MATHEMATICA®

SCIENTIFIC ASTRONOMER

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Software and manual written by: Terry Robb
Editor: Jan Progen
Proofreader: Laurie Kaufmann
Graphic design: Kimberly Michael

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Main Features of *Scientific Astronomer*

Star Charts: Five types of charts are defined in *Scientific Astronomer*, including two wide field star charts. With the star charts you can zoom into any portion of the sky. All the charts have options to show star spectral colors, mesh lines, a skyline, the horizon line, and the Milky Way; and to label constellations, stars, planets, deep sky objects, and so on.

Planet Plots: Planet plotting is done in two- and three-dimensional forms. Surface features for the Earth, the Moon, Mars, and Jupiter are shown on the plots. Moons and their shadows are displayed for the Earth and Jupiter. Related functions allow you to produce planet position finder charts and planet rise/set timing charts.

Eclipses: Several functions are provided for dealing with eclipses. These functions provide information about both solar and lunar eclipses, and are general enough to handle Galilean moon eclipses, occultation of stars by the Moon, and transits of Mercury or Venus across the solar disk. You can produce umbra and penumbra track plots and perform eclipse prediction.

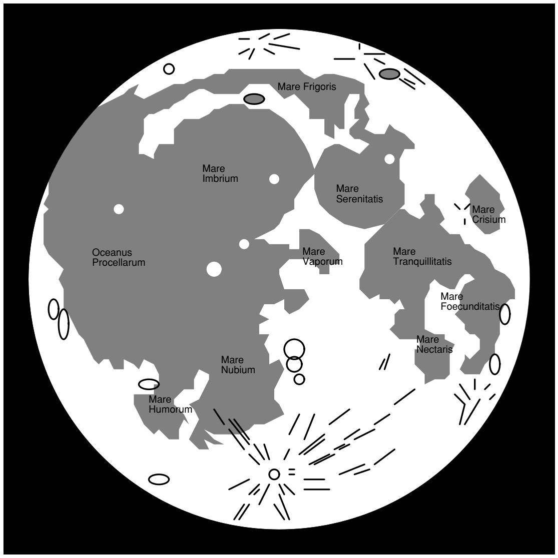
Satellite Tracking: Satellite tracking is another feature of *Scientific Astronomer*. You can create track plots, make visibility predictions, and project satellite tracks onto star charts.

Miscellaneous: Miscellaneous other features are available, such as producing planisphere plates, planet charts, and solar system plots. In addition, sunrise, moonrise, and full moon functions are provided, as well as functions for adding new objects, such as comets and satellites.

MATHEMATICA 3.0

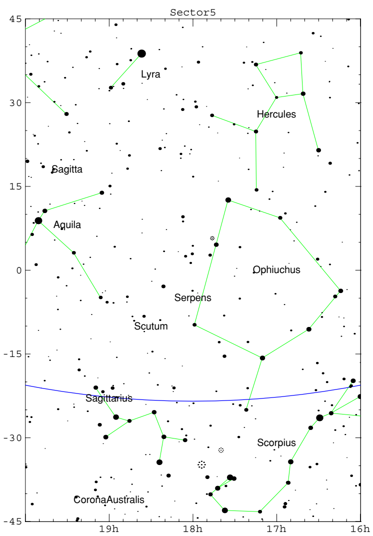
Scientific Astronomer is *Mathematica* 3 and 4 compatible. It has palettes and buttons and is fully integrated into the Help Browser system.

Feature Labeling on the Moon



Plot of a full moon with features labeled.

Star Chart of Ophiuchus



Star chart showing various constellations in the direction of Ophiuchus. Scorpius is visible on the bottom right. The blue line near the bottom is the ecliptic, which is the fixed path of the Sun through the sky. The planets and Moon all roughly move along that line as well.

Mercury Finder Chart

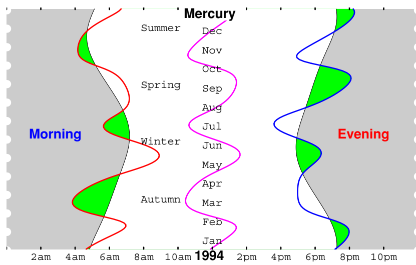


Chart showing rising and setting times of Mercury during 1994 for an observer 35 degrees south of the equator. Green areas (or the darker shade of gray) show when Mercury is visible above the horizon.

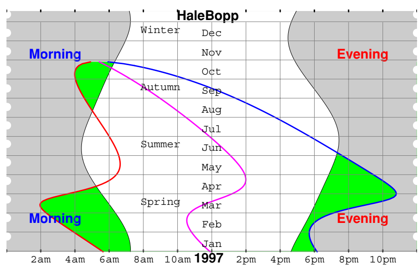
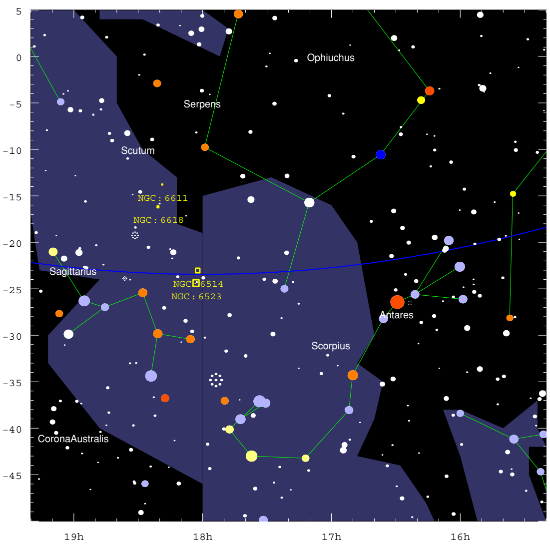


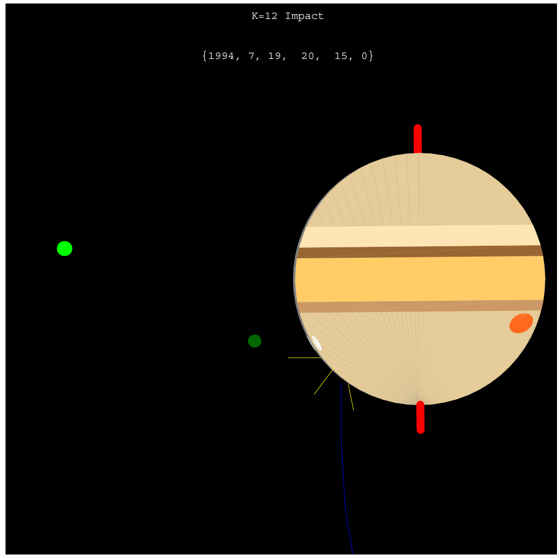
Chart showing rising and setting times of Comet Hale-Bopp during 1997 for an observer 40 degrees north of the equator. Green areas show when Hale-Bopp is visible.

Milky Way and Nebulae



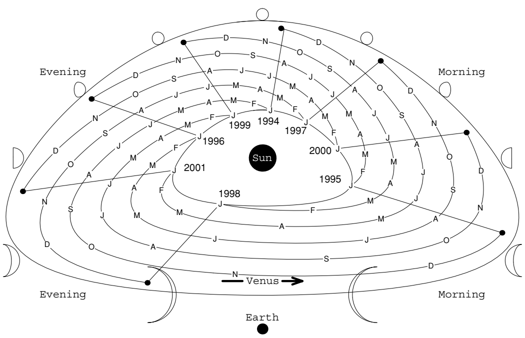
Star chart showing the Milky Way in the region of Scorpius and Sagittarius. Four binocular-visible nebulae are indicated by the position of the yellow NGC numbers. Star spectral colors of stars, such as red for Antares, are also indicated.

Jupiter's Moons and Great Red Spot



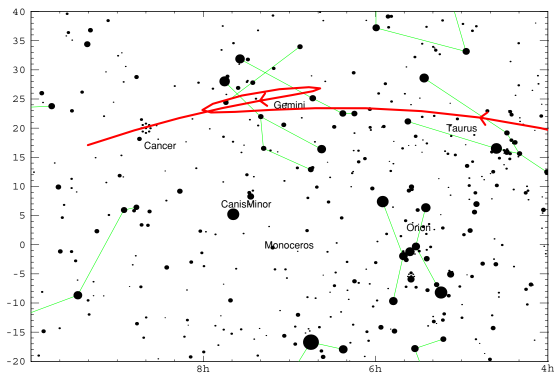
Fragment of Comet P/Shoemaker-Levy impacting on Jupiter. Two Jovian moons and the Great Red Spot are visible. This graphic is part of a large animation.

Eight-Year Venus Finder Chart



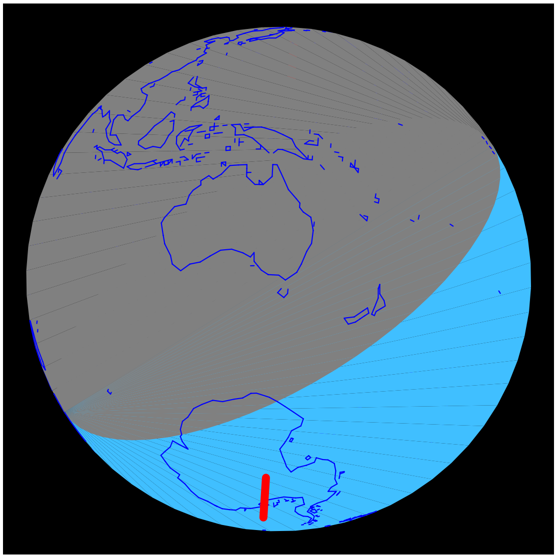
Finder chart for Venus for years 1994 through 2001.

Retrograde Motion of Mars



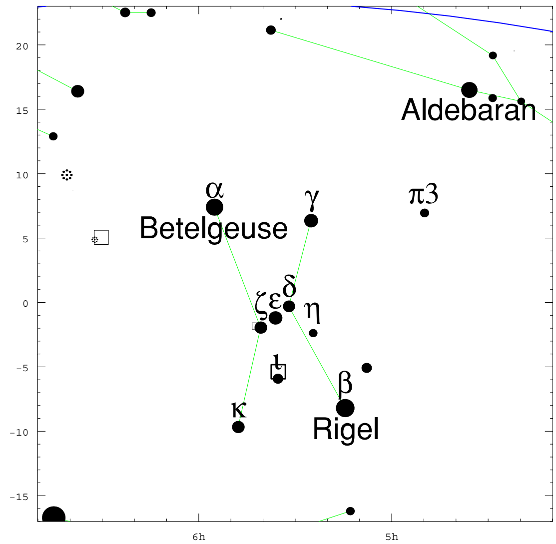
Star chart track of Mars undergoing retrograde motion during 1992.

Plot of Earth



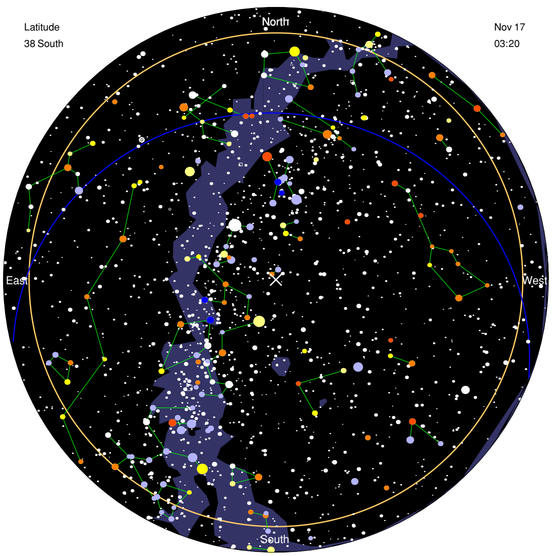
Plot of Earth as viewed from directly over Melbourne, Australia. The darker area represents night, which is the half of the globe not illuminated by the Sun.

Optional Labeling



Star chart of constellation Orion using double-size labeling.

Overhead Sky



Star chart showing entire overhead sky as seen from latitude 38 degree south at 03:20 on November 17. The Milky Way is the dark blue band across the sky.

Lunar Eclipse Chart

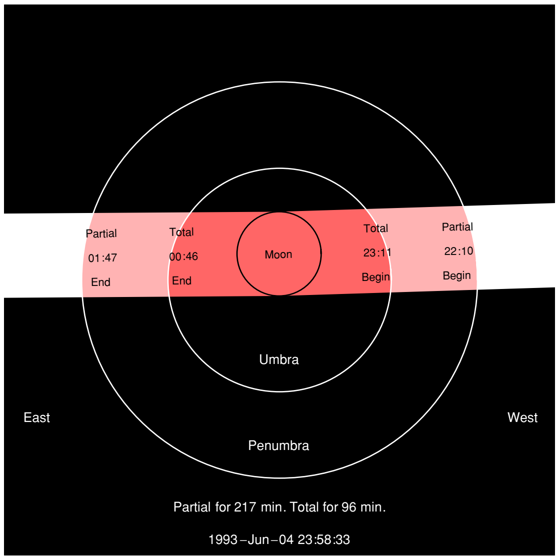


Chart showing circumstances of a total lunar eclipse.

Solar Eclipse Chart

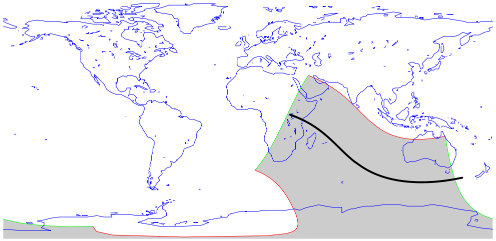
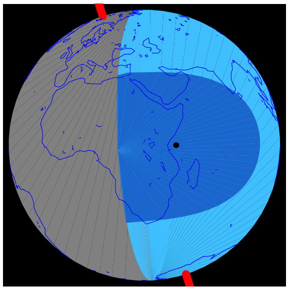
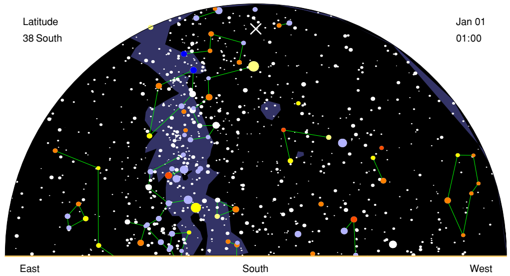


Chart showing circumstances of the total solar eclipse of 1948 November 1. The black line is the line of totality and the gray region is where a partial eclipse was visible.

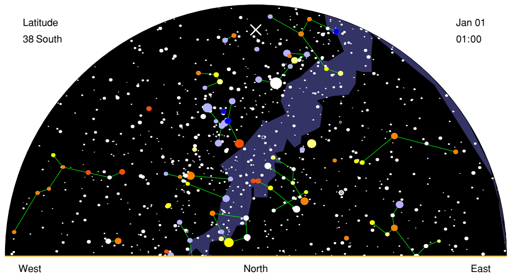


Plot of the eclipse as it moves off the eastern edge of Africa. The shaded region on the left side of the Earth is night.

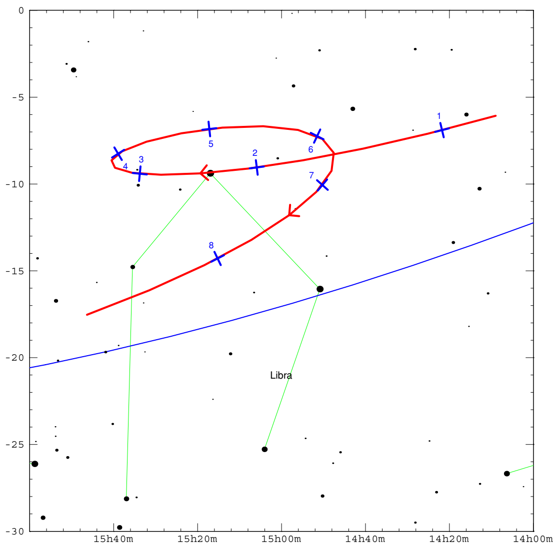
Compass Direction Star Chart



Star chart showing the southern aspect of the sky. Our Milky Way galaxy is the vertical blue band slightly to the left. The chart below shows the northern aspect.



Motion of Asteroid Vesta



Plot showing orbital track of asteroid Vesta during opposition in 1996. Blue numbers are months of that year; Vesta reaches its brightest at month 5 (May).

Solar Eclipse of 1998

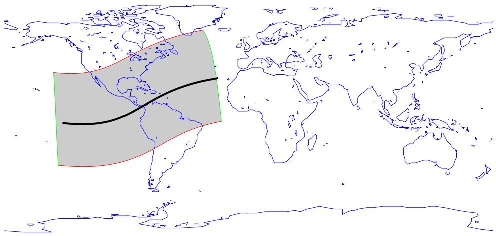


Chart showing circumstances of the total solar eclipse of 1998 February 26. The black line is the line of totality, which passes directly through Panama but otherwise is visible only over the ocean. The gray region is where a partial solar eclipse is visible.

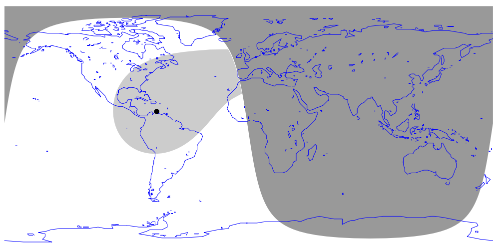
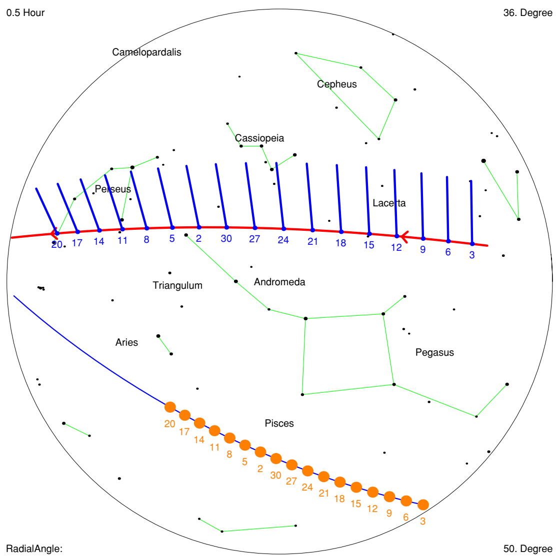


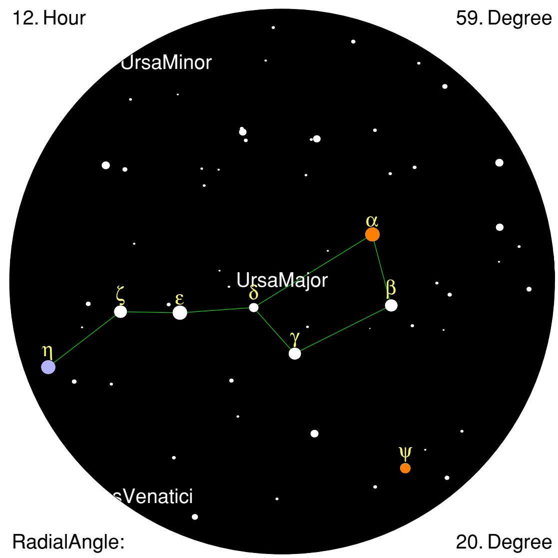
Chart showing eclipse shadow at a particular instant. The dark region covering most of the right of the graphic represents the night side of the Earth. The small black dot at the top of South America is the point of total eclipse at the given instant.

Comet Hale-Bopp Location



Star chart track of Comet Hale-Bopp (shown in red) during closest approach in March/April 1997. The track of the Sun (in orange) is also shown. Blue lines represent the direction of the comet tail.

Big Dipper with Greek Labels



Star chart of Ursa Major, also known as “The Big Dipper” or “The Plough”.

Annual Meteor Showers

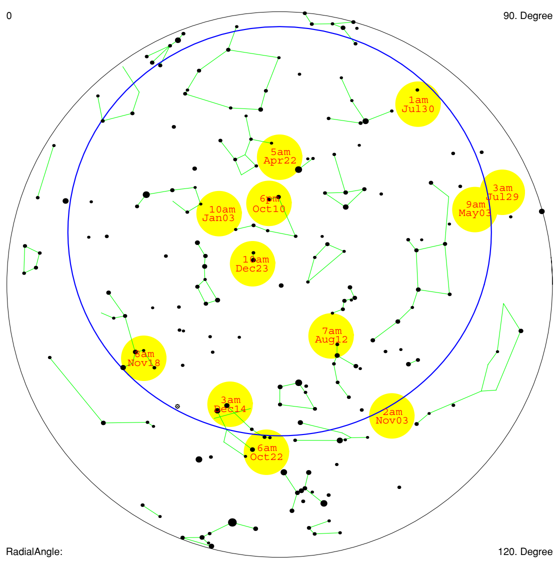
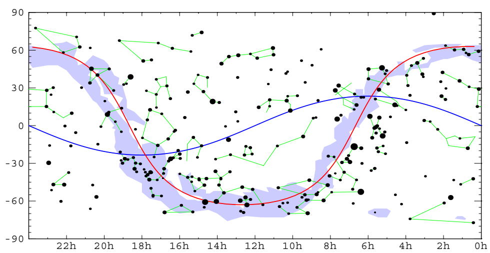
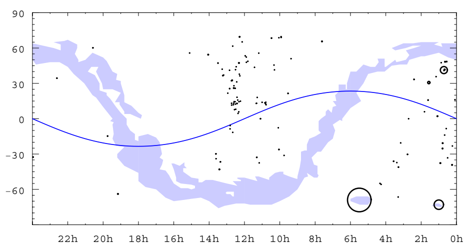


Chart showing main annual meteor showers visible from the Northern Hemisphere. The yellow disks indicate viewing direction, with date and best viewing hour given inside.

Mercator Projection of Sky

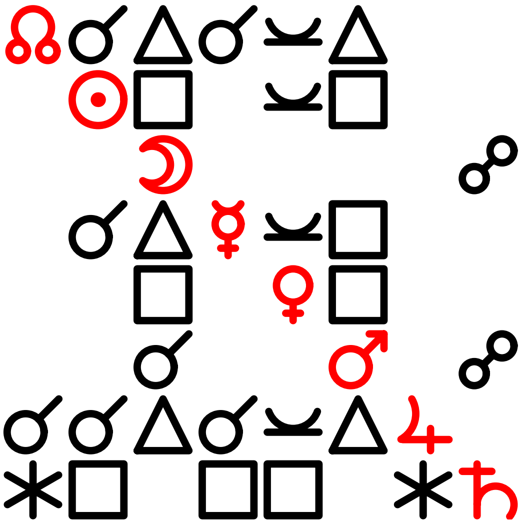


Star chart showing entire celestial sphere in Mercator projection. The light blue shaded area is our own Milky Way galaxy with the galactic plane shown in red.



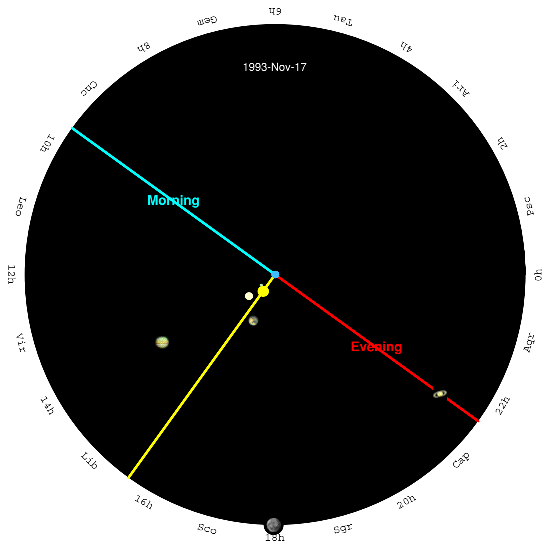
Star chart showing positions of many galaxies. Most galaxies lie in a plane (the plane of the local supercluster of galaxies). Note the Virgo Galaxy Cluster near the center of the graphic. The circles on the lower right are the Large and Small Magellanic Cloud Galaxies. The small circle to the top right is the Andromeda Galaxy.

Astrological Aspect Chart



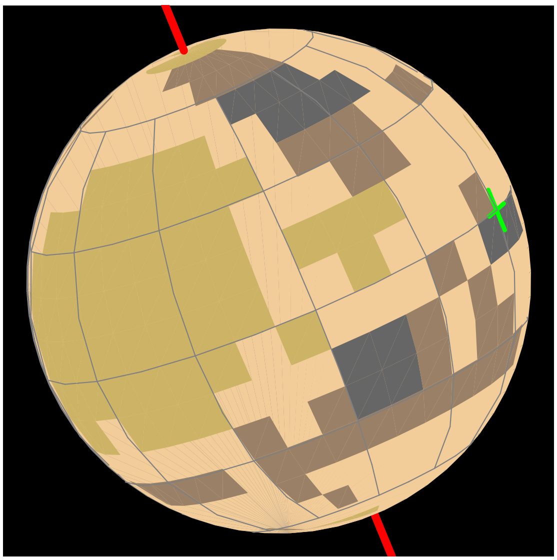
Astrological aspect chart for the main planets on a given date and location. The symbols on the diagonal are, from top-left to bottom-right: the ascendant, the Sun, the Moon, Mercury, Venus, Mars, Jupiter, and Saturn.

Solar System Plot



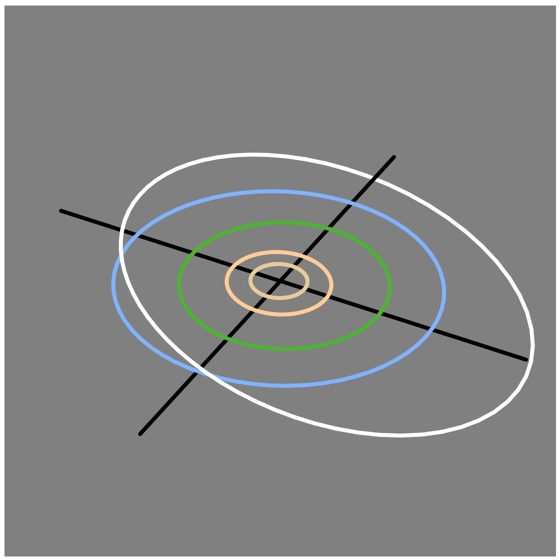
Solar system plot showing positions of planets out to Saturn. The Earth is in the center with the Sun shown in yellow and Mercury very close to it.

Mars as Seen from Earth



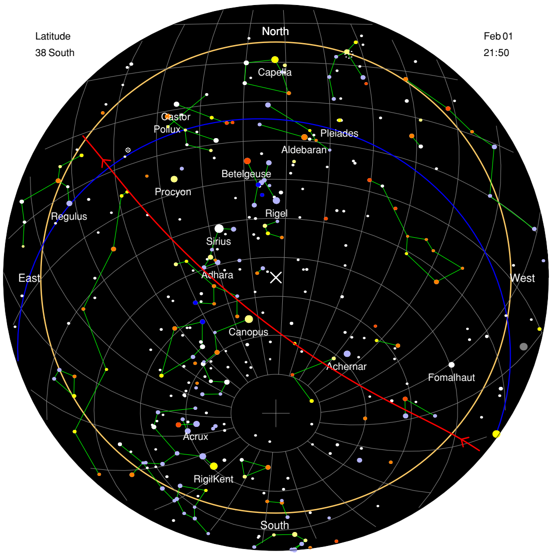
Plot of Mars as seen from Earth on a given date. The green cross on the far right is the position of zero Martian longitude and latitude.

Orbit Plot of Outer Planets



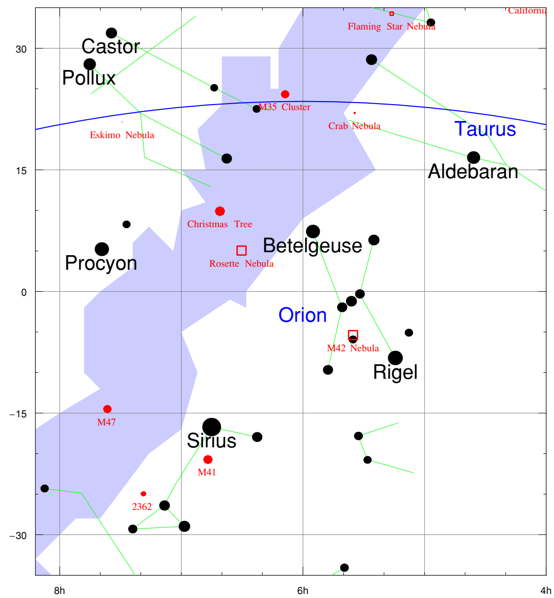
Plot showing orbits of the outer planets. Pluto's orbit is the outermost inclined ellipse, which can pass inside Neptune's orbit.

Mir Space Station Flyover



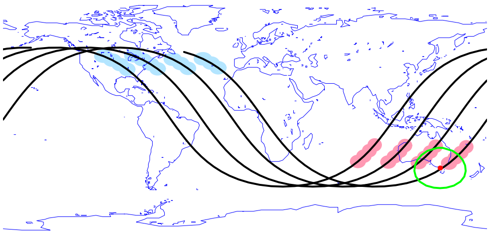
Track of Mir Space Station flying overhead. It takes about 10 minutes for Mir to pass from the southwest horizon over the zenith and down into the northeast horizon.

Deep Sky Objects



Finder chart for various interesting deep sky objects (such as nebulae, star clusters, and galaxies) in the direction of Orion.

Space Shuttle Orbit



Four orbits of a Space Shuttle mission. The light red areas indicate the locations on Earth, where the Space Shuttle will be visible to the naked eye just after dusk as it moves overhead. Similarly, the light blue area indicates visibility just before dawn.

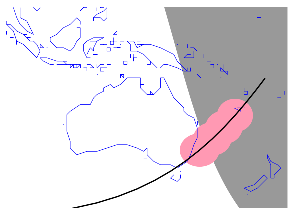
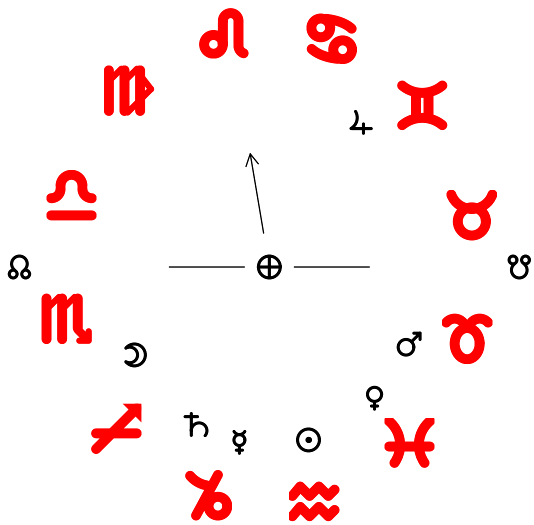


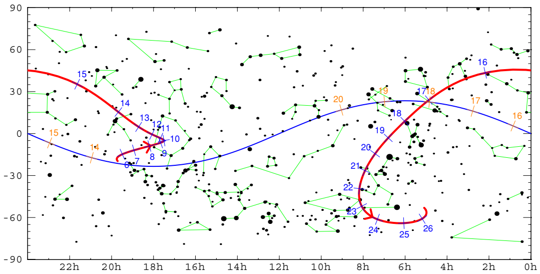
Chart zoomed into area around Australia showing the track of the Space Shuttle. The shading on the right is the approaching night.

Astrological Birth Chart

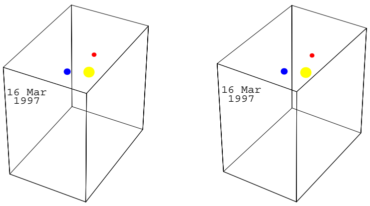


Birth chart for Charles Dickens, born at midnight on 1812 February 7 in England.

Comet Hale-Bopp 1996-1998

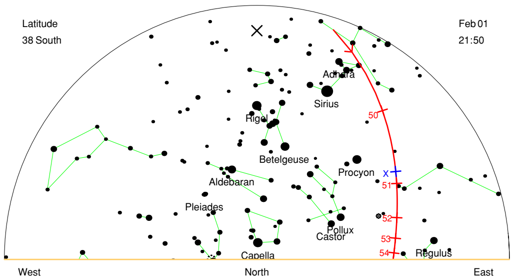


Star chart showing position of Comet Hale-Bopp from April 1996 through April 1998. The blue numbers represent months from the beginning of 1996. Orange numbers are the corresponding positions of the Sun.

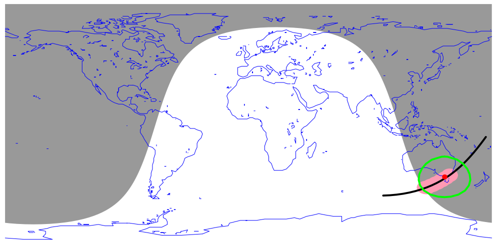


Part of a stereographic animation showing the motion of the Comet Hale-Bopp and Earth relative to the Sun at the center.

Motion of Mir Space Station

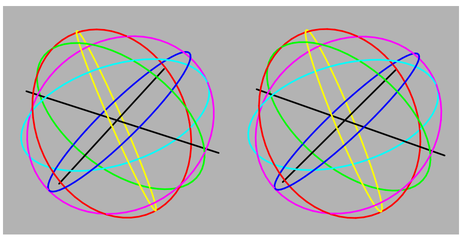


Star chart showing track of Mir Space Station setting into the northeast horizon. Red numbers represent minutes, and the blue X is where Mir will disappear when it moves into the Earth's shadow.

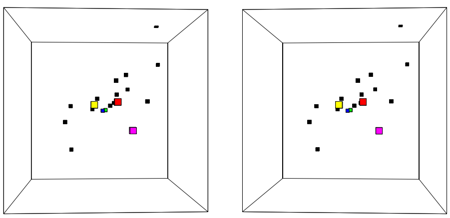


Orbit track showing the motion of Mir as it passes over Melbourne, Australia.

Stereographic Pairs

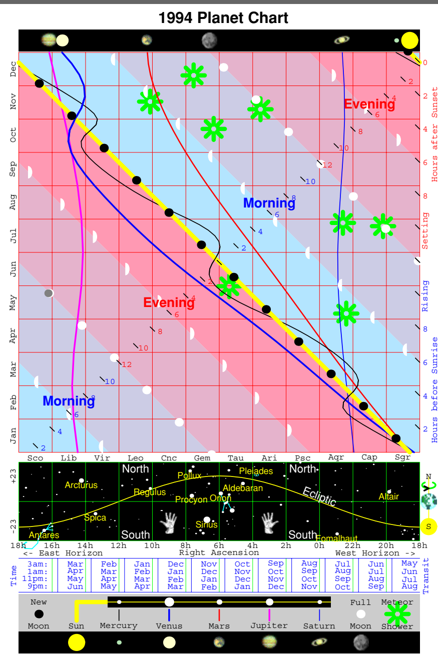


Stereographic pair showing orbital planes of the GPS (Global Positioning System) satellite network. Converge your eyes to view in full 3D. The red, green, and blue orbits are mutually orthogonal to each other, as are the cyan, magenta, and yellow orbits.



Stereographic pair showing the local supercluster of galaxies. Our Local Group of galaxies is the small blue object in the center of the graphic. Just next to it is the Virgo Galaxy Cluster shown in green. Beyond that is the Coma Galaxy Cluster in red, and the Pisces Galaxy Cluster in yellow. The large Centaurus Galaxy Cluster is shown in purple. The box is one billion light years across.

Planet Wall Chart



Wall chart showing positions of major planets throughout 1994.

1. Introduction

Scientific Astronomer is a *Mathematica* package implementing graphical and other tools of interest to amateur and professional astronomers.

The package produces charts, generates animations, and derives information to help you learn more about astronomical events. For instance, if you hear about a new event, such as a bright comet, an eclipse, or a lunar occultation, *Scientific Astronomer* allows you to determine the location and details of the event. Similarly, you can use the package to re-create the circumstances of ancient eclipses, planetary alignments, and other events of historical significance. A very simple application is to discover, for example, the phase of the Moon on the day you were born.

Scientific Astronomer generates finder charts for interesting objects in the sky. The night sky is full of familiar and unusual objects, many of which are visible to the naked eye. Most of us have seen the planet Venus and could identify a few constellations, but there are many other astronomical objects and events visible to the naked eye. A few possibilities include a meteor shower, the Mir Space Station, a lunar eclipse, the planet Mercury, the asteroid Vesta, a colorful star, a double star, a variable star, a star cluster, or a galaxy. All these objects are visible on clear dark nights at an appropriate time of the year.

The trick to sighting such objects is to know where and when to look. *Scientific Astronomer* gives you the tools to determine “the where” and “the when”.

Aided with good binoculars, you can see even more objects, such as Jupiter’s moons, Saturn’s rings, various comets, diffuse nebulae, and a few galaxies. Again, *Scientific Astronomer* gives you the tools to locate the objects and to reproduce and predict the circumstances of their appearance.

About the Package

Scientific Astronomer includes over 9,000 stars, and it can determine the positions of all the planets, the Sun, the Moon, and other objects on any given date for thousands of years into the past or future. It also includes a large number of deep sky objects.

Scientific Astronomer covers four main areas of astronomy. It has functions for star charting, planet plotting, eclipse predicting, and satellite tracking. There are, of course, a large number of other functions and features in the package.

Five types of charts are defined in *Scientific Astronomer*, including two wide field star charts. With the star charts you can zoom into any portion of the sky. All the star charts have options to show spectral colors, mesh lines, a sky line, the horizon line, and the Milky Way; and to label constellations, stars, planets, deep sky objects, and so on.

Planet plotting is done in either two- or three-dimensional forms. Surface features for the Earth, the Moon, Mars, and Jupiter are shown on the plots. Moons, and their shadows, are displayed for the Earth and Jupiter. Related functions allow you to produce planet position finder charts and planet rise/set timing charts.

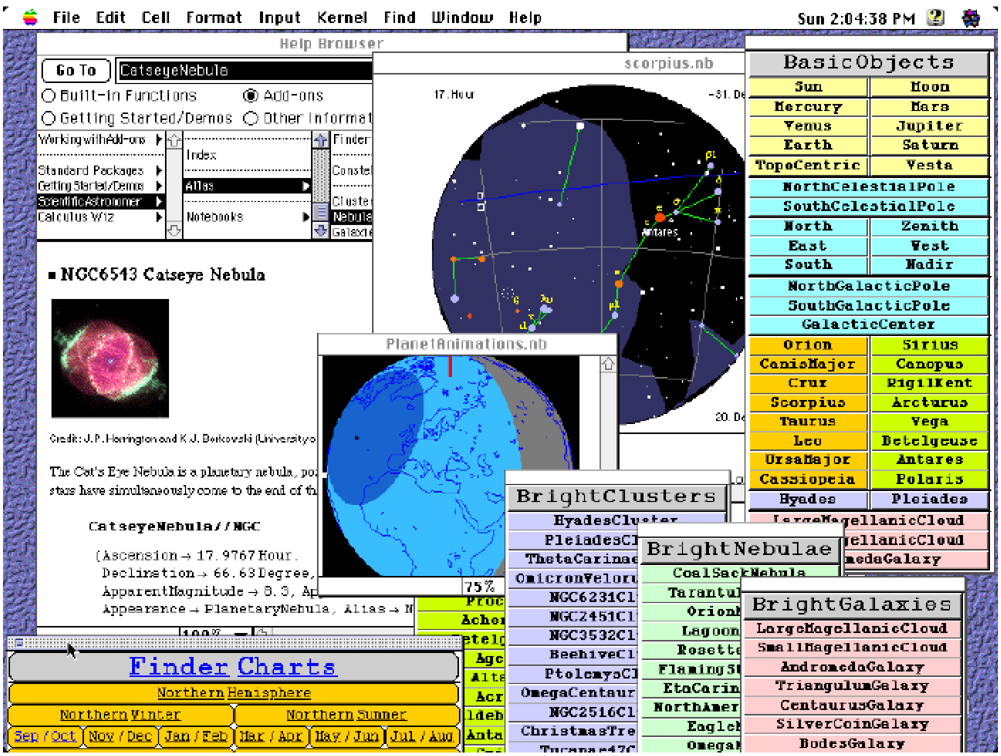
The package provides several functions for dealing with eclipses. These functions provide information about both solar and lunar eclipses, and are general enough to handle Galilean moon eclipses, occultation of stars by the Moon, and transits of Mercury or Venus across the solar disk. You can produce umbra and penumbra track plots and perform eclipse prediction.

The satellite tracking feature of *Scientific Astronomer* allows you to create track plots, make visibility predictions, and project satellite tracks onto star charts.

Miscellaneous features are available, such as producing planisphere plates, planet charts, and solar system plots. In addition, sunrise, moonrise, and full moon functions are provided, as well as functions for adding new objects such as comets and satellites.

Overall, *Scientific Astronomer* provides a large number of tools of interest to professional and amateur astronomers. Not only does the package contain standard planetarium-type features for generating star charts, but it has functions that when used in conjunction with *Mathematica* create a general astronomy computing environment.

Scientific Astronomer is fully compatible with *Mathematica* Versions 3 and 4. The package has many palettes and hyperlinks, and is fully documented in the Help Browser.



■ 1.1 Loading and Setup

Once you have installed the package, it is a simple matter to load it into *Mathematica*.

`<< Astronomer`HomeSite``	load the package and set details for your home site

Loading the package.

■ This loads the package into *Mathematica*.

```
In[1]:= <<Astronomer`HomeSite`
        Astronomer is Copyright (c) 1997 Stellar Software
```

Depending on your computer, it may take a minute or so to load if you are using *Mathematica* Version 2. *Scientific Astronomer* will take less than ten seconds to load using *Mathematica* Version 3, however.

Site Location

If you have not already edited the `HomeSite.m` file with your site details, then you need to use `SetLocation` to define your geographic longitude, latitude, and time zone.

`SetLocation[`*options*`]`	set the location and time zone on the surface of the Earth
`GeoLongitude ->` *longitude*	the geographic longitude, where east is positive
`GeoLatitude ->` *latitude*	the geographic latitude
`GeoAltitude ->` *altitude*	the geographic altitude in kilometers
`TimeZone :>` *timezone*	the time zone, or hours ahead of GMT (Greenwich Mean Time)

Setting your site location.

■ This is the setup for Melbourne, Australia during daylight-saving time.

```
In[2]:= SetLocation[GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    GeoAltitude  -> 0.0*KiloMeter,
                    TimeZone     -> 11];
```

You can put any `SetLocation` setting into your `HomeSite.m` file to avoid having to enter it every session. Typically you can use the option setting `TimeZone :> TimeZone[]` to dynamically compute your time zone. Throughout this user's guide, the `TimeZone` option is set to 11, which is appropriate for summertime in Melbourne, Australia. It is very important that you use the correct time zone for your own location, as some functions will give inappropriate results otherwise. In particular, be careful that daylight-saving time is taken into account. When daylight saving is in effect over summer, the value returned by `TimeZone[]` should be one hour greater than normal. Thus, the normal time zone values for the Pacific, Central, and Eastern zones of the United States are -8, -6, and -5, respectively; but for a period within April through October, the values are -7, -5, and -4, respectively.

Note that the sign of the option `GeoLongitude` is such that positive is east and negative is west. Thus, the geographic longitude of Champaign, Illinois is -88.2 degrees, a negative number because it is west of Greenwich.

You can rename the `HomeSite.m` file, if you wish. For example, you might want to call it `NewYork.m`, and configure it for the geographic location of New York. In that case, you can start *Scientific Astronomer* by typing ``<<Astronomer`NewYork` ``. Similarly, you can create other site files, such as `London.m` or `Tokyo.m`.

Degree Character

The degree symbol, which is used in the output from `Ephemeris` and other functions, might not print or display correctly if you are running *Scientific Astronomer* under a version of *Mathematica* earlier than 3.0. Some computer systems do not have an appropriate character available, and in such cases you need to set the variable `$DegreeCharacter` to something tolerable to your system.

Although *Scientific Astronomer* tries to figure out the correct character, it may become confused if you are running a remote kernel. If your front end is a Unix machine running X Windows or a PC running Windows, you may need to use character 176, that is, `$DegreeCharacter = FromCharacterCode[176]`. If your front end is a Macintosh, you may need to use character 161, that is, `$DegreeCharacter = FromCharacterCode[161]`. If all else fails, you can set the variable to the character "^", that is, `$DegreeCharacter = "^"`.

Under *Mathematica* Version 3.0 or later, `$DegreeCharacter` is always correctly set for you.

Font Names and Sizes

Labeling of star charts and other graphical output is mostly done with the default font "Helvetica". If you are not satisfied with that font, change it by setting the variable `$DefaultFontName` to another font name, such as "Arial", "Times-Italic", or "Courier", for instance.

`$DefaultFontScale`	increase the size of fonts in graphics; default is 1
`$PointSizeScale`	increase the size of points in graphics; default is 1
`$ThicknessScale`	increase the size of lines in graphics; default is 1

Adjusting sizes of fonts, points, and lines.

Similarly, if you prefer another size of labeling on your monitor or printer, you can set the variable `$DefaultFontScale` to a scale factor other than the default 1. To increase point sizes and line thicknesses, use the variables `$PointSizeScale` and `$ThicknessScale`. On a PC running Windows you will typically need to set `$PointSizeScale = 2`, but your screen resolution will determine whether this is actually an improvement.

These changes can be made globally and put in the `HomeSite.m` file if needed.

Note that although you can use `$DefaultFontScale` to adjust some font sizes used in the package, you will normally use the `TextStyle` option for this.

Extra Stars

By default, a small number of stars are built directly into the package. These stars are enough to allow all the *Scientific Astronomer* features to work. You need to load more stars if you require more detailed star charts.

`<< Astronomer`Star3000``	load the 3,000 naked-eye visible stars
`<< Astronomer`Star9000``	load the 9,000 binocular visible stars
`<< Astronomer`DeepSky``	load various nebulae, star clusters, and galaxies

Loading extra stars and objects.

■ This loads 3,000 extra stars. Similarly, you can load a file containing 9,000 extra stars.

```
In[3]:= <<Astronomer`Star3000`
```

One disadvantage to loading extra stars is that it potentially causes some of the star chart functions to slow down, especially on the first call.

The default setup, therefore, includes only the brightest 300 stars, which are more than enough to allow basic constellation identification. The default setup includes all the stars down to magnitude 3.5 and several additional ones.

Once `Star3000.m` has been loaded, all the 3,000 naked-eye visible stars down to magnitude 5.5 are used. Similarly, with `Star9000.m` loaded, all the 9,000 binocular visible stars down to magnitude 7.5 are used.

Stars represent only a part of what is in the universe; many nonstellar objects, such as galaxies, nebulae, and clusters are also present. Some well-known objects, such as the Andromeda Galaxy and the Pleiades star cluster, are already built into *Scientific Astronomer*, and it is possible to access many more by loading the `DeepSky.m` package.

■ This loads extra deep sky objects.

```
In[4]:= <<Astronomer`DeepSky`
```

See the corresponding `DeepSky.nb` notebook for a discussion on how to access and work with deep sky objects.

■ 1.2 Installation and Notebooks

Scientific Astronomer is distributed CD-ROM. The CD-ROM contains one folder called `Astronomer`.

To install the package you should use the installer program on the CD-ROM. Another way to install is to move the `Astronomer` folder inside *Mathematica*'s `AddOns/Applications/` directory. Optionally, you can move the `Astronomer` folder to the top level of your own home directory.

`README`	installation instructions
`HomeSite.m`	local site details
`Astronomer.m`	the package itself
`Star3000.m`	an optional load file
`Star9000.m`	an optional load file
`DeepSky.m`	an optional load file
`Documentation/`	user's guide
`FrontEnd/`	front end files
`Kernel/`	kernel files

Files needed by the package.

Refer to the `README` file for additional instructions on how to install the package, and on how to customize it for your purposes. The most important task is to edit the `HomeSite.m` file with your own site details. In that file you will see site details commented out for many cities. If you live in one of these cities, simply uncomment the setting.

The CD-ROM also includes an on-line version of this user's guide. Once you have installed *Scientific Astronomer*, you will need to open the **Help** menu in the *Mathematica* front end and choose **Rebuild Help Index**. This will make the user's guide, and other information, available in the front end Help Browser.

`Cover.nb`	cover page
`Contents.nb`	table of contents
`Chapter1.nb`	introduction
`Chapter2.nb`	basic functions
`Chapter3.nb`	coordinate functions
`Chapter4.nb`	star charting
`Chapter5.nb`	planet plotting
`Chapter6.nb`	eclipse predicting
`Chapter7.nb`	satellite tracking
`Chapter8.nb`	miscellaneous
`Chapter9.nb`	additional information
`Appendix.nb`	appendix
`Index.nb`	index
`Notebooks/`	sample notebooks
`Palettes/`	palettes

On-line version of the user's guide.

Worked Examples

Many worked examples are given in the sample notebooks that come with *Scientific Astronomer*. These sample notebooks are contained in the `Astronomer/Documentation/English/Notebooks/` directory. You can open the notebooks directly, or you can access them from within the Help Browser.

Apollo.nb	Apollo lunar landings
Asteroids.nb	asteroid trajectories
Astrology.nb	astrological readings
Charts.nb	star chart examples
Comets.nb	comets Halley and Hale-Bopp
DeepSky.nb	atlas of galaxies and nebulae
Eclipses.nb	solar and lunar eclipses
Features.nb	main features of package
Gallery.nb	some graphic examples
Impact.nb	Jupiter-comet impact
Lunar.nb	lunar libration
Meteors.nb	meteor showers
Mir.nb	visible satellites
PlanetAnimations.nb	planet animations
Satellites.nb	Earth satellites
Scale.nb	large-scale structure
StarMaps.nb	making sky maps
Variables.nb	variable stars
Viking.nb	Viking Mars landings
Voyager2.nb	Voyager II trajectory
Window.nb	star view from a window
585BC.nb	famous eclipse of 585 B.C.

Sample notebooks included with *Scientific Astronomer*.

The sample notebooks cover topics such as satellite tracking, annual meteor showers, eclipses, variable stars, comets, asteroids, and deep sky objects.

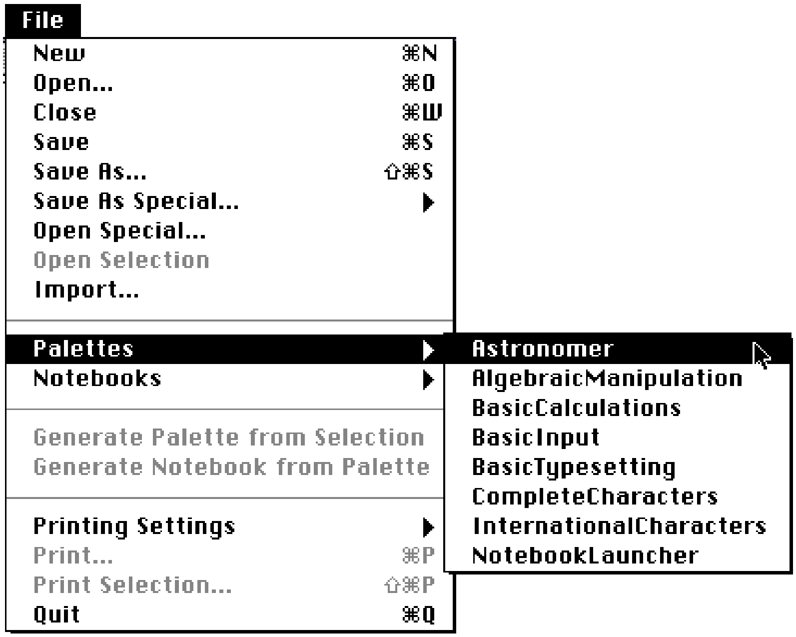
Each notebook deals with a particular aspect of astronomy and uses *Scientific Astronomer* to produce useful information. For instance, the deep sky notebook contains an atlas of galaxies, nebulae, and star clusters and it uses *Scientific Astronomer* to create finder charts for various interesting objects, sorted by location and date of visibility. The comets notebook shows how to make finder charts for comets such as Halley or Hale-Bopp. Similarly, the satellite tracking notebook shows how to track the Mir Space Station or a Space Shuttle mission. This notebook also includes an analysis of the 24 Global Positioning System (GPS) satellites. The variable stars notebook has *Mathematica* expressions for predicting the time of maximum brightness of eclipsing binaries and pulsating stars.

Studying the sample notebooks should give you a feel for the types of applications and calculations that *Scientific Astronomer* can handle.

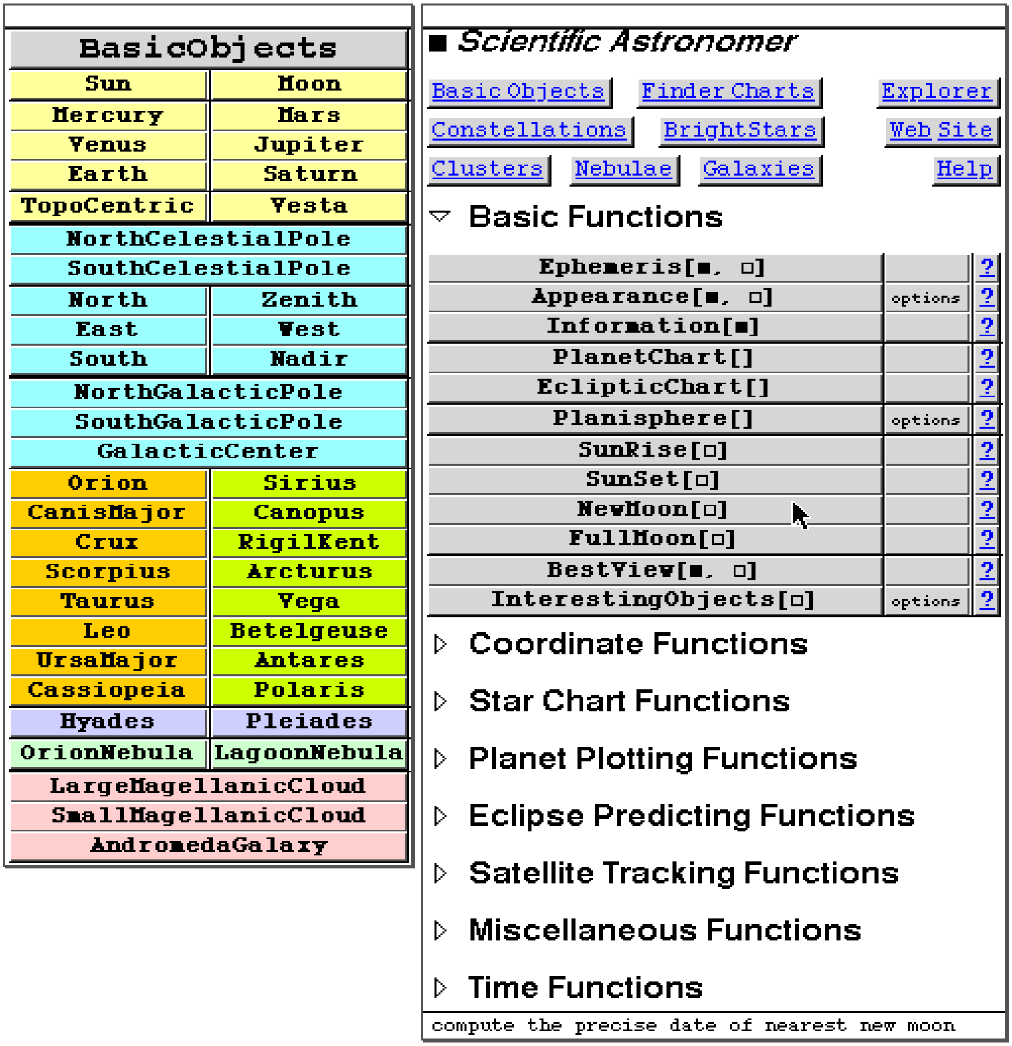
■ 1.3 Palettes and Buttons

Scientific Astronomer takes full advantage of palettes in *Mathematica* Versions 3 and 4.

To make a palette of common functions visible from within the front end via the **File ▷ Palettes** menu when running *Mathematica* Version 3, you should copy the palette notebook `Astronomer/FrontEnd/Palettes/Astronomer.nb` to `$TopDirectory/Configuration/FrontEnd/Palettes/Astronomer.nb`. This palette is also available in the Help Browser. Once you have placed the notebook in this directory, an Astronomer palette will be available. You can access it like any of the standard palettes that come with *Mathematica*.



To bring up the Astronomer palette, open the **File** menu, move to **Palettes**, then choose **Astronomer**.

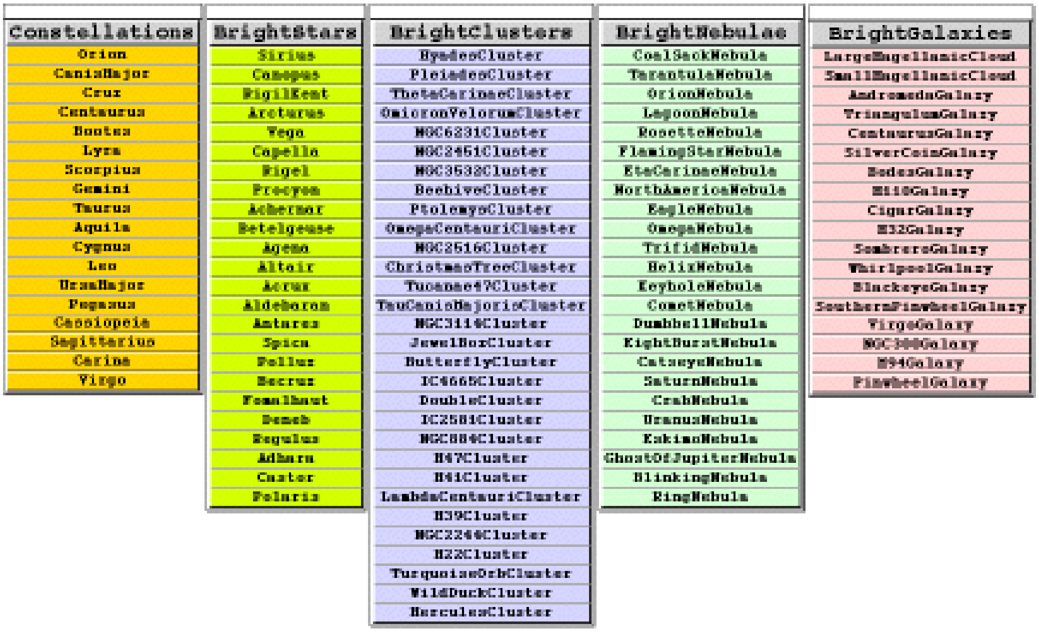


The main Astronomer palette contains a simplified function-usage listing. When you click a triangle on the left of the palette, a list of functions in the selected category is opened.

A short note is printed at the bottom of the palette to describe the purpose of the function that the mouse pointer is currently over. Click the options field to bring up a palette of options for the function. On-line help can be obtained by clicking the blue question mark on the right-hand side of each function.

If you type the name of an object in your current notebook, highlight it with the mouse, and then click a function in the Astronomer palette, the function wraps around the object. To save typing an object you can choose it from the basic objects palette. Alternatively, you can click the function, then choose an object.

The main Astronomer palette has buttons to launch additional palettes of astronomical objects.



Another feature of the main Astronomer palette allows you to launch an interactive star chart explorer.

2. Basic Functions

More than 70 functions are implemented in *Scientific Astronomer*. There are 24 graphical functions used to produce finder charts, planet plots, and star charts. Most of the other functions simply return numbers or rules relating to the conditions of planets, stars, and other objects.

Apart from star charts, which constitute a large portion of *Scientific Astronomer*, there are a number of basic functions that you may find useful, especially when first learning to use the package. This chapter discusses the general usage of those functions.

Before you can use the package, however, you need to understand a few basic concepts and conventions. Most functions require an object and/or a date as part of the argument list, and other arguments and options may also be needed in some cases. Once you become familiar with the objects and date format, then using each of the functions should be relatively straightforward.

Object Types

Usually an object is a planet, but it may be any other type of astronomical body, such as an asteroid, Galilean moon, star, or constellation. Many standard objects are already built into *Scientific Astronomer*.

Sun and Moon	`Sun, Moon`
Planets	`Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto`
Asteroids	`Ceres, Pallas, Vesta`
Galilean Moons	`Io, Europa, Ganymede, Callisto`
Special	`NorthCelestialPole, SouthCelestialPole, Zenith, Nadir, North, South, East, West, TopoCentric, GeoCentric, GalacticCenter, NorthGalacticPole, SouthGalacticPole`
Stars	`Sirius, Canopus, RigilKent, Arcturus, Vega, Capella, Rigel, Procyon, Achernar, Betelgeuse, Agena, Altair, Acrux, Aldebaran, Antares, Spica, Pollux, Fomalhaut, Deneb, Becrux, Regulus, Adhara, Castor, Gacrux, Bellatrix, Polaris, Algol, Mizar`
Constellations	`Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Pisces`

Some of the objects defined in *Scientific Astronomer*.

In general, an object represents some real or abstract point in the universe. You can add new objects such as satellites or comets whenever you wish. Many deep sky objects, such as galaxies, nebulae, and star clusters, can be loaded using the `DeepSky.m` package, which includes all nonstellar objects with a magnitude at least as low as 11.

Deep Sky Clusters	`Hyades`, `Pleiades`, `ThetaCarinaeCluster`, `BeehiveCluster`, `JewelBoxCluster`, etc.
Deep Sky Nebulae	`CoalSackNebula`, `TarantulaNebula`, `OrionNebula`, `LagoonNebula`, `RosetteNebula`, etc.
Deep Sky Galaxies	`LargeMagellanicCloud`, `SmallMagellanicCloud`, `AndromedaGalaxy`, `TriangulumGalaxy`, etc.

Some deep sky objects.

There are 110 deep sky objects built directly into *Scientific Astronomer*. Built-in deep sky objects are given special names, such as `BeehiveCluster`, `OrionNebula`, and `AndromedaGalaxy`; and they include all the most notable clusters, nebulae, and galaxies that an amateur is likely to see.

About a quarter of the built-in deep sky objects are visible to the naked eye, and another half only require binoculars. The remainder require a telescope.

Other built-in objects include the nine planets, some asteroids, many named stars, and all the constellations.

Date Formats

There are several conventions for writing calendar dates, with the two most widely used being the American and European formats. A less common convention, known as scientific format, is used by astronomers. Scientific format has been adopted for dates in this user's guide.

In scientific format, the year is written first, followed by the month, and then the day. For example, the 17th day of November in the year 1993 A.D. is written in scientific format as "1993 November 17". In American format that date would appear as "November 17, 1993"; and in European format, as "17 November 1993".

You may input dates into *Scientific Astronomer* in several formats. For example, you can use `{1993,11,17,3,20,0}` to specify the local time of 3:20am on 1993 November 17. This format is modeled exactly on the output of `Date`.

Another format is to use `{1993,11,17}`, which specifies local midnight. An alternative is to use `{1993,1,321}`, which means the 321st day of January, and is equivalent to `{1993,11,17,0,0,0}`. It is also possible to use `{1993,11,17.75}`, which represents 18:00 hours (or 6:00pm) local time on November 17.

All dates returned by *Scientific Astronomer* are in local time; that is, your time zone is always taken into account. To get Universal Time (UT) or Greenwich Mean Time (GMT), subtract your time zone value from any local date. For instance, in the examples used throughout this user's guide, where `TimeZone -> 11`, the local date `{1993,11,17,3,20,0}` corresponds to `{1993,11,16,16,20,0}` Universal Time.

In addition, all dates returned by *Scientific Astronomer* are based on the Gregorian calendar. To get the date according to the Julian calendar, which was in use prior to 1752 in most British colonies, add `2-Floor[y/100]+Floor[y/400]` days, where *y* is the year.

Setting Your Site Location

- This loads the *Scientific Astronomer* package.

```
In[1]:= <<Astronomer`HomeSite`

        Astronomer is Copyright (c) 1997 Stellar Software
```

Virtually all functions defined in *Scientific Astronomer* require a date as an input argument. Dates are given in local time, which depends on your time zone. In addition, a few functions, such as `Ephemeris` and `HorizonCoordinates`, give results that depend on your geographic location on the Earth. You must, therefore, always tell *Scientific Astronomer* the geographic location and time zone that you wish to use.

- This sets your location on the Earth. It also sets your time zone.

```
In[2]:= SetLocation[GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    GeoAltitude  ->   0.0*KiloMeter,
                    TimeZone     ->  11];
```

■ 2.1 The Ephemeris and Appearance Functions

`Ephemeris` returns all the common ephemeris data about a celestial object at the current time, date, and viewing location. It includes information such as the object's position and its rising and setting times.

`Ephemeris[`*object*`, `*date*`]`	generate ephemeris details for the *object* on the given *date*
`Ephemeris[`*object*`]`	generate ephemeris details using the current value of `Date[]`

Printing ephemeris information.

`Ephemeris` is typically applied to solar system objects such as `Mars`, `Moon`, and `Io`; stars such as `Sirius` and `Alpha.Centaurus`; constellations such as `Leo` and `UrsaMajor`; and special objects such as `SouthCelestialPole` and `Zenith`.

■ The ephemeris data for Mercury at 03:20 on 1993 November 17 shows that Mercury rises at about 05:19, or approximately 45 minutes before the Sun. At the given date and time, Mercury is below the horizon. When it does rise, Mercury has a magnitude of about 1.0 and is visible in the general direction of the zodiac constellation of Libra.

```
In[3]:= Ephemeris[Mercury, {1993,11,17,3,20,0}]

Mercury
-----------------------------------------
Date Time:   1993-Nov-17 03:20:00 (GMT+11)
Geo-place:     145°00'E,  37°48'S (Earth.)
------- For Date, Geo-place: -------------
Rising:          05:19  (Sunrise:    06:03)
Setting:         18:36  (Sunset:     20:06)
------- For Date Time, Geo-place: --------
Azimuth:       125°30' (SouthEast compass)
Altitude:      -21°35' (Below the horizon)
------- For Date Time: -------------------
Elongation:    -17°37' (Morning sky.  35%)
Distance:      0.85 AU (Magnitude:   +1.0)
------- For Date Time: -------------------
Ascension:    14h20.5m (Libra        215°)
Declination:   -11°36' (Ecliptic +  2°17')
-----------------------------------------

Out[3]= -EphemerisData-
```

You will note that additional information is given in the ephemeris output, such as the object's azimuth and altitude. Azimuth is the compass direction around the horizon, and altitude is the angle above the horizon. Ascension and declination values are included as well.

Basic information about the planets, asteriods, and even Galilean moons can be accessed using the `?` function.

■ `?Mercury` gives basic information about the fixed properties of the planet Mercury.

```
In[4]:= ?Mercury

Mercury is the first planet orbiting the Sun.
 EquatorialRadius : 2,439km
 RotationPeriod   : 58.646days
 RotationAxisTilt : 0 Degree
 Oblateness       : 0.00
 OrbitalSemiMajorAxis : 0.38709860 AU
 OrbitalPeriod        : 0.24084 Year
 OrbitalInclination   : 7.003 Degree
 OrbitalEccentricity  : 0.2056
```

■ `Ephemeris` can also be applied to the Moon and other objects. The fourth to last line on the right shows that the Moon is in the evening sky, as opposed to the morning sky. Its phase is 10%, which is almost a new moon; as seen from Earth only 10% of its surface is illuminated by the Sun.

```
In[5]:= Ephemeris[Moon, {1993,11,17,3,20,0}]

Moon
-------------------------------------------
Date Time:   1993-Nov-17 03:20:00 (GMT+11)
Geo-place:     145°00'E,  37°48'S (Earth.)
------- For Date, Geo-place: -------------
Rising:          08:54  (Sunrise:    06:03)
Setting:         23:27  (Sunset:     20:06)
------- For Date Time, Geo-place: --------
Azimuth:        186°30' (South     compass)
Altitude:       -31°02' (Below the horizon)
------- For Date Time: -------------------
Elongation:      37°17' (Evening sky.  10%)
Distance:     373.5 Mm (Magnitude:    -9.8)
------- For Date Time: -------------------
Ascension:    18h06.9m (Sagittarius  272°)
Declination:   -20°54' (Ecliptic +  2°32')
-------------------------------------------

Out[5]= -EphemerisData-
```

■ Here is the ephemeris data for the constellation of Leo.

```
In[6]:= Ephemeris[Leo, {1993,11,17,3,20,0}]

Leo
-------------------------------------------
Date Time:   1993-Nov-17 03:20:00 (GMT+11)
Geo-place:     145°00'E,  37°48'S (Earth.)
------- For Date, Geo-place: -------------
Rising:          02:56  (Sunrise:    06:03)
Setting:         13:17  (Sunset:     20:06)
------- For Date Time, Geo-place: --------
Azimuth:         66°08' (NorthEast compass)
Altitude:         3°59' (Above the horizon)
------- For Date Time: -------------------
Elongation:     -81°08' (Morning sky. 100%)
Distance:     ********* (Magnitude:  *****)
------- For Date Time: -------------------
Ascension:    10h29.7m (Leo          157°)
Declination:    16°02' (Ecliptic +  6°07')
-------------------------------------------

Out[6]= -EphemerisData-
```

In the case of the Moon, distance is given in Megameters (1 Mm = 1,000km). For most other objects, distance is expressed in astronomical units (1 AU = 149,597,900km). In some cases, such as for the constellations, distance does not have any meaning, and the entry in the `Ephemeris` output is simply left blank. For stars and other very distant objects, distance is measured in light years (1 LY = 63,240 AU).

As with other coordinate functions, the default for the option `ViewPoint` (*i.e.*, the point from which you make the observation) is calculated as if you were at the center of the Earth, but with the correct longitude and latitude for the purposes of determining the local horizon. In other words, the default setting is calculated as if you live on the surface of a very small ball at the center of the Earth.

On some occasions, as when viewing the Moon or a low-orbit satellite, parallax comes into play, and it is important to use your correct location on the surface of the Earth, which is provided by the `TopoCentric` object. The option setting `ViewPoint -> TopoCentric`, available in `Ephemeris` and other functions, accurately computes angles for your specific site, rather than approximating them as from the center of the Earth.

The Appearance Function

A related function is `Appearance`, which returns rules related to the appearance of an object on a given date. For instance, the phase rule represents the amount of the object's disk illuminated by the Sun as seen from the current viewpoint. A phase of 1 represents full illumination, whereas 0 represents no illumination, due to the Sun's location being directly behind the object.

`Appearance[`*object*`, `*date*`]`	information about the general appearance of the *object* on the given *date*
`Appearance[`*object*`]`	information using the current value of `Date[]`
`ViewPoint -> `*planet*	appearance as seen from *planet*

Computing appearance information.

■ The general appearance of the Moon on 1993 November 17 shows that the apparent diameter of the Moon is 0.533 degrees and its phase is 0.10, which means that only 10% of the Moon's surface, as seen from the Earth, is currently illuminated.

```
In[7]:= Appearance[Moon, {1993,11,17,3,20,0}]

Out[7]= {ApparentMagnitude → -9.8, ApparentDiameter → 0.533226 Degree,
         Phase → 0.103022, CentralLongitude → 6.44051 Degree,
         CentralLatitude → -3.25366 Degree}
```

■ This shows that Jupiter's phase is nearly 100% as is always the case when it is viewed from the Earth. Its apparent diameter is 0.0087 degrees, or about 31 arc-seconds, and its apparent magnitude is -1.7, which is slightly brighter than the brightest star at -1.5.

```
In[8]:= Appearance[Jupiter, {1993,11,17,3,20,0}]

Out[8]= {ApparentMagnitude → -1.7, ApparentDiameter → 0.00868686 Degree,
         Phase → 0.998732, CentralLongitude → 138.492 Degree,
         CentralLatitude → -2.8576 Degree}
```

Two important quantities returned by `Appearance` are the central longitude and latitude of an object. These are the local longitude and latitude of the spot at the very center of the object's disk as seen from the viewpoint on the given date. Section 9.6 discusses in detail the coordinate system used for the local longitude and latitude of various planets, the Moon, and the Sun.

The Moon always presents the same face toward the Earth, but due to an effect known as libration, the Moon rocks slightly from side to side about a mean state. The central longitude and latitude of the Moon are equivalent to the angles of libration if the viewpoint is the Earth.

■ A combination of libration and the viewing location on the surface of the Earth allows you to see 6.35 degrees around the western edge of the Moon; and 4.08 degrees above the northern edge of the Moon.

```
In[9]:= Appearance[Moon, {1993,11,17,3,20,0},
                   ViewPoint->TopoCentric]

Out[9]= {ApparentMagnitude → -9.8, ApparentDiameter → 0.528523 Degree,
         Phase → 0.102948, CentralLongitude → 6.35094 Degree,
         CentralLatitude → -4.07886 Degree}
```

■ The place with lunar longitude equal to 149.1 degrees has the Sun directly overhead.

```
In[10]:= Appearance[Moon, {1993,11,17,3,20,0},
                    ViewPoint->Sun]

Out[10]= {ApparentMagnitude → 0.7, ApparentDiameter → 0.00134912 Degree,
          Phase → 1., CentralLongitude → 149.143 Degree,
          CentralLatitude → -0.254465 Degree}
```

■ The place with Martian longitude equal to -64.5 degrees is facing the Earth on the given date and time. The central latitude is +8.15 degrees, so the north pole of Mars is tilted toward the Earth.

```
In[11]:= Appearance[Mars, {1993,11,17,3,20,0}]

Out[11]= {ApparentMagnitude → 1.3, ApparentDiameter → 0.00106106 Degree,
          Phase → 0.995964, CentralLongitude → -64.5383 Degree,
          CentralLatitude → 8.15848 Degree}
```

■ The coordinate system on Europa and the other Galilean moons is such that the zero of longitude and latitude is the point facing Jupiter. As with the Earth's moon, there is a small libration rocking the Galilean moons.

```
In[12]:= Appearance[Europa, {1993,11,17,3,20,0},
                    ViewPoint->Jupiter]

Out[12]= {ApparentMagnitude → -9.5, ApparentDiameter → 0.263313 Degree,
          Phase → 0.860972, CentralLongitude → -3.30328 Degree,
          CentralLatitude → -0.109676 Degree}
```

The `Appearance` function can be applied to stars, star clusters, nebulae, and galaxies. In the case of a star, the apparent magnitude and spectral color is returned by `Appearance`.

Every star has a particular temperature, which depends on its mass, age, and internal composition. This temperature is directly related to the color that we see. Some stars, such as Antares in Scorpius, have a very definite red appearance. In general, hot stars are blue in color, and cooler ones are red. Stars of intermediate temperature can be white, yellow, or orange.

Scientific Astronomer uses the standard spectral type sequence to classify the color of stars. The sequence begins with "O" and "B" to designate the hottest stars; "A", "F", and "G" refer to intermediate temperature stars; and the coolest stars are classified as "K" and "M". Each spectral type is further subdivided into ten divisions numbered 0 through 9. In this classification our own Sun is rated as a G2 star. The table shows the relationship between spectral type, color, and temperature. A G2 star like our Sun, for instance, has a yellow-white appearance.

Type	*Color*	*Temperature* (°K)	*Examples*
O	Blue	28, 000 – 40, 000	`Gamma . Vela, Zeta . Orion, Zeta . Puppis`
B	Blue	10, 000 – 28, 000	`Rigel, Spica, Regulus`
A	Blue-white	7, 500 – 10, 000	`Sirius, Vega, Deneb`
F	White	6, 000 – 7, 500	`Canopus, Procyon, Polaris`
G	Yellow-white	5, 000 – 6, 000	`Sun, RigilKent, Capella`
K	Orange	3, 500 – 5, 000	`Arcturus, Aldebaran, Epsilon . Eridanus`
M	Red	2, 500 – 3, 500	`Betelgeuse, Antares`

Spectral types.

■ `Appearance` is used to find the color of the star Betelgeuse. Spectral type M1 corresponds to a very red color.

```
In[13]:= Appearance[Betelgeuse]

Out[13]= {ApparentMagnitude → 0.5, ApparentDiameter → 0. Degree, Color → M1}
```

The reddest star known is the 5th magnitude `TX.Pisces`. Another extremely red star is the Mira-type variable `R.Lepus`. John Hind in 1845 described this star as appearing "like a drop of blood on a black field". The magnitude of `R.Lepus` ranges between 5.5 and 10.5 over a period of 432 days. Some notable blue stars include the 2nd magnitude supergiant ζ (zeta) Puppis and the 1st magnitude Spica.

■ 2.2 The PlanetChart and EclipticChart Functions

`PlanetChart` produces a graphic showing a calendar of planetary events for a specified year. You can use this function to make a wall chart.

`PlanetChart[`*year*`]`	chart a calendar of the heavens during the specified *year*
`PlanetChart[]`	display chart for the current year

Charting planetary positions for a year.

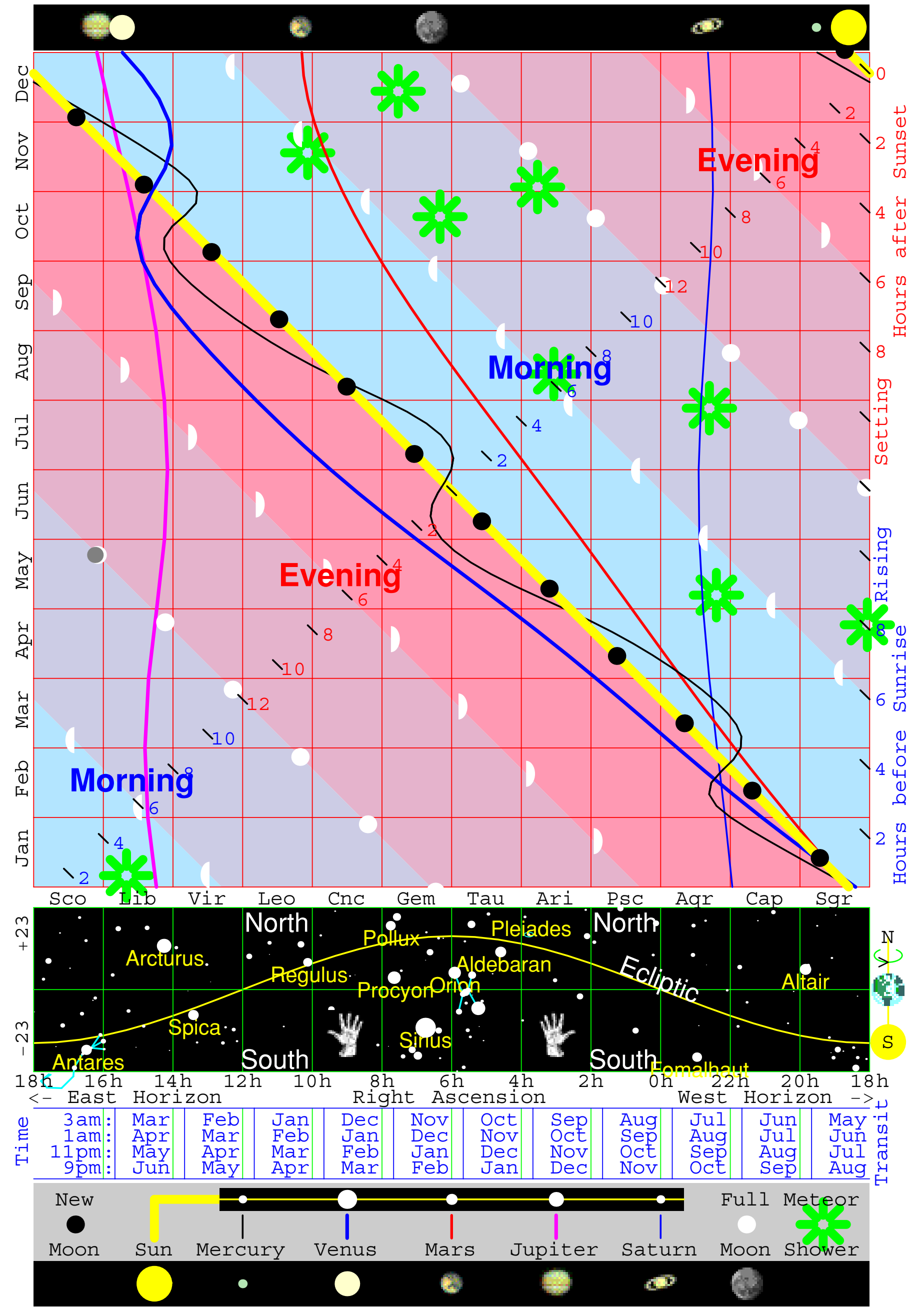
To use the chart, select the date from the left-hand side, and read horizontally across to find a particular planet. Planet images are sketched at the top and are labeled in the key at the bottom. Once you locate the point on the planet line, use the colored diagonal bands to determine whether the planet is visible in the evening or morning sky. Read vertically from the point to the ecliptic line in the star field to find where the planet is in relation to the stars on the specified date.

There is a wealth of information contained in the chart. It shows new, full, and half moons, along with any lunar eclipses that might occur during the year. In addition, annual meteor showers are represented as large green objects and are placed so as to indicate the date and star field position where you might be able to see them. Other features of the chart include a diagonal scale, labeled on the right-hand side, that you can use to determine rising and setting times for the planets. You can also use the chart to indirectly find the local horizon at any given hour in relation to the stars in the star field. Because the chart is independent of your latitude, you can use it anywhere in either the northern or southern hemispheres.

■ Here is the planet chart for 1994. Select the date from the left-hand side, and read horizontally across to find the planet of interest. Use the colored diagonal bands to determine whether the planet is visible in the evening or morning sky. Read vertically downward from the point to the ecliptic line in the star field to find where the planet is in relation to the stars on the specified date.

```
In[14]:= PlanetChart[1994, TextStyle -> {FontSize -> 8}];
```

1994 Planet Chart



Here is the kind of information that you can extract from the chart shown for 1994.

In the first month of 1994, all the major planets, with the exception of Jupiter, are behind the Sun. Jupiter rises in the morning about 4 to 6 hours before sunrise and is visible in the constellation of Libra. Later in the year, during the month of October, Jupiter and Venus are in conjunction and are visible in the evening sky for about 3 hours after sunset each night for two weeks. At the same time, Mercury is at its maximum eastern elongation from the Sun, which happens once every four months. You should be able to spot all three planets at the same time and in roughly the same place. Later in October, there is a meteor shower in the early morning hours, visible in the direction of Orion. At the same time, there is a full moon about 60 degrees, or 4 hours of right ascension, away in the constellation of Pisces. The full moon may make it difficult to see some of the less bright meteor trails. While waiting for that shower, you may try to find Mars in the constellation of Cancer, by looking about 45 degrees away to the east. It only rises above the horizon at about 5 hours before sunrise, so you will have to stay up late to see it. One other notable feature for 1994 is a lunar eclipse near the end of May. Like all lunar eclipses, it is visible from one side of the Earth only, where it can last for up to two hours.

The EclipticChart Function

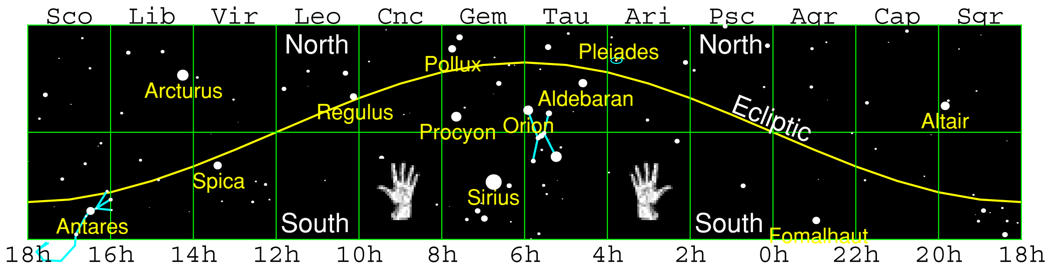
A brief guide to the main stars spread along the ecliptic line is shown at the bottom of the planet chart output. The `EclipticChart` function displays only that guide, which you can print and use for reference.

`EclipticChart[]`	chart the stars along the ecliptic line

Generating a chart of the zodiac constellations.

■ `EclipticChart` shows the stars along the ecliptic line.

```
In[15]:= EclipticChart[];
```



The key constellations to remember are Orion and Scorpius, which are in opposite parts of the sky. At any time of the night at least one of these constellations is visible. Orion is dominant in the evening sky during the beginning and end of each year. Scorpius is dominant in the evening sky during the middle of each year.

■ 2.3 The Planisphere Function

`Planisphere` produces either two or four graphic plates that you can use to build a planisphere for a given geographic latitude. A planisphere is a device for determining which stars are above the local horizon at any given hour for each day of the year.

`Planisphere[]`	produce two plates needed to construct a planisphere
`Fold -> True`	produce four plates for a more detailed planisphere
`GeoLatitude ->` *latitude*	produce plates for a specific geographic *latitude*

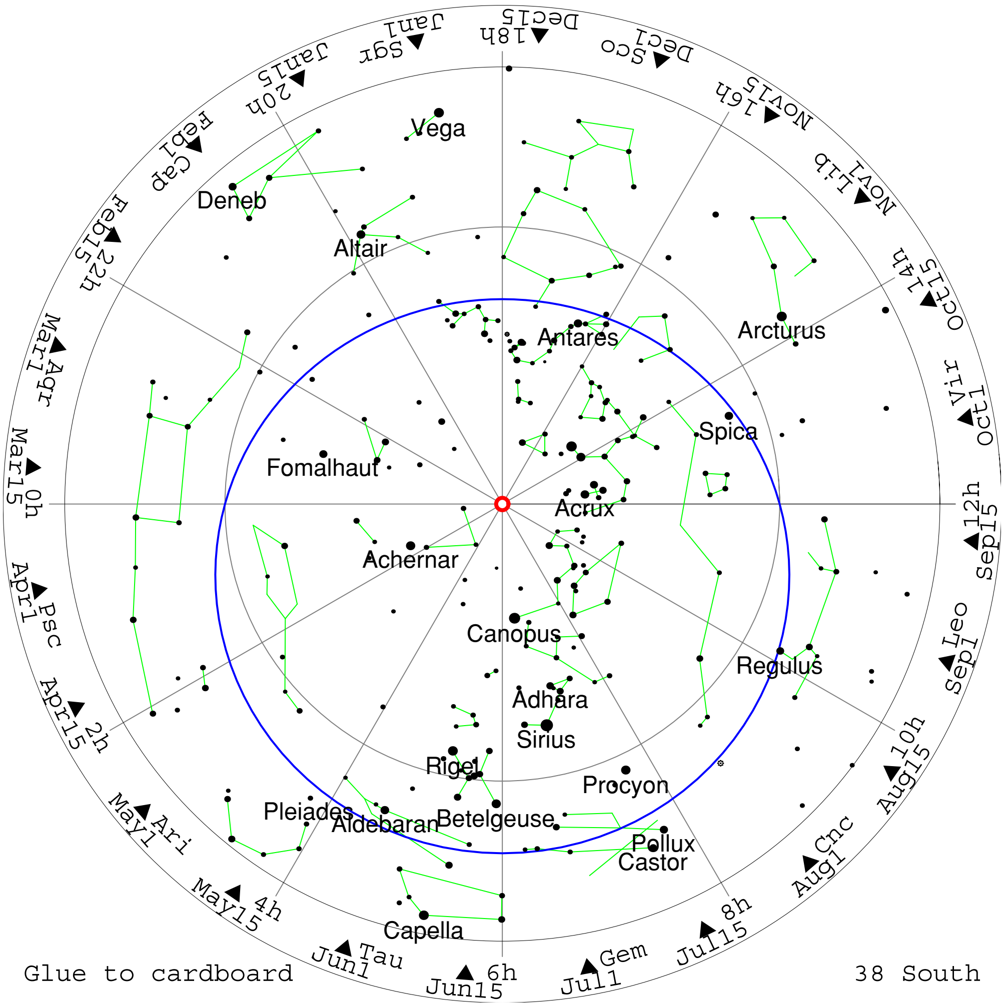
Producing planispheric plates.

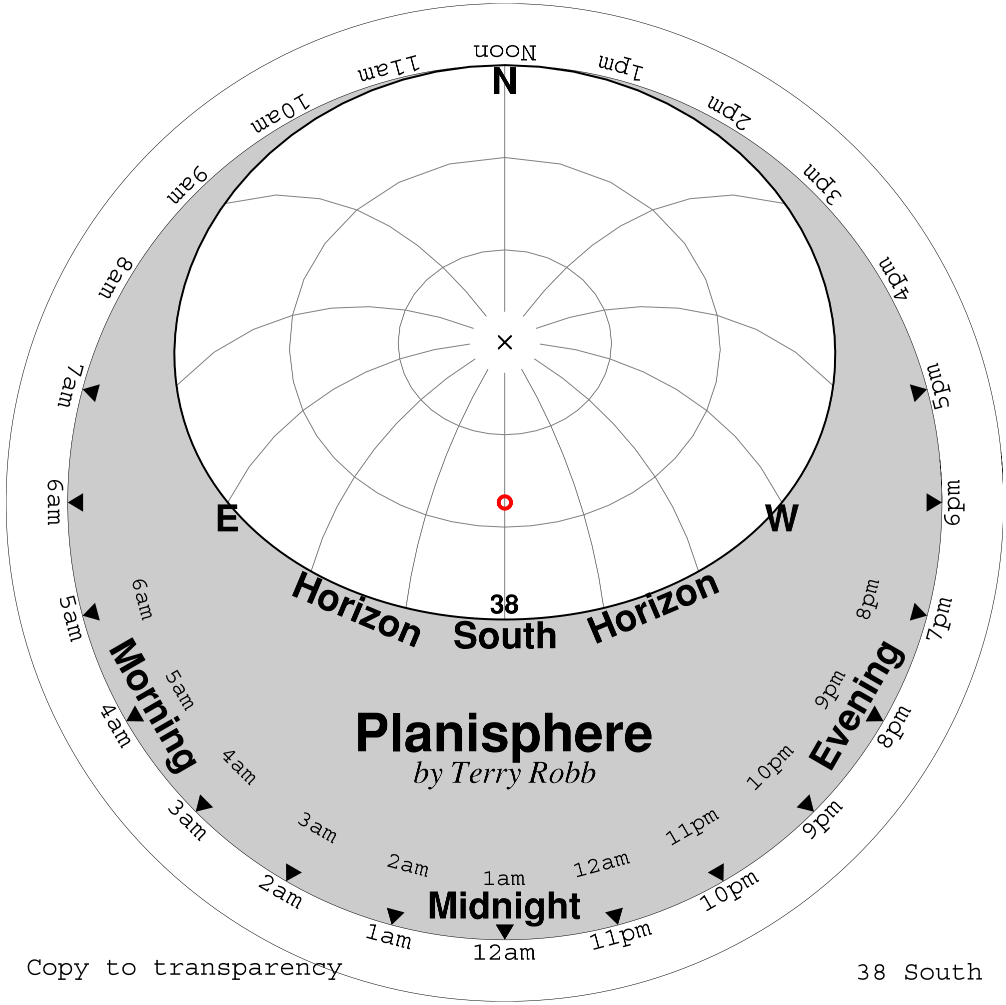
To construct the two-plate planisphere, print the first plate onto cardboard and the second plate onto a transparency. Then rivet the plates together at the center, which is marked with a small red circle. Trim the plates to the outer circle. You may also want to glue a graphic generated by `OuterPlanetChart` to the back of the planisphere. The `OuterPlanetChart` function is discussed in Section 5.5.

A two-plate planisphere is suitable for use in latitudes greater than 30 degrees north or south of the equator. There is, additionally, a four-plate planisphere suitable for latitudes less than 45 degrees north or south. If your latitude is between 30 and 45 degrees north or south, you can use either of the two styles. To generate the four-plate planisphere, use the option setting `Fold -> True`. Construction of the four-plate planisphere is similar to the two-plate planisphere except that the second set of two plates goes on the back of the first set of two plates, and there is no need to use the `OuterPlanetChart` graphic. The four-plate planisphere produces a more detailed and accurate representation of the sky than the two-plate planisphere. It is, however, more difficult to construct, as additional gluing and cutting is required.

■ This displays the two planisphere plates needed for latitude -38 degrees in the southern hemisphere. By default, stars with magnitude less than 3.5 are not displayed, but you can changed this using the option `MagnitudeRange`.

```
In[16]:= Planisphere[GeoLatitude -> -38*Degree,
                     StarLabels  -> True,
                     RotateLabel -> False];
```





To align the planisphere, hold it above your head and orient the North and South points to the corresponding true compass directions. The red circle, where the rivet is located, will point to your celestial pole, which is either north or south depending on your hemisphere. The cross in the middle of the second plate will represent the zenith point directly above your head, and the gray lines are 30 degrees apart.

To use the planisphere, keep the front plate stationary, and rotate the back plate with the stars on it, so that the month and day point to the desired hour on the front plate. Stars that are visible through the window in the front plate are the stars that are visible in the real sky at that time. Standard time is represented in the outer circle of hours and daylight-saving time in the inner circle.

On the back plate, the blue ring represents the ecliptic line along which all the planets and Moon approximately move. To find a planet you can either scan along that line in the real sky to find an unfamiliar object, or you can use `OuterPlanetChart` to create a finder chart. The finder chart is designed to be glued to the very back of the planisphere for easy reference. Another way to locate planets in the sky is to remember that planets do not twinkle, unlike stars, which do twinkle as a rule.

Labeled on the outer rim of the planisphere are the right ascension hour and the zodiac constellations.

Any of the options available to `StarChart` are available to `Planisphere`. However, `MagnitudeRange -> {-Infinity, 3.5}` is used by default in order to keep the star plate from becoming too cluttered.

■ 2.4 The SunRise and NewMoon Functions

Precise times for common solar and lunar events are provided by the `SunRise`, `SunSet`, `NewMoon`, and `FullMoon` functions.

`SunRise[`*neardate*`]`	compute the precise time of sunrise on the day of *neardate*
`SunSet[`*neardate*`]`	compute the precise time of sunset on the day of *neardate*
`NewMoon[`*neardate*`]`	compute the precise date of the new moon nearest to *neardate*
`FullMoon[`*neardate*`]`	compute the precise date of the full moon nearest to *neardate*

Determining the precise times of common events.

Sunrise and sunset times are computed according to your current location and time zone as set previously with `SetLocation`. The location used throughout this user's guide is Melbourne, Australia.

■ On 1993 November 17, sunrise at Melbourne is about 06:00 (or 6:00am).

```
In[17]:= SunRise[{1993,11,17}]

Out[17]= {1993, 11, 17, 6, 0, 25}
```

■ Sunset is about 20:10 (or 8:10pm).

```
In[18]:= SunSet[{1993,11,17}]

Out[18]= {1993, 11, 17, 20, 9, 52}
```

The `SunRise` and `SunSet` functions take into account atmospheric refraction. When light passes along the horizon to reach you, it is refracted by about 0.5 degrees, so that sunrise occurs about two minutes earlier than the time you would expect from simple geometry. Similarly, sunset occurs about two minutes later. You can use the option `Refract->False` to suppress refraction.

Related functions are `NewMoon` and `FullMoon`.

■ The new moon nearest to 1993 November 17 occurs on November 14.

```
In[19]:= NewMoon[{1993,11,17}]

Out[19]= {1993, 11, 14, 8, 35, 45}
```

■ The nearest full moon occurs fifteen days later on November 29.

```
In[20]:= FullMoon[{1993,11,17}]

Out[20]= {1993, 11, 29, 17, 32, 51}
```

All the dates and times returned are accurate to within one minute.

As with all the functions in *Scientific Astronomer*, if you omit the date or near date argument, the current date (as calculated from `Date[]`) is always used. Thus, `SunSet[]` returns the time when the Sun will set today, and `FullMoon[]` returns the date of the nearest full moon.

You can use the `NewMoon` function to calculate the date of the Chinese New Year. As a general rule, Chinese New Year begins on new moon nearest to February 4 in any given year. Thus, a definition is `ChineseNewYear[year_] := NewMoon[{year, 2, 4}]`.

A related event is a Harvest Moon, which occurs on the day of a full moon nearest the northern autumnal equinox. On the evening of a Harvest Moon the Sun sets directly in the west at the same time as a full moon rises in the east, thus extending the light at the end of the day. This symmetry greatly impressed ancient civilizations, many of which supposedly used the extra light to harvest crops. More often though it was used as the time of a celebration. A definition is `HarvestMoon[year_] := FullMoon[{year, 9, 23}]`.

Related functions, which are built into *Scientific Astronomer*, include `VernalEquinox[`*date*`]`, `AutumnalEquinox[`*date*`]`, `SummerSolstice[`*date*`]`, and `WinterSolstice[`*date*`]`.

■ 2.5 The BestView and InterestingObjects Functions

`BestView` is used to find when a planet, or any other object, is in a good viewing position relative to the Sun. This occurs when the object is furthest from the Sun in relation to your viewing angle.

`BestView[`*object*`, `*neardate*`]`	return some event dates, nearest to *neardate*, at which the object is at its best viewing condition
`BestView[`*object*`]`	return some event dates nearest the current value of `Date[]`

Determining the best viewing times for specified objects.

For the inner planets Mercury and Venus, the event dates are the evening and morning apparitions, which indicate when the planet appears in the evening or morning sky. For outer planets such as Mars, Jupiter, and Saturn, the event date is the time of opposition, which indicates when the planet is opposite in the sky to the Sun. For low-orbit Earth satellites, the event date is the transit visible time, which indicates when the satellite is visible above the horizon and is making a transit overhead. For other objects, such as stars and constellations, the event date is simply the transit time at which the object crosses the local meridian line.

`{Opposition -> date}`	event date for an outer planet, such as Mars, Jupiter or Saturn
`{EveningApparition -> date, MorningApparition -> date}`	event dates for the inner planets Mercury and Venus
`{TransitVisible -> date}`	event date for a low-orbit Earth satellite
`{Transit -> date}`	event date for other objects, such as stars

Event dates returned by BestView.

A typical use of `BestView` is to determine when, for instance, Mars is next in opposition.

■ This shows that Mars reaches opposition on 1993 January 8.

```
In[21]:= BestView[Mars, {1993,11,17}]

Out[21]= {Opposition → {1993, 1, 8}}
```

During an opposition, Mars is in the opposite direction to the Sun and consequently the orbits of Earth and Mars are close together. An opposition is a very good time to view Mars as it is at its largest apparent size. Every seventh opposition of Mars is particularly favorable as during those oppositions it is closer than normal to Earth. Mars oppositions are listed in Appendix A.11. In general, when any planet is in opposition, it is visible all night because it rises when the Sun sets, and sets when the Sun rises.

A planet is visible primarily in the morning sky before opposition, and in the evening sky after opposition. Retrograde motion also occurs around the opposition event date. In the case of Mars, retrograde motion lasts about 10 weeks and reverses 15 degrees in the sky. For Jupiter, retrograde motion lasts about 16 weeks and reverses 10 degrees. For Saturn, retrograde motion lasts about 20 weeks and reverses only 7 degrees.

Similarly, you can use `BestView` to find some good viewing dates for Mercury.

■ The inner planet Mercury is visible in the evening sky around 1993 October 14 and in the morning sky around 1993 November 23.

```
In[22]:= BestView[Mercury, {1993,11,17}]

Out[22]= {EveningApparition → {1993, 10, 14}, MorningApparition → {1993, 11, 23}}
```

Mercury is a particularly difficult planet to see because it is rarely in a good viewing position. `BestView` gives you the optimal dates to view it.

When an inner planet is at its greatest elongation east of the Sun as viewed from Earth, it is at its highest point in the evening sky just after dusk; at this time the planet is said to be making an evening apparition. The planet is also furthest from the glare of the Sun, so the time of an evening apparition is the best time for viewing the planet. Before an evening apparition, the planet is visible in the evening sky, whereas after the evening apparition, it quickly moves toward the Sun to reappear later in the morning sky.

Once you have determined an evening apparition date for Mercury, try searching the western sky just after dusk. The best evening apparitions are in spring. You should start searching for Mercury about 40 minutes after sunset, and you can give up by about 70 minutes after sunset. Similarly, once you have determined a morning apparition date for Mercury, try searching the eastern sky just before dawn.

Viewing Asteroids

Only one asteroid is visible with the naked eye, and it can only be seen during opposition when it is at its closest and brightest. `BestView` allows you to find the date.

■ This shows that Vesta reaches opposition on 1993 August 28.

```
In[23]:= BestView[Vesta, {1993,11,17}]

Out[23]= {Opposition → {1993, 8, 28}}
```

■ A call to `Ephemeris` on the opposition date determines the circumstances of the event. You can see that Vesta is 180 degrees from the Sun, and so it is indeed in opposition. Its apparent magnitude is 5.6, which is just visible to the naked eye under reasonable conditions.

```
In[24]:= Ephemeris[Vesta, Opposition /. %]

         Vesta
         ------------------------------------------
         Date Time:   1993-Aug-28 00:00:00 (GMT+11)
         Geo-place:     145°00'E,  37°48'S (Earth.)
         ------- For Date, Geo-place: -------------
         Rising:         18:37  (Sunrise:    07:53)
         Setting:        08:43  (Sunset:     18:50)
         ------- For Date Time, Geo-place: --------
         Azimuth:        55°43' (NorthEast compass)
         Altitude:       61°04' (Above the horizon)
         ------- For Date Time: -------------------
         Elongation:   -179°07' (Morning sky. 100%)
         Distance:      1.31 AU (Magnitude:   +5.6)
         ------- For Date Time: -------------------
         Ascension:    22h43.0m (Aquarius     341°)
         Declination:   -18°43' (Ecliptic -  9°48')
         ------------------------------------------

Out[24]= -EphemerisData-
```

Viewing Stars and Satellites

BestView can also be applied to stars, in which case it returns a transit date that is the precise time at which the star crosses the local meridian line.

■ BestView shows that the star Sirius crosses the local meridian at 04:22.

```
In[25]:= BestView[Sirius, {1993,11,17}]

Out[25]= {Transit → {1993, 11, 17, 4, 22, 26}}
```

The local meridian is the great circle that starts at the point on the horizon directly south of your location, and passes up through the zenith and then down to the point on the horizon directly north of your location. It also continues down to the nadir point directly below you, but that half of the meridian is not visible. The north and south celestial poles are fixed points on your local meridian, although one of the celestial poles is not visible below the horizon.

All stars cross your local meridian twice every day, once at a maximum angle above the horizon, and once at a minimum angle, usually below the horizon. The transit date is the time of the maximum crossing and is, therefore, a good time to view an object.

Another particularly useful application of BestView allows you to determine when a low-orbit satellite is visible. In this case a transit visible event date is returned.

When a low-orbit Earth satellite is crossing the local meridian line and is illuminated by the Sun but the viewer location is still in darkness, the satellite is said to be transit visible. This is a fairly rare event, as most satellites are only a few hundred kilometers above the Earth's surface, and hence normally eclipsed by the Sun when the Earth's surface is in darkness. However, there is a very small window, approximately five minutes wide, when the satellite becomes transit visible.

More details on transit visible event dates are given in Section 7.2.

The InterestingObjects Function

InterestingObjects is a function related to BestView. The BestView function determines a time when an object is in a good viewing circumstance; InterestingObjects takes the inverse approach and returns all interesting objects that are visible at a specified time.

InterestingObjects[*date*]	list all the interesting objects, such as galaxies, nebulae, clusters, as well as planets, constellations, and bright stars, that are above the local horizon
Altitude -> *altitude*	minimum *altitude* to begin the search; default is 15 Degree

Finding interesting objects above the horizon.

By default, only objects more than 15 degrees above the local horizon are returned. The `Altitude` option lets you set the lowest altitude above the local horizon to begin the search.

`InterestingObjects` searches for all planets as far out as Uranus, plus a few asteroids, several dominant constellations, and many bright stars. It also searches through a long list of bright clusters, nebulae, and galaxies. In each case it returns the brightest objects in each category and sorts them according to apparent magnitude.

- Here is a list of the dominant objects above the horizon for Melbourne at 22:00 on 1995 December 1.

```
In[26]:= Print /@ InterestingObjects[{1995,12,1,22,0,0}];

Planets → {Moon, Saturn, Uranus}

Constellations → {Orion, CanisMajor, Pegasus, Carina}

Stars :→ {Sirius, Canopus, Rigel, Achernar, Aldebaran, Fomalhaut, Adhara}

Galaxies → {LargeMagellanicCloudGalaxy, SmallMagellanicCloudGalaxy,
  TriangulumGalaxy, SilverCoinGalaxy, CigarGalaxy, NGC300Galaxy}

Nebulae → {TarantulaNebula, OrionNebula, HelixNebula, CometNebula, SaturnNebula}

Clusters → {HyadesCluster, PleiadesCluster, ThetaCarinaeCluster, OmicronVelorumCluster,
  NGC2451Cluster, NGC2516Cluster, Tucanae47Cluster, TauCanisMajorisCluster,
  NGC3114Cluster, M41Cluster, TurquoiseOrbCluster}
```

- This searches for all the interesting objects more than 30 degrees above the local horizon. It shows that the Moon and Saturn are above the local horizon. It also shows that there are no dominant constellations at this time, although from the earlier output you can conclude that Orion, Canis Major, and Pegasus are low on the horizon. The brightest stars are Canopus, Achernar, and Fomalhaut.

```
In[27]:= Print /@ InterestingObjects[{1995,12,1,22,0,0},
                                      Altitude -> 30*Degree];

Planets → {Moon, Saturn}

Constellations → {}

Stars :→ {Canopus, Achernar, Fomalhaut}

Galaxies → {LargeMagellanicCloudGalaxy, SmallMagellanicCloudGalaxy,
  SilverCoinGalaxy, CigarGalaxy, NGC300Galaxy}

Nebulae → {TarantulaNebula, HelixNebula, CometNebula}

Clusters → {Tucanae47Cluster, TurquoiseOrbCluster}
```

Some interesting open clusters that are built into *Scientific Astronomer* include `ThetaCarinaeCluster`, a 2nd magnitude cluster easily visible to the naked eye; `PtolemysCluster`, a large 3rd magnitude cluster in Scorpius separated by only 4 degrees from the 4th magnitude `ButterflyCluster`; `JewelBoxCluster`, a very colorful 4th magnitude cluster inside the Southern Cross; and

`WildDuckCluster`, one of the best open clusters, visible in binoculars as a 6th magnitude fuzzy patch in Scutum.

Two of the many globular clusters built into *Scientific Astronomer* are `OmegaCentauriCluster`, easily the finest globular cluster and visible to the naked eye at 4th magnitude; and `HerculesCluster`, the brightest globular cluster visible from the northern hemisphere, at 6th magnitude.

Some notable diffuse nebulae built into *Scientific Astronomer* include `OrionNebula`, a naked-eye emission nebula of 4th magnitude, greenish swirls visible in binoculars; `EtaCarinaeNebula`, a 6th magnitude emission nebula and the largest diffuse nebula in the sky; and `OmegaNebula`, a 6th magnitude red emission nebula in Sagittarius.

Notable planetary nebulae built into *Scientific Astronomer* include `HelixNebula`, the brightest planetary nebula at 6th magnitude in Aquarius; `DumbbellNebula`, a large 7th magnitude planetary nebulae in Vulpecula, 0.25 degrees in diameter and green in color; `CatseyeNebula`, an 8th magnitude green and red planetary in Draco, looks like a cat's eye; and `RingNebula`, a 9th magnitude planetary in Lyra, separated by 7 degrees from the star Vega.

Many bright galaxies are also built into *Scientific Astronomer*. The list includes the 3rd magnitude `AndromedaGalaxy` and the 7th magnitude `CentaurusGalaxy`. At 2.2 million light years the Andromeda Galaxy is the furthest object visible to the naked eye.

The lists `BrightClusters`, `BrightNebulae`, and `BrightGalaxies` contain many of these predefined deep sky objects that are built into *Scientific Astronomer*.

- `BrightClusters` gives a list of all the bright clusters, both open and globular, used by `InterestingObjects`. The list is sorted by apparent magnitude.

```
In[28]:= BrightClusters

Out[28]= {HyadesCluster, PleiadesCluster,
          ThetaCarinaeCluster, OmicronVelorumCluster,
          NGC6231Cluster, NGC2451Cluster, NGC3532Cluster, BeehiveCluster,
          PtolemysCluster, OmegaCentauriCluster, NGC2516Cluster,
          ChristmasTreeCluster, Tucanae47Cluster, TauCanisMajorisCluster,
          NGC3114Cluster, JewelBoxCluster, ButterflyCluster, IC4665Cluster,
          DoubleCluster, IC2581Cluster, NGC884Cluster, M47Cluster,
          M41Cluster, LambdaCentauriCluster, M39Cluster, NGC2244Cluster,
          M22Cluster, TurquoiseOrbCluster, WildDuckCluster, HerculesCluster}
```

■ `BrightNebulae` lists all the bright nebulae, both diffuse and planetary.

```
In[29]:= BrightNebulae

Out[29]= {CoalSackNebula, TarantulaNebula,
          OrionNebula, LagoonNebula, RosetteNebula, FlamingStarNebula,
          EtaCarinaeNebula, NorthAmericaNebula, EagleNebula, OmegaNebula,
          TrifidNebula, HelixNebula, KeyholeNebula, CometNebula,
          DumbbellNebula, EightBurstNebula, CatseyeNebula, SaturnNebula,
          CrabNebula, UranusNebula, EskimoNebula, GhostOfJupiterNebula,
          BlinkingNebula, RingNebula}
```

■ `BrightGalaxies` lists all the bright galaxies.

```
In[30]:= BrightGalaxies

Out[30]= {LargeMagellanicCloudGalaxy, SmallMagellanicCloudGalaxy,
          AndromedaGalaxy, TriangulumGalaxy, CentaurusGalaxy,
          SilverCoinGalaxy, BodesGalaxy, M110Galaxy, CigarGalaxy,
          M32Galaxy, SombreroGalaxy, WhirlpoolGalaxy, BlackeyeGalaxy,
          SouthernPinwheelGalaxy, VirgoGalaxy, NGC300Galaxy, M94Galaxy,
          PinwheelGalaxy}
```

3. Coordinate Functions

A system of coordinates is needed to represent the position of any object in space. This chapter discusses the systems that are built into *Scientific Astronomer*.

Coordinate Systems

The Earth's equatorial plane, when extended out into the sky, forms a great circle known as the celestial equator. The Sun moves along another great circle known as the ecliptic, which, due to the tilt of the Earth's axis, is inclined to the celestial equator by an angle of about 23.5 degrees. These two great circles intersect at two points known as equinoxes. One is called the vernal equinox and is the position of the Sun at about March 21 of each year. The other is the autumnal equinox.

You can use the celestial equator and the vernal equinox to define a coordinate system known as celestial coordinates, or equator coordinates. The equator coordinates system specifies the position of an object by its right ascension and declination. Right ascension measures the angle, in hours of time, from the vernal equinox along the celestial equator; declination measures the angle north of the celestial equator. Stars have fixed equator coordinates, unlike the planets, which continually wander through the celestial sphere, although always staying near the ecliptic. Sirius, the brightest star, has a fixed right ascension of 6h45m and a declination of -16°43'. The `EquatorCoordinates` function finds the equator coordinates of an object (such as a planet, the Moon, the Sun, or a star) on a given date.

Equator coordinates are useful in conjunction with star charts. There is, however, another more natural coordinate system that is useful out in the field and is based on the horizon. It is known as alt-azi coordinates, or more commonly as horizon coordinates.

Horizon coordinates specifies the position of an object by its azimuth and altitude. Azimuth measures the compass angle around the local horizon with 0 degrees being north and 90 degrees being east, and altitude measures the angle above the local horizon with +90 degrees being overhead and -90 degrees being an unviewable point directly below the observer. Apart from geo-stationary satellites, no object normally has fixed horizon coordinates because the local horizon constantly changes throughout the night. The `HorizonCoordinates` function finds the horizon coordinates of an object on a given date.

Yet another coordinate system is known as ecliptic coordinates. This system specifies the position of an object by its ecliptic longitude and latitude. Ecliptic longitude measures the angle around the plane of the Earth's orbit, with 0 degrees being the so-called first point in Aries. Ecliptic latitude measures the angle above the plane of the ecliptic. The `EclipticCoordinates` function finds the ecliptic coordinates of an object on a given date.

Complications

The Earth's axis gyrates around the pole of the ecliptic in a period of about 25,800 years. This effect, known as precession, can shift the celestial coordinates of objects by a few minutes of arc over several years. Stars, therefore, are not completely fixed on the celestial sphere, and the published celestial coordinates assigned to each star are valid only for a specified epoch, usually taken as 1950 January 1 or 2000 January 1. Most functions in *Scientific Astronomer* accept the option `Epoch` to let you choose something other than the current epoch.

Setting Your Site Location

As normal, before you use *Scientific Astronomer*, you must load the package and set your time zone and location on Earth.

■ Load the package.

```
In[1]:= <<Astronomer`HomeSite`

        Astronomer is Copyright (c) 1997 Stellar Software
```

■ This sets your location to Melbourne, Australia.

```
In[2]:= SetLocation[GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    GeoAltitude  ->   0.0*KiloMeter,
                    TimeZone     ->  11];
```

■ 3.1 The EquatorCoordinates Function

Equator coordinates are useful in conjunction with star charts.

`EquatorCoordinates[`*object*`,` *date*`]`	compute the right ascension, declination, and distance of the *object* on the given *date*
`EquatorCoordinates[`*object*`]`	compute the equator coordinates using the current value of `Date[]`
`EquatorCoordinates[`*horizoncoords*`,` *date*`]`	convert the *horizoncoords* for the current location and *date* into equator coordinates

Calculating an object's position in equator coordinates.

`EquatorCoordinates` is typically applied to solar system objects such as `Mars`, `Moon`, and `Io`; stars such as `Sirius` and `Alpha.Centaurus`; constellations such as `Leo` and `UrsaMajor`; special objects such as `SouthCelestialPole` and `Zenith`; and so on.

■ Here you see that Mars is 21.6 degrees below the celestial equator, with a right ascension of 16.2 hours.

```
In[3]:= EquatorCoordinates[Mars, {1993,11,17,3,20,0}]

Out[3]= {Ascension → 16.2237 Hour, Declination → -21.6327 Degree,
         Distance → 2.45249 AU}
```

In the `EquatorCoordinates` output, the first rule is used to represent the right ascension of the object, which is the angle (in hours) around the celestial equator. The second rule is used to represent the declination, which is the angle above the celestial equator. An `AU` is the standard astronomical unit, which equals about 149,597,900km and is the mean distance between the Earth and the Sun. `Hour` is used to denote the unit of right ascension, and equals exactly 15 degrees of angle.

Distance is typically given in astronomical units, as this is a sensible unit for measurement within the solar system. However, units of kilometers are used when a distance is less than 0.01 AU, and light years are used when a distance is greater than 1,000 AU. One light year equals about 63,240 AU.

■ The Sun is 0.988773 AU distant from the Earth on the given date.

```
In[4]:= EquatorCoordinates[Sun, {1993,11,17,3,20,0}]

Out[4]= {Ascension → 15.4637 Hour, Declination → -18.8526 Degree,
         Distance → 0.988773 AU}
```

■ The distance to the Moon is 373,502 kilometers (or 0.00253 AU) on the given date.

```
In[5]:= EquatorCoordinates[Moon, {1993,11,17,3,20,0}]

Out[5]= {Ascension → 18.1145 Hour, Declination → -20.9029 Degree,
         Distance → 373502. KiloMeter}
```

■ The ascension, declination, and distance of the Moon is now slightly different than in the previous call.

```
In[6]:= EquatorCoordinates[Moon, {1993,11,17,3,20,0},
                            ViewPoint -> TopoCentric]

Out[6]= {Ascension → 18.1089 Hour, Declination → -20.0767 Degree,
         Distance → 376825. KiloMeter}
```

You can use the option setting `ViewPoint ->` *object* to specify any viewpoint. The default is the center of the Earth (*i.e.*, `Earth`), but you can specify any other object. For instance, `TopoCentric` is used to specify the point on the surface of the Earth where you previously set your location.

With a TopoCentric viewpoint, the position of the Moon will appear slightly displaced relative to the position obtained using the default Earth viewpoint. For most objects, which are much further away than the Moon, it does not matter if you use TopoCentric or Earth as the viewpoint.

You can also find the equator coordinates of a star. The syntax for specifying a star name is the dot notation *star*.*constellation*, although the brightest 25 stars have been given aliases, so, for example, you can use Sirius, Canopus, and Polaris as star names.

Stars have fixed equator coordinates–that is, they do not change with time. (Actually they do change a little due to the precession of the Earth's axis, but the effect is very small. Use the option Epoch to see the effect.)

■ Here are the fixed equator coordinates of the star α (alpha) Centauri.

```
In[7]:= EquatorCoordinates[Alpha.Centaurus, {1993,11,17,3,20,0}]

Out[7]= {Ascension → 14.6522 Hour, Declination → -60.8038 Degree,
         Distance → 4.3 LightYear}
```

■ This gives the equator coordinates of the point currently 30 degrees above the horizon and 60 degrees east of north on the given date.

```
In[8]:= EquatorCoordinates[{Azimuth  -> 60*Degree,
                            Altitude -> 30*Degree},
                           {1993,11,17,3,20,0}]

Out[8]= {Ascension → 8.95884 Hour, Declination → 2.04553 Degree}
```

Allowing for Precession

The option Epoch is available in many functions, including EquatorCoordinates. The default setting is Epoch -> Automatic, which specifies the current epoch for the plane of the Earth's equator. However, you can use, say, Epoch -> 2000.0 to have ascension and declination returned relative to the equator at epoch year 2000.

EquatorCoordinates[*object*, *date*, Epoch -> *epoch*]	compute the equator coordinates relative to a given *epoch* year

Allowing for the effect of precession.

Precession causes the plane of the equator to rotate about 50 arc-seconds per year, and this precession makes an epoch specification necessary.

■ Use `Epoch` to find the epoch 2000.0 coordinates of the star α (alpha) Centauri.

```
In[9]:= EquatorCoordinates[Alpha.Centaurus, Epoch->2000.0]

Out[9]= {Ascension → 14.66 Hour, Declination → -60.83 Degree,
         Distance → 4.3 LightYear}
```

■ The numbers are very slightly different for the epoch 1950.0 coordinates.

```
In[10]:= EquatorCoordinates[Alpha.Centaurus, Epoch->1950.0]

Out[10]= {Ascension → 14.5963 Hour, Declination → -60.6149 Degree,
          Distance → 4.3 LightYear}
```

The EclipticCoordinates Function

Equator coordinates measure the position of an object relative to the plane passing through the Earth's equator. Ecliptic coordinates, in contrast, measure the position relative to the plane of the Earth's orbit. The two planes are tilted by just 23.5 degrees, and so the coordinate systems are closely related.

`EclipticCoordinates[`*object*`,` *date*`]`	return the ecliptic longitude, ecliptic latitude, and distance of the *object* on the given *date*
`ViewPoint -> Sun`	coordinates relative to the Sun; default is `Earth`

Calculating an objects position in ecliptic coordinates.

In the `EclipticCoordinates` output, the first rule is used to represent the value of the ecliptic longitude of an object. The value will be very close to the right ascension of the object. Similarly, the second rule is used to represent the value of the ecliptic latitude. The value will be close (within 23.5 degrees) to the declination of the object.

■ By definition the ecliptic latitude of the Sun is zero.

```
In[11]:= EclipticCoordinates[Sun, {1993,11,17,3,20,0}]

Out[11]= {EclipticLongitude → 234.324 Degree, EclipticLatitude → 0. Degree,
          Distance → 0.988773 AU}
```

■ On the same date, Mars is just 0.44 degrees below the ecliptic line. It has an ecliptic longitude of 245 degrees.

```
In[12]:= EclipticCoordinates[Mars, {1993,11,17,3,20,0}]

Out[12]= {EclipticLongitude → 245.362 Degree,
          EclipticLatitude → -0.442809 Degree, Distance → 2.45249 AU}
```

■ 3.2 The HorizonCoordinates Function

Horizon coordinates are useful when you are out in the field. The `HorizonCoordinates` function computes the position of an object relative to the local horizon. The output, therefore, depends on your geographic location on Earth.

`HorizonCoordinates[`*object*`,` *date*`]`	compute the azimuth, altitude, and distance of the *object* on the given *date*
`HorizonCoordinates[`*object*`]`	compute the horizon coordinates using the current value of `Date[]`
`HorizonCoordinates[`*equatorcoords*`,` *date*`]`	convert the *equatorcoords* into horizon coordinates for the current location and *date*

Calculating an object's position in horizon coordinates.

- Mars, on the given date and time, is 26.9 degrees below the horizon and 156 degrees east of north, which is approximately south-southeast.

```
In[13]:= HorizonCoordinates[Mars, {1993,11,17,3,20,0}]

Out[13]= {Azimuth → 156.591 Degree, Altitude → -26.9461 Degree,
          Distance → 2.45249 AU}
```

In the `HorizonCoordinates` output, the first rule is used to represent the compass angle around the horizon, and the second rule is used to represent the angle above the horizon. A negative altitude means the object is currently below the local horizon. Azimuth is defined so that 0 degrees is the direction north and 90 degrees is the direction east.

`HorizonCoordinates` can be applied to stars and other objects as normal.

- Discover the current horizon coordinates of the star α (alpha) Centauri using `HorizonCoordinates`.

```
In[14]:= HorizonCoordinates[Alpha.Centaurus,
                             {1993,11,17,3,20,0}]

Out[14]= {Azimuth → 158.658 Degree, Altitude → 15.4941 Degree,
          Distance → 4.3 LightYear}
```

■ This gives the current azimuth and altitude of the fixed point on the celestial sphere with an ascension of 6 hours and a declination of 30 degrees.

```
In[15]:= HorizonCoordinates[{Ascension   ->  6*Hour,
                             Declination -> 30*Degree},
                            {1993,11,17,3,20,0}]

Out[15]= {Azimuth → 3.97086 Degree, Altitude → 22.0836 Degree}
```

The Refract Function

A function related to HorizonCoordinates is Refract. Refract adds an atmospheric refraction correction to horizon coordinates. Atmospheric refraction can amount to about 0.5 degrees for an object close to the horizon, but requires a very minor correction for objects well above the horizon.

Refract[*horizoncoords*]	convert the true *horizoncoords* into apparent horizon coordinates by adding an atmospheric refraction correction

Allowing for the effect of atmospheric refraction.

SunRise and SunSet correctly take into account atmospheric refraction. However, this means that the true horizon coordinates of the Sun place it approximately half a degree below the horizon at sunrise or sunset. To correct this for refraction, you can apply Refract.

Refraction has its strongest effect on horizon coordinates with an altitude near zero, in which case it adds about half a degree to that altitude. When horizon coordinates reach about 15 degrees of altitude, refraction has very little effect.

■ The true position of the Sun is 0.55 degrees below the horizon at sunset.

```
In[16]:= HorizonCoordinates[Sun, SunSet[],
                            ViewPoint -> TopoCentric]

Out[16]= {Azimuth → 253.988 Degree, Altitude → -0.549684 Degree,
          Distance → 0.994219 AU}
```

■ The atmospherically refracted position of the Sun at sunset lies almost exactly on the horizon, with an altitude of just -0.002 degrees, which is where it should be at that time.

```
In[17]:= HorizonCoordinates[Sun, SunSet[],
                            ViewPoint -> TopoCentric]//Refract

Out[17]= {Azimuth → 253.988 Degree, Altitude → -0.00224249 Degree,
          Distance → 0.994219 AU}
```

■ 3.3 The Coordinates Function

`Coordinates` is useful for producing various three-dimensional plots.

`Coordinates[`*object*`, `*date*`]`	return the *x*, *y*, *z* coordinates (in astronomical units) of the *object* on the given *date*
`ViewPoint -> `*planet*	coordinates relative to the given *planet*

Calculating an object's position in *x*,*y*,*z* coordinates.

The three-dimensional coordinate system used by `Coordinates` is aligned so that the *z* coordinate is perpendicular to the plane of the Earth's orbit about the Sun, and the *x* coordinate points in the direction of the 0h line of right ascension. For historical reasons, the 0h line is called the first point of Aries, even though the point is currently in the direction of Pisces. Several thousand years ago the 0h line of right ascension was in Aries, but precession has been slowly moving it, so that now it lies in Pisces and is moving into Aquarius.

Output position is given in astronomical units.

■ The `Coordinates` function gives you the *x*,*y*,*z* coordinates of Mars on the given date.

```
In[18]:= Coordinates[Mars, {1993,11,17,3,20,0}]

Out[18]= {-1.02237, -2.22915, -0.0189538}
```

■ Here `Coordinates` gives the *x*,*y*,*z* coordinates of the Moon.

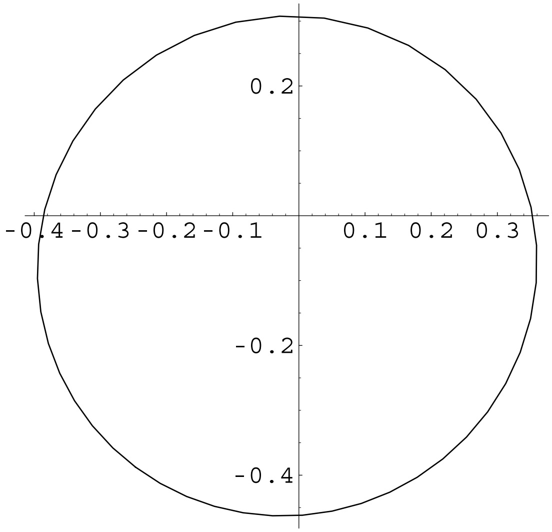
```
In[19]:= Coordinates[Moon, {1993,11,17,3,20,0}]

Out[19]= {0.0000699065, -0.0024933, 0.000110107}
```

A default viewpoint of Earth is used here, but any viewpoint is allowed.

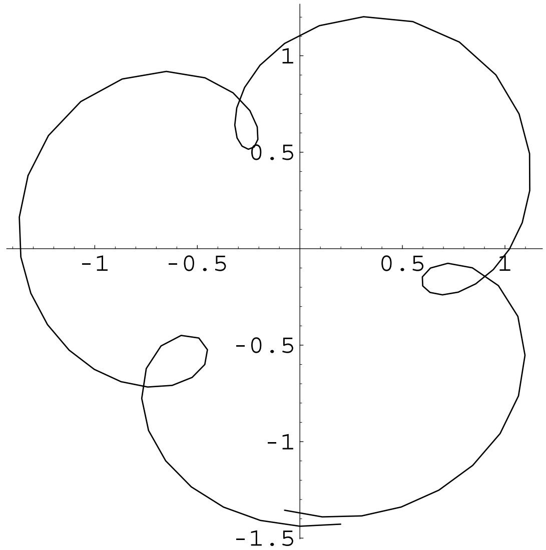
■ This plots the orbit of Mercury as viewed from the Sun. You can see the expected elliptical orbit with the Sun centered at one focal point. Observe the somewhat eccentric shape of the ellipse.

```
In[20]:= ListPlot[
         Table[Take[Coordinates[Mercury, {1993,1,d},
                                 ViewPoint -> Sun], 2],
               {d, 1, 89, 2}],
         PlotJoined  -> True, AspectRatio -> 1];
```



- Using Earth as the viewpoint, it becomes clear that Mercury makes roughly three close approaches to the Earth each year.

```
In[21]:= ListPlot[
           Table[Take[Coordinates[Mercury, {1993,1,d},
                                  ViewPoint -> Earth], 2],
                 {d, 1, 366, 5}],
           PlotJoined  -> True, AspectRatio -> 1];
```



■ 3.4 The JupiterCoordinates Function

`JupiterCoordinates` determines the precise positions of the main moons of Jupiter. It can also determine the positions of various cloud features on the surface of Jupiter, such as the Great Red Spot.

`JupiterCoordinates[`*moon*`,` *date*`]`	return the relative x, y, z coordinates (in Jovian radii) of a Galilean moon
`JupiterCoordinates[`*moon*`]`	return the relative x, y, z coordinates using the current value of `Date[]`

Calculating position in Jovian coordinates.

The first coordinate returned by `JupiterCoordinates` indicates the number of Jovian radii east (in the right ascension direction) of Jupiter. The second coordinate is the number of Jovian radii north (in the declination direction) of Jupiter. The third coordinate is the object's distance from Jupiter in Jovian radii in the direction away from Earth.

You can apply `JupiterCoordinates` to the four Galilean moons Io, Europa, Ganymede, and Callisto. You can also apply the function to the Great Red Spot `JupiterGreatRedSpot`.

■ Find the Jupiter coordinates of the moon Io on the given date.

```
In[22]:= JupiterCoordinates[Io, {1993,11,17,3,20,0}]

Out[22]= {3.0396, -0.247141, 5.03695}
```

■ `JupiterGreatRedSpot` gives the Jupiter coordinates of the Great Red Spot on the same date.

```
In[23]:= JupiterCoordinates[JupiterGreatRedSpot,
                            {1993,11,17,3,20,0}]

Out[23]= {0.0332883, -0.358368, 0.932987}
```

Remember that the position of the Great Red Spot is somewhat unpredictable. However, once its position, or Jovian longitude, is known on a particular date, it moves slowly relative to that position over time.

`$JupiterGreatRedSpotLongitude`	global variable that can be set to the current Jovian longitude of the Great Red Spot; default is `-40 Degree`

Specifying the position of the Great Red Spot.

The Great Red Spot stays roughly fixed in the System II coordinate system of Jupiter, but over the years it slowly drifts. Apart from that drift, the spot moves around Jupiter about once every 9 hours 55 minutes. Some values for `$JupiterGreatRedSpotLongitude` are -45° (June 1990), -33° (June 1992), -40° (June 1994), -41° (July 1994), -42° (July 1995), -49° (November 1995), -51° (September 1996), and -61° (November 1996). The default is -40°. You can sometimes obtain current values by consulting the magazine *Sky & Telescope*, published by Sky Publishing Corporation, Belmont, MA. Note that they use the opposite direction than the one used here for the definition of positive Jovian longitude–that is, west is positive, rather than east–so you must remember to use the negative of these Jovian longitudes in *Scientific Astronomer*.

Jupiter Coordinates

The central meridian of Jupiter is the semicircular line passing through the poles of Jupiter and the center of the disk as seen from Earth. Features on Jupiter rotate with respect to the central meridian roughly every 10 hours. The rotation rate is, however, latitude dependent, but it neatly splits into two systems. System I is the equatorial belt with latitudes between +10 and -10 degrees. This system makes a full rotation in a period of about 9 hours 50 minutes 30 seconds, although System I is actually defined so that the mean motion is exactly 877.90 degrees per day. System II consists of all latitudes outside System I. All features in this region complete a full rotation in a period of about 9 hours 55 minutes 40 seconds, although System II is defined so that the mean motion is exactly 870.27 degrees per day. The Great Red Spot is near the top of the southern portion of System II.

4. Star Charting Functions

Four main types of star charts are implemented in *Scientific Astronomer*. They are created by the functions `RadialStarChart`, `ZenithStarChart`, `CompassStarChart`, and `StarChart`. A fifth star charting function is `Planisphere`.

Why Four Star Charts?

Each star charting function has its own advantages and disadvantages. For instance, `StarChart` works quickly because it simply draws a direct map of the ascension and declination coordinates of each star. However, this function is really only suitable for charting close to the celestial equator, as there is considerable distortion near the celestial poles. To overcome this problem, `RadialStarChart` can be used.

`RadialStarChart` can plot any part of the sky with little or no distortion in the center of the chart. Some distortion may occur on the edges if the field of view is large. This function is slower than `StarChart` because it has to transform the raw star positions as a function of the field of view. One feature of both `StarChart` and `RadialStarChart` is that they can zoom into small regions. They are not good at encompassing large fields of view; the two global star chart functions are more useful in this case.

`ZenithStarChart` and `CompassStarChart` can plot only large global sections of the sky. They do this in such a way as to minimize distortion as much as possible. With `ZenithStarChart`, the full sky above the local horizon and up to the zenith point is displayed. There is little or no distortion in the center, which is the zenith point, but around the edges and along the horizon there is some stretching. `CompassStarChart` takes the opposite tack and has no distortion along the horizon, but in order to do this it can display only one half of the sky above the horizon.

Setting Your Site Location

■ Load the package.

```
In[1]:= <<Astronomer`HomeSite`

        Astronomer is Copyright (c) 1997 Stellar Software
```

■ This sets your location to Melbourne, Australia.

```
In[2]:= SetLocation[GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    GeoAltitude  ->   0.0*KiloMeter,
                    TimeZone     ->  11];
```

Stars and Constellations

In `EquatorCoordinates`, `HorizonCoordinates`, and many other functions, you can specify a star as well as a planet, asteriod, or any other celestial object. Stars are specified using a dot notation to separate star label and constellation name, that is, *star*`.`*constellation*. The sky is arbitrarily divided up into a standard set of 88 constellations.

■ Here is a list of the 88 constellations.

```
In[3]:= ?Constellation`*

Andromeda          Cygnus           Orion
Antlia             Delphinus        Pavo
Apus               Dorado           Pegasus
Aquarius           Draco            Perseus
Aquila             Equuleus         Phoenix
Ara                Eridanus         Pictor
Aries              Fornax           Pisces
Auriga             Gemini           PiscisAustrinus
Bootes             Grus             Puppis
Caelum             Hercules         Pyxis
Camelopardalis     Horologium       Reticulum
Cancer             Hydra            Sagitta
CanesVenatici      Hydrus           Sagittarius
CanisMajor         Indus            Scorpius
CanisMinor         Lacerta          Sculptor
Capricornus        Leo              Scutum
Carina             LeoMinor         Serpens
Cassiopeia         Lepus            Sextans
Centaurus          Libra            Taurus
Cepheus            Lupus            Telescopium
Cetus              Lynx             Triangulum
Chamaeleon         Lyra             TriangulumAustrale
Circinus           Mensa            Tucana
Columba            Microscopium     UrsaMajor
ComaBerenices      Monoceros        UrsaMinor
CoronaAustralis    Musca            Vela
CoronaBorealis     Norma            Virgo
Corvus             Octans           Volans
Crater             Ophiuchus        Vulpecula
Crux
```

Prior to 1930, there was no agreement on constellation boundaries and names–different authors often used different systems. In 1930, astronomers decided to rationalize the system and have 88 constellations and give them all Latin names. This internationally recognized system is used by *Scientific Astronomer*. In this system the popularly known Scorpio is referred to as Scorpius. Similarly the Big Dipper is referred to as Ursa Major, which in Latin means Great Bear.

Within each constellation, individual stars are typically labeled with Greek letters. The letter α (alpha) is usually, but not always, the brightest star in a given constellation. The convention for the full name of a star is to use the Greek letter followed by the possessive form of the constellation name. In Latin, the possessive form of Centaurus is Centauri therefore the brightest star in the constellation of Centaurus is known as α (alpha) Centauri. In *Scientific Astronomer*, however, this star is referred to as

`Alpha.Centaurus`–that is, the nonpossessive form of the constellation name is used and a dot is used to separate star label and constellation name. Similarly, the brightest star in Ursa Major is α (alpha) Ursae Majoris, but in *Scientific Astronomer* it is referred to as `Alpha.UrsaMajor`.

Bright Star Names

The 25 brightest stars are also given special names in *Scientific Astronomer*. For instance, there is `Sirius`, which is the same as `Alpha.CanisMajor`; and also `Polaris`, which is the same as `Alpha.UrsaMinor`.

As normal, basic information about an object is obtained by using the `?` function.

- `BrightStar` is a *Mathematica* context that contains all the stars down to magnitude 1.5, but also includes `Polaris` at magnitude 2.02. Additionally, it includes the eclipsing variable star `Algol` and the wide double star `Mizar`.

```
In[4]:= ?BrightStar`*

    Achernar   Altair     Canopus    Mizar      Rigel
    Acrux      Antares    Capella    Polaris    RigilKent
    Adhara     Arcturus   Castor     Pollux     Sirius
    Agena      Becrux     Deneb      Procyon    Spica
    Aldebaran  Bellatrix  Fomalhaut  Regulus    Vega
    Algol      Betelgeuse Gacrux
```

- `Sirius` is an alias for `Alpha.CanisMajor` or α (alpha) Canis Majoris.

```
In[5]:= ?Sirius

    Sirius = Alpha.CanisMajor; Magnitude = -1.46
```

The SetStars Function

If you have your own list of stars, or you want to modify the current list of stars, you need to use `SetStars`.

`SetStars[`*starlist*`]`	set the list of stars to be used
`MagnitudeRange -> `*range*	a subset of the stars

Setting the stars to use in the package.

Each star in the star list should consist of a constellation name, star name, magnitude, ascension (in degrees, not hours), and declination (in degrees).

You rarely need to use this function, which simply sets a value for the list `TheStars`. Initially this list is set to the value of the list `Stars300`, but if you load ``<<Astronomer`Star3000`;`` then it is set to `Stars3000`. Similarly, it can be set to `Stars9000`. You can use the option `MagnitudeRange` to filter out a subset of the stars.

■ This loads 3,000 extra stars and automatically calls `SetStars` to make them available.

```
In[6]:= <<Astronomer`Star3000`
```

■ 4.1 The StarChart Function

`StarChart` is used to show a rectangular section of the sky. Several other types of star charts are available, but this one is the fastest. Like all the other star chart functions in *Scientific Astronomer*, `StarChart` accepts a large number of options for producing a wide variety of output styles.

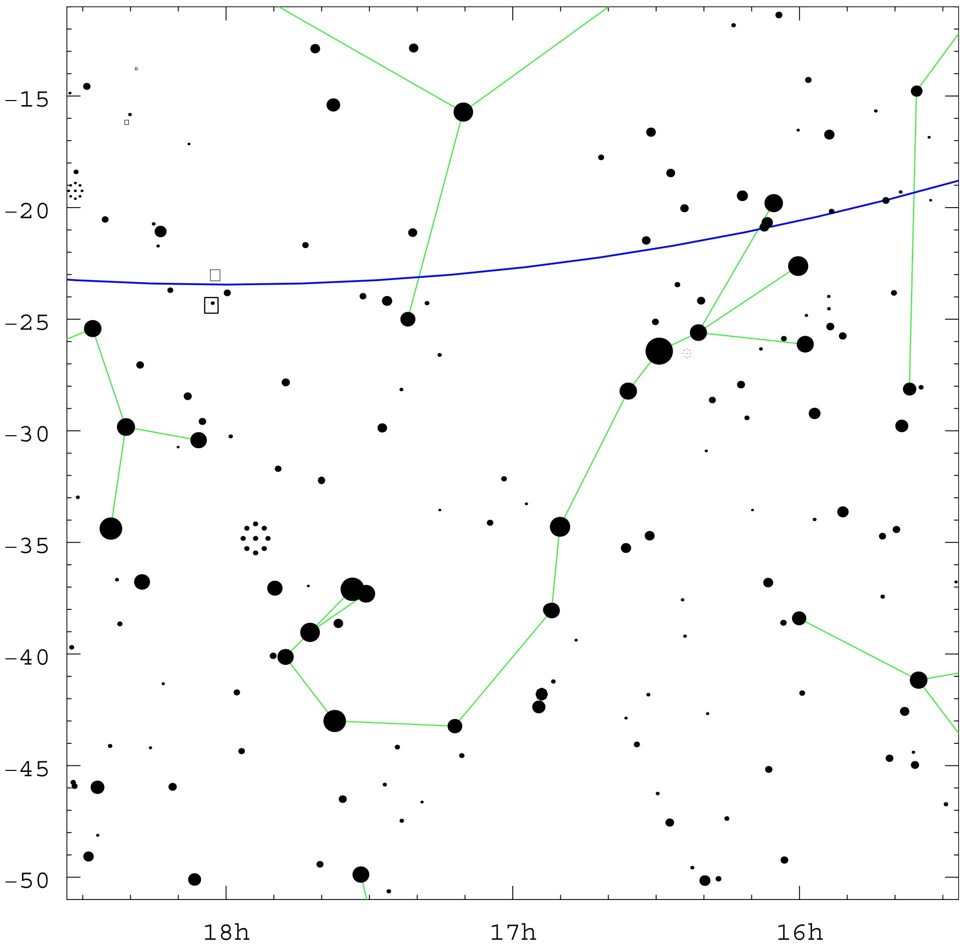
`StarChart[`*object*`]`	plot a rectangular region of the sky centered on the *object*; this can be one of the 88 constellations or any other object, such as a star
`StarChart[{{`*asc1*`, `*asc2*`}, {`*dec1*`, `*dec2*`}}]`	plot a rectangular region of the sky with right ascension between *asc1* and *asc2*, and declination between *dec1* and *dec2*

Plotting stars in a rectangular region.

Like most other functions, `StarChart` is typically applied to solar system objects such as `Mars`, `Moon`, and `Io`; stars such as `Sirius` and `Alpha.Centaurus`; constellations such as `Leo` and `UrsaMajor`; special objects such as `SouthCelestialPole` and `Zenith`; and so on.

- The solid angle covered by this chart of the Scorpius constellation is about four times the area of your hand when held at arm's length. The vertical axis indicates declination and the horizontal axis shows right ascension.

```
In[7]:= StarChart[Scorpius];
```



In some of the star chart graphical output you may notice a blue line crossing the field of view. This represents the ecliptic, which is the precise line that the Sun moves along during the course of a year. The Moon and all the planets approximately move along this line, too, so the ecliptic is very important. All the 12 zodiac constellations are located near the ecliptic as well.

To switch off the line, you can use the `Ecliptic -> False` option. The default is `Ecliptic -> True`.

All the star charts use thin green lines to join together some of the brighter stars to form the constellations. By default, constellation outlines are drawn, but you can suppress them using the option setting `Constellations -> False`.

A feature of all the star charts is that you can, on appropriate front ends, hold down the CMD key, click inside a graphic, and copy the pair of numbers representing the point where you clicked. That pair of numbers can then be used in other functions as if they were an object.

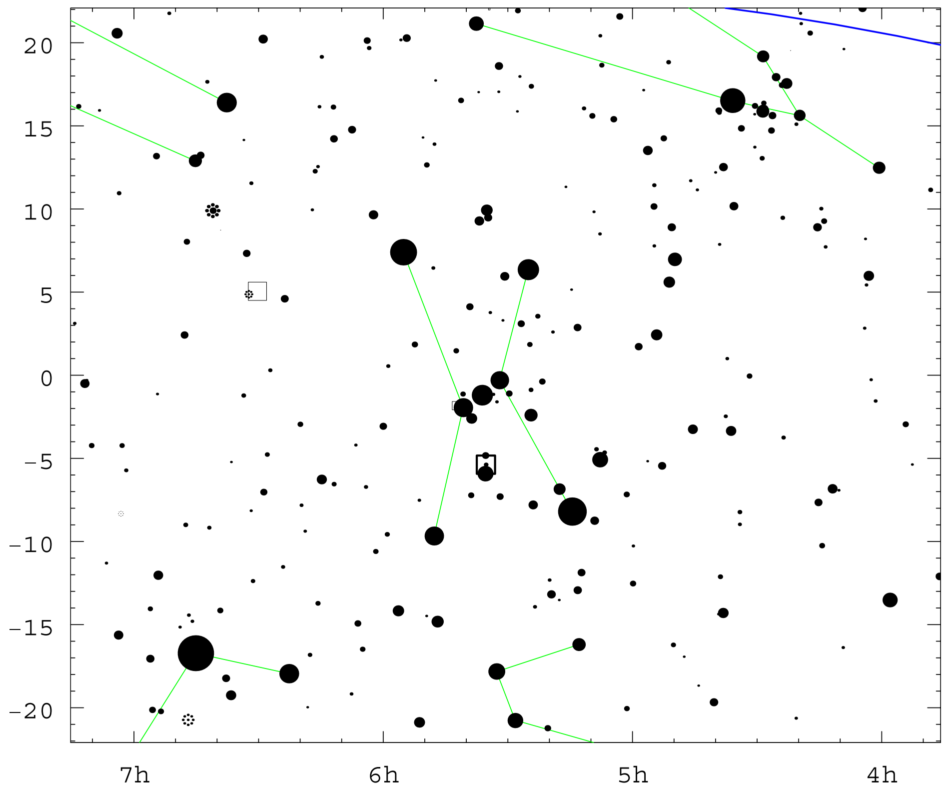
In the case of `StarChart` you can also hold down CMD-OPTION and select a rectangle, and then copy that pair of number pairs into another `StarChart` call. This allows you to interactively zoom into a smaller portion of the sky. (Note the CMD-OPTION feature may not be available on all front ends.)

Suppose, for example, that you generate a large section of the sky that contains the constellation of Orion. By using the CMD-OPTION-select-and-copy feature you can place a rectangle around Orion to get a bounding box that you can use as the argument in a subsequent `StarChart` call.

Bounding boxes are a pair of number pairs giving first the minimum and maximum x values, and then the minimum and maximum y values of the rectangle. An x range of `{-108.818, -56.455}` corresponds to a right ascension range of 7.25 hours (from +108.818/15) to 3.76 hours. Similarly, a y range of `{-22.091, 22.091}` corresponds to a declination range of -22.09 degrees to +22.09 degrees.

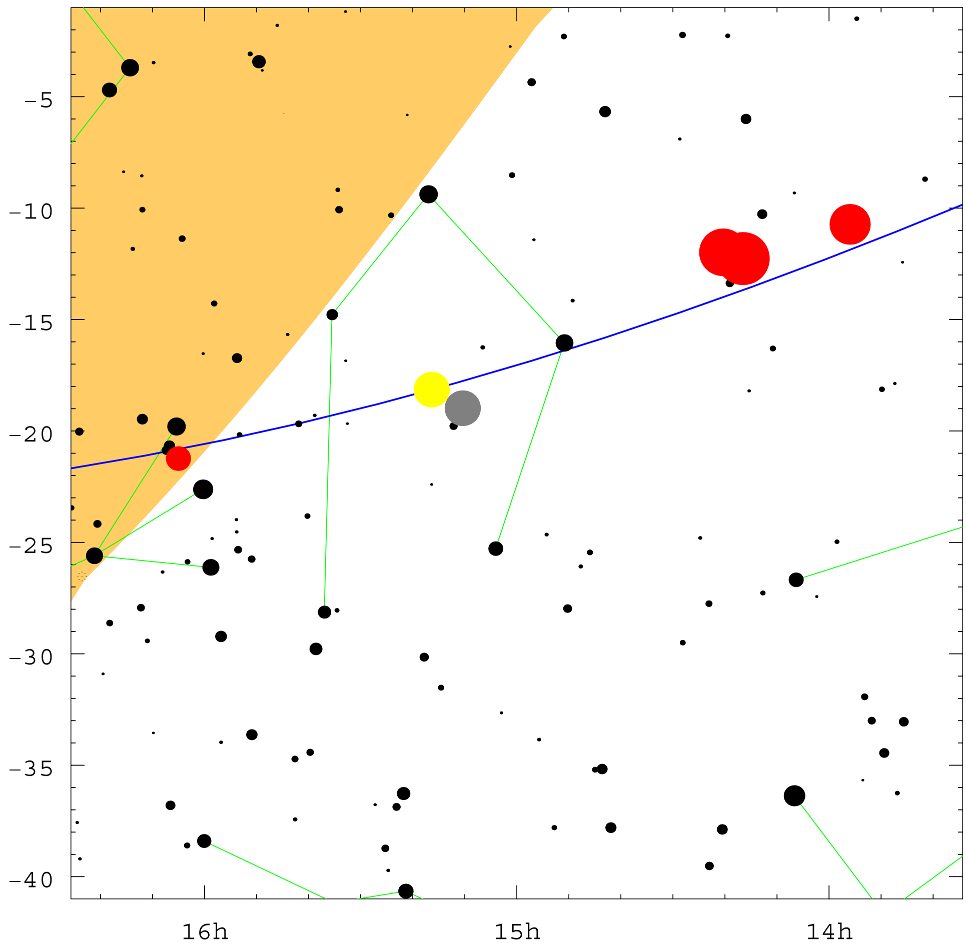
■ In a chart zoomed into a smaller part of the sky, the CMD-OPTION-select-and-copy feature is used in a previous `StarChart` graphic to get the bounding box that is used as the argument in this call.

```
In[8]:= StarChart[{{-108.818, -56.455}, {-22.091, 22.091}}];
```



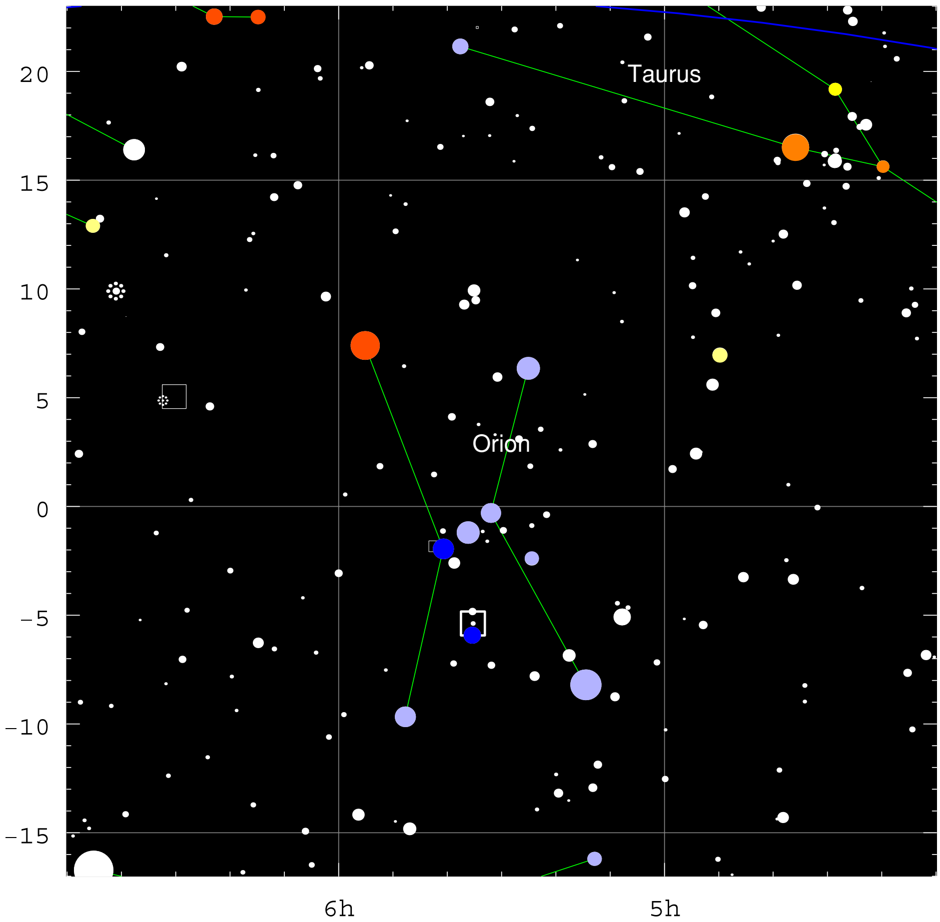
■ A chart of the daytime sky near the constellation of Libra shows the Sun and the Moon superimposed. These are their positions 2 hours before the new moon nearest 1993 November 17, which occurs on 1993 November 14. The brown area on the upper left is the horizon, with the ground below it.

```
In[9]:= StarChart[Libra,
                  NewMoon[{1993,11,17}]+{0,0,0,-2,0,0},
                  Planets -> All, Horizon -> True];
```



- Here is a chart of the constellation of Orion with constellation labeling and an equator coordinates mesh superimposed. Spectral colors of the stars are also shown. Betelgeuse is the orange-red star on the right shoulder, which is our left, of Orion. Of course, in the southern hemisphere it appears upside down. If you look at Orion in the actual sky you should have little trouble identifying the unusual color of Betelgeuse.

```
In[10]:= StarChart[Orion,
                   ConstellationLabels -> True,
                   Mesh        -> True,
                   StarColors -> True];
```



Star charts use black stars on a white background, because that is how you would typically print a chart. Sometimes, however, a more realistic rendering of the night sky is required. You can use the option `StarColors -> True` to color the brighter stars according to their actual visual spectral color. In this case the background sky is rendered as black. The default is `StarColors -> False`.

option name	*default value*	
RadialAngle	20 Degree	the angular size of the chart
MagnitudeRange	{-Infinity, Infinity}	the range of star magnitudes
MagnitudeScale	1	the scale size of the star dots
Skyline	{}	a skyline along the horizon
Horizon	False	drawing of the horizon line
MilkyWay	False	drawing of an outline of the Milky Way
GalacticPlane	False	drawing of the plane of our galaxy
Ecliptic	True	drawing of the ecliptic line
Constellations	True	outlines for constellations
Planets	None	markings for the given planets
Stars	True	markings for stars
Clusters	True	markings for clusters
Nebulae	True	markings for nebulae
Galaxies	False	markings for galaxies
ConstellationLabels	False	labeling of constellations
PlanetLabels	False	labeling of planets
StarLabels	False	labeling of brighter stars
ClusterLabels	False	labeling of clusters
NebulaeLabels	False	labeling of nebulae
GalaxyLabels	False	labeling of galaxies
RotateLabel	True	rotated text for all labeling
StarColors	False	coloring of stars
Mesh	False	an equator coordinates mesh
Background	Automatic	background color of the chart
ViewVertical	Automatic	rotation of chart
Epilog	{}	graphics primitives to be rendered after the main plot
Prolog	{}	graphics primitives to be rendered before the main plot

Some of the options for StarChart, RadialStarChart, CompassStarChart, ZenithStarChart, and Planisphere.

There are many other options to `StarChart` and the other star chart functions. To display stars on a black sky you can use the option setting `Background -> RGBColor[0,0,0]`, and to label constellations you can use `ConstellationLabels -> True`. Similarly, you can label planets, superimpose an equator coordinates mesh, and color stars according to their spectral colors.

By default, only the brightest 300 stars are used by `StarChart` and the other star chart functions, but you can load extra stars such as those in the `Star3000.m` file, which includes the brightest 3,000 stars. You can artificially brighten or dim the stars by using the option `MagnitudeScale`.

Stars are drawn as small dots with a radius in proportion to their magnitude. You can use the `MagnitudeScale` option to increase the size of the dots if you decide they are too small. For example, to double the radius of the dots, use the setting `MagnitudeScale -> 2`. Similarly, you can use the setting `MagnitudeScale -> 0.3` to decrease the size of the dots. The default value is, of course, `MagnitudeScale -> 1`.

Sometimes, when you load extra stars from the `Star3000.m` or `Star9000.m` files, you may not want to see all of these stars. In such a case, you can use the `MagnitudeRange` option with any star chart function to select the range of star magnitudes to be displayed.

The syntax is `MagnitudeRange -> {`*min*`,` *max*`}` or `MagnitudeRange ->` *max*. The default is `MagnitudeRange -> {-Infinity, Infinity}`, which means display stars of all magnitudes. An option value of `MagnitudeRange -> 4.0` would request that only stars down to magnitude 4.0 be displayed.

■ 4.2 The RadialStarChart Function

`RadialStarChart` is useful for displaying the relative layout of stars. You specify a direction and a field of view, and the appropriate graphic is returned.

`RadialStarChart[`*object*`,` *date*`]`	plot a circle of the sky centered on the *object* on the given *date*
`RadialStarChart[`*object*`]`	plot a circle of the sky using the current value of `Date[]`
`RadialStarChart[`*constellation*`]`	plot a circle of the sky centered on one of the 88 constellations
`RadialStarChart[`*horizoncoords*`,` *date*`]`	plot a circle of the sky centered on *horizoncoords* on the given *date*
`Planets ->` *planets*	additional red dots for the position of the *planets* on the given *date*
`RadialAngle ->` *angle*	a bigger or smaller field of view; default is `20 Degree`

Plotting stars near a central point.

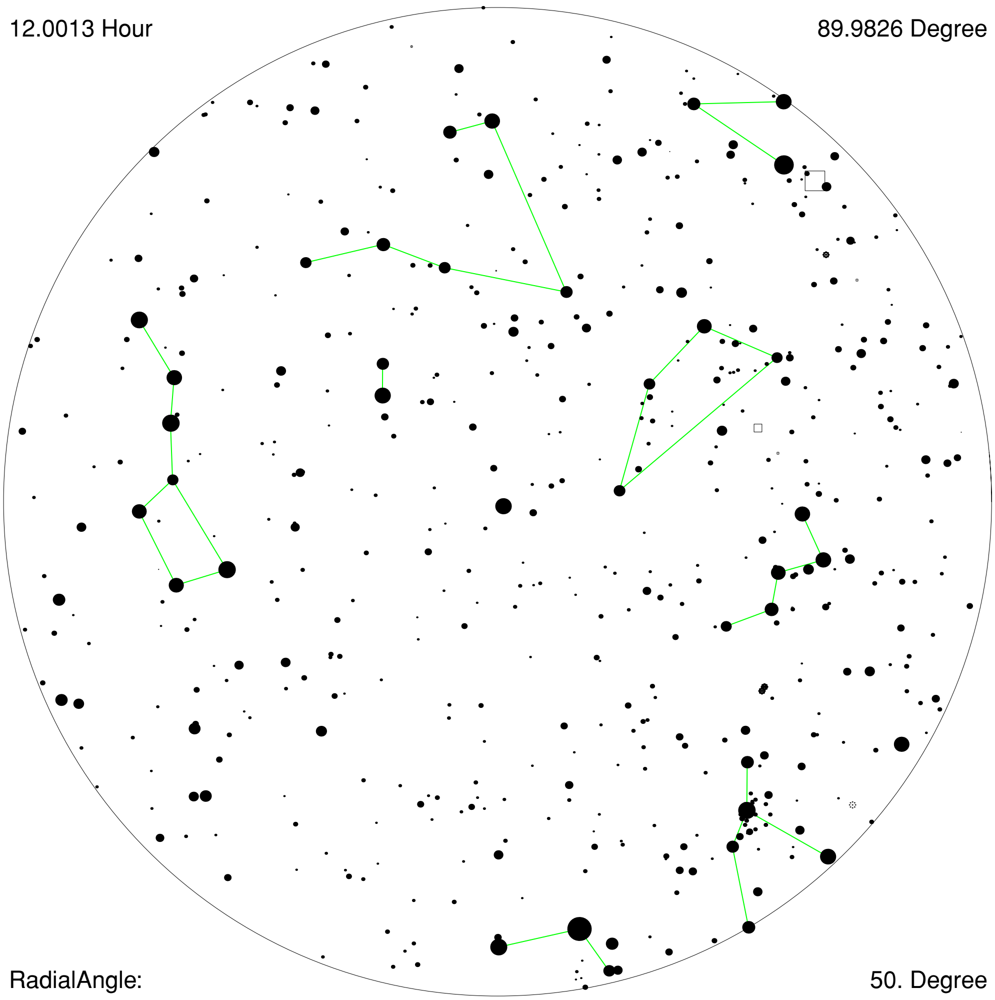
An advantage of `RadialStarChart` over `StarChart` is that it can produce a plot with much less distortion. No matter which direction in the celestial sphere you look, `RadialStarChart` gives you a relatively undistorted representation, whereas `StarChart` has considerable distortion near the celestial poles.

As with the other star charts, green lines are used to highlight common constellations to aid identification. These lines can be switched off with the option setting `Constellations -> False`.

Many options are available with `RadialStarChart`.

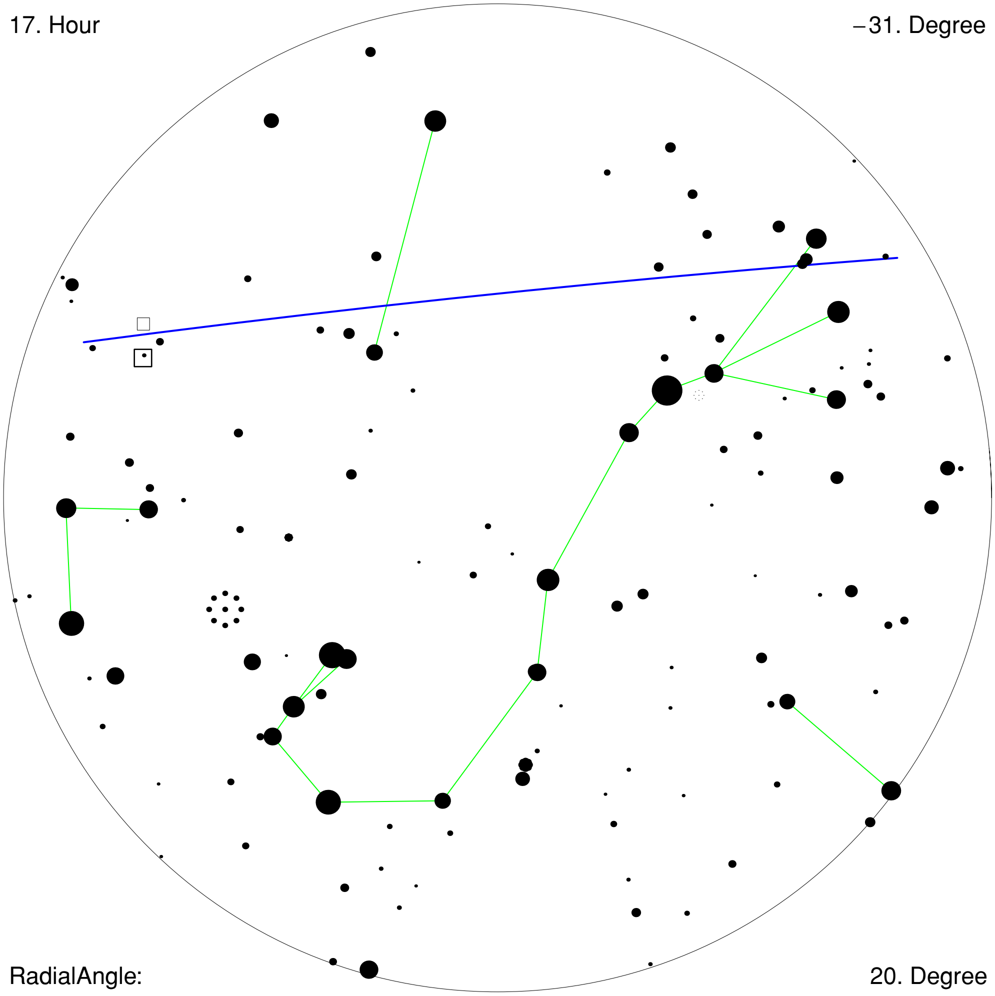
- A chart looking in the direction of the north celestial pole shows the pole star `Polaris` in the center and the Big Dipper `UrsaMajor` to the left. The field of view is 50 degrees in angular radius, so the graphic is 100 degrees across.

```
In[11]:= RadialStarChart[NorthCelestialPole,
                         RadialAngle -> 50*Degree];
```



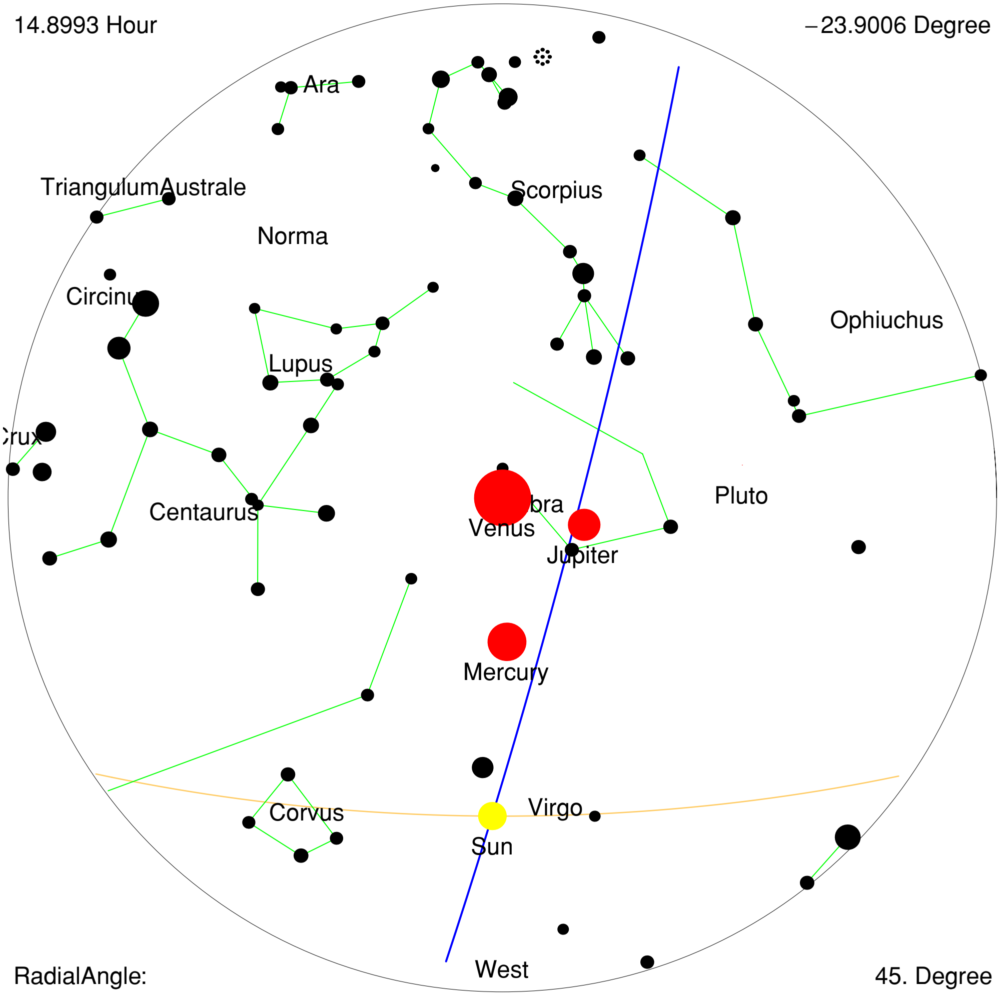
■ `RadialStarChart[Scorpius]` creates a chart of the Scorpius constellation. The two special nine-dot symbols to the left of Scorpius are open star clusters. The bigger cluster is M7 and the much smaller one is M6, which is sometimes known as the Butterfly cluster. To remove star clusters use the option setting `Clusters -> False`.

In[12]:= **`RadialStarChart[Scorpius];`**



■ This is a chart looking toward Venus at sunset. Note the use of the option setting `Horizon -> True` as well as the other options. The brown-colored curve at the bottom is the line of the local horizon, into which the yellow Sun is setting. At the very bottom the compass direction is written. The Sun, which is shown sitting directly on the horizon, obviously sets into the west.

```
In[13]:= RadialStarChart[Venus, SunSet[{1994,10,13}],
             RadialAngle          -> 45*Degree,
             Planets              -> All,
             PlanetLabels         -> True,
             ConstellationLabels  -> True,
             Horizon              -> True,
             MagnitudeRange       -> {-Infinity, 3.5}];
```



You can project the line of the local horizon onto a star chart by using the `Horizon -> True` option. The `Horizon` option is applicable to `StarChart` and `RadialStarChart`, with the default being `Horizon -> False`. Since the horizon changes with time, you need to supply a date to the star chart function.

When the `Horizon -> True` option is used in a `RadialStarChart`, the graphic is rotated so that the horizon line is horizontal. This is not possible with the plain `StarChart` function, which has a more rigidly aligned coordinate system. In that function, the horizon line and the ground below it are colored brown.

Stars have generally fixed positions in the rotating sky and so are easy to display consistently in the various star charts. Planets, however, continually wander through the sky (although always near the ecliptic) and so are not normally displayed in the star charts. To render planets in a star chart you can set the `Planets` option to the value `All`, or to a list of planet names, or even to other objects. The default is `Planets -> None`.

When planets are displayed you might have trouble identifying which planet is which. To remedy this the option `PlanetLabels -> True` is available to place labels below the planets. The default is `PlanetLabels -> False`.

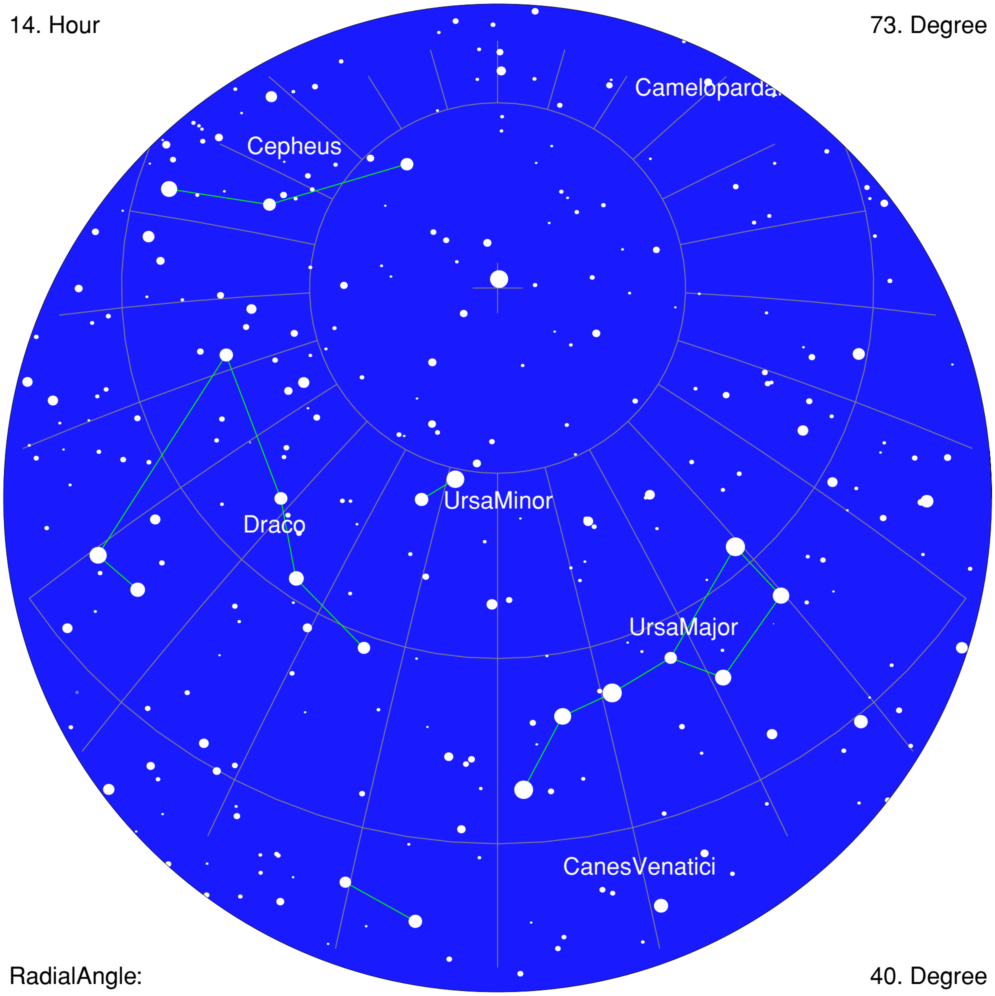
Sometimes it is useful to have constellations labeled as well, since not all constellations are easily identifiable by sight. This is where the `ConstellationLabels -> True` option is useful. The default value is `ConstellationLabels -> False`.

By default, the background sky is white unless the `StarColor` option is set to `True`, in which case the background sky is black. If neither of these colors is suitable to you, then you can use the `Background` option. Whatever background color you choose, contrasting colors are used for stars. The `Background` option can be a `CMYKColor`, `GrayLevel`, `Hue`, or `RGBColor` directive. The default is `Automatic`, which chooses between `GrayLevel[0]` and `GrayLevel[1]` depending on whether `StarColor` is `True` or `False`.

There are many other options available to the star charts. For example, `Mesh -> True` superimposes an equator coordinates mesh. Mesh lines units are 1 hour of right ascension, and 15 degrees of declination. Crosses are placed at the north and south celestial poles. To suppress the text around the edges use the option `Text -> False`.

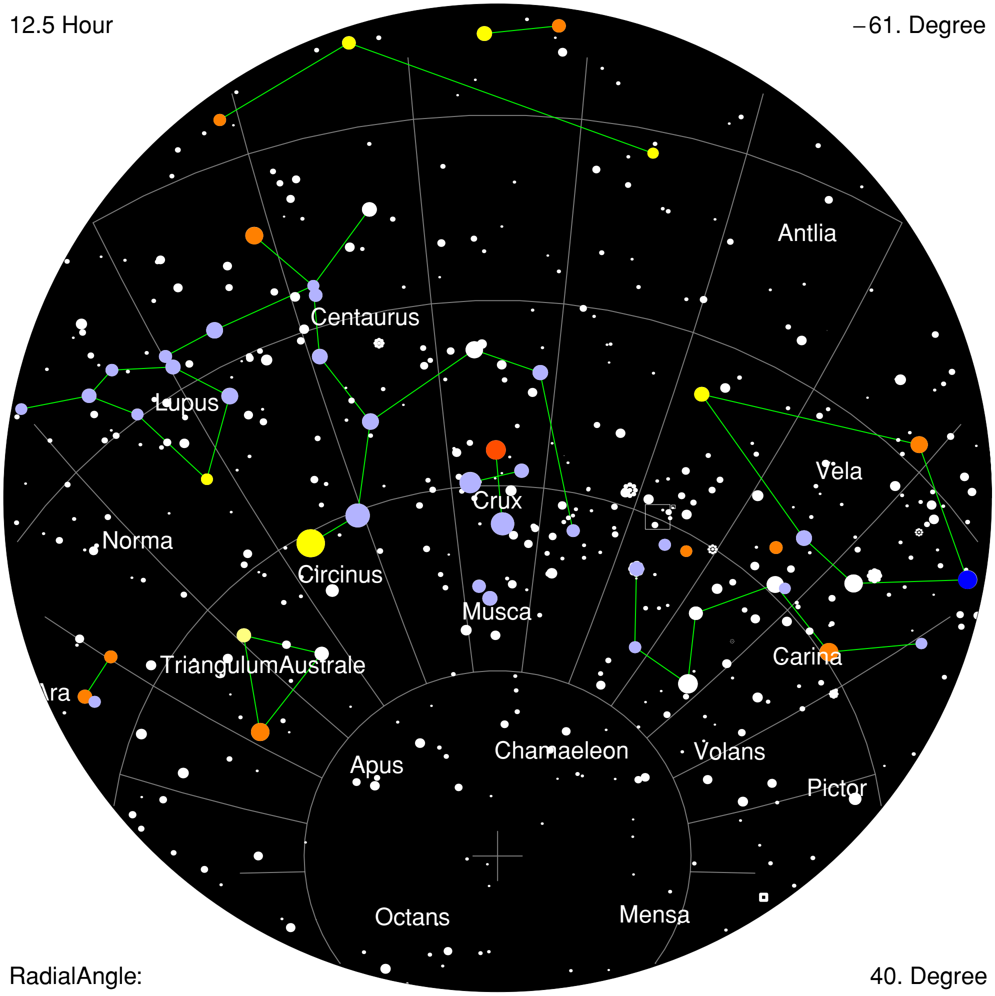
■ The `Background` and `Mesh` settings designate a blue background and a gray equator coordinates mesh in this star chart.

```
In[14]:= RadialStarChart[UrsaMinor,
           RadialAngle -> 40*Degree,
           Background  -> RGBColor[0.1,0.1,1],
           Mesh        -> True,
           ConstellationLabels -> True];
```



■ When you request star colors, a black background appears by default.

```
In[15]:= RadialStarChart[Crux,
           RadialAngle -> 40*Degree,
           Mesh        -> True,
           StarColors  -> True,
           ConstellationLabels -> True];
```



As normal, you can look at any named object, such as `Mars`, `Sirius`, `Leo`, or `Zenith`, but it is also possible to look at a fixed point in the sky relative to the local horizon by using horizon coordinates. For example, `RadialStarChart[{Azimuth -> 180*Degree, Altitude -> 20*Degree}, {1993,11,17,3,20,0}];` generates a chart centered on the point directly south and 20 degrees up in the sky. Similarly, you can use equator coordinates.

■ 4.3 The CompassStarChart Function

`CompassStarChart` displays a global section of the sky. You specify a compass direction, and a graphic showing all the stars in that direction is displayed.

`CompassStarChart[`*direction*`, `*date*`]`	chart the star field in the compass *direction*, which can be either `North`, `South`, `East`, `West`, or a compass angle in degrees, on the given *date*
`CompassStarChart[`*direction*`]`	chart the star field using the current value of `Date[]`

Plotting stars in half the sky.

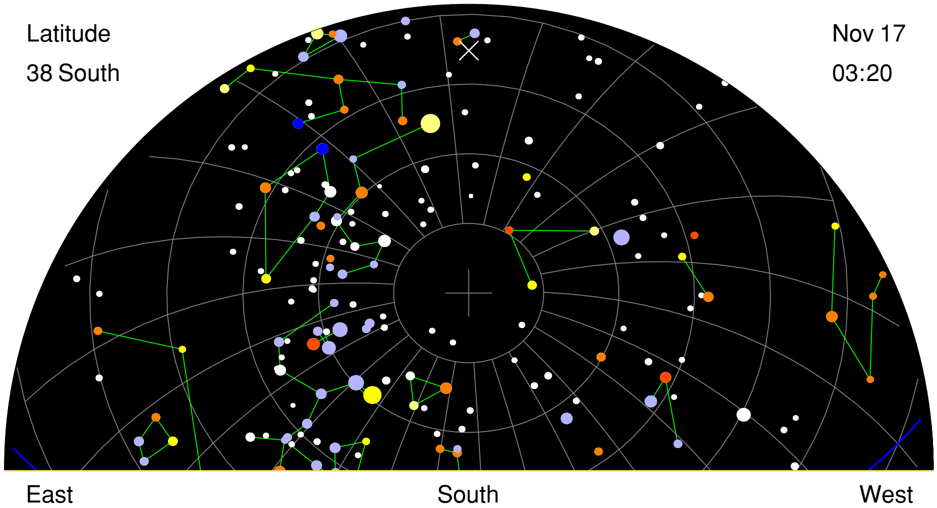
Two `CompassStarChart` calls can be used to cover the entire sky above the local horizon.

At the top of the graphic, a cross is used to represent the zenith, which is the point directly above your head. The field of view is 180 degrees along the horizon and is shown as the brown line along the bottom. The blue line is the ecliptic, which can be removed using the option setting `Ecliptic -> False`.

As with other star chart functions, numerous options are available. The options are identical to those for `StarChart`. For instance, to add an equator coordinates mesh use `Mesh -> True`. To show the Milky Way use `MilkyWay -> True`. Use the option `Text -> False` to suppress the text printed at the top left and right edges of the graphic.

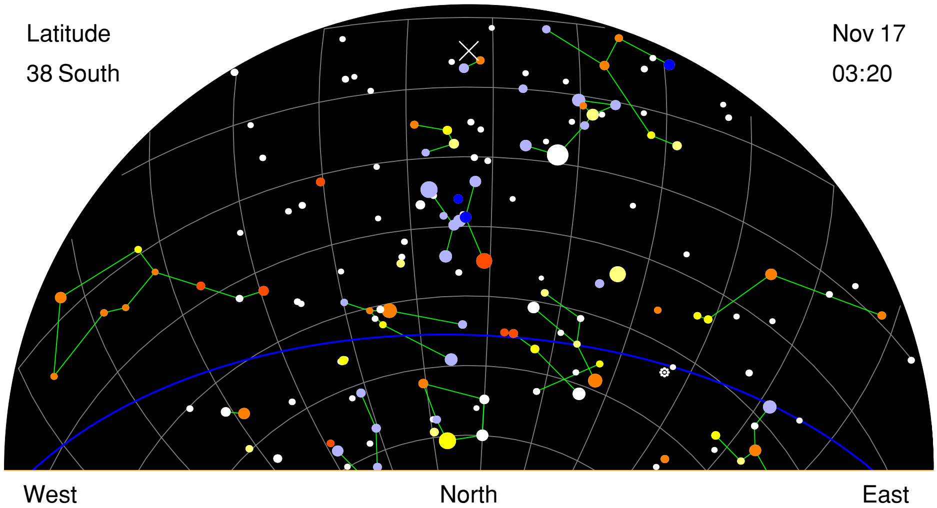
■ Observe the southern aspect of the sky above the horizon at 03:20 on 1993 November 17 as seen from Melbourne, Australia.

```
In[16]:= CompassStarChart[South, {1993,11,17,3,20,0},
                          Mesh           -> True,
                          StarColors     -> True,
                          MagnitudeRange -> 4.0];
```



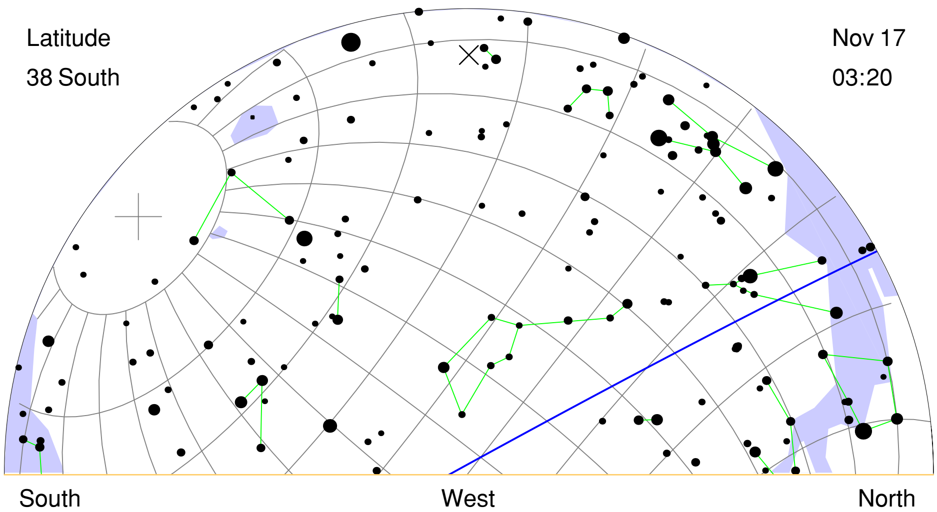
■ This chart shows the northern aspect of the same sky.

```
In[17]:= CompassStarChart[North, {1993,11,17,3,20,0},
                          Mesh            -> True,
                          StarColors      -> True,
                          MagnitudeRange  -> 4.0];
```



■ The western aspect of the sky displays part of the Milky Way, which can be seen on both the right and the left. The blue line sweeping from the western horizon to a point above north is the ecliptic.

```
In[18]:= CompassStarChart[West, {1993,11,17,3,20,0},
                          Mesh          -> True,
                          MilkyWay      -> True,
                          MagnitudeRange -> 4.0];
```



Note the usefulness of the option `Mesh`. Stars effectively move along the equatorial mesh lines, and the intersecting curves are one hour apart. You can, therefore, easily estimate where a given star will be in relation to the horizon in one or more hours time by simply following an equatorial mesh line.

If you select the graphic returned by `CompassStarChart` and then press the CMD key, the horizon coordinates of the mouse position are displayed in the bottom left hand corner of your notebook window. The first number is degrees east of north (*e.g.*, 270 is west), and the second is altitude in degrees, with 90 being the zenith point.

As with all the star chart functions, if you copy the pair of numbers obtained by holding down the CMD key and clicking in a star chart, you can paste that pair into any other function. The pair of numbers is treated as an object corresponding to the point selected in the last star chart graphic.

One further option available to all the star charts is `Skyline`, which lets you map a sky line along the local horizon. The default value is `Skyline -> {}`, which does not draw a sky line, but you can set it to a more complicated value.

The value required by the `Skyline` option must be built out of normal graphics primitives such as `Point`, `Line`, `Rectangle`, `Disk`, `Circle`, `Polygon`, and `Text`. You can also use attributes such as `RGBColor`, `PointSize`, and `Thickness`.

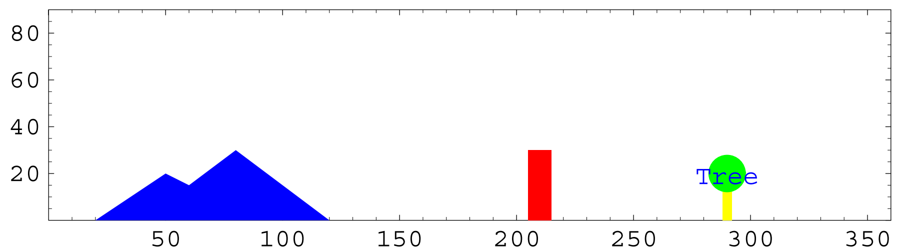
The coordinates supplied to the graphics primitives must be given as horizon coordinates; that is, the first number must be the azimuth or compass direction in degrees and the second number must be the altitude in degrees. For example, the primitive `{RGBColor[1,0,0], Rectangle[{85, 0}, {95, 15}]}` corresponds to a red rectangular "building" in the east that is 10 degrees wide and 15 degrees high. Depending on how creative you are, you can create trees, hills, and other features. You can also use the `Text` primitive to label the features along the horizon.

■ Consider the sky line consisting of a building 30 degrees high and 10 degrees wide in the direction 210 degrees around the compass. Add a tree located at 290 degrees with a height of 20 degrees, and a mountain in the east.

```
In[19]:= myskyline = {
       {RGBColor[1,0,0], Rectangle[{205, 0}, {215,30}]},
       {RGBColor[1,1,0], Rectangle[{288, 0}, {292,20}]},
       {RGBColor[0,1,0], Disk[{290, 20}, 8]},
       {RGBColor[0,0,1], Text["Tree", {290, 20}]},
       {RGBColor[0,0,1], Polygon[{{ 20,  0}, { 35, 10},
                                  { 50, 20}, { 60, 15},
                                  { 80, 30}, {100, 15},
                                  {120,  0}, {100,  0},
                                  { 80,  0}, { 60,  0},
                                  { 40,  0}, { 20,  0}}]}};
```

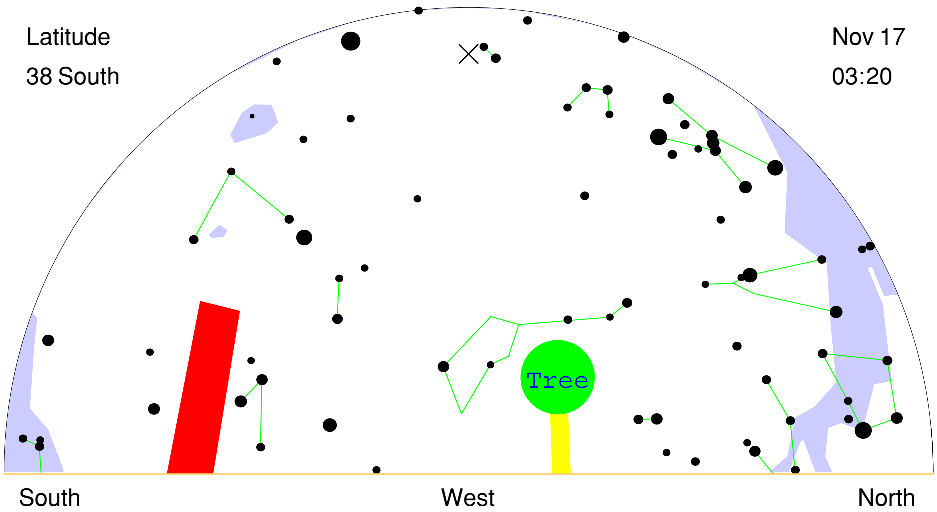
■ This is a plot of the elementary sky line.

```
In[20]:= Show[Graphics[myskyline, AspectRatio->Automatic],
         PlotRange -> {{0,360}, {0,90}},
         Frame     -> True];
```



■ The `Skyline` option maps the given sky line onto the star chart. Note the distortion at the edge of the plot. The normally rectangular building is somewhat tilted in this projection.

```
In[21]:= CompassStarChart[West, {1993,11,17,3,20,0},
                    MilkyWay        -> True,
                    MagnitudeRange -> 3.5,
                    Ecliptic        -> False,
                    Skyline         -> myskyline];
```



■ 4.4 The ZenithStarChart Function

`ZenithStarChart` displays the entire sky above the local horizon.

`ZenithStarChart[`*date*`]`	chart the full overhead star field on the given *date*
`ZenithStarChart[]`	chart the full overhead star field using the current value of `Date[]`

Plotting the stars overhead.

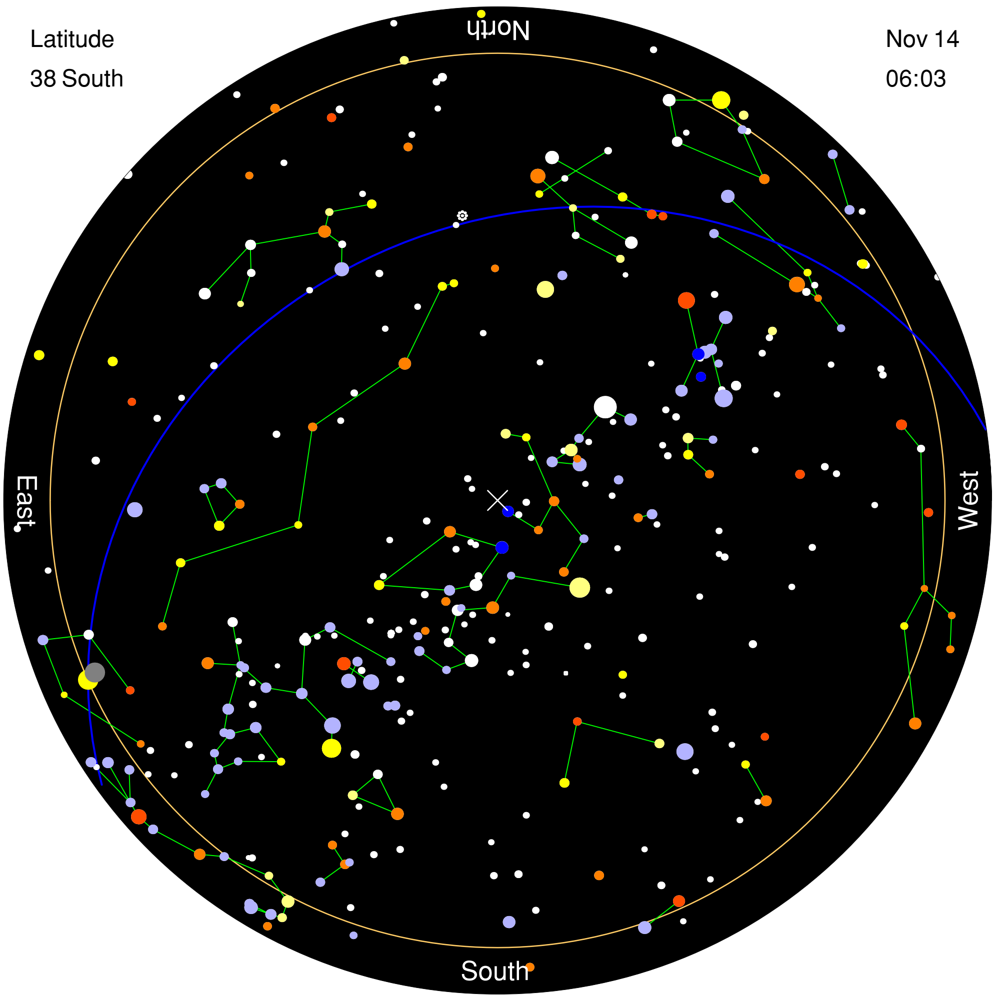
The field of view in the graphic is 100 degrees in radial angle, and the horizon is shown as the brown ring near the outer edge, with the zenith shown in the center. The graphic is essentially the same as that produced by `RadialStarChart[Zenith,` *date*`, RadialAngle -> 100*Degree, Horizon -> True, Planets -> {Sun, Moon}]`, except that the labeling around the edges is different.

Compass directions are written around the local horizon. Normally the chart is generated so that north is at the top, but you can use the option `ViewVertical ->` *object* to rotate the graphic so that a given object is located at the top. As with most star charts, a `ZenithStarChart` graphic must be held above your head in order to be aligned correctly.

`ZenithStarChart` accepts all the options available to `StarChart`.

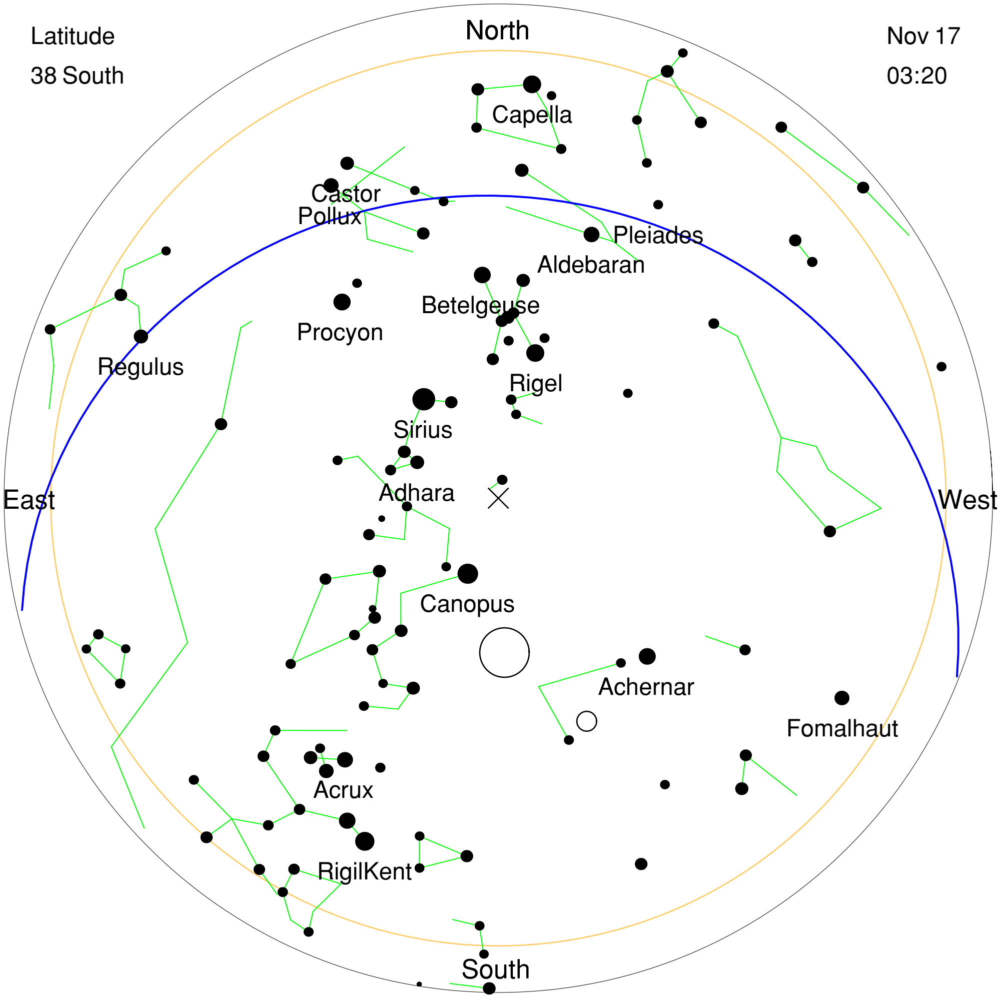
- The stars are not actually visible at sunrise, but star positions in the chart are nevertheless correct. Note the position of the Sun in the east, with the new moon just in front of it.

```
In[22]:= ZenithStarChart[SunRise[NewMoon[{1993,11,17}]],
                         StarColors      -> True,
                         MagnitudeRange -> 4.0];
```



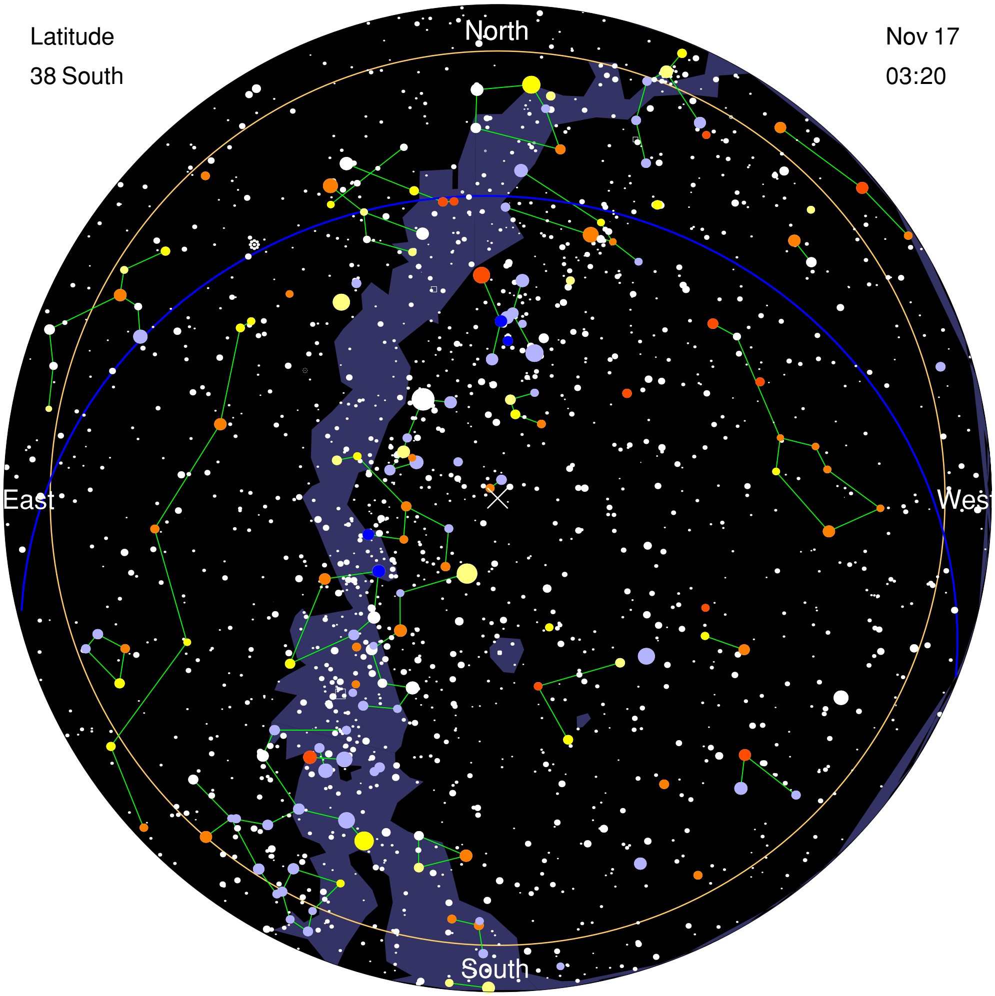
■ Toward the center bottom of this graphic, observe both a large and a small circle. These represent the Large and Small Magellanic Clouds.

```
In[23]:= ZenithStarChart[{1993,11,17,3,20,0},
                         Galaxies       -> True,
                         StarLabels     -> True,
                         RotateLabel    -> False,
                         MagnitudeRange -> 3.0];
```



■ The Milky Way is shown as a dark blue band across the sky in this star chart. The Large and Small Magellanic Clouds are also shaded with dark blue.

```
In[24]:= ZenithStarChart[{1993,11,17,3,20,0},
                         MilkyWay    -> True,
                         StarColors  -> True,
                         RotateLabel -> False];
```



The `MilkyWay` option can be used with all star chart functions. If `MilkyWay -> True`, a shaded area representing our own Milky Way galaxy, plus the Large and Small Magellanic Clouds, is drawn on the chart. The default for this option is `MilkyWay -> False`.

As with planets and constellations, you may choose to have automatic labeling of stars. However, because there are so many stars, only the 25 brightest will be labeled. The option to invoke this is `StarLabels -> True`, with the default being `StarLabels -> False`.

Stars and planets are not the only objects that you can display on a star chart. There are many star clusters, some nebulae, and a few galaxies that are visible to the naked eye or binoculars. The `Clusters`, `Nebulae`, and `Galaxies` options display deep sky objects.

Clusters are displayed as special nine-dot symbols. These clusters can be removed from a star chart using the option `Clusters -> False`. Similarly, nebulae are displayed as squares representing the actual apparent size of the object. You can remove `Nebulae` from a star chart using the option `Nebulae -> False`. Although clusters and nebulae are displayed by default, the various galaxies are not. To display galaxies you need to use the option `Galaxies -> True`. Galaxies are displayed as circles with radii reflecting the actual size of the object.

Finally, use the option setting `RotateLabel -> False` to prevent rotated text being used for star and constellation labeling. The default is to rotate such labeling.

■ 4.5 The StarNames Function

`StarNames` can be used to label individual stars in a constellation. This function can be passed via the options `Epilog` or `Prolog` to any of the star chart functions.

`StarNames[`*constellation*`]`	print Greek letters for the individual stars within the given *constellation*; this function must be passed via the options `Epilog` or `Prolog` to a star chart
`MagnitudeRange ->` *range*	magnitude *range* of stars to print; default range is `{-Infinity, 3.5}`

Labeling stars in a constellation.

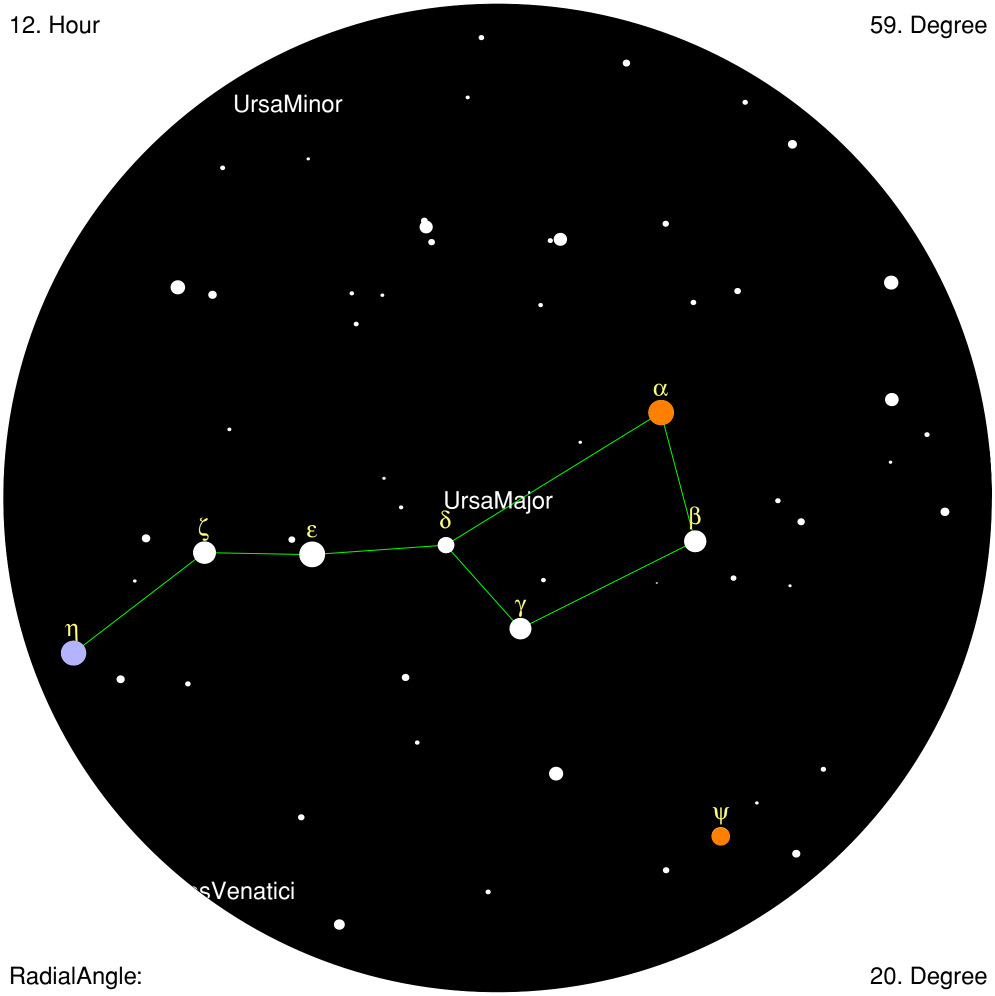
For example, you can label the stars in the constellation Ursa Major, also known as the Big Dipper, by simply passing the option `Epilog -> StarNames[UrsaMajor]` to any star chart.

Similarly, you can identify all the stars in the Pleiades star cluster by using the option `Epilog -> StarNames[Taurus, MagnitudeRange->6]`. Pleiades, also known as the Seven Sisters, contains many stars clustered in a small region of the sky in the constellation of Taurus. Some of the stars are on the edge of naked-eye visibility, so to label them you need to set a lower magnitude limit.

Typically, stars are named with Greek letters, with α (alpha) commonly referring to the brightest star in a given constellation. In the case of Pleiades, the central star is named η (eta). Eventually the Greek alphabet is exhausted and numbers are used to name stars. Fainter stars in Pleiades, therefore, are called simply 19, 23, 27, and so on. Variable stars, however, are named using a special two-letter system. For instance, there is a faint variable star called BU in Pleiades.

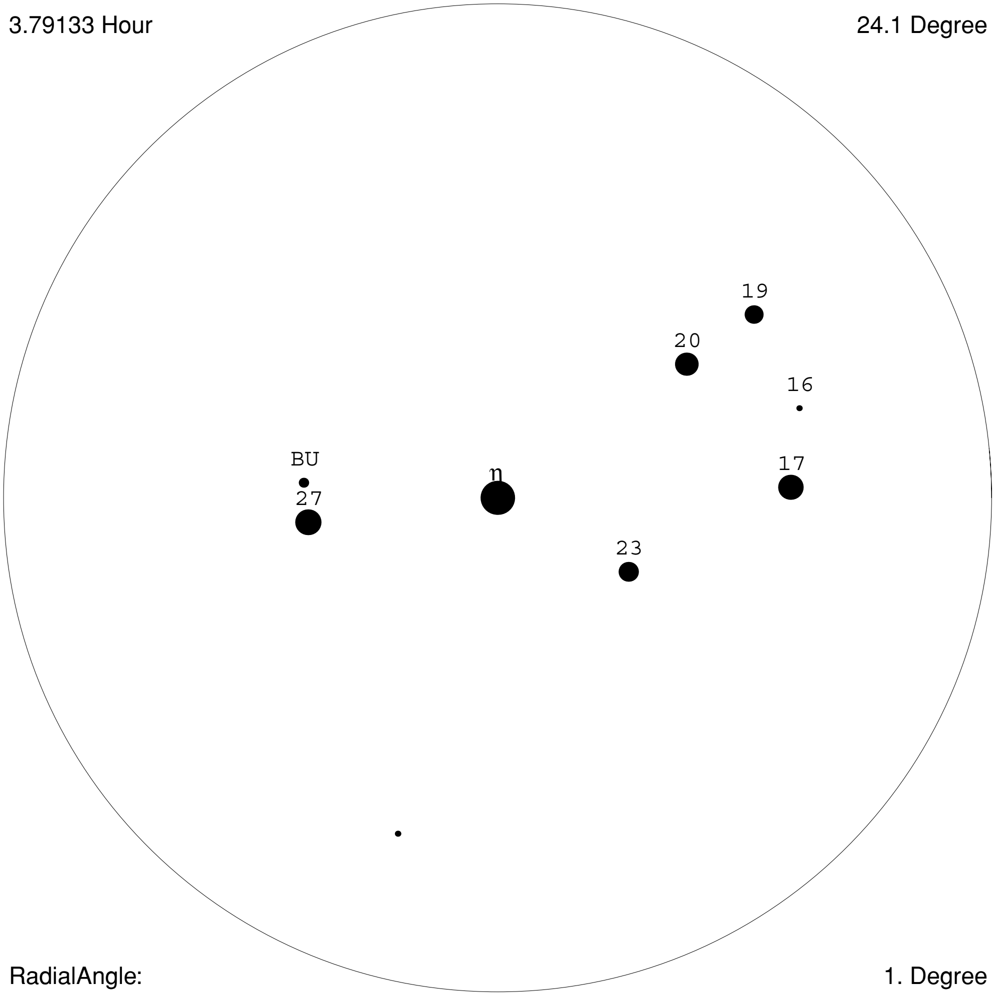
■ The star ζ (zeta) Ursa Majoris, also known as Mizar, on the left center of this graphic is the famous double star visible to the naked eye. A mere 0.2 degrees away is its partner Alcor, which is not visible in the graphic.

```
In[25]:= RadialStarChart[UrsaMajor,
           StarColors -> True,
           ConstellationLabels -> True,
           Epilog     -> {RGBColor[1,1,.5],
                          StarNames[UrsaMajor]}];
```



■ This star chart uses `StarNames` to label the seven brightest stars in the Pleiades star cluster.

```
In[26]:= RadialStarChart[Eta.Taurus,
            RadialAngle -> 1*Degree,
            MagnitudeScale -> 0.5,
            Epilog       -> StarNames[Taurus,
                                    MagnitudeRange->5.6]];
```



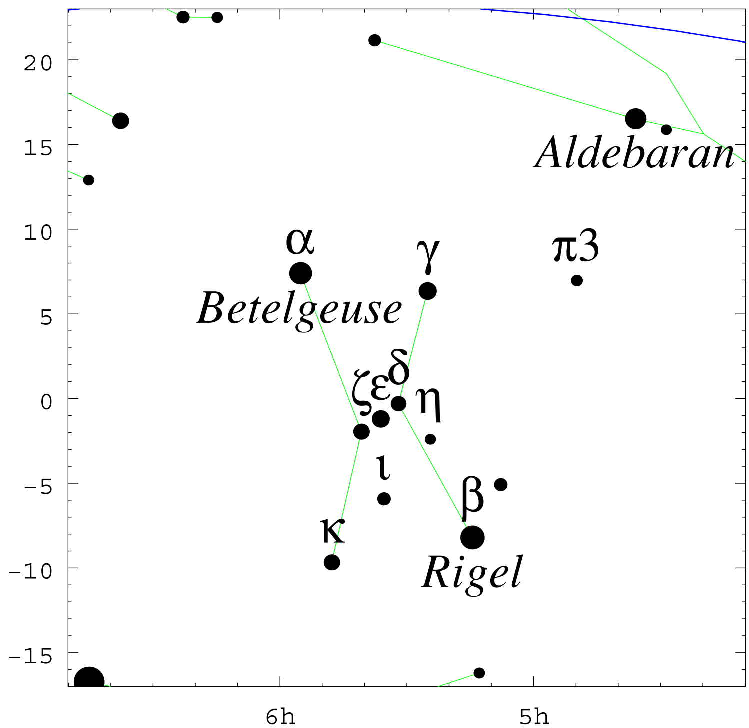
Font Sizes and Names

A default font name and various font sizes are used throughout the star charts and other functions. The default font is "Helvetica", but you might want to use a different font for display purposes on some platforms. To do this set `$DefaultFontName` to the name of the font you want.

Sometimes, the size of the fonts can look small on the screen, but this is adjustable, too. By setting `$DefaultFontScale` to a scale factor other than 1, you can increase or decrease the font size. By default, the scale factor is 1.

- This modifies the values of `$DefaultFontName` and `$DefaultFontScale` to change the font name and size used in this graphic. Note that the brighter stars are now labeled using double-sized "Times-Italic" font. The labels above the stars are still in Greek letters, or "Symbol" font, but are now double sized, too.

```
In[27]:= Block[{$DefaultFontName = "Times-Italic",
                $DefaultFontScale = 2},
            StarChart[Orion,
                     MagnitudeRange -> 3.5,
                     StarLabels     -> True,
                     Epilog         -> StarNames[Orion]]];
```



■ 4.6 The OrbitTrack and OrbitMark Functions

All the standard graphics options are available to the star charts. The `Prolog` and `Epilog` options in particular will add improvements to these charts. For instance, `Prolog` lets you add a more complicated background than the `Background` option alone would allow. Similarly, the `Epilog` option allows you to enhance the foreground more than the `Skyline` option alone.

One important use of the `Epilog` option, in relation to star charts, involves the ability it gives you to add orbit tracks of satellites or planets, as well as to add other coordinate-dependent information. The functions that aid you in this are `OrbitTrack`, `OrbitMark`, `DeepSkyMark`, and `ChartCoordinates`.

`OrbitTrack` allows you to easily display the track of an object onto a star chart.

`OrbitTrack[`*object*`,` *date1*`,` *date2*`]`	
	draw the orbit track of the *object* between *date1* and *date2*; this function must be passed via the options `Epilog` or `Prolog` to a star chart
`OrbitMark[`*object*`,` *date*`]`	draw a small mark for the *object* on the given *date*
`PlotLabel -> `*label*	labeling of the mark
`PlotPoints -> `*n*	the number of line segments to use in the track; default is 25

Drawing orbit tracks and labels on a star chart.

You can project the trajectory of Mars, showing its occasional retrograde motion, onto a star chart using `OrbitTrack`. Retrograde motion always occurs around opposition.

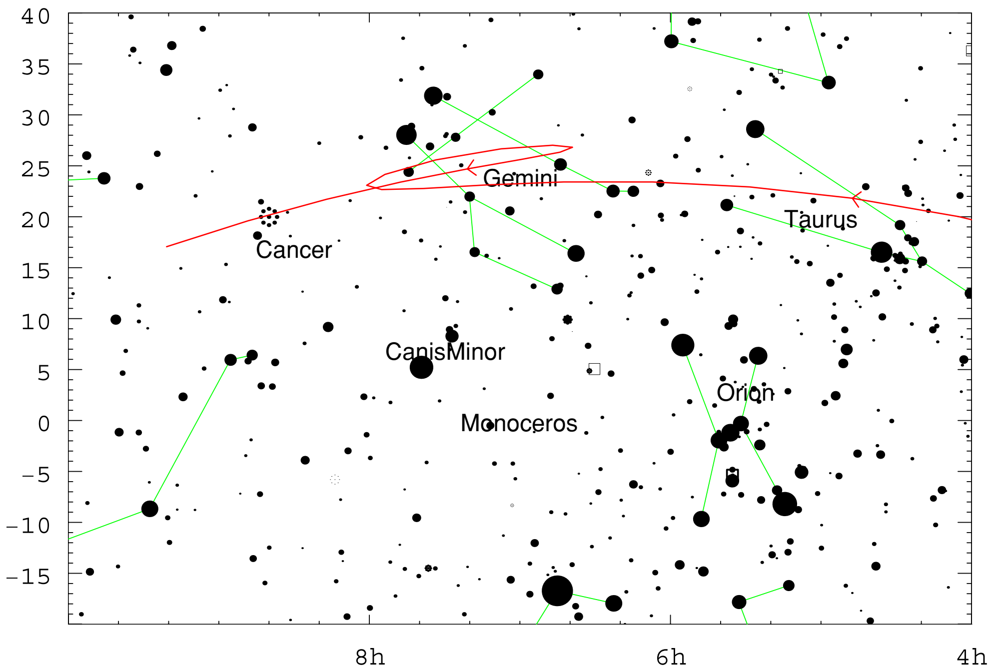
■ Mars is at opposition on 1993 January 8.

```
In[28]:= BestView[Mars, {1993,11,17}]

Out[28]= {Opposition → {1993, 1, 8}}
```

■ The trajectory of Mars during 1992–1993 is projected onto a star chart here. The motion of Mars is mostly right to left, or equivalently west to east, but note the retrograde motion.

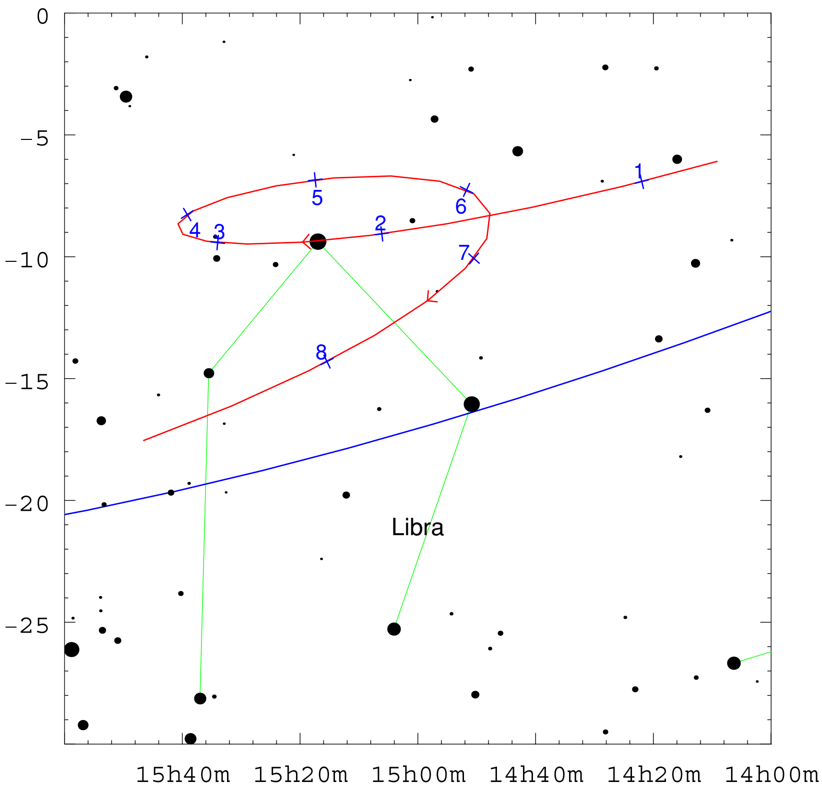
```
In[29]:= StarChart[{{60,150}, {-20,40}},
                Ecliptic -> False,
                ConstellationLabels -> True,
                Epilog -> {RGBColor[1,0,0],
            OrbitTrack[Mars, {1992,6,1}, {1993,6,1}]}];
```



You can superimpose orbit tracks and other items on all the different types of star charts. A related function is `OrbitMark`, which lets you annotate marks and text onto a star chart. For example, you can mark the position of the asteroid Vesta month by month onto a star chart. Asteroid Vesta is in opposition on 1996 May 9; hence it is at its closest and brightest as seen from the Earth. During opposition it also undergoes retrograde motion.

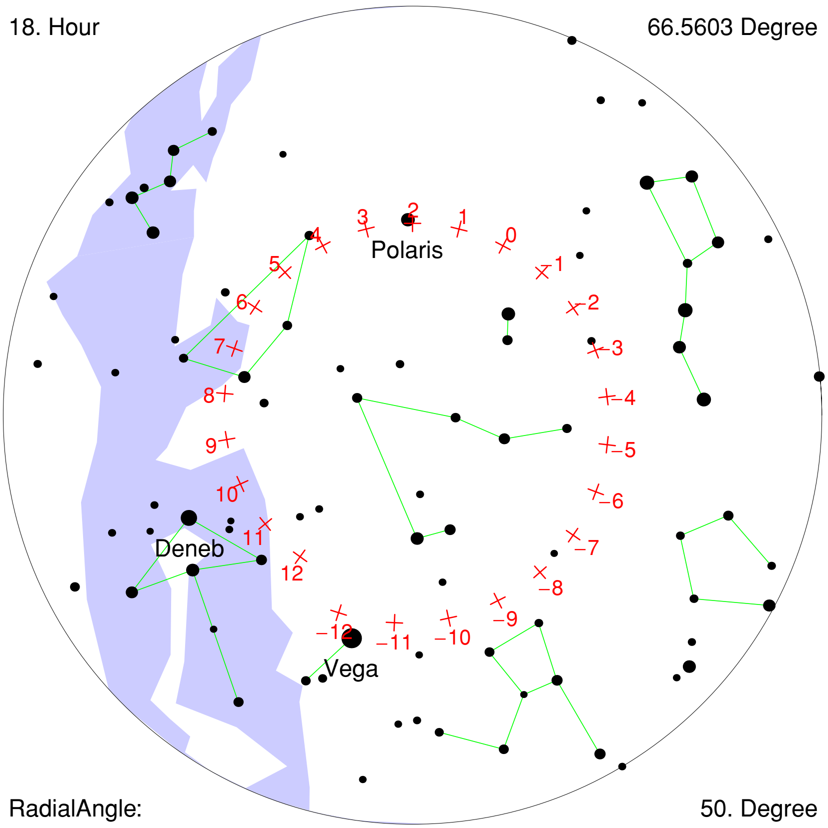
■ `OrbitMark` is used to annotate the track of the asteroid Vesta. Blue crosses and text are used to mark the position of Vesta for each month during 1996. During month 5 (May) it is at its brightest.

```
In[30]:= StarChart[{{210, 240}, {-30, 0}},
                ConstellationLabels -> True,
                Epilog -> {RGBColor[1,0,0],
              OrbitTrack[Vesta, {1996,1,1}, {1996,9,1}],
              RGBColor[0,0,1],
              Table[OrbitMark[Vesta, {1996,m,9},
                              PlotLabel->m],
                   {m,1,8}]}];
```



■ Using `OrbitMark` in this chart allows you to observe the position of the north celestial pole for the years from 12000 B.C. to 12000 A.D. This illustrates the precession effect of the Earth's axis–every 25,000 years the axis rotates in a full circle of radius 23.5 degrees. Note that the view direction `{0,0,1}` represents the ecliptic north pole, that is, the point directly above the plane of the Earth's orbit.

```
In[31]:= RadialStarChart[{0,0,1},
           RadialAngle     -> 50*Degree,
           MagnitudeRange -> 4.0,
           StarLabels      -> True,
           MilkyWay        -> True,
           Epilog          -> {RGBColor[1,0,0],
              Table[OrbitMark[NorthCelestialPole,
                              {year,1,1},
                              PlotLabel -> year/1000],
                    {year, -12000, 12000, 1000}]}];
```



■ At year 2000, the north celestial pole is near Polaris.

```
In[32]:= FindNearestObject[NorthCelestialPole, {2000,1,1},
                          MagnitudeRange->3.5] === Polaris

Out[32]= True
```

■ However, at year -12000, the north celestial pole was near Vega.

```
In[33]:= FindNearestObject[NorthCelestialPole, {-12000,1,1},
                          MagnitudeRange->3.5] === Vega

Out[33]= True
```

The DeepSkyMark Function

Faint deep sky objects are not normally shown on the star charts because there are so many of them. A function called `DeepSkyMark` is provided to let you easily annotate any star chart to place a mark where a deep sky object is located.

`DeepSkyMark[`*object*`]`	use a special mark for the deep sky *object*; this function must be passed via the option `Epilog` or `Prolog` to a star chart
`PlotLabel -> `*label*	labeling of the mark

Labeling of deep sky objects.

Specific marks are used for different types of objects. For instance, circles are used for galaxies, squares for nebulae, and nine-dot symbols for star clusters. The size of the mark represents the true apparent angular size of the object.

With this function you can use the option `Epilog -> DeepSkyMark[TriangulumGalaxy]` to mark the location of the Triangulum Galaxy on any star chart. More complicated forms, such as `Epilog -> {RGBColor[1,1,0], DeepSkyMark /@ {EagleNebula, OmegaNebula, TrifidNebula, LagoonNebula}}` are also possible.

There is a `PlotLabel` option available to suppress or add a new label to the mark. Thus, `Epilog -> DeepSkyMark[TriangulumGalaxy, PlotLabel -> ""]` marks the location of the Triangulum Galaxy, but will not label it as such. The default labels the mark with the NGC or IC name of the object. See Section 8.5 for a discussion on NGC and IC numbers.

■ 4.7 The ChartCoordinates and ChartPosition Functions

`ChartCoordinates` and `ChartPosition` allow you to easily display points, lines, and other graphics primitives onto a star chart.

`ChartCoordinates[`*object*`, `*date*`]`	generate internal chart coordinates of the *object*, on the given *date*; this function must be passed via the option `Epilog` or `Prolog` to a star chart
`ChartPosition[`*ascension*`, `*declination*`]`	generate internal chart coordinates; this function must be passed via the option `Epilog` or `Prolog` to a star chart

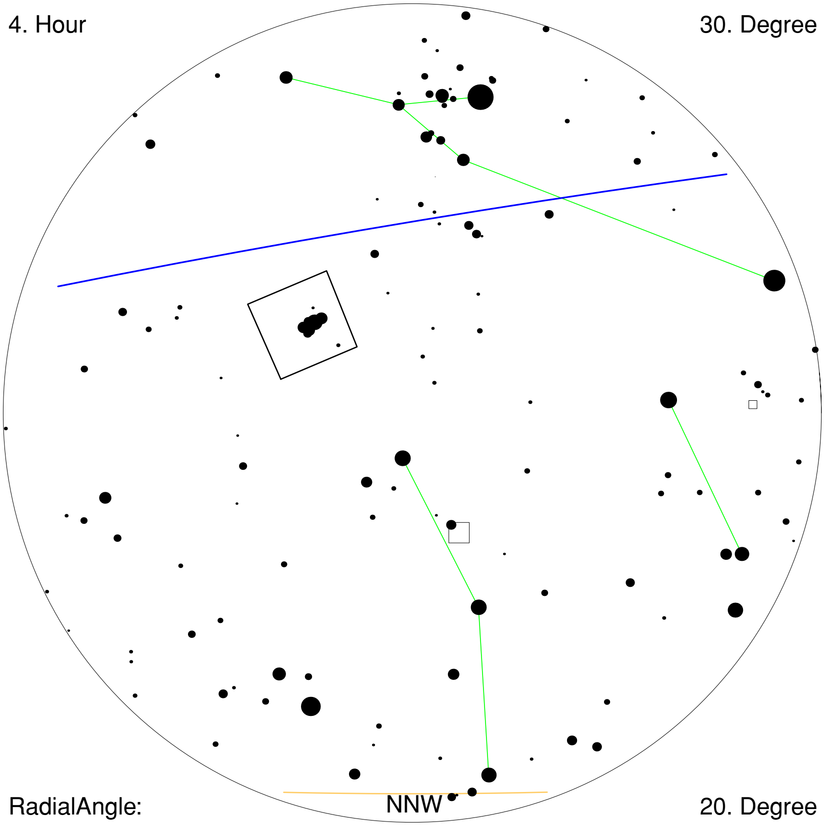
Generating internal coordinates for use in star charts.

To put a green ring around the Southern Cross constellation (`Crux`) you can supply, say, the option setting `Epilog -> {RGBColor[0,1,0], Circle[ChartCoordinates[Crux], 5]}` to any star chart.

A call to `ChartCoordinates` is immediately evaluated to give an expression with a `ChartPosition` head. Such an expression is evaluated further only when it is passed via the `Epilog` or `Prolog` options to a star chart function.

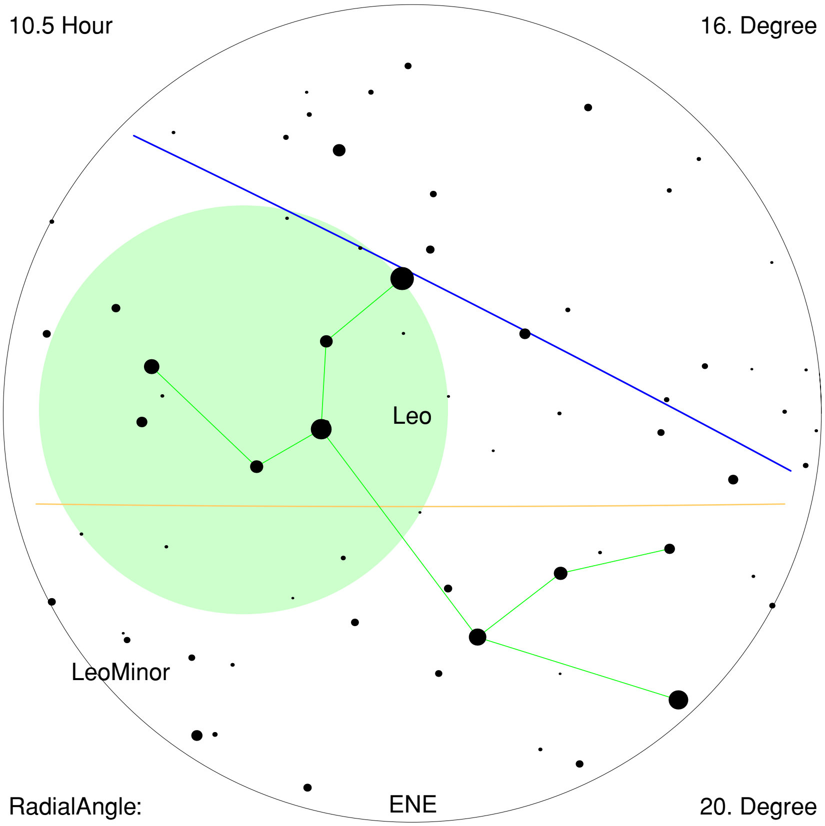
■ `ChartPosition` puts an outline around the Pleiades star cluster. The cluster is indicated by the box.

```
In[34]:= RadialStarChart[
           {Ascension->4*Hour, Declination->30*Degree},
           {1993,11,17,3,20,0},
           Horizon -> True,
           Epilog -> Line[{
              ChartPosition[3.6*Hour, 26*Degree],
              ChartPosition[3.9*Hour, 26*Degree],
              ChartPosition[3.9*Hour, 22*Degree],
              ChartPosition[3.6*Hour, 22*Degree],
              ChartPosition[3.6*Hour, 26*Degree] }]];
```



■ The direction and apparent radial size of the annual Leonid's meteor shower is shown by the light green disk in this graphic. Using `Prolog`, rather than `Epilog`, places the green disk behind the stars.

```
In[35]:= RadialStarChart[Leo, {1993,11,17,3,20,0},
             Horizon                -> True,
             ConstellationLabels -> True,
             Prolog                 -> {RGBColor[0.8,1,0.8],
               Disk[ChartPosition[10.1*Hour, 22*Degree], 10]}];
```



5. Planet Plotting Functions

Scientific Astronomer has two functions for plotting the general appearance of a planet or the Moon. `PlanetPlot` and `PlanetPlot3D` show the general color, axis orientation, and the region illuminated by the Sun for each planet or the Moon. A more detailed graphic is rendered in the case of Mars, Jupiter, Saturn, the Earth, and the Moon. In some cases eclipses are rendered as well.

Planet-plotting functions are concerned with plotting the appearance of a planet or moon. Other functions are provided for producing finder charts to aid in locating the position of planets or moons. For instance, `VenusChart` generates a graphic showing the apparitions of Venus during a given eight-year interval. You can print this chart and refer to it whenever you need to know whether Venus is visible on a given night. A similar function is `OuterPlanetChart`, which shows the position of the outer planets over at least an eleven-year interval.

One other function available is `JupiterMoonChart`, which is similar to `PlanetChart`, except that it shows the position of the Galilean moons of Jupiter over a specified time interval.

Setting Your Site Location

■ Load the package.

```
In[1]:= <<Astronomer`HomeSite`

        Astronomer is Copyright (c) 1997 Stellar Software
```

If you have not already configured the `HomeSite.m` file with your site location and time zone, then you must make a call to `SetLocation`. Many of the functions used in this chapter produce results that are independent of your specific site location; however, a few functions will produce results that are dependent on your time zone.

■ This sets your location to Melbourne, Australia.

```
In[2]:= SetLocation[GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    GeoAltitude  ->   0.0*KiloMeter,
                    TimeZone     ->  11];
```

■ 5.1 The PlanetPlot Function

`PlanetPlot` is useful for showing a Mercator projection of the surface of a planet. In the case of the Earth, the shadow of the Moon is also shown during a solar eclipse. Features on the surface of Mars and the clouds on Jupiter are displayed with this function as well.

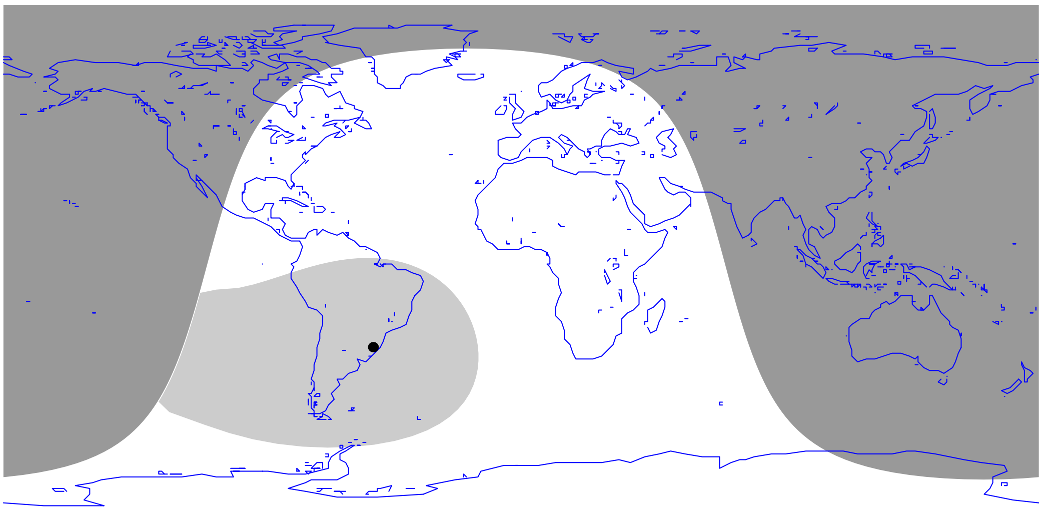
PlanetPlot[*planet*, *date*]	plot the *planet* on the given *date*
Shading -> False	the night side of the *planet* unshaded
FeatureLabels -> True	labeling of features on the *planet*
Features -> *features*	additional surface features
PlotRange -> *range*	a smaller part of the plot

Plotting surface features in two dimensions.

A typical use of PlanetPlot is to plot the shadow of the Moon on the surface of the Earth during a solar eclipse.

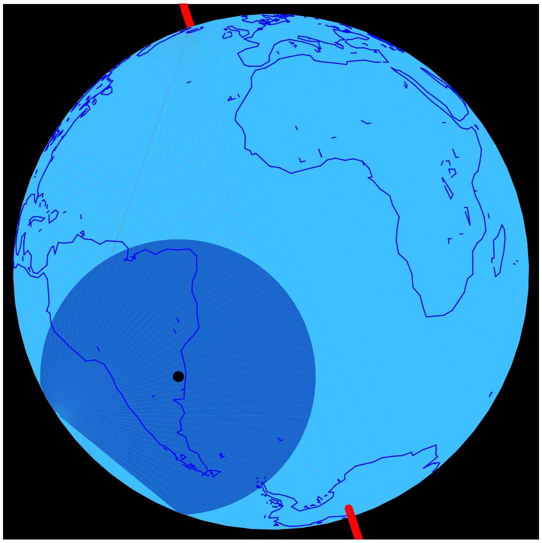
■ Here PlanetPlot creates a plot of part of the 1994 solar eclipse that passed across South America. The region of totality is shown with a small black dot, and the region where a partial eclipse is visible is indicated by the shadow around that dot. The darker region over Asia and the Pacific is the night side of the Earth.

```
In[3]:= PlanetPlot[Earth, {1994,11,4,0,0,0}];
```



■ Here is a three-dimensional plot of the same eclipse in 1994.

```
In[4]:= PlanetPlot3D[Earth, {1994,11,4,0,0,0}];
```



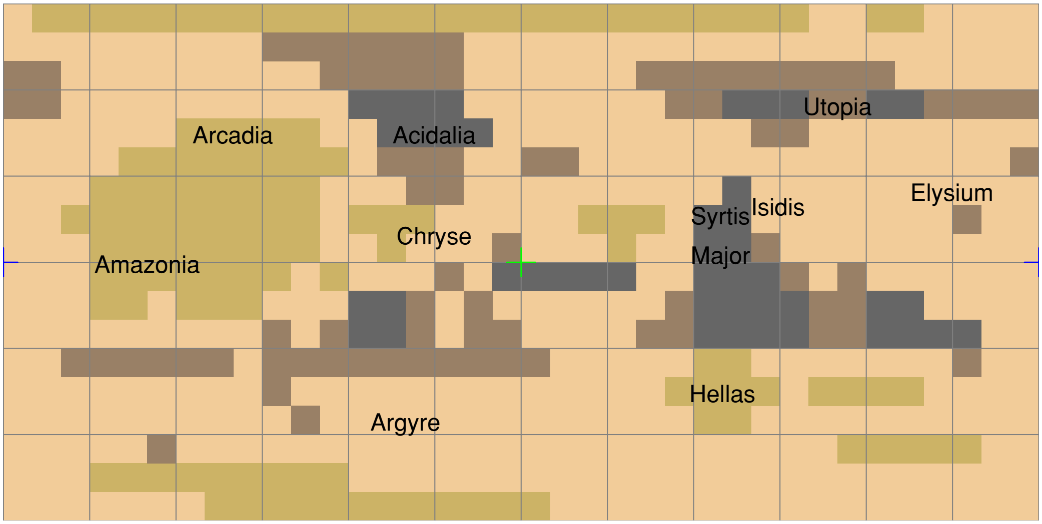
When using `PlanetPlot` to display the state of the Earth during a solar eclipse, you will notice additional gray areas that represent the shadow of the Moon. The shadow is split into two distinct regions. The center part of the shadow is where the Sun is totally blocked out by the Moon, and its size is typically about 100km across. This center portion sweeps across the surface of the Earth at roughly 2000km/hour, and so any given point is in darkness for at most a few minutes. `PlanetPlot` represents this total eclipse region as a very small black dot.

The outer part of the shadow is where the Sun is only partly blocked by the Moon, and is very much larger at approximately 7,000km in diameter, or about half the diameter of the Earth itself. `PlanetPlot` shows this partial eclipse region as a slightly grayed out area surrounding the black dot signifying total eclipse.

Plots of other planets can be produced as well.

■ This is a two-dimensional map of Mars, with the shaded region away from the Sun not shown.

```
In[5]:= PlanetPlot[Mars, {1993,11,17,3,20,0},
                 Shading       -> False,
                 FeatureLabels -> True];
```



By default the full Mercator projection of the planet is shown, extending from longitude -180 to 180, and from latitude -90 to 90. You can use the option `PlotRange` to zoom into a smaller region.

■ 5.2 The PlanetPlot3D Function

`PlanetPlot3D` is useful for displaying how a planet would look from a given viewpoint on a given date. Typically, the default viewpoint is the Earth, but if the planet is the Earth itself, then the default viewpoint is the Sun.

`PlanetPlot3D[`*planet*`,` *date*`]`	make a three-dimensional plot of the *planet* on the given *date*
`Shading -> False`	the night side of the *planet* unshaded
`FeatureLabels -> True`	labeling of features on the *planet*
`Features ->` *features*	additional surface features
`ViewPoint ->` *object*	view from another *object*
`ViewVertical ->` *object*	rotation of plot to make *object* appear vertical

Plotting surface features in three dimensions.

For any planet, the general color, axis orientation, and solar illumination is always shown by `PlanetPlot3D`. However, for the Earth, the Moon, and Mars, surface features are also shown. For Jupiter, cloud features such as the Great Red Spot are shown; and for Saturn, rings are displayed.

There are other special circumstances that the `PlanetPlot3D` function can indicate. For example, the Moon's shadow is shown on the Earth during a solar eclipse, and the Earth's shadow is shown over the Moon during a lunar eclipse. All the transits, occultations, shadows, and eclipses of the Galilean moons are shown with Jupiter. Similarly, transits of Mercury and Venus are shown on the Sun's disk.

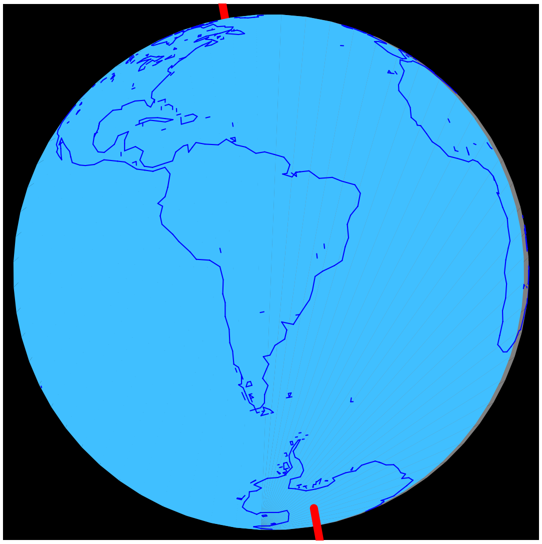
`PlanetPlot3D[Earth,` *date*`]`	show umbra and penumbra shadows on the surface of the Earth during a solar eclipse
`PlanetPlot3D[Moon,` *date*`]`	show umbra and penumbra shadows on the surface of the Moon during a lunar eclipse
`PlanetPlot3D[Sun,` *date*`]`	show transits of Mercury and Venus across the solar disk; show Moon during a solar eclipse
`PlanetPlot3D[Mars,` *date*`]`	show surface features and polar caps
`PlanetPlot3D[Jupiter,` *date*`]`	show the Great Red Spot, the three lesser known White Spots, and the four Galilean satellites
`PlanetPlot3D[Saturn,` *date*`]`	show the orientation of the rings

Listing of planetary details returned by PlanetPlot3D.

`PlanetPlot3D` also works with `Moon`. The function lets you label features as well.

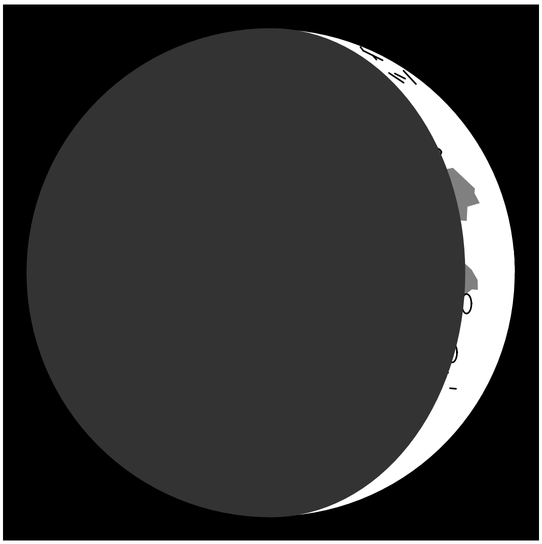
■ Here `PlanetPlot3D` displays a three-dimensional plot of the Earth as seen from Mars on the given date.

```
In[6]:= PlanetPlot3D[Earth, {1993,11,17,3,20,0},
                     ViewPoint -> Mars];
```



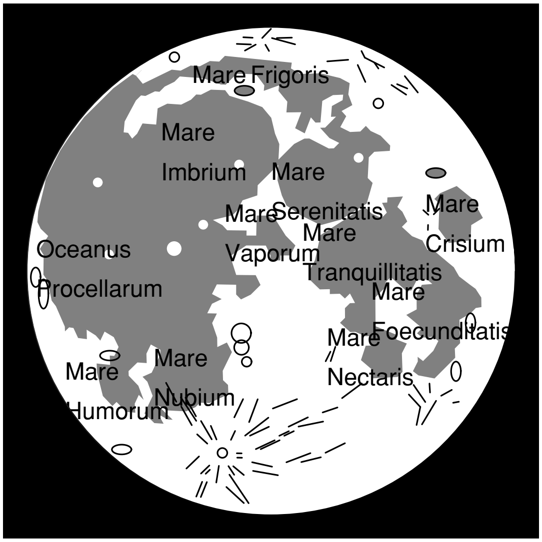
■ A plot from Earth's viewpoint shows the crescent shape of the Moon just after the new moon.

```
In[7]:= PlanetPlot3D[Moon, {1993,11,17,3,20,0},
                     ViewPoint -> Earth];
```



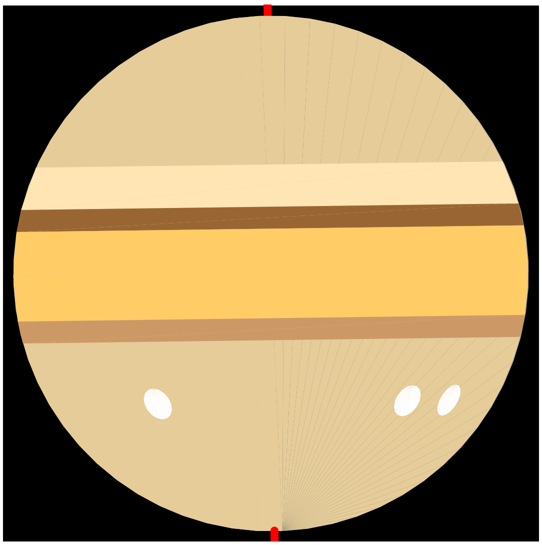
■ Use `FeatureLabels -> True` to label the surface features on a full moon.

```
In[8]:= PlanetPlot3D[Moon, FullMoon[], FeatureLabels->True];
```



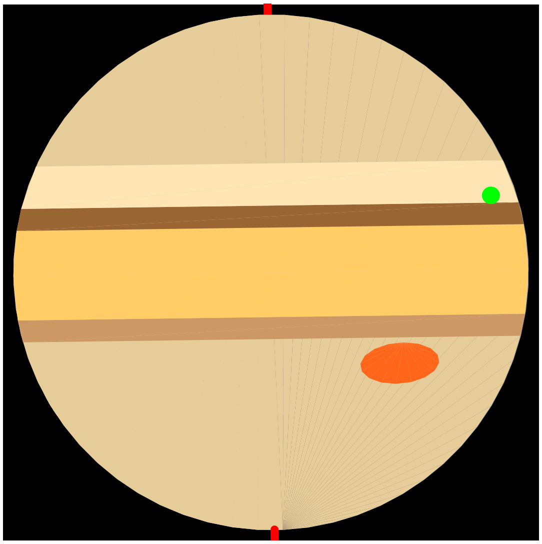
■ The Great Red Spot happens to be at the back of Jupiter at 03:20 on 1993 November 17. The Great Red Spot and the three White Spots make one full rotation around Jupiter in a period of nearly 10 hours. The precise position of the Great Red Spot is adjusted by setting `$JupiterGreatRedSpotLongitude`.

```
In[9]:= PlanetPlot3D[Jupiter, {1993,11,17,3,20,0}];
```



- In this plot, one day later, the Great Red Spot is visible on the lower right. The Galilean moon Io, represented by the green dot, is in transit across the Jovian disk and is just about to egress on the right, or westward, side of Jupiter.

```
In[10]:= PlanetPlot3D[Jupiter, {1993,11,16,3,20,0}];
```



In the plot of Jupiter, black dots show the shadows of the Galilean moons when they happen to fall on the Jovian disk. Similarly, Galilean moons are shown in a slightly darker green color if they are eclipsed from the Sun but still visible from the Earth.

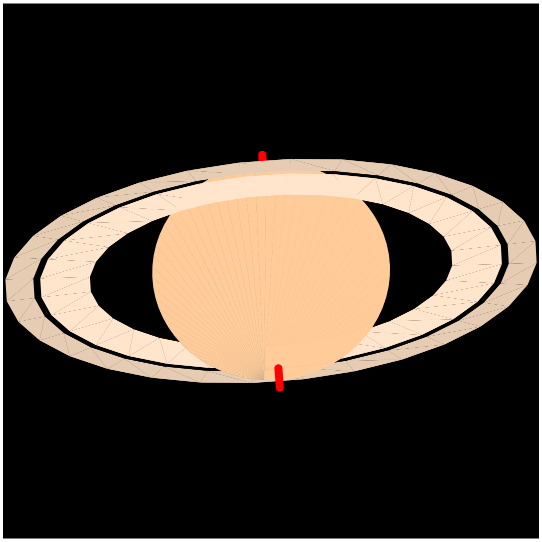
Other Planets

During 1995 the rings of Saturn appeared edge-on as viewed from the Earth, but seven years later, in the year 2002, they become fully open again, just as they were in 1987. Ring features such as these are shown in the graphic.

In the case of Mars, surface features you might see in a telescope are displayed in the graphic. To help you align the features with a two-dimensional map, a green cross is placed at zero longitude and latitude, and grid lines are marked 30 degrees apart from that point. During a Martian winter, the appropriate polar cap is indicated with a white area, although this is not always visible through a telescope.

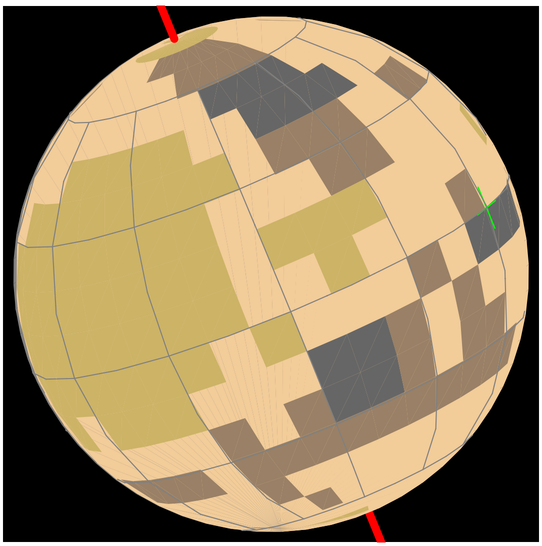
- In this plot, you can see that the closer part of the rings are covering the northern tip of Saturn, which is in the direction of the north celestial pole.

```
In[11]:= PlanetPlot3D[Saturn, {2002,1,1}];
```



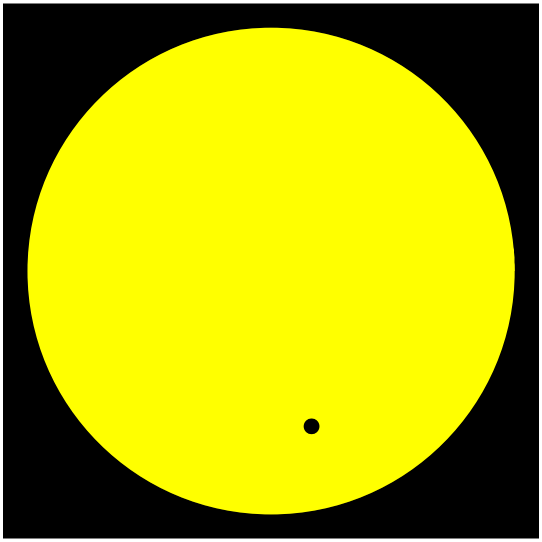
- Note the zero of longitude and latitude, indicated with the green cross, on the right edge of Mars. The main feature covering most of the left is Amazonia.

```
In[12]:= PlanetPlot3D[Mars, {1993,11,17,3,20,0}];
```



■ This plot shows the transit of Venus across the solar disk on 1882 December 7.

```
In[13]:= PlanetPlot3D[Sun, {1882,12,7,4,0,0}];
```



Finally, you can show transits of Venus across the solar disk. Transits of Venus are quite rare, but the next one is expected in the year 2004. See the Appendix for a list of the years when transits occur. `EclipseBegin` can be used to compute the precise dates.

Options

There are a number of options available with `PlanetPlot3D`. The `ViewPoint` and `ViewVertical` options are particularly useful. By default `ViewVertical -> {0,0,1}` causes the graphic to be aligned so that the vertical is perpendicular to the plane of the Earth's orbit around the Sun. That is, the horizontal is parallel to the ecliptic. However, you can set that option to any object; for example, `ViewVertical -> Zenith` aligns the graphic so that up corresponds to your local vertical.

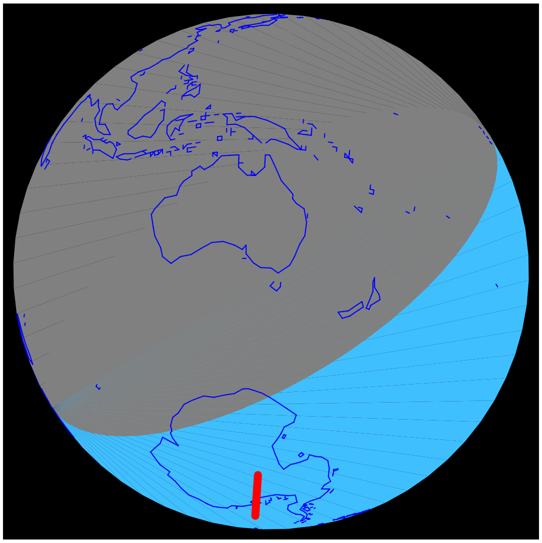
Thus, `PlanetPlot3D[Saturn, {1993,11,17,3,20,0}, ViewVertical -> Zenith];` effectively gives you the telescopic view of Saturn, with the horizontal and vertical in the graphic corresponding to the horizontal and vertical of your current location on Earth. Of course if you are using a telescope which inverts the view (and most telescopes do invert the image–that is, rotate it 180 degrees) then use the option `ViewVertical -> Nadir`.

Similarly, you can set `ViewVertical -> Sun` to align so that the Sun is in the direction of the top of the graphic.

Another option available is `ViewPoint`. The default value is `Automatic`, which refers to either `Earth` or `Sun` depending on the planet you are viewing. If you are viewing Earth, the default is `ViewPoint -> Sun`, which shows the Sun's viewpoint. However, you can use, say, `ViewPoint -> Zenith` to show the Earth as viewed from directly above your current location. Similarly, `ViewPoint -> SouthCelestialPole` shows the Earth as seen from below the South Pole.

- Observe a plot of the Earth as seen from directly above the current location, which is Melbourne, Australia in this case. The part of the globe that is not illuminated by the Sun is correctly shown here. Shading can be switched off with the option setting `Shading -> False`.

```
In[14]:= PlanetPlot3D[Earth, {1994,11,17,3,20,0},
                      ViewPoint -> Zenith];
```



Yet another option, available to both `PlanetPlot3D` and `PlanetPlot`, is `Features`. This option lets you add surface features and other markings to an object. The default value is `Features -> {}`.

The value required by the `Features` option must be built using normal graphics primitives such as `Point`, `Line`, `Rectangle`, `Disk`, `Circle`, `Polygon`, and `Text`. You can also use attributes such as `RGBColor`, `PointSize`, and `Thickness`.

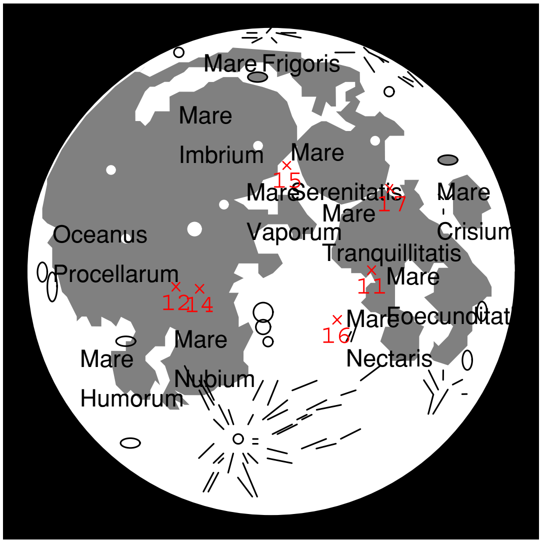
The coordinates supplied to the graphics primitives must be given in essentially planetographic coordinates; that is, the first number must be the longitude in degrees, and the second number must be the latitude in degrees. An optional third number adds altitude in kilometers. For example, the option `Features -> {RGBColor[1,0,0], Circle[{-11, -43}, 1.2]}` corresponds to a red circular "crater" at a planetographic longitude of -11 degrees and latitude of -43 degrees. It is 1.2 degrees in radius as measured from the center of the planet. Be careful to give angles in degrees, rather than radians.

■ Here are specific graphics primitives to label the Apollo lunar landing sites.

```
In[15]:= myfeatures = Apply[{RGBColor[1,0,0],
              Line[{#2+{1, 1}, #2-{1, 1}}],
              Line[{#2+{1,-1}, #2-{1,-1}}],
              Text[#1, #2+{0,-3}]}&, {
                     {"11", {+23.82,+ 0.67}},
                     {"12", {-23.38,- 3.20}},
                     {"14", {-17.47,- 3.67}},
                     {"15", {+ 3.65,+26.10}},
                     {"16", {+15.52,-11.00}},
                     {"17", {+30.77,+20.17}}}, 1];
```

■ This displays the features of the Moon. The `Shading` option is used to suppress the shading of the night side of the Moon.

```
In[16]:= PlanetPlot3D[Moon, {1998, 1, 4},
                 Shading      -> False,
                 FeatureLabels -> True,
                 Features     -> myfeatures];
```



■ 5.3 The RiseSetChart Function

`RiseSetChart` is useful for determining when a planet is visible above the horizon at night, during the course of a year.

`RiseSetChart[`*object*`,` *year*`]`	chart the local rising and setting times of the *object* during the course of the *year*
`GeoLatitude ->` *latitude*	a different geographic *latitude*
`DaylightSaving -> Automatic`	an allowance for clocks being shifted forward one hour for four months over summer

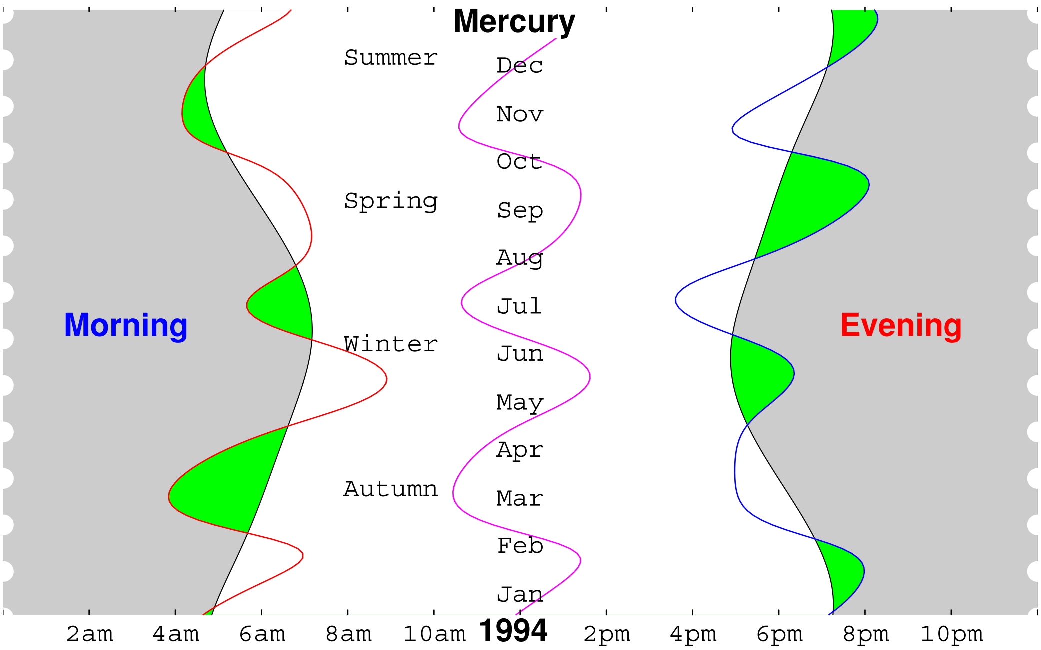
Producing a chart of rising and setting times.

In the graphic, gray areas represent night and green areas show when the object is visible above the horizon during the night. Meridian transits occur on the cyan line. The red line is the local rising time and the blue line is the local setting time. These local times depend on your geographic latitude; this can be changed using `SetLocation`, or more simply by passing a value for the option `GeoLatitude` to `RiseSetChart`.

Focus on the green areas, as they will tell you month by month whether the planet is visible in the evening or morning hours. You can read precise times at the bottom of the graphic.

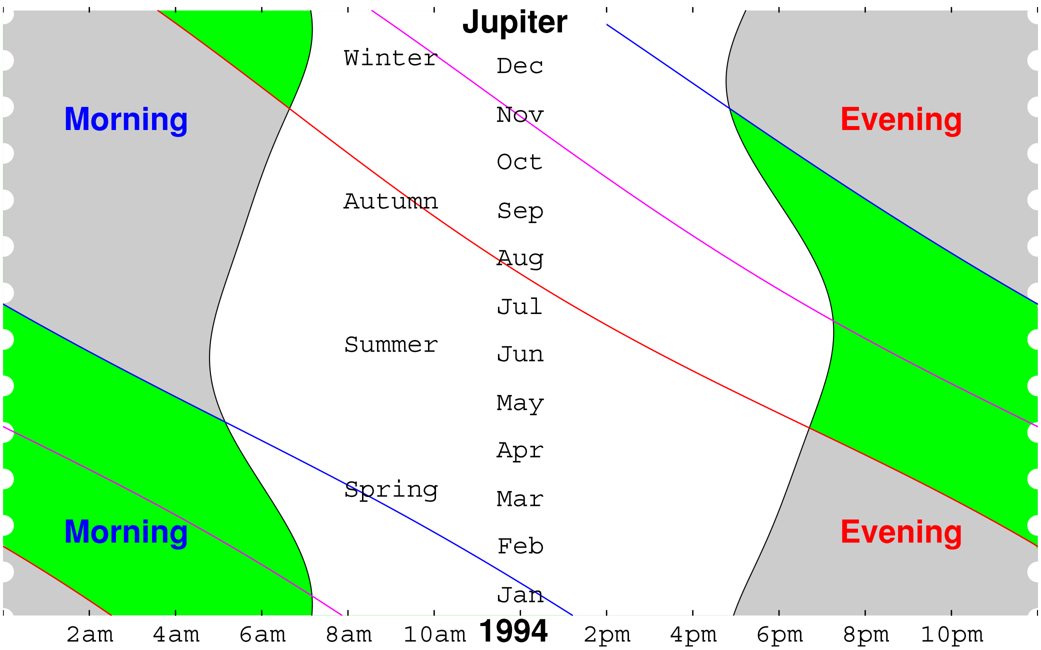
- A `RiseSetChart` shows the rising and setting times of Mercury during the year 1994, appropriate for an observer situated 35 degrees south of the equator. By focusing on the green areas, you can see that Mercury is visible in the evening just after dusk during late January, late May, and September.

```
In[17]:= RiseSetChart[Mercury, 1994, GeoLatitude -> -35Degree];
```



- A chart of Jupiter shows the rising and setting times during the year 1994, appropriate for an observer situated 35 degrees north of the equator. By focusing on the green areas, you can see that Jupiter is visible in the evening from about May through October.

```
In[18]:= RiseSetChart[Jupiter, 1994, GeoLatitude -> 35Degree];
```



Daylight-saving time can be correctly included, too. The option setting `DaylightSaving -> Automatic` causes clocks to be shifted one hour forward for the four months over summer. The summer months in the vertical axis are highlighted when daylight-saving time is in effect, and a separate horizontal hour axis, shifted one hour to the left, is given at the bottom.

The default value for the option `DaylightSaving` is `None`. In general, you can use `DaylightSaving -> {`*startdate*`,` *stopdate*`}` to set the start and stop dates of daylight-saving time. If you use `DaylightSaving -> Automatic`, the start and stop dates are taken as `{{`*year*`,5,1}, {`*year*`,9,1}}` for the northern hemisphere and `{{`*year*`,11,1}, {`*year*`,3,1}}` for the southern hemisphere.

Other options include `Text->False`, which prevents seasons being printed; and `Mesh->True`, which draws a monthly and two-hourly mesh. You can use the option `AspectRatio` to adjust the aspect ratio of the chart.

■ 5.4 The VenusChart Function

`VenusChart` produces a wall chart that can be used to determine when Venus is visible in the morning or evening sky.

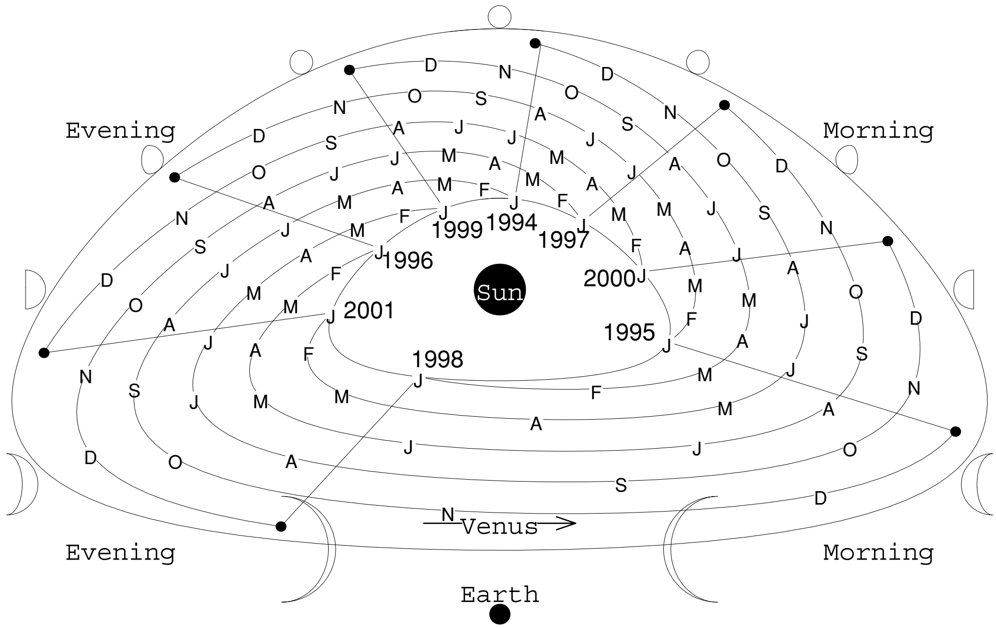
`VenusChart[`*baseyear*`]`	chart the elongation of Venus month by month for the next eight years after the *baseyear*

Charting the future positions of Venus.

Venus is in a near perfect orbital resonance with the Earth, with the result that the `VenusChart` graphic approximately repeats after eight years. Elongations to the right in the graphic are such that Venus rises before the Sun, and hence is visible in the morning hours just before dawn. Similarly, elongations to the left are such that Venus sets after the Sun, and hence is visible in the evening hours just after dusk. The phase and magnitude of Venus is indicated by icons scattered around the rim of the graphic.

- This is the Venus finder chart beginning in year 1994 and ending in 2002.

```
In[19]:= VenusChart[1994];
```



To read the chart, locate the month (labeled with the letters J, F, M, A, M, J, J, A, S, O, N, D) and year desired, then move radially out to the outer ring to see the phase. If Venus is to the left of the graphic, it is visible in the evening sky just after dusk, and if it is to the right, it is visible in the morning sky just before dawn.

For instance, during April 1996, Venus is at its maximum elongation from the Sun and is visible in the evening sky.

■ 5.5 The OuterPlanetChart Function

`OuterPlanetChart` produces a graphic plate that is typically glued to the back of a planisphere created with `Planisphere`. It lets you determine the position of the outer planets month by month for the next few years (15 years for Mars; 11 years for Jupiter; and 28 years for Saturn).

`OuterPlanetChart[`*baseyear*`]`	chart the position of the outer planets beginning at *baseyear*

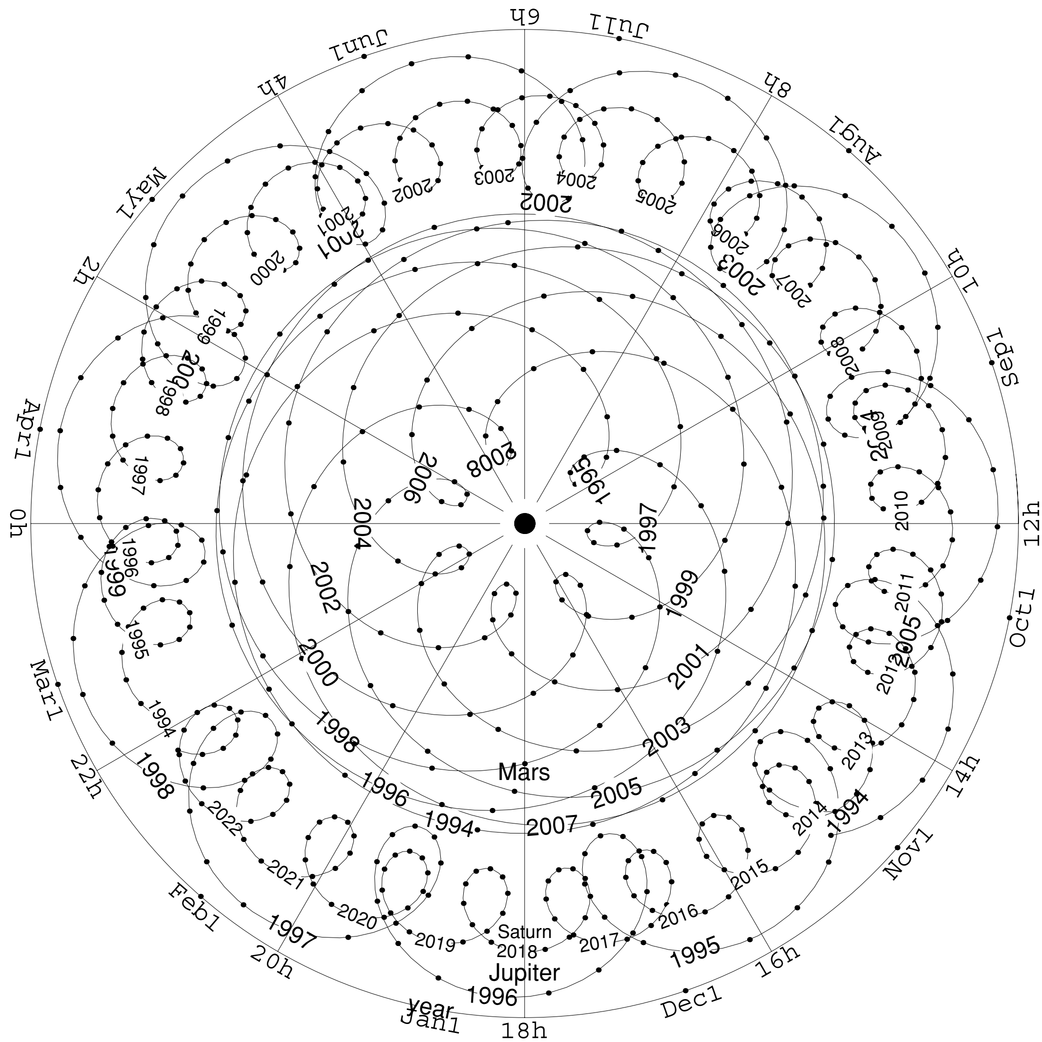
Charting the future positions of the outer planets.

The general procedure for using `OuterPlanetChart` is to generate it once and then glue it to the back of the `Planisphere` plate. The existing curves will last for 11 years or more before you need to generate another `OuterPlanetChart` graphic.

Once the `OuterPlanetChart` graphic is printed, you can easily read off the position of the outer planets for any given month. To find the position of a planet, look for its curve line and locate the year mark you are interested in. Then count dots along the curve to reach the month you want, remembering that the initial year mark is January, the immediate dot after that is February, and so on. After finding the dot, move radially out to the rim to read off the right ascension.

■ Here is the `OuterPlanetChart` starting at year 1994. From this chart you can see that in March 1996, Jupiter has a right ascension of about 19h. If you paste this graphic to the back of a `Planisphere` plate, then you can turn over the plate and locate the 19h point on the ecliptic line to find where Jupiter is in relation to the stars during that month.

```
In[20]:= OuterPlanetChart[1994];
```



Month names are written around the rim of the graphic, as well as right ascension hours. The position of a month name indicates the direction of the Sun at the start of that month.

One final point to note in the graphic is that you can clearly see the retrograde motion of Mars nearly every couple of years. Jupiter and Saturn also have retrograde motion about once a year, but the angle that these planets move backward in the sky is much less than for Mars. In the case of Mars, the distance of the curve from the center, which represents the Earth, gives an indication of true distance and hence the apparent brightness.

The graphic produced by `OuterPlanetChart` is only suitable for printing on, say, a laser-quality printer. It is not intended to be readable on the screen.

■ 5.6 The PtolemyChart Function

`PtolemyChart` produces a graphic plate that can be glued to the back of a planisphere created with `Planisphere`. This function is not as useful as `OuterPlanetChart`, which produces a more accurate graphic. The `PtolomyChart` function lets you determine the position of the planets month by month for the next few years (5 years for Mercury; 8 years for Venus; 15 years for Mars; 11 years for Jupiter; and 28 years for Saturn).

`PtolemyChart[`*baseyear*`]`	chart the universe according to Ptolemy beginning at *baseyear*

Charting the future positions of the planets.

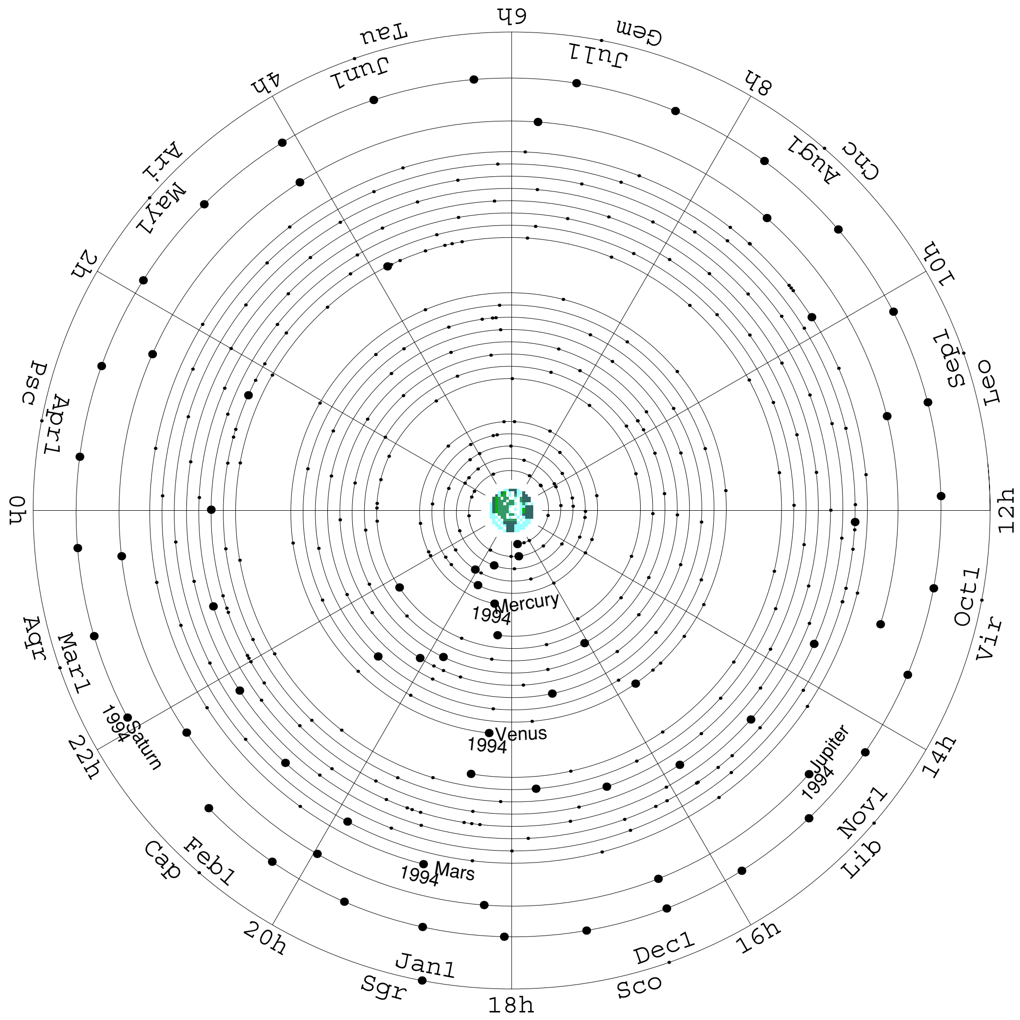
Mercury and Venus are always quite close to the Sun so it is relatively easy to determine their approximate positions for many years in advance. In the graphic, the Sun's position is shown in the outer ring, even though Ptolemy would have placed it in the third ring.

An important point to remember is that the position of Venus repeats almost exactly after eight years. Similarly, the position of Mars repeats roughly every fifteen years.

Big dots represent the start of a new year, that is, January 1, and smaller dots represent months within that year. The smaller dots can sometimes clump together when the planet is undergoing retrograde motion as seen from Earth.

- This graphic shows, for example, that Jupiter is in the constellation of Capricornus throughout the years 1997 and 1998. Mars is in Virgo from January to August, 1997.

```
In[21]:= PtolemyChart[1994];
```



■ 5.7 The SolarSystemPlot Function

`SolarSystemPlot` is useful for displaying a plot of the solar system on a given date.

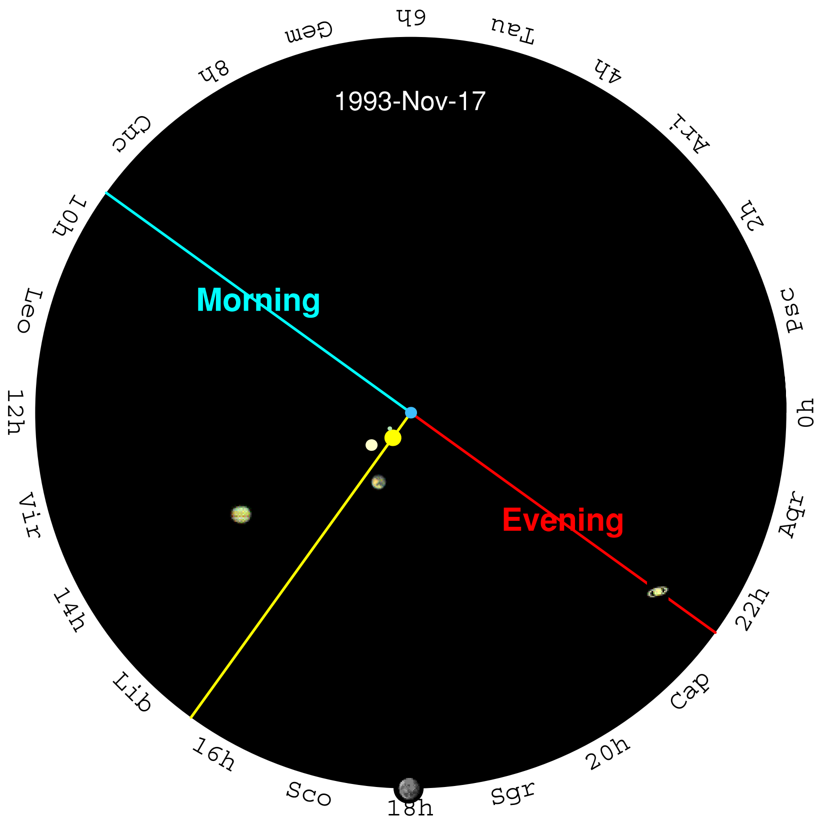
`SolarSystemPlot[`*date*`]`	plot the general layout of the solar system on the given *date*
`Distance -> `*distance*	a bigger or smaller field of view; default is `12 AU`, which goes out to just past Saturn
`Moon -> False`	suppression of lunar image on the edge of the graphic
`ViewPoint -> Sun`	the Sun, rather than the default Earth, at the center
`Text -> False`	suppression of the date text at the top of the graphic
`MagnitudeScale -> `*scale*	increase the size of the planet images

Plotting a representation of the solar system.

Earth is the blue dot at the center, and the Sun is the bigger yellow dot. Planets that happen to be near the yellow line can only be seen from the Earth at dusk or dawn. Examples are Venus and Mercury, which are always close to the yellow line. Planets near the red line are high in the sky when the Sun sets, and hence they are visible only in the evening sky for a certain length of time, until they set in the west. Similarly, planets near the blue line are high in the sky when the Sun rises, and hence they are visible only in the morning sky for a period of time after they rise in the east. Planets nearly 180 degrees away from the yellow line are visible all night long.

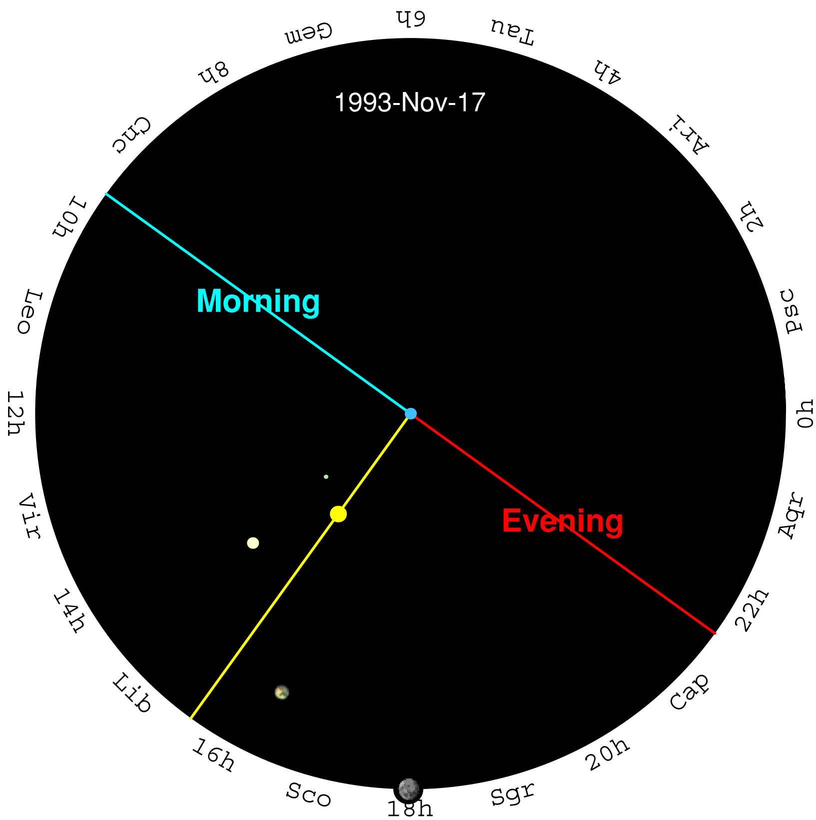
■ Here is a plot of the solar system on 1993 November 17. Most of the planets are in the direction of the Sun, represented by the yellow line, and hence not easily visible from the Earth. However, Saturn is a good distance away from the yellow line and close to the red line, so it is visible in the evening sky for about half the night after sunset.

```
In[22]:= SolarSystemPlot[{1993,11,17}];
```



■ The option `Distance` is used to show the plot just out to the orbit of Mars. The direction of the Moon is shown on the outer rim, in this case near the 18h mark.

```
In[23]:= SolarSystemPlot[{1993,11,17}, Distance->3*AU];
```



To zoom into a smaller region showing, for instance, as far out as the orbit of Mars, you can use the option `Distance`.

By default the Earth is placed at the center, but you can use `ViewPoint -> Sun` to put the Sun at the center. In this case the "Morning" and "Evening" lines will not be shown. To stop the lines being drawn in the case of Earth at the center, use `ViewPoint -> GeoCentric`.

The AspectChart Function

Scientific Astronomer includes functions that astrologers can use. `AspectChart` uses ancient astrological symbols to represent the aspects, or relative positions, of the planets. The chart is, in effect, the same as `SolarSystemPlot`, but is represented in a more symbolic and less graphical manner.

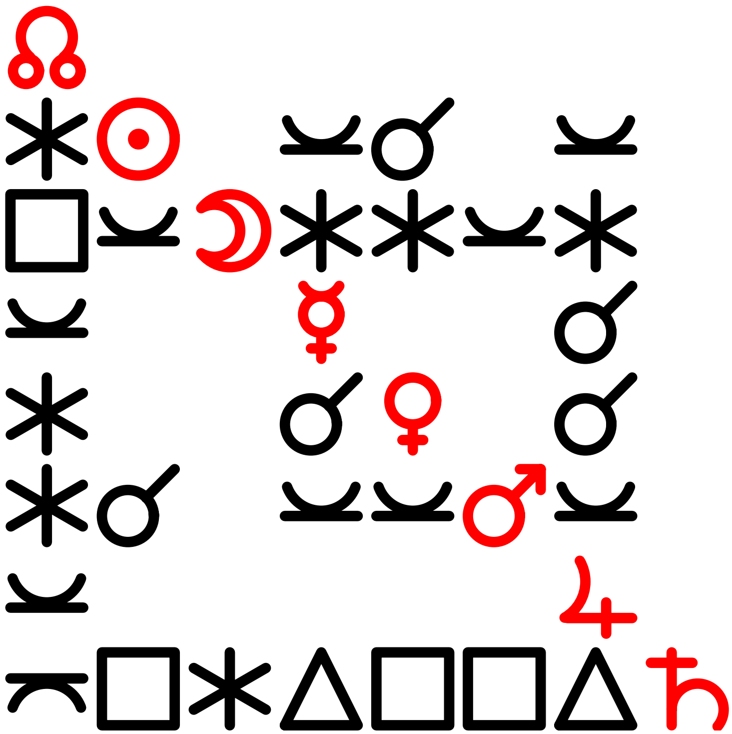
`AspectChart[`*date*`]`	return the astrological aspect chart for the given *date*
`GeoLongitude -> `*longitude*	the geographic longitude to use for the chart
`GeoLatitude -> `*latitude*	the geographic latitude to use for the chart
`TimeZone -> `*timezone*	the time zone to use for the chart

Generating an astrological aspect chart.

Although `AspectChart` returns a seemingly incomprehensible array of mystical symbols, it is in some contexts a useful representation of the relative positions of the Sun, Moon, and planets.

- This is the astrological aspect chart for the given date, with the specified geographic location and time zone.

```
In[24]:= AspectChart[{1993,11,17,3,20,0},
                    GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    TimeZone     ->  11];
```



Astrological symbols on the diagonal denote the ascendant ☊, Sun ☉, Moon ☽, Mercury ☿, Venus ♀, Mars ♂, Jupiter ♃, and Saturn ♄. The ascendant is the name of the point on the zodiac that is rising (or ascending) near the eastern horizon. Note that the symbols for Venus and Mars are also the symbols for female and male.

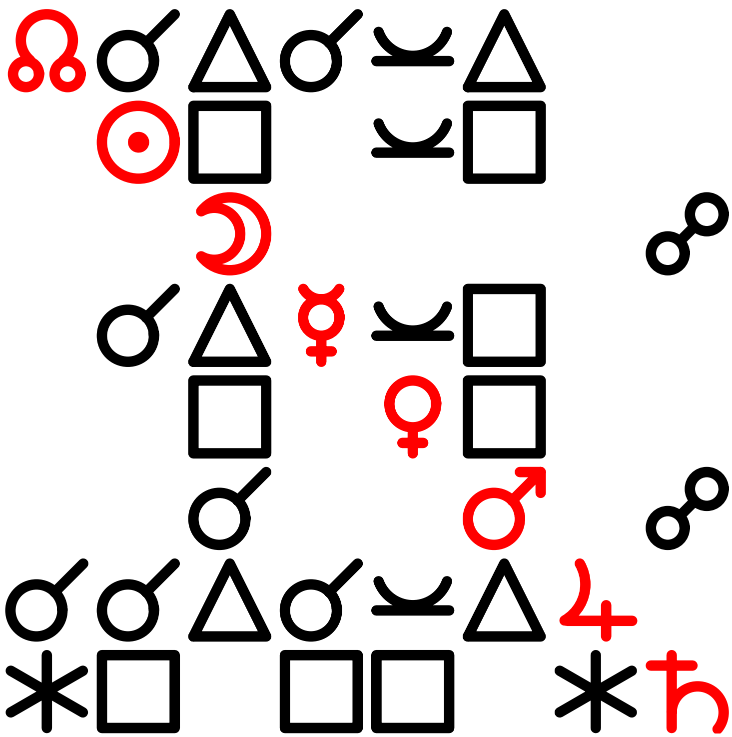
The off-diagonal entries show the aspect, or relative position, of pairs of objects on the diagonal. There are five main aspects. The first is *conjunction* ☌, which occurs when two objects lie approximately in the same direction (*i.e.*, as if they were conjoined); the second aspect is *sextile* ⚹, which occurs when two objects are approximately 60 degrees apart (or a sixth of a full circle; note that the sextile symbol has six points); the third aspect is *quadrature* □, which indicates when the objects are approximately 90 degrees apart (or a quarter of a full circle); the next aspect is *trine* △, which indicates a 120 degree separation (or a third of a full circle); and the final aspect is *opposition* ☍, which indicates when two objects are 180 degrees apart (or opposite to each other in the sky).

The five main aspects cover most possibilities; two additional minor aspects are *semisextile* ⚺, for objects approximately 30 degrees apart (which is half of a sixth of a full circle); and *quincunx* ⚻, for objects approximately 150 degrees apart (which is five twelfths of a full circle).

The entries in the chart are arranged so that the object in the same row as an aspect rises before the object in the same column. Thus, when any aspect symbol is in the first row (the ascendant row), the corresponding object on the diagonal will be above the horizon.

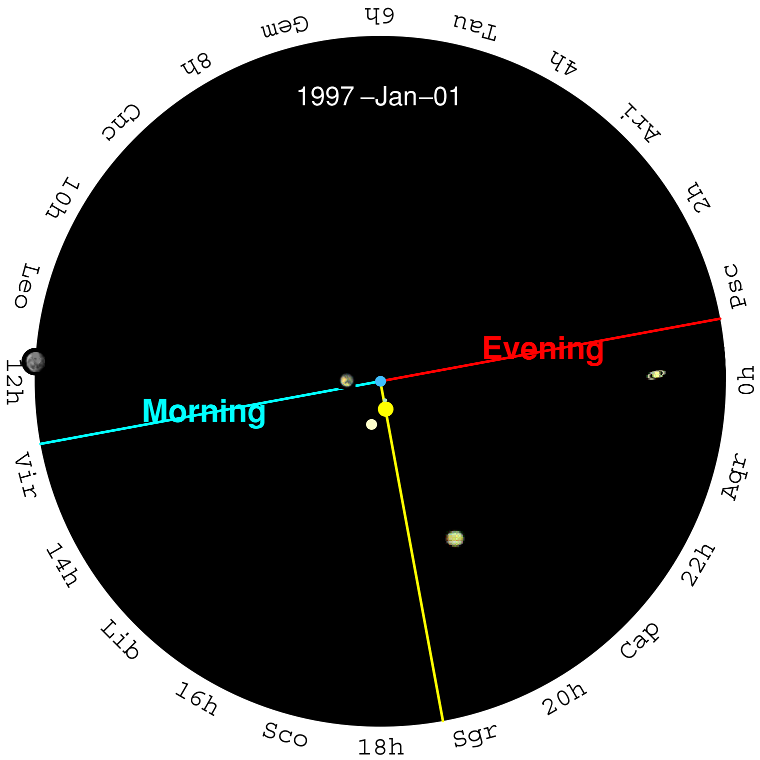
- This instance of `AspectChart` is for the default location at 07:00 on 1997 January 1. To read the chart, first consider the case of the Moon ☽, the third object on the diagonal. You can find all the aspects of the Moon by looking in the same column and row as the Moon. There is only one aspect symbol in the same row as the Moon; an opposition ☍ to Saturn ♄. All other objects listed on the diagonal rise later than the Moon. For instance, the aspect with the ascendant ☊ is trine △, and so the Moon is 120 degrees higher than the point on the eastern horizon. Hence the Moon has been above the horizon for 8 hours. The next aspect of the Moon is quadrature □ with the Sun ☉, which indicates the Moon is at quarter phase. Looking further down the column, you see the Moon is in conjunction ☌ with Mars ♂. For Venus ♀, there are only three major aspects. Venus is in quadrature □ with the Moon ☽ and Mars ♂, and so rises 6 hours later than these objects. Venus is also in quadrature □ with Saturn ♄, but rises 6 hours earlier because the aspect is in Venus' column. Note that at sunrise the Sun ☉ must be in conjunction ☌ with the ascendant ☊, as in this example. Similary, at sunset the Sun must be at opposition ☍ to the ascendant ☊.

```
In[25]:= AspectChart[{1997,1,1,7,0,0}];
```



■ The information returned by `AspectChart` is also contained in `SolarSystemPlot`. In this graphic you see all the aspects between the planets, Sun, and Moon. For instance, the conjunction of the Moon and Mars and the opposition of the Moon and Saturn are visible. Remember that the Earth is in the center of this graphic.

```
In[26]:= SolarSystemPlot[{1997,1,1,7,0,0}];
```

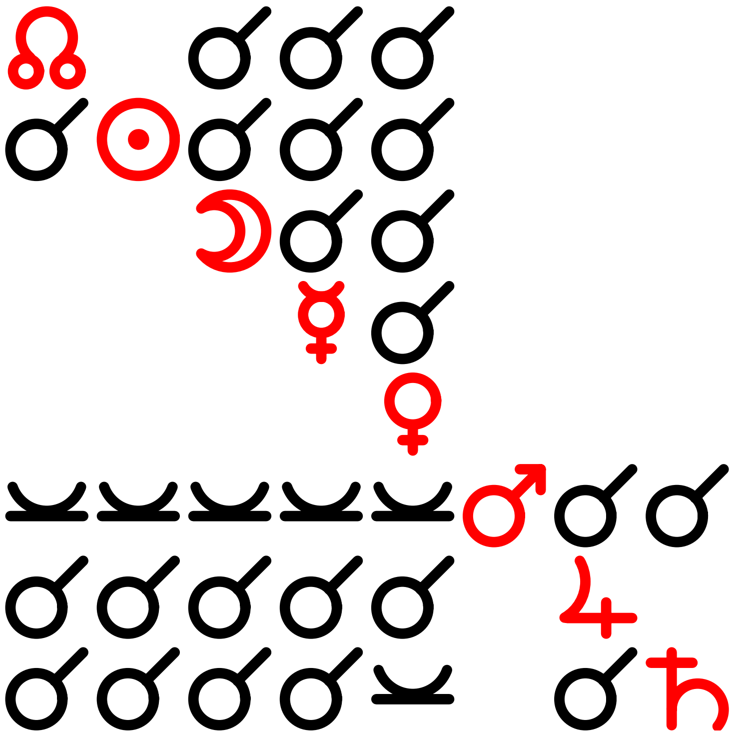


Some key points to be aware of are that the rising of any planet occurs when the planet is in conjunction with the ascendant. Similarly, a planet sets when it is in opposition to the ascendant. A full moon is in opposition to the Sun, and a new moon is in conjunction with the Sun. Venus is at its brightest when it is not in conjunction with the Sun. Any object in quadrature with the ascendant is at its highest point in the sky. These rules apply to other combinations of planets and aspects as well. Remember that the object in the same row as an aspect rises before the object in the same column as the aspect.

When there are many alignments between the planets, `AspectChart` will indicate this with many conjunction ☌ symbols.

- At sunrise on 2000 May 4, the Sun, the Moon, and all the bright planets will rise as one above the eastern horizon. Although this type of cosmic alignment is relatively rare, it has happened before during the previous millenia (a similar event occurred at sunrise on 748 November 1). Here is an aspect chart clearly showing the alignment, with almost all objects in conjunction ☌ with the others. Mars ♂ is slightly out of the alignment, rising an hour too early.

```
In[27]:= AspectChart[SunRise[{2000,5,4}]];
```



The BirthChart Function

`BirthChart` produces a chart containing essentially the same information as `SolarSystemPlot`, except that it uses astrological symbols to represent the planets and the zodiac constellations. The horizontal line in the chart demarcates the regions above and below the horizon of an observer at the center of the chart. Thus, any planet symbol above this line corresponds to a planet above the observer's horizon.

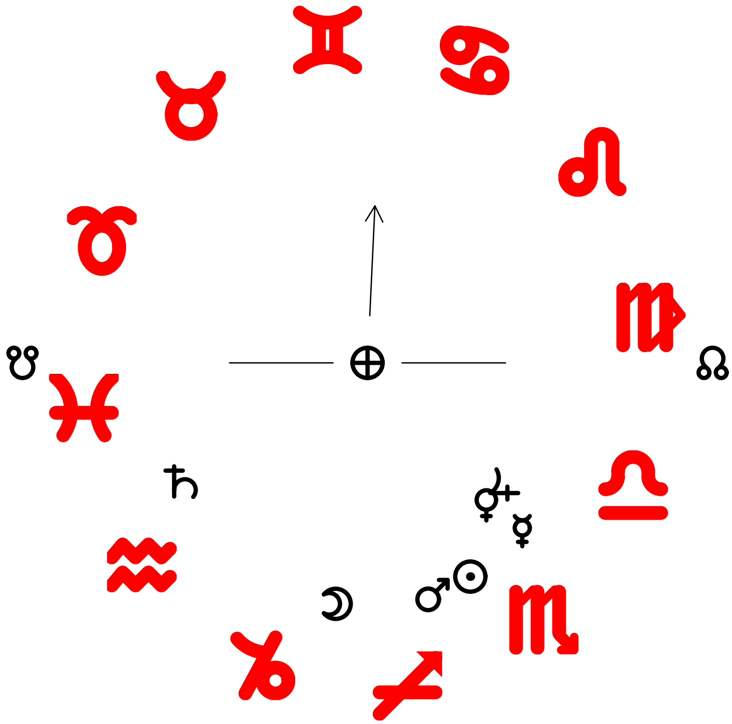
BirthChart[*date*]	return the astrological birth chart for the given *date*
GeoLongitude -> *longitude*	the geographic longitude to use for the chart
GeoLatitude -> *latitude*	the geographic latitude to use for the chart
TimeZone -> *timezone*	the time zone to use for the chart
Epoch -> Automatic	the epoch to use for the position of the zodiac constellations; default is – 500.0 (corresponding to the year 500 B.C.)

Generating a birth chart.

The chart shows a circle containing the 12 zodiac signs with the position of the Sun, Moon, and main planets indicated relative to those signs. At the center of the chart is the Earth ⊕, and on the eastern and western horizons are the ascendant ☊ and descendant ☋. Astrologers use the zodiac constellation nearest the Sun ☉, at the time of birth, as the astrological sign of a person. The position of each zodiac constellation is taken as it appeared in the year 500 B.C., however. Precession, as of the year 2000 A.D., has moved the position of all the zodiac constellations more than one zodiac sign away, but this is not normally taken into account by astrologers. In `BirthChart` you can use the option `Epoch -> Automatic` to get the true position of the zodiac constellations at the time of birth. The default is `Epoch -> -500.0`, which corresponds to the position of the zodiac constellations in the year 500 B.C.

- This is the birth chart for the given date, with the specified geographic location and time zone. All the main planets are below the horizon.

```
In[28]:= BirthChart[{1993,11,17,3,20,0},
                    GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    TimeZone     ->  11];
```

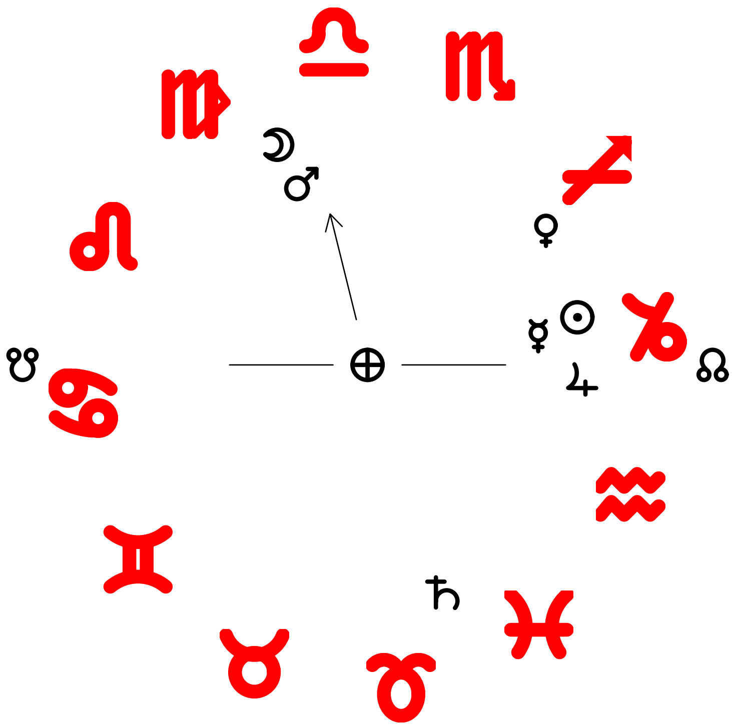


Astrological symbols used for the zodiac constellations are Aries ♈, Taurus ♉, Gemini ♊, Cancer ♋, Leo ♌, Virgo ♍, Libra ♎, Scorpius ♏, Sagittarius ♐, Capricornus ♑, Aquarius ♒, and Pisces ♓.

The arrow in the chart corresponds to the direction of the meridian. For northern hemisphere observers the meridian is due south, and for southern hemisphere observers it is due north. The meridian arrow is always near the vertical in the chart, but it can vary up to 23 degrees on either side of the vertical due to the tilt of the Earth's axis.

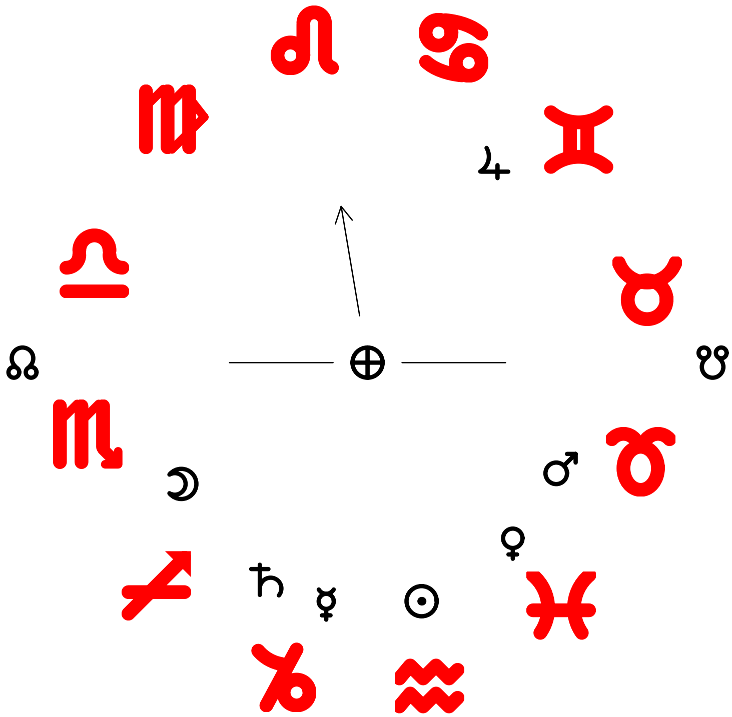
■ This `BirthChart` is for the default location at 07:00 on 1997 January 1. It shows the Sun ☉, Jupiter ♃, and Mercury ☿ rising (or ascending) above the eastern horizon. This chart is for the southern hemisphere, so the ascendant ☊ is on the right, which is the opposite of its location on a northern hemisphere chart. Venus ♀ is higher in the sky near the zodiac sign of Sagittarius ♐. The Moon ☽ and Mars ♂ are in conjunction near Virgo ♍.

```
In[29]:= BirthChart[{1997,1,1,7,0,0}];
```



■ This is the birth chart for Charles Dickens, born at midnight on 1812 February 7. It shows all the planets below the horizon, with the exception of Jupiter ♃. The position of the Sun ☉ is in Aquarius ♒.

```
In[30]:= BirthChart[{1812,2,7,0,0,0},
                   GeoLongitude -> 0*Degree,
                   GeoLatitude  -> 51*Degree,
                   TimeZone     -> 0];
```



■ 5.8 The JupiterSystemPlot Function

`JupiterSystemPlot` is useful for displaying a plot of the four Galilean moons orbiting Jupiter on a given date.

`JupiterSystemPlot[`*date*`]`	plot the general layout of the Galilean moons around Jupiter on the given *date*

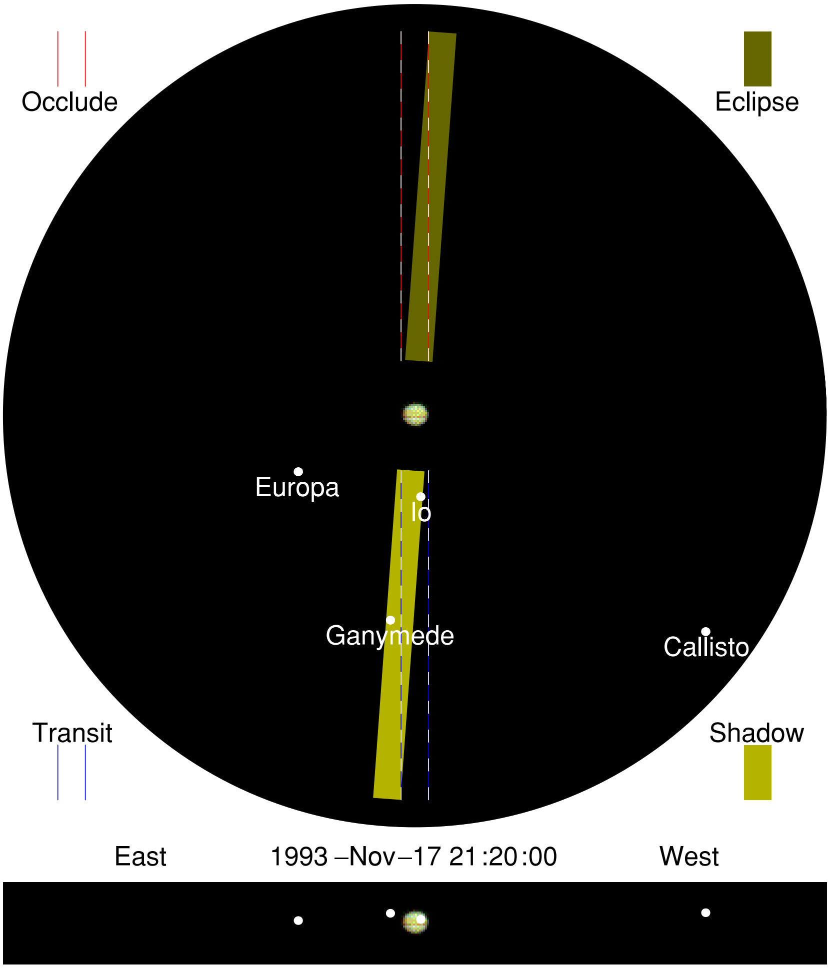
Plotting a representation of the Jovian moon system.

As seen from the Earth, the Galilean moons around Jupiter can undergo various special events every few days. Four types of events are possible. First, a moon can transit across the Jovian disk; second, a moon can cast a shadow on the Jovian disk; third, a moon can hide (or be occluded) behind the Jovian disk; and fourth, a moon can be eclipsed in the shadow of the Jovian disk.

All of these special events are indicated in the `JupiterSystemPlot` graphic for a given date and time.

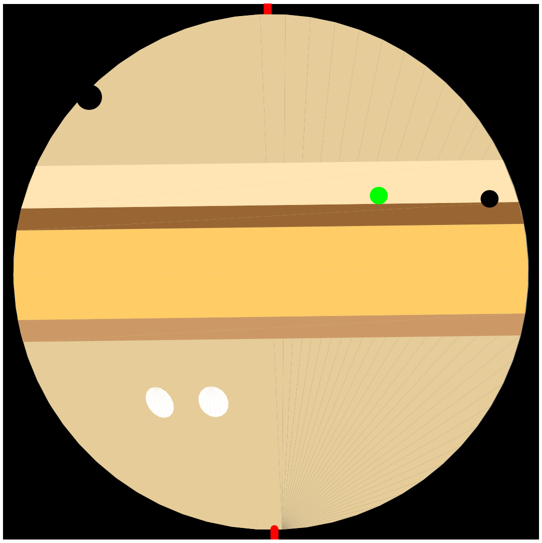
■ The moons Io and Ganymede both fall in the "Shadow" colored region in this graphic, which means their shadows are cast onto the Jovian disk. Similarly, Io falls in the "Transit" region, which means it is in front of the Jovian disk as seen from the Earth. You can confirm this with a call to `PlanetPlot3D`.

```
In[31]:= JupiterSystemPlot[{1993,11,17,21,20,0}];
```



■ As expected, Ganymede's shadow is ingressing on the left or eastern edge, and Io's shadow is egressing on the right or western edge. The green dot is Io itself, which is making a transit.

```
In[32]:= PlanetPlot3D[Jupiter, {1993,11,17,21,20,0}];
```



■ 5.9 The JupiterMoonChart Function

`JupiterMoonChart` produces a plot, for a specified period of time, of the positions of the four Galilean moons orbiting Jupiter.

`JupiterMoonChart[`*date1*`,` *date2*`]`	chart the positions of the four Galilean moons as seen from Earth between the dates *date1* and *date2*
`JupiterMoonChart[`*date*`]`	produce a chart appropriate for the next four days after *date*

Charting Jovian moon positions.

In the graphic that is returned, the four Galilean moons Io, Europa, Ganymede, and Callisto are colored black, red, green, and blue respectively. Jupiter is colored purple, with the width of the line corresponding to one Jovian diameter. The white line above the purple Jovian disk indicates when the Great Red Spot is visible. It is visible for half of its roughly 10-hour rotation period. (You can adjust the position of the spot by setting `$JupiterGreatRedSpotLongitude`.)

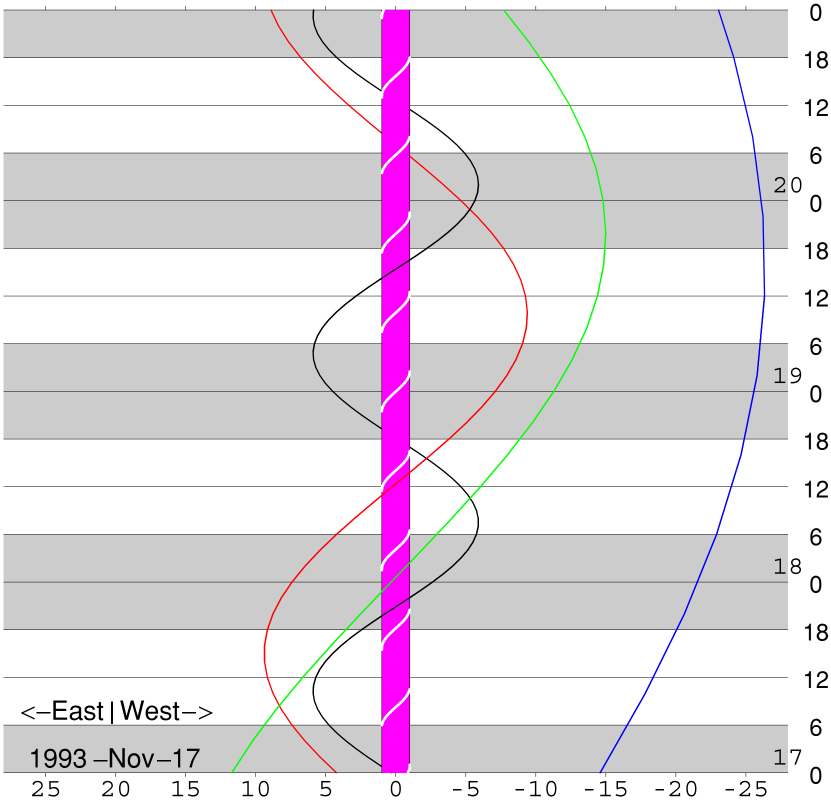
The horizontal scale is in Jovian radii, and the vertical axis shows time marked off in 6-hour intervals of local time, along with the day of the month.

■ A `JupiterMoonChart` graphic displays a Jupiter moon finder chart beginning 1993 November 17 and ending four days later. Local night is shaded with gray bands.

Callisto, in blue and on the right in the graphic, starts off at about 15 Jovian radii west of Jupiter. Over the next couple of nights it moves further away to more than 26 Jovian radii before moving across to the eastern side of Jupiter.

Similary, Io, in black, is first hidden behind Jupiter and then moves to the east; by about 22:00 local time on November 17 it crosses back in front of Jupiter.

```
In[33]:= JupiterMoonChart[{1993,11,17}];
```



Use the option `Text->False` to prevent the date being printed at the bottom of the chart.

6. Eclipse Predicting Functions

During a typical year the Moon orbits the Earth nearly 13 times. Two of those orbits usually pass so close to the direction of the Sun that the Moon casts a shadow onto the surface of the Earth; such events are called solar eclipses. Depending on how close (from the Earth's viewpoint) the Moon and the Sun are to each other, the event is termed either a partial, total, or annular solar eclipse.

You can compute and display such events using *Scientific Astronomer*. For instance, the package provides a function called `Separation` to compute the angular separation between any two celestial objects on any given date, as seen from any viewpoint. When the separation is zero, then one of the objects is eclipsed by the other. You can compute the precise date of such an event with a function like `SolarEclipse`, and then use the `PlanetPlot` function to see how the shadow falls on the object. Additional functions, such as `MoonShadow`, are available to compute the precise position of the shadow; and `EclipseBegin` and `EclipseEnd` are used to give the precise start and end times of the eclipse as seen from a specific location.

Eclipses traditionally refer to alignments involving the Earth, the Moon, and the Sun. *Scientific Astronomer*, however, can handle alignments among any three objects. Typical cases are the Earth, the Moon, and a star for lunar occultations; the Sun or the Earth, with Jupiter and a Galilean moon for various types of shadows, transits, occultations, and eclipses; and the Sun, the Earth, and an inner planet for transits of the planet across the solar disk.

Setting Your Time Zone

■ Load the *Scientific Astronomer* package.

```
In[1]:= <<Astronomer`HomeSite`

        Astronomer is Copyright (c) 1997 Stellar Software
```

This chapter does not include any function that requires a knowledge of your geographic location. Most functions still require that you input your time zone, however; you can set this using `SetLocation` as normal.

■ This sets your time zone to 11 hours ahead of GMT.

```
In[2]:= SetLocation[TimeZone -> 11];
```

■ 6.1 The EclipseTrackPlot Function

`EclipseTrackPlot` is useful for displaying details of the umbra and penumbra regions of either a solar or lunar eclipse. It can also be used to display tracks of occultations of stars or planets by the Moon.

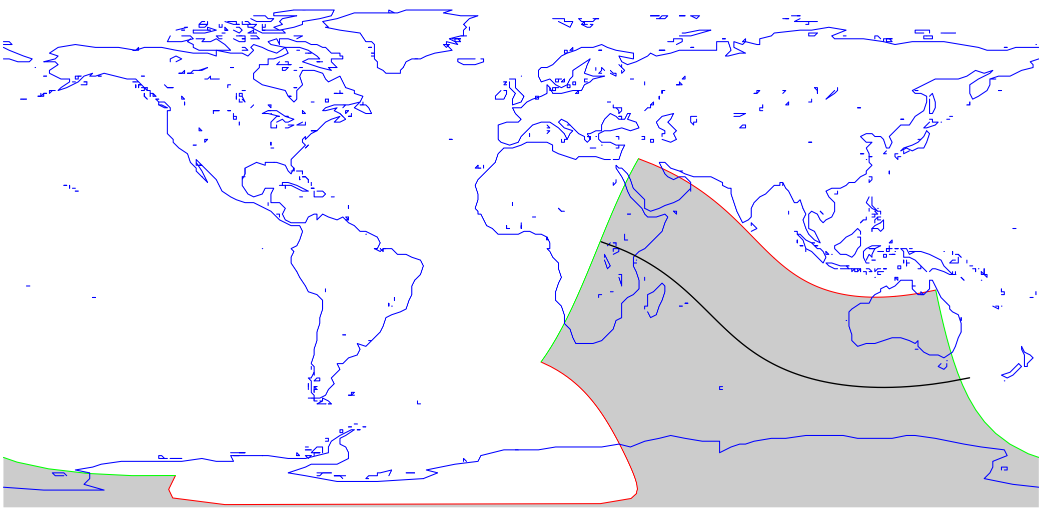
`EclipseTrackPlot[`*object1*`,` *object2*`,` *object3*`,` *date*`]`	plot the track of umbra / penumbra shadows of *object2* caused by the light from *object3* as cast on the surface of *object1* around the given *date*
`EclipseTrackPlot[`*neardate*`]`	plot either the Earth or the Moon, depending on whether *neardate* is near a new moon (for a solar eclipse) or a full moon (for a lunar eclipse)

Plotting the track of a solar or lunar eclipse.

In the graphic that is returned by `EclipseTrackPlot`, the gray area is the region that experiences a partial eclipse at some point during the eclipse. The upper and lower red lines represent the edges of the partial eclipse shadow, and the green lines at the end represent the edges where the partial eclipse ceases because of either sunrise or sunset.

- Here you see the track of the total solar eclipse of 1948 November 1.

```
In[3]:= EclipseTrackPlot[SolarEclipse[{1948,11,1}]];
```



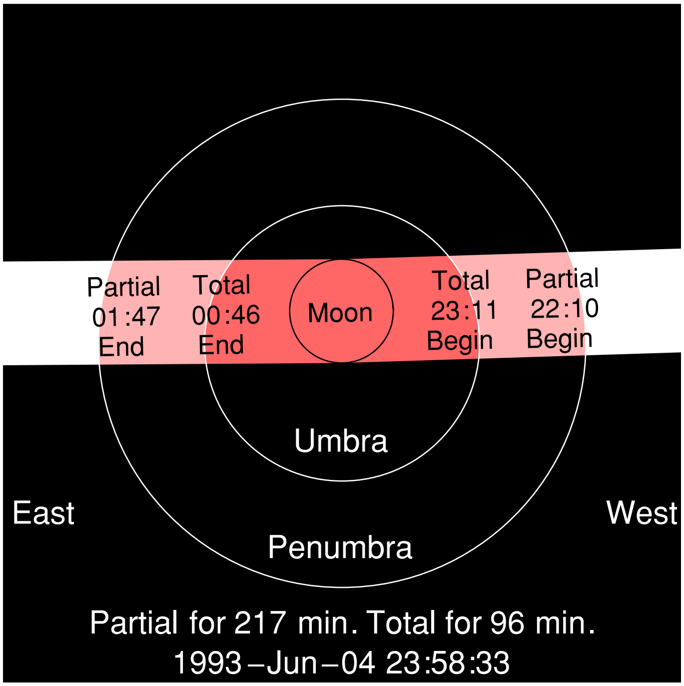
A solar eclipse is only visible from a small portion of the Earth, perhaps a band 100km across, indicated with the black line.

Lunar Eclipses

A lunar eclipse is visible from half the Earth. You can view the eclipse from any point on the side of the Earth facing the Moon at the time it is occurring.

■ The lunar eclipse of June 1993 is total for 96 minutes and begins at 23:11 local time in Melbourne.

```
In[4]:= EclipseTrackPlot[LunarEclipse[{1993,6,5}]];
```



In the graphic, the Moon is the small circle in the center, and over time it sweeps across the band from right to left. The two bigger disks represent the fixed umbra and penumbra shadows of the Earth.

Lunar Occultations

`EclipseTrackPlot` can also be used to find the regions on Earth in which you can see an occultation of a star or a planet by the Moon. A solar eclipse is also an occultation of the Sun by the Moon.

`EclipseTrackPlot[Earth, Moon, Sun, `*date*`]`	plot a solar eclipse track
`EclipseTrackPlot[Earth, Moon, Spica, `*date*`]`	plot a lunar occultation track of the star Spica

Plotting the track of a lunar occultation on the surface of the Earth.

■ On 1995 January 23, there is an occultation of the star Spica by the Moon, but it is visible only from North America. This is a track of the precise region from which the occultation is visible.

```
In[5]:= EclipseTrackPlot[Earth, Moon, Spica,
                          {1995,1,23,11+11,0,0}];
```

As with `PlanetPlot`, you can use the option `PlotRange` to zoom into a smaller part of the surface of the Earth. The default is `PlotRange -> {{-180, 180}, {-90, 90}}`, which shows the entire surface.

Note that you can use the function `EclipseBegin` to determine when the star Spica or any other star is eclipsed by the Moon.

■ 6.2 The MoonShadow and SolarEclipse Functions

`MoonShadow` is useful for computing details of the Moon's shadow during either a total or annular solar eclipse. To determine the precise time of the solar eclipse, use `SolarEclipse`.

`MoonShadow[`*date*`]`	give the geographic location of the center of the Moon's shadow, assuming it falls on the surface of the Earth on the given *date*
`SolarEclipse[`*neardate*`]`	compute the precise time of the next solar eclipse after the given *neardate*
`SolarEclipse[]`	compute the time of the next solar eclipse
`Separation -> `*separation*	the *separation* to use; default is `1.16 Degree`, which is large enough to catch both partial and total solar eclipses

Determing circumstances of solar eclipses.

A total solar eclipse is visible from only a small spot on the Earth, where it can last up to 7.6 minutes. You can use the option `Separation` to adjust how close the Sun and Moon have to be for the event to be considered an eclipse. The default is `Separation -> 1.16*Degree`, which is large enough to catch both partial and total solar eclipses. Reduce the separation if you are only interested in total solar eclipses.

Note that the time returned by `SolarEclipse` is such that the separation of the Sun and the Moon is a local minimum; that is, `Separation[Sun, Moon, SolarEclipse[]]` is a local minimum.

■ This is the precise date and time of the middle of the annular solar eclipse in 1994.

```
In[6]:= SolarEclipse[{1994,1,1}]

Out[6]= {1994, 5, 11, 4, 11, 55}
```

■ The location of the center of the shadow on the Earth's surface at this time corresponds to a spot in North America. The degree of totality is only 0.89 at this particular time, so only 89% of the Sun is covered by the Moon; hence this is an annular eclipse. The annular eclipse lasts 6.0 minutes.

```
In[7]:= MoonShadow @ SolarEclipse[{1994,1,1}]

Out[7]= {GeoLongitude → -84.0582 Degree, GeoLatitude → 41.8139 Degree,
         Totality → 0.891507, Duration → -6.04025 Minute}
```

■ The precise date and time of the middle of the total solar eclipse in 1994 is shown here.

```
In[8]:= SolarEclipse[{1994,6,1}]

Out[8]= {1994, 11, 4, 0, 38, 45}
```

- In this example, the geographic location is off the coast of Argentina. The degree of totality is now 1.11, so 100% of the Sun is covered; hence this is a total eclipse. The total eclipse lasts 4.3 minutes.

```
In[9]:= MoonShadow @ SolarEclipse[{1994,6,1}]

Out[9]= {GeoLongitude → -35.9361 Degree, GeoLatitude → -35.8296 Degree,
         Totality → 1.10998, Duration → 4.32553 Minute}
```

- At the time of eclipse, and as viewed from the Moon's shadow on the surface of the Earth, the Sun and Moon are separated by an extremely small angle.

```
In[10]:= Separation[Sun, Moon, SolarEclipse[{1994,6,1}],
                   ViewPoint -> %]

Out[10]= 0.00012357 Degree
```

The third rule output from `MoonShadow` tells you how much of the area of the Sun is covered by the Moon as seen from Earth. The rule, therefore, represents the totality of the eclipse. If the totality is greater than 1, the eclipse is total; if less than 1, the eclipse is annular.

The fourth rule tells you how long the Moon is in front of the Sun as seen from the returned geographic location given by the first two rules. This duration rule is the time interval between when the trailing edge of the Moon enters the solar disk and the leading edge of the Moon leaves the solar disk. Total eclipses, therefore, have a positive duration, but annular eclipses, where the Sun is never fully covered, have a negative duration because the trailing edge of the Moon enters before the leading edge leaves.

The EarthShadow Function

A function related to `MoonShadow` is `EarthShadow`, which computes details of the Earth's shadow during a lunar eclipse. To determine the precise time of the lunar eclipse use `LunarEclipse`.

`EarthShadow[`*date*`]`	give the position and size of the Earth's shadow projected at the distance of the Moon on the given *date*
`LunarEclipse[`*neardate*`]`	compute the precise time of the next lunar eclipse after the given *neardate*
`LunarEclipse[]`	compute the time of the next lunar eclipse
`Separation ->` *separation*	the *separation* to use; default is `0.70 Degree`, which is large enough to catch both partial and total lunar eclipses

Determing circumstances of lunar eclipses.

A total lunar eclipse is visible from half the Earth (*i.e.*, the side facing the Moon), where it can last up to 1 hour 44 minutes. A partial lunar eclipse can last 4 hours. Use the option `Separation` to adjust how close the Sun and Earth have to be, as seen from the Moon, for the event to be considered an eclipse. The default is `Separation -> 0.70*Degree`, which is large enough to catch both partial and total lunar eclipses. Reduce the separation if you are only interested in total lunar eclipses.

Note that the time returned by `LunarEclipse` is such that the separation of the Sun and the Moon is a local maximum near 180 degrees. That is, `Separation[Sun, Moon, LunarEclipse[]]` is a local maximum.

■ This is the precise time of the middle of a lunar eclipse in 1993.

```
In[11]:= LunarEclipse[{1993,11,17}]

Out[11]= {1993, 11, 29, 17, 27, 46}
```

■ The Earth's shadow is only 0.36 degrees away from the Moon at the middle of the lunar eclipse of 1993 November 29. The Moon itself is only half a degree in diameter, so this event is a total lunar eclipse.

```
In[12]:= Separation[Moon, EarthShadow[%], %]

Out[12]= 0.36338 Degree
```

■ The shadow of the Earth during this lunar eclipse is a cone pointing in a direction specified by 4.3 hours of right ascension and 21.5 degrees of declination. The total shadow, at the distance of the Moon, is 1.3 degrees in diameter.

```
In[13]:= EarthShadow @ LunarEclipse[{1993,11,17}]

Out[13]= {Ascension → 4.34806 Hour, Declination → 21.4871 Degree,
          UmbraDiameter → 1.30801 Degree, PenumbraDiameter → 2.38874 Degree}
```

The output from `EarthShadow` contains information about the size of the umbra and penumbra shadows of the Earth projected at the distance of the Moon. The shadow of the Earth is a cone-shaped region centered on the Sun and passing by the edges of the Earth. The third rule output from `EarthShadow` gives the angular diameter of the umbra, or total shadow, of the Earth; the second rule gives the angular diameter of the penumbra, or partial shadow.

■ 6.3 The EclipseBegin and EclipseEnd Functions

`EclipseBegin` and `EclipseEnd` are useful for determining the precise times when an object is eclipsed by a second object from the light from a third object. The diameters of the first and second objects are taken into account, but the third object is treated as a point source.

`EclipseBegin[`*object1*`,` *object2*`,` *object3*`,` *neardate*`]`	
	compute the precise date, nearest to *neardate*, at which *object1* begins to be eclipsed by *object2* from the light from *object3*
`EclipseEnd[`*object1*`,` *object2*`,` *object3*`,` *neardate*`]`	
	compute the precise date, nearest to *neardate*, at which *object1* ceases to be eclipsed by *object2* from the light from *object3*
`EclipseBegin[`*object*`,` *neardate*`]`	compute the precise date, nearest to *neardate*, at which *object* begins to be eclipsed by the Earth from the light of the Sun; this is equivalent to `EclipseBegin[`*object*`, Earth, Sun,` *neardate*`]`
`EclipseEnd[`*object*`,` *neardate*`]`	compute the precise date, nearest to *neardate*, at which *object* ceases to be eclipsed by the Earth from the light of the Sun; this is equivalent to `EclipseEnd[`*object*`, Earth, Sun,` *neardate*`]`

Beginning and ending times of an eclipse.

You can determine, for instance, when the Galilean moon Io is just beginning to be eclipsed from the Sun by Jupiter moving between the two objects. Similarly, you can determine when the Great Red Spot is next visible.

■ Io is eclipsed from the Sun at 16:46 on 1993 November 18.

```
In[14]:= EclipseBegin[Io, Jupiter, Sun, {1993,11,17,3,20,0}]

Out[14]= {1993, 11, 18, 16, 45, 54}
```

■ A short time later, at 17:05, Io moves behind the Jovian disk, as seen from Earth.

```
In[15]:= EclipseBegin[Io, Jupiter, Earth, {1993,11,17,3,20,0}]

Out[15]= {1993, 11, 18, 17, 5, 10}
```

■ Io reappears, in sunlight, on the other side of the Jovian disk about two hours later, at 19:17.

```
In[16]:= EclipseEnd[Io, Jupiter, Earth, {1993,11,17,3,20,0}]

Out[16]= {1993, 11, 18, 19, 17, 4}
```

■ The Great Red Spot is next visible at 05:45 on 1993 November 17.

```
In[17]:= EclipseBegin[Jupiter, JupiterGreatRedSpot, Earth,
                      {1993,11,17,3,20,0}]

Out[17]= {1993, 11, 17, 5, 45, 34}
```

■ It rotates out of view roughly 5 hours later at 10:43.

```
In[18]:= EclipseEnd[Jupiter, JupiterGreatRedSpot, Earth,
                {1993,11,17,3,20,0}]

Out[18]= {1993, 11, 17, 10, 43, 28}
```

Other Uses

Since three objects are normally supplied to `EclipseBegin` and `EclipseEnd`, you can search for many different types of events. Use them for solar and lunar eclipses; satellites disappearing into Earth's shadow; transits of Mercury or Venus across the solar disk; transits, shadows, occultations, and eclipses of the Galilean moons; and lunar occultations of stars by the Moon.

`EclipseBegin[Sun, Moon, TopoCentric]`	compute the time when a solar eclipse is overhead
`EclipseBegin[Earth, Moon, Sun]`	compute the time of the next solar eclipse somewhere on Earth
`EclipseBegin[Moon, Earth, Sun]`	compute the time of the next lunar eclipse

Beginning time of a solar or lunar eclipse.

`EclipseBegin[Sun, Mercury, Earth]`	compute the time when Mercury transits across the solar disk
`EclipseBegin[Sun, Venus, Earth]`	compute the time when Venus transits across the solar disk

Beginning time of a transit of Mercury or Venus.

`EclipseBegin[Jupiter, Io, Earth]`	compute the time when Io transits across the Jovian disk
`EclipseBegin[Jupiter, Io, Sun]`	compute the time when Io's shadow is cast on the Jovian disk
`EclipseBegin[Io, Jupiter, Earth]`	compute the time when Io is occulted by the Jovian disk
`EclipseBegin[Io, Jupiter, Sun]`	compute the time when Io is eclipsed from the Sun by the Jovian disk

Beginning time of various Jovian moon events.

`EclipseBegin[Jupiter, JupiterGreatRedSpot, Earth]`	
	compute the time when the Great Red Spot is visible

Beginning time of Great Red Spot visibility.

`EclipseBegin[Earth, Moon, Spica]`	
	compute the time of a lunar occultation of the star Spica
`EclipseBegin[Spica, Moon, TopoCentric]`	
	compute the time of the next lunar occultation overhead

Beginning time of a lunar occultation.

`EclipseBegin[Mir, Earth, Sun]`	
	compute the time when a satellite disappears into the Earth's shadow

Beginning time of satellite disappearance.

Although the order of the objects might appear confusing, there is a consistency to it. Remember that the last object is the one treated as a point source, whereas the first two objects are treated as disks of the correct size.

Thus `EclipseBegin[Earth, Moon, Sun]` determines when any part of the Moon's disk begins to move in front of any part of the disk of the Earth, as viewed from the center of the Sun. This is the time when a partial solar eclipse becomes visible from somewhere on Earth.

Similarly, `EclipseBegin[Sun, Moon, TopoCentric]` determines when any part of the Moon's disk begins to move between any part of the disk of the Sun and the current location on Earth. This is the time when a solar eclipse becomes visible from the current topocentric location.

■ A near total solar eclipse occurred over the lower part of the Pacific in February, 1981.

```
In[19]:= eclipse1981 = SolarEclipse[{1981,2,5}]

Out[19]= {1981, 2, 5, 9, 10, 22}
```

■ The eclipse nearly passed over Melbourne, Australia. Here the site location of Melbourne is set.

```
In[20]:= SetLocation[GeoLongitude -> 145.0*Degree,
                     GeoLatitude  -> -37.8*Degree,
                     GeoAltitude  ->   0.0*KiloMeter,
                     TimeZone     ->  11];
```

- The partial eclipse phase begins at 06:33 for observers located at Melbourne, Australia. (`TopoCentric` represents the location set earlier with `SetLocation`.)

```
In[21]:= EclipseBegin[Sun, Moon, TopoCentric, eclipse1981]

Out[21]= {1981, 2, 5, 6, 33, 11}
```

- The partial eclipse phase ends at 08:34 for observers located at Melbourne, Australia.

```
In[22]:= EclipseEnd[Sun, Moon, TopoCentric, eclipse1981]

Out[22]= {1981, 2, 5, 8, 34, 23}
```

- The average of the two times above is the approximate time of maximum eclipse for the location. By trial and error minimizing `Separation[Sun, Moon, `*date*`, ViewPoint->TopoCentric]` you find the actual time of maximum eclipse occurs about three minutes earlier.

```
In[23]:= besttime = {1981,2,5,7,30,59}

Out[23]= {1981, 2, 5, 7, 30, 59}
```

- The maximum eclipse happens only an hour after sunrise for observers located at Melbourne.

```
In[24]:= SunRise[eclipse1981]

Out[24]= {1981, 2, 5, 6, 39, 32}
```

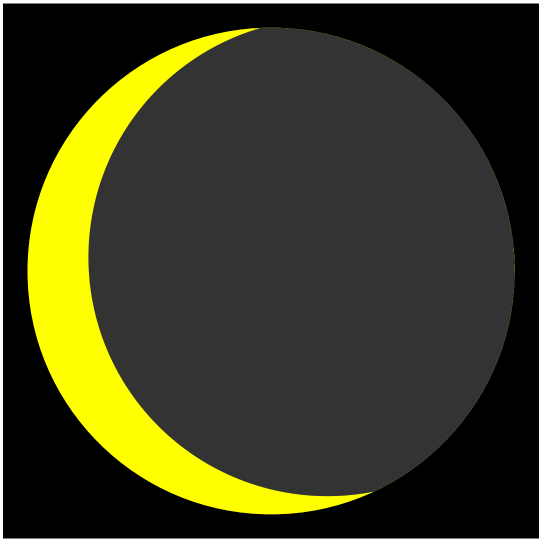
- The eclipse appears 9 degrees above the eastern horizon.

```
In[25]:= HorizonCoordinates[Moon, besttime,
                              ViewPoint -> TopoCentric]

Out[25]= {Azimuth → 103.305 Degree, Altitude → 9.21132 Degree,
          Distance → 375203. KiloMeter}
```

■ This is how the eclipse appeared at its maximum.

```
In[26]:= PlanetPlot3D[Sun, besttime,
                      ViewPoint    -> TopoCentric,
                      ViewVertical -> Zenith];
```



Jovian Moon Events

As mentioned earlier, `EclipseBegin` and `EclipseEnd` can be used to determine the precise time of various alignments involving the Earth, the Sun, Jupiter, and a Galilean moon. There are essentially four types of events that can take place.

A Jovian eclipse occurs when a moon of Jupiter is blocked from the light of the Sun; this is an alignment involving the Jovian moon, Jupiter, and the Sun. A Jovian occultation occurs when a moon of Jupiter is hidden behind the Jovian disk as seen from the Earth; this is an alignment involving the Jovian moon, Jupiter, and the Earth. A Jovian shadow occurs when the shadow of a moon of Jupiter passes across the Jovian disk; this is an alignment involving Jupiter, the Jovian moon, and the Sun. A Jovian transit occurs when a moon of Jupiter passes across the Jovian disk as seen from the Earth; this is an alignment involving Jupiter, the Jovian moon, and the Earth.

■ Here are two functions which compute the disappearance and reappearance times of a Jovian eclipse (*i.e.*, a Jovian moon blocked from the light of the Sun).

```
In[27]:= EclipseDisappear[jovianMoon_, neardate___] :=
           EclipseBegin[jovianMoon, Jupiter, Sun, neardate]

In[28]:= EclipseReappear[jovianMoon_, neardate___] :=
           EclipseEnd[jovianMoon, Jupiter, Sun, neardate]
```

- Here are two functions which compute the disappearance and reappearance times of a Jovian occultation (*i.e.*, a Jovian moon hidden behind the Jovian disk).

```
In[29]:= OccludeDisappear[jovianMoon_, neardate___] :=
           EclipseBegin[jovianMoon, Jupiter, Earth, neardate]
```

```
In[30]:= OccludeReappear[jovianMoon_, neardate___] :=
           EclipseEnd[jovianMoon, Jupiter, Earth, neardate]
```

- Here are two functions which compute the ingress and egress times of a Jovian moon's shadow across the Jovian disk.

```
In[31]:=  ShadowIngress[jovianMoon_, neardate___] :=
           EclipseBegin[Jupiter, jovianMoon, Sun, neardate]
```

```
In[32]:=  ShadowEgress[jovianMoon_, neardate___] :=
            EclipseEnd[Jupiter, jovianMoon, Sun, neardate]
```

- Here are two functions which compute the ingress and egress times of a transit of a Jovian moon across the Jovian disk.

```
In[33]:= TransitIngress[jovianMoon_, neardate___] :=
           EclipseBegin[Jupiter, jovianMoon, Earth, neardate]
```

```
In[34]:= TransitEgress[jovianMoon_, neardate___] :=
           EclipseEnd[Jupiter, jovianMoon, Earth, neardate]
```

■ 6.4 The EclipseQ Function

`EclipseQ` is useful for deciding when an object is eclipsed by a second object from the light of a third object. The diameters of the first and second objects are taken into account, but the third object is treated as a point source.

`EclipseQ[`*object1*`,` *object2*`,` *object3*`,` *date*`]`	test if *object1* is eclipsed by *object2* from the light of *object3* on the given *date*
`EclipseQ[`*object*`,` *date*`]`	test if *object* is eclipsed by the Earth from the light of the Sun on the given *date*; this is equivalent to `EclipseQ[`*object*`, Earth, Sun,` *date*`]`

Testing for eclipses.

The `EclipseQ` function returns either `True` or `False` to questions you input concerning eclipse events. `EclipseQ` will sometimes tell you something you already know. You can, for example, confirm that the Moon is really eclipsed by the Earth from the Sun during a lunar eclipse. Similarly, you can confirm that the Earth is really eclipsed by the Moon from the Sun during a solar eclipse.

■ By definition, the Moon is eclipsed during a lunar eclipse.

```
In[35]:= EclipseQ[Moon, LunarEclipse[]]

Out[35]= True
```

■ Part of the Earth is eclipsed by the Moon from the Sun during a solar eclipse.

```
In[36]:= EclipseQ[Earth, Moon, Sun, SolarEclipse[]]

Out[36]= True
```

Other uses of `EclipseQ` are possible. For instance, a transit of Venus occurred in the year 1769; to determine its precise time you can experiment with different date arguments.

■ The transit of Venus has not started at this time.

```
In[37]:= EclipseQ[Sun, Venus, Earth, {1769,6,4,6,0,0}]

Out[37]= False
```

■ Now Venus is in transit.

```
In[38]:= EclipseQ[Sun, Venus, Earth, {1769,6,4,9,0,0}]

Out[38]= True
```

■ Now it has finished its transit.

```
In[39]:= EclipseQ[Sun, Venus, Earth, {1769,6,4,13,0,0}]

Out[39]= False
```

Of course, the precise beginning and ending of the transit can more easily be determined with `EclipseBegin` and `EclipseEnd`.

■ The transit begins at 06:16 Melbourne time on 1769 June 4.

```
In[40]:= EclipseBegin[Sun, Venus, Earth, {1762,1,1}]

Out[40]= {1769, 6, 4, 6, 15, 41}
```

■ It ends 6 hours later at 12:34.

```
In[41]:= EclipseEnd[Sun, Venus, Earth, {1762,1,1}]

Out[41]= {1769, 6, 4, 12, 34, 3}
```

Additionally, `EclipseQ` will test for conjunctions or lunar occultations. You can also determine when the Galilean moons Io, Europa, Ganymede, and Callisto undergo, say, a transit or occultation from the Earth, or an eclipse or shadow from the Sun.

- This confirms the rare Mars-Venus conjunction in the year 1590.

```
In[42]:= EclipseQ[Mars, Venus, Earth, {1590,10,13,15,58,0}]

Out[42]= True
```

- This verifies the lunar occultation of the star Spica in 1995. The Moon passed directly between the Earth and Spica on 1995 January 23 at 22:00.

```
In[43]:= EclipseQ[Earth, Moon, Spica, {1995,1,23,22,0,0}]

Out[43]= True
```

- On the given date, Io is not in transit across the Jovian disk.

```
In[44]:= EclipseQ[Jupiter, Io, Earth, {1993,11,17,3,20,0}]

Out[44]= False
```

■ 6.5 The Conjunction and ConjunctionEvents Functions

When two objects move close together in the sky, they are said to be in conjunction. The `Conjunction` function is useful for determining the approximate date of such an event.

Conjunctions are usually of little astronomical importance, but they do make interesting events for casual observers to witness. A grazing occultation, however, can give detailed information about the shape and atmosphere of the occluding object.

`Conjunction[`*object1*`,` *object2*`,` *neardate*`]`	find the date, nearest to *neardate*, at which the right ascension of *object1* will align with the right ascension of *object2*
`Conjunction[`*object1*`,` *object2*`]`	find the conjunction date nearest the current value of `Date[]`

Determing the time of a conjunction.

You can use `Conjunction` to find the approximate date when Jupiter and Mars align nearest a given date. The correct date for the nearest conjunction to 1995 January 1 is 1995 November 17, and you can determine this date precisely using `Separation`.

■ Jupiter and Mars align 10 months after the given date on about 1995 November 17.

```
In[45]:= Conjunction[Jupiter, Mars, {1995,1,1}]

Out[45]= {1995, 11, 17}
```

■ On 1995 November 17, Jupiter and Mars are just 1.2 degrees apart in the sky.

```
In[46]:= Separation[Jupiter, Mars, {1995,11,17}]

Out[46]= 1.20348 Degree
```

Precise Conjunctions

A very precise conjunction between Venus and Mars took place in the year 1590. At the time of the conjunction, the angular radius of Venus is bigger than the Mars-Venus separation, so you can conclude that Venus totally occluded Mars on 1590 October 13. This was a very rare event.

■ During 1590, Mars and Venus align on about October 14.

```
In[47]:= Conjunction[Mars, Venus, {1590,8,1}]

Out[47]= {1590, 10, 14}
```

■ The precise time of the conjunction is October 13, at 15:58, at which point the separation is just 0.0016 degrees.

```
In[48]:= Separation[Mars, Venus, {1590,10,13,15,58,0}]

Out[48]= 0.00164543 Degree
```

■ The angular radius of Venus is 0.0018 degrees, which is greater than the separation.

```
In[49]:= ApparentDiameter/2 /.
            Appearance[Venus, {1590,10,13,15,58,0}]

Out[49]= 0.00181081 Degree
```

The ConjunctionEvents Function

A related function is `ConjunctionEvents`, which finds all the conjunctions between major solar system objects during a given month. It returns a list of days in the month showing the objects that align, and how close they are to each other.

`ConjunctionEvents[`*neardate*`]`	list all the conjunctions between the major planets, asteroids, ecliptic stars, and the Moon, during the month nearest *neardate*
`ConjunctionEvents[]`	list the conjunctions for the current month

Searching for conjunction events.

Most objects in the solar system move near the ecliptic line, so chance alignments between pairs of objects are relatively common. A close conjunction between Venus and a new moon is a sight worth seeing.

■ This shows all the conjunctions between the major solar system objects during November, 1993. It shows, for instance, that Jupiter is 0.4 degrees north of Venus on November 9. The Moon and the Sun are 0.2 degrees apart on November 15, so there is a solar eclipse visible at some location on the Earth on this date.

```
In[50]:= ConjunctionEvents[{1993,11,17}]

        Conjunctions during November, 1993 are
          Nov  3: Aldebaran  4.5° south of Moon
          Nov  5: Spica      3.5° south of Venus
          Nov  9: Jupiter    0.4° south of Venus
          Nov  9: Regulus    5.7° north of Moon
          Nov 13: Jupiter    3.9° north of Moon
          Nov 13: Mercury    1.7° north of Sun
          Nov 13: Spica      0.7° north of Moon
          Nov 14: Venus      2.9° north of Moon
          Nov 15: Mercury    2.2° north of Moon
          Nov 15: Moon       0.2° south of Sun
          Nov 16: Mars       1.6° south of Moon
          Nov 16: Antares    5.7° south of Moon
          Nov 19: Uranus     4.7° south of Moon
          Nov 22: Saturn     6.8° south of Moon
          Nov 23: Vesta     12.9° south of Moon
          Nov 23: Antares    4.1° south of Mars
          Nov 26: Mercury    1.2° north of Venus
          Nov 29: Pleiades   3.6° north of Moon

Out[50]= -ConjunctionData-
```

7. Satellite Tracking Functions

Many low-orbit Earth satellites are visible to the naked eye, but to spot them requires a knowledge of exactly when to look. The window of opportunity is about two minutes wide and occurs at a time just after dusk or just before dawn.

The Mir Space Station is the best and brightest object to see. It can appear as bright as the brightest stars. A Space Shuttle can also appear as bright as Mir, but missions are relatively infequent.

Other satellites that sometimes appear bright are the Hubble Space Telescope (HST), the Upper Atmosphere Research Satellite (UARS), and the Cosmic Background Explorer (COBE).

Scientific Astronomer provides several functions for adding and analyzing the orbit of satellites. These functions are able to add comets and extra asteroids as well as objects in orbit around other planets or moons.

■ Load the package.

```
In[1]:= <<Astronomer`HomeSite`

        Astronomer is Copyright (c) 1997 Stellar Software
```

■ This sets your location and time zone.

```
In[2]:= SetLocation[GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    GeoAltitude  ->   0.0*KiloMeter,
                    TimeZone     ->  11];
```

■ 7.1 The SetOrbitalElements Function

`SetOrbitalElements` lets you add a new object. Many objects, such as planets and asteroids, are already built into *Scientific Astronomer*, but occasionally you may need to add other objects such as low-orbit Earth satellites or comets.

Most objects are in orbit around a parent body. To add such an object to *Scientific Astronomer*, you need to know the orbital elements of the object.

SetOrbitalElements[*newobject*, *elements...*]	define a new object with the given orbital *elements*
Date -> *date*	elements for the given *date*
ViewPoint -> *parentbody*	orbit centered on *parentbody*
OrbitalSemiMajorAxis -> *length*	the semimajor axis length of the orbit
OrbitalEccentricity -> *eccentricity*	the eccentricity of the orbit
OrbitalInclination -> *inclination*	the inclination of the orbit to the equator
OrbitalPeriod -> *period*	the period of the orbit in days
MeanAnomaly -> *anomaly*	the mean anomaly of the orbit
PerigeeArgument -> *perigee*	the perigee argument of the orbit
AscendingLongitude -> *ascension*	the longitude of the ascending node of the orbit

Setting the elements of a new object.

Orbital elements are a set of numbers that describe the shape, and other details, of an object's orbit. The elements are represented by the quantities `OrbitalSemiMajorAxis`, `OrbitalEccentricity`, `OrbitalInclination`, `MeanAnomaly`, `PerigeeArgument`, `AscendingLongitude`, `OrbitalMeanMotion`, and `OrbitalDecayRate`. You may choose to specify `OrbitalPerigee` rather than `OrbitalSemiMajorAxis`, and `PerigeeDate` rather than `MeanAnomaly`. Similarly, you may choose to specify `OrbitalPeriod` rather than `OrbitalMeanMotion`. Conversion formulae are discussed at the end of this section.

You can use `SetOrbitalElements` to add comets, such as Halley or Hale-Bopp, or other objects such as asteroids. You can even use it to add satellites in orbit about the Earth.

Often, however, you only know the NORAD two-line elements of a low-orbit satellite, rather than the proper orbital elements. Two-line elements for thousands of satellites are available and regularly updated on the Internet. You can use a function called `TwoLineElements` to convert the NORAD two-line elements into a form suitable for use with `SetOrbitalElements`.

SetOrbitalElements[*newobject*, *line1*, *line2*]	define a new object with the given NORAD two-line orbital elements *line1* and *line2*
TwoLineElements[*line1*, *line2*]	convert from standard NORAD two-line orbital element set format, to rules suitable for use with `SetOrbitalElements`

Converting NORAD elements.

■ Convert the two-line elements of the Mir Space Station into a form suitable for use with `SetOrbitalElements`.

```
In[3]:= TwoLineElements[
  "1 16609U 86017A   95025.53583445  .00005100  00000-0  71581-4 0  9062",
  "2 16609  51.6458 152.6933 0001412 164.2374 195.8663 15.58639897510653"]

Out[3]= {ViewPoint → Earth, Date → 34723.5, OrbitalMeanMotion →
   15.58639897 Revs / Day, OrbitalDecayRate → 0.000051 Revs / Day^2,
   OrbitalSemiMajorAxis → 6792.12 KiloMeter,
   OrbitalEccentricity → 0.0001412, OrbitalInclination → 51.6458 Degree,
   MeanAnomaly → 195.8663 Degree, PerigeeArgument → 164.2374 Degree,
   AscendingLongitude → 152.6933 Degree}
```

■ Here the two-line elements are directly used to set the elements of Mir.

```
In[4]:= SetOrbitalElements[Mir,
  "1 16609U 86017A   95025.53583445  .00005100  00000-0  71581-4 0  9062",
  "2 16609  51.6458 152.6933 0001412 164.2374 195.8663 15.58639897510653"];
```

■ These are the orbital elements of the STS-58 Space Shuttle mission.

```
In[5]:= SetOrbitalElements[STS58,
    ViewPoint -> Earth,
    Date      -> {1993, 1, 280.67747791,
                  TimeZone /. GetLocation[], 0, 0},
    OrbitalMeanMotion    -> 15.96123499*Revs/Day,
    OrbitalDecayRate     ->  0.00119475*Revs/Day^2,
    OrbitalSemiMajorAxis -> 6684.521 * KiloMeter,
    OrbitalEccentricity  -> 0.0007676,
    OrbitalInclination   ->  39.0114*Degree,
    MeanAnomaly          ->  89.5676*Degree,
    PerigeeArgument      -> 272.4217*Degree,
    AscendingLongitude   -> 117.7673*Degree];
```

`SetOrbitalElements` allows you to add virtually any type of new object orbiting any other object. Use the function `SetCoordinates` if you do not want the object to gravitationally orbit another object. This function lets you define the *x*,*y*,*z* coordinates of the object as a function of time.

Remember that the two-line elements of any low-orbit satellite are accurate for only a few months around the epoch date, beyond which considerable error may result in an orbit calculation. The epoch date for the Mir element set used in the example earlier is the 25.5th day of 1995, so by the end of February 1995, you would not use the element set if you required high accuracy.

Element dates are usually expressed in Universal Time (UT). *Scientific Astronomer*, however, uses local time for all dates. Therefore, if you enter an element date via the `Date` option to `SetOrbitalElements`, you must add a time zone correction.

The element date for the STS-58 Space Shuttle example above is the instant 280.67747791 days after the beginning of 1993 in UT. Thus, the element date is entered as `Date -> {1993, 1, 280.67747791, TimeZone /. GetLocation[], 0, 0}`, which includes the time zone correction for your location.

An alternative is to supply the option `TimeZone -> 0` to `SetOrbitalElements`, which temporarily switches to UT (or time zone 0). In this case, you can enter the element date as `Date -> {1993,1,280.67747791}`.

Tracking a Satellite

Once a new object like `Mir` has been added, you can begin to use it in other functions. In particular, you can use the object in `OrbitTrack` to superimpose a track of the Mir Space Station onto a star chart, if it makes a transit directly over your location.

At some point along the track, Mir disappears as it moves into the Earth's shadow. It takes less than five seconds to fade, and you can compute the precise time of the disappearance using `EclipseBegin` applied to the object `Mir`. The precise altitude, or angle above the horizon, of the disappearance is determined using `HorizonCoordinates`.

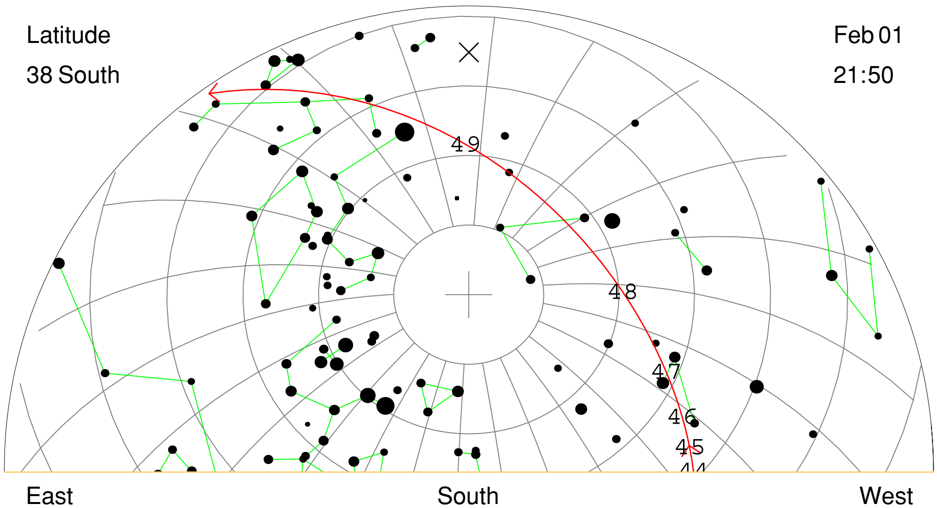
■ Compute a best visibility date of Mir.

```
In[6]:= BestView[Mir, {1995,1,31}]

Out[6]= {TransitVisible → {1995, 2, 1, 21, 48, 59}}
```

■ During transit visibility, Mir takes about 10 minutes to cross from the southwest horizon to the northeast horizon. To show the track in the southern part of the sky use `CompassStarChart` with an `Epilog` option containing an `OrbitTrack` function.

```
In[7]:= CompassStarChart[South, {1995,2,1,21,50,0},
          Mesh           -> True,
          MagnitudeRange -> 4.0,
          Ecliptic       -> False,
          Epilog         -> {
             RGBColor[1,0,0],
             OrbitTrack[Mir, {1995,2,1,21,49-6,0},
                             {1995,2,1,21,49+6,0},
                        ViewPoint  -> TopoCentric,
                        PlotPoints -> 200],
             RGBColor[0,0,0],
             Table[Text[m, ChartCoordinates[Mir,
                                  {1995,2,1,21,m,0},
                                  ViewPoint -> TopoCentric]],
                   {m, 49-6, 49+6, 1}]}];
```



■ This shows that Mir disappears at 9:50:46 local time. Before this disappearance time there are several minutes of visibility.

```
In[8]:= EclipseBegin[Mir, {1995,2,1,21,49,0}]

Out[8]= {1995, 2, 1, 21, 50, 46}
```

■ Mir disappears at about 29 degrees up in the east-northeast sky.

```
In[9]:= HorizonCoordinates[Mir, {1995,2,1,21,50,46},
                            ViewPoint -> TopoCentric]

Out[9]= {Azimuth → 60.8869 Degree, Altitude → 28.7719 Degree,
         Distance → 801.665 KiloMeter}
```

Do not forget to use the option setting `ViewPoint -> TopoCentric` in a function like `HorizonCoordinates`, when dealing with a low-orbit satellite. This applies to functions like `OrbitTrack`, `Ephemeris`, `HorizonCoordinates`, `EquatorCoordinates`, `ChartCoordinates`, `Separation`, `Elongation`, and `Conjunction`. The default for those functions is `ViewPoint -> Earth`, so you must specify `ViewPoint -> TopoCentric` as it is important to measure angles from the surface of the Earth, rather than the center, when dealing with satellites.

Adding a Comet

Although `SetOrbitalElements` is mainly used to add Earth satellites, such as the Mir Space Station or a Space Shuttle mission, you can use it to add other objects. For instance, if you know the orbital elements you can add Comet Halley.

■ This adds the new object named `Halley`.

```
In[10]:= SetOrbitalElements[Halley,
            ViewPoint             -> Sun,
            Date                  -> {1986, 2, 9.4589, TimeZone
                                        /. GetLocation[], 0, 0},
            OrbitalSemiMajorAxis -> 17.9416 * AU,
            OrbitalEccentricity  -> 0.967277,
            OrbitalInclination   -> 162.2422*Degree,
            MeanAnomaly          ->   0      *Degree,
            PerigeeArgument      -> 111.8657*Degree,
            AscendingLongitude   ->  58.8601*Degree];
```

Once `Halley` has been added, you can begin to use it in other functions. For example, you can project its motion onto a star chart just like `Mir`.

Sometimes the published orbital elements of an object, such as a comet, use the perigee distance rather than the semimajor axis distance. To convert, simply use the relation *OrbitalSemiMajorAxis* `=` *OrbitalPerigee* `/ (1 -` *OrbitalEccentricity*`)`, where *OrbitalPerigee* is the published perigee distance in astronomical units. Similarly, the perigee date, rather than the mean anomaly, might be given. In this case use the relation *MeanAnomaly* `= Mod[-(`*PerigeeDate* `-` *Date*`) / (`*OrbitalPeriod*`/Day), 1] * 360*Degree`. If the orbital period is not specified, use the relation *OrbitalPeriod* `=` (*OrbitalSemiMajorAxis*`/AU`)$^{3/2}$`*365.25*Day`, which is applicable if the object is orbiting the Sun. Of course, if the mean motion is given, simply use *OrbitalPeriod* `= Revs/`*OrbitalMeanMotion*. For Comet Halley the orbital period is approximately `27757.7*Day`, which is nearly 76 years.

■ 7.2 The GetLocation Function

`GetLocation` computes the location of an object in a coordinate system similar to that used by `SetLocation`.

`GetLocation[`*object*`,` *date*`]`	return the geographic location of the *object* on the given *date*
`GetLocation[]`	return the current geographic location, as set using `SetLocation`

Computing an object's position in geographic coordinates.

Consider, for example, the Mir Space Station. Once an object representing Mir has been added, you can use `BestView` to determine the times when Mir is making a visible transit pass overhead. Then use `GetLocation` to determine the location of Mir at that transit visible time. The location returned will be very close to the current site location, because Mir is traveling overhead. It is only visible for a minute or so on either side of the transit visible time; as mentioned earlier, the window for viewing a low-orbit satellite is always very narrow.

■ This adds the new object `Mir`, with elements appropriate for its orbit in late January 1995.

```
In[11]:= SetOrbitalElements[Mir,
          "1 16609U 86017A   95025.53583445  .00005100  00000-0  71581-4 0  9062",
          "2 16609  51.6458 152.6933 0001412 164.2374 195.8663 15.58639897510653"];
```

■ The next transit visible pass after January 20 is on January 30.

```
In[12]:= BestView[Mir, {1995,1,20}]

Out[12]= {TransitVisible → {1995, 1, 30, 22, 5, 7}}
```

■ At 21:49 on 1995 February 1, it is possible to see Mir from the current location.

```
In[13]:= BestView[Mir, {1995,1,31}]

Out[13]= {TransitVisible → {1995, 2, 1, 21, 48, 59}}
```

■ This gives the geographic location of Mir during the transit visible pass overhead.

```
In[14]:= GetLocation[Mir, {1995,2,1,21,49,0}]

Out[14]= {GeoLongitude → 145.061 Degree, GeoLatitude → -39.0522 Degree,
          GeoAltitude → 422.66 KiloMeter}
```

■ Mir is 70.4 degrees above the horizon, and thus very high in the sky, traveling overhead at the given time.

```
In[15]:= HorizonCoordinates[Mir, {1995,2,1,21,49,0},
                               ViewPoint -> TopoCentric]

Out[15]= {Azimuth → 177.925 Degree, Altitude → 70.3724 Degree,
          Distance → 446.491 KiloMeter}
```

If you are tracking a satellite with radio equipment, visibility is not so important since all you need to know is approximately when the object is overhead. `Culmination` gives you the time when an object is next highest in the sky, and you can apply `Ephemeris` to determine the circumstances of the pass.

■ `Culmination` gives the time when Mir is next highest in the sky overhead.

```
In[16]:= Culmination[Mir, {1995,2,1,15,0,0}]

Out[16]= {1995, 2, 1, 15, 21, 21}
```

`GetLocation` can, of course, be applied to other objects and not simply low-orbit Earth satellites. For example, use `GetLocation` to determine the part of the Earth that has the Moon directly overhead at any given time.

■ On the given date, the Moon is directly over the point with longitude -29 degrees and latitude -21 degrees, which is a location off the east coast of Brazil.

```
In[17]:= GetLocation[Moon, {1993,11,17,3,20,0}]

Out[17]= {GeoLongitude → -29.0329 Degree, GeoLatitude → -20.9029 Degree,
          GeoAltitude → 367126. KiloMeter}
```

■ 7.3 The OrbitTrackPlot Function

`OrbitTrackPlot` is useful for displaying the track of a low-orbit satellite onto the surface of the Earth.

`OrbitTrackPlot[`*object*`,` *date1*`,` *date2*`]`	
	plot the track of the *object* as projected onto the Earth's surface between *date1* and *date2*
`OrbitTrackPlot[{`*object1*`,` *object2*`,` ...`},` *date1*`,` *date2*`]`	
	display the tracks of several objects at once
`LocationRing -> True`	a 15 degree green ring around your current location on Earth
`Shading -> True`	shading of the night side of the Earth
`FeatureLabels -> True`	labeling of features on the *planet*
`Features ->` *features*	additional surface features
`PlotPoints ->` *n*	the number of line segments; default is 25
`PlotRange ->` *range*	a smaller section of the plot
`PlotStyle ->` *styles*	individual graphic *styles* for the tracks

Plotting orbital tracks.

Locations along the track are such that the object is directly overhead at some time between the given dates. The object will normally be an Earth satellite, but it can be a planet or any other object. The red regions indicate where the object is located overhead just after dusk in the evening sky. Similarly, the blue regions indicate the object's location overhead just before dawn in the morning sky.

If the object you are tracking is a low-orbit Earth satellite, then the red and blue regions represent the windows of opportunity to view the satellite. These are time periods of perhaps 5 or 10 minutes, while the satellite is still illuminated by the Sun but your viewing location is in darkness.

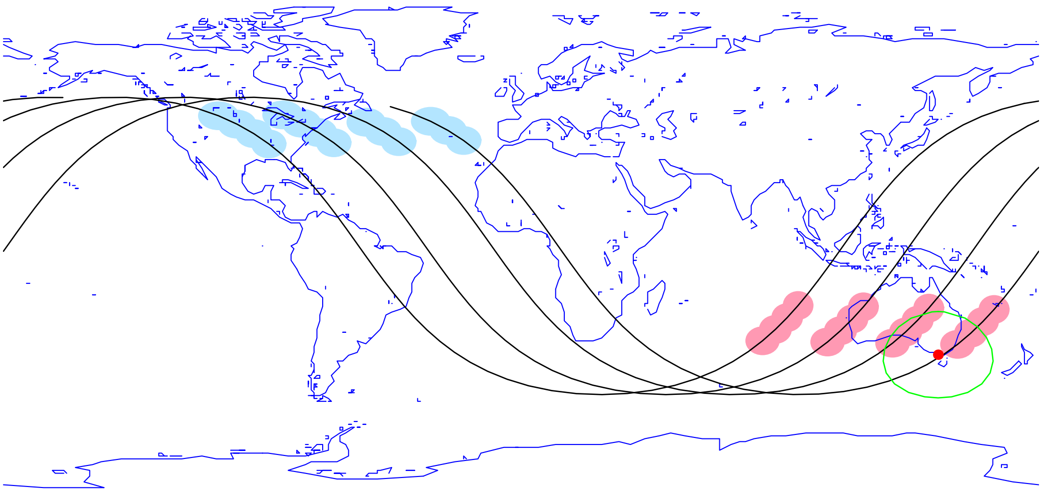
A sequence of tracks is displayed if you supply a list of objects, rather than a single object, as the first argument to `OrbitTrackPlot`. In this case, you can also use the option `PlotStyle` to set a different style for each track.

■ Enter the orbital elements of a Space Shuttle mission.

```
In[18]:= SetOrbitalElements[STS63,
           ViewPoint -> Earth,
           Date      -> {1995,2,3,6+11,48,13},
           OrbitalMeanMotion    -> 15.82619484*Revs/Day,
           OrbitalDecayRate     ->  0.00000387*Revs/Day^2,
           OrbitalSemiMajorAxis -> 6723.340*KiloMeter,
           OrbitalEccentricity  -> 0.0026128,
           OrbitalInclination   ->  51.6614*Degree,
           MeanAnomaly          -> 156.9459*Degree,
           PerigeeArgument      -> 202.9294*Degree,
           AscendingLongitude   -> 109.1408*Degree];
```

■ This graphic shows the track of the Space Shuttle mission for 6 hours, or about 4 orbits. Various evening passes are visible over parts of Australia, in addition to some morning passes over parts of North America.

```
In[19]:= OrbitTrackPlot[STS63, {1995,2,6, 8+11,0,0},
                               {1995,2,6,14+11,0,0},
                        PlotPoints    -> 250,
                        LocationRing -> True];
```



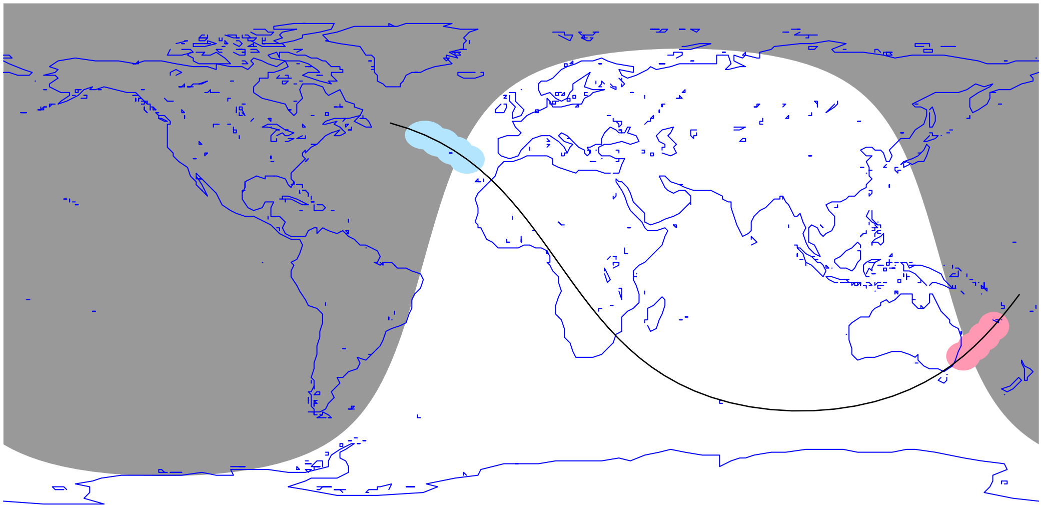
The option setting `LocationRing -> True` draws a green ring around the current site location. If any track passes within that ring, then the object is above the local horizon. When this occurs the object may be tracked with radio equipment.

If the start and stop dates used by `OrbitTrackPlot` are sufficiently close, it makes sense to use the option setting `Shading -> True`. This option works just as it does in `PlanetPlot`, shading the night-time region.

Again, the option `PlotRange` is available if you need to zoom into a smaller region on the surface of the Earth. The default is `PlotRange -> {{-180, 180}, {-90, 90}}`.

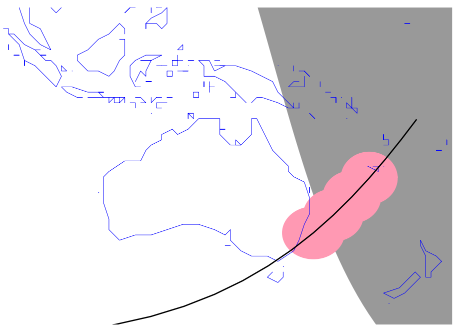
■ This shows that visibility occurs around dawn and dusk only.

```
In[20]:= OrbitTrackPlot[STS63, {1995,2,6,8+11,0,0},
                               {1995,2,6,9+11,0,0},
                        PlotPoints -> 50,
                        Shading    -> True];
```



■ The option `PlotRange` is used here to zoom into the area over Australia.

```
In[21]:= OrbitTrackPlot[STS63, {1995,2,6,8+11,0,0},
                               {1995,2,6,9+11,0,0},
                        PlotPoints -> 50,
                        Shading    -> True,
                        PlotRange  -> {{90, 180},
                                       {-50, 10}}];
```



■ 7.4 The OrbitPlot and OrbitPlot3D Functions

`OrbitPlot` plots the elliptical orbit of an object or objects about a common center.

`OrbitPlot[{`*object1*`, `*object2*`, `...`}]`	plot the full elliptical orbit of all the objects about their common center; you can specify a date if the orbit changes with time
`OrbitPlot3D[{`*object1*`, `*object2*`, `...`}]`	make a three-dimensional plot of the full elliptical orbit of all the objects about their common center; you can specify a date if the orbit changes with time
`PlotStyle -> `*styles*	individual graphic *styles* for the orbits
`Distance -> `*distance*	a bigger or smaller field of view; default is `12 AU`

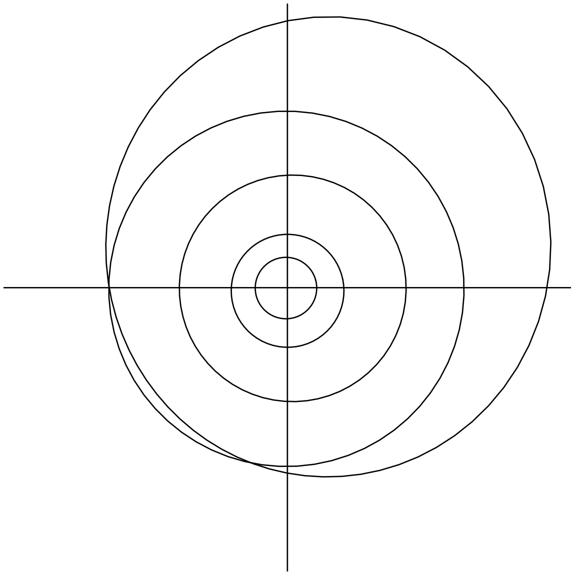
Plotting the shape of an orbit.

In the two-dimensional form, the horizontal axis is aligned so that the right points to the zero hour of right ascension, and the vertical points to the 6 hour of right ascension. You can switch these axes off by using the normal option setting `Axes -> False`. The graphic returned is that seen by an observer situated above the ecliptic plane looking down.

You can show the orbital layout of the planets using these functions.

- A plots of the orbit of the outer planets shows that Pluto is in an elliptical orbit, which can take it just inside the orbit of Neptune.

```
In[22]:= OrbitPlot[{Jupiter, Saturn, Uranus, Neptune, Pluto},
                  Distance -> 48*AU];
```

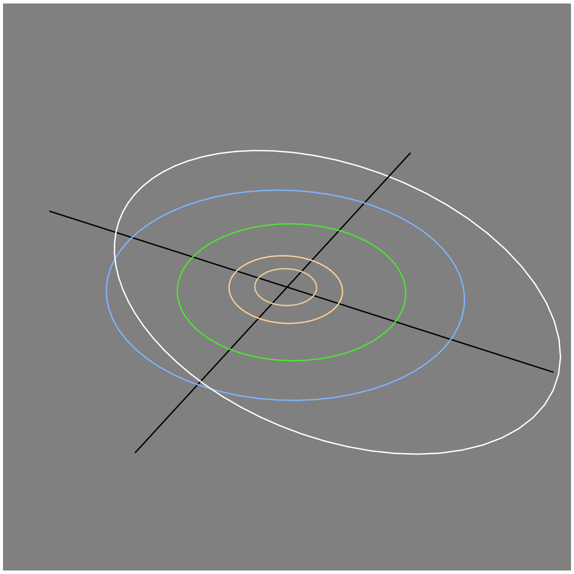


A related function is `OrbitPlot3D`, which does essentially the same thing as `OrbitPlot` except that it shows the full three-dimensional orbit. Use the option `ViewPoint` to adjust the viewpoint.

Like `OrbitPlot`, `OrbitPlot3D` accepts the option `PlotStyle` to let you select an individual style for each orbit.

■ This three-dimensional plot makes it clear that Pluto is in an orbit tilted to the plane of the other planets.

```
In[23]:= OrbitPlot3D[{Jupiter, Saturn, Uranus, Neptune, Pluto},
           Distance   -> 48*AU,
           PlotStyle  -> {RGBColor[0.9,0.8,0.6],
                          RGBColor[1.0,0.8,0.6],
                          RGBColor[0.3,0.9,0.2],
                          RGBColor[0.5,0.7,1.0],
                          RGBColor[1.0,1.0,1.0]},
           Background -> GrayLevel[0.5],
           PlotRegion -> {{-0.4,1.4},{-0.4,1.4}},
           SphericalRegion -> True];
```



There are many ways to use the functions `OrbitPlot` and `OrbitPlot3D`. For instance, you can show the shape and orientation of the orbit of Comet Halley. You can also show the orbit of satellites around the Earth.

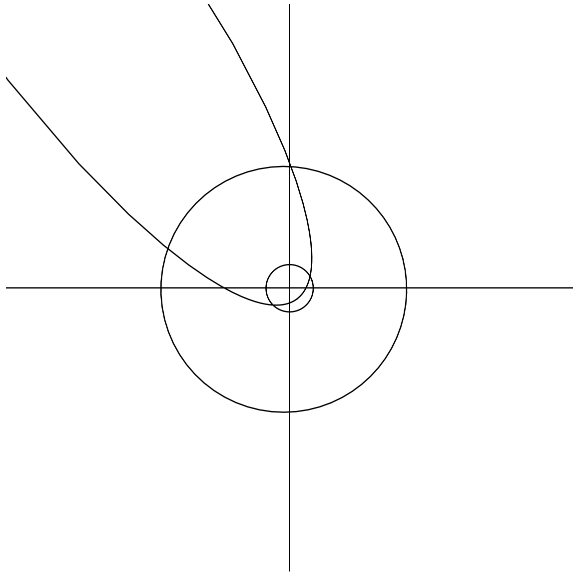
In the case of Comet Halley, you would first add its orbital elements to the package. It is then an easy matter to display its orbit relative to, say, Earth and Jupiter.

■ This adds a new object called `Halley`. Note `OrbitalPeriod` is used rather than `OrbitalSemiMajorAxis`. See the end of Section 7.1 for the conversion.

```
In[24]:= SetOrbitalElements[Halley,
           ViewPoint             -> Sun,
           Date                  -> {1986, 2, 9.4589, TimeZone
                                       /. GetLocation[], 0, 0},
           OrbitalEccentricity  -> 0.967277,
           OrbitalInclination   -> 162.2422*Degree,
           OrbitalPeriod        -> 27757.7 * Day,
           MeanAnomaly          ->   0     *Degree,
           PerigeeArgument      -> 111.8657*Degree,
           AscendingLongitude   ->  58.8601*Degree];
```

■ Comet Halley follows the elliptical orbit approaching from the top left.

```
In[25]:= OrbitPlot[{Halley, Earth, Jupiter}];
```



The orbital elements of Comet Halley are such that its inclination is 162.2 degrees, which is greater than 90 degrees. Comet Halley, therefore, travels in the opposite direction (*i.e.*, clockwise) to the main planets, which orbit counterclockwise around the Sun.

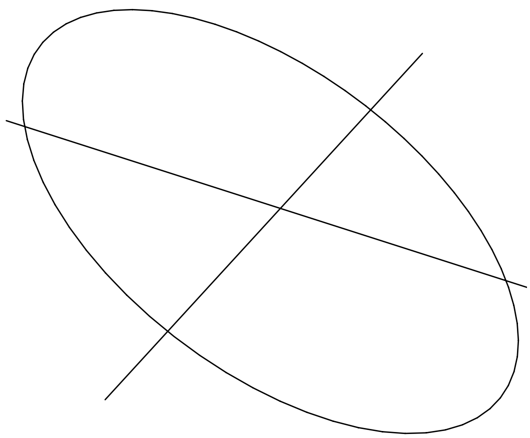
In the case of a satellite, such as the Hubble Space Telescope (HST), you must have current orbital elements.

■ Here are the two-line orbital elements for the Hubble Space Telescope.

```
In[26]:= SetOrbitalElements[HST,
         "1 20580U 90037B   97046.42217324  .00050250  00000-0  48781-2 0  9267",
         "2 20580  28.4680  94.8927 0005837 191.3643 168.6802 14.91366889174923"];
```

■ This plots the three-dimensional shape of the orbit. Note that because the orbit decays with time, you need to specify a date.

```
In[27]:= OrbitPlot3D[HST, {1997,2, 19},
                     Distance   -> 8000*KiloMeter,
                     PlotRegion -> {{-0.4,1.4},{-0.4,1.4}}];
```



8. Miscellaneous Functions

This chapter discusses miscellaneous functions and features not included in earlier chapters.

As in the previous chapters, you need to set your site location and time zone before you can use various functions.

- Load the package.

```
In[1]:= <<Astronomer`HomeSite`

        Astronomer is Copyright (c) 1997 Stellar Software
```

- Set your location and time zone.

```
In[2]:= SetLocation[GeoLongitude -> 145.0*Degree,
                    GeoLatitude  -> -37.8*Degree,
                    GeoAltitude  ->   0.0*KiloMeter,
                    TimeZone     ->  11];
```

- This loads some extra stars.

```
In[3]:= <<Astronomer`Star3000`
```

■ 8.1 The Separation and PositionAngle Functions

`Separation` is useful for testing the degree of conjunctions, eclipses, and transits, but it has other applications as well.

`Separation[`*object1*`,` *object2*`,` *date*`]`	compute the angular separation of the two objects on the given *date*
`Separation[`*object1*`,` *object2*`]`	compute the separation using the current value of `Date[]`
`ViewPoint ->` *object3*	viewpoint from *object3*

Computing the apparant angular separation between objects.

You can use the function to find out the degree of an eclipse. If the separation of the Moon and the Sun is less than approximately one degree, then there is a partial solar eclipse visible from some point on the surface of the Earth.

Similarly, you can test for transits of Venus across the solar disk.

- The planets Mars and Jupiter are 34 degrees apart in the sky on the given date.

```
In[4]:= Separation[Mars, Jupiter, {1993,11,17,3,20,0}]

Out[4]= 34.1389 Degree
```

- On this date, the Moon and the Sun are just 0.55 degrees apart relative to the center of the Earth. A partial solar eclipse, therefore, occurs on the given date.

```
In[5]:= Separation[Moon, Sun, {1994,11,4}]

Out[5]= 0.55308 Degree
```

- Venus and the Sun are separated by just 0.33 degrees; hence, Venus is nearly passing across the solar disk, which is 0.5 degrees wide.

```
In[6]:= Separation[Venus, Sun, {1882,12,7}]

Out[6]= 0.332286 Degree
```

- This shows that the Mars-Sun-Earth angle is about 162 degrees.

```
In[7]:= Separation[Mars, Earth, {1993,11,17,3,20,0},
                   ViewPoint -> Sun]

Out[7]= 161.668 Degree
```

- Venus and the Sun are separated by only 0.17 degrees during the transit of 1769.

```
In[8]:= Separation[Venus, Sun, {1769,6,4,9,0,0}]

Out[8]= 0.17235 Degree
```

In 1769 Captain Cook sailed to the Pacific to witness a transit of Venus across the solar disk. Transit of Venus happens only four times every 243 years. The 1769 transit occurred at about 09:00 on June 4 local time in Melbourne, but would have been about midday on June 3 in Tahiti (Captain Cook's location). You can compute the degree, or closeness, of the event using `Separation`.

In addition, the duration of the transit can be determined using the expressions `EclipseBegin[Sun, Venus, Earth, {1769,1,1}]` and `EclipseEnd[Sun, Venus, Earth, {1769,1,1}]`.

The PositionAngle Function

A related function is `PositionAngle`. `Separation` gives the apparent angular separation of any two objects, but it does not give information about the orientation. Astronomers use a quantity called the position angle to represent the orientation of two objects. The position angle of one object relative to a second is the angle between the first object and the north celestial pole as measured relative to the second object.

`PositionAngle[`*object2*`,` *object3*`,` *date*`]`	compute the position angle of *object3* with respect to *object2* on the given *date*
`PositionAngle[`*object1*`,` *object2*`,` *object3*`,` *date*`]`	find the angle from *object1* to *object3* moving counterclockwise around *object2* on the given *date*
`PositionAngle[NorthCelestialPole,` *object2*`,` *object3*`,` *date*`]`	equivalent to the usual definition of the position angle of *object3* with respect to *object2*
`PositionAngle[Zenith,` *object2*`,` *object3*`,` *date*`]`	return an angle between 90 and 270 degrees, if *object3* is lower in the sky than *object2*

Computing the apparent angle between three objects.

The constellation of Gemini consists of the two bright stars Castor and Pollux. These stars are separated by about 4.5 degrees, and the position angle from Castor out to Pollux can be computed using `PositionAngle`.

- This shows that Pollux is rotated about 148 degrees around Castor. Remember that the usual definition of position angle is such that 0 degrees is in the direction of the north celestial pole, and counterclockwise is positive.

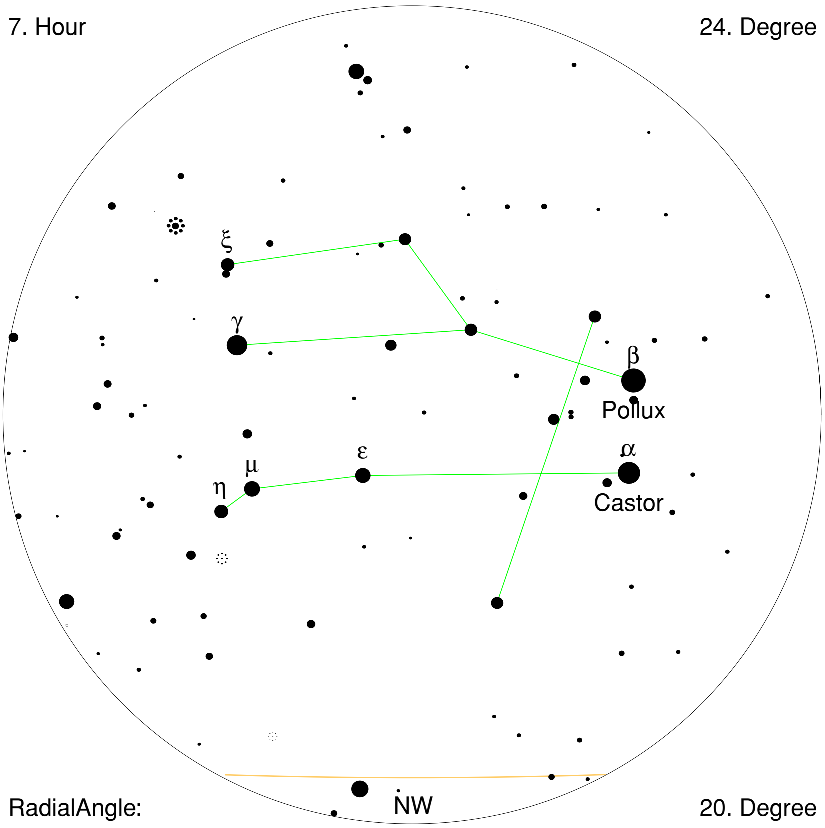
```
In[9]:= PositionAngle[Castor, Pollux]

Out[9]= 148.209 Degree
```

There are other uses of `PositionAngle`. Consider, for example, the following graphic, which uses the `Horizon -> True` option to make the horizon line horizontal.

- Castor and Pollux are setting into the northwest horizon. It appears that Pollux is almost directly above Castor.

```
In[10]:= RadialStarChart[Gemini, {1993,11,17,7,20,0},
                          Horizon    -> True,
                          Ecliptic   -> False,
                          StarLabels -> True,
                          Epilog     -> StarNames[Gemini]];
```



- The zenith-Castor-Pollux angle is about 354 degrees. That is, 354 degrees is needed to rotate counterclockwise from the zenith about Castor to Pollux. This is equivalent to 6 degrees clockwise.

```
In[11]:= PositionAngle[Zenith, Castor, Pollux,
                       {1993,11,17,7,20,0}]

Out[11]= 354.039 Degree
```

The Elongation Function

Another related function is `Elongation`, which is useful for indirectly determining the rising and setting times of a planet relative to local sunrise and sunset.

`Elongation[`*object*`,` *date*`]`	return the elongation of the *object*; if positive, then the object is mainly visible in the evening, and if negative, then the object is mainly visible in the morning
`Elongation[`*object*`]`	return the elongation using the current value of `Date[]`

Computing the angle along the ecliptic of an object to the Sun.

If the elongation of an object is sufficiently positive, the object is visible chiefly in the evening sky after dusk. If, however, the elongation is sufficiently negative, the object is mainly visible in the morning sky before dawn.

- This shows that Mars is only 11 degrees east of the Sun on the given date. This is fairly close to the Sun, so Mars is hard to spot on this date.

```
In[12]:= Elongation[Mars, {1993,11,17,3,20,0}]

Out[12]= 11.0382 Degree
```

- By definition the elongation of the Sun is zero.

```
In[13]:= Elongation[Sun, {1993,11,17,3,20,0}]

Out[13]= 0
```

- The Moon has a positive elongation on this date; hence, it appears mostly in the evening sky after dusk.

```
In[14]:= Elongation[Moon, {1993,11,17,3,20,0}]

Out[14]= 37.2822 Degree
```

You can easily convert the elongation angle into a time by remembering that the Earth rotates 360 degrees in 24 hours, and that therefore each 15 degrees of positive elongation corresponds to 1 hour of time after sunset. Thus, an elongation of -45 degrees corresponds to 3 hours before sunrise.

Note that the definition of a new or full moon relates to the elongation of the Moon. The time returned by `NewMoon` is such that the ecliptic longitude of the Sun and the Moon are the same at that instant. That is, by definition, the value of `Elongation[Moon, NewMoon[]]` is zero.

Similarly, the time returned by `FullMoon` is such that the ecliptic longitude of the Sun and the Moon differs by 180 degrees. Therefore, by definition, the value of `Elongation[Moon, FullMoon[]]` is 180 degrees.

■ 8.2 The FindNearestObject Function

`FindNearestObject` is useful for identifying the name of a star or other object that is near to a known object.

`FindNearestObject[`*object*`,` *date*`]`	find the name of the star, cluster, nebula, galaxy, or planet nearest to the *object* on the given *date*
`MagnitudeRange -> `*range*	magnitude *range* of stars to search; default is `{-Infinity, Infinity}`
`Stars -> False`	stars are not searched; default is `True`
`Clusters -> False`	clusters are not searched; default is `True`
`Nebulae -> False`	nebulae are not searched; default is `True`
`Galaxies -> True`	galaxies are searched; default is `False`
`Planets -> True`	planets are searched; default is `False`

Finding the brightest star near an object.

Use `FindNearestObject`, for example, to find the name of the star nearest to the Moon, at a given time, that is brighter than magnitude 3.5.

You can also identify a star name by first clicking inside any star chart graphic (it must be the last graphic you have computed) and then while holding the CMD key down, clicking again near a star. If you then use **Copy** followed by **Paste** into `FindNearestObject`, the function returns the name of the star nearest to where you clicked in the graphic. This method works with all functions that require an object. For example, you can also find the equator coordinates of the selection.

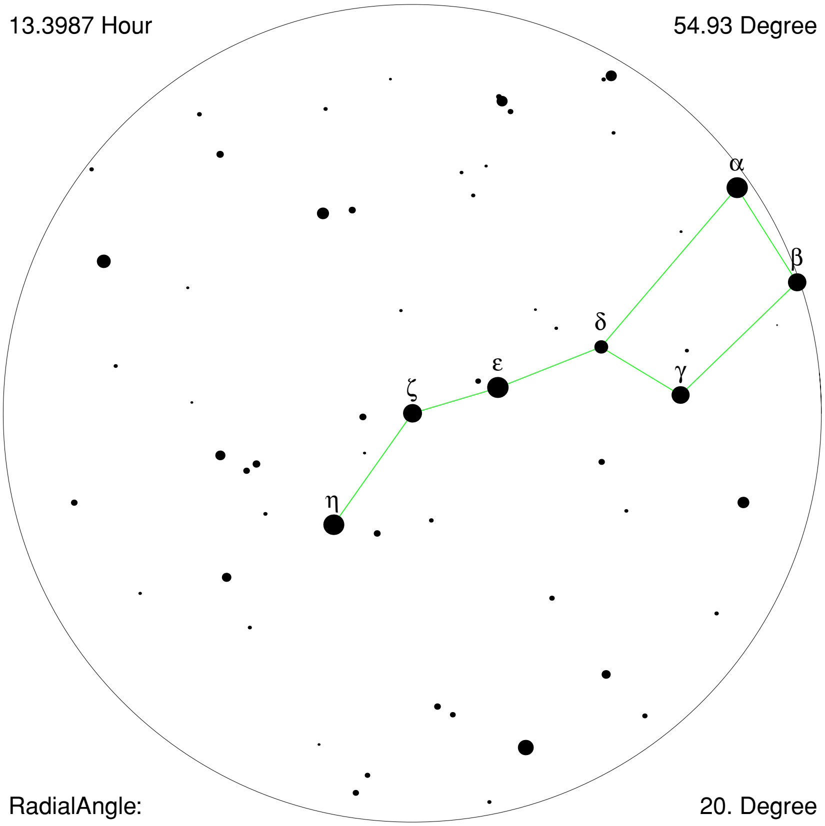
■ At the given time the Moon and the returned star are separated by about 6 degrees, determined precisely using `Separation`.

```
In[15]:= FindNearestObject[Moon, {1993,11,17,3,20,0},
                          MagnitudeRange -> 3.5,
                          Clusters -> False,
                          Nebulae  -> False]

Out[15]= Lambda . Sagittarius
```

■ This is a plot of Ursa Major centered on Mizar, which is also known as ζ (zeta) Ursae Majoris. If you hold the CMD key down and click on the star just to the left of ε (epsilon), you get the numbers {3.05, 1.55}.

```
In[16]:= RadialStarChart[Mizar,
                Epilog -> StarNames[UrsaMajor]];
```



■ Input the numbers selected from the previous graphics to determine the name of the small star just to the left of ε (epsilon) Ursae Majoris.

```
In[17]:= FindNearestObject[{3.05414, 1.55386},
                MagnitudeRange -> 5.5]

Out[17]= 78. UrsaMajor
```

■ Similarly, you can find the equator coordinates of the point that was clicked.

```
In[18]:= EquatorCoordinates[{3.05414, 1.55386}]

Out[18]= {Ascension → 13.0307 Hour, Declination → 56.3627 Degree}
```

You can use `FindNearestObject` to determine the name of a partner in a double star system.

- β (beta) Cygni is one of the most beautiful double stars. The main component is a third magnitude gold-colored (K3) star. In *Scientific Astronomer* notation the star is referred to as `Beta.Cygnus`.

```
In[19]:= Appearance[Beta.Cygnus]

Out[19]= {ApparentMagnitude → 3.1, ApparentDiameter → 0. Degree, Color → K3}
```

- The other component is a star called `Beta2.Cygnus`.

```
In[20]:= FindNearestObject[Beta.Cygnus]

Out[20]= Beta2 . Cygnus
```

- β2 (beta2) Cygni is a fifth magnitude blue (B8) star, separated by 0.009 degrees from the main gold-colored star. The contrasting blue and gold colors give this pair a distinctive appearance in a telescope.

```
In[21]:= Separation[Beta2.Cygnus, Beta.Cygnus]

Out[21]= 0.00883193 Degree
```

■ 8.3 The SiderealTime and HourAngle Functions

`SiderealTime` determines which right ascension line on a star chart is crossing the local meridian at a given date and time.

Similarly, `HourAngle` determines the number of hours before an object will cross the local meridian. You can also use this function to determine when a star will cross the meridian.

`Culmination` determines at what time an object will cross the meridian.

`SiderealTime[`*date*`]`	return the right ascension of the meridian line on the given *date*; this is equivalent to sidereal time
`HourAngle[`*object*`, `*date*`]`	compute the time elapsed since the *object* crossed the meridian line on the given *date*
`Culmination[`*object*`, `*neardate*`]`	return the date, nearest to *neardate*, when the *object* crosses the local meridian line

Timing information.

■ This shows that the 5.7 hour right ascension line, which roughly corresponds to the constellation of Taurus, is crossing the local meridian at the given date and time.

```
In[22]:= SiderealTime[{1993,11,17,3,20,0}]

Out[22]= 5.71672 Hour
```

■ The star Sirius crosses the meridian in just over one hour's time from the given date.

```
In[23]:= HourAngle[Sirius, {1993,11,17,3,20,0}]

Out[23]= -1.03139 Hour
```

■ On 1993 November 17, Sirius crosses the local meridian at 04:22. At this time the star is at its highest point in the sky.

```
In[24]:= Culmination[Sirius, {1993,11,17}]

Out[24]= {1993, 11, 17, 4, 22, 26}
```

Time Conversion

`ModifiedJulianDay` returns the modified Julian day number of a local date. To get the true Julian day number, add 2415019.5 to the output.

`ModifiedJulianDay[`*date*`]`	return the modified Julian day number of the *date*, such that day 1 is the start of the first day of the year 1900; the true Julian day number is obtained by adding 2415019.5
`LocalDate[`*mjd*`]`	return the local date corresponding to the modified Julian day number *mjd*

Converting dates to and from Julian days.

■ This is the modified Julian day number of 1993 November 17, 03:20 local time.

```
In[25]:= ModifiedJulianDay[{1993,11,17,3,20,0}]

Out[25]= 34288.7
```

■ Add 2415019.5 to get the true Julian day number.

```
In[26]:= % + 2415019.5
```

Out[26]= 2.44931×10^{6}

■ Here is the true Julian day number expressed in nonexponential form.

```
In[27]:= AccountingForm[%, 20]

Out[27]//AccountingForm=
        2449308.180555555
```

■ This converts a modified Julian day number into a local date and time.

```
In[28]:= LocalDate[34288.68055555556]

Out[28]= {1993, 11, 17, 3, 20, 0}
```

All dates returned by *Scientific Astronomer* are in local time; that is, your time zone is always taken into account. To get Universal Time (UT) or Greenwich Mean Time (GMT), subtract your time zone value from any local date. For instance, in the examples used throughout this user's guide, where `TimeZone -> 11`, the local date `{1993,11,17,3,20,0}` corresponds to `{1993,11,16,16,20,0}` Universal Time.

In addition, all dates returned by *Scientific Astronomer* are based on the Gregorian calendar. To get the date according to the Julian calendar, which was in use prior to 1752 in most British colonies, add `2-Floor[y/100]+Floor[y/400]` days, where *y* is the year.

Remember also that *Scientific Astronomer* includes a year zero, although it was not historically used. Hence, the year 0 is the same as 1 B.C., and the year -1 is 2 B.C., and so on.

Thus, the date `{-584,5,22}` corresponds to May 22, 585 B.C. In the Julian calendar this date would be called May 28, 585 B.C. because `2-Floor[-584/100]+Floor[-584/400]` is 6 days.

■ 8.4 The Lunation and LunationNumber Functions

`Lunation` allows the dates of new moons to be addressed sequentially.

`Lunation[n]`	give the date on which the n^{th} new moon occurs; new moons are arbitrarily numbered so that $n = 0$ is the new moon that occurred on 1900 January 1
`LunationNumber[neardate]`	return the lunation number nearest the given *neardate*; this essentially counts the number of new moons that have occurred since 1900 January 1

Numbering new moons.

■ The thousandth new moon since 1900 January 1 occurs on 1980 November 8.

```
In[29]:= Lunation[1000]

Out[29]= {1980, 11, 8, 7, 42, 8}
```

■ This confirms that the previous new moon date is the thousandth new moon.

```
In[30]:= LunationNumber[%]

Out[30]= 1000
```

`Lunation[`*n*`]`, with *n* as an integer, gives the date of a new moon. If *n* is a half-integer, `Lunation` instead returns the date of a full moon. Thus `Lunation[999.5]` is the thousandth full moon since 1900 January 1. To produce a sequence of full moon dates, use `LunationNumber` to determine the starting value of *n* and then add `0.5` to get a full moon. Add any integer to get later full moons. An expression like `Table[Lunation[LunationNumber[{1993,1,1}] - 0.5 + i], {i, 1, 13}]`, therefore, returns the dates of the 13 full moons that occur in the year 1993.

It is also possible to determine the precise rising and setting times of the Moon with the functions `MoonRise` and `MoonSet`. Atmospheric refraction is taken into account in the same way as with the `SunRise` and `SunSet` functions. You can use the option `Refract -> False` to suppress refraction.

`MoonCalendar` is a function that produces a text table showing the dates and zodiac positions of all the full and new moons in a given year. It also shows the dates when the Moon is at its halfway waxing and waning phases.

`MoonRise[`*neardate*`]`	compute the precise time of moonrise on the day of the given *neardate*
`MoonSet[`*neardate*`]`	compute the precise time of moonset on the day of the given *neardate*
`MoonCalendar[`*year*`]`	return a calendar of Moon phases for the given *year*

Rising and setting times of the Moon.

■ The Moon rises at 08:50 local time in Melbourne on 1993 November 17.

```
In[31]:= MoonRise[{1993,11,17}]

Out[31]= {1993, 11, 17, 8, 50, 16}
```

■ This shows that the first full moon of 1993 occurs on January 9 in the direction of the zodiac constellation of Gemini.

```
In[32]:= MoonCalendar[1993]

              FULL  MOON         WANING          NEW   MOON         WAXING
                                                                Jan  1 (Psc)
            Jan  9 (Gem)     Jan 16 (Vir)     Jan 24 (Cap)     Jan 31 (Ari)
            Feb  7 (Cnc)     Feb 15 (Lib)     Feb 22 (Aqr)     Mar  2 (Tau)
            Mar  9 (Leo)     Mar 16 (Sco)     Mar 24 (Psc)     Mar 31 (Gem)
            Apr  7 (Vir)     Apr 15 (Sgr)     Apr 22 (Ari)     Apr 30 (Cnc)
            May  7 (Lib)     May 14 (Cap)     May 22 (Tau)     May 29 (Leo)
Out[32]= {  Jun  6 (Sco)  ,  Jun 13 (Aqr)  ,  Jun 20 (Tau)  ,  Jun 28 (Vir)  }
            Jul  5 (Sgr)     Jul 12 (Psc)     Jul 20 (Gem)     Jul 27 (Lib)
            Aug  4 (Cap)     Aug 11 (Ari)     Aug 18 (Cnc)     Aug 26 (Sco)
            Sep  2 (Aqr)     Sep  9 (Tau)     Sep 17 (Leo)     Sep 24 (Sgr)
            Oct  2 (Psc)     Oct  9 (Gem)     Oct 16 (Vir)     Oct 24 (Cap)
            Oct 31 (Ari)     Nov  8 (Cnc)     Nov 15 (Lib)     Nov 22 (Aqr)
            Nov 30 (Tau)     Dec  7 (Leo)     Dec 14 (Sco)     Dec 22 (Psc)
            Dec 29 (Gem)
```

■ 8.5 The NGC and IC Functions

You can access the New General Catalog, Index Catalog, and Messier's catalog of nonstellar objects using *Scientific Astronomer*.

The New General Catalog is a large list of nonstellar objects including galaxies, nebulae, and clusters. The Index Catalog is a supplement to the New General Catalog. Messier's catalog is a small, but popular, list of objects compiled by Charles Messier in the 18th century.

To access the New General Catalog or Index Catalog, you can use the `NGC` and `IC` functions. Only a small number of catalog objects are built into *Scientific Astronomer*, but to access a more extensive list, you can load the `DeepSky.m` package.

`NGC[`*index*`]`	select an object with the given *index* from the New General Catalog of nonstellar objects
`IC[`*index*`]`	select an object from the Index Catalog
`M[`*index*`]`	select an object from Messier's catalog
object `//NGC`	find the catalog information for the *object*

Accessing deep sky catalogs.

`NGC`, `IC`, and `M` return a set of rules that you can use as an object. Specifically, the functions return the right ascension, declination, distance, apparent magnitude, apparent diameter, appearance type, and catalog alias of an index item in the catalog. The appearance type is either a galaxy, diffuse nebula, planetary nebula, open cluster, or globular cluster.

As an example, `M[45]` returns information about M45, or the Pleiades star cluster. Similarly, `NGC[224]` returns details about the M31 Andromeda Galaxy, also known as NGC 224.

■ This loads a file containing many deep sky objects.

```
In[33]:= <<Astronomer`DeepSky`
```

■ Information about NGC 224 is given here.

```
In[34]:= NGC[224]

Out[34]= {Ascension → 0.713333 Hour, Declination → 41.27 Degree,
          Distance → 2.2 × 10^6 LightYear, ApparentMagnitude → 3.5,
          ApparentDiameter → 3. Degree, Appearance → Galaxy, Alias → NGC : 224}
```

■ IC 2621 is a planetary nebula located in the southern skies with declination -65 degrees. It has an apparent magnitude of 10.5.

```
In[35]:= IC[2621]

Out[35]= {Ascension → 11.0047 Hour, Declination → -65.25 Degree,
          Distance → 3500. LightYear, ApparentMagnitude → 10.5,
          ApparentDiameter → 0. Degree, Appearance → PlanetaryNebula,
          Alias → IC : 2621}
```

The catalogs are typically accessed using the index number of the object you want information on. However, as noted in Chapter 2, many objects of interest to amateur astronomers have names defined in *Scientific Astronomer*. You can also access the catalogs using these names, rather than the index numbers.

■ Here is the catalog entry for the Orion Nebula, the brightest nebula in the sky.

```
In[36]:= OrionNebula//NGC

Out[36]= {Ascension → 5.588 Hour, Declination → -5.38 Degree,
          Distance → 1500. LightYear, ApparentMagnitude → 4.,
          ApparentDiameter → 1.1 Degree, Appearance → DiffuseNebula,
          Alias → NGC : 1976}
```

■ The catalog entry for the well-known Andromeda Galaxy shows that it is 2.2 million light years from Earth.

```
In[37]:= AndromedaGalaxy//NGC

Out[37]= {Ascension → 0.713333 Hour, Declination → 41.27 Degree,
          Distance → 2.2 × 10^6 LightYear, ApparentMagnitude → 3.5,
          ApparentDiameter → 3. Degree, Appearance → Galaxy, Alias → NGC : 224}
```

9. Additional Information

■ 9.1 Ephemeris Accuracy

The orbital elements used by *Scientific Astronomer* are fairly accurate. Planet positions are accurate to about one arc-minute during this and the next century (*i.e.*, the years 1900 to 2100), and you should be able to go several thousand years into the past or future with very little error. The orbital elements used to calculate the Moon's position are also accurate to one arc-minute, and are sufficient to predict precise times for lunar and solar eclipses. Terms like *evection*, *variation*, *annual-equation*, *reduction*, and many more are all included in the equations for the Moon's position. Perturbations due to Venus are incorporated as well.

One thing that is not computed with high accuracy is the rising/setting time reported by `Ephemeris`. A difference of several minutes may exist between the true rising and setting times and those reported, since the full calculations with astmospheric corrections are not done. Another consideration is that right ascension and declination are relative to the time of observation epoch, not a fixed epoch year of, say, 2000. If you have a printed star chart for epoch 1950.0 or epoch 2000.0, you can expect a few arc-minutes discrepency due to the precession of the Earth's tilt, which `Ephemeris` correctly takes into account. The option `Epoch` is available in most functions to choose a specific epoch, other than the current one.

Scientific Astronomer correctly adjusts for light travel time when the option `ViewPoint` is set to an object other than the Earth. When you view a planet, you are actually seeing it as it was when the light first left it, not as it is now. The correction is very small, but sometimes it can make a difference. For example, it makes a difference in `PlanetPlot3D[Jupiter, {1993,11,17,3,20,0}, ViewPoint -> Mars]`, where the positions of the Galilean moons and the Great Red Spot would be slightly wrong if the light travel time were not taken into account.

A final note about the time system used: *Scientific Astronomer* correctly uses Terrestrial Dynamic Time (TDT) for internal ephemeris calculations, and only converts to Universal Time (UT) when showing the date and time on input or output. Universal Time is the time you effectively use in the everyday world; that is, your watch is set to UT plus a time zone correction in hours. The problem with UT, however, is that it is related to the rotation of the Earth, which is now known to be irregular and slowly running down. For midnight to remain in the middle of the night it is necessary to add leap seconds to UT every now and then. Such jumps in UT are determined only by observation of the unpredictable rotation of the Earth. A more satisfactory time measure is TDT, which is completely regular (without leap seconds, for instance) and is governed by atomic clocks. In about the year 1900, TDT and UT corresponded almost exactly, but by the year 2000 the TDT-UT difference will amount to about 67 seconds. The TDT-UT difference increases at roughly a quadratic rate, assuming the Earth is uniformly slowing down. Thus, by the year 2100, this difference will probably be over 4 minutes.

■ 9.2 Using PlanetChart

Basic information on how to read the `PlanetChart` output has been given in Section 2.2. There are, however, many other details and features built into the chart.

All planets, as well as the Sun and the Moon, move along the ecliptic indicated by the yellow line in the star field at the bottom of the chart. The star field shows a 360 degrees swathe of sky for the region 36 degrees above and below the celestial equator. Only half of the stars shown in the star field are visible at any given time, however; the rest are below the horizon. In general, the east and west horizons correspond to roughly vertical lines in the star field. Those horizons move slowly to the left, with increasing right ascension, as the night goes by. For each hour of time, right ascension increases by one hour as well.

To orient the star field, first turn so that your back is to the Pole Star if you are viewing from the northern hemisphere. (If you are in the southern hemisphere, turn so that your back is to the Southern Cross.) Next hold the star field above your head with the top (bottom) pointing back over your head to the Pole Star (Southern Cross). Then, in front of you, in a great circle about 90 degrees away from the Pole Star (Southern Cross), you should see approximately half the stars shown in the star field, with the other half below the horizon. This can take some practice to do quickly, so first try finding the constellation of Orion, which is in the center of the star field with a right ascension between 5h and 6h. At some time during the night Orion is visible above the horizon, as are all the constellations in the star field. The transit table near the bottom of the chart should help you find the stars in the star field that are directly in front of you at various hours in each month of the year. Stars are said to transit when they are directly south (north) of your location. If you orient the star field correctly, then, for example, at 23:00 (or 11pm) each night during the month of January you should be facing the zodiac constellation of Gemini. Two hours later, at 01:00 (or 1am), you should be facing the zodiac constellation of Cancer, and so on. These times may need to be adjusted if you are using daylight-saving time, and if you are not in the exact center of your time zone.

To get a sense of scale, two hands are shown in the star field, separated by 90 degrees. For most people, a hand span (measuring from index finger to little finger), when held at arm's length, subtends an angle of about 15 degrees, or 1 hour of right ascension. This is illustrated to scale in the star field. The constellation of Orion covers a solid angle approximately equal to the size of your hand at arm's length.

To get a sense of how bright the planets are, note that the three stars forming the belt in the constellation of Orion are each nearly magnitude 2, and the two brighter stars above the belt are magnitudes 1 and 2. The two brighter stars below the belt are magnitudes 2 and 1. Also note that Sirius, the brightest star in the sky, is brighter than magnitude -1. Sirius is the bright star one hand span away from Orion, with a right ascension of about 7h. Most of the major planets are usually quite bright and easily found if you know where to look. For example, Mars is often much brighter than the brightest stars in Orion, Jupiter is considerably brighter at about magnitide -2, and Venus is even brighter still at magnitude -3 or -4, depending on its phase. When visible, Jupiter and Venus are the brightest objects in the sky, with the exception, of course, of the Moon, which is obviously much brighter at approximately magnitude -12. Saturn and Mercury are as bright as the brightest stars in Orion. In the key at the bottom of the chart, the mean magnitude of each major planet is displayed as a dot along an ecliptic line. You can directly compare these planet dots with the star magnitude dots used in the star field.

The planet chart has diagonal lines labeled with hours either before sunrise or after sunset. To make reading the chart easier, the words “Morning” and “Evening” are shown to indicate whether the planets are visible in the morning before sunrise or in the evening after sunset. For example, on 1994 September 1, the planet Jupiter is visible in the evening sky. By reading the diagonal scale you see that it is visible for about 4 hours after sunset before it sets in the west. If a planet is along the line of full moons, it is at opposition to the Sun and is visible the whole night, whereas if it is within 1 hour of the Sun, it is generally not visible because of the glare after sunset or before sunrise.

Other features to note are that the half moon crescents are facing in the correct direction in relation to the star field, and that lunar eclipses are indicated along the full moon line. The lines for the outer planets, Mars, Jupiter, and Saturn, are always drawn behind the Sun’s yellow line, which is correct since these planets always pass behind the Sun. However, for the inner planets, Mercury and Venus, the lines may be in front of the Sun as well. The thickness of a planet line is meant to convey a sense of apparent brightness or magnitude, which is why the Venus and Jupiter lines are thick, and the Sun’s line is even thicker.

The planet chart contains some necessary simplifications. First, a given planet will not always lie exactly on the line of the ecliptic in the star field because its orbital plane may be slightly inclined to that of Earth’s. The maximum departures, either above or below the ecliptic, for each planet are: Mercury, 3°; Venus, 3°; Mars, 2°; Jupiter, 1°; and Saturn, 2°. These are all fairly insignificant angles in the star field. The Moon, however, may be as much as 5° above or below the ecliptic, which is a more noticeable effect. A second simplication involves the transit table, which, as mentioned earlier, assumes that you live in the center of your time zone. The potential error is only 30 minutes of time, since in theory no one lives more than 7.5 degrees of longitude from the center of a time zone. You will, of course, have to add one hour to the transit times when you are experiencing daylight-saving time. A final simplification involves the dots representing the brightness of each planet shown in the key at the bottom of the chart. During the course of a year, the brightness of Venus and Mars will vary significantly because these planets are in orbits close to Earth. The dots for Venus and Mars, therefore, simply represent the mean brightness; the true brightness depends on how close the planet is to the Earth at the time of viewing.

■ 9.3 Using StarChart

`StarChart` shows a section of the sky. There are several ways to call this function.

First, you can supply a constellation name, such as `Scorpius`, and you will see a region that includes that constellation. This is the standard way to use the function. Instead of a constellation name, you can also supply any other type of object, such as a star or planet name, to view the region surrounding that object.

Second, you can supply a bounding rectangle to specify the minimum and maximum right ascension and declination that you wish to view. The easiest way to obtain numbers for the rectangle is to use CMD-OPTION and copy on a previous `StarChart` graphic, and then paste the result into a new `StarChart` call.

In the graphic returned by `StarChart` the green lines join together some of the brighter stars to form constellations. The blue line represents the ecliptic; all the planets and the Moon move approximately along this line. The Sun moves precisely along the ecliptic.

To display red dots for the positions of all the planets at the current date, you can use the option setting `Planets -> All`. To display a subset of all the planets you can use, for example, `Planets -> {Mercury, Venus, Mars}`. You can use the `Sun` and `Moon` in the list, but they are displayed as yellow and gray dots, respectively. The default setting is `Planets -> None`. Label planets with the option setting `PlanetLabels -> True`. If you use the setting `StarColors -> True`, accurate colors are used for the planets, rather than simply red dots.

The region below the local horizon is shaded with a brown area by using the option setting `Horizon -> True`. If you set the option `Skyline` to specific graphic primitives, involving `Line`, `Rectangle`, `Disk`, `Circle`, `Point`, `Polygon`, and `Text`, then a sky line is mapped along the horizon line.

By default, constellation outlines and the ecliptic line are drawn. These are suppressed by using the option settings `Constellations -> False` and `Ecliptic -> False`.

Use the option setting `ConstellationLabels -> True` to display the names of the constellations that appear in the field of view. The option setting `StarLabels -> True` displays the names of the brightest stars. Another way to identify a particular star in the output from `StarChart` is to select the graphic, use CMD and click near a star. Then copy and paste the pair of numbers into `FindNearestObject` to get the name of the star nearest to the point where you clicked. You can also find the nearest deep sky object or planet with the `FindNearestObject` function.

One way to label all the stars in a particular constellation is to use the expression `StarNames[`*constellation*`]` as part of an `Epilog` option. For example, the option setting `Epilog -> {StarNames[Scorpius], StarNames[Ophiuchus]}` labels all the stars in the given constellations.

`StarChart` is based initially on a database of the 300 brightest stars. A set of the 3,000 brightest stars is used if you load the file called ``Astronomer`Star3000` ``. This file contains all the stars visible to the naked eye. An additional file, called ``Astronomer`Star9000`,`` contains the 9,000 brightest stars.

To filter out a subset of the stars use the option `MagnitudeRange`. As an example, `MagnitudeRange -> {3, 5}` displays only those stars whose magnitudes are between 3 and 5. The default is `MagnitudeRange -> {-Infinity, Infinity}`.

You can enhance the brightness of stars by using the option `MagnitudeScale`. This is useful if you zoom into a small area of the sky, since you can use, say, `MagnitudeScale -> 2` to artificially double the brightness of the stars so that bigger dots appear in the graphic output.

Use the option setting `Background -> RGBColor[`*r*`,`*g*`,`*b*`]` when you want to create a colored background for the sky field. The default is white, and in this case black stars and text are used. If the background is a dark color, then stars and text are displayed in white. Stars can also be colored according to their visible spectral type; to use this feature choose the option setting `StarColors -> True`.

The option settings `Clusters -> True`, `Nebulae -> True`, and `Galaxies -> True`, will display special symbols indicating star clusters, nebulae, and galaxies. You can additionally label the objects using the options `ClusterLabels -> True`, `NebulaLabels -> True`, and `GalaxyLabels -> True`.

Finally, as with all graphics functions in *Scientific Astronomer*, `StarChart` inherits the standard set of `Graphics` options.

■ 9.4 Using RadialStarChart

`RadialStarChart` shows a radial region of the sky. There are several ways to call this function.

First, if you supply an object name, such as a constellation, star, or planet, you will see a radial region centered on that object's position. This is the standard way to use the function. Examples are `RadialStarChart[Andromeda]`, `RadialStarChart[Sirius]`, and `RadialStarChart[Mars]`.

A second way to call the function is to supply equator coordinates; you will then see a radial region centered on the position specified by the coordinates. An example is
`RadialStarChart[{Ascension -> 6*Hour, Declination -> 30*Degree}]`.

Third, you can supply horizon coordinates; again the function produces a radial region centered on this position. Typically, you need to supply the date as well, since horizon coordinates depend on your location and time of day. An example would be `RadialStarChart[{Azimuth -> 270*Degree, Altitude -> 30*Degree}, {1993,11,17,3,20,0}]`.

When you use the option setting `Horizon -> True`, the radial star chart aligns so that the local vertical is pointing upward, and the horizon line is horizontal. The local compass direction appears at the bottom of the chart. For example, ENE means east-northeast. Use the option `ViewVertical` to rotate the chart so that any other point or object is at the top of the graphic. The setting `ViewVertical -> Zenith` is similar in effect to `Horizon -> True`.

Use the option setting `Mesh -> True` to superimpose an equator coordinates mesh. The mesh has 1 hour spacing in the right ascension direction and 15 degree spacing in the declination direction. The option also places crosses at the north and south celestial poles. For various reasons, this option can make the final graphic slow to compute.

Use the option `Text->False` to prevent labels being printed around the chart. This option applies to `RadialStarChart`, `CompassStarChart`, `ZenithStarChart`, and `Planisphere`.

See the previous section on using ordinary star charts for other options and details.

To determine the equator coordinates of a point in the output from `RadialStarChart`, simply select the graphic, hold down CMD and click on the point. Then copy and paste the pair of numbers into `EquatorCoordinates` to return the equator coordinates of the point you clicked. This feature works with all star charts.

The default options to `RadialStarChart` are the same as `Options[StarChart]`.

■ 9.5 Planetographic Coordinates

`Appearance` returns the central longitude and latitude of the point at the apparent center of an object. The longitude and latitude are given relative to a specific coordinate system on the surface of the object. Similarly, the `Features` option, available to `PlanetPlot`, `PlanetPlot3D`, and certain other functions, uses longitude and latitude relative to the same coordinate system. A uniform coordinate system is used throughout *Scientific Astronomer* for specifying longitude and latitude on the surface of an object.

Geographic coordinates are used on the surface of the Earth. An equivalent system called planetographic coordinates is used for other planets. Alternative titles, such as areographic coordinates on Mars, selenographic coordinates on the Moon, and heliographic coordinates on the Sun, are sometimes used to refer to the equivalent systems.

The definition of planetographic coordinates requires a scheme for assigning longitude and latitude lines.

For each planet, a system of longitude lines is set up by first defining a prime meridian to act as the origin of longitude. A meridian is any line that begins at one pole of the planet and ends at the other pole. The prime meridian is an arbitrarily chosen meridian, typically passing through a prominent feature of the planet, such as a crater. In the case of the Earth, the prime meridian passes through the original Royal observatory at Greenwich, England. Once a zero of longitude is specified, by convention positive longitude is taken to be in the direction of rotation of the planet. That direction also corresponds to the direction east. There are 360 degrees of longitude lines wrapping around a planet.

The other component of planetographic coordinates is latitude. Latitude lines are circles centered on the axis of a planet. The zero of latitude is at the equator, and 90 degrees is at the north pole. The north pole is distinguished from the south by the fact that when viewed from above, the planet's rotation is counterclockwise.

In summary, planetographic coordinates are a system of coordinates created by the setting up of longitudinal and latitudinal lines on planets. A prime meridian is defined by the position of some prominent feature; positive longitude is in the direction of rotation, and positive latitude is in the direction of the north pole.

Specifics of Planetographic Coordinates

On the Moon, selenographic coordinates are used. The prime meridian passes through the mean center of the lunar disk as it faces the Earth. Positive longitude is toward Mare Crisium and positive latitude is toward Mare Serenitatis.

Heliographic coordinates are used on the Sun. The prime meridian passes through the center of the solar disk as seen from the Earth on the date 1853 November 9.9. This was the beginning of solar Synodic Rotation Number 1. By convention, the solar sidereal rotation period is taken to be exactly 25.38 days. Based on this value, the mean synodic period between rotation numbers is 27.2752316 days. The central latitude reaches a maximum of +7.25 degrees on September 9 and a minimum of -7.25 degrees on March 6 of each year. The central latitude is zero on June 6 and December 7 of each year.

On Mercury, the prime meridian is defined to be 20 degrees away from the crater Hun Kal (a name that means 20 in the Mayan language). Positive longitude is east of Hun Kal and positive latitude is toward Planitia Borealis.

The prime meridian on Venus passes through the crater Eve in Alpha Regio. Positive longitude is toward Thetis Regio and positive latitude is toward the Maxwell Mountains.

On the Earth, geographic coordinates are used. As stated earlier, the prime meridian passes through Greenwich. Positive longitude is toward Asia and positive latitude is toward the Arctic.

Areographic coordinates are used on Mars. The prime meridian passes through the crater Airy-O. Positive longitude is toward Syrtis Major and positive latitude is toward Acidalia.

Jupiter has several coordinate systems because different latitudes rotate at different rates. *Scientific Astronomer* uses System II coordinates, based on the mean atmospheric rotation of the north and south equatorial belts. Positive latitude is in the opposite hemisphere away from the Great Red Spot.

Saturn, Uranus, and Neptune also have several coordinate systems. This package uses the System III coordinates, based on the rotating magnetic field.

In the case of the Galilean moons, Io, Europa, Ganymede, and Callisto, a coordinate system similar to selenographic coordinates on the Moon is used. The prime meridian passes through the mean center of the moon's disk as it faces Jupiter.

Appendix. Special Events

This appendix contains tables and other details of special astronomical events. In some cases you can use *Scientific Astronomer* to check the information given in the tables.

■ A.1 Meteor Showers (10-20 every hour; occur at night)

Some important showers are given in the following table.

SHOWER-NAME	PEAK	[RANGE]	(RADIANT)	(ZHRATE)	CULM
Quadrantids	Jan 03	[-2, +2]	(15h20m, +49°)	(100/hour)	8am
Pi-Puppids II	Jan 10	[-4, +4]	(07h32m, -43°)	(/hour)	12am
Delta-Cancrids	Jan 17	[-12, +7]	(08h40m, +20°)	(5/hour)	1am
Alpha-Crucids	Jan 19	[-13, +9]	(12h48m, -63°)	(5/hour)	5am
Lambda-Velids II	Jan 21	[-3, +5]	(08h52m, -46°)	(/hour)	1am
Alpha-Carinids	Jan 31	[-7, +9]	(06h20m, -54°)	(/hour)	10pm
Theta-Centaurids	Feb 01	[-9,+40]	(14h00m, -40°)	(/hour)	5am
Alpha-Centaurids	Feb 07	[-10,+14]	(14h00m, -59°)	(20/hour)	5am
Omicron-Centaurids	Feb 11	[-11, +8]	(11h48m, -56°)	(/hour)	2am
Delta-Leonids	Feb 15	[-10,+33]	(10h36m, +19°)	(5/hour)	1am
Gamma-Normids	Mar 14	[-18, +8]	(16h36m, -51°)	(10/hour)	5am
Beta-Pavonids	Apr 07	[-27, +9]	(20h32m, -63°)	(10/hour)	7am
Lyrids	Apr 22	[-6, +3]	(18h04m, +34°)	(100/hour)	4am
Pi-Puppids	Apr 23	[-8, +5]	(07h20m, -45°)	(50/hour)	5pm
Alpha-Bootids	Apr 27	[-13,+15]	(14h32m, +19°)	(5/hour)	12am
Eta-Aquarids*	May 03	[-14,+25]	(22h24m, -02°)	(50/hour)	8am
Alpha-Scorpids	May 03	[-38, +9]	(16h00m, -27°)	(10/hour)	1am
Ophiuchids N	May 10	[-15,+21]	(16h36m, -14°)	(/hour)	1am
Corona Australids	May 15	[-22,+15]	(18h56m, -40°)	(/hour)	3am
Kappa-Scorpids	May 19	[-15, +8]	(17h48m, -39°)	(/hour)	2am
Ophiuchids S	May 20	[-7, +6]	(17h12m, -24°)	(/hour)	1am
Omega-Scorpids	Jun 04	[-12,+11]	(16h12m, -22°)	(/hour)	11pm
Chi-Scorpids	Jun 05	[-12,+15]	(16h32m, -14°)	(/hour)	12am
Gamma-Sagittarids	Jun 06	[-15, +7]	(18h08m, -28°)	(/hour)	1am
Theta-Ophiuchids	Jun 13	[-9,+32]	(17h48m, -20°)	(/hour)	12am
Lyrids (Jun)	Jun 16	[-5, +5]	(18h32m, +35°)	(5/hour)	1am
Bootids (Jun)	Jun 28	[-2, +2]	(14h36m, +49°)	(2/hour)	8pm
Lambda-Sagittarids	Jul 01	[-26,+24]	(18h24m, -25°)	(/hour)	12am
Pegasids	Jul 10	[-3, +1]	(22h40m, +15°)	(10/hour)	3am
Phoenicids (Jul)	Jul 15	[-21, +3]	(01h24m, -43°)	(/hour)	6am
Piscis Austrinids	Jul 29	[-20,+19]	(22h44m, -30°)	(10/hour)	2am
Delta-Aquarids S	Jul 29	[-21,+21]	(22h36m, -16°)	(20/hour)	2am
Alpha-Capricornids	Jul 30	[-27,+26]	(20h28m, -10°)	(10/hour)	12am
Iota-Aquarids S	Aug 04	[-20,+21]	(22h12m, -15°)	(5/hour)	1am
Delta-Aquarids N	Aug 12	[-28,+13]	(22h28m, -05°)	(5/hour)	1am
Perseids	Aug 12	[-26,+12]	(03h04m, +58°)	(100/hour)	6am
Kappa-Cygnids	Aug 19	[-16,+12]	(19h04m, +59°)	(5/hour)	9pm
Iota-Aquarids N	Aug 20	[-9,+31]	(21h48m, -06°)	(5/hour)	12am
Pi-Eridanids	Aug 29	[-9, +7]	(03h28m, -15°)	(/hour)	5am
Alpha-Aurigids	Sep 01	[-8, +4]	(05h36m, +42°)	(20/hour)	7am

```
Delta-Aurigids      Sep 09 [ -4,+31] (04h00m, +47°)  ( 10/hour)  5am
Piscids             Sep 20 [-36,+24] (00h32m,  00°)  (  5/hour)  1am
Kappa-Aquarids      Sep 21 [-13, +9] (22h36m, -02°)  (  5/hour) 11pm
Capricornids (Oct)  Oct 03 [-13,+11] (20h12m, -10°)  (  5/hour)  7pm
Sigma-Orionids      Oct 05 [-25,+21] (05h44m, -03°)  (  5/hour)  5am
Draconids           Oct 10 [ -4, +0] (17h28m, +54°)  (   STORM)  4pm
Epsilon-Geminids    Oct 20 [ -6, +7] (06h56m, +27°)  (  5/hour)  5am
Orionids*           Oct 22 [-20,+16] (06h20m, +16°)  ( 20/hour)  4am
Taurids S           Nov 03 [-49,+22] (03h20m, +14°)  ( 10/hour) 12am
Taurids N           Nov 13 [-61,+12] (04h00m, +23°)  ( 10/hour)  1am
Leonids             Nov 18 [ -4, +3] (10h08m, +22°)  (   STORM)  6am
Alpha-Monocerotids  Nov 21 [ -6, +4] (07h48m, -06°)  (  5/hour)  4am
Chi-Orionids        Dec 02 [ -6,+13] (05h28m, +23°)  (  5/hour)  1am
Phoenicids (Dec)    Dec 06 [ -8, +3] (01h12m, -53°)  (100/hour) 10pm
Sigma-Puppids II    Dec 06 [ -9, +6] (06h48m, -45°)  (   /hour)  2am
Monocerotids (Dec)  Dec 10 [-13, +7] (06h40m, +14°)  (  5/hour)  1am
Sigma-Hydrids       Dec 11 [ -8, +4] (08h28m, +02°)  (  5/hour)  3am
Geminids            Dec 14 [ -7, +3] (07h28m, +33°)  (100/hour)  2am
Coma Berenicids     Dec 19 [ -7,+34] (11h40m, +25°)  (  5/hour)  6am
Ursids              Dec 23 [ -6, +3] (14h28m, +75°)  ( 50/hour)  8am
Tau-Puppids         Dec 23 [ -4, +7] (06h56m, -50°)  (   /hour)  1am
```

* Associated with debris from Comet Halley.

Major meteor showers, extracted from the above list, are given in the following table (in parenthesis is the solar longitude at the peak of the shower).

```
SHOWER-NAME          PEAK   [RANGE]    (RADIANT)      (ZHRATE)  CULM  SOLAR
                                                                      LONG.
Quadrantids         Jan 03 [ -2, +2] (15h20m, +49°)  (100/hour)  8am  283.2°
Lyrids              Apr 22 [ -6, +3] (18h04m, +34°)  (100/hour)  4am   31.4°
Eta-Aquarids*       May 03 [-14,+25] (22h24m, -02°)  ( 50/hour)  8am   44  °
Delta-Aquarids S    Jul 29 [-21,+21] (22h36m, -16°)  ( 20/hour)  2am  125  °
Perseids            Aug 12 [-26,+12] (03h04m, +58°)  (100/hour)  6am  139.6°
Orionids*           Oct 22 [-20,+16] (06h20m, +16°)  ( 20/hour)  4am  207.8°
Taurids S           Nov 03 [-49,+22] (03h20m, +14°)  ( 10/hour) 12am  220  °
Leonids             Nov 18 [ -4, +3] (10h08m, +22°)  (   STORM)  6am  235  °
Geminids            Dec 14 [ -7, +3] (07h28m, +33°)  (100/hour)  2am  262.0°
Ursids              Dec 23 [ -6, +3] (14h28m, +75°)  ( 50/hour)  8am  270.7°
```

The range, in brackets, is the number of days before and after the peak of the shower. The center of the radiant is given in ascension and declination coordinates; typically the diameter of a radiant is about 5 or 10 degrees. The last column gives the culmination hour, which is the local time at which the radiant is highest in the sky.

On an average night there are about 10-20 meteors per hour that are visible, having a magnitude of 2 or brighter. During a meteor shower there are many more. The best time to see meteors is during the early morning, from about two hours after midnight until dawn, since your side of the Earth is then moving head on into any space debris.

The meteor showers listed above recur every year. See the `Meteors.nb` notebook.

■ A.2 Sunspots (max every 11 years; occur in daylight)

Maximum sunspot activity occurred in the following years.

```
1770 1781 1791 1807 1820 1835 1841 1852 1863 1876
1891 1902 1913 1924 1935 1946 1957 1968 1979 1990
```

Minimum activity, with almost no spots, occurred halfway between the maximums indicated here. Sunspot activity usually reaches a maximum every 11 years. This 11-year period, however, is not uniform; for example, there is a 16-year gap from 1791 to 1807, and from 1645 to 1715 activity virtually ceased.

■ A.3 Solar Eclipses (240 every century; occur in daylight)

New moons occur on the Julian days 2449129.09 + 29.53058885 $n \pm 0.5$, where n is an integer. Note 2415020.00 = 1900 January 0.50 (UT); 2444239.00 = 1980 January 0.50 (UT); 2449129.09 = 1993 May 21.59 (UT); and 2451544.00 = 2000 January 0.50 (UT).

Solar eclipses are a special case of new moons, and occur when n mod 223 appears as shown in the next table.

```
  0,   6,  12,  18,  24,  30,  36,  42,
 47,  53,  59,  65,  71,  77,  83,  89,
 88,  94, 100, 106, 112, 118, 124, 130,
135, 141, 147, 153, 159, 165, 171, 177,
182, 188, 194, 200, 206, 212, 218
```

The cycle repeats after 223 synodic months; that is, after 18 years, 11 (10) days, 8 hours assuming the 18 years includes four (five) leap years.

Total solar eclipses last up to 7.6 minutes. Annular solar eclipses last up to 12.5 minutes.

See `SolarEclipse[`*neardate*`]`, `EclipseBegin[Earth, Moon, Sun, `*neardate*`]`, `EclipseBegin[Sun, Moon, TopoCentric, `*neardate*`]`.

■ A.4 Lunar Eclipses (150 every century; occur at night)

Full moons occur on the Julian days 2449129.09 + 29.53058885 $n \pm 0.5$, where n is a half-integer.

Lunar eclipses are a special case of full moons, and occur when n mod 223 appears as shown in the next table.

```
  0.5,   6.5,  12.5,    *,    23.5,    *,    35.5,  41.5,
 47.5,  53.5,    *,     *,      *,    76.5,  82.5,    *,
 88.5,  94.5, 100.5,    *,      *,      *,   123.5, 129.5,
135.5, 141.5,    *,   153.5, 158.5, 164.5, 170.5, 176.5,
182.5, 188.5,    *,     *,   205.5, 211.5, 217.5
```

The cycle repeats after 223 synodic months; that is, after 18 years, 11 (10) days, 8 hours assuming the 18 years includes four (five) leap years.

Total lunar eclipses last up to 1 hour 44 minutes. Partial lunar eclipses are as long as 4 hours.

See `LunarEclipse[`*neardate*`]`, `EclipseBegin[Moon, Earth, Sun,` *neardate*`]`.

■ A.5 Transits of Mercury (5-7 every 46 years; occur in daylight)

Transits occur around November 10 (or May 9, indicated by *) in the following years.

1677			1690		1697	1707*	1710	
1723			1736	1740*	1743	1753*	1756	
1769		1776	1782	1786*	1789	1799*	1802	
1815		1822		1832*	1835	1845*	1848	
1861		1868		1878*	1881	1891*	1894	
1907		1914		1924*	1927		1940	
1953	1957*	1960		1970*	1973		1986	1993
1999	2003*	2006		2016*	2019		2032	2039
	2049*	2052		2062*	2065		2078	2085
	2095*	2098		2108*	2111		2124	2131
	2141*	2144		2154*	2157		2170	2177

Transits repeat approximately every 46 years after a series of 5-7 transits. The intervals within the series are 3.5, 7, 9.5, or 13 years. Note that 145 Mercury synodic orbits = 46 solar years + 1.1 days.

Transits of Mercury last up to 6 hours.

See `EclipseBegin[Sun, Mercury, Earth,` *neardate*`]`.

■ A.6 Transits of Venus (4 every 243 years; occur in daylight)

Transits occur around June 6 (or December 7, indicated by *) in the following years.

1526	1631*	1639*	1761
1769	1874*	1882*	2004
2012	2117*	2125*	2247

The cycle of transits repeats every 243 years, after 4 transits. The intervals between the transits are 105.5, 8, 121.5, and 8 years, respectively. Note that 152 Venus synodic orbits = 243 solar years + 2 days, and 5 Venus synodic orbits = 8 solar years + 0.83 days.

Transits of Venus last up to 6 hours.

See `EclipseBegin[Sun, Venus, Earth,` *neardate*`]`.

■ A.7 Saturn's Rings Edge On (2 every 29.5 years; occur at night)

Saturn's rings are viewed edge on (fully open is indicated by *) in the following years.

(Leo)	(Sgr)	(Aqr)	(Tau)
1980	1987*	1995	2002*
2009	2016*	2024	2031*

The cycle repeats every 29.5 years, after the rings are twice edge on, with intervals of 15.75 and 13.75 years.

■ A.8 Uranus' Poles Side On (2 every 84 years; occur at night)

Uranus' poles are viewed side on (* is head on) in the following years.

(Leo)	(Sco)	(Aqr)	(Tau)
1882	1901*	1923	1946*
1966	1985*	2007	2030*

When Uranus is in Leo, its poles are side on and the spin is bottom to top. When in Scorpius, the south pole of Uranus is head on and the spin is clockwise. When in Aquarius, the poles are side on and the spin is top to bottom. When in Taurus, the north pole of Uranus is head on and the spin is counterclockwise.

The cycle repeats every 84.01 years after the poles are twice head on. The intervals are 39.0 and 45.0 years.

■ A.9 Mercury Apparitions (6 every year; occur at dusk/dawn)

Mercury is at greatest eastern (evening) or western (morning) elongation on the following dates.

	EVEN	MORN	EVEN	MORN	EVEN	MORN	EVEN	MORN
1990		Feb 1	Apr 14	May 31	Aug 12	Sep 24	Dec 6	
1991		Jan 14	Mar 28	May 13	Jul 25	Sep 8	Nov 19	Dec 28
1992			Mar 10	Apr 24	Jul 6	Aug 21	Nov 1	Dec 10
1993			Feb 21	Apr 6	Jun 18	Aug 4	Oct 14	Nov 23
1994			Feb 5	Mar 19	May 30	Jul 18	Sep 27	Nov 6
1995			Jan 19	Mar 1	May 12	Jun 30	Sep 9	Oct 21
1996	Jan 3	Feb 12	Apr 23	Jun 10	Aug 22	Oct 3	Dec 16	
1997		Jan 24	Apr 6	May 23	Aug 4	Sep 17	Nov 29	
1998		Jan 7	Mar 20	May 5	Jul 17	Aug 31	Nov 11	Dec 20
1999			Mar 4	Apr 17	Jun 29	Aug 15	Oct 25	Dec 3
2000			Feb 15	Mar 29	Jun 10	Jul 27	Oct 6	Nov 15
2001			Jan 29	Mar 11	May 22	Jul 10	Sep 19	Oct 30
2002	Jan 12	Feb 22	May 4	Jun 22	Sep 1	Oct 13	Dec 26	
2003		Feb 4	Apr 17	Jun 3	Aug 15	Sep 27	Dec 9	
2004		Jan 17	Mar 30	May 15	Jul 27	Sep 10	Nov 21	Dec 30
2005			Mar 13	Apr 27	Jul 9	Aug 24	Nov 4	Dec 13
2006			Feb 24	Apr 9	Jun 21	Aug 7	Oct 17	Nov 26
2007			Feb 8	Mar 22	Jun 2	Jul 21	Sep 30	Nov 9
2008			Jan 21	Mar 3	May 14	Jul 2	Sep 11	Oct 22
2009	Jan 1	Feb 14	Apr 26	Jun 13	Aug 25	Oct 6	Dec 19	
2010		Jan 27	Apr 9	May 26	Aug 7	Sep 20	Dec 2	

The cycle of Mercury apparitions repeats every 4 months (115.88 days).
See `BestView[Mercury,` *neardate*`]`.

■ A.10 Venus Apparitions (10 every 8 years; occur at dusk/dawn)

Venus is at greatest eastern (evening) or western (morning) elongation on the following dates.

	EVEN	MORN		EVEN	MORN		EVEN	MORN
1990		Mar 30	1998		Mar 28	2006		Mar 25
1991	Jun 14	Nov 2	1999	Jun 12	Oct 31	2007	Jun 9	Oct 29
1992			2000			2008		
1993	Jan 20	Jun 11	2001	Jan 17	Jun 8	2009	Jan 15	Jun 6
1994	Aug 25		2002	Aug 23		2010	Aug 20	
1995		Jan 13	2003		Jan 11	2011		Jan 9
1996	Apr 1	Aug 20	2004	Mar 30	Aug 18	2012	Mar 27	Aug 15
1997	Nov 6		2005	Nov 4		2013	Nov 1	

An eastern elongation corresponds to an evening apparition.

The cycle repeats every 19 months (583.92 days); there are five morning and five evening apparitions occurring every 8 years. See `BestView[Venus,` *neardate*`]`.

■ A.11 Mars Opposition (1 every 2.1 years; occur at night)

Mars is at opposition on the following dates (the parentheses show the distance in millions of kilometers).

1975 Dec 16 (85)	1990 Nov 28 (78)	2005 Nov 7 (70)	2020 Oct 14 (63)
1978 Jan 22 (98)	1993 Jan 8 (94)	2007 Dec 25 (89)	2022 Dec 8 (82)
1980 Feb 25 (101)	1995 Feb 12 (101)	2010 Jan 30 (99)	2025 Jan 16 (96)
1982 Mar 31 (95)	1997 Mar 17 (99)	2012 Mar 4 (101)	2027 Feb 20 (101)
1984 May 11 (80)	1999 Apr 25 (87)	2014 Apr 9 (93)	2029 Mar 25 (97)
1986 Jul 10 (61)	2001 Jun 14 (68)	2016 May 22 (76)	2031 May 4 (84)
1988 Sep 28 (59)	2003 Aug 29 (56)	2018 Jul 27 (58)	2033 Jun 28 (64)

Mars oppositions occur every two years and seven weeks (779.9 days), or 7 times every 15 years. Due to the eccentric nature of Mars' orbit, favorable oppositions, when Mars is very close to Earth, occur at 15-year intervals. Favorable oppositions are listed in the bottom row of the table.

See `BestView[Mars,` *neardate*`]`.

■ A.12 Jupiter Opposition (1 every 1.1 years; occur at night)

Jupiter is at opposition on the following dates.

1990	2002 Jan 1	2014 Jan 6
1991 Jan 29	2003 Feb 2	2015 Feb 7
1992 Feb 29	2004 Mar 4	2016 Mar 8
1993 Mar 30	2005 Apr 4	2017 Apr 8

```
1994 Apr 30   2006 May  5   2018 May  9
1995 Jun  1   2007 Jun  6   2019 Jun 11
1996 Jul  4   2008 Jul  9   2020 Jul 14
1997 Aug 10   2009 Aug 15   2021 Aug 20
1998 Sep 16   2010 Sep 21   2022 Sep 27
1999 Oct 24   2011 Oct 29   2023 Nov  3
2000 Nov 28   2012 Dec  3   2024 Dec  8
2001          2013          2025
```

Jupiter oppositions repeat after one year and one month (398.9 days). There are 11 oppositions every 12 years.

See `BestView[Jupiter,` *neardate*`]`.

■ A.13 Saturn Opposition (1 every 1.0 years; occur at night)

Saturn is at opposition on the following dates.

```
1990 Jul 15   2005 Jan 14   2020 Jul 21
1991 Jul 27   2006 Jan 28   2021 Aug  2
1992 Aug  7   2007 Feb 10   2022 Aug 14
1993 Aug 20   2008 Feb 24   2023 Aug 27
1994 Sep  1   2009 Mar  9   2024 Sep  7
1995 Sep 14   2010 Mar 22   2025 Sep 20
1996 Sep 26   2011 Apr  4   2026 Oct  4
1997 Oct 10   2012 Apr 16   2027 Oct 17
1998 Oct 23   2013 Apr 28   2028 Oct 30
1999 Nov  6   2014 May 11   2029 Nov 13
2000 Nov 19   2015 May 23   2030 Nov 27
2001 Dec  3   2016 Jun  3   2031 Dec 11
2002 Dec 17   2017 Jun 15   2032 Dec 24
2003 Dec 31   2018 Jun 27   2033
2004          2019 Jul  9   2034 Jan  7
```

Saturn oppositions occur every one year and two weeks (378.1 days), or 29 times every 30 years.

See `BestView[Saturn,` *neardate*`]`.

■ A.14 Lunar Occultations (1 every 18.6 years; occur at night)

Four major stars lie near the ecliptic, and may be occulted by the Moon passing directly in front of them.

Occultations of these major stars occur in the following years, where n is an integer.

```
   Regulus: 1961.8 ± 0.7 + 18.613 n, 1970.5 ± 0.7 + 18.613 n
     Spica: 1957.4 ± 0.7 + 18.613 n, 1969.2 ± 0.7 + 18.613 n
Aldebaran: 1961.0 ± 1.8 + 18.613 n
   Antares: 1970.2 ± 2.5 + 18.613 n
```

Here 1961.8 ± 0.7 refers to the interval 0.7 years on either side of 1961.8, which indicates roughly October 1961.

Occultations occur in cycles that repeat every 18.613 years due to the plane of the Moon, which is tilted to the ecliptic by about 5.1 degrees, rotating in that time.

Regulus		Spica		Aldebaran	Antares
1961.8±0.7,	1970.5±0.7	1957.4±0.7,	1969.2±0.7	1961.0±1.8	1970.2±2.5
1980.4±0.7,	1989.1±0.7	1976.0±0.7,	1987.8±0.7	1979.6±1.8	1988.8±2.5
1999.0±0.7,	2007.7±0.7	1994.6±0.7,	2006.4±0.7	1998.2±1.8	2007.4±2.5
2017.6±0.7,	2026.3±0.7	2013.2±0.7,	2025.0±0.7	2016.8±1.8	2026.0±2.5
2036.2±0.7,	2044.9±0.7	2031.8±0.7,	2043.6±0.7	2035.4±1.8	2044.6±2.5

Occultations occur each lunar month (that is, each 27.321 days) during the above periods. Thus, Regulus is occluded by the Moon every lunar month from the year 1961.1 to 1962.5; that is, February 1961 to June 1962.

Lunar occultations repeat every 18.613 years (6798.36328 days).

See `EclipseBegin[Earth, Moon,` *star*`,` *neardate*`]`.

■ A.15 Eclipse Table

The eclipse cycle repeats after 223 synodic months. Note that one synodic month = 29.53058885 days, but varies between 29.25 and 29.75. 223 synodic months = 6585.321 days = 18 years, 11 (10) days, 8 hours. 19 eclipse years = 6585.780 days, and the node rotates once.

The total solar eclipses, sorted by cycle, for the 20th century are given in the following table.

n=188:	1900 May 28,	1918 Jun 8,	1936 Jun 19,	1954 Jun 30,	1972 Jul 10,	1990 Jul 22,
n=200:	1901 May 18,	1919 May 29,	1937 Jun 8,	1955 Jun 20,	1973 Jun 30,	1991 Jul 11,
n=212:				1956 Jun 8,	1974 Jun 20,	1992 Jun 30,
n= 18:	1904 Sep 9,	1922 Sep 21,	1940 Oct 1,	1958 Oct 12,	1976 Oct 23,	1994 Nov 3,
n= 30:	1905 Aug 30,	1923 Sep 10,	1941 Sep 21,	1959 Oct 2,	1977 Oct 12,	1995 Oct 24,
n= 47:	1907 Jan 14,	1925 Jan 24,	1943 Feb 4,	1961 Feb 15,	1979 Feb 26,	1997 Mar 9,
n= 59:	1908 Jan 3,	1926 Jan 14,	1944 Jan 25,	1962 Feb 5,	1980 Feb 16,	1998 Feb 26,
n= 77:	1909 Jun 18,	1927 Jun 29,	1945 Jul 9,	1963 Jul 20,	1981 Jul 31,	1999 Aug 11,
n=100:	1911 Apr 28,	1929 May 9,	1947 May 20,	1965 May 30,	1983 Jun 11,	2001 Jun 21,
n=118:	1912 Oct 10,	1930 Oct 21,	1948 Nov 1,	1966 Nov 12,	1984 Nov 22,	2002 Dec 4,
n=141:	1914 Aug 21,	1932 Aug 31,	1950 Sep 12,	1968 Sep 22,		2003 Nov 23,
n=147:						2005 Apr 8,
n=159:	1916 Feb 3,	1934 Feb 14,	1952 Feb 25,	1970 Mar 7,	1988 Mar 18,	2006 Mar 29,

See `SolarEclipse[`*neardate*`]`.

The solar and lunar eclipses from 1980 to 2020 are given in the following table.

Solar Eclipses:		Lunar Eclipses:	
n= 53: 1979 Aug 23	Partial	n= 53.5: 1979 Sep 6, 10:54 (UT)	110%
n= 59: 1980 Feb 16	Total		
n= 65: 1980 Aug 10	Annular		
n= 71: 1981 Feb 4	Annular		
n= 77: 1981 Jul 31	Total	n= 76.5: 1981 Jul 17, 4:48 (UT)	60%
n= 83: 1982 Jan 25	Partial	n= 82.5: 1982 Jan 9, 19:56 (UT)	130%
n= 88: 1982 Jun 21	Partial	n= 88.5: 1982 Jul 6, 7:30 (UT)	170%

```
n= 89: 1982 Jul 21  Partial
n= 94: 1982 Dec 15  Partial          n= 94.5: 1982 Dec 30, 11:26 (UT)  120%
n=100: 1983 Jun 11  Total            n=100.5: 1983 Jun 25,  8:25 (UT)   30%
n=106: 1983 Dec  4  Annular
n=112: 1984 May 30  Annular/Total
n=118: 1984 Nov 22  Total
n=124: 1985 May 19  Partial          n=123.5: 1985 May  4, 19:57 (UT)  129%
n=130: 1985 Nov 12  Partial          n=129.5: 1985 Oct 28, 17:43 (UT)  110%
n=135: 1986 Apr  9  Partial          n=135.5: 1986 Apr 24, 12:44 (UT)  120%
n=141: 1986 Oct  3  Annular/Total    n=141.5: 1986 Oct 17, 19:19 (UT)  130%
n=147: 1987 Mar 29  Annular/Total
n=153: 1987 Sep 23  Annular          n=153.5: 1987 Oct  7,  3:59 (UT)    1%
n=159: 1988 Mar 18  Total            n=158.5: 1988 Mar  3, 16:30 (UT)    1%
n=165: 1988 Sep 11  Annular          n=164.5: 1988 Aug 27, 11:06 (UT)   30%
n=171: 1989 Mar  7  Partial          n=170.5: 1989 Feb 20, 15:37 (UT)  130%
n=177: 1989 Aug 31  Partial          n=176.5: 1989 Aug 17,  3:04 (UT)  160%
n=182: 1990 Jan 26  Annular          n=182.5: 1990 Feb  9, 19:12 (UT)  110%
n=188: 1990 Jul 22  Total            n=188.5: 1990 Aug  6, 14:07 (UT)   70%
n=194: 1991 Jan 15  Annular
n=200: 1991 Jul 11  Total
n=206: 1992 Jan  4  Annular          n=205.5: 1991 Dec 21, 10:34 (UT)   10%
n=212: 1992 Jun 30  Total            n=211.5: 1992 Jun 15,  4:57 (UT)   70%
n=218: 1992 Dec 24  Partial          n=217.5: 1992 Dec  9, 23:43 (UT)  130%
n=  0: 1993 May 21  Partial          n=  0.5: 1993 Jun  4, 13:00 (UT)  160%
n=  6: 1993 Nov 13  Partial          n=  6.5: 1993 Nov 29,  6:26 (UT)  110%
n= 12: 1994 May 10  Annular          n= 12.5: 1994 May 25,  3:28 (UT)   30%
n= 18: 1994 Nov  3  Total
n= 24: 1995 Apr 29  Annular          n= 23.5: 1995 Apr 15, 12:17 (UT)   10%
n= 30: 1995 Oct 24  Total
n= 36: 1996 Apr 17  Partial          n= 35.5: 1996 Apr  4,  0:09 (UT)  140%
n= 42: 1996 Oct 12  Partial          n= 41.5: 1996 Sep 27,  2:53 (UT)  120%
n= 47: 1997 Mar  9  Total            n= 47.5: 1997 Mar 24,  4:41 (UT)   90%
n= 53: 1997 Sep  2  Partial          n= 53.5: 1997 Sep 16, 18:47 (UT)  120%
n= 59: 1998 Feb 26  Total
n= 65: 1998 Aug 22  Annular
n= 71: 1999 Feb 16  Annular
n= 77: 1999 Aug 11  Total            n= 76.5: 1999 Jul 28, 11:36 (UT)   40%
n= 83: 2000 Feb  5  Partial          n= 82.5: 2000 Jan 21,  4:44 (UT)  130%
n= 88: 2000 Jul  1  Partial          n= 88.5: 2000 Jul 16, 14:10 (UT)  170%
n= 89: 2000 Jul 31  Partial
n= 94: 2000 Dec 25  Partial          n= 94.5: 2001 Jan  9, 20:26 (UT)  TOT%
n=100: 2001 Jun 21  Total            n=100.5: 2001 Jul  5, 15:05 (UT)  PAR%
n=106: 2001 Dec 14  Annular
n=112: 2002 Jun 10  Annular
n=118: 2002 Dec  4  Total
n=124: 2003 May 31  Annular          n=123.5: 2003 May 16,  3:36 (UT)  TOT%
n=130: 2003 Nov 23  Total            n=129.5: 2003 Nov  9,  1:16 (UT)  TOT%
n=135: 2004 Apr 19  Partial          n=135.5: 2004 May  4, 20:34 (UT)  TOT%
n=141: 2004 Oct 14  Partial          n=141.5: 2004 Oct 28,  3:08 (UT)  TOT%
n=147: 2005 Apr  8  Total
n=153: 2005 Oct  3  Annular          n=153.5: 2005 Oct 17, 12:14 (UT)  PAR%
n=159: 2006 Mar 29  Total            n=158.5: 2006 Mar 14, 23:35 (UT)  ???%
n=165: 2006 Sep 22  Annular          n=164.5: 2006 Sep  7, 18:45 (UT)  PAR%
n=171: 2007 Mar 19  Partial          n=170.5: 2007 Mar  3, 23:18 (UT)  TOT%
```

```
n=177: 2007 Sep 11  Partial         n=176.5: 2007 Aug 28, 10:37 (UT)  TOT%
n=182: 2008 Feb  7  Annular         n=182.5: 2008 Feb 21,  3:30 (UT)  TOT%
n=188: 2008 Aug  1  Total           n=188.5: 2008 Aug 16, 21:18 (UT)  PAR%
n=194: 2009 Jan 26  Annular
n=200: 2009 Jul 22  Total
n=206: 2010 Jan 15  Annular         n=205.5: 2009 Dec 31, 19:15 (UT)  PAR%
n=212: 2010 Jul 11  Total           n=211.5: 2010 Jun 26, 11:30 (UT)  PAR%
n=218: 2011 Jan  4  Partial         n=217.5: 2010 Dec 21,  8:16 (UT)  TOT%
n=  0: 2011 Jun  1  Partial         n=  0.5:
n=  6: 2011 Nov 25  Partial         n=  6.5:
n= 12: 2012 May 20  Annular         n= 12.5:
n= 18: 2012 Nov 13  Total
n= 24: 2013 May 10  Annular         n= 23.5:
n= 30: 2013 Nov  3  Total
n= 36: 2014 Apr 29  Annular         n= 35.5:
n= 42: 2014 Oct 23  Partial         n= 41.5:
n= 47: 2015 Mar 20  Total           n= 47.5:
n= 53: 2015 Sep 13  Partial         n= 53.5:
n= 59: 2016 Mar  9  Total
n= 65: 2016 Sep  1  Annular
n= 71: 2017 Feb 26  Annular         n= 70.5:
n= 77: 2017 Aug 21  Total           n= 76.5:
n= 83: 2018 Feb 15  Partial         n= 82.5:
n= 88: 2018 Jul 13  Partial         n= 88.5:
n= 89: 2018 Aug 11  Partial
n= 94: 2019 Jan  6  Partial         n= 94.5:
n=100: 2019 Jul  2  Total           n=100.5:
n=106: 2019 Dec 26  Annular         n=106.5:
n=112: 2020 Jun 21  Annular
n=118: 2020 Dec 14  Total
```

See `SolarEclipse[`*neardate*`]`, `LunarEclipse[`*neardate*`]`, and `MoonShadow[`*date*`]`.

■ A.16 Deep Sky Data

Open Star Clusters

Name	Catalog	Mag	Asc	Dec	Size
Hyades		0.5	04h30.2m	+16°01'	(5.5° dia)
Pleiades	(M45)	1.2	03h47.0m	+24°08'	(1.9° dia)
ThetaCarinaeCluster	(IC 2602)	1.9	10h43.2m	-64°24'	(0.8° dia)
OmicronVelorumCluster	(IC 2391)	2.5	08h40.3m	-53°04'	(0.8° dia)
NGC6231Cluster	(NGC 6231)	2.6	16h54.0m	-41°48'	(0.3° dia)
NGC2451Cluster	(NGC 2451)	2.8	07h45.4m	-37°58'	(0.7° dia)
NGC3532Cluster	(NGC 3532)	3.0	11h06.4m	-58°40'	(0.9° dia)
BeehiveCluster	(NGC 2632, M44)	3.1	08h40.1m	+19°59'	(1.6° dia)
PtolemysCluster	(NGC 6475, M7)	3.3	17h53.9m	-34°49'	(1.3° dia)
NGC2516Cluster	(NGC 2516)	3.8	07h58.3m	-60°52'	(0.5° dia)
ChristmasTreeCluster	(NGC 2264)	3.9	06h41.1m	+09°53'	(0.7° dia)
NGC2362Cluster	(NGC 2362)	4.1	07h17.8m	-24°57'	(0.1° dia)
IC4665Cluster	(IC 4665)	4.2	17h46.3m	+05°43'	(0.7° dia)
NGC3114Cluster	(NGC 3114)	4.2	10h02.7m	-60°07'	(0.6° dia)
JewelBoxCluster	(NGC 4755)	4.2	12h53.6m	-60°20'	(0.2° dia)
ButterflyCluster	(NGC 6405, M6)	4.2	17h40.1m	-32°13'	(0.2° dia)

Globular Clusters

Name	Catalog	Mag	Asc	Dec	Size
OmegaCentauriCluster	(NGC 5139)	3.7	13h26.8m	-47°29'	(0.6° dia)
Tucanae47Cluster	(NGC 104)	4.0	00h24.1m	-72°05'	(0.2° dia)
M22Cluster	(NGC 6656, M22)	5.1	18h36.4m	-23°54'	(0.4° dia)
TurquoiseOrbCluster	(NGC 6752)	5.4	19h10.9m	-59°59'	(0.3° dia)
NGC6397Cluster	(NGC 6397)	5.7	17h40.7m	-53°40'	(0.3° dia)
HerculesCluster	(NGC 6205, M13)	5.9	16h41.7m	+36°28'	(0.3° dia)
M4Cluster	(NGC 6121, M4)	5.9	16h23.6m	-26°32'	(0.4° dia)
M15Cluster	(NGC 7078, M15)	6.3	21h30.0m	+12°10'	(0.2° dia)
NGC2808Cluster	(NGC 2808)	6.3	09h12.0m	-64°52'	(0.3° dia)
M2Cluster	(NGC 7089, M2)	6.5	21h33.5m	+00°49'	(0.2° dia)
M92Cluster	(NGC 6341, M92)	6.5	17h17.1m	+43°08'	(0.2° dia)

Diffuse Nebulae

Name	Catalog	Mag	Asc	Dec	Size
CoalSackNebula			12h54.0m	-63°00'	(5.5° dia)
TarantulaNebula	(NGC 2070)	3.0	05h38.7m	-69°06'	(0.5° dia)
OrionNebula	(NGC 1976, M42)	4.0	05h35.5m	-05°23'	(1.1° dia)
LagoonNebula	(NGC 6523, M8)	5.0	18h03.3m	-24°23'	(0.7° dia)
RosetteNebula	(NGC 2237)	5.5	06h30.5m	+05°03'	(1.1° dia)
EtaCarinaeNebula	(NGC 3372)	6.0	10h44.0m	-59°54'	(2.0° dia)
NorthAmericaNebula	(NGC 7000)	6.0	20h58.9m	+44°21'	(2.0° dia)
EagleNebula	(NGC 6611, M16)	6.0	18h19.0m	-13°47'	(0.1° dia)
OmegaNebula	(NGC 6618, M17)	6.0	18h21.0m	-16°11'	(0.2° dia)
TrifidNebula	(NGC 6514, M20)	6.3	18h02.5m	-23°02'	(0.5° dia)
KeyholeNebula	(NGC 3324)	6.7	10h37.4m	-58°39'	(0.0° dia)

Planetary Nebulae

Name	Catalog	Mag	Asc	Dec	Size
HelixNebula	(NGC 7293)	6.3	22h29.8m	-20°47'	(0.22° dia)
CometNebula	(NGC 1360)	7.0	03h33.3m	-25°51'	(0.11° dia)
DumbbellNebula	(NGC 6853, M27)	7.3	19h59.8m	+22°44'	(0.25° dia)
EightBurstNebula	(NGC 3132)	8.2	10h07.0m	-40°26'	(0.01° dia)
CatseyeNebula	(NGC 6543)	8.3	17h58.6m	+66°38'	(0.10° dia)
SaturnNebula	(NGC 7009)	8.3	21h04.2m	-11°22'	(0.04° dia)
CrabNebula	(NGC 1952, M1)	8.4	05h34.5m	+22°01'	(0.10° dia)
UranusNebula	(NGC 3918)	8.4	11h50.3m	-57°11'	(0.00° dia)
CetusBubbleNebula	(NGC 246)	8.5	00h47.1m	-11°53'	(0.06° dia)
EskimoNebula	(NGC 2392)	8.6	07h29.2m	+20°55'	(0.01° dia)
GhostOfJupiterNebula	(NGC 3242)	8.6	10h24.8m	-18°38'	(0.01° dia)
BlueSnowballNebula	(NGC 7662)	8.6	23h25.9m	+42°33'	(0.04° dia)
BlinkingNebula	(NGC 6826)	8.8	19h44.8m	+50°31'	(0.04° dia)
RingNebula	(NGC 6720, M57)	9.0	18h53.6m	+33°02'	(0.04° dia)

Galaxies

		Mag	Asc	Dec	Size
LargeMagellanicCloud	(LMC)	0.9	05h30m	-69°	(11° by 9°)
SmallMagellanicCloud	(SMC)	2.3	01h	-73°	(5° by 3°)
AndromedaGalaxy	(NGC 224, M31)	3.5	00h43.0m	+41°18'	(3° by 1°)
TriangulumGalaxy	(NGC 598, M33)	5.7	01h34.1m	+30°41'	(1.0° dia)
CentaurusGalaxy	(NGC 5128)	7.0	13h25.5m	-43°02'	(0.3° dia)
SilverCoinGalaxy	(NGC 253)	7.1	00h47.7m	-25°17'	(0.3° dia)
BodesGalaxy	(NGC 3031, M81)	7.9	09h55.6m	+69°04'	(0.2° dia)
M110Galaxy	(NGC 205)	8.0	00h40.4m	+41°41'	(0.4° dia)
CigarGalaxy	(NGC 55)	8.2	00h15.1m	-39°14'	(0.3° dia)
M32Galaxy	(NGC 221)	8.2	00h42.8m	+40°52'	(0.1° dia)
SombreroGalaxy	(NGC 4594,M104)	8.3	12h39.9m	-11°37'	(0.1° dia)
WhirlpoolGalaxy	(NGC 5194, M51)	8.4	13h30.0m	+47°11'	(0.1° dia)
SouthernPinwheelGalaxy	(NGC 5236, M83)	8.5	13h37.1m	-29°52'	(0.2° dia)
VirgoGalaxy	(NGC 4486, M87)	8.6	12h30.9m	+12°24'	(0.1° dia)
NGC300Galaxy	(NGC 300)	8.7	00h55.0m	-37°42'	(0.3° dia)
M94Galaxy	(NGC 4736)	8.7	12h50.9m	+41°08'	(0.1° dia)
PinwheelGalaxy	(NGC 5457,M101)	8.7	14h03.3m	+54°22'	(0.3° dia)
NGC247Galaxy	(NGC 247)	8.9	00h47.0m	-20°45'	(0.3° dia)
M66Galaxy	(NGC 3627)	8.9	11h20.2m	+12°59'	(0.1° dia)
BlackeyeGalaxy	(NGC 4826, M64)	8.9	12h56.7m	+21°41'	(0.1° dia)

See `InterestingObjects[`*date*`]`, `BrightClusters`, `BrightNebulae`, and `BrightGalaxies`.

See the `DeepSky.nb` notebook.

■ A.17 Brightest Stars

		Mag	Asc	Dec	Spectral
Sirius	= Alpha.CanisMajor	-1.46	06h45.2m	-16°44'	A1
Canopus	= Alpha.Carina	-0.72	06h24.0m	-52°41'	F0
RigilKent	= Alpha.Centaurus	-0.29d	14h39.7m	-60°50'	G2
Arcturus	= Alpha.Bootes	-0.01	14h15.7m	+19°11'	K1
Vega	= Alpha.Lyra	0.03	18h37.0m	+38°47'	A0
Capella	= Alpha.Auriga	0.08	05h16.7m	+46°00'	G5
Rigel	= Beta.Orion	0.12	05h14.5m	-08°12'	B8
Procyon	= Alpha.CanisMinor	0.38	07h39.3m	+05°14'	F5
Achernar	= Alpha.Eridanus	0.46	01h37.7m	-57°15'	B3
Betelgeuse	= Alpha.Orion	0.50v	05h55.2m	+07°24'	M1
Agena	= Beta.Centaurus	0.61	14h03.8m	-60°22'	B1
Altair	= Alpha.Aquila	0.77	19h50.8m	+08°52'	A7
Acrux	= Alpha.Crux	0.83d	12h26.6m	-63°06'	B0
Aldebaran	= Alpha.Taurus	0.85	04h35.9m	+16°30'	K5
Antares	= Alpha.Scorpius	0.96v	16h29.4m	-26°26'	M1
Spica	= Alpha.Virgo	0.98v	13h25.2m	-11°09'	B1
Pollux	= Beta.Gemini	1.14	07h45.3m	+28°01'	K0
Fomalhaut	= Alpha.PiscisAustrinus	1.16	22h57.6m	-29°37'	A3
Deneb	= Alpha.Cygnus	1.25	20h41.4m	+45°16'	A2
Becrux	= Beta.Crux	1.25v	12h47.7m	-59°42'	B0
Regulus	= Alpha.Leo	1.35	10h08.4m	+11°58'	B7
Adhara	= Epsilon.CanisMajor	1.50	06h58.6m	-28°58'	B2
Castor	= Alpha.Gemini	1.59	07h34.6m	+31°53'	A1
Gacrux	= Gamma.Crux	1.63	12h31.2m	-57°07'	M3
Bellatrix	= Gamma.Orion	1.64	05h25.1m	+06°21'	B2
...		...			
Polaris	= Alpha.UrsaMinor	2.02	02h31.8m	+89°16'	F7
Algol	= Beta.Perseus	2.12v	03h08.2m	+40°57'	B8
Mizar	= Zeta.UrsaMajor	2.27d	13h23.9m	+54°56'	A1

See `?BrightStar`*`.

■ A.18 Double Stars

		Mag	Asc	Dec	Sep	Spectral	
Alpha.Centaurus,		0.0,1.2	14h39.6m	-60°50'	.005°	G2,K1	
Alpha.Crux,	Alpha2	0.8,2.1	12h26.6m	-63°06'	.001°	B1,B3	
Gamma.Vela,	Gamma1	1.8,4.3	08h09.5m	-47°20'	.011°	O0,B3	
Gamma.Leo,	Gamma2	1.9,3.8	10h20.0m	+19°51'	.001°	K0,G7	
Zeta.UrsaMajor,	80	2.3,4.0	13h23.9m	+54°56'	.200°	A2,A5	(Mizar)
Gamma1.Andromeda,	Gamma2	2.3,4.8	02h03.9m	+42°20'	.003°	K2,A0	
Beta1.Scorpius,	Beta2	2.6,4.9	16h05.4m	-19°48'	.004°	B0,B2	
Alpha2.Libra,	Alpha1	2.7,5.1	14h50.6m	-16°02'	.064°	A2,F5	
Alpha2.CanesVenatici,	Alpha1	2.9,5.6	12h56.0m	+38°19'	.008°	A0,F0	(CorCaroli)
Beta.Cygnus,	Beta2	3.1,5.1	19h30.7m	+27°58'	.010°	K3,B8	(Albireo)
Theta2.Taurus,	Theta1	3.4,3.8	04h28.4m	+15°52'	.094°	A7,F	
Theta1.Eridanus,	Theta2	3.4,4.4	02h58.3m	-40°18'	.002°	A2,A2	
Alpha2.Capricornus,	Alpha1	3.6,4.2	20h17.8m	-12°34'	.105°	G3,G9	
Omicron1.Cygnus	30	3.8,4.9	20h13.6m	+46°43'	.110°	K, A	
Gamma2.Delphinus,	Gamma1	4.3,5.1	20h46.6m	+16°07'	.003°	G5,F8	
Beta1.Tucana,	Beta2	4.4,4.5	00h31.5m	-62°58'	.008°	B8,A2	
Theta1.Serpens,	Theta2	4.6,5.0	18h50.7m	+04°12'	.006°	A5,A5	
Sigma2.Taurus,	Sigma1	4.7,5.1	04h39.0m	+15°55'	.120°	F, F	
Delta1.Apus,	Delta2	4.7,5.3	16h19.7m	-78°41'	.029°	K5,M4	
Nu2.Draco,	Nu1	4.9,4.9	17h32.2m	+55°10'	.017°	F, F	

■ A.19 Variable Stars

Eclipsing–Algol Type

	Asc	Dec	Mag Max-Min	Period (days)	Mid-Eclipse (JD)	
Beta.Perseus	03h08.2m	+40°57'	2.12-3.39	2.8673043	2445641.5135	(Algol)
Epsilon.Auriga	05h02.0m	+43°49'	2.92-3.83	9892.0	2435629.0	
Lambda.Taurus	04h00.7m	+12°29'	3.37-3.91	3.9529478	2421506.8506	
Zeta.Phoenix	01h08.4m	-55°15'	3.91-4.42	1.6697671	2441643.6890	

Eclipsing–Beta.Lyra Type

	Asc	Dec	Mag Max-Min	Period (days)	Mid-Eclipse (JD)
Beta.Lyra	18h50.1m	+33°22'	3.25-4.36	12.913834	2408247.950

Pulsating–Cepheid Type

	Asc	Dec	Mag Max-Min	Period (days)	Brightest (JD)
ZZ.Carina	09h45.2m	-62°30'	3.28-4.18	35.53584	2440736.9
Beta.Dorado	05h33.6m	-62°29'	3.46-4.08	9.84260	2440905.3
Delta.Cepheus	22h29.2m	+58°25'	3.48-4.37	5.366341	2436075.445
Eta.Aquila	19h52.5m	+01°00'	3.48-4.39	7.176641	2436084.656
Zeta.Gemini	07h04.1m	+20°34'	3.62-4.18	10.150730	2443805.927

Pulsating–Mira Type

	Asc	Dec	Mag Max-Min	Period (days)	Brightest (JD)	
Omicron.Cetus	02h19.4m	-02°59'	2.00-10.10	331.96	2444839.0	(Mira)
Chi.Cygnus	19h50.6m	+32°55'	3.30-14.20	408.05	2442140.0	

Pulsating–Semi-Regular

	Asc	Dec	Mag Max-Min	Period (days)
Alpha.Orion	05h55.2m	+07°24'	0.00-1.30	2335.0
L.Puppis	07h13.5m	-44°38'	2.60-6.20	140.6
Alpha1.Hercules	17h14.6m	+14°23'	2.74-4.00	100.0
Eta.Gemini	06h14.9m	+22°30'	3.15-3.90	232.9
Rho.Perseus	03h05.2m	+38°50'	3.30-4.00	50.0
Mu.Cepheus	21h43.5m	+58°47'	3.43-5.10	730.0

Pulsating–Slow Irregular

	Asc	Dec	Mag Max-Min
Epsilon.Pegasus	21h44.2m	+09°53'	0.70-3.50
Beta.Pegasus	23h03.8m	+28°05'	2.31-2.74

See the `Variables.nb` notebook.

■ A.20 Planetary Data

The Sun and Its Planets

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Equator Tilt (Deg)
Sun:	696	25.6	7.2 *					7.2
Mercury	57910	87.969	7.00*	0.206	2439	58.65	-1.9	2.
Venus	108200	224.701	3.39*	0.007	6052	-243.16	-4.4	178.
Earth	149600	365.256	0.00*	0.017	6378	0.99		23.45
Mars	227940	686.980	1.85*	0.093	3397	1.03	-2.0	23.98
Ceres	413400	1681.25	10.6 *	0.077	470	0.38	7.5	
Jupiter	778330	4332.59	1.31*	0.048	71492	0.41	-2.7	3.07
Saturn	1429400	10759.20	2.49*	0.056	60268	0.45	0.7	26.73
Uranus	2870990	30684.9	0.77*	0.047	25559	-0.72	5.5	97.92
Neptune	4504300	60190.3	1.77*	0.009	24764	0.67	7.8	28.80
Pluto	5913520	90465.	17.15*	0.248	1160	-6.39	15.1	122.50

The Earth and Its Moon

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Equator Tilt (Deg)
Earth:	6	0.99	23.45*					23.45
Moon	384	27.321	5.11*	0.055	1738	Synchro	-12.7	1.54

Mars and Its Moons

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Radii Dimensions (km)
Equator	3	1.03	0					
Phobos	9	0.319	1.00	0.01	11	Synchro	11.3	13x 11x 9
Deimos	23	1.262	1.80	0.00	6	Synchro	12.3	7x 6x 5

Jupiter and Its Moons

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Radii Dimensions (km)
Equator	71	0.41	0					
Metis	128	0.290	0.	0.	20	?	17.5	
Adrastea	129	0.298	0.	0.	10	?	18.7	13x 10x 8
Amalthea	181	0.498	0.40	0.003	94	Synchro	14.1	131x 83x 72
Thebe	222	0.675	0.80	0.013	50	Synchro	16.0	55x 45
Io	422	1.769	0.04	0.	1815	Synchro	5.0	
Europa	671	3.551	0.47	0.009	1569	Synchro	5.3	
Ganymede	1070	7.155	0.19	0.002	2631	Synchro	4.6	
Callisto	1883	16.689	0.28	0.007	2400	Synchro	5.6	
Leda	11094	238.72	27.	0.148	8	?	20.2	
Himalia	11480	250.57	28.	0.168	93	0.4	15.0	
Lysithea	11720	259.22	29.	0.107	18	?	18.2	
Elara	11737	259.65	28.	0.207	38	0.5	16.6	
Ananke	21200	-631.	147.	0.17	15	?	18.9	
Carme	22600	-692.	163.	0.21	20	?	17.9	
Pasiphae	23500	-735.	147.	0.38	25	?	16.9	
Sinope	23700	-758.	153.	0.28	18	?	18.0	

Saturn and Its Moons

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Radii Dimensions (km)
Equator	60	0.45	0					
Pan	134	0.57	0.	0.	10	?	?	
Atlas	138	0.602	0.	0.002	15	?	18.0	18x 17x 13
Prometheus	139	0.613	0.	0.004	46	?	15.8	72x 43x 32
Pandora	142	0.629	0.	0.004	42	?	16.5	57x 42x 31
Epimetheus	151	0.694	0.34	0.009	57	Synchro	15.7	72x 54x 49
Janus	151	0.695	0.14	0.007	89	Synchro	14.5	98x 96x 75
Mimas	186	0.942	1.53	0.020	196	Synchro	12.9	
Enceladus	238	1.370	0.02	0.004	250	Synchro	11.7	
Tethys	295	1.888	1.09	0.000	530	Synchro	10.2	
Telesto	295	1.888	0.00	0.	15	?	18.7	17x 14x 13
Calypso	295	1.888	0.00	0.	13	?	19.0	17x 11x 11
Dione	377	2.737	0.02	0.002	560	Synchro	10.4	
Helene	377	2.737	0.20	0.005	16	?	18.4	18x 16x 15
Rhea	527	4.518	0.35	0.001	765	Synchro	9.7	
Titan	1222	15.495	0.33	0.029	2575	Synchro	8.3	
Hyperion	1481	21.277	0.43	0.104	143	Chaotic	14.2	205x130x110
Iapetus	3561	79.331	14.72	0.028	730	Synchro	11.1	
Phoebe	12952	-550.48	175.30	0.163	110	0.4	16.5	

Uranus and Its Moons

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Radii Dimensions (km)
Equator	26	0.72	0					
Cordelia	50	0.330	0.14	0.	13	?	24.0	
Ophelia	54	0.372	0.09	0.	16	?	24.0	
Bianca	59	0.433	0.16	0.	22	?	23.0	
Cressida	62	0.463	0.04	0.	33	?	22.0	
Desdemona	63	0.475	0.16	0.	29	?	22.0	
Juliet	64	0.493	0.06	0.	42	?	22.0	
Portia	66	0.513	0.09	0.	55	?	21.0	
Rosalind	70	0.558	0.28	0.	27	?	22.0	
Belinda	75	0.622	0.03	0.	34	?	22.0	
Puck	86	0.762	0.31	0.	77	?	20.0	
Miranda	130	1.414	4.22	0.027	236	Synchro	16.5	240x234x233
Ariel	191	2.520	0.03	0.003	579	Synchro	14.4	581x578x578
Umbriel	266	4.144	0.04	0.004	585	Synchro	15.3	
Titania	436	8.706	0.01	0.002	789	Synchro	14.0	
Oberon	583	13.463	0.01	0.001	761	Synchro	14.2	

Neptune and Its Moons

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Radii Dimensions (km)
Equator	25	0.67	0					
Naiad	48	0.296	0.	0.	29	?	25.0	
Thalassa	50	0.312	4.5	0.	40	?	24.0	
Despina	53	0.333	0.	0.	74	?	23.0	
Galatea	62	0.429	0.	0.	79	?	23.0	
Larissa	74	0.544	0.	0.	96	?	21.0	104x 89
Proteus	118	1.121	0.	0.	209	?	20.0	218x208x201
Triton	355	-5.877	157.	0.000	1350	Synchro	13.6	
Nereid	5513	360.15	29.	0.749	170	?	18.7	

Pluto and Its Moon

Object	Semi-Major Distance (1000km)	Orbit Period (days)	Orbit Incl (Deg)	Eccen	Equator Radius (km)	Rotate Period (days)	Mean Oppo Magn	Radii Dimensions (km)
Pluto:	1	-6.39	122.50*					
Charon	20	-6.39	98.80*	0.000	635	Synchro	16.8	

■ A.21 Visible Earth Satellites

Mir Space Station Complex (MIR, 16609/1986-17A)

Mir is in an orbit 340km from the surface of the Earth and tilted 51.6 degrees to the equator. It was launched from Tyuratam on 1986 February 19. Mir appears very bright, at approximately magnitude 0, but it can reach magnitude -1, and occasionally shows flashes of around magnitude -3.

Space Shuttle (STS)

Space Shuttle missions are typically launched into orbits a few hundred kilometers up and tilted at perhaps 28 degrees to the equator. Missions to the Mir Space Station are tilted higher at 51.6 degrees. A Space Shuttle can appear very bright, at magnitude 0 or better. Missions are usually referred to by labels such as STS-71, where STS stands for Space Transportation System.

Hubble Space Telescope (HST, 20580/1990-037B)

The Hubble Space Telescope (HST) is in orbit 580km up and tilted 28.5 degrees to the equator. It was launched from a Space Shuttle on 1990 February 6.

Upper Atmospheric Research Satellite (UARS, 21701/1991-63B)

The Upper Atmospheric Research Satellite (UARS) is in orbit 570km up and tilted 57.0 degrees to the equator. It was launched from the Space Shuttle Discovery, STS-48 mission, on 1991 September 12.

Cosmic Background Explorer (COBE, 20322/1989-89A)

The Cosmic Background Explorer (COBE) is in orbit 880km up and tilted 99.0 degrees to the equator; that is, in a polar orbit. It was launched from the Vandenberg Air Force Base on 1989 November 18. COBE appears at magnitudes between +1 and +3.

See the `Mir.nb` and `Satellites.nb` notebooks.

■ A.22 Deep Sky Objects

The built-in list of deep sky objects includes all open clusters down to magnitude 4.5, all globular clusters down to magnitude 6.5, all diffuse nebulae down to magnitude 6.5, all planetary nebulae down to magnitude 9.0, and all galaxies down to magnitude 9.0.

Distribution of the built-in objects is fairly uniform over the sky, with 30 objects located above the North Pole region, 30 below the South Pole region, and 50 around the equator.

The following four tables list all of the 110 deep sky objects that are built into *Scientific Astronomer*. The column on the far right lists three different right ascension and declination ranges corresponding to three different parts of the table. Below the right ascension and declination headings are listed any dominant constellations or stars that appear in the region.

Northern Objects

```
                         Name  Mag, Diam, Alias
+North-Hemisphere:-------------------------------------+------------+
| N1:           BubbleNebula  7.0, 0.2,  NGC7635       | 60<=dec    |
| N2:             CaveNebula  7.7, 0.8                 | UrsaMajor  |
| N3:          CatseyeNebula+ 8.3, 0.10, NGC6543       | Cassiopeia |
| N4:            BodesGalaxy  7.9, 0.2,  NGC3031, M81  | Polaris    |
+Northern-Winter:--------------------------------------+------------+
| N5:     AlphaPerseiCluster  3.0, 3.0                 | 30<=dec<60 |
| N6:          DoubleCluster  4.3, 0.5,  NGC 869       |  0<=asc<12 |
| N7:          NGC884Cluster  4.4, 0.5,  NGC 884       |            |
| N8:            M34Cluster  5.2, 0.6,  NGC1039, M34  |            |
| N9:            M37Cluster  5.6, 0.4,  NGC2099, M37  |            |
| N10:  PhiCassiopeiaeCluster  6.4, 0.2,  NGC 457       |            |
| N11:      FlamingStarNebula  6.0, 0.4,   IC 405      |            |
| N12:             OwlNebula+11.0, 0.05, NGC3587, M97  |            |
| N13:       CaliforniaNebula       1.0,  NGC1499       |            |
| N14:        AndromedaGalaxy  3.5, 3.0,  NGC 224, M31 |            |
| N15:       TriangulumGalaxy  5.7, 1.0,  NGC 598, M33 |            |
| N16:            M110Galaxy  8.0, 0.4,  NGC 205, M110 | Capella    |
| N17:             M32Galaxy  8.2, 0.3,  NGC 221, M32  | Castor     |
+Northern-Summer:--------------------------------------+------------+
| N18:            M39Cluster  4.6, 0.5,  NGC7092, M39  | 30<=dec<60 |
| N19:        HerculesCluster* 5.9, 0.3,  NGC6205, M13  | 12<=asc<24 |
| N20:            M92Cluster* 6.5, 0.2,  NGC6341, M92  |            |
| N21:     NorthAmericaNebula  6.0, 2.0,  NGC7000       | Lyra       |
| N22:         CrescentNebula  7.5, 0.3,  NGC6888       | Cygnus     |
| N23:     BlueSnowballNebula+ 8.6, 0.04, NGC7662       |            |
| N24:         BlinkingNebula+ 8.8, 0.04, NGC6826       |            |
| N25:             RingNebula+ 9.0, 0.04, NGC6720, M57  |            |
| N26:           CocoonNebula 10.0, 0.2,   IC5146       |            |
| N27:             VeilNebula       1.0,  NGC6992       |            |
| N28:         WhirlpoolGalaxy  8.4, 0.1,  NGC5194, M51  |            |
| N29:             M94Galaxy  8.7, 0.1,  NGC4736, M94  | Vega       |
| N30:         PinwheelGalaxy  8.7, 0.3,  NGC5457, M101 | Deneb      |
+------------------------------------------------------+------------+
```

East Equatorial Objects

```
                         Name  Mag, Diam, Alias
+Equator-Oct&Nov:--------------------------------------+------------+
| E1:         PleiadesCluster  1.2, 1.9,  NGC1432, M45  | -30<dec<30 |
| E2:             CometNebula  7.0, 0.11, NGC1360       |   0<=asc<4  |
| E3:       CetusBubbleNebula+ 8.5, 0.06, NGC 246       |            |
| E4:        SilverCoinGalaxy  7.1, 0.3,  NGC 253       |            |
| E5:            NGC247Galaxy  8.9, 0.3,  NGC 247       |            |
+Equator-Dec&Jan:--------------------------------------+------------+
| E6:           HyadesCluster  0.5, 5.5                 | -30<dec<30 |
| E7:    ChristmasTreeCluster  3.9, 0.7,  NGC2264       |   4<=asc<8  |
| E8:  TauCanisMajorisCluster  4.1, 0.1,  NGC2362       |            |
| E9:              M47Cluster  4.4, 0.5,  NGC2422, M47  | Orion      |
| E10:             M41Cluster  4.5, 0.6,  NGC2287, M41  | CanisMajor |
| E11:         NGC2244Cluster  4.8, 0.4,  NGC2244       | Gemini     |
| E12:             M35Cluster  5.1, 0.5,  NGC2168, M35  | Taurus     |
| E13:             M50Cluster  5.9, 0.3,  NGC2323, M50  |            |
| E14:            OrionNebula  4.0, 1.1,  NGC1976, M42  | Sirius     |
| E15:          RosetteNebula  5.5, 1.1,  NGC2237       | Rigel      |
| E16:             CrabNebula+ 8.4, 0.10, NGC1952, M1   | Procyon    |
| E17:           EskimoNebula+ 8.6, 0.01, NGC2392       | Betelgeuse |
| E18:  HubblesVariableNebula 10.0, 0.0,  NGC2261       | Aldebaran  |
| E19:    HindsVariableNebula 10.0, 0.0,  NGC1554       | Pollux     |
| E20:        HorseheadNebula        0.5,  NGC2024       | Adhara     |
+Equator-Feb&Mar:--------------------------------------+------------+
| E21:         BeehiveCluster  3.1, 1.6,  NGC2632, M44  | -30<dec<30 |
| E22:             M48Cluster  5.8, 0.9,  NGC2548, M48  |  8<=asc<12 |
| E23:   GhostOfJupiterNebula+ 8.6, 0.01, NGC3242       | Leo        |
| E24:              M66Galaxy  8.9, 0.1,  NGC3627, M66  |            |
| E25:          SpindleGalaxy 10.1, 0.1,  NGC3115       | Regulus    |
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West Equatorial Objects

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                          Name  Mag, Diam, Alias
+Equator-Apr&May:----------------------------------------+------------+
| E26:        ComaStarCluster  5.0, 5.0                  | -30<dec<30 |
| E27:              M5Cluster* 5.7, 0.3,  NGC5904, M5    | 12<=asc<16 |
| E28:              M3Cluster* 6.4, 0.2,  NGC5272, M3    |            |
| E29:         SombreroGalaxy  8.3, 0.1,  NGC4594, M104  | Bootes     |
| E30:         BlackeyeGalaxy  8.5, 0.1,  NGC4826       | Virgo      |
| E31:  SouthernPinwheelGalaxy  8.5, 0.2,  NGC5236, M83  |            |
| E32:            VirgoGalaxy  8.6, 0.1,  NGC4486, M87   |            |
| E33:             M100Galaxy 10.6, 0.1,  NGC4321, M100  | Arcturus   |
| E34:         AntennaeGalaxy 10.7, 0.0,  NGC4038       | Spica      |
+Equator-Jun&Jul:----------------------------------------+------------+
| E35:      CoathangerCluster  4.0, 1.0                  | -30<dec<30 |
| E36:          IC4665Cluster  4.2, 0.7,   IC4665        | 16<=asc<20 |
| E37:             M25Cluster  4.6, 0.7,   IC4725, M25   |            |
| E38:             M22Cluster* 5.1, 0.4,  NGC6656, M22   | Aquila     |
| E39:        WildDuckCluster  5.8, 0.2,  NGC6705, M11   | Sagittarius|
| E40:              M4Cluster* 5.9, 0.4,  NGC6121, M4    |            |
| E41:           LagoonNebula  5.0, 0.7,  NGC6523, M8    |            |
| E42:            EagleNebula  6.0, 0.1,  NGC6611, M16   |            |
| E43:            OmegaNebula  6.0, 0.2,  NGC6618, M17   |            |
| E44:           TrifidNebula  6.3, 0.5,  NGC6514, M20   |            |
| E45:         DumbbellNebula+ 7.3, 0.25, NGC6853, M27   | Altair     |
| E46:         BarnardsGalaxy 10.0, 0.2,  NGC6822       | Antares    |
+Equator-Aug&Sep:----------------------------------------+------------+
| E47:             M15Cluster* 6.3, 0.2,  NGC7078, M15   | -30<dec<30 |
| E48:              M2Cluster* 6.5, 0.2,  NGC7089, M2    | 20<=asc<24 |
| E49:            HelixNebula+ 6.3, 0.22, NGC7293        | Pegasus    |
| E50:           SaturnNebula+ 8.3, 0.04, NGC7009        | Fomalhaut  |
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Southern Objects

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                          Name  Mag, Diam, Alias
+South-Hemisphere:-------------------------------------+------------+
| S1:     ThetaCarinaeCluster  1.9, 0.8,   IC2602       | dec<=-60   |
| S2:          NGC2516Cluster  3.8, 0.5,  NGC2516       |            |
| S3:        Tucanae47Cluster* 4.0, 0.2,  NGC 104       | Crux       |
| S4:          NGC3114Cluster  4.2, 0.6,  NGC3114       | Carina     |
| S5:         JewelBoxCluster  4.2, 0.2,  NGC4755       |            |
| S6:   LambdaCentauriCluster  4.5, 0.3,   IC2944       |            |
| S7:          NGC2808Cluster* 6.3, 0.3,  NGC2808       |            |
| S8:          CoalSackNebula       5.5                 |            |
| S9:         TarantulaNebula  3.0, 0.5,  NGC2070       | RigilKent  |
| S10:   LargeMagellanicCloud  0.9,10.0                 | Agena      |
| S11:   SmallMagellanicCloud  2.3, 4.0,  NGC 292       | Acrux      |
+Southern-Summer:--------------------------------------+------------+
| S12:  OmicronVelorumCluster  2.5, 0.8,   IC2391       | -60<dec<=-30
| S13:         NGC2451Cluster  2.8, 0.7,  NGC2451       |  0<=asc<12 |
| S14:         NGC3532Cluster  3.0, 0.9,  NGC3532       |            |
| S15:          IC2581Cluster  4.3, 0.1,   IC2581       |            |
| S16:          IC2395Cluster  4.6, 0.5,   IC2395       |            |
| S17:       EtaCarinaeNebula  6.0, 2.0,  NGC3372       |            |
| S18:          KeyholeNebula  6.7, 0.3,  NGC3324       |            |
| S19:       EightBurstNebula+ 8.2, 0.01, NGC3132       |            |
| S20:           UranusNebula+ 8.4, 0.00, NGC3918       |            |
| S21:            CigarGalaxy  8.2, 0.3,  NGC  55       |            |
| S22:           NGC300Galaxy  8.7, 0.3,  NGC 300       | Canopus    |
| S23:          FornaxGalaxy 10.5, 0.1,  NGC1316       | Achernar   |
+Southern-Winter:--------------------------------------+------------+
| S24:         NGC6231Cluster  2.6, 0.3,  NGC6231       | -60<dec<=-30
| S25:        PtolemysCluster  3.3, 1.3,  NGC6475, M7   | 12<=asc<24 |
| S26:   OmegaCentauriCluster* 3.7, 0.6,  NGC5139       |            |
| S27:       ButterflyCluster  4.2, 0.2,  NGC6405, M6   | Centaurus  |
| S28:    TurquoiseOrbCluster* 5.4, 0.3,  NGC6752       | Scorpius   |
| S29:         NGC6397Cluster* 5.7, 0.3,  NGC6397       |            |
| S30:        CentaurusGalaxy  7.0, 0.3,  NGC5128       | Becrux     |
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