SkyChart 2000.0

version 1.0.2 by Tim DeBenedictis, ©1993
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1. Introduction

SkyChart 2000.0 is a program for calculating and displaying the appearance of the night sky. Becuase *SkyChart 2000.0* is a computer program, it can do things that no paper star atlas ever could— for instance, it can show the positions of the sun, moon, planets, asteroids, and comets at any time, or show the sky as it would appear from a planet other than Earth, or even animate the constellations as the stars move over thousands of years.

SkyChart 2000.0 will run on any Macintosh with a math coprocessor. That includes Mac IIs, Centris 650s, Quadras, and LCs with math coprocessors. *SkyChart 2000.0* requires at least 2048K of memory to run, and is both System 6 and System 7 compatible.

The files that should be included with this *SkyChart 2000.0* distribution are:

• The *SkyChart 2000.0* application;
• A *SkyChart 2000.0* document called “Sky Data”;
• A text file called “Nearby Stars 1950.txt”;
• A text file called “Asteroids & Comets 1950.txt”;
• The “SkyChart 2000.0 README” file;
• The *SkyChart 2000.0* Manual, in Microsoft Word format.

This manual assumes that you are familiar with the Macintosh environment; i.e., you know to know how to do things like “double-click” and use the standard “Open...” and “Save As...” dialogs. It also assumes you have some knowledge of astronomical terms like “right ascension” and “magnitude.”

Finally, please note that *SkyChart 2000.0* is shareware. Feel free to give away as many copies as you like, but if you use the program frequently, please register your copy by sending the shareware fee, $20.00 (US) to the author at the following address:

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Note— after the end of August, 1993, my address will be changing. After that date, you should send the registration fee to the new address given below. (You can still send e-mail to the address given above, however.)

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Registering will put you on the *SkyChart 2000.0* mailing list so you'll be notified of future updates and upgrades. Also, I'll send you*SkyChart 2000.0*'s THINK C source code, which includes a portable library of astronomical functions, upon requent; *and* you'll be helping me pay off my college loans! I've found that e-mail is the fastest and most reliable way for me to get in touch with registered users, so if you have an e-mail address and wouldn't mind sending it on, I'd greatly appreciate it. My e-mail address is given above.

2. Using *SkyChart 2000.0*

This section is a tutorial introduction to *SkyChart 2000.0's* features. The program is almost easy enough to use that this is unnecessary, but going through the demos listed below will give you a feel for how *SkyChart 2000.0* operates, and will show you some of its capabilities. Later sections give a more detailed discussion of *SkyChart 2000.0*'s advanced features.

2.1 Setting the Field of View

Begin running *SkyChart 2000.0* by double-clicking on its icon from the Finder, just as you would with any other Macintosh application. *SkyChart 2000.0* takes a few seconds to read the "Sky Data" file, then it displays a view of the night sky centered on the north celestial pole, with the Big Dipper to the left and Cassiopeia on the right. (This is the view that *SkyChart 2000.0* always starts up with.) The bottom of the window shows the location of the observer, the local date and time, and a legend for the symbols in the window.

To center on a different part of the sky, go to the Display menu and select the Centering... command (or press K). This opens a dialog box where you can enter new coordinates to center the view on. Try entering "17 30 00.0" for the right ascension, and "-30 00 00" for the declination, and press the OK button. This should give you a view of Sagittarius and Scorpius.

Alternatively, you could press the Zenith button. This will automatically enter the coordinates of the point on the celestial sphere that is overhead right now. After you press the OK button, you'll be treated to a view of the stars that are overhead at your particular location right now.

A quick way to recenter the SkyChart window is to command-click in the window (hold the "" key while clicking in the window). This will automatically re-center the window where you clicked.

You can also use the Centering... dialog to expand or shrink the field of view. Enter the width of the field of view you wish to display (in degrees) in the area provided, and press the OK button. An alternative is to select Zoom In or Zoom Out from the Display menu (or, equivalently, press [or] on the keyboard). These will, respectively, halve and double the width of the field of view. You can only zoom out, however, until you've reached a 180° field of view, which displays the entire sky in the window.

2.2 Finding and Selecting Objects

Now choose an object in the SkyChart window, and click on it. A window opens in which the object's name, right ascension, declination, distance, magnitude, time of rising, and time of setting are displayed. If you clicked on a star or deep sky object, some additional information is given— namely, the star's annual proper motions in R.A. and declination, and radial velocity in kilometers per second. If you clicked on a solar system object such as the sun, the moon, a planet, an asteroid, or a comet, different information is given. This is the planet's angular size (in arcseconds) and phase (illuminated fraction). For the sun, moon, and major planets, the longitude and latitude of the central point on the planet's disk, and the position angle of the planet's north pole are also displayed. (This information describes the orientation of the planet's disk as it appears in the sky.)

When you click an object in the SkyChart window, it becomes the selected object. Another way to select an object is to choose the Find Object... command from the Settings menu. For instance, let's say you want to know where the planet Mercury is right now. Select Find Object...; a dialog box appears in which you are asked to enter the name of the object you wish to find. Type "Mercury" and press the Select button. *SkyChart 2000.0* searches the object database for the name you named. When it finds it, it selects the object, and displays information for it in the Selected Object window. If you made a typo or otherwise entered the name of an object which doesn't exist in the database, you'll get an error message instead.

Now Mercury has become the selected object. To show Mercury in the SkyChart window, click the Center button in the Selected Object dialog. The view is automatically recentered on Mercury. How can you tell if Mercury is visible in the sky right now? An easy way is to go to Coordinates under the Display menu. This leads to a submenu which gives different coordinate systems. Select Horizon coordinates (or press 4), and then center the cursor over Mercury. The azimuth and altitude of the point the cursor is over are now displayed in the upper left hand corner of the screen. If Mercury's altitude is positive, then it's above the horizon; otherwise, it's below.

2.3 Animation!

Now press and hold the "" and "+" keys (the "+" key is the one marked "+" on the numerical keypad, not the "=" key on the main part of the keyboard). This will animate the SkyChart window, and show how Mercury moves against the backdrop of the stars. To animate backwards, press and hold - instead. The default animation rate is one day at every step. To change this, select Animation... from the Settings menu. Try entering "7.00" in the area labelled Time Step:. This will change the date one week at a step instead of one day at a step.

You can do other things with the Animation... dialog as well. If you check the box marked Center on selected object, the SkyChart window will stay centered on Mercury as long as you keep the + or - keys pressed. If you check the Trail for selected object box, *SkyChart 2000.0* will leave a path for Mercury as it moves across the stars.

If you have a older Macintosh, animation may be slow. One way to speed it up is to avoid drawing as many objects in the SkyChart window. Do this by selecting the Symbols...

command from the Display menu (B). In the field labelled Faintest magnitude shown:, enter "3.5" instead of "5.5," and press the OK button. This will show only the brightest stars; animation should be much faster now. You can also speed things up by not drawing deep sky objects; do this by unchecking the Draw deep sky box.

While you are still in the Symbols... dialog box, check the box marked Draw as disks under the Draw Planets box. This tells *SkyChart 2000.0* to draw the planets as they would actually appear. Planet disks will be magnified relative to the rest of the window by the factor displayed to the right of the Draw as disks box.

Now hit the OK button, and center on Mercury again. If Mercury appears too small in the sky to be drawn as a disk, select Zoom In a few times until the planet's disk appears. This is how Mercury would actually look in the sky at the time displayed in the bottom of the SkyChart window; the shaded part of the disk is filled with a stippled pattern.

You can also display and animate the appearance of Jupiter's Galilean satellites. Do this by selecting Jupiter's Moons... from the Display menu. A separate window opens, showing the configuration of the moons at the time given in the upper left hand corner of the window. To see which moon is which, check the Label moons box at the bottom. To invert the view so the north is at the bottom and east is at the right (such as would be the case when looking at Jupiter through an inverting telescope), check the Inverted view box. You can animate the moons' motion by pressing + or -, as with the SkyChart window itself.

You can print the contents of the SkyChart window by selecting Print... from the File menu (P). You may wish to choose Page Setup first, though, to print the window sideways so nothing will get cut off along the side of the page. The window will be printed black on white instead of white on black to save ink. You can see what this will look like by selecting Invert Sky from the Display menu (I). Selecting Invert Sky again will switch back to white on black. You can also copy the SkyChart window and paste it into other documents by selecting Copy from the Edit menu (C).

2.4 Viewing Celestial Events

You can use *SkyChart 2000.0*'s planet-drawing capabilities to view events such as eclipses and transits. An example, try reproducing the total eclipse of the sun on July 11th 1991, as viewed from Honolulu, Hawaii. First go back to the Symbols... dialog box, and change the planet magnification factor to 1 (so the sun and moon will be drawn at their correct sizes). Then go the Settings menu, and choose Location... (or press L). This opens the "Location" dialog box, which sets the observer location that the SkyChart window is drawn for. Make sure the radio button marked On Earth: is on, then enter Honolulu's longitude, latitude, and time zone in the appopriate areas. These are 157° 52' west, 21° 19' north, and 10 hours west. East is positive, so make sure the longitude and time zone are negative. Then choose Date and Time... from the Settings menu (T), and set the time to just before the eclipse— try entering "1992/07/11" for the date and "05:00:00" for the local time.

Now you are ready to view the eclipse. Use the Find Object... command to select and center the sun. You probably also want to change the animation step to a smaller interval, say 0.01 days, and perhaps check the Center on selected object box as well. Then press and hold the + keys— you'll see the moon approach, eclipse the sun, and retreat across on the other side.

With *SkyChart 2000.0*, you can view celestial events that no human being has ever witnessed. Here is one: With the Date and Time... command, set the date to "1984/05/10". Now choose Location.... In the "Location" dialog box, click on the radio button marked A planet:, and enter "Mars" for the name of the planet. Then choose Find Object... to find center the sun. Set the animation rate to, say, 0.1 days per step, and make sure the planet disk magnification is 1. Then zoom in until the sun fills most of the SkyChart window, and animate away... If you had been on Mars on May 11th, 1984, you would have witnessed what *SkyChart 2000.0* just showed you: a transit of Earth across the sun. (The very bright "star" that follows the earth across the sun is actually our moon.)

You can return to your original location by selecting Location..., then pressing the button marked Here in the dialog box. This reads your machine's longitude, latitude, and time zone from the "Map" control panel, and enters them in the appropriate spots in the dialog box. Similarly, you can set the time back to the present by choosing Date and Time..., then pressing the Now button. This reads the time from the system clock, and enters it in the dialog box. (*SkyChart 2000.0* does both these things automatically every time it starts up, so the "Map" control panel and the system clock and set the startup values for the observer location and time.)

2.5 Some Really Cool Demos

You can not only view the sky from other planets, but from other star systems as well. For instance, use the Location... command to set your location to the star α^1 Centauri. (Click the radio button labelled A star:, and type "a1 Cen" in the text field to the right.) Then choose Centering..., and center the view on R.A. 01^h, Dec. +60°. You get a view of the constellation Cassiopeia with an extra star: our sun.

SkyChart 2000.0 lets you animate across great spans of time to view celestial phenomena which happen over thousands of human lifetimes. One such phenomenon is the precession of the equinoxes. This is the wobbling motion of the Earth's north pole, one cycle of which takes 26,500 years to complete. To view it, first return to your original location (select Location..., and click the Here button in the dialog box). Then select the Precision... command from the Settings menu. Check the box labelled Current epoch, under Precession Epoch. This will display the stars' positions relative to the current orientation of the Earth's axis. You may also want to show a coordinate grid; do this by selecting Grid... from the Display menu, and check the Draw coordinate grid box.

Now set the time to the year -11000, and center on the north celestial pole (Dec. +90°). You can see that this long ago, Polaris was nowhere near the north pole— in fact, at that time, the "North Star" was Vega! You can watch the whole 26,500 year precessional cycle by animating the SkyChart window. Set the time step to 365250 days (1000 years), and animate. You might select a particular star (say Polaris), and leave a trail for it to show its precessional path. (If you animate even further into the past or future, the precessional motion apparently becomes chaotic — this, however, doesn't happen in reality, since the precession formulae *SkyChart 2000.0* uses are only valid for a few thousand years around the present.)

One last demonstration illustrates the motion of the stars themselves through space over the millenia. Center the SkyChart window on R.A. 12^h, Dec. +60° to get a view of the Big Dipper. Now select Precision... from the Settings menu, and check the Space Motion box, under Correct star positions for:. Turn off the Current epoch option to remove the effects of precession. You will also probably want to make the animation step even bigger (say 10,000 years or 3652500 days), and set the time to the year -100000. Then animate to watch the how the stars in the Big Dipper moved into their current configuration, and to see how they will look hundreds of thousands or even millions of years from today.

3. The Object Database

The file called "Sky Data" that comes with *SkyChart 2000.0* contains the data for the objects that *SkyChart 2000.0* displays. You can add new objects to the database, as well as import other kinds of files to make new databases. Databases are opened with the Open...

command from the File menu (O), just as with any other Macintosh application. You can have more than one database open at a time, just as long as the total number of objects in memory does not exceed the program's limits (see below).

SkyChart 2000.0 will automatically look for a file called "Sky Data" every time it starts up, so you can make a different database into the startup file simply by renaming it "Sky Data" and calling the existing "Sky Data" file something else.

3.1 Adding New Objects

To add individual new objects to the database, use the New command under the File menu. This command leads to a submenu which lets you create two classes of new objects: stars and planets. *SkyChart 2000.0* considers all non-solar system objects to be "stars"— this includes single-, multiple-, variable- star systems, as well as star clusters, nebulae, and galaxies. All solar system objects are considered to be "planets," which includes the sun, moon, major planets, asteroids, and comets. When it starts up, *SkyChart 2000.0* allocates enough memory to hold 10,000 stars and 1000 planets.

When you select either option under the New menu, a dialog box opens up in which you enter the information for the new object. For a new star, the information you need to enter is the star's right ascension and declination, its annual proper motion in right ascension and declination, its apparent magnitude and color index, its distance in parsecs, and its radial velocity in km/sec. (For most of these fields you can enter "0" if you don't have the information available.) Additionally, you need to select a specific type for the star from the popup menu provided in the dialog. This will determine which symbol the star gets drawn with in the SkyChart window. Finally, you need to name the star. You can enter a name and other miscellaneous information (up to a total of 255 characters) in the text field at the top of the dialog box.

When the box marked Draw labels in the "Symbols" dialog is checked, everything in the name field up to the first semicolon (";") will be drawn next to the object in the SkyChart window as a label. If the first character in the name is a dollar sign ("$"), the next character will be drawn using Apple's "Symbol" font. You can label objects with Greek letters this way.

When you select the new planet option, you are also asked to enter a name, and to select a planet type from a popup menu provided in the dialog. The planet type determines what symbol the planet is drawn with in the SkyChart window. Traditional astronomical symbols are used for the sun, moon, and major planets; asteroids are drawn as "+" signs, and comets as "+" signs with tails extending to the upper right. If the Draw as disks box is checked in the "Symbols" dialog, of course, planets will be drawn as disks instead (or as stars corresponding to their magnitudes, if they appear to small to be drawn as disks).

Additionally, the planet type determines how the planet's position, appearance, and magnitude are calculated. If the planet's type is Sun, Moon, or any of the major planets (Mercury through Pluto) *SkyChart 2000.0* disregards any other information you enter for the planet, and calculates the above quantities using its own internal formulae. On the other hand, if you selected Asteroid or Comet for the planet type, it computes those quantities using the orbital elements and magnitude parameters you enter below. Those elements are the mean anomaly, in degrees; the epoch of the mean anomaly, expressed as a Julian Day number; the eccentricity; the semimajor axis in Astronomical Units; the argument of perihelion; the inclination; and the longitude of the ascending node, all in degrees. If you enter a negative value for the semimajor axis, it will be interpreted by *SkyChart 2000.0* as a perihelion distance instead (this, rather than the semimajor axis, is usually given for objects with very eccentric orbits, like comets.) Sometimes the longitude of perihelion is given instead of the argument of perihelion; to convert this to the argument, subtract the longitude of the ascending node. Similarly, if you have the mean longitude instead of the mean anomaly, you can convert it to the mean anomaly by subtracting the longitude of perihelion (or, equivalently, by subtracting both the argument of perihelion and the longitude of the ascending node). Orbital elements for the major planets, and a selection of asteroids and comets, are published every year in the *Astronomical Almanac*, and in the IAU's *Minor Planet Circulars*. Elements can also be obtained (at cost) from the Minor Planet Center, Smithsonian Astrophysical Observatory, Cambridge MA 02138, USA.

You are also asked to enter the object's magnitude parameters, H and G. The first of these is the absolute magnitude (how bright the object would appear if fully illuminated at 1 AU from both the earth and sun); the second is describes how fast the object's brightness falls off with phase. For comets, the second parameter instead describes how the object's brightness changes with distance from the sun.

Important note: when entering coordinates for new stars or elements for new planets, first set the Precession epoch: field in the "Precision" to the same date those coordinates or elements are referenced to. For instance, if you have the orbit for a comet referred to the equinox of epoch 1950.0, make sure you set the precession epoch to 1950.0 beforehand— otherwise the positions *SkyChart 2000.0* calculates will be wrong, relative to the rest of the database. You can also use this to your advantage, though. Say you have the position of a star in 1950.0 coordinates, and you want its position for 2000.0. Set the precession epoch to 1950.0, then enter the star's position, then set the precession epoch to 2000.0, and select the object. The position given in the Selected Object window will be for the last precession epoch you entered, i.e. 2000.0.

3.2 Importing Text Files

As mentioned previously, you can also create new objects by importing them from text files. Two examples of such text files are distributed with *SkyChart 2000.0*. The first, "Nearby Stars 1950.txt," contains information for every star system within 10 parsecs of the sun, as given in the *Catalog of Nearby Stars*, 3rd ed. The second, "Asteroids & Comets 1950.txt," contains recent orbital elements for a selection of asteroids and comets, supplied by David Tholen. You can look at these files yourself with your favorite word processor; they simply contain tab-delimited columns of text.

The first column gives the type of object. The first character, either "s" or "p", tells whether the object is a star or planet; the second is a number giving the star or planet type. This is the same number as the menu item in the star or planet type popup menus in the New star and New planet dialogs. For example, "s5" means Open Cluster, since that's the 5th item in the Star type menu; while "p12" means Asteroid, the 12th item in the Planet type menu.

The information in the remaining columns varies, depending on the type of object. For stars, the format is:

Column 2— R.A. hours
Column 3— R.A. minutes
Column 4— R.A. seconds
Column 5— Dec. degrees, with a "-" if the sign of dec. is negative.
Column 6— Dec. minutes
Column 7— Dec. seconds
Column 8— Annual proper motion in R.A., in seconds of time
Column 9— Annual proper motion in Dec., in arcseconds
Column 10— Magnitude (V)
Column 11— Color index (B-V)
Column 12— Radial velocity, km/sec
Column 13— Distance, in parsecs

Column 14— Label, name, and other miscellaneous information.

For planets, the information is:

Column 2— Semimajor axis in AU, or perihelion distance if negative
Column 3— Eccentricity
Column 4— Inclination, in degrees
Column 5— Argument of perihelion, in degrees
Column 6— Longitude of the ascending node, in degrees
Column 7— Mean anomaly at Julian Day given in column 2
Column 8— Epoch of mean anomaly, as a Julian Day
Column 9— H magnitude parameter
Column 10— G magnitude parameter
Column 11— Label, name, and other information

SkyChart 2000.0 will assume that all the orbits and/or coordinates in the text file are for whatever precessional epoch is currently indicated in the "Precision" dialog. For instance, if the file contains elements for epoch 1950.0, as does the "Asteroids & Comets.txt" file provided with *SkyChart 2000.0*, make sure to set the precession epoch to 1950.0 before opening the file.

After reading a text file, *SkyChart 2000.0* needs to compile the information into its own internal binary format. This may take several minutes for large files. However, after it has compiled the file, you can save it in binary format as an object database, which *SkyChart 2000.0* can open and read again much faster.

3.3 The "Sky Data" File

I made up the "Sky Data" file distributed with *SkyChart 2000.0* exactly this way. I reformatted a machine-readable version of the *Bright Star Catalog*, 4th ed., into a tab-delimited text file as described above, then opened and compiled it with *SkyChart 2000.0*. The deep sky objects and planets started out as MS Excel spreadsheets I entered by hand from the *Astronomical Almanac*, then they were opened and compiled by *SkyChart 2000.0*, and saved into the "Sky Data" file.

For stars in *Bright Star Catalog*, I computed distances using two different methods. If the star's trignonometric parallax was given in the catalog as equal to or greater than 0.04" (corresponding to a distance of 25 parsecs or closer), I computed the distance from the parallax. Otherwise, I estimated the star's absolute magnitude from its spectral type as given in the catalog, and found its distance by comparing the absolute magnitude to the apparent magnitude. I computed absorption of starlight due to galactic dust as three times the color excess. Stars whose distance couldn't be computed either way were arbitratily given a distance of 1000 parsecs.

The comments in the label field give the star's Bayer (greek) letter, Flamsteed number, and HR (Bright Star catalog) number, along with the common name as given in the *Bright Star Catalog*. If the star has a variable-star designation, it is also given, along with the type of variablility, magnitude range, and period in days as taken from the machine-readable version of the *General Catalog of Variable Stars*, 4th ed. An "SB" means the star is a spectoscopic binary. If the star is multiple, the number of components is given, along with the letter designations, separation in arcseconds, and magnitude difference between the two brightest components. Finally, the star's spectral type is listed as given in the *Bright Star Catalog*.

Since almost every entry in the *Bright Star Catalog* is a multiple or variable star, I decided to cut down the number of multiple- and/or variable-star entries that would be plotted in the SkyChart window. In the "Sky Data" file, only stars with optical companions closer than 1 arcminute are given the Multiple star symbol, and only stars that vary by 0.1 magnitude or more are plotted with the Variable star symbol.

The "Sky Data" file also contains information for all 110 deep sky objects in the Messier catalog. In addition, it also contains information for open clusters to magnitude 7.5, globular clusters to 8.5, a selection of large and well-known diffuse nebulae, planetary nebulae to magnitude 10.5, and galaxies to magnitude 10.5. For the open clusters, globular clusters, and galaxies, information was taken from the Astronomical Almanac. For the nebulae, information was taken from *Sky Catalog 2000.0*, volume 2. The comments for the deep sky objects give their Messier catalog and NGC numbers, common names, and approximate angular sizes in arcminutes. For the galaxies, morphological types are also given.

3.4 Ephemeris Files

There is one more type of file you can generate with *SkyChart 2000.0*: an ephemeris. This is a list of positions for an object at different times. *SkyChart 2000.0* can make these for any object in the database, and save it as a text file which you can open with a word processor, spreadsheet, or graphing program. To generate an ephemeris file, select Save Ephemeris... under the File menu. A dialog opens, where you are asked to enter the name of the object you wish to generate the ephemeris for, a start and end date for the ephemeris, and a time step in days. For example, an ephemeris from 1990/01/01 to 1990/01/31 with a 1 day step would have 30 entries. After you have entered this information, press the Save As... button. This opens the familiar "Save As..." dialog, where you are asked to name the ephemeris file. After you hit Save, *SkyChart 2000.0* generates the ephemeris file. This may take a minute or two if your file contains hundreds of entries.

The ephemeris is just a tab-delimited text file, which will appear as a MS Excel document. The file's columns contain the following information:

Column 1— year/month/day
Column 2— R.A., h m s
Column 3— Dec., ° ' "
Column 4— Distance; in parsecs for stars, AU for planets, earth-radii for the moon
Column 5— Magnitude
Column 6— Local rise time, h:m
Column 7— Local set time, h:m

For the sun, moon, and major planets, the following additional information is given:

Column 6— Angular size, arcsec
Column 7— Phase
Column 8— Longitude of central meridian (both system I and II for Jupiter)
Column 9— Latitude of central point
Column 10— Position angle of north pole

This information is calculated using the current settings in the "Location" and "Precision" dialogs.

4. Accuracy

I've tried to make *SkyChart 2000.0* as accurate as possible. Generally, star positions should be accurate to 1 arcsecond, which is the precision of the *Bright Star Catalog*. The formulae *SkyChart 2000.0* uses to compute the positions of the planets were taken from a 1979 paper by T. C. Van Flandern and K. F. Pulkkinnen, "Low-Precision Formulae for the Positions of the Planets." This advertises a precision of 1 arcminute for any time within 300 years of the present. However, spot-checking the results against recent *Astronomical Almanacs* seems to indicate that these formulae actually do somewhat better than that, at least for dates close to 2000.0. For the inner planets, the discrepancy was rarely more than an arcsecond or two, and for the outer planets, the formulae usually gave positions within ten or twenty arcseconds of the *Almanac's*. (For Pluto, the paper warns that positions may only be accurate to perhaps 15 arcminutes; this seems in fact to be the case.)

For asteroids and comets, the situation is somewhat different. Because of the gravitational perturbations of the other planets, the orbit of any object in the solar system is always changing. Therefore, a single set of elements will gradually grow inaccurate and out of date. That's why no asteroids or comets were included in the "Sky Data" file. However, the elements in the text file I've given are recent enough that they should give positions good to about an arcminute for the next few years, which ought to be sufficient for locating them in the sky. New sets of orbital elements, as mentioned above, are published in the *Astronomical Almanac* as well as the IAU's *Minor Planet Circulars*. A catalog of up-to-date orbital elements is available at cost from the Minor Planet Center, Smithsonian Astrophysical Observatory, Cambridge MA 02138, USA.

These are the fundamental limits on *SkyChart 2000.0*'s accuracy. However, a number of additional factors can make its results more or less accurate, depending on how they are taken into account. Large errors can come from entering data for the wrong precessional epoch, as mentioned above. Secondly, there are a number of other factors which influence an object's position. Most of these are covered in the Precision… dialog.

4.1 Position Corrections

Nutation is a small wobble superimposed on the larger precessional motion, which constantly changes the direction of the earth's rotational axis (and hence the celestial coordinate system) slightly. A position referred to the coordinate system of a particular precessional epoch without the effect of nutation is called a "mean place"; with nutation taken into account it becomes the "true place". To correct positions for nutation using *SkyChart 2000.0*, check the Nutation box in the Precision… dialog. The correction for nutation, however, is never more than about 20 arcseconds.

Aberration is caused by the fact that we as observers on earth are moving relative to the things we're looking at. The analogy is driving into the rain: even though the rain may be falling straight down, it looks like it's coming at you horizontally because you're moving. As the earth orbits the sun, aberration causes the stars' apparent directions to shift slightly. A position corrected for aberration is called the "apparent place". To have *SkyChart 2000.0* make this correction, check the Aberration box in the Precision… dialog. Aberration never amounts to more than 20.5 arcseconds, though, and if you are observing from a location other than earth, *SkyChart 2000.0* does not calculate it at all, regardless of whether or not you have checked the Aberration box. (Note— actually, there are two kinds of aberration to worry about— annual aberration, caused by the earth's motion around the sun, and diurnal aberration, caused by the daily rotation of the earth. *SkyChart 2000.0* completely ignores the latter effect, since it never amounts to more than about 0.3 arcseconds.)

For stars, two other corrections can be made. First, there is the star's own motion trough space. Correct for this by checking the Space Motion box. As you've seen, though, this is barely noticeable except over periods of hundreds or thousands of years. (Barnard's star, which has the largest apparent motion of any known star, moves 10.31 arcseconds per year, but it's also the third-closest star to earth, after the sun and the Alpha Centauri system.) Second, there is *annual* or *heliocentric parallax*. Star positions are usually given for an observer at the center of the solar system— but we're looking at the star from the earth, not the center of the solar system. The difference is tiny, less than 0.8 arcseconds even for the closest star, Alpha Centauri. However, the difference in a star's position observed from the Earth and from, say, Neptune, could be much greater. If you decide to correct for this effect, check the Heliocentric Parallax box.

For planets and other objects within the solar system, two other corrections apply. The first of these is geocentric parallax. Planet positions in the *Astronomical Almanac* are calculated for an observer at the center of the earth (*geocentric* positions), rather than for a location on its surface (*topocentric* positions). For most objects, the difference is only a few arcseconds— except in the case of the moon, where it can amount to half a degree. For this reason, *SkyChart 2000.0* corrects for geocentric parallax by default. To turn this option off, uncheck the Geocentric Parallax box in the Precision dialog. (To see what a difference this makes, try watching the July 11th, 1991 solar eclipse again, but without geocentric parallax taken into account.)

The final correction *SkyChart 2000.0* can make for a planetary position is due to light travel time. When you're looking at a planet in the sky, you're seeing where it was when the light left it, rather than where it is now. Therefore, for high precision, *SkyChart 2000.0* actually needs to calculate the planets' positions for a given time antedated by the light time from the planet itself. This is not a large correction, and it slows down calculations signficantly since each planet's position now has to be calculated iteratively. Therefore *SkyChart 2000.0* does not make this correction by default.

Where light time makes a big difference, though, is in computing the central longitude of a planet's disk. For instance, light time from Jupiter is typically 45 minutes, and while Jupiter may not move very much in 45 minutes, it may rotate more than 25° around its axis! Thus, light time is critical in calculating planetary central meridians correctly. To have *SkyChart 2000.0* take it into account, check the Light time box in the Precision... dialog.

4.2 Rising and Setting

SkyChart 2000.0 calculates the local times that an object rises and sets. However, you often want to know when the object will reach a particular altitude, say 30°, rather than when it will appear exactly on the horizon (since observing an object actually on the horizon is very difficult). In the Precision... dialog, you can change the altitude which rise/set times will be calculated for in the text field labelled Horizon altitude:. The local horizon line will also be drawn for this altitude in the SkyChart window if you have checked the Draw horizon box in the Grid... dialog.

SkyChart 2000.0 assumes that objects' positions are fixed when calculating rise and set times. For solar system objects, this is not strictly true; however, it is usually close enough that the error introduced is less than a minute. (The moon may be an exception.) Also, *SkyChart 2000.0* does not take atmospheric refraction or the angular sizes of objects into account. For instance, sunrise, which ocurrs when the sun's upper limb is on the horizon, actually takes place when the center of the sun's disk is 50' below the true horizon. To calculate a better time for sunrise, then, you would want to use a horizon altitude of -50' or -0.83°. Similarly, the times of civil twilight can be calculated by setting the horizon altitude to -6°; nautical twilight, by setting it to -12°; and astronomical twilight, by setting it to -18°.

Checking the Refraction box will correct the altitudes displayed in the upper left hand corner of the SkyChart window for atmospheric refraction (if Horizon is selected in the Coordinates submenu, 4). It will not, however, affect the horizon altitude you set. If you want a refracted horizon, set the horizon altitude to -0.5 degrees.

An additional correction is found in the Date and Time... dialog box. The world's civil time scale, Universal Time or UT, is based on the rotation of the earth. Unfortunately, the earth's rotation rate is not perfectly regular (that's where "leap seconds" come from), and astronomical calculations require a uniform time scale. Such a time scale, called Terrestrial Dynamic Time or TDT, has been devised. (Before 1984, this time scale was referred to as Ephemeris Time or ET). The difference between UT and TDT, called ΔT, is currently about 59 seconds, and has been less than two minutes since the beginning of the 17th century. At least for the present, correcting for ΔT is usually not important, except perhaps for calculating planetary central meridians. Over thousands of years, though, the difference may be greater— perhaps several hours at the time of Christ. If you check the Convert to TDT box in the Date and Time... dialog, the date and time you give in the dialog will be converted to TDT by adding ΔT.

Some additional calendar notes: The Gregorian calendar was introduced by Pope Gregory XIII in 1582 to replace the older Julian calendar, which had simpler leap-year rules and had gotten out of sync with the seasons. Since the Gregorian calendar has now come into universal use, *SkyChart 2000.0* uses it by default. However, the changeover from the Julian to the Gregorian calendar did not happen everywhere at once: not until 1752 in England and the American colonoies, until 1873 in Japan, and until 1927 in Turkey. If you would like to examine an event that happened on a particular date in the Julian calendar, uncheck the Gregorian calendar box in the "Date and Time" dialog, and SkyChart will assume that you now mean a Julian calendar date. Finally, note that years B.C. should be entered as 0 for 1 B.C, -1 for 2 B.C., -2 for 3 B.C., and so on (since the year immediately before 1 A.D. is 1 B.C., not "0 A.D.")

There are a few more corrections that could be made— for example, the "polar motion" of the Earth's crust, and gravitational light deflection by the sun— but these are much less than an arcsecond, so *SkyChart 2000.0* does not make them. However, the corrections is does provide should be sufficient for accurately calculating the positions of the stars and planets for many hundreds of years. I hope it provides useful information for you, and I'll be glad to answer any questions you might have.

5. References

SkyChart 2000.0 was written in THINK C, version 5.0.3, on a Macintosh LC II with a math coporcessor, running system 7.1. I used the following sources most in developing the code and obtaining information for the object database:

The Astronomical Almanac for the Year 1984. Washington: US Government Printing Office.

Gottlieb, David M. "SKYMAP: A New Catalog of Stellar Data." *The Astrophysical Journal Supplement Series,* 38: 287-308: 1978 November.

Hirshfeld, Alan, and Sinnott, Roger W. *Sky Catalog 2000.0,* volume 2. Cambridge: Sky Publishing Corp., 1985

Meeus, Jean. *Astronomical Formulae for Calculators.* Richmond: Willmann-Bell, Inc., 1979.

Royal Astronomical Society of Canada. *Observer's Handbook, 1990.* Toronto: University of Toronto Press, 1990.

Van Flandern, T. C., and Pulkkinnen, K.F. "Low-Precision Formulae for Planetary Positions." *The Astrophysical Journal Supplement Series*, 41: 391-411, 1979 November.

Machine-readable versions of the following astronomical catalogs were obtained on CD-ROM from the National Space Science Data Center, Goddard Spaceflight Center, Greenbelt, MD

20771:

Hoffleit, D. *The Bright Star Catalogue,* 4th revised ed. New Haven: Yale University Observatory, 1982.

Kholopov, P.N. et al. *General Catalogue of Variable Stars,* 4th ed. Moscow: Nauka Publishing House, 1988.

Gliese, Wilhelm and Jahreiss, Hartmut. *Third Catalogue of Nearby Stars.* Heidelberg: Astronomisches Rechen-Institut, 1989.

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