger the aperture, the brighter the image. The ratio of the focal length *f* to the *aperture D* of a telescope is defined as the *focal ratio*. This describes the light gathering power of a telescope. 'Fast' telescopes have smaller focal ratios, as they obtain brighter images in a smaller exposure time. As the focal ratio gets bigger, the telescope needs more exposure time in order to obtain a bright image, which is why it is 'slower'. The focal ratio is usually denoted as 'f/n', where n is the ratio of the focal length to the aperture.

9.21.2 Aberrations

In order to obtain an image, telescopes use lenses or mirrors. Unfortunately, if we use both of them we obtain image distortions known as *aberrations*. Some aberrations are common for both lenses and mirrors, like *astigmatism* and *curvature of field*.

Astigmatism appears when different parts of the lens or mirror make the rays of the incoming light to converge in slightly different locations on the focal plane. When corrected for astigmatism, *curvature of field* may appear on the surface of the lens/ mirror, which makes the light to converge on a curve rather than on a plane.

Still, there are also lens specific aberrations and mirror specific aberrations.

Chromatic aberration is a feature of telescopes that use lenses to converge the light. Mainly, the focal length of a lens is wavelength dependent, which means that the focal point of blue light differs from that of the red light. This results in a blurred image. The effect of chromatic aberration can be diminished by adding correcting lenses into the system. *Spherical* aberration may also be a problem for lenses, resulting from their shape. Spheroid surfaces will not make the incoming light to converge to a single point, which is why other optical surfaces like paraboloids are preferred. Even by using them we aren't still out of trouble, as coma aberration appears in this case. It results from the dependence of the focal length on the angle between the direction of the incoming ray and the optical axis of the system. Thus, images of points that lie off the optical axis are elongated, rather than being simple points, as it would be normal.

9.21.3 Magnification

Magnification, the increase in angular size of an object as viewed in a telescope, is described as the ratio of the focal length of the objective to the focal length of the eyepiece. So the greater the focal length of the objective, the greater the magnification. If you want to have a large image then you need a long focal length objective and a short focal length eyepiece.

As an example, if you have a 500 mm objective and a 25 mm eyepiece the resulting magnification will be 500 / 25, which is 20, or 20X.

9.21.4 Field of View

The field of view is the angle covered on the sky by the telescope.*The apparent* field of view of a telescope is determined only by the eyepiece. It is a specific characteristic of it, usually around 52

degrees. In order to find the *true field of view* of a telescope, you need to divide the apparent field of view by the magnification. The true field of view is the actual angle covered on the sky by the telescope.

TIP

KStars has a tool to find and display (on the virtual sky) a true field of view called the **FOV Indicator**. Launch it by heading under the **Settings** → **FOV Symbols** → **Edit FOV Symbols...** menu item. Clicking **New...** will open a dialog with four different tabs: **Eyepiece**, **Camera**, **Binocular** and **Radiotelescope**. To compute the field of view, select the tab that applies and enter the specifications of the equipment. Finally, clicking **Compute FOV** will calculate and display the field of view immediately below. KStars can now also display this as a shape of that size on the virtual sky. To do so, enter a name for this particular field of view (such as `20mm eyepiece` or `DSLR with refractor`) and select a shape and color to be displayed. For **Eyepiece**, use **Circle** or **Semitransparent circle** as the shape since an eyepiece's field is round. For **Camera**, use **Square** (which is actually a rectangle) assuming the sensor or film is rectangular or square. When using multiple eyepieces and/or telescopes, it is good to distinguish them with different colors. Click **OK** to close the dialog. To show the shape on the screen, go back under the **Settings** → **FOV Symbols** submenu, then select the new menu item with the name of whatever it was given. To disable it again, click the menu item again.

9.21.5 Types of Telescopes

As telescopes are used in observations over the entire electromagnetic spectrum, they are classified in Optical Telescopes, Ultraviolet, Gamma Ray, X-Ray, Infrared and Radio Telescopes. Each one of them has its own, well defined role in obtaining a detailed analysis of a celestial object.

9.21.6 Optical Telescopes

Used for observations in the visible field of view, Optical Telescopes are mainly Refractors and Reflectors, the difference between the two of them being the way of collecting light from a star.

Refracting Telescopes use two lenses in order to create an image, a primary or *objective lens*, which collects the incoming light, forming an image in the focal plane and the *eyepiece*, which is acting as a magnifying glass used for observing the final image. The two lenses are situated at opposite ends of a moving tube and the distance between the two of them can be adjusted in order to obtain the final image.

The largest refracting telescope in the world is at the *Yerkes Observatory* in Williams Bay, Wisconsin. Built in 1897, it has a 1.02-m (40-in) objective and a focal length of 19.36 m.

Reflecting Telescopes, on the other side, use mirrors instead of lenses in order to obtain the final image. By replacing the objective lens with a mirror, we obtain a focal point that lies on the path of the incoming light. An observer situated at this point could see an image, but he would block part of the incoming light. The focal point of the principal mirror is called *prime focus*, and this is also the name of the first category of reflecting telescopes. Thus, prime focus telescopes use a mirror in order to collect light from a celestial object and by reflection the image of the object may be observed from the prime focus of the telescope. Other types of reflecting telescopes are *Newtonian*, *Cassegrain* and *Coude*.

The Newtonian one uses an additional flat mirror placed in the vicinity of the prime focus, in the path of the reflected light. This results in moving the focal point to a different location, on one of the sides of the telescope, more accessible for observing. Of course, a mirror placed in the path of the reflected light will also block part of the incoming one, but if the ratio of the surface aeries of the primary mirror to the second one is big enough, the amount of the blocked incoming light is negligible.

The Cassegrain telescope is similar to the Newtonian one but this time the secondary mirror reflects light to the bottom of the telescope. There is a hole at the center of the primary mirror that lets the reflected light to go on its way until it converges to the focal point. The secondary mirror needs to be convex, as it is increasing the focal length of the optical system. The primary mirror of a Cassegrain Telescope is a paraboloid. By replacing it with a hyperboloid we obtain a Ritchey-Chretien telescope. The advantage of using a *Ritchey-Chretien* telescope is that it removes the coma of the classical reflectors.

The Coude type consists of more than one mirror that reflects the light to a special room, the Coude room, which is located below the telescope. The advantages of using a Coude telescope are varied, from obtaining a long focal length useful in different fields of astronomy and astrophysics, like spectroscopy to avoiding the usage of a massive instrument. But there are also disadvantages in using a Coude telescope, because the more mirrors are placed in the system, the less amount of light arrives at the detector. This happens because by using Aluminum mirrors, only 80 % of the incident light gets reflected.

Catadioptrics are types of telescopes that use systems of both lenses and mirrors for making the light to converge. The most popular catadioptric is the *Schmidt-Cassegrain* telescope. It has the advantage of providing a large angle field of view. In order to minimize coma, it uses a primary spheroidal mirror with a thin correcting lens that removes spherical aberrations. The secondary mirror is placed in the center of the correcting lens, reflecting light through a hole made in the primary mirror. Not as famous as the Schmidt-Cassegrain telescope but common though is the *Maksutov* telescope that also uses a correcting lens with the primary mirror, this time their surfaces being concentric.

9.21.7 Observations in Other Wavelengths

For a detailed analysis of the sky, observations are also carried in other regions of the electromagnetic spectrum. Very popular and efficient are *radio telescopes*, developed mostly in the last century. A common problem for both radio and optical telescopes is the need for better resolution. We can derive the resolution of a telescope by using Rayleigh criterion, that states the resolving power is equal to the ratio of the incoming wavelength to the diameter of the aperture (times 1.22 for circular apertures). So for a good resolution we need a diameter as big as possible. The biggest radio telescope in the world is the Arecibo telescope from Puerto Rico that uses a huge dish of 305 m diameter. In order to solve the problem for resolutions, astronomers have developed a new technique called interferometry. The basic principal of interferometry is that by observing the same object with two distinct telescopes we can obtain a final image by "connecting" the two initial ones. Nowadays, the most efficient observatory that uses interferometry is the Very Large Array located near Socorro, New Mexico. It uses 27 telescopes placed in a "Y" shape, with 25 m aperture each. There also exists a technique called Very Long Baseline Interferometry (VLBI) that allows astronomers to resolve images over the size of continents. The biggest project of the century in this domain is the building of the Atacama Large Millimeter Array (ALMA), which will be using 66 telescopes placed in the Atacama desert of northern Chile.

9.21.8 Space-Based Observations

Because Earth-based observations are affected by extinction due Earth's atmosphere, observations carried out in space are more successful. We mention the *Hubble Space Telescope (HST)* that has a 2.4, f/24 primary mirror, the smoothest mirror ever constructed. The Hubble Space Telescope is placed on a low-orbit around Earth and because of the lack of atmosphere it can observe very faint objects. Another Space Telescope is the *James Webb Space Telescope (JWST)* which is planned to be launched in 2018. It will have a 6.5m primary mirror and it will orbit around a gravitation stable point on the Sun-Earth line known as the Second Lagrange Point (L2). Here the gravitational attractions due to both Sun and Earth balances the centrifugal force of an object set in motion around the Sun. This point has the special property that if an object is placed here, it is in equilibrium with respect to the Sun-Earth system. The second Lagrange Point lies on the line connecting Sun and Earth, on the other side of the Earth. So a telescope placed here will receive less thermal radiation, which will improve Infrared Observations.

9.22 Blackbody Radiation

A *blackbody* refers to an opaque object that emits *thermal radiation*. A perfect blackbody is one that absorbs all incoming light and does not reflect any. At room temperature, such an object would appear to be perfectly black (hence the term *blackbody*). However, if heated to a high temperature, a blackbody will begin to glow with *thermal radiation*.

In fact, all objects emit thermal radiation (as long as their temperature is above Absolute Zero, or -273.15 degrees Celsius), but no object emits thermal radiation perfectly; rather, they are better at emitting/absorbing some wavelengths of light than others. These uneven efficiencies make it difficult to study the interaction of light, heat and matter using normal objects.

Fortunately, it is possible to construct a nearly-perfect blackbody. Construct a box made of a thermally conductive material, such as metal. The box should be completely closed on all sides, so that the inside forms a cavity that does not receive light from the surroundings. Then, make a small hole somewhere on the box. The light coming out of this hole will almost perfectly resemble the light from an ideal blackbody, for the temperature of the air inside the box.

At the beginning of the 20th century, scientists Lord Rayleigh, and Max Planck (among others) studied the blackbody radiation using such a device. After much work, Planck was able to empirically describe the intensity of light emitted by a blackbody as a function of wavelength. Furthermore, he was able to describe how this spectrum would change as the temperature changed. Planck's work on blackbody radiation is one of the areas of physics that led to the foundation of the wonderful science of Quantum Mechanics, but that is unfortunately beyond the scope of this article.

What Planck and the others found was that as the temperature of a blackbody increases, the total amount of light emitted per second increases, and the wavelength of the spectrum's peak shifts to bluer colors (see Figure 1).
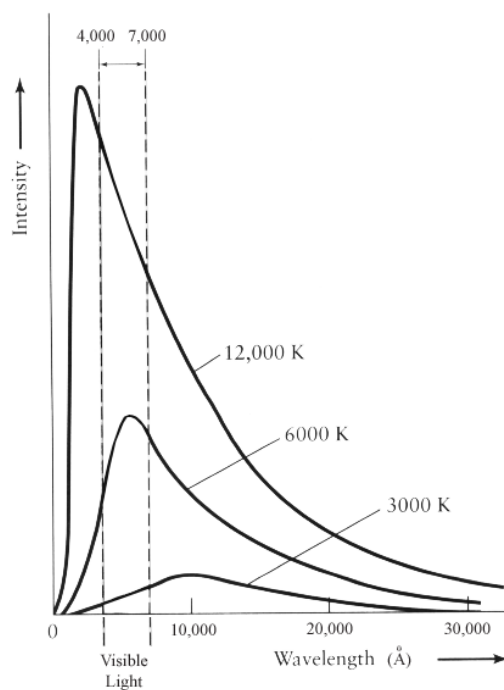

Figure 1

For example, an iron bar becomes orange-red when heated to high temperatures and its color progressively shifts toward blue and white as it is heated further.

In 1893, German physicist Wilhelm Wien quantified the relationship between blackbody temperature and the wavelength of the spectral peak with the following equation:

$$\lambda_{max} \cdot T = 0.29 \; cm \; K$$

where T is the temperature in Kelvin. Wien's law (also known as Wien's displacement law) states that the wavelength of maximum emission from a blackbody is inversely proportional to its temperature. This makes sense; shorter-wavelength (higher-frequency) light corresponds to higher-energy photons, which you would expect from a higher-temperature object.

For example, the sun has an average temperature of 5800 K, so its wavelength of maximum emission is given by:

$$\lambda_{max} = \frac{0.29 \; cm}{5800} = 500 \; nm$$

This wavelengths falls in the green region of the visible light spectrum, but the sun's continuum radiates photons both longer and shorter than lambda(max) and the human eyes perceives the sun's color as yellow/white.

In 1879, Austrian physicist Stephan Josef Stefan showed that the luminosity, L, of a black body is proportional to the 4th power of its temperature T.

$$L = A \cdot \alpha \cdot T^4$$

where A is the surface area, alpha is a constant of proportionality, and T is the temperature in Kelvin. That is, if we double the temperature (e.g. 1000 K to 2000 K) then the total energy radiated from a blackbody increase by a factor of 2^4 or 16.

Five years later, Austrian physicist Ludwig Boltzman derived the same equation and is now known as the Stefan-Boltzman law. If we assume a spherical star with radius R, then the luminosity of such a star is

$$L = 4\pi R^2 \cdot \alpha \cdot T^4$$

where R is the star radius in cm, and the alpha is the Stefan-Boltzman constant, which has the value:

$$\alpha = 5.670 \cdot 10^{-5} \; ergs/s/cm^2/K^{-4}$$

9.23 Dark Matter

Scientists are now quite comfortable with the idea that 90% of the mass in the universe is in a form of matter that cannot be seen.

Despite comprehensive maps of the nearby universe that cover the spectrum from radio to gamma rays, we are only able to account of 10% of the mass that must be out there. As Bruce H. Margon, an astronomer at the University of Washington, told the New York Times in 2001: 'It's a fairly embarrassing situation to admit that we can't find 90 percent of the universe.'

The term given this 'missing mass' is *Dark Matter*, and those two words pretty well sum up everything we know about it at this point. We know there is 'Matter', because we can see the effects of its gravitational influence. However, the matter emits no detectable electromagnetic radiation at all, hence it is 'Dark'. There exist several theories to account for the missing mass ranging from exotic subatomic particles, to a population of isolated black holes, to less exotic brown and white dwarfs. The term 'missing mass' might be misleading, since the mass itself is not missing, just its light. But what is exactly dark matter and how do we really know it exists, if we cannot see it?

The story began in 1933 when Astronomer Fritz Zwicky was studying the motions of distant and massive clusters of galaxies, specifically the Coma cluster and the Virgo cluster. Zwicky

estimated the mass of each galaxy in the cluster based on their luminosity, and added up all of the galaxy masses to get a total cluster mass. He then made a second, independent estimate of the cluster mass, based on measuring the spread in velocities of the individual galaxies in the cluster. To his surprise, this second *dynamical mass* estimate was *400 times* larger than the estimate based on the galaxy light.

Although the evidence was strong at Zwicky's time, it was not until the 1970s that scientists began to explore this discrepancy comprehensively. It was at this time that the existence of Dark Matter began to be taken seriously. The existence of such matter would not only resolve the mass deficit in galaxy clusters; it would also have far more reaching consequences for the evolution and fate of the universe itself.

Another phenomenon that suggested the need for dark matter is the rotational curves of *Spiral Galaxies*. Spiral Galaxies contain a large population of stars that orbit the Galactic center on nearly circular orbits, much like planets orbit a star. Like planetary orbits, stars with larger galactic orbits are expected to have slower orbital speeds (this is just a statement of Kepler's 3rd Law). Actually, Kepler's 3rd Law only applies to stars near the perimeter of a Spiral Galaxy, because it assumes the mass enclosed by the orbit to be constant.

However, astronomers have made observations of the orbital speeds of stars in the outer parts of a large number of spiral galaxies, and none of them follow Kepler's 3rd Law as expected. Instead of falling off at larger radii, the orbital speeds remain remarkably constant. The implication is that the mass enclosed by larger-radius orbits increases, even for stars that are apparently near the edge of the galaxy. While they are near the edge of the luminous part of the galaxy, the galaxy has a mass profile that apparently continues well beyond the regions occupied by stars.

Here is another way to think about it: Consider the stars near the perimeter of a spiral galaxy, with typical observed orbital velocities of 200 kilometers per second. If the galaxy consisted of only the matter that we can see, these stars would very quickly fly off from the galaxy, because their orbital speeds are four times larger than the galaxy's escape velocity. Since galaxies are not seen to be spinning apart, there must be mass in the galaxy that we are not accounting for when we add up all the parts we can see.

Several theories have surfaced in literature to account for the missing mass such as WIMPs (Weakly Interacting Massive Particles), MACHOs (MAssive Compact Halo Objects), primordial black holes, massive neutrinos, and others; each with their pros and cons. No single theory has yet been accepted by the astronomical community, because we so far lack the means to conclusively test one theory against the other.

TIP
You can see the galaxy clusters that Professor Zwicky studied to discover Dark Matter. Use the KStars **Find Object** window (**Ctrl**+**F**) to center on 'M 87' to find the Virgo Cluster, and on 'NGC 4884' to find the Coma Cluster. You may have to zoom in to see the galaxies. Note that the Virgo Cluster appears to be much larger on the sky. In reality, Coma is the larger cluster; it only appears smaller because it is further away.

9.24 Flux

The *flux* is the amount of energy that passes through a unit area each second.

Astronomers use flux to denote the apparent brightness of a celestial body. The apparent brightness is defined as the amount of light received from a star above the earth atmosphere passing through a unit area each second. Therefore, the apparent brightness is simply the flux we receive from a star.

The flux measures the *rate of flow* of energy that passes through each cm^2 (or any unit area) of an object's surface each second. The detected flux depends on the distance from the source that radiates the energy. This is because the energy has to spread over a volume of space before it reaches us. Let us assume that we have an imaginary balloon that encloses a star. Each dot on

the balloon represents a unit of energy emitted from the star. Initially, the dots in an area of one cm^2 are in close proximity to each other and the flux (energy emitted per square centimeter per second) is high. After a distance d, the volume and surface area of the balloon increased causing the dots to *spread away* from each. Consequently, the number of dots (or energy) enclosed in one cm^2 has decreased as illustrated in Figure 1.
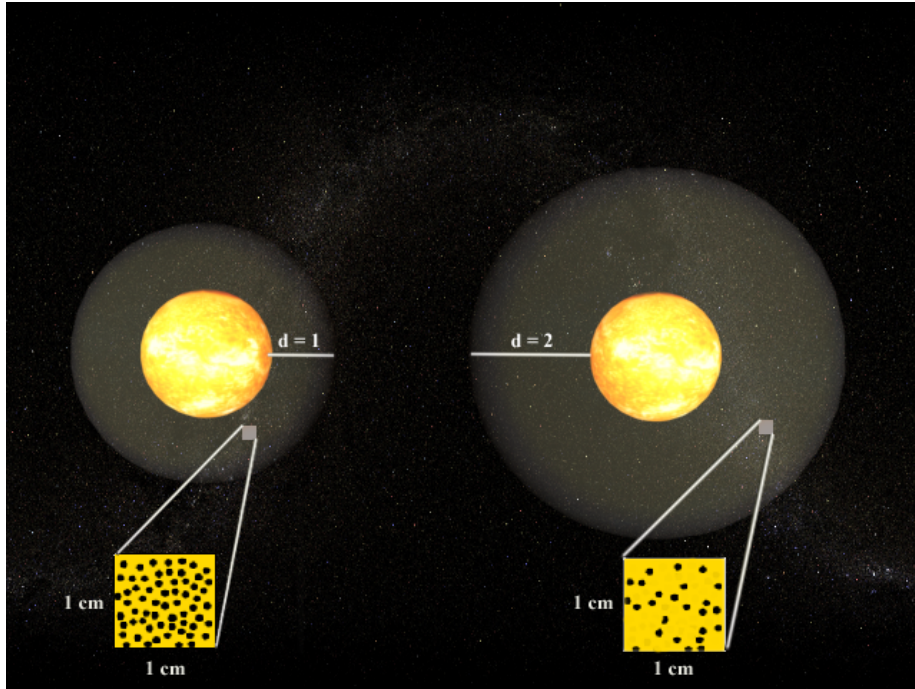

Figure 1

The flux is inversely proportional to distance by a simple r^2 relation. Therefore, if the distance is doubled, we receive $1/2^2$ or 1/4th of the original flux. From a fundamental standpoint, the flux is the luminosity per unit area:

$$F = \frac{L}{A} = \frac{L}{4 \cdot \pi \cdot R^2}$$

where $(4 * \pi * R^2)$ is the surface area of a sphere (or a balloon!) with a radius R. Flux is measured in Watts/m^2/s or as commonly used by astronomers: Ergs/cm^2/s. For example, the luminosity of the sun is $L = 3.90 * 10^{26}$ W. That is, in one second the sun radiates $3.90 * 10^{26}$ joules of energy into space. Thus, the flux we receive passing through one square centimeter from the sun at a distance of one AU ($1.496 * 10^{13}$ cm) is:

$$F = \frac{L}{4 \cdot \pi \cdot R^2} = \frac{3.90 \cdot 10^{26}}{4 \cdot \pi \cdot (1.496 \cdot 10^{13})^2} = 0.14 \; joules/cm^2/sec$$

9.25 Luminosity

Luminosity is the amount of energy emitted by a star each second.

All stars radiate light over a broad range of frequencies in the electromagnetic spectrum from the low energy radio waves up to the highly energetic gamma rays. A star that emits predominately

in the ultra-violet region of the spectrum produces a total amount of energy magnitudes larger than that produced in a star that emits principally in the infrared. Therefore, luminosity is a measure of energy emitted by a star over all wavelengths. The relationship between wavelength and energy was quantified by Einstein as E = h * v where v is the frequency, h is the Planck constant, and E is the photon energy in joules. That is, shorter wavelengths (and thus higher frequencies) correspond to higher energies.

For example, a wavelength of lambda = 10 meter lies in the radio region of the electromagnetic spectrum and has a frequency of f = c / lambda = $3 * 10^8$ m/s / 10 = 30 MHz where c is the speed of light. The energy of this photon is E = h * v = $6.625 * 10^{-34}$ J s * 30 Mhz = $1.988 * 10^{-26}$ joules. On the other hand, visible light has much shorter wavelengths and higher frequencies. A photon that has a wavelength of lambda = $5 * 10^{-9}$ meters (A greenish photon) has an energy E = 3.975 $* 10^{-17}$ joules which is over a billion times higher than the energy of a radio photon. Similarly, a photon of red light (wavelength lambda = 700 nm) has less energy than a photon of violet light (wavelength lambda = 400 nm).

Luminosity depends both on temperature and surface area. This makes sense because a burning log radiates more energy than a match, even though both have the same temperature. Similarly, an iron rod heated to 2000 degrees emits more energy than when it is heated to only 200 degrees.

Luminosity is a very fundamental quantity in Astronomy and Astrophysics. Much of what is learnt about celestial objects comes from analyzing their light. This is because the physical processes that occur inside stars gets recorded and transmitted by light. Luminosity is measured in units of energy per second. Astronomers prefer to use Ergs, rather than Watts, when quantifying luminosity.

9.26 Parallax

Parallax is the apparent change of an observed object's position caused by a shift in the observer's position. As an example, hold your hand in front of you at arm's length, and observe an object on the other side of the room behind your hand. Now tilt your head to your right shoulder, and your hand will appear on the left side of the distant object. Tilt your head to your left shoulder, and your hand will appear to shift to the right side of the distant object.

Because the Earth is in orbit around the Sun, we observe the sky from a constantly moving position in space. Therefore, we should expect to see an *annual parallax* effect, in which the positions of nearby objects appear to 'wobble' back and forth in response to our motion around the Sun. This does in fact happen, but the distances to even the nearest stars are so great that you need to make careful observations with a telescope to detect it[2].

Modern telescopes allow astronomers to use the annual parallax to measure the distance to nearby stars, using triangulation. The astronomer carefully measures the position of the star on two dates, spaced six months apart. The nearer the star is to the Sun, the larger the apparent shift in its position will be between the two dates.

Over the six-month period, the Earth has moved through half its orbit around the Sun; in this time its position has changed by 2 *Astronomical Units* (abbreviated AU; 1 AU is the distance from the Earth to the Sun, or about 150 million kilometers). This sounds like a really long distance, but even the nearest star to the Sun (alpha Centauri) is about 40 *trillion* kilometers away. Therefore, the annual parallax is very small, typically smaller than one *arcsecond*, which is only 1/3600 of one degree. A convenient distance unit for nearby stars is the *parsec*, which is short for "parallax arcsecond". One parsec is the distance a star would have if its observed parallax angle was one arcsecond. It is equal to 3.26 light-years, or 31 trillion kilometers[3].

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[2]The ancient Greek astronomers knew about parallax; because they could not observe an annual parallax in the positions of stars, they concluded that the Earth could not be in motion around the Sun. What they did not realize was that the stars are millions of times further away than the Sun, so the parallax effect is impossible to see with the unaided eye.

[3]Astronomers like this unit so much that they now use 'kiloparsecs' to measure galaxy-scale distances, and 'Megaparsecs' to measure intergalactic distances, even though these distances are much too large to have an actual, observable parallax. Other methods are required to determine these distances

9.27 Retrograde Motion

Retrograde Motion is the orbital motion of a body in a direction opposite that which is normal to spatial bodies within a given system.

When we observe the sky, we expect most objects to appear to move in a particular direction with the passing of time. The apparent motion of most bodies in the sky is from east to west. However it is possible to observe a body moving west to east, such as an artificial satellite or space shuttle that is orbiting eastward. This orbit is considered Retrograde Motion.

Retrograde Motion is most often used in reference to the motion of the outer planets (Mars, Jupiter, Saturn, and so forth). Though these planets appear to move from east to west on a nightly basis in response to the spin of the Earth, they are actually drifting slowly eastward with respect to the stationary stars, which can be observed by noting the position of these planets for several nights in a row. This motion is normal for these planets, however, and not considered Retrograde Motion. However, since the Earth completes its orbit in a shorter period of time than these outer planets, we occasionally overtake an outer planet, like a faster car on a multiple-lane highway. When this occurs, the planet we are passing will first appear to stop its eastward drift, and it will then appear to drift back toward the west. This is Retrograde Motion, since it is in a direction opposite that which is typical for planets. Finally, as the Earth swings past the planet in its orbit, they appear to resume their normal west-to-east drift on successive nights.

This Retrograde Motion of the planets puzzled ancient Greek astronomers, and was one reason why they named these bodies 'planets' which in Greek means 'wanderers'.

9.28 Elliptical Galaxies

Elliptical galaxies are spheroidal concentrations of billions of stars that resemble Globular Clusters on a grand scale. They have very little internal structure; the density of stars declines smoothly from the concentrated center to the diffuse edge, and they can have a broad range of ellipticities (or aspect ratios). They typically contain very little interstellar gas and dust, and no young stellar populations (although there are exceptions to these rules). Edwin Hubble referred to Elliptical galaxies as 'early-type' galaxies, because he thought that they evolved to become Spiral Galaxies (which he called 'late-type' galaxies). Astronomers actually now believe the opposite is the case (i.e., that Spiral galaxies can turn into Elliptical galaxies), but Hubble's early- and late-type labels are still used.

Once thought to be a simple galaxy type, ellipticals are now known to be quite complex objects. Part of this complexity is due to their amazing history: ellipticals are thought to be the end product of the merger of two Spiral galaxies. You can view a computer simulation MPEG movie of such a merger at this NASA HST webpage (warning: the file is 3.4 MB).

Elliptical galaxies span a very wide range of sizes and luminosities, from giant Ellipticals hundreds of thousands of light years across and nearly a trillion times brighter than the sun, to dwarf Ellipticals just a bit brighter than the average globular cluster. They are divided to several morphological classes:

cD galaxies:

Immense and bright objects that can measure nearly 1 Megaparsec (3 million light years) across. These titans are only found near the centers of large, dense clusters of galaxies, and are likely the result of many galaxy mergers.

Normal Elliptical galaxies

Condensed Object with relatively high central surface brightness. They include the giant ellipticals (gE'e), intermediate-luminosity ellipticals (E's), and compact ellipticals.

Dwarf elliptical galaxies (dE's)

This class of galaxies is fundamentally different from normal ellipticals. Their diameters on the order of 1 to 10 kiloparsec with surface brightness that is much lower than normal ellipticals, giving them a much more diffuse appearance. They display the same characteristic gradual decline of star density from a relatively dense core out to a diffuse periphery.

Dwarf spheroidal galaxies (dSph's)

Extreme low-luminosity, low surface-brightness and have only been observed in the vicinity of the Milky Way, and possibly other very nearby galaxy groups, such as the Leo group. Their absolute magnitudes are only -8 to -15 mag. The Draco dwarf spheroidal galaxy has an absolute magnitude of -8.6, making it fainter than the average globular cluster in the Milky Way!

Blue compact dwarf galaxies (BCD's)

Small galaxies that are unusually blue. Thehave photometric colors of B-V = 0.0 to 0.30 mag, which is typical for relatively young stars of *spectral type* A. This suggests that BCDs are currently actively forming stars. These systems also have abundant interstellar gas (unlike other Elliptical galaxies).

TIP

You can see examples of Elliptical galaxies in KStars, using the **Find Object** window (**Ctrl**+**F**). Search for NGC 4881, which is the Giant cD galaxy in the Coma cluster of galaxies. M 86 is a normal Elliptical galaxy in the Virgo cluster of galaxies. M 32 is a dwarf Elliptical that is a satellite of our neighbor, the Andromeda galaxy (M 31). M 110 is another satellite of M 31 that is a borderline dwarf spheroidal galaxy ('borderline' because it is somewhat brighter than most other dwarf spheroidals).

9.29 Spiral Galaxies

Spiral galaxies are huge collections of billions of stars, most of which are flattened into a disk shape, with a bright, spherical bulge of stars at its center. Within the disk, there are typically bright arms where the youngest, brightest stars are found. These arms wind out from the center in a spiral pattern, giving the galaxies their name. Spiral galaxies look a bit like hurricanes, or like water flowing down a drain. They are some of the most beautiful objects in the sky.

Galaxies are classified using a 'tuning fork diagram'. The end of the fork classifies elliptical galaxies on a scale from the roundest, which is an E0, to those that appear most flattened, which is rated as E7. The 'tines' of the tuning fork are where the two types of spiral galaxies are classified: normal spirals, and 'barred' spirals. A barred spiral is one whose nuclear bulge is stretched out into a line, so it literally looks like it has a 'bar' of stars in its center.

Both types of spiral galaxies are sub-classified according to the prominence of their central 'bulge' of stars, their overall surface brightness, and how tightly their spiral arms are wound. These characteristics are related, so that an Sa galaxy has a large central bulge, a high surface brightness, and tightly-wound spiral arms. An Sb galaxy has a smaller bulge, a dimmer disk, and looser arms than an Sa, and so on through Sc and Sd. Barred galaxies use the same classification scheme, indicated by types SBa, SBb, SBc, and SBd.

There is another class of galaxy called S0, which is morphologically a transitional type between true spirals and ellipticals. Its spiral arms are so tightly wound as to be indistinguishable; S0 galaxies have disks with a uniform brightness. They also have an extremely dominant bulge.

The Milky Way galaxy, which is home to earth and all of the stars in our sky, is a Spiral Galaxy, and is believed to be a barred spiral. The name 'Milky Way' refers to a band of very faint stars in the sky. This band is the result of looking in the plane of our galaxy's disk from our perspective inside it.

Spiral galaxies are very dynamic entities. They are hotbeds of star formation, and contain many young stars in their disks. Their central bulges tend to be made of older stars, and their diffuse halos are made of the very oldest stars in the Universe. Star formation is active in the disks because that is where the gas and dust are most concentrated; gas and dust are the building blocks of star formation.

Modern telescopes have revealed that many Spiral galaxies harbor supermassive black holes at their centers, with masses that can exceed that of a billion Suns. Both elliptical and spiral galaxies are known to contain these exotic objects; in fact many astronomers now believe that *all* large galaxies contain a supermassive black hole in their nucleus. Our own Milky Way is known to harbor a black hole in its core with a mass millions of times bigger than a star's mass.

TIP

There are many fine examples of spiral galaxies to be found in KStars, and many have beautiful images available in their popup menu. You can find them by using the Find Object window. Here is a list of some spiral galaxies with nice images available:

- M 64, the Black-Eye Galaxy (type Sa)

- M 31, the Andromeda Galaxy (type Sb)

- M 81, Bode's Galaxy (type Sb)

- M 51, the Whirlpool Galaxy (type Sc)

- NGC 300 (type Sd) [use DSS image link]

- M 83 (type SBa)

- NGC 1530 (type SBb)

- NGC 1073 (type SBc)

9.30 Magnitude Scale

2500 years ago, the ancient Greek astronomer Hipparchus classified the brightnesses of visible stars in the sky on a scale from 1 to 6. He called the very brightest stars in the sky 'first magnitude', and the very faintest stars he could see 'sixth magnitude'. Amazingly, two and a half millenia later, Hipparchus's classification scheme is still widely used by astronomers, although it has since been modernized and quantified.

NOTE

The magnitude scale runs backwards to what you might expect: brighter stars have *smaller* magnitudes than fainter stars).

The modern magnitude scale is a quantitative measurement of the *flux* of light coming from a star, with a logarithmic scaling:

$m = m_0 - 2.5 \log (F / F_0)$

If you do not understand the math, this just says that the magnitude of a given star (m) is different from that of some standard star (m_0) by 2.5 times the logarithm of their flux ratio. The 2.5 *log factor means that if the flux ratio is 100, the difference in magnitudes is 5 mag. So, a 6th magnitude star is 100 times fainter than a 1st magnitude star. The reason Hipparchus's simple classification translates to a relatively complex function is that the human eye responds logarithmically to light.

There are several different magnitude scales in use, each of which serves a different purpose. The most common is the apparent magnitude scale; this is just the measure of how bright stars (and other objects) look to the human eye. The apparent magnitude scale defines the star Vega to have magnitude 0.0, and assigns magnitudes to all other objects using the above equation, and a measure of the flux ratio of each object to Vega.

It is difficult to understand stars using just the apparent magnitudes. Imagine two stars in the sky with the same apparent magnitude, so they appear to be equally bright. You cannot know just by looking if the two have the same *intrinsic* brightness; it is possible that one star is intrinsically brighter, but further away. If we knew the distances to the stars (see the parallax article), we could account for their distances and assign *Absolute magnitudes* which would reflect their true, intrinsic brightness. The absolute magnitude is defined as the apparent magnitude the star would have if observed from a distance of 10 parsecs (1 parsec is 3.26 light-years, or 3.1×10^{18} cm). The absolute magnitude (M) can be determined from the apparent magnitude (m) and the distance in parsecs (d) using the formula:

M = m + 5 - 5 * log(d) (note that M=m when d=10).

The modern magnitude scale is no longer based on the human eye; it is based on photographic plates and photoelectric photometers. With telescopes, we can see objects much fainter than Hipparchus could see with his unaided eyes, so the magnitude scale has been extended beyond 6th magnitude. In fact, the Hubble Space Telescope can image stars nearly as faint as 30th magnitude, which is one *trillion* times fainter than Vega.

A final note: the magnitude is usually measured through a color filter of some kind, and these magnitudes are denoted by a subscript describing the filter (i.e., m_V is the magnitude through a 'visual' filter, which is greenish; m_B is the magnitude through a blue filter; m_{pg} is the photographic plate magnitude, etc.).

9.31   Stars: An Introductory FAQ

1. *What are the stars?*

   Stars are gigantic, self-gravitating spheres of (mostly) Hydrogen gas. Stars are also thermonuclear engines; nuclear fusion takes place deep in the cores of stars, where the density is extreme and the temperature reaches tens of millions of degrees Celsius.

2. *Is the Sun a star?*

   Yes, the Sun is a star. It is the dominant centerpiece of our solar system. Compared to other stars, our Sun is rather ordinary; it appears to be so much bigger and brighter to us because it is millions of times closer than any other star.

3. *Why do stars shine?*

   The short answer is: star shine because they are very hot. It is really no more complicated than that. Any object heated to thousands of degrees will radiate light, just like stars do.

4. *The obvious next question is: why are stars so hot?*

   This is a tougher question. The usual answer is that stars get their heat from the thermonuclear fusion reactions in their cores. However, this cannot be the ultimate cause for the stars' heat, because a star must be hot in the first place for nuclear fusion to be triggered. Fusion can only sustain the hot temperature; it cannot make a star hot. A more correct answer is that stars are hot because they have collapsed. Stars form from diffuse gaseous nebulae; as the nebulous gas condenses to form a star, the gravitational potential energy of the material is released, first as kinetic energy, and ultimately as heat as the density increases.

5. *Are stars all the same?*

   Stars have many things in common: they are all collapsed spheres of hot, dense gas (mostly Hydrogen), and nuclear fusion reactions are occurring at or near the centers of every star in the sky.

However, stars also show a great diversity in some properties. The brightest stars shine almost 100 million times as brightly as the faintest stars. Stars range in surface temperature from only a few thousand degrees to almost 50,000 degrees Celsius. These differences are largely due to differences in mass: massive stars are both hotter and brighter than lower-mass stars. The temperature and Luminosity also depend on the *evolutionary state* of the star.

6. *What is the Main Sequence?*

   The main sequence is the evolutionary state of a star when it is fusing Hydrogen in its core. This is the first (and longest) stage of a star's life (not including protostar phases). What happens to a star after it runs out of core Hydrogen is addressed in the stellar evolution article (coming soon).

7. *How long do stars last?*

   The lifetime of a star depends very much on its mass. More massive stars are hotter and shine much more brightly, causing them to consume their nuclear fuel much more rapidly. The largest stars (roughly 100 times as massive as the Sun), will run out of fuel in only a few million years; while the smallest stars (roughly ten percent the mass of the Sun), with their much more frugal consumption rate, will shine on (albeit dimly) for *trillions* of years. Note that this is much longer than the Universe has yet been in existence.

9.32 Star Colors and Temperatures

Stars appear to be exclusively white at first glance. But if we look carefully, we can notice a range of colors: blue, white, red, and even gold. In the winter constellation of Orion, a beautiful contrast is seen between the red Betelgeuse at Orion's "armpit" and the blue Bellatrix at the shoulder. What causes stars to exhibit different colors remained a mystery until two centuries ago, when Physicists gained enough understanding of the nature of light and the properties of matter at immensely high temperatures.

Specifically, it was the physics of blackbody radiation that enabled us to understand the variation of stellar colors. Shortly after blackbody radiation was understood, it was noticed that the spectra of stars look extremely similar to blackbody radiation curves of various temperatures, ranging from a few thousand Kelvin to ~50,000 Kelvin. The obvious conclusion is that stars are similar to blackbodies, and that the color variation of stars is a direct consequence of their surface temperatures.

Cool stars (i.e., Spectral Type K and M) radiate most of their energy in the red and infrared region of the electromagnetic spectrum and thus appear red, while hot stars (i.e., Spectral Type O and B) emit mostly at blue and ultra-violet wavelengths, making them appear blue or white.

To estimate the surface temperature of a star, we can use the known relationship between the temperature of a blackbody, and the wavelength of light where its spectrum peaks. That is, as you increase the temperature of a blackbody, the peak of its spectrum moves to shorter (bluer) wavelengths of light. This is illustrated in Figure 1 where the intensity of three hypothetical stars is plotted against wavelength. The "rainbow" indicates the range of wavelengths that are visible to the human eye.
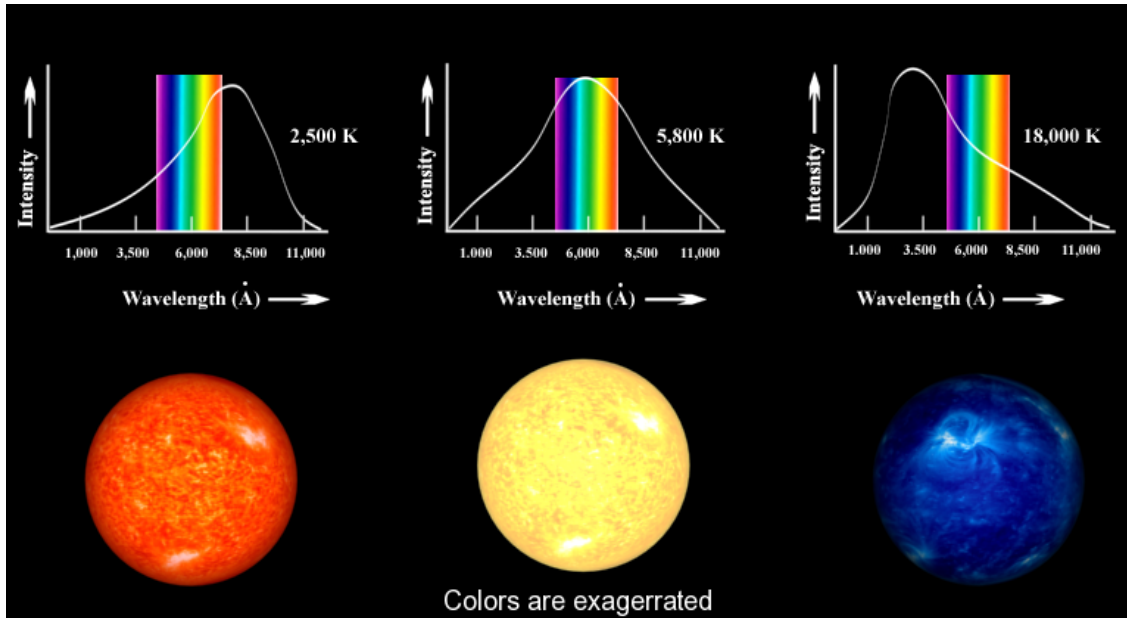
Figure 1

This simple method is conceptually correct, but it cannot be used to obtain stellar temperatures accurately, because stars are *not* perfect blackbodies. The presence of various elements in the star's atmosphere will cause certain wavelengths of light to be absorbed. Because these absorption lines are not uniformly distributed over the spectrum, they can skew the position of the spectral peak. Moreover, obtaining a usable spectrum of a star is a time-intensive process and is prohibitively inefficient for large samples of stars.

An alternative method utilizes photometry to measure the intensity of light passing through different filters. Each filter allows *only* a specific part of the spectrum of light to pass through while rejecting all others. A widely used photometric system is called the *Johnson UBV system*. It employs three bandpass filters: U ("Ultra-violet"), B ("Blue"), and V ("Visible"); each occupying different regions of the electromagnetic spectrum.

The process of UBV photometry involves using light sensitive devices (such as film or CCD cameras) and aiming a telescope at a star to measure the intensity of light that passes through each of the filters individually. This procedure gives three apparent brightnesses or fluxes (amount of energy per cm^2 per second) designated by Fu, Fb, and Fv. The ratio of fluxes Fu/Fb and Fb/Fv is a quantitative measure of the star's "color", and these ratios can be used to establish a temperature scale for stars. Generally speaking, the larger the Fu/Fb and Fb/Fv ratios of a star, the hotter its surface temperature.

For example, the star Bellatrix in Orion has Fb/Fv = 1.22, indicating that it is brighter through the B filter than through the V filter. furthermore, its Fu/Fb ratio is 2.22, so it is brightest through the U filter. This indicates that the star must be very hot indeed, since the position of its spectral peak must be somewhere in the range of the U filter, or at an even shorter wavelength. The surface temperature of Bellatrix (as determined from comparing its spectrum to detailed models that account for its absorption lines) is about 25,000 Kelvin.

We can repeat this analysis for the star Betelgeuse. Its Fb/Fv and Fu/Fb ratios are 0.15 and 0.18, respectively, so it is brightest in V and dimmest in U. So, the spectral peak of Betelgeuse must be somewhere in the range of the V filter, or at an even longer wavelength. The surface temperature of Betelgeuse is only 2,400 Kelvin.

Astronomers prefer to express star colors in terms of a difference in magnitudes, rather than a ratio of fluxes. Therefore, going back to blue Bellatrix we have a color index equal to

B - V = -2.5 log (Fb/Fv) = -2.5 log (1.22) = -0.22,

Similarly, the color index for red Betelgeuse is

B - V = -2.5 log (Fb/Fv) = -2.5 log (0.18) = 1.85

The color indices, like the magnitude scale, run backward. *Hot and blue* stars have *smaller and negative* values of B-V than the cooler and redder stars.

An Astronomer can then use the color indices for a star, after correcting for reddening and interstellar extinction, to obtain an accurate temperature of that star. The relationship between B-V and temperature is illustrated in Figure 2.
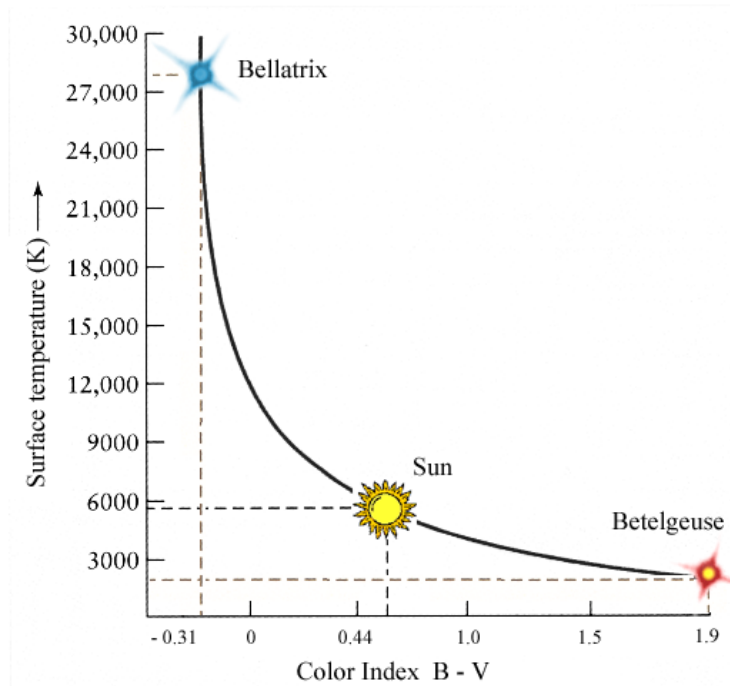

Figure 2

The Sun with surface temperature of 5,800 K has a B-V index of 0.62.

9.33 Cosmic Distance Ladder

The cosmic distance ladder refers to the succession of different methods that astronomers use to measure distances to objects in the sky. Some methods, like parallax, work well for only nearby objects. Other methods, like using the *cosmological redshift*, work only for very distance galaxies. Thus, there are several methods, each with its own limited validity, and hence the name.

9.33.1 Direct measurements

The bottom of the ladder consists of objects whose distances can be directly measured, like the moon (see Lunar Laser Ranging). The same technique, using radio waves, is applied to find distances to planets as well.

For nearby stars, measuring the parallax is possible and yields the distance to the star.

9.33.2 Standard candles

"Standard candles" are objects whose intrinsic brightnesses we can know for sure. The apparent magnitude, which is easy to measure, tells us how bright an object appears, not how bright it

actually is. Distant objects appear less brighter, because their light gets spread out over a larger area.

In accordance with the *inverse square law* for light intensities, the amount of light we receive from an object drops with the distance squared. Thus, we may compute the distance to an object if we know both how bright it actually is (absolute magnitude; 'M') and how bright it appears to us on earth (apparent magnitude; 'm'). We may define the *distance modulus* as follows:

Distance Modulus = M - m = $5 \log_{10} d - 5$

Here 'd' is the distance measured in parsecs.

For these special standard candle objects, we have some other way of knowing their intrinsic brightness, and thereby can calculate their distance.

Common "standard candles" used in astronomy are:

- Cepheid Variables: A kind of periodic variable star, whose variation period is related to the luminosity

- RR Lyrae Variables: Another such periodic variable star with a well-known period-luminosity relationship

- Type-Ia supernovae: These supernovae have a very well-defined luminosity as a result of the physics that governs them and hence serve as standard-candles

9.33.3 Other methods

There are many other methods. Some of them rely on the physics of stars, such as the relationship between luminosity and color for various types of stars (this is usually represented on a *Hertzsprung-Russel Diagram*). Some of them work for star clusters, such as the *Moving cluster method* and the *main-sequence fitting method*. The *Tully-Fisher relation* that relates the brightness of a spiral galaxy to its rotation can be used to find the distance modulus, since the rotation of a galaxy is easy to measure using *Doppler shift*. Distances to distant galaxies may be found by measuring the *Cosmological redshift*, which is the redshift of light from distance galaxies that results from the expansion of the universe.

For further information, consult Wikipedia on Cosmic Distance Ladder

Chapter 10

Credits and License

KStars

Program copyright 2001-2021 The KStars Team mutlaqja@ikarustech.com

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Data Sources:

- Object catalogs and planet position tables: NASA Astronomical Data Center

- Detailed credit information for all of the images used in the program is presented in the file README.images

References:

- 'Practical Astronomy With Your Calculator' by Peter Duffet-Smith

- 'Astronomical Algorithms' by Jean Meeus

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