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EXPLORING THE ASTRONOMY OF ANCIENT EGYPT WITH SIMULATIONS I: THE SUN, MOON, AND MILKY WAY

BY

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Many of the creation myths and religious concepts of ancient Egypt are related to the cycles of celestial objects. While there are few original sources that describe the techniques or the observational results of Egyptian astronomy, the Egyptians did follow a lunar calendar at least as early as 3000 BC. From about 2800 BC onwards they also made systematic use of a yearly cycle of 365 days. They carefully monitored the heliacal rising of Sirius. They divided the night into 12 equal parts with "hours" that varied in length with the seasons.

The goal of this article is to investigate aspects of Egyptian astronomy by combining the available archeological information with a variety of computer simulations of the Egyptian sky in the third millennium BC. If we could travel back in time and look over the shoulder of an Egyptian priest as he made his observations, we might be able to gain a better understanding of the fundamentals of Egyptian astronomy. The article is divided into two parts. Part I includes simulations to investigate Egyptian observations of the myth of *Nut* and the rebirth of *Ra,* winter solstices, the beginning a lunar month, and the 25-year lunar cycle. Part II includes simulations to investigate characteristics of the heliacal rise of Sirius, and the use of decans to mark the hours of the night.

Simulations and Ancient Astronomical Practices

Astronomical events can be accurately simulated with relative ease, using low-cost planetarium programs such as *Starry Night*[1] . With such programs, complex mathematical calculations[2] are carried out automatically and results are displayed graphically. Simulations allow you to view a virtual sky in any particular direction, at any particular time, in any particular geographical location. In addition, simulations of ancient astronomical events can:

- provide insights into the methods employed by ancient astronomers,
- provide useful data about the events that were observed,
- provide the ability to make sets of virtual observations that can stretch over hundreds, or even thousands, of years.

A Brief Introduction to Ancient Egypt

Egyptian astronomy was closely tied to the religious and social life of their civilization. A review of the basic characteristics of this civilization provides a background for exploring their astronomical techniques and observations.

The Egyptian civilization prospered from at least 3500 BC until 55 BC, when Egypt became a Roman province. The ancient Egyptians created public monuments and temple complexes. They created works of art and complex tomb structures. They recorded many of their thoughts and actions in hieroglyphic script on papyrus scrolls. Unfortunately, most of these works have been lost through the ravages of time: decay and erosion, vandalism, religious and political cleansing, and looting. Fortunately, Egypt's dry climate has helped to preserve some of these structures, artifacts, and scripts. Archeologists and scholars have analyzed surviving material to construct political, social, economic, and technological models of life in ancient Egypt.

The scripts and artifacts related directly to astronomy are scarce and often fragmentary. Most of our knowledge of Egyptian astronomy is derived from about two-dozen sources, as summarized by von Bombhard (1999). The available evidence suggests that Egyptian astronomical knowledge was based on relatively simple, but systematic observations. Much of this knowledge was integrated into the social and religious life of ancient Egypt.

The Geographical Setting

The Egyptian civilization flourished along the Nile River valley. The Nile and its tributaries form one of the world's longest river systems. However, it is the last 1200 km, from the first cataract at Aswan (24°N) to the Nile delta (31°N) that formed the heart of ancient Egypt. In this region, the Nile flows basically from south to north. Annual floods of the Nile brought sediments from the interior of Africa that left fertile mud flats for farming along the valley and across the Nile delta. The surface of the Nile provided a natural highway from one end of Egypt to the other. Prevailing winds drove sailboats towards the south, while river currents carried boats north again.

The annual flooding of the Nile was a major event in Egypt, until the construction of the Aswan dam across the Nile in 1970. Monsoon winds from the Atlantic swept across Africa in early spring and deposited vast amounts of water in the mountains of Ethiopia. This water collected in the headwaters of the Nile and by midsummer floods began in the Nile valley. In a typical year, the flood crested about eight metres above the low water mark

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[1] *Starry Night* is a computer program produced by Imaginova Canada Ltd., `www.starrynight.com`.

[2] Such as those included in *Astronomical Algorithms,* by J. Meeus, 1991.

as it flowed by Cairo in late August. Typically, the flooding lasted through September (James 1979).

The Political Background

The economy of Egypt was based on agriculture and new wealth gained through trading and conquest in Nubia to the south, and in Palestine and Syria in the northeast. Pre-dynastic Egypt consisted of the separate states of Upper Egypt (south) and Lower Egypt (north). The earliest records suggest that Upper and Lower Egypt were first united about 3050 BC under the rule of King Narmer. The politics during the next 3000 years did not flow smoothly. There were palace intrigues with new dynasties replacing the old approximately once every 100 years. There were internal revolts and invasions from without. However, a religious social class and the temple complexes they administered were more stable, and many survived for thousands of years, such as those at Aswan, Thebes, and Heliopolis.

The Religious Background

> "...the world began as a watery chaos called *Nun,* from which the Sun-god *Ra* emerged on a mound. By his own power he engendered the twin deities *Shu* [air] and *Tefnut* [moisture], who in turn bore *Geb* [earth] and *Nut* [sky]. *Geb* and *Nut* finally produced *Osiris* [god of the underworld], *Isis* [wife of Osiris and mother of *Horus*] and *Seth* [brother of *Osiris* and god of violence], and *Nephthys* [sister of *Isis*]. ...the universe [is] represented as a figure of the air-god *Shu* standing and supporting with his hands the outstretched body of the sky-goddess *Nut,* with *Geb* the earth-god lying at his feet" (James 1979, p. 145)[3].

The religious beliefs and practices of ancient Egypt were complex, and varied from place to place, and from one era to another. The following concepts were usually involved:

- a pantheon of gods led by *Ra,* the powerful Sun god, was represented by celestial objects,
- cycles of birth and death were represented by the rising of celestial objects in the east and the setting of celestial objects in the west,
- it was possible for mortal souls to join the gods among the stars,
- the gods followed a perilous nightly journey through the underworld, or *Duat,* from the region of death at the western horizon towards the region of rebirth at the eastern horizon.

Some Basic Concepts in Egyptian Astronomy

The association of celestial objects with gods, and the cyclic behaviour of celestial objects, formed the basis for Egyptian astronomy.

- The Egyptians preferred to make observations on the eastern horizon, the region of rebirth.
- The year was divided into three seasons based on the activity of the Nile river: four months of inundation, four months of planting and growth, and four months of harvest.
- Ancient calendars were based on the cycles of the Moon and were used to determine the dates of important festivals and to determine dates within a particular annual cycle. Historical dates were defined by the number of the year in the reign of the current Pharaoh.
- The heliacal rise[4] of Sirius in July was an important annual event. It marked the beginning of another cycle in the flooding of the Nile.

Simulations with Starry Night

The specific procedures for using the *Starry Night* program to create each of the following simulations are provided in the appendix.

Simulation I: *Nut* and the Birth of *Ra*

One of the oldest Egyptian myths describes the beginning of *Nut's* pregnancy at the vernal equinox and rebirth of *Ra* at the winter solstice. Wells (1996) contends that this myth has an astronomical foundation. *Nut,* the sky goddess, is associated with the Milky Way. At the vernal equinox, the Egyptians would have seen *Ra* set in the west and as the sky darkened, the mouth of *Nut* would be briefly visible before it followed *Ra* over the horizon. The consumption of *Ra* would have occurred below the horizon. Nine months later, near the winter solstice, the figure of *Nut* rises feet-first in the east a few hours before dawn, and as the Sun rises *Ra* is reborn. Wells also claims that this association was most pronounced at about 4500 BC, suggesting that this may be the date of origin for this myth.

The astronomical conditions related to this myth can be simulated using the steps provided in Simulation I, in the appendix. After following these steps, the western horizon is seen, just before sunset near the date of the vernal equinox in 3000 BC. The Sun can be seen near the intersection of the ecliptic and the celstial equator. The Milky Way forms the body of *Nut,* and the constellation of Gemini marks her mouth. At the vernal equinox her arms are stretched over her head towards the western horizon.

In the *Time Bar* step [forward] 10 minutes at a time to observe *Ra* setting in the west followed by the upturned mouth of *Nut.* Below the horizon, according to the myth, *Nut* swallowed *Ra* and was thus impregnated. To observe how this annual event changed over the centuries reset the time to 6:50 p.m. and change the date first to April 18, 3500 BC; then to April 22, 4000 BC; and finally to April 26, 4500 BC. As you move to vernal equinoxes further back in time, the Sun can be seen to move a little closer to Gemini just before sunset.

To view a simulation of the birth of *Ra* at a winter solstice shift the date to January 6, 2999 BC; set the time to 6:50 a.m.; and in the *Button Bar* switch the view to the East. Above the horizon at the left of your screen the figure of *Nut* can be seen rising feet first. The constellation of Cygnus marks the pelvic region. At the bottom right, the Sun is just below the horizon. Step [forward] 10 minutes at a time. The Egyptians would have seen the legs of *Nut* rising upward in the eastern sky, and then fade as *Ra* rose above the horizon a little further to the south.

To observe how the appearance of the celestial birth of *Ra* changed over the centuries: reset the date first to January 6, 3500 BC; then to January 6, 4000 BC; and finally to January 6, 4500 BC. At earlier winter solstices the legs of *Nut* can be seen to move to a more vertical position.

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[3] The italics and contents of the square brackets have been added for clarification and emphasis.

[4] The heliacal rising of a star is the annual date on which the star can first be seen again in the east, just before sunrise.

Assuming, as Wells explains, that the Egyptians had a flexible approach to the concept of insemination, then the Egyptian creation myth can be represented by correlations between the positions of the Milky Way and the Sun. The Egyptians saw *Ra* reborn in a yearly cycle, as well as in the daily cycle of night and day. There is some indication that the myth and astronomical events were more closely aligned at dates earlier than 3000 BC. However, on the basis of these simulations it would be difficult to assign a specific date for the origin of the myth.

Simulation II: Observing the Winter Solstice

In theory, determining the date of a winter solstice from horizon measurements is a simple procedure. All you need is a fixed observation post, a level wall facing east, and an assistant. To make an observation, you ask your assistant to move a marker along the top of the wall until it corresponds with the position of the rising Sun. When the day arrives that the southernmost position of the marker has been reached, you have determined the date of the winter solstice. The date of an ancient Egyptian winter solstice can be determined in a similar manner by observing the simulated sunrise on successive mornings.

Follow these steps to become familiar with the Sun's annual motion along the eastern horizon:

- Use the setup procedure outlined in Simulation II in the appendix.
- Play time [forward] in the *Time Bar* to observe a time-lapse movie showing the rising Sun on successive days, on the eastern horizon at Thebes during 3000 BC.
- Watch the movie through the equivalent of several years as the Sun cycles from north to south, and back again. With the time set at 6:00 a.m. each day, the Sun also cycles above the horizon during the longer summer days and below the horizon during the shorter winter days, as the Earth follows its elliptical orbit around the Sun. Combining these two motions, the Sun's position traces out the shape of an analemma on the celestial sphere.
- Note also that the Sun rises due east about the time of the equinoxes.

The date of an ancient winter solstice can be determined as follows:

- [Stop] the action as the Sun approaches its southernmost position.
- From the *Time Bar* select *Sunrise*, point at the Sun, push [control], and record the Sun's azimuth.
- [Step forward] another day, select Sunrise and record the Sun's azimuth again.
- Repeat this process, day-by-day until the Sun's azimuth reaches a maximum value for that year.

For the year 3000 BC, this procedure leads to January 5 as the likely date for the winter solstice.

Notice that near the date of the solstice, the azimuth angle of the Sun changes less than 0.01° a day. An Egyptian priest might have anticipated the date of the winter solstice and announced it on a given day, but observationally the priest would have been unable to confirm that the winter solstice had been reached until several days after the event had occurred. Also notice that this is a YES/NO observation; a priest would either declare that the Sun had risen at its southernmost position on a given day, or that it had not. In the above simulation, there is no attempt to determine the hour of the day when the solstice was reached. If the Egyptians had counted the number of days between successive winter solstices they could have estimated the length of the year to be approximately 365 days. However, since it is difficult to determine the precise day of a solstice with this technique, there would have been some uncertainty associated with this estimate.

Using horizon measurements to determine the date of a solstice contains a systematic factor involving the latitude of the observer. At the latitude of Luxor, 26°N, the date of a winter solstice obtained using horizon measurements is about seven days earlier than the date of the true solstice.

Pebble-in-a-Jar Technique

Counting the number of days between celestial events would have required a procedure for recording dates and the counts of days. A pebble-in-a-jar technique is proposed as one of the simplest possible counting procedures. Using this technique, an Egyptian priest would have placed a pebble in an empty jar on the day an event, such as a winter solstice, was observed. A pebble would be added each day until the next occurrence of the event. The jar would be labeled with a date such as "year 5 in the reign of Cheop." Counting the number of pebbles in the jar would have provided a measure of the length of time between the events. Saving the jar of pebbles would preserve the count for future reference. If pebble-in-a-jar counts were continued for tens, or even hundreds, of years, the results could be averaged to obtain a more accurate estimate of the number of days between celestial events. This type of averaging would be very effective since observing errors would tend to cancel rather than accumulate over time.

Lunar Calendars

> "Like all ancient peoples, the proto-dynastic Egyptians used a lunar calendar, but unlike their neighbours they began their lunar month, not with the first appearance of the new crescent in the west at sunset, but rather with the morning when the old crescent of the waning moon could no longer be seen just before sunrise in the east" (Parker 1974, p. 52)

The lunar year consisted of 12 lunar months. Since 12 lunar months average just 354 days, at two-or-three-year intervals an extra month was inserted to keep the seasons and feasts in place. Evidence for this type of calendar suggests that it was in use in Egypt before 3000 BC.

The Lunar Calendar in Upper Egypt

In Upper Egypt, the annual flood of the Nile was regarded as the most vital natural event and the helical rising of Sirius was used to regulate the insertion of the extra lunar month. The twelfth month was named for the rising of Sirius. Whenever the heliacal rising of Sirius occurred during the last 11 days of its month, an extra month was added to the year. The cult centre for Sirius was on the island of Elephantine, near the first cataract of the Nile at Aswan.

The Lunar Calendar in Lower Egypt

The ancient lunar calendar in Lower Egypt was keyed to the ceremony celebrating the rebirth of *Ra*, at the winter solstice. The chief cult centre for *Ra* was established at Heliopolis, just north of modern Cairo. (Wells 1996, p. 34)

Simulation III: The Beginning of the Lunar Month

The Egyptians marked the beginning of the lunar month on the morning when the old crescent of the waning moon could no longer be seen in the east, just before sunrise. This moment might be considered the beginning of the regular celestial union of the Sun and the Moon before the start of the next lunar cycle.

The observational task of the Egyptians was straightforward: "On this day, is the Moon observable before sunrise, or not?" Each morning, the waning Moon moves closer to the Sun, has a narrower crescent, and is more likely to be lost in the glare of the Sun. The optimal condition for viewing the last remnant of the waning Moon occurs when the Moon is just above the eastern horizon, with the Sun just below the horizon. Morning civil twilight lasts until the Sun is within 6° of the horizon (*Observer's Handbook 2004,* p. 113). A typical celestial object needs to be at least 5° above the horizon to be visible (Schafer 2000). A difference in altitude of 11° between the Sun and the Moon corresponds to a lunar illumination of about 2% and occurs about 1.5 days before a new Moon. For the purpose of this simulation, the beginning of a new lunar month is declared on the first morning that the separation between the altitudes of the Sun and the waning Moon falls below 11°. Since the Moon moves about 12° a day relative to the Sun, this date can be clearly defined on most occasions. Choosing an altitude-separation standard of 11° facilitates the search for simulated dates for the beginning of Egyptian lunar months. The only ambiguity occurs when the difference in altitudes is close to 11° just before sunrise. If the actual Egyptian altitude-separation standard was the equivalent of a few degrees larger or smaller, then for ambiguous cases, their dates would have tended to be one day earlier, or one day later.

Refer to the setup for Simulation III in the appendix. Check the altitude[5] of the Sun and Moon for January 27, 3000 BC at 8:20 a.m. Would a new lunar month begin on this day, the previous day, or the next day? To answer that question, [Step forward] in time until the Sun is just more than 6° below the horizon. If at that moment the altitude of the Moon is more than 5°, then the new lunar month has not yet begun. Continue to advance the date by one day and repeat the altitude checks. In this case, the Moon is just outside the 11° altitude-separation standard on January 29, but is clearly inside it on January 30. In this simulation, the new lunar month would have begun on January 30.

Skip ahead 28 days to February 27, 3000 BC and determine the date for the beginning of the next lunar month. You may have to step forward or backward a day or two. And you may have to run Time [forward], or [backward], a few minutes until the Sun is just more than 6° below the horizon.

The Egyptians could have estimated the average length of the lunar cycle using the pebble-in-a-jar technique and then averaged the results over a number of cycles. Again, any errors would tend to cancel out rather than accumulate.

Simulation IV: The 25-Year Lunar Cycle

The Egyptians made systematic lunar observations over extended periods of time and discovered an intriguing 25-year lunar cycle. From modern observations it is known that one lunar cycle lasts 29.530,589 days (*Observer's Handbook 2004,* p. 28). Multiplying, one finds that 309 lunar cycles last 9124.952 days. If it is assumed that a solar year has exactly 365 days, then 25 solar years consist of 9125.000 days. The difference between 309 lunar cycles and 25 solar cycles of 365 days is less than an hour and ten minutes. This means that every 25 years the Moon will be in the same phase, at the same time of day, on the same day of the year, in the same part of the sky, with the same stellar background!

One might think that extensive observations would be required to detect such a cycle. However, the observations the Egyptians made to detect the beginning of a new lunar month provided most of the needed information. The last remnant of a waning Moon fixes the phase, the moment before sunrise fixes the time of day, the eastern horizon fixes the location in the sky. The only extra information needed is the day of the year on which a new Moon occurs, within a 365-day calendar. There is clear evidence that the Egyptians used a 365-day calendar for civil functions (Depuydt 1997). The Egyptian year also included a number of annual festivals. Suppose that during one year a particular festival happened to occur on the same day as a new Moon, and that this coincidence was recorded. The next year, on the day of the same festival there would not be another new Moon. Nor would there be the next year, nor the next year after that. But 25 years later, there would again be a new Moon on the same day as the original festival. If records were kept for more than 25 years, then it would have been possible for an astute ancient Egyptian archivist to discover that a new Moon had also occurred on the same day in the calendar, 25 years previously. With a little more research the archivist would have discovered a 25-year cycle for new Moons at other festivals. One can try to imagine the excitement that would have accompanied this discovery of a new 25-year cycle, within the other celestial cycles of the gods.

The setup for Simulation IV is provided in the appendix. The date of January 30, 3000 BC has been chosen to display the beginning of a new lunar month. Note that the Moon is in the constellation of Aquarius. To test the reality of the 25-year cycle, advance the Julian Day by 9125 days (from JD 625701.68055 to JD 634826.68055)[6]. After this jump in time, note that the Sun and the Moon are still in essentially the same positions. You can use the *Forward* and *Back* buttons at the left of the *Button Bar* to cycle back and forth between these two dates. The 25-year cycle is impressive, but not perfect. Each time that you jump forward or backward 9125 days, the stellar background does shift a few degrees.

Summary

The four simulations described above provide insights into possible ancient astronomical practices. In Simulation I, the myth of *Nut* and the annual rebirth of *Ra* was illustrated using the annual motion of the Milky Way across the sky. The simulation can also be used to

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[5] An accurate measure of the altitude of an object can be found by placing the cursor on the object, and pushing the [control] key. The difference in altitude between two objects can be estimated using the *angle separation* cursor.

[6] 0.68055 is the fraction of a day that corresponds to 7:20 a.m. in Egypt.

examine Wells' contention that this myth originated about 4500 BC. Egyptian observations of solar and lunar cycles were probably based on simple YES/NO observations. In Simulation II, the counting of whole days between winter solstices, and the averaging of results over several years, would have led to an estimate of 365 days for a solar year. Simulations III and IV illustrate how Egyptian observations of the new Moon, combined with records of feast days over several decades, could have led to the discovery of a 25-year lunar cycle, within a 365-day calendar system.

If you have access to a planetarium program such as *Starry Night,* you are encouraged to work though these simulations. Take your time. Repeat a simulation several times and experiment with variations. Try to visualize yourself observing the crisp desert sky in ancient Egypt while pondering the cycles within cycles that were created at the beginning of time.

Part II includes simulations of the heliacal rise of Sirius, and of measuring the hours of the night with the "decans."

Appendix

The *Starry Night Pro 5.0* program used in these simulations has many options that let users customize its features. The options suggested below have been selected to facilitate investigations of the astronomy of ancient Egypt. Similar options can be implemented with other planetarium programs. In *Starry Night,* the *Tool Bar* refers to the uppermost horizontal tool bar. Just below that is the *Time Bar.* The *Button Bar* is a third tool bar that can be displayed just under the *Time Bar.* The *Side Pane* is a vertical set of option menus that can be accessed down the left side of the screen.

General Settings for Simulations in Ancient Egypt

From the *Tool Bar* select:

- File > Preferences > Number Formats: Change all the positional angles to dd.ddd° format to simplify the comparison of angle sizes.
- File > Preferences > Cursor Tracking: Check *Show info in upper* left and *When the control key is down.* These choices will minimize unwanted pop-up information. If do you point at an object with the cursor and at the same time push the [control] key, a listing of that object's properties are shown in the upper left of the screen. This information includes the object's altitude and azimuth.

View: Check *Hide Horizon.*

View > Alt/Az Guides > Options: Check *Local equator (horizon line)* and set the colour to red. Check *Background grid,* set the colour to pink and the Spacing to *Medium* (the altitude grid lines are then 20° apart, starting at ± 10°).

View > Celestial Guides > Options: Check *Celestial equator* and set the colour to green. Do not check any other items.

View > Ecliptic Guides > Options: Check *The Ecliptic* and set the colour to blue. Do not check any other items.

View > Solar System: Check *Planets-Moons.*

View: Select *Show Button Bar* and then select *E* for East.

Options > Viewing Location > Latitude/Longitude: Set Latitude to 26°N, Longitude to 33°E, Time Zone to +3h, and DST off. Then *Add Location to List as Thebes, Egypt.*

Options > Viewing Location > List: Select *Thebes* and push *Set Location.*

From the *Time Bar* select:

- The *Hand* tool and use it to move the red horizon line so that it is about a third of the way up the screen.
- Set the *Time and Date* to 6:00 a.m., January 1, 3000 BC.
- Set the *Time Flow Rate* to 1 minute.

Under File > Save as => Save all the above settings as ANCIENT EGYPT.

Simulation I: *Nut* and the Birth of the Sun

Open the file for ANCIENT EGYPT.
From the *Tool Bar* select:

- Options > Stars > Milky Way: Set the brightness to maximum and select *Visible Spectrum* for a realistic portrayal of the Milky Way. Selecting *Molecular Hydrogen* will make it easier to locate the Milky Way, but the correlation with the figure of *Nut* is made more obscure.

From the *Button Bar* select: Constellations.
In the Time Bar:

- Set the *Time and Date* to 6:50 p.m., April 15, 3000 BC (close to the vernal equinox). Note that at the time of the equinox the Sun is at the intersection of the green celestial equator and the blue ecliptic plane.
- Set the *Time Flow Rate* to 10 minutes.

Simulation II: Observing the Winter Solstice

Open the file for ANCIENT EGYPT.
In the *Time Bar* set the *Time Flow Rate* to 1 day.

Simulation III: The Beginning of the Lunar Month

Open the file for ANCIENT EGYPT.
In the *Tool Bar:* View > Solar System: Select *Planets-Moons.*
In the *Side Panel:* Find: the Moon. This step labels the Moon and makes the new Moon much easier to locate.
In the Time Bar:

- Set the *Time and Date* to January 27, 3000 BC at 7:00 a.m.
- Set the *Time Flow Rate* to 1 minute.

Use the *Hand* cursor to raise the horizon to about a third of the way up from the bottom.

Simulation IV: The 25-Year Lunar Cycle

Repeat the setup for Simulation III, but set the Date to January 30, 3000 BC and from the *Button Bar* select: Constellations.

Note that at the right of the *Time and Date* window there is a pop-up menu with an item *Set Julian Day*. Selecting this item allows the user to change the Julian Day . Changing the Julian Day[7] produces corresponding changes in the *Time and Date* window.

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[7] See the *Observer's Handbook 2004,* p. 52, for a definition of Julian Dates.

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