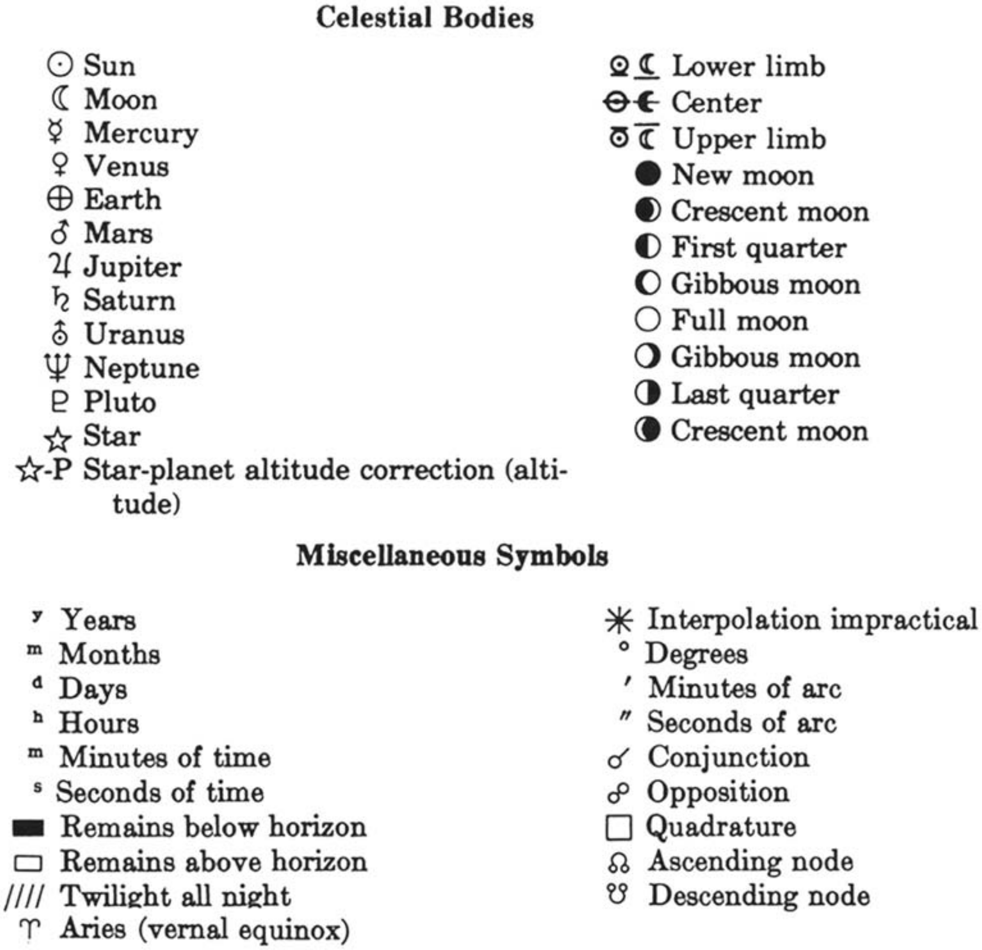
CHAPTER 13

NAVIGATIONAL ASTRONOMY

PRELIMINARY CONSIDERATIONS

1300. Definitions

The science of Astronomy studies the positions and motions of celestial bodies and seeks to understand and explain their physical properties. Navigational astronomy deals with their coordinates, time, and motions. The symbols commonly recognized in navigational astronomy are given in Table 1300.



Celestial Bodies

☉	Sun
☾	Moon
☿	Mercury
♀	Venus
⊕	Earth
♂	Mars
♃	Jupiter
♄	Saturn
♅	Uranus
♆	Neptune
♇	Pluto
☆	Star
☆-P	Star-planet altitude correction (altitude)
$\underline{☉}$ $\underline{☾}$	Lower limb
⊖ ☾	Center
$\overline{☉}$ $\overline{☾}$	Upper limb
●	New moon
◐	Crescent moon
◐	First quarter
◐	Gibbous moon
○	Full moon
◑	Gibbous moon
◑	Last quarter
◑	Crescent moon

Miscellaneous Symbols

y	Years
m	Months
d	Days
h	Hours
m	Minutes of time
s	Seconds of time
▬	Remains below horizon
▭	Remains above horizon
////	Twilight all night
♈	Aries (vernal equinox)
✳	Interpolation impractical
°	Degrees
′	Minutes of arc
″	Seconds of arc
☌	Conjunction
☍	Opposition
□	Quadrature
☊	Ascending node
☋	Descending node

Table 1300. Astronomical symbols.

1301. The Celestial Sphere

Looking at the sky on a dark night, imagine that celestial bodies are located on the inner surface of a vast, Earth-centered sphere (see Figure 1301). This model is useful since we are only interested in the relative positions and motions of celestial bodies on this imaginary surface. Understanding the concept of the celestial sphere is most important when discussing sight reduction in Chapter 19.

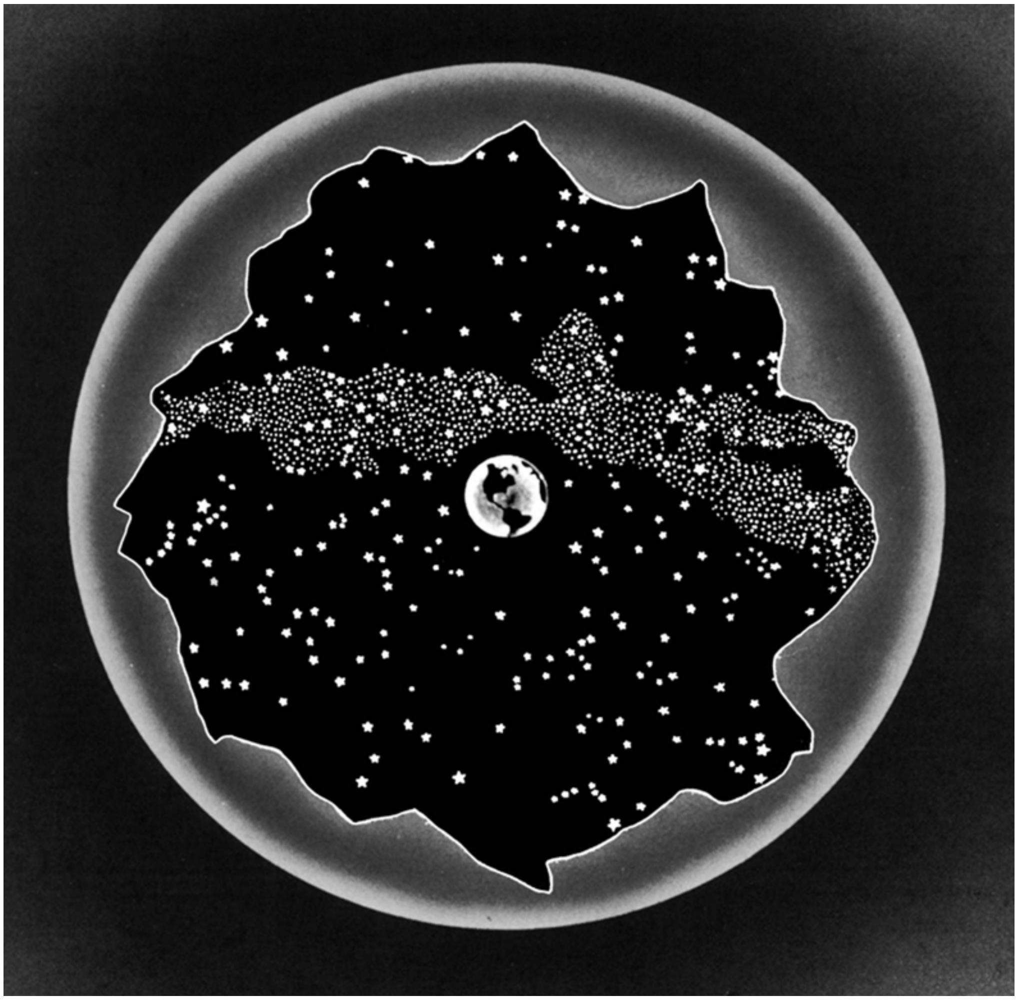


Figure 1301. The celestial sphere.

1302. Relative and Apparent Motion

Celestial bodies are in constant motion. There is no fixed position in space from which one can observe absolute motion. Since all motion is relative, the position of the observer must be noted when discussing planetary motion. From the Earth we see apparent motions of celestial bodies on the celestial sphere. In considering how planets follow their orbits around the Sun, we assume a hypothetical observer at some distant point in space. When discussing the rising or setting of a body on a local horizon, we must locate the observer at a particular point on the Earth because the setting Sun for one observer may be the rising Sun for another.

Apparent motion on the celestial sphere results from the motions in space of both the celestial body and the Earth. Without special instruments, motions toward and away from the Earth cannot be discerned.

1303. Astronomical Distances

We can consider the celestial sphere as having an infinite radius because distances between celestial bodies are so vast. For an example in scale, if the Earth were represented by a ball one inch in diameter, the Moon would be a ball one-fourth inch in diameter at a distance of 30 inches, the Sun would be a ball nine feet in diameter at a distance of nearly a fifth of a mile, and Pluto would be a ball half an inch in diameter at a distance of about seven miles. The nearest star would be one-fifth of the actual distance to the Moon.

Because of the size of celestial distances, it is inconvenient to measure them in common units such as the mile or kilometer. The mean distance to our nearest neighbor, the Moon, is 238,855 miles. For convenience this distance is sometimes expressed in units of the equatorial radius of the Earth: 60.27 Earth radii.

Distances between the planets are usually expressed in terms of the **astronomical unit (au)**, which closely corresponds to the average distance between the Earth and the

Sun. This is approximately 92,960,000 miles. Thus the mean distance of the Earth from the Sun is 1 au. The mean distance of the dwarf planet Pluto is about 39.5 au. Expressed in astronomical units, the mean distance from the Earth to the Moon is 0.00257 au.

Distances to the stars require another leap in units. A commonly-used unit is the **light-year**, the distance light travels in one year. Since the speed of light is about 1.86 ´ 10^5 miles per second and there are about 3.16 ´ 10^7 seconds per year, the length of one light-year is about 5.88 ´ 10^{12} miles. The nearest stars, Alpha Centauri and its neighbor Proxima, are 4.3 light-years away. Relatively few stars are less than 100 light-years away. The nearest galaxy of comparable size to our own Milky Way is the Andromeda Galaxy, at a distance of about 2.5 million light years. The most distant galaxies observed by astronomers are 13 billion light years away, just at the edge of the visible universe.

1304. Magnitude

The relative brightness of celestial bodies is indicated by a scale of stellar **magnitudes**. Initially, astronomers divided the stars into 6 groups according to brightness. The 20 brightest were classified as of the first magnitude, and the dimmest were of the sixth magnitude. In modern times, when it became desirable to define more precisely the limits of magnitude, a first magnitude star was considered 100 times brighter than one of the sixth magnitude. Since the fifth root of 100 is 2.512, this number is considered the **magnitude ratio**. A first magnitude star is 2.512 times as bright as a second magnitude star, which is 2.512 times as bright as a third magnitude star,. A second magnitude is 2.512 ´ 2.512 = 6.310 times as bright as a fourth magnitude star. A first magnitude star is 2.512^{20} times as bright as a star of the 21st magnitude, the dimmest that can be seen through a 200-inch telescope. It is important to note the higher the magnitude, the dimmer the object.

Stars vary in color; i.e., some are more red than others. Therefore, the brightness of a star is a function of what "detector" is being used. For example, stars that are more red than others appear brighter using a detector that is most sensitive in red wavelengths. Thus, it is common when defining magnitudes to include an idea of the detector. For navigation, most magnitudes are described as "visual", or how the object would look to the unaided eye, but sometimes you will see other magnitude bands. If no band is given assume that the magnitude is visual.

Brightness is normally tabulated to the nearest 0.1 magnitude, about the smallest change that can be detected by the unaided eye of a trained observer. All stars of magnitude 1.50 or brighter are popularly called "first magnitude" stars. Those between 1.51 and 2.50 are called "second magnitude" stars, those between 2.51 and 3.50 are called "third magnitude" stars, etc. Sirius, the brightest star, has a magnitude of –1.6. The only other star with a negative magnitude is Canopus, –0.9. At greatest brilliance Venus has a magnitude of about –4.4. Mars, Jupiter, and Saturn are sometimes of negative magnitude. The full Moon has a magnitude of about –12.7, but varies somewhat. The magnitude of the Sun is about –26.7.

THE UNIVERSE

1305. The Solar System

The Sun, the most conspicuous celestial object in the sky, is the central body of the solar system. Associated with it are eight planets, five dwarf planets like Pluto, and thousands of asteroids, comets, and meteors. All planets other than Mercury and Venus have moons.

1306. Motions of Bodies of the Solar System

Astronomers distinguish between two principal motions of celestial bodies. **Rotation** is a spinning motion about an axis within the body, whereas **revolution** is the motion of a body in its orbit around another body. The body around which a celestial object revolves is known as that body's **primary**. For the moons (satellites), the primary is a planet. For the planets, the primary is the Sun. The entire solar system is held together by the gravitational force of the Sun. The whole system revolves around the center of the Milky Way galaxy and the Milky Way is in motion relative to its neighboring galaxies.

The hierarchies of motions in the universe are caused by the force of gravity. As a result of gravity, bodies attract each other in proportion to their masses and to the inverse square of the distances between them. This force causes the planets to go around the sun in nearly circular, elliptical orbits.

The laws governing the motions of planets in their orbits were discovered by Johannes Kepler, and are now known as **Kepler's laws**:

1. The orbits of the planets are ellipses, with the sun at the common focus.
2. The straight line joining the sun and a planet (the **radius vector**) sweeps over equal areas in equal intervals of time.
3. The squares of the sidereal periods of any two planets are proportional to the cubes of their mean distances from the sun.

In 1687 Isaac Newton stated three "laws of motion," which he believed were applicable to the planets. **Newton's laws of motion** are:

1. Every body continues in a state of rest or of uniform motion in a straight line unless acted upon by an external force.
2. When a body is acted upon by an external force, its acceleration is directly proportional to that force, and inversely proportional to the mass of the body, and acceleration take place in the direction in which the force acts.
3. To every action there is an equal and opposite reaction.

Newton also stated a single **universal law of gravitation**, which he believed applied to all bodies, although it was based upon observations with the solar system only:

Every particle of matter attracts every other particle with a force that varies directly as the product of their masses and inversely as the square of the distance between them.

From these fundamental laws of motion and gravitation, Newton derived Kepler's empirical laws. He proved rigorously that the gravitational interaction between any two bodies results in an orbital motion of each body about the barycenter of the two masses that form a conic section, that is a circle, ellipse, parabola, or hyperbola.

Circular and parabolic orbits are unlikely to occur in nature because of the precise speeds required. Hyperbolic orbits are open, that is one body, due to is speed, recedes into space. Therefore, a planet's orbit must be elliptical as found by Kepler.

Both the sun and each body revolve about their common center of mass. Because of the preponderance of the mass of the sun over that of the individual planets, the common center of the sun and each planet except Jupiter lies with the sun. The common center of the combined mass of the solar system moves in and out of the sun.

The various laws governing the orbits of planets apply equally well to the orbit of any body with respect to its primary.

In each planet's orbit, the point nearest the Sun is called the **perihelion**. The point farthest from the Sun is called the **aphelion**. The line joining perihelion and aphelion is called the **line of apsides**. In the orbit of the Moon, the point nearest the Earth is called the **perigee**, and that point farthest from the Earth is called the **apogee**. Figure 1306 shows the orbit of the Earth (with exaggerated eccentricity), and the orbit of the Moon around the Earth.

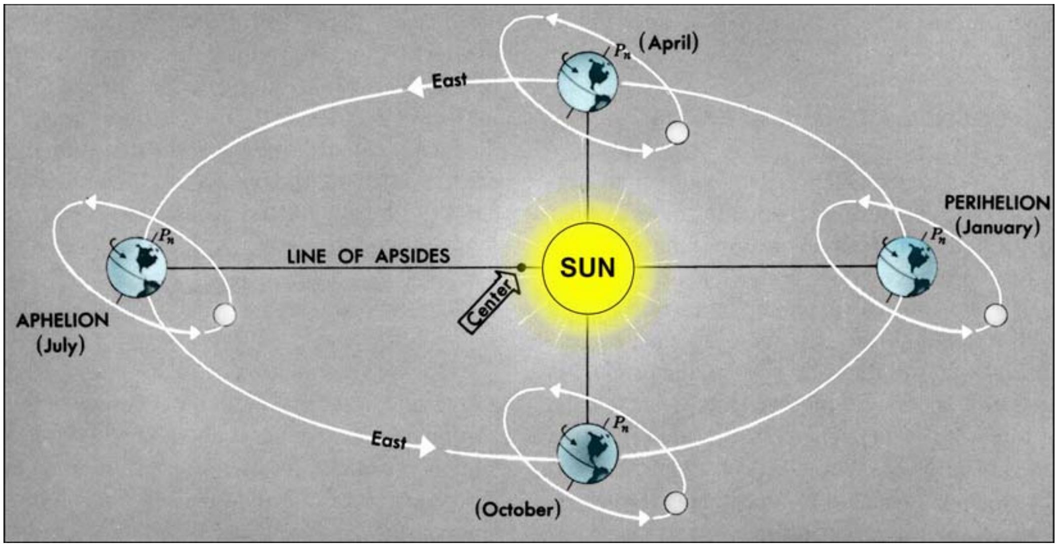


Figure 1306. Orbits of the Earth and Moon.

1307. The Sun

The Sun dominates our solar system. Its mass is nearly a thousand times that of all other bodies of the solar system combined. Its diameter is about 865,000 miles. Since it is a star, it generates its own energy through a thermonuclear reaction, thereby providing heat and light for the entire solar system.

The distance from the Earth to the Sun varies from 91,300,000 at perihelion to 94,500,000 miles at aphelion. When the Earth is at perihelion, which always occurs early in January, the Sun appears largest, 32.6' of arc in diameter. Six months later at aphelion, the Sun's apparent diameter is a minimum of 31.5'. Reductions of celestial navigation sights taken of the Sun's limb take this change of apparent size into account.

Observations of the Sun's surface (called the **photosphere**) reveal small dark areas called **sunspots**. These are areas of intense magnetic fields in which relatively cool gas (at 7000°F.) appears dark in contrast to the surrounding hotter gas (10,000°F.). Sunspots vary in size from perhaps 50,000 miles in diameter to the smallest spots that can be detected (a few hundred miles in diameter). They generally appear in groups. See Figure 1307.

Surrounding the photosphere is an outer **corona** of very hot but tenuous gas. This can only be seen during an eclipse of the Sun, when the Moon blocks the light of the photosphere.

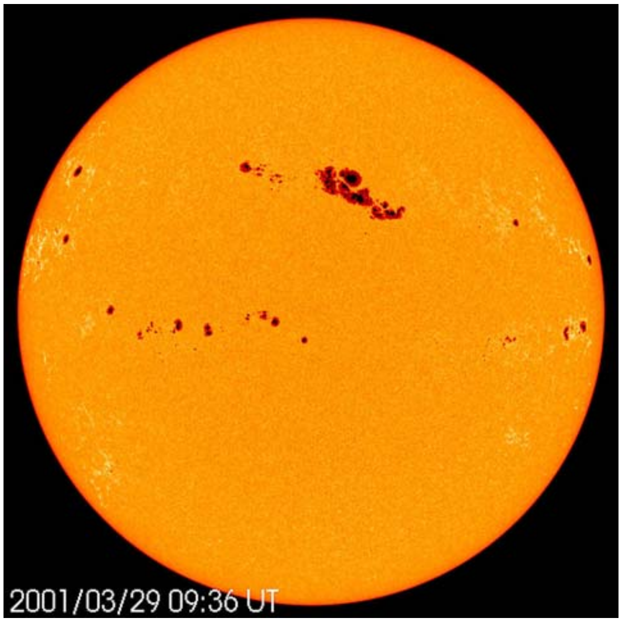


Figure 1307. The huge sunspot group observed on March 30, 2001 spanned an area 13 times the entire surface of the Earth. Courtesy of SOHO, a project of international cooperation between ESA and NASA.

The Sun is continuously emitting charged particles, which form the **solar wind**. As the solar wind sweeps past the Earth, these particles interact with the Earth's magnetic field. If the solar wind is particularly strong, the interaction can produce magnetic storms which adversely affect radio signals on the Earth and can interfere with satellite communications. At such times the **auroras** are particularly brilliant and widespread.

The Sun is moving approximately in the direction of Vega at about 12 miles per second, or about two- thirds as fast as the Earth moves in its orbit around the Sun.

1308. The Planets

The principal bodies orbiting the Sun are called **planets**. Eight planets are known; in order of their distance from the Sun, they are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Pluto, formerly considered a planet, is now classified as a dwarf planet. All of the planets revolve around the Sun in the same direction in nearly circular orbits. All of the planets are spherical or nearly so, all have regular rotation rates, and all shine by reflected sunlight. All except Mercury have substantial atmospheres. Only four of the planets are commonly used for celestial navigation: Venus, Mars, Jupiter, and Saturn.

The orbits of the planets lie in nearly the same plane as the Earth's orbit. Therefore, as seen from the Earth, the planets are confined to a strip of the celestial sphere near the **ecliptic**, which is the intersection of the mean plane of the Earth's orbit around the Sun with the celestial sphere. Except for Uranus and Neptune, the planets are bright enough to be easily seen by the unaided eye, although the brightness of each at any given time depends on its distance from the Earth and the fraction of the sunlit part observed.

Mercury and Venus, the two planets with orbits closer to the Sun than that of the Earth, are called **inferior planets**, and the others, with orbits farther from the Sun are called **superior planets**. The four planets nearest the Sun (Mercury through Mars) are called the inner planets, and the others (Jupiter through Neptune) are referred to as the outer planets. The outer planets are sometimes also called gas giants because they are so much larger than the others and have deep, dense atmospheres.

Planets can sometimes be identified in the sky by their appearance, because-unlike the stars-they do not twinkle. The stars are so distant that they are point sources of light. Therefore the stream of light from a star is easily disrupted by turbulence in the Earth's atmosphere, causing **scintillation** (the twinkling effect). The naked-eye planets, however, are close enough to present perceptible disks. The broader stream of light from a planet is not so easily disrupted.

The orbits of many thousands of minor planets, also called asteroids, lie chiefly between the orbits of Mars and Jupiter. These are all too faint to be seen without a telescope.

1309. The Earth

In common with other planets, the Earth **rotates** on its axis and **revolves** in its orbit around the Sun. These motions are the principal source of the daily apparent motions of other celestial bodies. The Earth's rotation also causes a deflection of water and air currents to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. Because of the Earth's rotation, high tides on the open sea lag behind the meridian transit of the Moon.

For most navigational purposes, the Earth can be considered a sphere. However, like the other planets, the Earth is approximately an **oblate spheroid**, or **ellipsoid of revolution**, flattened at the poles and bulged at the equator. See Figure 1309. Therefore, the polar diameter is less than the equatorial diameter, and the meridians are slightly elliptical, rather than circular. The dimensions of the Earth are recomputed from time to time, as additional and more precise measurements become available. Since the Earth is not exactly an ellipsoid, results differ slightly when equally precise and extensive measurements are made on different parts of the surface.

1310. Inferior Planets (Mercury and Venus)

The orbits of Mercury and Venus are closer to the Sun than the Earth's orbit, thus they always appear in the neighborhood of the Sun. Over a period of weeks or months, they appear to oscillate back and forth from one side of the Sun to the other.

They are seen either in the eastern sky before sunrise or in the western sky after sunset. For brief periods they disappear into the Sun's glare. At this time they are between the Earth and Sun (known as **inferior conjunction**) or on the opposite side of the Sun from the Earth (**superior conjunction**). On rare occasions at inferior conjunction, the planet will cross the face of the Sun as seen from the Earth. This is known as a **transit of the Sun**.

When Mercury or Venus appears most distant from the Sun in the evening sky, it is at greatest eastern elongation. (Although the planet is in the western sky, it is at its easternmost point from the Sun.) From night to night the planet will appear to approach the Sun until it disappears into the glare of twilight. At this time it is moving between the Earth and Sun to inferior conjunction. A few days later, the planet will appear in the morning sky at dawn. It will gradually appear to move away from the Sun to its greatest western elongation, then move back toward the Sun. After disappearing in the morning twilight, it will move behind the Sun to superior conjunction. After this it will reappear in the evening sky, heading toward eastern elongation, beginning the cycle again. See Figure 1310.

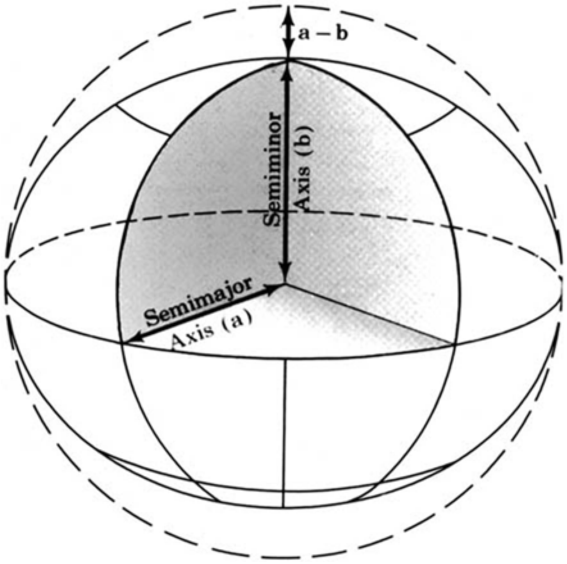


Figure 1309. Oblate spheroid or ellipsoid of revolution.

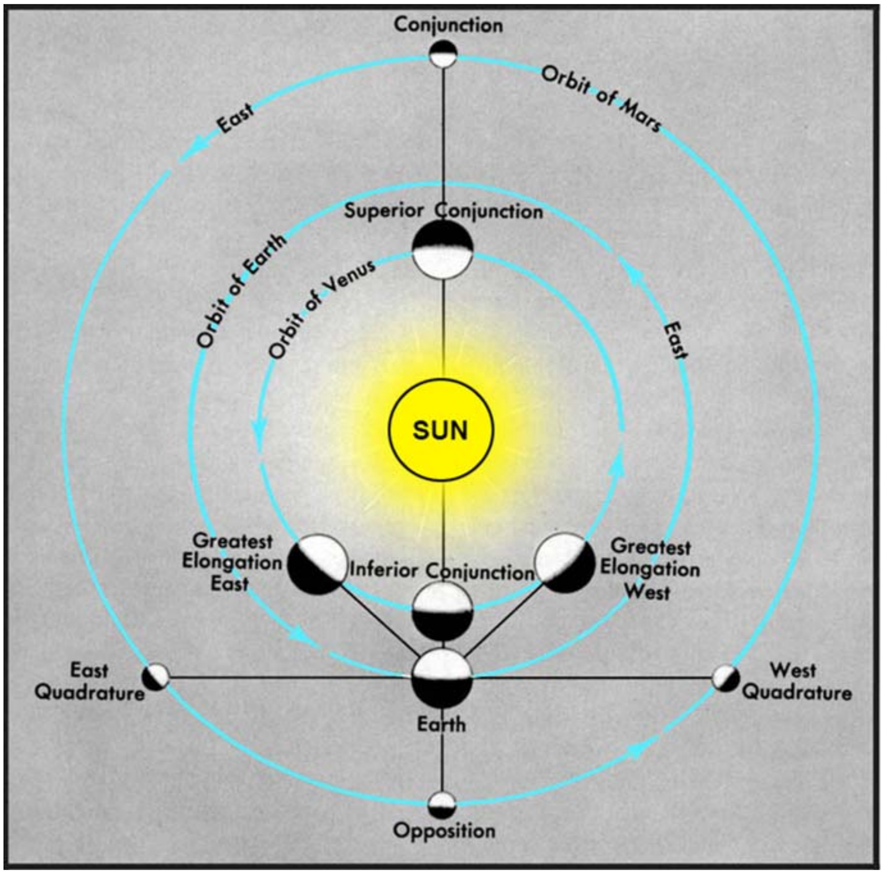


Figure 1310. Planetary configurations.

Mercury is never seen more than about 28° from the Sun. For this reason it is not commonly used for navigation. Near greatest elongation it appears near the western horizon after sunset or the eastern horizon before sunrise. At these times it resembles a first magnitude star and is sometimes reported as a new or strange object in the sky. The interval during which it appears as a morning or evening star can vary from about 30 to 50 days. Around inferior conjunction, Mercury is difficult to observe for about 5 days; near superior conjunction, it is as long as 35 days. Observed with a telescope, Mercury is seen to go through phases similar to those of the Moon.

Venus can reach a distance of 47° from the Sun, allowing it to dominate the morning or evening sky. At maximum brilliance, about five weeks before and after inferior conjunction, it has a magnitude of about –4.4 and is brighter than any other object in the sky except the Sun and Moon. At these times it can be seen during the day and is sometimes observed for a celestial line of position. It appears as a morning or evening "star" for approximately 263 days in succession. Near inferior conjunction Venus disappears for 8 days; around superior conjunction it disappears for 50 days. Through strong binoculars or a telescope, Venus can be seen to go through a full set of phases. This actually has the effect of offsetting Venus' center of light from its center of mass. Reductions of celestial navigation sights taken of Venus take this offset into account.

1311. Superior Planets (Mars, Jupiter, Saturn, Uranus, and Neptune)

All other planets besides Mercury and Venus have orbits further from the Sun than Earth's orbit; these are called superior planets. While Mercury and Venus never appear too far from the Sun, the superior planets are not confined to the proximity of the Sun as seen from the Earth. They can pass behind the Sun (**conjunction**), but they cannot pass between the Sun and the Earth. We see them move away from the Sun until they are opposite the Sun in the sky (**opposition**). When a superior planet is near conjunction, it rises and sets approximately with the Sun and is thus lost in the Sun's glare. Gradually it becomes visible in the early morning sky before sunrise. From day to day, it rises and sets earlier, becoming increasingly visible through the late night hours until dawn. At opposition, it will rise about when the Sun sets, be visible throughout the night, and set about when the Sun rises.

Observed against the background stars, the planets normally move eastward in what is called **direct motion**. Approaching opposition, however, a planet will slow down, pause (at a stationary point), and begin moving westward (**retrograde motion**), until it reaches the next stationary point and resumes its direct motion. This is not because the planet is moving strangely in space. This relative, observed motion results because the faster moving Earth is "catching up" with and "passing" by the slower moving superior planet.

The superior planets are brightest and closest to the Earth at opposition, when they are visible throughout the night. The interval between oppositions is known as the **synodic period**. This period is longest for the closest planet, Mars, and becomes increasingly shorter for the outer planets.

Unlike Mercury and Venus, the superior planets do not go through a full cycle of phases. They are always full or highly gibbous. With the exception of Mars, the offset between a superior planet's center of light from its center of mass (due to phase) does not need to be accounted for in traditional celestial navigation. Reductions of celestial navigation sights of Mars often take this offset into account.

Mars can usually be identified by its orange color. It can become as bright as magnitude –2.8 but is more often between –1.0 and –2.0 at opposition. Oppositions occur at intervals of about 780 days. The planet is visible for about 330 days on either side of opposition. Near conjunction it is lost from view for about 120 days. Its two satellites can only be seen in a large telescope.

Jupiter, largest of the known planets, normally outshines Mars, regularly reaching magnitude –2.0 or brighter at opposition. Oppositions occur at intervals of about 400 days, with the planet being visible for about 180 days before and after opposition. The planet disappears for about 32 days at conjunction. Four satellites (of a total 67 currently known) are bright enough to be seen with binoculars. Their motions around Jupiter can be observed over the course of several hours.

Saturn, the outermost of the navigational planets, comes to opposition at intervals of about 380 days. It is visible for about 175 days before and after opposition, and disappears for about 25 days near conjunction. At opposition it becomes as bright as magnitude +0.8 to –0.2. Through good, high powered binoculars, Saturn appears as elongated because of its system of rings. A telescope is needed to examine the rings in any detail. Saturn is now known to have at least 62 satellites, none of which are visible to the unaided eye.

Uranus, **Neptune** and the dwarf planet, **Pluto,** are too faint to be used for navigation; Uranus, at about magnitude 5.5, is faintly visible to the unaided eye.

1312. The Moon

The **Moon** is the only satellite of direct navigational interest. It revolves around the Earth once in about 27.3 days, as measured with respect to the stars. This is called the **sidereal month**. Because the Moon rotates on its axis with the same period with which it revolves around the Earth, the same side of the Moon is always turned toward the Earth. The cycle of phases depends on the Moon's revolution with respect to the Sun. This **synodic month** is approximately 29.53 days, but can vary from this average by up to a quarter of a day during any given month.

When the Moon is in conjunction with the Sun (new Moon), it rises and sets with the Sun and is lost in the Sun's glare. The Moon is always moving eastward at about 12.2° per day, so that sometime after conjunction (as little as 16 hours, or as long as two days), the thin lunar crescent can be observed after sunset, low in the west. For the next couple of weeks, the Moon will **wax**, becoming more fully illumi-

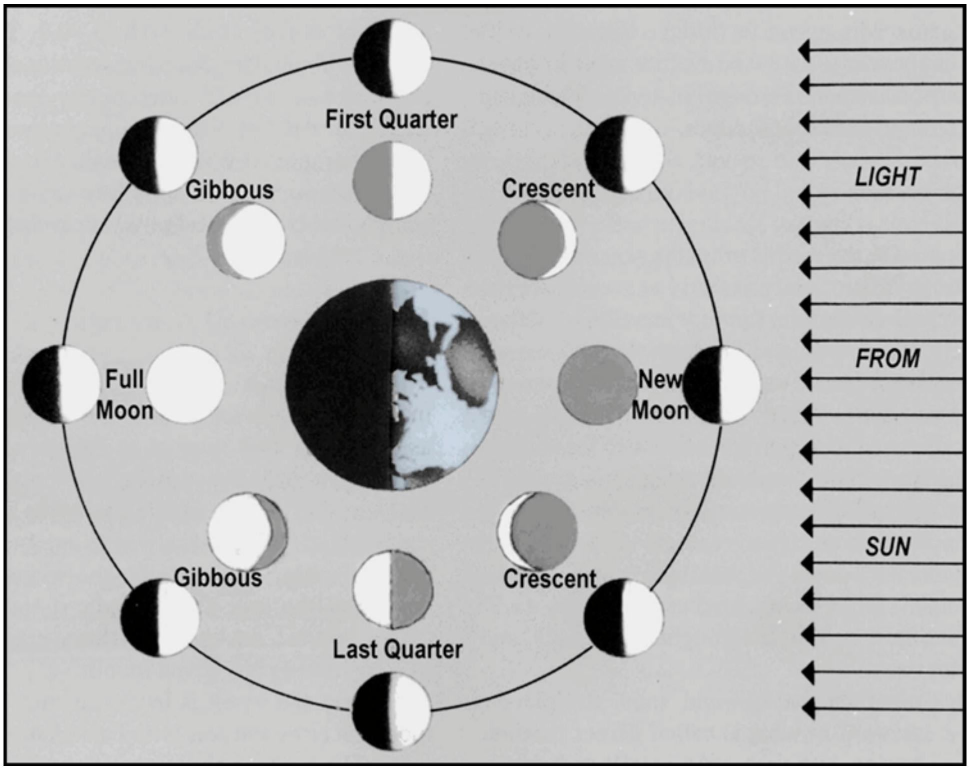


Figure 1312a. Phases of the Moon. The inner figures of the Moon represent its appearance from the Earth.

nated. From day to day, the Moon will rise (and set) later, becoming increasingly visible in the evening sky, until (about 7 days after new Moon) it reaches first quarter, when the Moon rises about noon and sets about midnight. Over the next week the Moon will rise later and later in the afternoon until full Moon, when it rises about sunset and dominates the sky throughout the night. During the next couple of weeks the Moon will **wane**, rising later and later at night. By last quarter (a week after full Moon), the Moon rises about midnight and sets at noon. As it approaches new Moon, the Moon becomes an increasingly thin crescent, and is seen only in the early morning sky. Sometime before conjunction (16 hours to 2 days before conjunction) the thin crescent will disappear in the glare of morning twilight.

At full Moon, the Sun and Moon are on opposite sides of the ecliptic. Therefore, in the winter the full Moon rises early, crosses the celestial meridian high in the sky, and sets late; as the Sun does in the summer. In the summer the full Moon rises in the southeastern part of the sky (Northern Hemisphere), remains relatively low in the sky, and sets along the southwestern horizon after a short time above the horizon.

At the time of the autumnal equinox, the part of the ecliptic opposite the Sun is most nearly parallel to the horizon. Since the eastward motion of the Moon is approximately along the ecliptic, the delay in the time of rising of the full Moon from night to night is less than at other times of the year. The full Moon nearest the autumnal equinox is called the **Harvest Moon**; the full Moon a month later is called the **Hunter's Moon**. See Figure 1312a for an image of the Phases of the Moon.

See Figure 1312b for a depiction of Earthrise from the surface of the moon.

Figure 1312b. Earthrise from the surface of the Moon. Image courtesy of NASA.

1313. Comets and Meteors

Although **comets** are noted as great spectacles of nature, very few are visible without a telescope. Those that become widely visible do so because they develop long, glowing tails. Comets consist of a solid, irregularly shaped nucleus, a few kilometers across, composed of rock and ice. As the nucleus approaches the Sun in its orbit, the ice evaporates and forms an atmosphere around the nucleus, called the coma, and the tail. The tail, which may eventually extend tens of millions of kilometers or more, consists of both gas and dust; the dust reflects sunlight while the gases fluoresce. The tail is driven away from the direction of the Sun by radiation pressure and solar wind. The tail is so thin that stars can easily be seen through it.

Compared to the well-ordered orbits of the planets, comets are erratic and inconsistent. Some travel east to west and some west to east, in highly eccentric orbits inclined at any angle to the ecliptic. Periods of revolution range from about 3 years to thousands of years. Some comets may speed away from the solar system after gaining velocity as they pass by Jupiter or Saturn.

Of the known comets in our solar system, Halley's comet is the most famous because it returns about every 75 years. Its appearance in 1910 was spectacular but its 1986 apparition was hardly noticed, especially in the northern hemisphere. It will return in 2061. Comet Hale-Bopp, easily visible from the northern hemisphere in the spring of 1997, is said to have been seen by more people than any other comet in history. Other recent bright comets include Comet Ikeya-Seki (1965), Comet West (1976), and Comet McNaught (2007), the last of which was most spectacular from the southern hemisphere.

The short-period comets long ago lost the gasses needed to form a tail. Long period comets, such as comet Hyakutake, are more likely to develop tails. See Figure 1313. The visibility of a comet depends very much on how close it approaches the Earth. Hyakutake's passage on March 25, 1996 was one of the closest cometary approaches of the previous 200 years.

The visibility of a comet depends very much on how close it approaches the Earth. In 1910, Halley's comet spread across the sky. Yet when it returned in 1986, the Earth was not well situated to get a good view, and it was barely visible to the unaided eye.

Meteors, popularly called **shooting stars**, are rocks or rock particles from space that fall toward the Earth and are heated to incandescence by air friction in the Earth's upper atmosphere. They are visible as streaks of light in the night sky that generally last no longer than a few seconds. The particles involved, called meteoroids, range in size from dust grains to boulders, with the former much more frequent than the latter. A particularly bright meteor is called a **fireball**. One that explodes is called a **bolide**. The rare meteoroid that survives its trip through the atmosphere and lands as a solid particle is called a **meteorite**.

Figure 1313. Comet Hyakutake made its closest approach to the Earth on March 25, 1996. Image courtesy of NASA.

Millions of meteors large enough to be seen enter the Earth's atmosphere each hour, and many times this number undoubtedly enter, but are too small to be seen. The cosmic dust they create constantly rains down on the Earth, tons per day. Meteors are seen more frequently in the pre-dawn hours than at other times of the night because the pre-dawn sky is on the leading side of the Earth as it moves along its orbit, where more meteoroid particles collect.

Meteor showers occur at certain times of the year when the Earth passes through **meteor swarms** (streams of meteoroid particles), the scattered remains of comets that have broken apart. At these times the number of meteors observed is many times the usual number.

A faint glow sometimes observed extending upward approximately along the ecliptic before sunrise and after sunset has been attributed to the reflection of sunlight from quantities of this material. This glow is called **zodiacal light**. A faint glow at that point of the ecliptic 180° from the Sun is called the **gegenschein** or **counterglow**.

1314. Stars

Stars are distant Suns, in many ways resembling our own. Like the Sun, stars are massive balls of gas that create their own energy through thermonuclear reactions.

Although stars differ in size and temperature, these differences are apparent only through analysis by astronomers. Some differences in color are noticeable to the unaided eye. While most stars appear white, some (those of lower temperature) have a reddish hue. Orion, blue Rigel and red Betelgeuse, located on opposite sides of the belt, constitute a noticeable contrast.

The stars are not distributed uniformly around the sky. Stars appearing in the same area of the sky can bring to mind patterns. Ancient peoples supplied star patterns with names and myths; today we call them **constellations**. Today professional astronomers recognize 88 "modern" constellations, used to identify areas of the sky.

Under ideal viewing conditions, the dimmest star that can be seen with the unaided eye is of the sixth magnitude. In the entire sky there are about 6,000 stars of this magnitude or brighter. Half of these are below the horizon at any time. Because of the greater absorption of light near the horizon, where the path of a ray travels for a greater distance through the atmosphere, not more than perhaps 2,500 stars are visible to the unaided eye at any time. However, the average navigator seldom uses more than perhaps 20 or 30 of the brighter stars.

Stars which exhibit a noticeable change of magnitude are called **variable stars**. A star which suddenly becomes several magnitudes brighter and then gradually fades is called a **nova**. A particularly bright nova is called a **supernova**. Supernovae that are visible to the unaided eye are very rare, occurring less than once per century on average.

Two stars which appear to be very close together are called a **double star system**. They may just lie in the same direction of the sky and not be physically related to each other. If they are gravitational bound to each other, they are known as a **binary star system**. The bright star Sirius is actually one component of a binary star system; the other component is too faint to be seen without a telescope. If more than two stars are included in a group, it is called a **multiple star system**.

A group of a few dozen to several hundred stars moving through space together is called an **open cluster**. The Pleiades is an example of an open cluster. There are also spherically symmetric clusters of hundreds of thousands of stars known as **globular clusters**. The globular clusters are all too distant to be seen with the naked eye.

A cloudy patch of matter in the heavens is called a **nebula**. If it is within the galaxy of which the Sun is a part, it is called a **galactic nebula**; if outside, it is called an **extragalactic nebula**.

Motion of a star through space can be classified by its vector components. That component in the line of sight is called **radial motion**, while that component across the line of sight, causing a star to change its apparent position relative to the background of more distant stars, is called **proper motion**.

1315. Galaxies

A **galaxy** is a vast collection of clusters of stars and clouds of gas. In many galaxies the stars tend to congregate in groups called **star clouds** arranged in long spiral arms. The spiral nature is believed due to matter density waves that propagate through the galaxy over time (Figure 1315).

Figure 1315. Spiral nebula Messier 51. Image courtesy of NASA.

The Earth is located in the Milky Way galaxy, a slowly spinning disk more than 100,000 light years in diameter. All the bright stars in the sky are in the Milky Way. However, the most dense portions of the galaxy are seen as the great, broad band that glows in the summer nighttime sky. When we look toward the constellation Sagittarius, we are looking toward the center of the Milky Way, 25,000 light years away.

Despite their size and luminance, almost all other galaxies are too far away to be seen with the unaided eye. An exception in the northern hemisphere is the Great Galaxy (sometimes called the Great Nebula) in Andromeda, which appears as a faint glow. In the southern hemisphere, the Large and Small Magellanic Clouds (named after Ferdinand Magellan) are the nearest known neighbors of the Milky Way. They are approximately 200,000 light years distant. The Magellanic Clouds can be seen as sizable glowing patches in the southern sky.

APPARENT MOTION

1316. Apparent Motion due to Rotation of the Earth

The **apparent motion** of the heavens arising from the Earth's rotation is much greater than other motions of celestial bodies. This motion causes celestial bodies to appear to rise along the eastern half of the horizon, climb to their maximum altitude as they cross the meridian, and set along the western horizon, at about the same point relative to due west as the rising point was to due east. This apparent motion of a body along the daily path, or **diurnal circle**, is approximately parallel to the plane of the equator. It would be exactly so if rotation of the Earth were the only motion and the axis of rotation of the Earth were stationary in space.

The apparent effect due to rotation of the Earth varies with the latitude of the observer. At the equator, where the equatorial plane is perpendicular to the horizon (since the axis of rotation of the Earth is parallel to the plane of the horizon), bodies appear to rise and set vertically. Every celestial body is above the horizon approximately half the time. The celestial sphere as seen by an observer at the equator is called the right sphere, shown in Figure 1316a.

For an observer at one of the poles, bodies having constant declination neither rise nor set, remaining parallel to the horizon (neglecting precession of the equinoxes and changes in refraction). They circle the sky, always at the same altitude, making one complete trip around the horizon each sidereal day (See Section 1611). At the North Pole the motion is clockwise, and at the South Pole it is counterclockwise. Approximately half the stars are always above the horizon and the other half never are. The parallel sphere at the poles is illustrated in Figure 1316b.

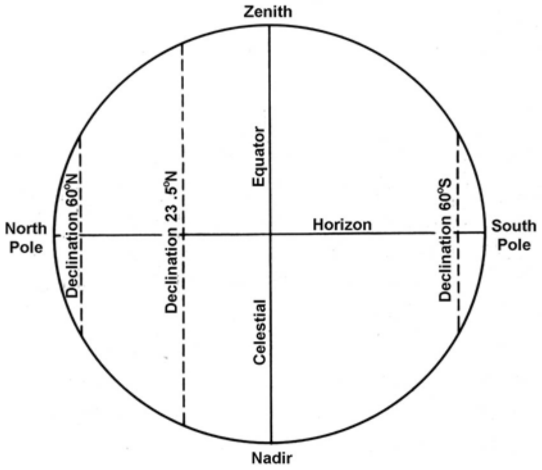


Figure 1316a. The right sphere.

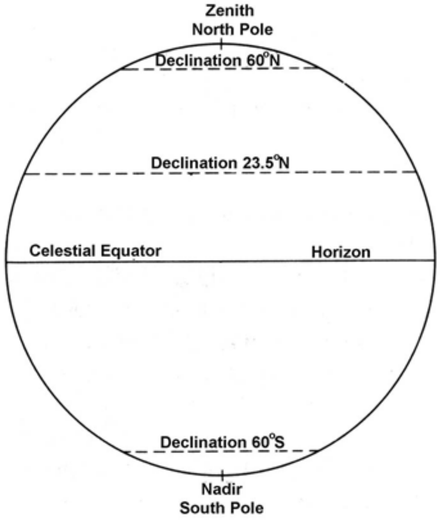


Figure 1316b. The parallel sphere.

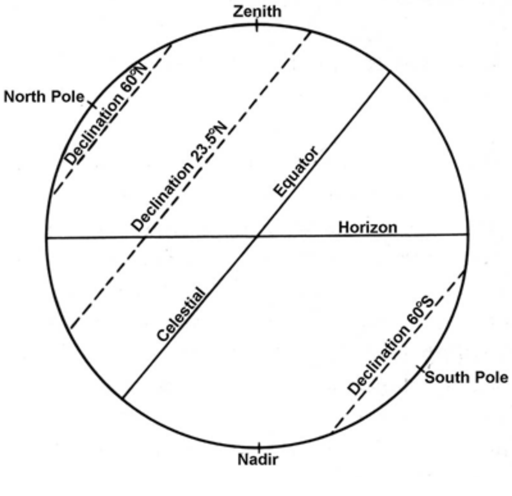


Figure 1316c. The oblique sphere at latitude 40°N.

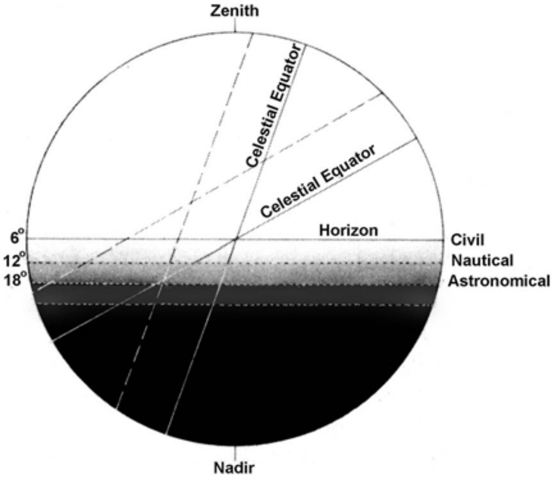


Figure 1316d. The various twilight at latitude 20°N and latitude 60°N.

Between these two extremes, the apparent motion is a combination of the two. On this oblique sphere, illustrated in Figure 1316c, circumpolar celestial bodies are those that remain above the horizon during the entire 24 hours, circling the elevated celestial pole. The portion of the sky where bodies are circumpolar extends from the elevated pole to approximately the declination equal to 90º minus the observer's latitude. For example, the stars of Ursa Major (the Big Dipper) and Cassiopeia are circumpolar for many observers in the United States.

An area of the celestial sphere approximately equal to the circumpolar area around the depressed pole remains constantly below the horizon. For example, Crux is not visible to most observers in the United States. Other celestial bodies rise obliquely along the eastern horizon, climb to maximum altitude at the celestial meridian, and set along

Twilight	Lighter limit	Darker limit	At darker limit
Civil	sunrise/set	–6°	Horizon clear; bright stars visible
Nautical	–6°	–12°	Horizon not visible
Astronomical	–12°	–18°	Full night

Table 1316. Limits of the three twilights.

the western horizon. The length of time above the horizon and the altitude at meridian transit vary with both the latitude of the observer and the declination of the body. Days and nights are always about the same length in the tropics. At higher latitudes the increased obliquity result in a greater change in the length of the day and longer periods of twilight. North of the Arctic Circle and south of the Antarctic Circle the Sun is circumpolar for part of the year. This is sometimes termed the land of the midnight Sun, where the Sun does not set during part of the summer and does not rise during part of the winter.

The increased obliquity at higher latitudes explains why days and nights are always about the same length in the tropics, and the change of length of the day becomes greater as latitude increases, and why twilight lasts longer in higher latitudes. Evening twilight begins at sunset, and morning twilight ends at sunrise. The darker limit of twilight occurs when the center of the Sun is a stated number of degrees below the celestial horizon. Three kinds of twilight are defined: civil, nautical and astronomical. See Table 1316.

The conditions at the darker limit are relative and vary considerably under different atmospheric conditions.

In Figure 1316d, the twilight band is shown, with the darker limits of the various kinds indicated. The nearly vertical celestial equator line is for an observer at latitude 20°N. The nearly horizontal celestial equator line is for an observer at latitude 60°N. The broken line for each case is the diurnal circle of the Sun when its declination is 15°N. The portion of the diurnal circle between the lighter and the darker limits indicates the relative duration of a particular type of twilight at the two example latitudes. But the relative duration is not directly proportional to the relative length of line shown since the projection is orthographic. Note that complete darkness will not occur at latitude 60°N when the declination of the Sun is 15°N.

1317. Apparent Motion due to Revolution of the Earth

If it were possible to stop the rotation of the Earth so that the celestial sphere would appear stationary, the effects of the revolution of the Earth would become more noticeable. The Sun would appear to move eastward a little less than 1° per day, to make one complete trip around the Earth in a year. If the Sun and stars were visible at the same time this motion could be observed by watching the changing position of the Sun with respect to the stars. A better way is to observe the constellations at the same time each night. Each night, a star rises nearly four minutes earlier than on the previous night. The period from star rise on one night to its rise on the next night is called a **sidereal day**. Thus, the celestial sphere appears to shift westward nearly 1° each night, so that different constellations are associated with different seasons of the year.

Apparent motions of planets and the Moon are due to a combination of their motions and those of the Earth. If the rotation of the Earth were stopped, the combined apparent motion due to the revolutions of the Earth and other bodies would be similar to that occurring if both rotation and revolution of the Earth were stopped. Stars would appear nearly stationary in the sky but would undergo a small annual cycle of change due to aberration. The motion of the Earth in its orbit is sufficiently fast to cause the light from stars to appear to shift slightly in the direction of the Earth's motion. This is similar to the effect one experiences when walking in vertically-falling rain that appears to come from ahead due to the observer's own forward motion. The apparent direction of the light ray from the star is the vector difference of the motion of light and the motion of the Earth, similar to that of apparent wind on a moving vessel. This effect is most apparent for a body perpendicular to the line of travel of the Earth in its orbit, for which it reaches a maximum value of 21.2 seconds of arc. The effect of aberration can be noted by comparing the coordinates (declination and sidereal hour angle) of various stars throughout the year. A change is observed in some bodies as the year progresses, but at the end of the year the values have returned almost to what they were at the beginning. The reason they do not return exactly is due to proper motion and precession of the equinoxes. It is also due to nutation, an irregularity in the motion of the Earth due to the disturbing effect of other celestial bodies, principally the Moon. Polar motion is a slight wobbling of the Earth about its axis of rotation and sometimes wandering of the poles. This motion, which does not exceed 40 feet from the mean position, produces slight variation of latitude and longitude of places on the Earth.

1318. Apparent Motion due to Movement of other Celestial Bodies

Each celestial body makes its own contribution to its apparent motion:

The Moon revolves about the Earth each month, rising in the west and setting in the east. Its orbital plane is slightly inclined to the ecliptic (see Section 1319), and is continuously changing in response to perturbations in its motion, primarily by the Sun.

The planets revolve about the Sun (technically, the solar system barycenter, which is within the sun's interior). The inferior planets, Mercury and Venus, appear to move eastward and westward relative to the Sun. The period for Mercury's motion is 116 days and the period for Venus is 584 days (see Section 1310). The superior planets make an apparent revolution around the Earth, from west to east. The periods for their motion varies from 780 to 367 days, depending on the planet (see Section 1311).

The stars revolve about the galactic center. As they move about the galactic center, the stars, including the Sun, move with respect to one another. The component of their motion across the line of sight is called proper motion. The maximum observed proper motion is that of Barnard's Star, which is moving at the rate of 10.3 seconds of arc per year. Barnard's Star is a tenth-magnitude star, not visible to the unaided eye. Rigil Kentaurus has the greatest proper motion of the 57 stars listed on the daily pages of the almanacs, about 3.7 seconds per year. Arcturus has the greatest proper motion of the navigational stars in the Northern Hemisphere, 2.3 seconds per year. Over the course of a few years, proper motions are very small; they can be ignored when reducing celestial navigation sights. A few thousand years of proper motion is sufficient to materially alter the look of some familiar constellations.

1319. The Ecliptic and the Inclination of the Earth's Axis

The **ecliptic** is the mean path of the Sun through the heavens arising from the annual revolution of the Earth in its orbit and appears as a great circle on the celestial sphere. The ecliptic is currently inclined at an angle of about 23°26' to the celestial equator. This angle is called the **obliquity of the ecliptic** and is due to the inclination or tilt of Earth's rotational axis relative to its orbital plane. The perturbations of the other planets on the Earth's orbital plane decreases the obliquity of the ecliptic by about 2/3 of an arc minute per century. The obliquity of the ecliptic causes the Sun to appear to move north and south over the course of the year, giving the Earth its seasons and changing lengths of periods of daylight.

Refer to Figure 1319a. The **vernal equinox** occurs when the center of the Sun crosses the equator going north. It occurs on or about March 21, and is the start of astronomical spring in the northern hemisphere. At this time the Sun is rising at the North Pole and setting at the South Pole, the Sun shines equally on both hemispheres, and day and night are approximately the same length over the entire world. The **summer solstice** occurs on or about June 21. On this date, the northern pole of the Earth's axis is tilted toward the Sun. The north polar regions are continuously in sunlight; the Northern Hemisphere is having its summer with long, warm days and short nights; the Southern Hemisphere is having winter with short days and long, cold nights; and the south polar region is in continuous darkness. The **autumnal equinox** occurs on or about September 23. On this date, the Sun is setting at the North Pole and rising at the South Pole, the Sun again shines equally on both hemispheres, and day and night are approximately the same length over the entire world. The **winter solstice** occurs on or about December 22. On this date, the Southern Hemisphere is tilted toward the Sun and conditions are the reverse of those six months earlier; the Northern Hemisphere is having its winter, and the Southern Hemisphere its summer.

The word **equinox** means “equal nights”. At the equinoxes, the Sun is directly over the equator. It remains above the horizon for approximately 12 hours. The length of daylight is not exactly 12 hours because of refraction, the solar semidiameter, and the height of the eye of the observer. These cause the Sun to be above the horizon a few minutes longer than below the horizon. Following the **vernal equinox**, the Sun's declination increases (becomes more northerly), and the Sun climbs higher in the sky each day (at the latitudes of the United States), until the summer solstice, when a declination of about 23°26' north of the celestial equator is reached. The word **solstice**, meaning “Sun stands still,” is used because the Sun halts its apparent northward or southward motion and momentarily “stands still” before it starts in the opposite direction. This action, somewhat analogous to the “stand” of the tide, refers to the motion in a north-south direction, not to the daily apparent revolution around the Earth.

Over the course of a year the distance between the Earth and the Sun changes by about 1.7%. The Earth is closest to the Sun during the northern hemisphere winter. To conserve angular momentum, the Earth travels faster when nearest the Sun, like a spinning ice skater pulling her arms in. As a result, the northern hemisphere (astronomical) winter is shorter than its summer by about seven days.

The distance between the Earth and Sun is not the primary source for the difference in temperature during the different seasons. Over a year, the change in Earth-Sun distance changes the solar energy flux only 3% from the average value. The tilt of the Earth's axis has a much larger affect. During the summer the rays are more nearly vertical, and hence more concentrated, as shown in Figure 1319b. At the polar circle on the summer solstice for a hemisphere, the solar flux (energy per unit area per unit time) is 73% of the flux at the tropic where the Sun is directly overhead. Winter sunlight is distributed over a larger area and shines fewer hours each day, causing less total heat energy to reach the

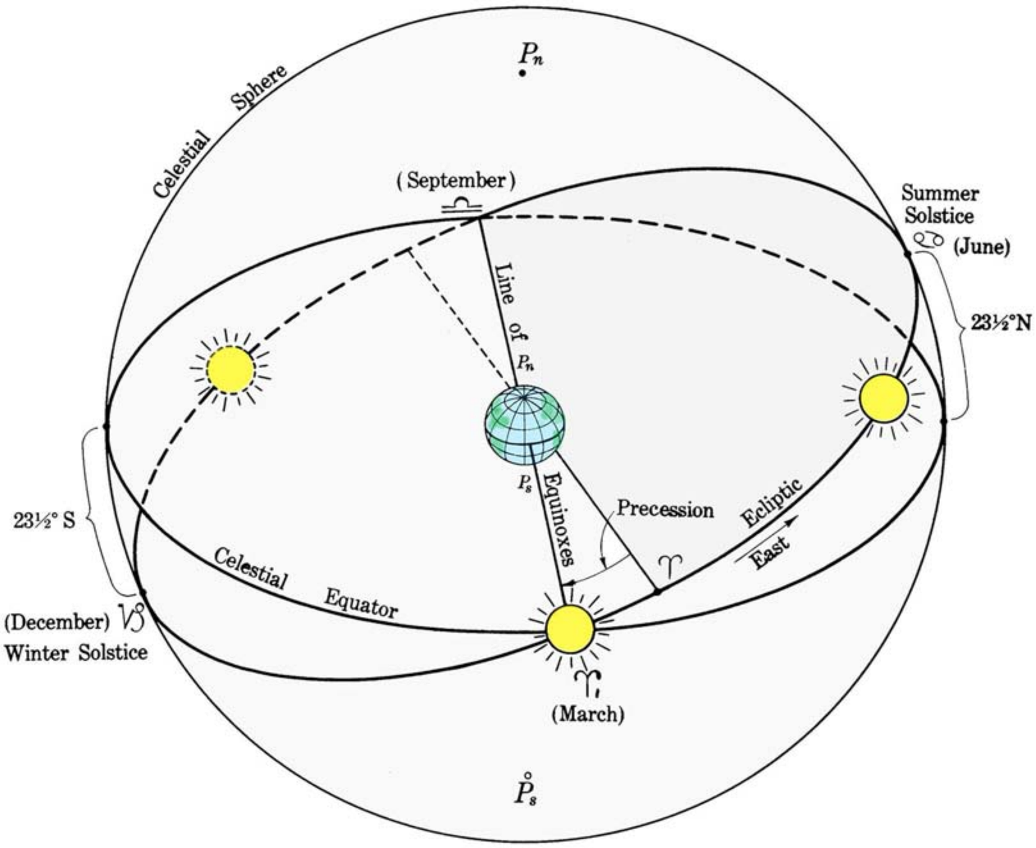


Figure 1319a. Apparent motion of the Sun in the ecliptic.

Earth. The solar flux at the polar circle on the winter solstice is nearly zero and the flux at the tropic is only 69% of the flux at the summer solstice.

Astronomically, the seasons begin at the equinoxes and solstices. Meteorologically, they differ from place to place. During the summer the Sun is above the horizon more than half the time. So, the total energy being added by absorption during a longer period than it is being lost by radiation. Following the summer solstice, the surface at a given latitude continues to receive more energy than it dissipates, but a decreasing amount. Gradually, the amount decreases until the surface is losing more energy than it gains from the Sun. This effect explains the lag of the seasons. It is analogous to the day, when the highest temperatures normally occur several hours after the Sun reaches maximum altitude at local noon.

At some time during the year, the Sun is directly overhead everywhere between the latitudes of about 23°26'N and about 23°26'S. Except at the limits, this occurs twice: once as the Sun appears to move northward, and the second time as it moves southward. The area on Earth between these latitudes is called the Tropics, or the **torrid zone**. The northern limit is the **Tropic of Cancer**, and the southern limit is the **Tropic of Capricorn**. These names come from the constellations the Sun entered at the solstices when the names were first used more than 2,000 years ago. Today, the Sun is in the next constellation to the west because of precession of the equinoxes. The parallels about 23°26' from the poles, marking the approximate limits of the circumpolar Sun, are called **polar circles**. The polar circle in the Northern Hemisphere is called the **Arctic Circle**, and the one in the Southern Hemisphere is called the **Antarctic Circle**. The areas inside the polar circles are the north and south **frigid zones**. The regions between the frigid zones and the torrid zones are the north and south **temperate zones**.

The expression "**vernal equinox**" and associated expressions are applied both to the times and points of occurrence of these phenomena. The vernal equinox is also called the **first point of Aries** (symbol ♈) because, when the name was given, the Sun entered the constellation Aries, the ram, as the Sun crossed the equator going north. The vernal equinox is of interest to navigators because it is the origin for measuring **sidereal hour angle**. The terms March equinox, June solstice, September equinox, and December solstice are occasionally applied as appropriate, because the more common names are associated with the seasons in the Northern Hemisphere and are six months out of step for the Southern Hemisphere.

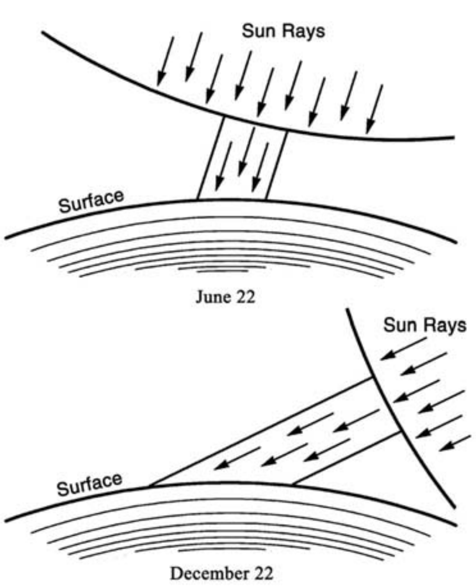


Figure 1319b. Sunlight in summer and winter. Winter sunlight is distributed over a larger area and shines fewer hours each day, causing less heat energy to reach the Earth.

1320. Precession and Nutation

The Earth's axis precesses: the motion of its rotation axis is similar to that of a top spinning with its axis tilted. The precession is in response to torques principally by the Sun and Moon. The spinning Earth responds to these torques in the manner of a gyroscope. The result is a slow westward movement of the equinoxes and solstices. This westward motion of the equinoxes along the ecliptic is called precession of the equinoxes. The precession has a period of about 25,800 years. There are also a series of short period motions of the Earth's axis of rotation called nutation. See Figure 1320. The nutations are all quite small. The largest nutation has an amplitude of 0.'2 and a period of 18.6 years. The next largest nutation has an amplitude of just 0.'01 and a period of 0.5 years.

The sidereal hour angle is measured from the vernal equinox, and declination from the celestial equator, so the coordinates of celestial bodies change because of precession. The total motion with respect to the ecliptic, called general precession, is about 50."29 per year. It may be divided into two components with respect to the celestial equator: precession in right ascension (about 46."12 per year) measured along the celestial equator, and precession in declination (about 20."04 per year) measured perpendicular to the celestial equator. The annual change in the coordinates of any given star, due to precession alone, depends upon its position on the celestial sphere.

Since precession changes the direction of Earth's pole, Polaris will not always be Earth's “Pole Star”. Currently, the north celestial pole is moving closer to Polaris because of precession. It will pass at a distance of approximately 28' about the year 2102. Afterward, the polar distance will increase, and eventually other stars, in their turn, will become the Pole Star.

1321. The Zodiac

The **zodiac** is a circular band of the sky extending 8° on each side of the ecliptic. The navigational planets and the Moon are within these limits. The zodiac is divided into 12 sections of 30° each, each section being given the name and symbol (“sign”) of a constellation. These are shown in Figure 1321. The names were assigned more than 2,000 years ago, when the Sun entered Aries at the vernal equinox, Cancer at the summer solstice, Libra at the autumnal equinox, and Capricornus at the winter solstice. Because of precession, the zodiacal signs have shifted with respect to the constellations. Thus at the time of the vernal equinox, the Sun is said to be at the “first point of Aries,” though it is in the constellation Pisces.

1322. Time and the Calendar

Traditionally, astronomy has furnished the basis for measurement of time, a subject of primary importance to the navigator. The **year** is associated with the revolution of the Earth in its orbit. The **day** is one rotation of the Earth about its axis.

The duration of one rotation of the Earth depends upon the external reference point used, the most common is using the Sun. One rotation relative to the Sun is called a **solar day**. However, an actual solar day varies in length. This variation is removed by using a “fictitious **mean**” **Sun**, leading to what we refer to as “**mean time.**” For a more complete discussion see Chapter 16 - Time; Section 1600 discusses apparent and mean solar time.

Universal Time (UT) is a generic reference to one (of several) time scales that approximate the mean diurnal motion of the Sun. Loosely, UT is mean solar time on the Greenwich meridian. The terms “Universal Time” and **“Greenwich Mean Time”** are sometimes used interchangeably, but the latter is being deprecated. Universal Time is the standard in the application of astronomy to navigation. See Chapter 16 - Section 1602 for a more complete discussion.

If the vernal equinox is used as the reference, a **sidereal day** is obtained, and from it, **sidereal time**. This indicates the approximate positions of the stars, and for this reason it is the basis of star charts and star finders. Because of the revolution of the Earth around the Sun, a sidereal day is about 3 minutes 56 seconds shorter than a solar day, and there is one more sidereal than solar days in a year. One mean solar day equals 1.00273791 mean sidereal days. Because of precession of the equinoxes, one rotation of the Earth with respect to the stars is not quite the same as one

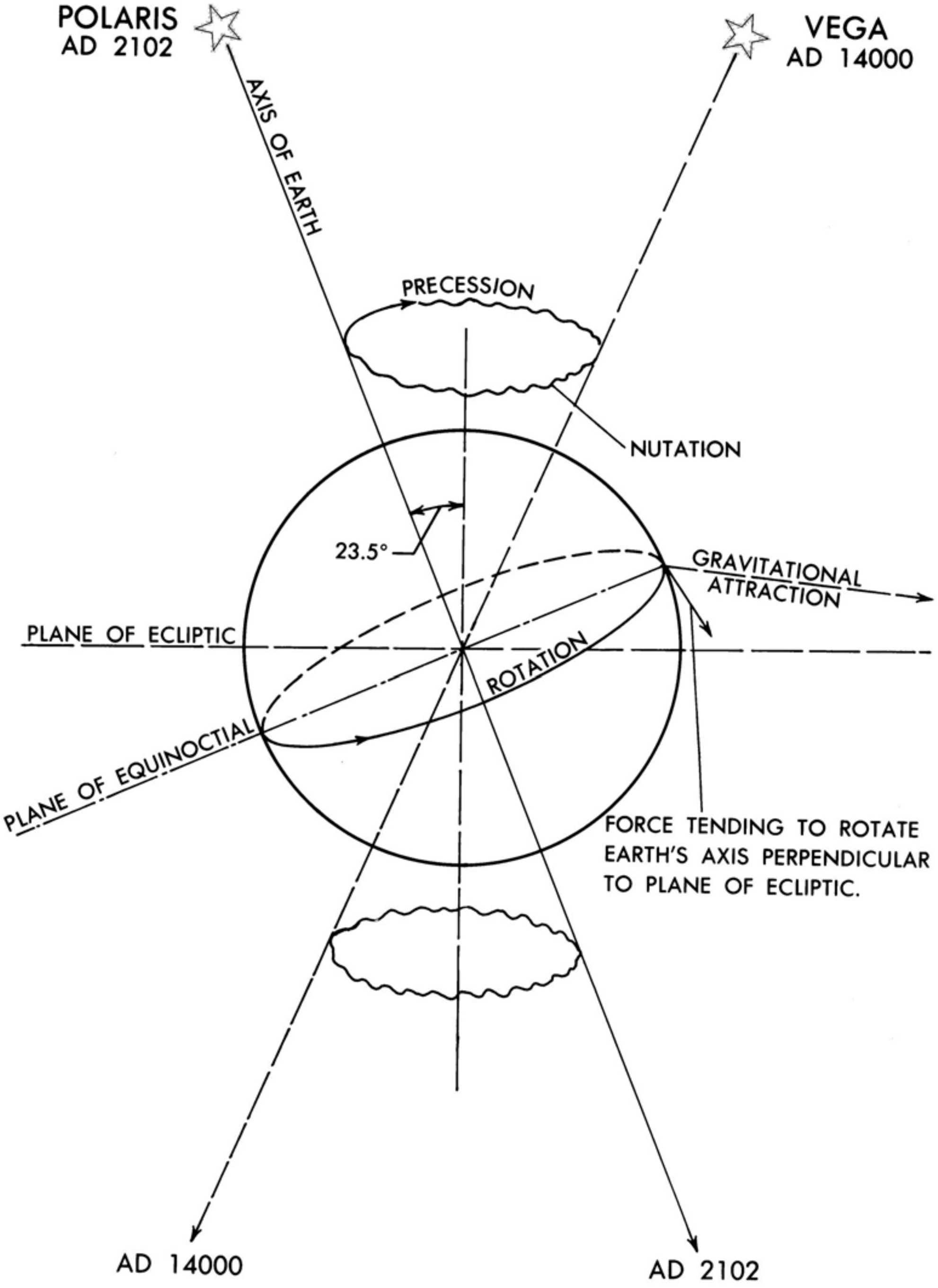


Figure 1320. Precession and nutation.

rotation with respect to the vernal equinox. One mean solar day averages 1.0027378118868 rotations of the Earth with respect to the stars.

In tide analysis, the Moon is sometimes used as the reference, producing a **lunar day** averaging 24 hours 50 minutes (mean solar units) in length, and lunar time.

Since each kind of day is divided arbitrarily into 24 hours, each hour having 60 minutes of 60 seconds, the length of each of these units differs somewhat in the various kinds of time.

Time is also classified according to the terrestrial meridian used as a reference. **Local time** results if one's own meridian is used, **zone time** if a nearby reference meridian is used over a spread of longitudes, and **Greenwich** or **Universal Time** if the Greenwich meridian is used.

The period from one vernal equinox to the next (the

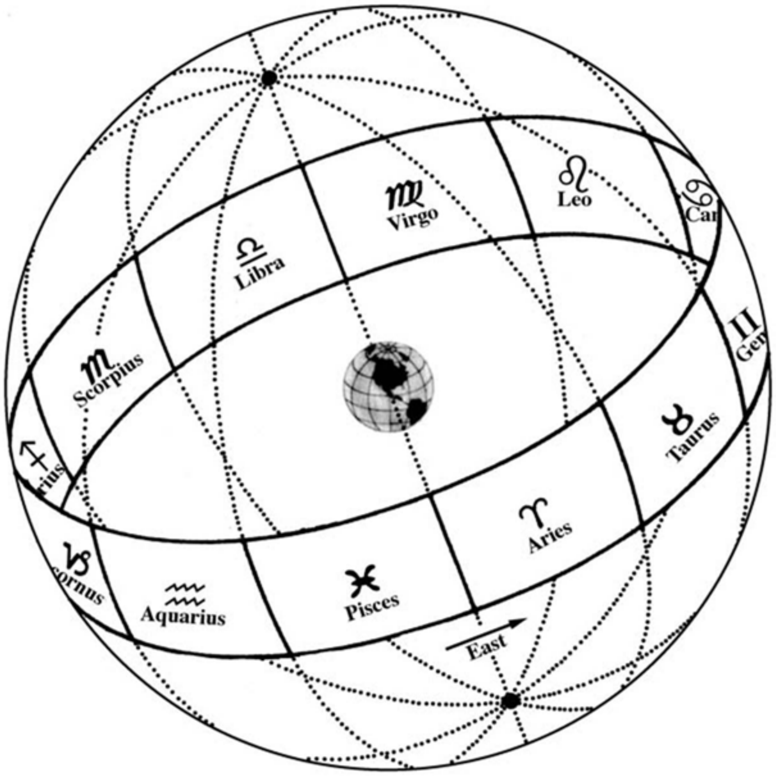


Figure 1321. The Zodiac.

cycle of the seasons) is known as the **tropical year**. It is approximately 365 days, 5 hours, 48 minutes, 45 seconds, though the length has been slowly changing for many centuries. Our calendar, the **Gregorian calendar**, approximates the tropical year with a combination of common years of 365 days and leap years of 366 days. A **leap year** is any year divisible by four, unless it is a century year, which must be divisible by 400 to be a leap year. Thus, 1700, 1800, and 1900 were not leap years, but 2000 was. A critical mistake was made by John Hamilton Moore in calling 1800 a leap year, causing an error in the tables in his book, The Practical Navigator. This error caused the loss of at least one ship and was later discovered by Nathaniel Bowditch while writing the first edition of The New American Practical Navigator.

See Chapter 16 for an in-depth discussion of time.

1323. Eclipses

If the orbit of the Moon coincided with the plane of the ecliptic, the Moon would pass in front of the Sun at every new Moon, causing a solar eclipse. At full Moon, the Moon would pass through the Earth's shadow, causing a lunar eclipse. Because of the Moon's orbit is inclined 5° with respect to the ecliptic, the Moon usually passes above or below the Sun at new Moon and above or below the Earth's shadow at full Moon. However, there are two points at which the plane of the Moon's orbit intersects the ecliptic. These are the **nodes** of the Moon's orbit. If the Moon passes one of these points at the same time as the Sun, a **solar eclipse** takes place. This is shown in Figure 1323.

The Sun and Moon are of nearly the same apparent size to an observer on the Earth. If the Moon is near perigee (the point in its orbit closest to the Earth), the Moon's apparent diameter is larger than that of the Sun, and its umbra (darkest part of the shadow) reaches the Earth as a nearly round dot. The dot moves rapidly across the Earth, from west to east, as the Moon continues in its orbit. Within the dot, the Sun is completely hidden from view, and a **total eclipse** of the Sun occurs. The width of this dot on the Earth's surface varies from eclipse to eclipse, but can be as large as a couple hundred miles. On the **path of totality**, a **partial eclipse** occurs as the disk of the Moon appears to move slowly across the face of the Sun, hiding an ever-increasing part of it, until the total eclipse occurs. Because of the uneven edge of the mountainous Moon, the light is not cut off evenly. But several last illuminated portions appear through the Moon's valleys or passes between the Moon's mountain peaks. These are called **Baily's Beads**. For a considerable distance around the umbral shadow, part of the surface of the Sun is obscured, and a partial eclipse occurs.

A total eclipse is a spectacular phenomenon. As the last light from the Sun is cut off, the solar **corona**, or envelope of thin, illuminated gas around the Sun becomes visible. Wisps of more dense gas may appear as **solar prominences**. The only light reaching the observer is that diffused by the atmosphere surrounding the shadow. As the Moon appears to continue on across the face of the Sun, the Sun finally emerges from the other side, first as Baily's Beads, and then as an ever widening crescent until no part of its surface is obscured by the Moon.

The duration of a total eclipse depends upon how nearly the Moon crosses the center of the Sun, the location of the shadow on the Earth, the relative orbital speeds of the Moon and Earth, and (principally) the relative apparent diameters of the Sun and Moon. The maximum length that can occur is a little more than seven minutes.

If the Moon is near apogee, its apparent diameter is less than that of the Sun, and its shadow does not quite reach the Earth. Over a small area of the Earth directly in line with the Moon and Sun, the Moon appears as a black disk almost covering the surface of the Sun, but with a thin ring of the Sun around its edge. This is known as an **annular eclipse**; these occur a little more often than total eclipses.

If the **umbral shadow** of the Moon passes close to the Earth, but not directly in line with it, a partial eclipse may occur without a total or annular eclipse.

An eclipse of the Moon (or **lunar eclipse**) occurs when the Moon passes through the shadow of the Earth, as shown in Figure 1323. Since the diameter of the Earth is about $3^1/_2$ times that of the Moon, the Earth's shadow at the distance of the Moon is much larger than that of the Moon. A total eclipse of the Moon can last nearly $1^3/_4$ hours, and some part of the Moon may be in the Earth's shadow for almost 4 hours.

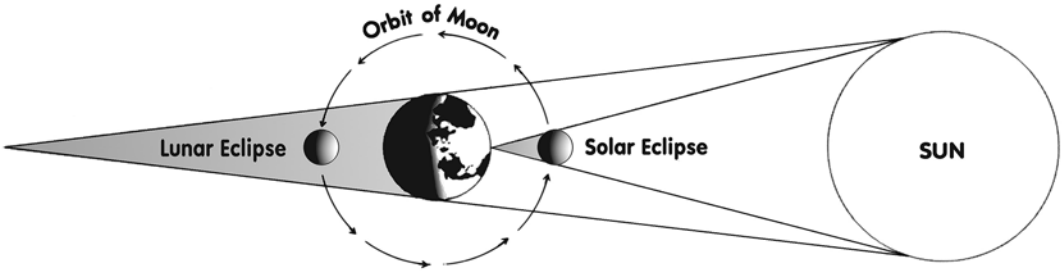


Figure 1323. Eclipses of the Sun and Moon.

During a total solar eclipse no part of the Sun is visible because the Moon is in the line of sight. But during a lunar eclipse some light does reach the Moon, diffracted by the atmosphere of the Earth, and hence the eclipsed full Moon is visible as a faint reddish disk. A lunar eclipse is visible over the entire hemisphere of the Earth facing the Moon. Anyone who can see the Moon can see the eclipse.

During any one year there may be as many as five eclipses of the Sun, and always there are at least two. There may be as many as three eclipses of the Moon, or none. The total number of eclipses during a single year does not exceed seven, and can be as few as two. There are more solar than lunar eclipses, but the latter can be seen more often because of the restricted areas over which solar eclipses are visible.

The Sun, Earth, and Moon are nearly aligned on the line of nodes twice each "eclipse year" of 346.6 days. This is less than a calendar year because of **regression of the nodes**. In a little more than 18 years the line of nodes returns to approximately the same position with respect to the Sun, Earth, and Moon. During an almost equal period, called the **saros**, a cycle of eclipses occurs. During the following saros the cycle is repeated with only minor differences.

COORDINATES

1324. Latitude and Longitude

Latitude and **longitude** are coordinates used to locate positions on the Earth. This section discusses three different definitions of these coordinates.

Astronomic latitude is the angle (ABQ, Figure 1324) between a line in the direction of gravity (AB) at a station and the plane of the equator (QQ'). **Astronomic longitude** is the angle between the plane of the celestial meridian at a station and the plane of the celestial meridian at Greenwich. These coordinates are customarily found by means of celestial observations. If the Earth were perfectly homogeneous and round, these positions would be consistent and satisfactory. However, because of deflection of the vertical due to uneven distribution of the mass of the Earth, lines of equal astronomic latitude and longitude are not circles, although the irregularities are small. In the United States the east-west component of the deflection of the vertical (affecting longitude) may be a little more than 18", and the north-south component (affecting latitude) may be as much as 25".

Geodetic latitude is the angle (ACQ, Figure 1324) between a normal to the spheroid (AC) at a station and the plane of the geodetic equator (QQ'). **Geodetic longitude** is the angle between the plane defined by the normal to the spheroid and the axis of the Earth and the plane of the geo-

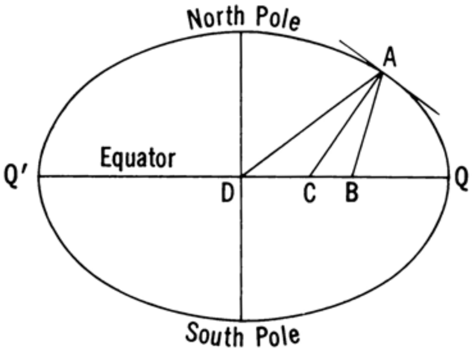


Figure 1324. Three kinds of latitude at point A.

detic meridian at Greenwich. These values are obtained when astronomical latitude and longitude are corrected for deflection of the vertical. These coordinates are used for charting and are frequently referred to as **geographic latitude** and **geographic longitude**, although these expressions are sometimes used to refer to astronomical latitude.

Geocentric latitude is the angle (ADQ, Figure 1324) at the center of the ellipsoid between the plane of its equator (QQ') and a straight line (AD) to a point on the surface of the Earth. This differs from geodetic latitude because the Earth is a spheroid rather than a sphere, and the meridians are ellipses. Since the parallels of latitude are considered to be circles, geodetic longitude is geocentric, and a separate expression is not used. The difference between geocentric and geodetic latitudes is a maximum of about 11.6' at latitude 45°.

Because of the oblate shape of the ellipsoid, the length of a degree of geodetic latitude is not everywhere the same, increasing from about 59.7 nautical miles at the equator to about 60.3 nautical miles at the poles. The value of 60 nautical miles customarily used by the navigator is correct at about latitude 45°.

MEASUREMENTS ON THE CELESTIAL SPHERE

1325. Elements of the Celestial Sphere

The **celestial sphere** (Section 1301) is an imaginary sphere of infinite radius with the Earth at its center (Figure 1325a). The north and south celestial poles of this sphere, PN and PS respectively, are located by extension of the Earth's mean pole of rotation. The **celestial equator** (sometimes called **equinoctial**) is the projection of the plane of the Earth's equator to the celestial sphere. A **celestial meridian** is a great circle passing through the celestial poles and the zenith of any location on the Earth.

The point on the celestial sphere vertically overhead of an observer is the **zenith**, and the point on the opposite side of the sphere vertically below him or her is the **nadir**. The zenith and nadir are the extremities of a diameter of the celestial sphere through the observer and the common center of the Earth and the celestial sphere. The arc of a celestial meridian between the poles is called the **upper branch** if it contains the zenith and the **lower branch** if it contains the nadir. The upper branch is frequently used in navigation, and references to a celestial meridian are understood to mean only its upper branch unless otherwise stated.

In order to uniquely define every point on the celestial sphere, a coordinate system must be defined. One such coordinate system uses **hour angles** and **declination**. With these two angular measurements, every position on the celestial sphere can be uniquely described.

Hour circles are great circles on the celestial sphere that pass through the celestial poles, and are therefore perpendicular to the **celestial equator**. An **hour angle** is the angle from a "reference" hour circle to the hour circle of a point (or object). There are three main "reference" hour circles used in celestial navigation. The first is the hour circle through the **vernal equinox** (also known as the **first point of Aries** (♈)). The angular distance west of this reference circle is called the **sidereal hour angle** (SHA) (Figure 1325b). The second is using the local meridian as the reference hour circle. The angular distance west of the local meridian is known as a **local hour angle** (LHA). And the third reference is the Greenwich meridian. Measurements west from the Greenwich meridian are known as **Greenwich hour angles**, or GHA. See Figure 1325c for a depiction of how to locate a point on the celestial sphere.

Since hour circles are perpendicular to the celestial equator, hour angles can be thought of as angular measurements along the equator. This give us one of our two coordinates needed to define every point on the celestial sphere. The second coordinate, **declination**, is the angular distance from the celestial equator along an hour circle and is measured north or south of the celestial equator in degrees, from 0° through 90°, similar to latitude on the Earth. Northern and southern declinations are sometime labeled with positive or negative values, respectively if not labeled N or S. A circle parallel to the celestial equator is called a **parallel of declination**, since it connects all points of equal declination. It is similar to a parallel of latitude on the Earth.

It is sometimes more convenient to measure hour angle either eastward or westward, as longitude is measured on the Earth, in which case it is called **meridian angle** (designated "t").

A point on the celestial sphere may also be located using **altitude** and **azimuth**, which are topocentric coordinates based upon the observer's local horizon as the primary great circle instead of the celestial equator.

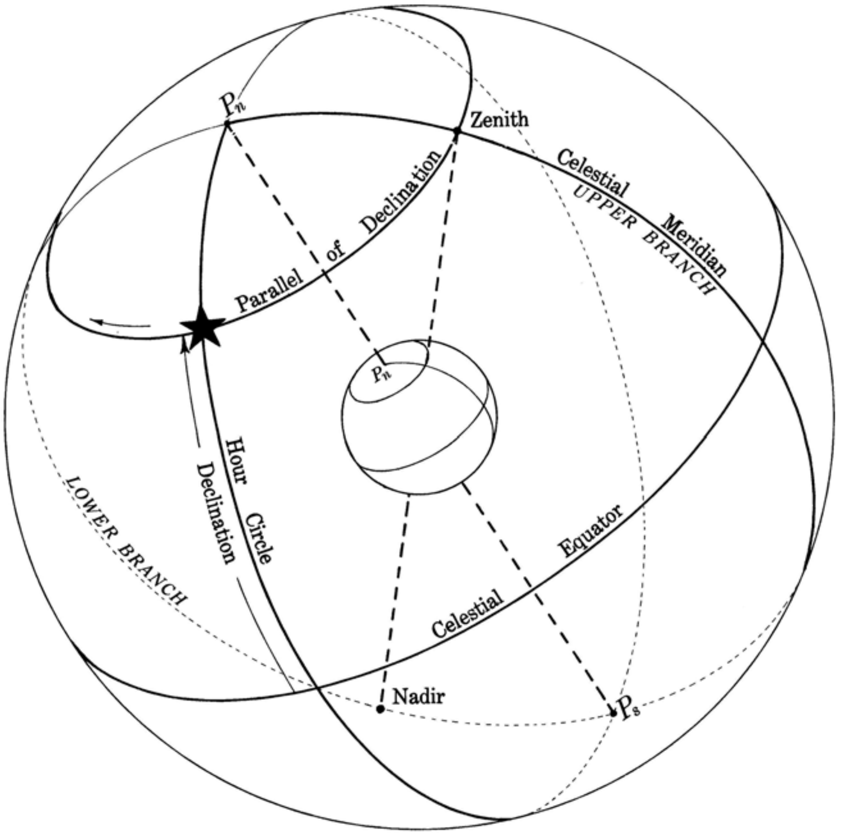


Figure 1325a. Elements of the celestial sphere.

COORDINATE SYSTEMS

1326. The Celestial Equator System of Coordinates

The familiar graticule of latitude and longitude lines, expanded until it reaches the celestial sphere, forms the basis of the **celestial equator system** of coordinates. On the celestial sphere latitude becomes **declination**, while longitude becomes **sidereal hour angle**, measured from the **vernal equinox**.

Polar distance (p) is angular distance from a celestial pole, or the arc of an hour circle between the celestial pole and a point on the celestial sphere. It is measured along an hour circle and may vary from 0° to 180°, since either pole may be used as the origin of measurement. It is usually considered the complement of declination, though it may be either 90° – d or 90° + d, depending upon the pole used. See Figure 1326a.

Local hour angle (LHA) is angular distance west of the local celestial meridian, or the arc of the celestial equator between the upper branch of the local celestial meridian and the hour circle through a point on the celestial sphere, measured westward from the local celestial meridian, through 360°. It is also the similar arc of the parallel of declination and the angle at the celestial pole, similarly measured. If the Greenwich (0°) meridian is used as the reference, instead of the local meridian, the expression **Greenwich hour angle (GHA)** is applied. It is sometimes convenient to measure the arc or angle in either an easterly or westerly direction from the local meridian, through 180°, when it is called **meridian angle (t)** and labeled E or W to indicate the direction of measurement. All bodies or other points having the same hour angle lie along the same hour circle.

Because of the apparent daily rotation of the celestial sphere, the hour angle of an object continually increases, but meridian angle increases from 0° at the celestial meridian to 180°W, which is also 180°E, and then decreases to 0° again. The rate of change in meridian angle for the mean Sun is 15° per hour. The rate of all other bodies except the Moon is within 3' of this value. The average rate of the Moon is about 15.5°.

As the celestial sphere rotates, each body crosses each branch of the celestial meridian approximately once a day. This crossing is called **meridian transit** (sometimes called

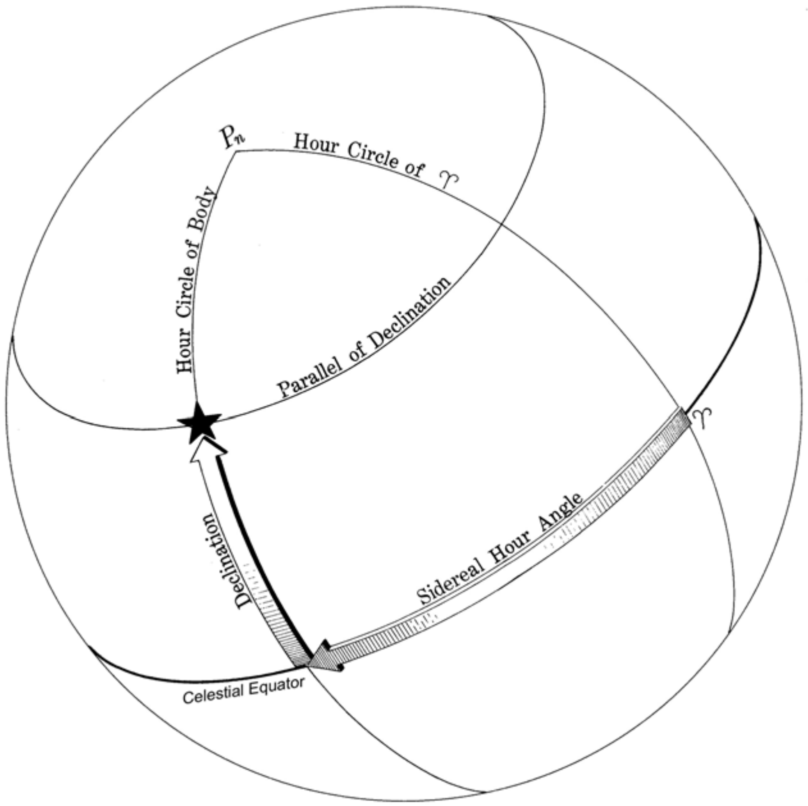


Figure 1325b. A point on the celestial sphere can be located by its declination and sidereal hour angle.

culmination). For circumpolar bodies, it is called **upper transit** to indicate crossing the upper branch of the meridian and **lower transit** to indicate crossing the lower branch.

The **time diagram** shown in Figure 1326b illustrates the relationship between the various hour angles and meridian angle. The circle is the celestial equator as seen from above the South Pole, with the upper branch of the observer’s meridian (P_SM) at the top. The radius P_SG is the Greenwich meridian; P_S ♈ is the hour circle of the vernal equinox. The Sun’s hour circle is to the east of the observer’s meridian; the Moon’s hour circle is to the west of the observer’s meridian Note that when LHA is less than 180°, it is numerically the same and is labeled W, but that when LHA is greater than 180°, t = 360° – LHA and is labeled E. In Figure 1326b arc GM is the longitude, which in this case is west. The relationships shown apply equally to other arrangements of radii, except for relative magnitudes of the quantities involved.

1327. Atmospheric Refraction of Light

The Earth's atmosphere acts like a lens which causes light rays to bend. This bending of a light ray or path is called **refraction**. The amount of the angular change caused by refraction is primarily a function of the atmospheric density gradient. An incoming light ray is bent or refracted towards the direction of increasing atmospheric density. The apparent path of the refracted light ray is always closer to perpendicular to the atmospheric density gradient than the path of the unrefracted ray. A light ray approaching the observer from the zenith is perpendicular to the density gradient. So, the refraction angle for the zenith is 0, and the direction of the refraction angle for other light rays is towards the zenith, making an object appear higher than if it were not refracted. In other words, an object's observed altitude is increased due to refraction. The greatest angular change occurs near the horizon where the light path is almost parallel to a given atmospheric density layer. The mean refraction angle near the horizon is approximately 34'. The density gradient and refraction angle are a function of the atmospheric pressure and temperature. So, observations made near the horizon should be corrected for changes from the standard pressure (1010 mb) and temperature (10ºC) used in calculating the refraction.

1328. The Horizons

The second set of celestial coordinates with which the navigator is directly concerned is based upon the horizon as the primary great circle. However, since several different horizons are defined, these should be thoroughly understood before proceeding with a consideration of the

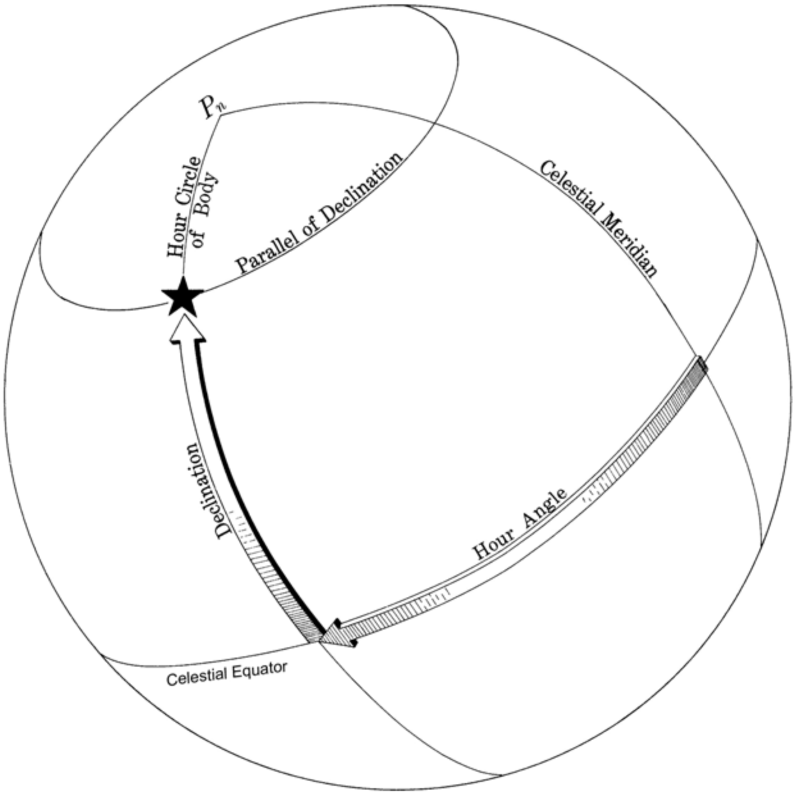


Figure 1325c. A point on the celestial sphere can be located by its declination and hour angle.

horizon system of coordinates.

The line where Earth and sky appear to meet is called the **visible** or **apparent horizon**. On land this is usually an irregular line unless the terrain is level. At sea the visible horizon appears very regular and is often very sharp. However, its position relative to the celestial sphere depends primarily upon (1) the refractive index of the air and (2) the height of the observer's eye above the surface.

In Figure 1328, the observer's eye is a height h above the Earth at A. The line through A and the center of the Earth is the vertical of the observer and contains the zenith. The plane perpendicular to the vertical is the **sensible horizon**. If the observer is at the Earth's surface, h = 0, then the plane of the sensible horizon is called the **geoidal horizon**. And if the observer is at the center of the Earth, then the plane of the sensible horizon is called the **celestial horizon**. The radius of the Earth is negligible with respect to that of the celestial sphere. Most measurements are referred only to the celestial horizon.

If the eye of the observer is at the surface of the Earth, the sensible horizon coincides with the geoidal horizon; but above the Earth's surface, at height h, the observer's eye is at the vertex of a cone, which is tangent to the Earth at the geometric horizon. The angle between the sensible and geometric horizon is the **geometric dip**. So, it is possible to observe a body, which is above the geometric horizon but below the celestial horizon. That is, the body's altitude is negative and its zenith distance is greater than 90°.

The apparent (or visible) horizon, that is the horizon seen by the observer, is not identical to the geometric horizon because of the refraction of light by the atmosphere. The direction of refraction is towards the zenith, so the apparent horizon is above the geometric horizon. However, because the path of the light is bent the position of the apparent horizon, the place on the Earth's surface where the light path is tangent to the surface, is farther away than the geometric horizon. The difference between the geometric dip and the refraction angle is the **total dip**.

1329. The Horizon System of Coordinates

This system is based upon the celestial horizon as the primary great circle and a series of secondary vertical circles which are great circles through the zenith and nadir of the observer and hence perpendicular to his or her horizon (Figure 1329a). Thus, the celestial horizon is similar to the equator, and the vertical circles are similar to meridians, but with one important difference. The celestial horizon and vertical circles are dependent upon the position of the observer and hence move with changes position, while the

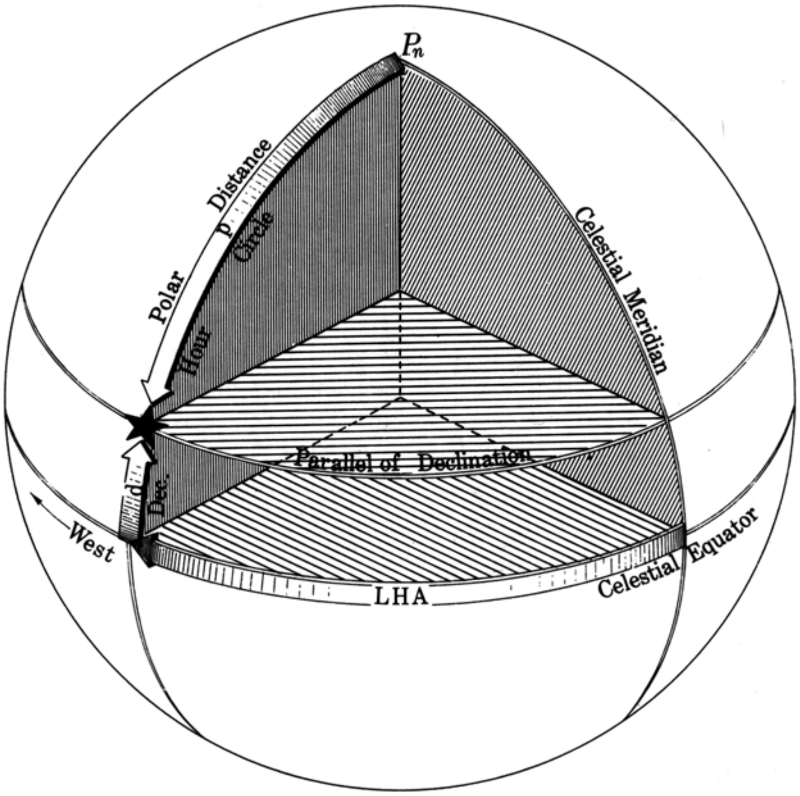


Figure 1326a. The celestial equator system of coordinates, showing measurements of declination, polar distance, and local hour angle.

primary and secondary great circles of both the geographical and celestial equator systems are independent of the observer. The horizon and celestial equator systems coincide for an observer at the geographical pole of the Earth and are mutually perpendicular for an observer on the equator. At all other places the two are oblique.

The **celestial** or **local meridian** passes through the observer's zenith, nadir, and poles of the celestial equator system of coordinates. As such, it passes through north and south on

As shown in Figure 1329b, altitude is angular distance above the horizon. It is measured along a vertical circle, from 0° at the horizon through 90° at the zenith. Altitude measured from the visible horizon may exceed 90° because of the dip of the horizon, as shown in Figure 1329a. Altitude is nominally a positive value, however, angular distance below the celestial horizon, called negative altitude, is provided for by including certain negative altitudes in some tables for use in celestial navigation. All points having the same altitude lie along a parallel of altitude.

Zenith distance (z) is angular distance from the zenith, or the arc of a vertical circle between the zenith and a point on the celestial sphere. It is measured along a vertical circle from 0° through 180°. It is usually considered the complement of altitude. For a body measured with respect to the

the observer's horizon. One of these poles (having the same name, N or S, as the latitude) is above the horizon and is called the **elevated pole**. The other, called the **depressed pole**, is below the horizon. In the horizon system it is called the principal vertical circle. The vertical circle through the east and west points of the horizon, and hence perpendicular to the principal vertical circle, is called the **prime vertical circle**, or simply the **prime vertical**.

celestial horizon $z = 90° - h$.

The horizontal direction of a point on the celestial sphere, or the bearing of the geographical position, is called **azimuth** or **azimuth angle** depending upon the method of measurement. In both methods it is an arc of the horizon (or parallel of altitude). It is true azimuth (Zn) if measured east from north on the horizon through 360°, and azimuth angle (Z) if measured either direction along the horizon through 180°, starting at the north for an observer in north latitudes and the south in south latitudes.

1330. The Ecliptic System of Coordinates

The **ecliptic system** is based upon the ecliptic as the primary great circle, analogous to the equator. The **ecliptic**

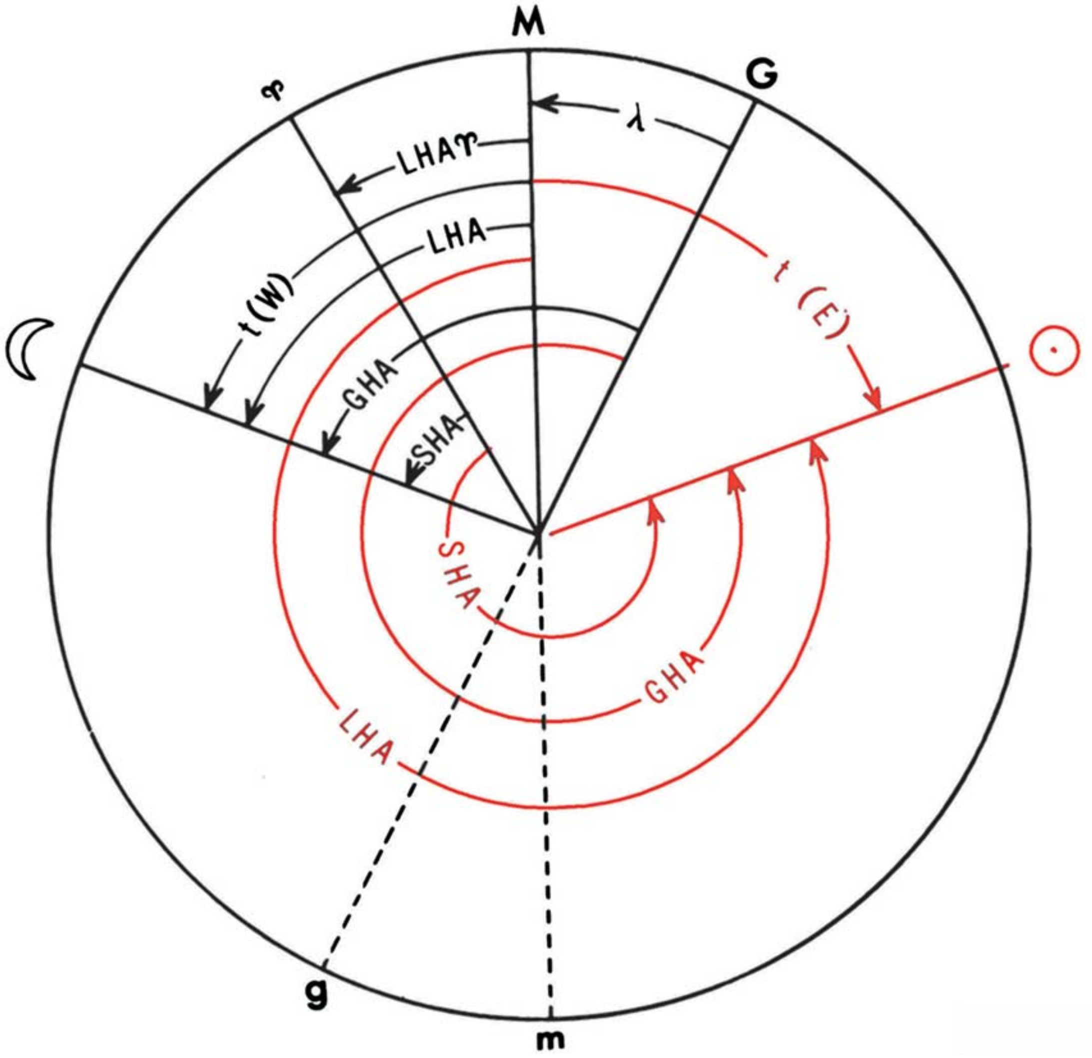


Figure 1326b. Time diagram.

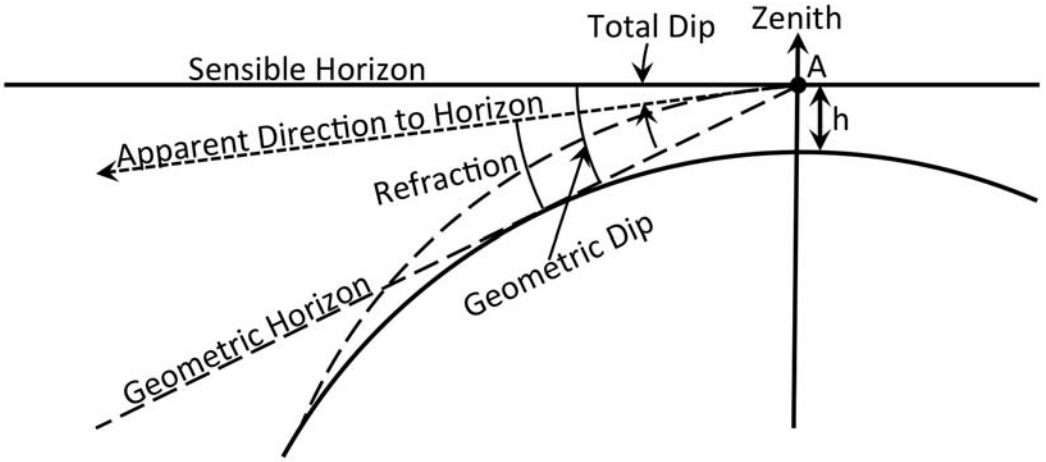


Figure 1328. The sensible horizon.

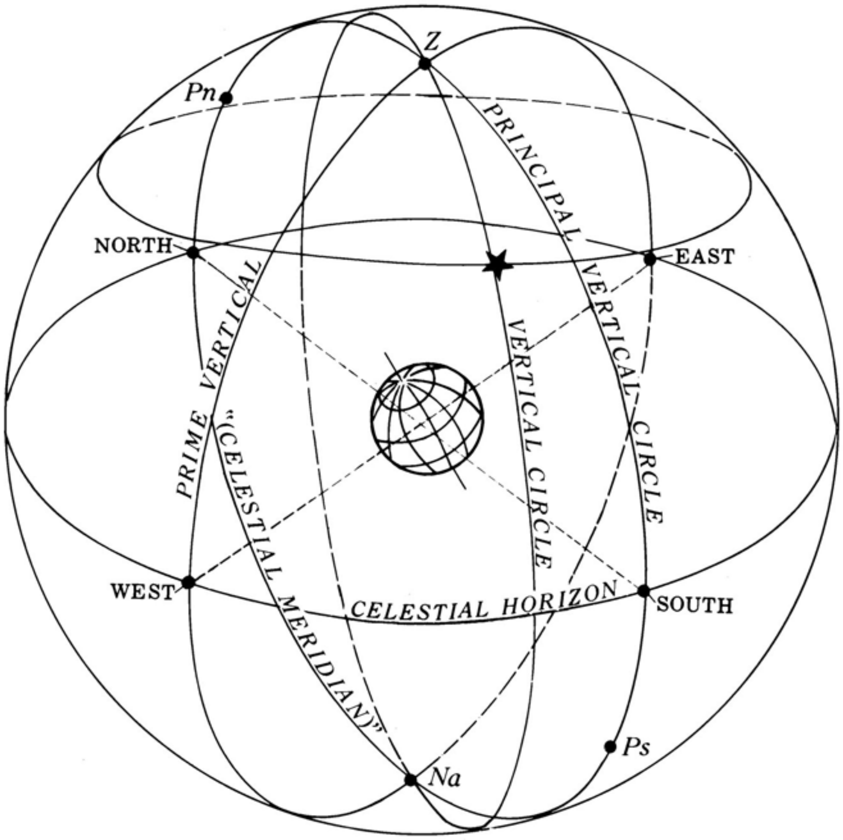


Figure 1329a. Elements of the celestial sphere. The celestial horizon is the primary great circle.

Earth	Celestial Equator	Horizon	Ecliptic
equator	celestial equator	horizon	ecliptic
poles	celestial poles	zenith; nadir	ecliptic poles
meridians	hours circle; celestial meridians	vertical circles	circles of latitude
prime meridian	hour circle of Aries	principal or prime vertical circle	circle of latitude through Aries
parallels	parallels of declination	parallels of altitude	parallels of latitude
latitude	declination	altitude	ecliptic altitude
colatitude	polar distance	zenith distance	ecliptic colatitude
longitude	SHA; RA; GHA; LHA; t	azimuth; azimuth angle; amplitude	ecliptic longitude

Table 1329. The four systems of celestial coordinates and their analogous terms.

is the apparent path of the Sun around the celestial sphere. The points 90° from the ecliptic are the north and south ecliptic poles. The series of great circles through these poles, analogous to meridians, are **circles of latitude**. The circles parallel to the plane of the ecliptic, analogous to parallels on the Earth, are parallels of latitude or **circles of longitude**. Angular distance north or south of the ecliptic, analogous to latitude, is ecliptic latitude. Ecliptic longitude is measured eastward along the ecliptic through 360°, starting at the vernal equinox. The mean plane of the Sun's orbit lies in the ecliptic and the planes of the orbits of the Moon and planets are near the ecliptic. Because the planes of their orbits lie near the ecliptic, it is easier to predict the positions of the Sun, Moon, and planets using ecliptic coordinates.

The four systems of celestial coordinates are analogous to each other and to the terrestrial system, although each has distinctions such as differences in primary reference planes. Table 1329 indicates the analogous term or terms under each system. Also see Table 1330.

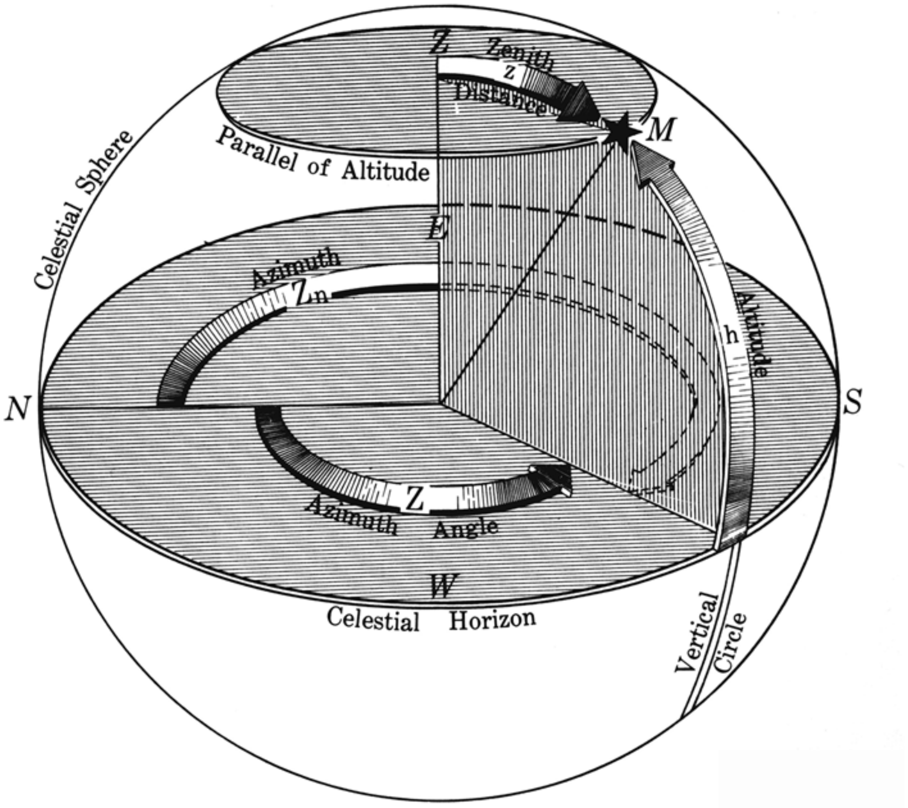


Figure 1329b. Elements of the celestial sphere. The celestial horizon.

NAVIGATIONAL COORDINATES

Coordinate	Symbol	Measured from	Measured along	Direc-tion	Measured to	Units	Preci-sion	Maximum value	Labels
latitude	L, lat.	equator	meridian	N, S	parallel	°, ¢	0¢.1	90°	N, S
colatitude	colat.	poles	meridian	S, N	parallel	°, ¢	0¢.1	90°	—
longitude	l, long.	prime meridian	parallel	E, W	local meridian	°, ¢	0¢.1	180°	E, W
declination	d, dec.	celestial equator	hour circle	N, S	parallel of declination	°, ¢	0¢.1	90°	N, S
polar distance	p	elevated pole	hour circle	S, N	parallel of declination	°, ¢	0¢.1	180°	—
altitude	h	horizon	vertical circle	up	parallel of altitude	°, ¢	0¢.1	90°*	—
zenith distance	z	zenith	vertical circle	down	parallel of altitude	°, ¢	0¢.1	180°	—
azimuth	Zn	north	horizon	E	vertical circle	°	0°.1	360°	—
azimuth angle	Z	north, south	horizon	E, W	vertical circle	°	0°.1	180° or 90°	N, S...E, W
amplitude	A	east, west	horizon	N, S	body	°	0°.1	90°	E, W...N, S
Greenwich hour angle	GHA	Greenwich celestial meridian	parallel of declination	W	hour circle	°, ¢	0¢.1	360°	—

Table 1330. Navigational Coordinates.

NAVIGATIONAL COORDINATES

Coordinate	Symbol	Measured from	Measured along	Direction	Measured to	Units	Precision	Maximum value	Labels
local hour angle	LHA	local celestial meridian	parallel of declination	W	hour circle	°, ¢	0¢.1	360°	—
meridian angle	t	local celestial meridian	parallel of declination	E, W	hour circle	°, ¢	0¢.1	180°	E, W
sidereal hour angle	SHA	hour circle of vernal equinox	parallel of declination	W	hour circle	°, ¢	0¢.1	360°	—
right ascension	RA	hour circle of vernal equinox	parallel of declination	E	hour circle	h, m, s	1^s	24^h	—
Greenwich mean time	GMT	lower branch Greenwich celestial meridian	parallel of declination	W	hour circle mean Sun	h, m, s	1^s	24^h	—
local mean time	LMT	lower branch local celestial meridian	parallel of declination	W	hour circle mean Sun	h, m, s	1^s	24^h	—
zone time	ZT	lower branch zone celestial meridian	parallel of declination	W	hour circle mean Sun	h, m, s	1^s	24^h	—
Greenwich apparent time	GAT	lower branch Greenwich celestial meridian	parallel of declination	W	hour circle apparent Sun	h, m, s	1^s	24^h	—
local apparent time	LAT	lower branch local celestial meridian	parallel of declination	W	hour circle apparent Sun	h, m, s	1^s	24^h	—
Greenwich sidereal time	GST	Greenwich celestial meridian	parallel of declination	W	hour circle vernal equinox	h, m, s	1^s	24^h	—
local sidereal time	LST	local celestial meridian	parallel of declination	W	hour circle vernal equinox	h, m, s	1^s	24^h	—

Table 1330. Navigational Coordinates.

1331. The Navigational Triangle

A triangle formed by arcs of great circles of a sphere is called a **spherical triangle**. A spherical triangle on the celestial sphere is called a **celestial triangle**. The spherical triangle of particular significance to navigators is called the **navigational triangle**, formed by arcs of a celestial meridian, an hour circle, and a vertical circle. Its vertices are the elevated pole, the zenith, and a point on the celestial sphere (usually a celestial body). The terrestrial counterpart is also called a navigational triangle, being formed by arcs of two meridians and the great circle connecting two places on the Earth, one on each meridian. The vertices are the two places and a pole. In great-circle sailing these places are the point of departure and the destination. In celestial navigation they are the **assumed position (AP)** of the observer and the **geographical position (GP)** of the body (the point on the Earth's surface having the body in its zenith). The GP of the Sun is sometimes called the **subsolar point**, that of the Moon the **sublunar point**, that of a satellite (either natural or artificial) the **subsatellite point**, and that of a star its **substellar** or **subastral point**. When used to solve a celestial observation, either the celestial or terrestrial triangle may be called the **astronomical triangle**.

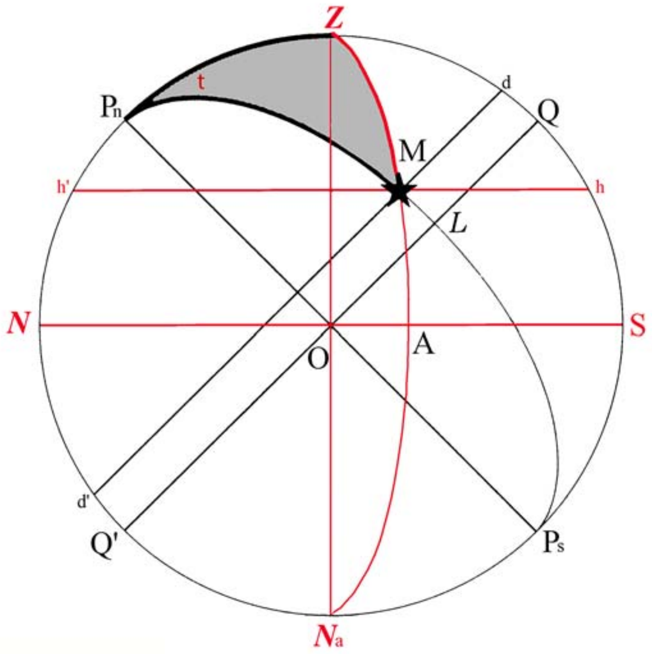


Figure 1331a. The navigational triangle.

The navigational triangle is shown in Figure 1331a on a diagram on the plane of the celestial meridian. The Earth is at the center, O. The star is at M, dd' is its parallel of declination, and hh' is its altitude circle.

In the figure, arc QZ of the celestial meridian is the latitude of the observer, and PnZ, one side of the triangle, is the colatitude. Arc AM of the vertical circle is the altitude of the body, and side ZM of the triangle is the zenith distance, or coaltitude. Arc LM of the hour circle is the declination of the body, and side PnM of the triangle is the polar distance, or codeclination.

The angle at the elevated pole, ZPnM, having the hour circle and the celestial meridian as sides, is the meridian angle, t. The angle at the zenith, PnZM, having the vertical circle and that arc of the celestial meridian, which includes the elevated pole, as sides, is the azimuth angle. The angle at the celestial body, ZMPn, having the hour circle and the vertical circle as sides, is the parallactic angle (q) (sometimes called the position angle), which is not generally used by the navigator.

A number of problems involving the navigational triangle are encountered by the navigator, either directly or indirectly. Of these, the most common are:

1. Given latitude, declination, and meridian angle, to find of a celestial observation to establish a line of position.
2. Given latitude, altitude, and azimuth angle, to find declination and meridian angle. This is used to identify an unknown celestial body.
3. Given meridian angle, declination, and altitude, to find azimuth angle. This may be used to find azimuth when the altitude is known.
4. Given the latitude of two places on the Earth and the difference of longitude between them, to find the initial great-circle course and the great-circle distance. This involves the same parts of the triangle as in 1, above, but in the terrestrial triangle, and hence is defined differently.

Both celestial and terrestrial navigational triangles were shown in Figure 1529b of the Bowditch 2002 edition.

IDENTIFICATION OF STARS AND PLANETS

1332. Introduction

A basic requirement of celestial navigation is the ability to identify the bodies observed. This is not difficult because relatively few stars and planets are commonly used for navigation, and various aids are available to assist in their identification. See Figure 1332, Figure 1333, Figure 1334a and Figure 1334b.

Identification of the Sun and Moon is straightforward, however, the planets can be mistaken for stars. A person working continually with the night sky recognizes a planet by its changing position among the relatively fixed stars. The planets are identified by noting their positions relative to each other, the Sun, the Moon, and the stars. They remain within the narrow limits of the ecliptic, but are in almost constant motion relative to the stars. The magnitude (brightness) and color may be helpful; they are some of the brightest objects in the sky. The information needed is found in the *Nautical Almanac*. The "Planet Notes" near the front of that volume are particularly useful. Planets can also be identified by planet diagram, star finder, sky diagram, or by computation.

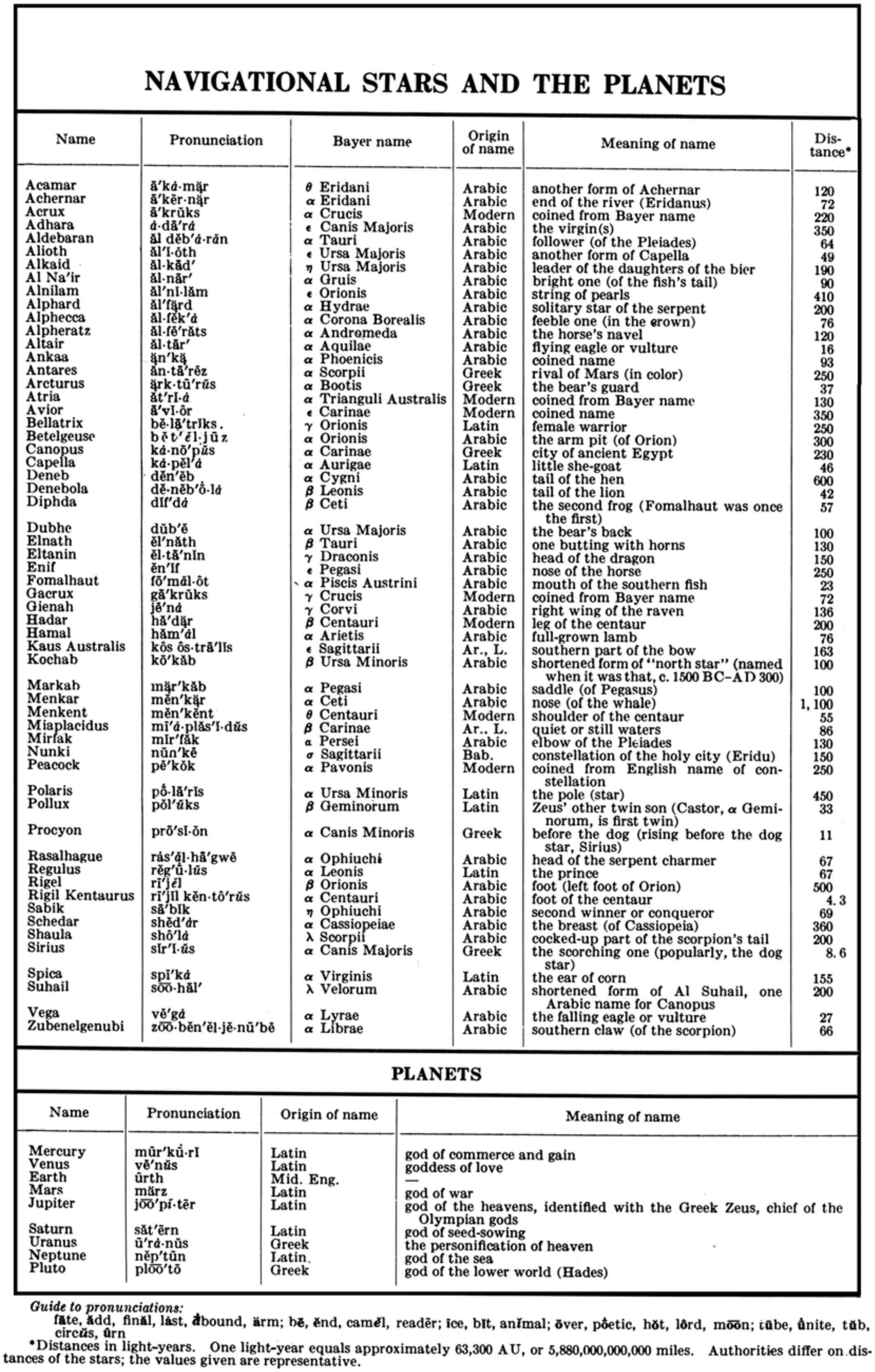
1333. Stars

The *Nautical Almanac* lists full navigational information on 19 first magnitude stars and 38 second magnitude stars, plus Polaris given its proximity to the north celestial pole. These are known as "selected stars" and are listed in the Index to Selected Stars in the *Nautical Almanac*. These stars can also be seen in Figure 1333 - Distribution of Selected Stars from the *Nautical Almanac*. These are some of the brightest stars, and span declinations from 70° south to 89° north on the celestial sphere. Abbreviated information is listed for 115 more, known as "tabulated stars." Additional stars are listed in the Astronomical Almanac and in various star catalogs. About 6,000 stars are visible to the unaided eye on clear, dark nights across the entire sky.

Stars are designated by one or more of the following naming systems:

- **Common Name:** Most names of stars, as now used, were given by the ancient Arabs and some by the Greeks or Romans. One of the stars of the *Nautical Almanac*, Nunki, was named by the Babylonians. Only a relatively few stars and often only the brightest have common names. Several of the stars on the daily pages of the almanacs had no name prior to 1953.

- **Bayer's Name:** Most bright stars, including those with names, have been given a designation consisting of a Greek letter followed by the possessive form of the name of the constellation. For example, the brightest star in the constellation Cygnus is known as (Greek letter "alpha") Cygni, and also by its common name, Deneb. Roman letters are used when there are not enough Greek letters. Usually, the letters are assigned in order of brightness within the constellation; however, this is not always the case. For example, the letter designations of the stars in Ursa Major or the Big Dipper are assigned in order from the outer rim of the bowl to the end of the handle. This system of star designation was suggested by John Bayer of



NAVIGATIONAL STARS AND THE PLANETS

Name	Pronunciation	Bayer name	Origin of name	Meaning of name	Distance*
Acamar	ā′kȧ·mär	θ Eridani	Arabic	another form of Achernar	120
Achernar	ā′kẽr·när	α Eridani	Arabic	end of the river (Eridanus)	72
Acrux	ā′krŭks	α Crucis	Modern	coined from Bayer name	220
Adhara	ȧ·dā′rȧ	ε Canis Majoris	Arabic	the virgin(s)	350
Aldebaran	ăl dĕb′ȧ·rȧn	α Tauri	Arabic	follower (of the Pleiades)	64
Alioth	ăl′ĭ·ŏth	ε Ursa Majoris	Arabic	another form of Capella	49
Alkaid	ăl·kād′	η Ursa Majoris	Arabic	leader of the daughters of the bier	190
Al Na′ir	ăl·nār′	α Gruis	Arabic	bright one (of the fish's tail)	90
Alnilam	ăl′nĭ·lăm	ε Orionis	Arabic	string of pearls	410
Alphard	ăl′färd	α Hydrae	Arabic	solitary star of the serpent	200
Alphecca	ăl·fĕk′ȧ	α Corona Borealis	Arabic	feeble one (in the crown)	76
Alpheratz	ăl·fē′răts	α Andromeda	Arabic	the horse's navel	120
Altair	ăl·tār′	α Aquilae	Arabic	flying eagle or vulture	16
Ankaa	ăn′kä	α Phoenicis	Arabic	coined name	93
Antares	ăn·tā′rēz	α Scorpii	Greek	rival of Mars (in color)	250
Arcturus	ärk·tū′rŭs	α Bootis	Greek	the bear's guard	37
Atria	ăt′rĭ·ȧ	α Trianguli Australis	Modern	coined from Bayer name	130
Avior	ā′vĭ·ôr	ε Carinae	Modern	coined name	350
Bellatrix	bĕ·lā′trĭks	γ Orionis	Latin	female warrior	250
Betelgeuse	bĕt′ĕl·jūz	α Orionis	Arabic	the arm pit (of Orion)	300
Canopus	kȧ·nō′pŭs	α Carinae	Greek	city of ancient Egypt	230
Capella	kȧ·pĕl′ȧ	α Aurigae	Latin	little she-goat	46
Deneb	dĕn′ĕb	α Cygni	Arabic	tail of the hen	600
Denebola	dĕ·nĕb′ō·lȧ	β Leonis	Arabic	tail of the lion	42
Diphda	dĭf′dȧ	β Ceti	Arabic	the second frog (Fomalhaut was once the first)	57
Dubhe	dŭb′ē	α Ursa Majoris	Arabic	the bear's back	100
Elnath	ĕl′năth	β Tauri	Arabic	one butting with horns	130
Eltanin	ĕl·tā′nĭn	γ Draconis	Arabic	head of the dragon	150
Enif	ĕn′ĭf	ε Pegasi	Arabic	nose of the horse	250
Fomalhaut	fō′măl·ôt	α Piscis Austrini	Arabic	mouth of the southern fish	23
Gacrux	gā′krŭks	γ Crucis	Modern	coined from Bayer name	72
Gienah	jē′nȧ	γ Corvi	Arabic	right wing of the raven	136
Hadar	hā′där	β Centauri	Modern	leg of the centaur	200
Hamal	hăm′ȧl	α Arietis	Arabic	full-grown lamb	76
Kaus Australis	kôs ôs·trā′lĭs	ε Sagittarii	Ar., L.	southern part of the bow	163
Kochab	kō′kăb	β Ursa Minoris	Arabic	shortened form of "north star" (named when it was that, c. 1500 BC–AD 300)	100
Markab	mär′kăb	α Pegasi	Arabic	saddle (of Pegasus)	100
Menkar	mĕn′kär	α Ceti	Arabic	nose (of the whale)	1, 100
Menkent	mĕn′kĕnt	θ Centauri	Modern	shoulder of the centaur	55
Miaplacidus	mī′ȧ·plăs′ĭ·dŭs	β Carinae	Ar., L.	quiet or still waters	86
Mirfak	mĭr′făk	α Persei	Arabic	elbow of the Pleiades	130
Nunki	nŭn′kē	σ Sagittarii	Bab.	constellation of the holy city (Eridu)	150
Peacock	pē′kŏk	α Pavonis	Modern	coined from English name of constellation	250
Polaris	pō·lā′rĭs	α Ursa Minoris	Latin	the pole (star)	450
Pollux	pŏl′ŭks	β Geminorum	Latin	Zeus' other twin son (Castor, α Geminorum, is first twin)	33
Procyon	prō′sĭ·ŏn	α Canis Minoris	Greek	before the dog (rising before the dog star, Sirius)	11
Rasalhague	rȧs′ăl·hā′gwē	α Ophiuchi	Arabic	head of the serpent charmer	67
Regulus	rĕg′ū·lŭs	α Leonis	Latin	the prince	67
Rigel	rī′jĕl	β Orionis	Arabic	foot (left foot of Orion)	500
Rigil Kentaurus	rī′jĭl kĕn·tô′rŭs	α Centauri	Arabic	foot of the centaur	4. 3
Sabik	sā′bĭk	η Ophiuchi	Arabic	second winner or conqueror	69
Schedar	shĕd′ȧr	α Cassiopeiae	Arabic	the breast (of Cassiopeia)	360
Shaula	shô′lȧ	λ Scorpii	Arabic	cocked-up part of the scorpion's tail	200
Sirius	sĭr′ĭ·ŭs	α Canis Majoris	Greek	the scorching one (popularly, the dog star)	8. 6
Spica	spī′kȧ	α Virginis	Latin	the ear of corn	155
Suhail	sōō·hāl′	λ Velorum	Arabic	shortened form of Al Suhail, one Arabic name for Canopus	200
Vega	vē′gȧ	α Lyrae	Arabic	the falling eagle or vulture	27
Zubenelgenubi	zōō·bĕn′ĕl·jĕ·nū′bē	α Librae	Arabic	southern claw (of the scorpion)	66

PLANETS

Name	Pronunciation	Origin of name	Meaning of name
Mercury	mûr′kū·rĭ	Latin	god of commerce and gain
Venus	vē′nŭs	Latin	goddess of love
Earth	ûrth	Mid. Eng.	—
Mars	märz	Latin	god of war
Jupiter	jōō′pĭ·tẽr	Latin	god of the heavens, identified with the Greek Zeus, chief of the Olympian gods
Saturn	săt′ẽrn	Latin	god of seed-sowing
Uranus	ū′rȧ·nŭs	Greek	the personification of heaven
Neptune	nĕp′tūn	Latin	god of the sea
Pluto	plōō′tō	Greek	god of the lower world (Hades)

Guide to pronunciations:
fāte, ădd, finăl, lȧst, ȧbound, ärm; bē, ĕnd, camēl, readẽr; īce, bĭt, anĭmal; ōver, pȯetic, hŏt, lôrd, mōōn; tūbe, ůnite, tŭb, circŭs, ûrn

*Distances in light-years. One light-year equals approximately 63,300 AU, or 5,880,000,000,000 miles. Authorities differ on distances of the stars; the values given are representative.

Figure 1332. Navigational stars and the planets.

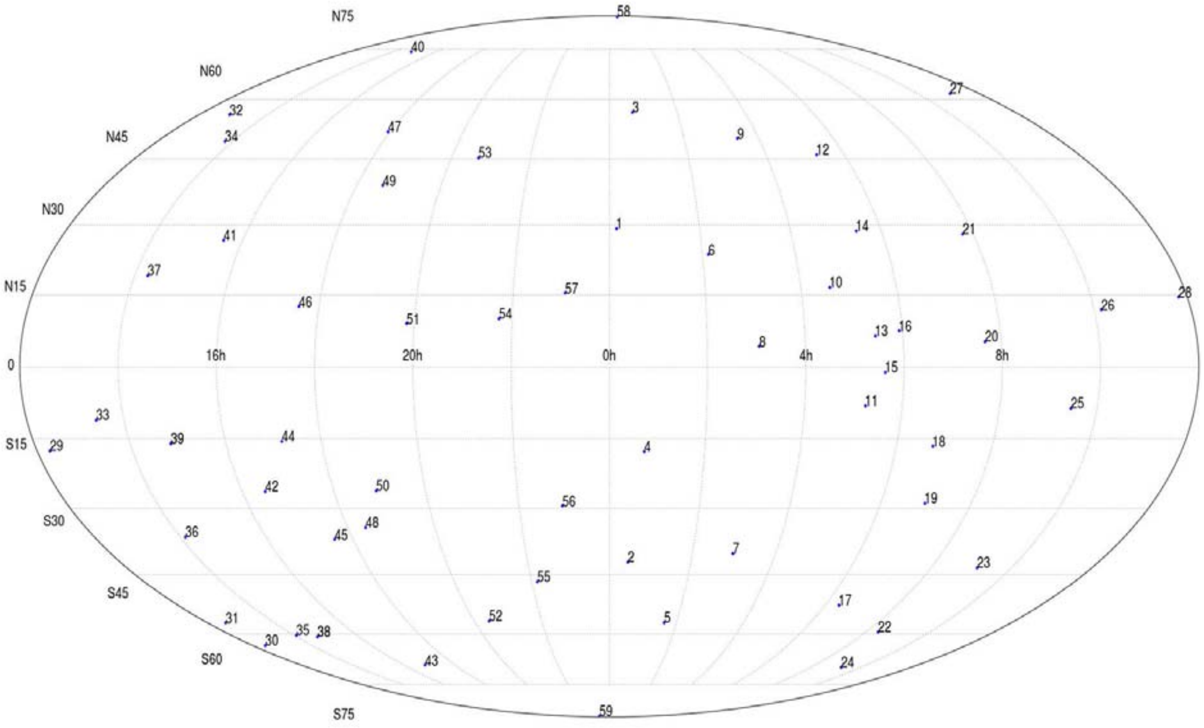


Figure 1333. Distribution of Selected Stars from the Nautical Almanac.

Augsburg, Germany, in 1603. All of the 173 stars included in the list near the back of the *Nautical Almanac* are listed by Bayer's name, and, when applicable, their common name.

- **Flamsteed's Number:** This system assigns numbers to stars in each constellation, from west to east in the order in which they cross the celestial meridian. An example is 95 Leonis, the 95th star in the constellation Leo. This system was suggested by John Flamsteed (1646-1719).

- **Catalog Number:** Stars are sometimes designated by the name of a star catalog and the number of the star as given in the catalog, such as the Henry Draper or Hipparcos catalogs. Stars are frequently listed in catalogs by increasing right ascension coordinate, without regard to constellation, for example, Polaris is known as HD 8890 and HIP 11767 in these catalogs. Navigators seldom have occasion to use this system.

1334. Star Charts

It is useful to be able to identify stars by relative position. A **star chart** (Figure 1334a and Figure 1334b) is helpful in locating these relationships and others which may be useful. This method is limited to periods of relatively clear, dark skies with little or no overcast. Stars can also be identified by the Air Almanac **sky diagrams**, a **star finder**, *Pub. No. 249*, or by computation by hand, navigational calculator, computer software or even smart phone applications.

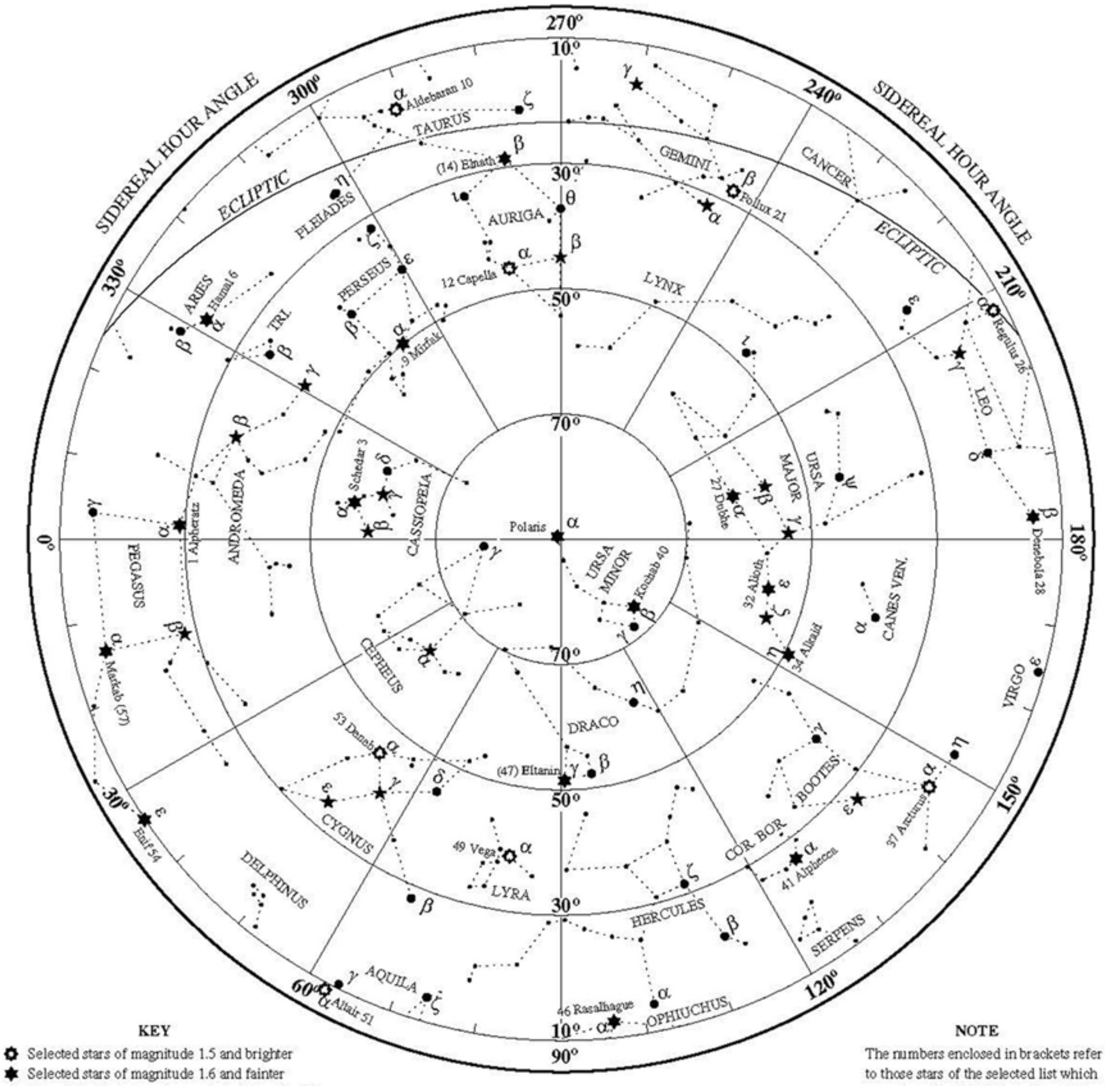
Star charts are based upon the celestial equator system of coordinates, using declination and sidereal hour angle (or right ascension). See Figure 1334c for a graphical depiction of right ascension. The zenith of the observer is at the intersection of the parallel of declination equal to his or her latitude, and the hour circle coinciding with his or her celestial meridian. This hour circle has an SHA equal to 360° – LHA ♈ (or RA = LHA ♈). The horizon is everywhere 90° from the zenith.

A **star globe** is similar to a terrestrial sphere, but with stars (and often constellations) shown instead of geographical positions. The Nautical Almanac (page 260) includes instructions for using this device. On a star globe the celestial sphere is shown as it would appear to an observer outside the sphere. Constellations appear reversed. Star charts may show a similar view, but more often they are based upon the view from inside the sphere, as seen from the Earth. On these charts, north is at the top, as with maps, but east is to the left and west to the right. The directions seem correct when the chart is held overhead, with the top toward the north, so the relationship is similar to the sky.

The *Nautical Almanac* has four star charts, located on pages 266 and 267. Two are polar projections of each hemisphere, and two are Mercator projections from 30°N to 30°S. On any of these charts, the zenith can be located as indicated, to determine which stars are overhead. The horizon is 90° from the zenith. The charts can also be used to determine the location of a star relative to surrounding stars.

STAR CHARTS

NORTHERN STARS



KEY

- ✪ Selected stars of magnitude 1.5 and brighter
- ✸ Selected stars of magnitude 1.6 and fainter
- ★ Other tabulated stars of magnitude 2.5 and brighter
- ● Other tabulated stars of magnitude 2.6 and fainter
- • Untabulated stars

NOTE

The numbers enclosed in brackets refer to those stars of the selected list which are not used in Sight Reduction Tables A.P. 3270, N.P. 303.

EQUATORIAL STARS (SHA 0° to 180°)

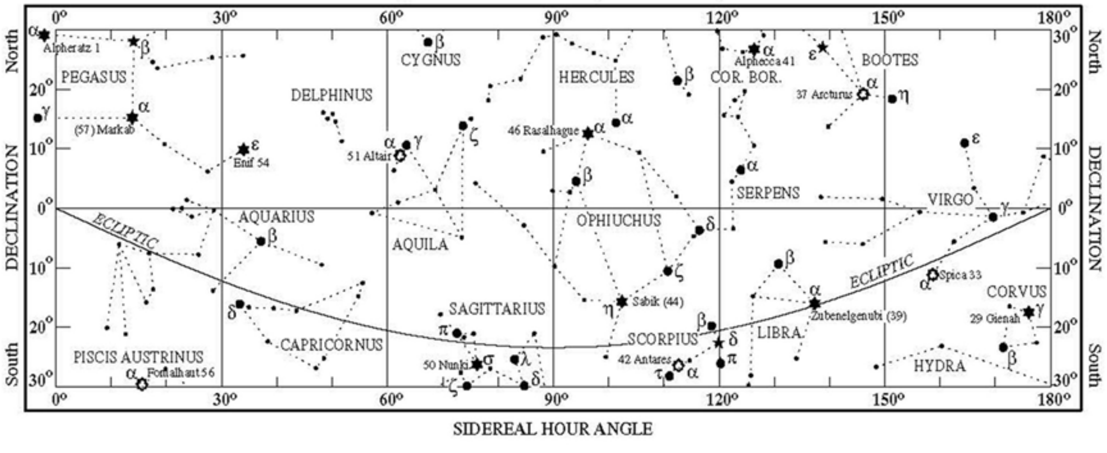
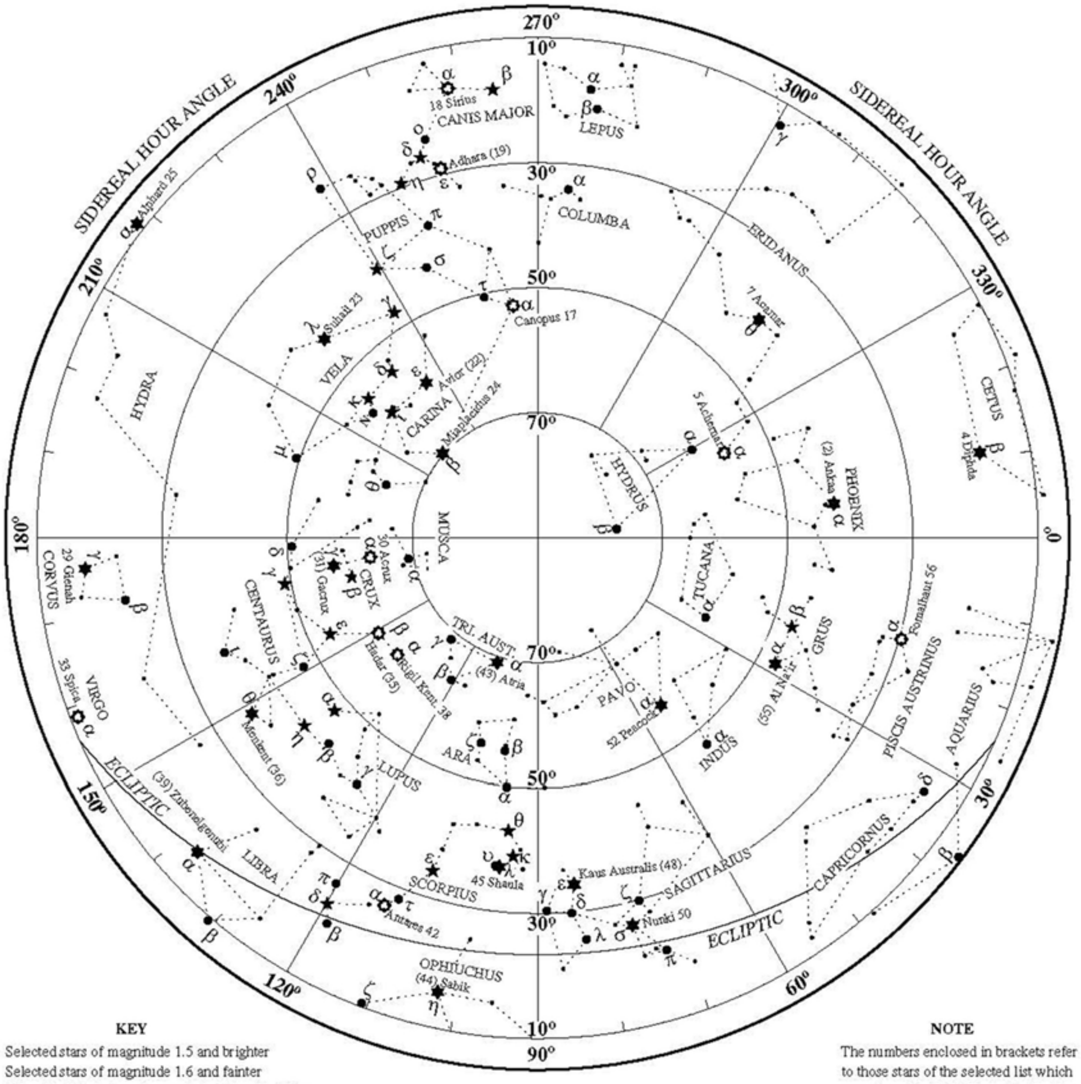


Figure 1334a. Star chart from Nautical Almanac.

STAR CHARTS

SOUTHERN STARS



KEY

- ✪ Selected stars of magnitude 1.5 and brighter
- ✸ Selected stars of magnitude 1.6 and fainter
- ★ Other tabulated stars of magnitude 2.5 and brighter
- ● Other tabulated stars of magnitude 2.6 and fainter
- • Untabulated stars

NOTE

The numbers enclosed in brackets refer to those stars of the selected list which are not used in Sight Reduction Tables A.P. 3270, N.P. 303.

EQUATORIAL STARS (SHA 180° to 360°)

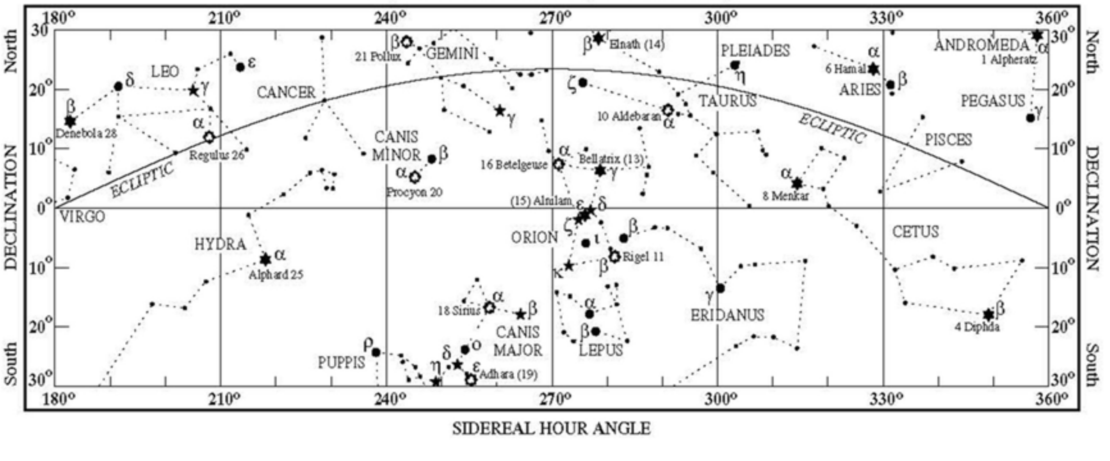


Figure 1334b. Star chart from Nautical Almanac.

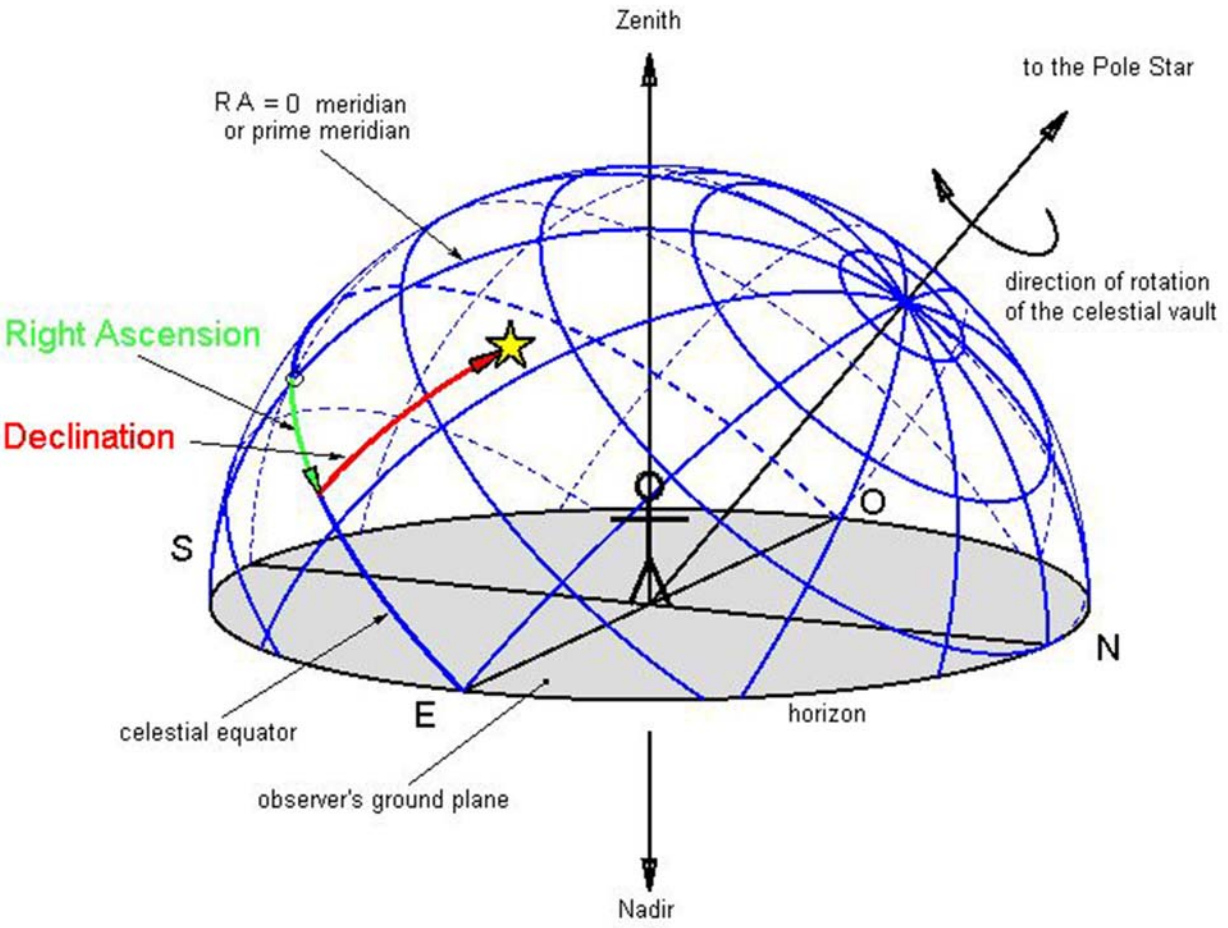


Figure 1334c. Star chart from Nautical Almanac.

	Fig. 1335	Fig.1336	Fig. 1337	Fig. 1338
Local sidereal time	0000	0600	1200	1800
LMT 1800	Dec. 21	Mar. 22	June 22	Sept. 21
LMT 2000	Nov. 21	Feb. 20	May 22	Aug. 21
LMT 2200	Oct. 21	Jan. 20	Apr. 22	July 22
LMT 0000	Sept. 22	Dec. 22	Mar. 23	June 22
LMT 0200	Aug. 22	Nov. 21	Feb. 21	May 23
LMT 0400	July 23	Oct. 22	Jan 21	Apr. 22
LMT 0600	June 22	Sept. 21	Dec. 22	Mar. 23

Table 1334. Locating the zenith on the star diagrams.

The star charts shown in Figure 1335 through Figure 1338 on the transverse Mercator projection, are designed to assist in learning Polaris and the stars listed on the daily pages of the *Nautical Almanac*. Each chart extends about 20° beyond each celestial pole, and about 60° (four hours) each side of the central hour circle (at the celestial equator). Therefore, they do not coincide exactly with that half of the celestial sphere above the horizon at any one time or place. The zenith, and hence the horizon, varies with the position of the observer on the Earth. It also varies with the rotation of the Earth (apparent rotation of the celestial sphere). The charts show all stars of fifth magnitude and brighter as they appear in the sky, but with some distortion toward the right and left edges.

The overprinted lines add certain information of use in locating the stars. Only Polaris and the 57 stars listed on the daily pages of the *Nautical Almanac* are named on the charts. The almanac star charts can be used to locate the additional stars given near the back of the *Nautical Almanac* and the Air Almanac. Dashed lines connect stars of some of the more prominent constellations. Solid lines indicate the celestial equator and useful relationships among stars in different constellations. The celestial poles are marked by crosses, and labeled. By means of the celestial equator and the poles, an observer can locate the zenith approximately along the mid hour circle, when this coincides with the celestial meridian, as shown in Table 1334. At any time earlier than those shown in Table 1334. The zenith is to the right of center, and at a later time it is to the left, approximately one-quarter of the distance from the center to the outer edge (at the celestial equator) for each hour that the time differs from that shown. The stars in the vicinity of the north celestial pole can be seen in proper perspective by inverting the chart, so that the zenith of an observer in the Northern Hemisphere is up from the pole.

1335. Stars in the Vicinity of Pegasus

In autumn the evening sky has few first magnitude stars. Most are near the southern horizon of an observer in the latitudes of the United States. A relatively large number of second and third magnitude stars seem conspicuous, perhaps because of the small number of brighter stars. High in the southern sky three third magnitude stars and one second magnitude star form a square with sides nearly 15° of arc in length. This is Pegasus, the winged horse.

Only Markab at the southwestern corner and Alpheratz at the northeastern corner are listed on the daily pages of the *Nautical Almanac*. Alpheratz is part of the constellation Andromeda, the princess, extending in an arc toward the northeast and terminating at Mirfak in Perseus, legendary rescuer of Andromeda.

A line extending northward through the eastern side of the square of Pegasus passes through the leading (western) star of M-shaped (or W-shaped) Cassiopeia, the legendary mother of the princess Andromeda. The only star of this constellation listed on the daily pages of the *Nautical Almanac* is Schedar, the second star from the leading one as the configuration circles the pole in a counterclockwise direction. If the line through the eastern side of the square of Pegasus is continued on toward the north, it leads to second magnitude Polaris, the North Star (less than 1° from the north celestial pole) and brightest star of Ursa Minor, the Little Dipper. Kochab, a second magnitude star at the other end of Ursa Minor, is also listed in the almanacs. At this season Ursa Major is low in the northern sky, below the celestial pole. A line extending from Kochab through Polaris leads to Mirfak, assisting in its identification when Pegasus and Andromeda are near or below the horizon.

Deneb, in Cygnus, the swan, and Vega are bright, first magnitude stars in the northwestern sky. The line through the eastern side of the square of Pegasus approximates the hour circle of the vernal equinox, shown at Aries on the celestial equator to the south. The Sun is at Aries on or about March 21, when it crosses the celestial equator from south to north. If the line through the eastern side of Pegasus is extended southward and curved slightly toward the east, it leads to second magnitude Diphda. A longer and straighter line southward through the western side of Pegasus leads to first magnitude Fomalhaut. A line extending northeasterly from Fomalhaut through Diphda leads to Menkar, a third magnitude star, but the brightest in its vicinity. Ankaa, Diphda, and Fomalhaut form an isosceles triangle, with the apex at Diphda. Ankaa is near or below the southern horizon of observers in latitudes of the United States. Four stars farther south than Ankaa may be visible when on the celestial meridian, just above the horizon of observers in latitudes of the extreme southern part of the United States. These are Acamar, Achernar, Al Na'ir, and Peacock. These stars, with each other and with Ankaa, Fomalhaut, and Diphda, form a series of triangles as shown in Figure 1335. Almanac stars near the bottom of Figure 1335 are discussed in succeeding articles.

Two other almanac stars can be located by their positions relative to Pegasus. These are Hamal in the constellation Aries, the ram, east of Pegasus, and Enif, west of the southern part of the square, identified in Figure 1335. The line leading to Hamal, if continued, leads to the Pleiades (the Seven Sisters), not used by navigators for celestial observations, but a prominent figure in the sky, heralding the approach of the many conspicuous stars of the winter evening sky.

1336. Stars in the Vicinity of Orion

As Pegasus leaves the meridian and moves into the western sky, Orion, the hunter, rises in the east. With the possible exception of Ursa Major, no other configuration of stars in the entire sky is as well known as Orion and its immediate surroundings. In no other region are there so many first magnitude stars.

The belt of Orion, nearly on the celestial equator, is visible in virtually any latitude, rising and setting almost on the prime vertical, and dividing its time equally above and below the horizon. Of the three second magnitude stars forming the belt, only Alnilam, the middle one, is listed on the daily pages of the *Nautical Almanac.*

Four conspicuous stars form a box around the belt. Rigel, a hot, blue star, is to the south. Betelgeuse, a cool, red star lies to the north. Bellatrix, bright for a second magnitude star but overshadowed by its first magnitude neighbors, is a few degrees west of Betelgeuse. Neither the second magnitude star forming the southeastern corner of the box, nor any star of the dagger, is listed on the daily pages of the *Nautical Almanac.*

A line extending eastward from the belt of Orion, and curving toward the south, leads to Sirius, the brightest star in the entire heavens, having a magnitude of –1.6. Only

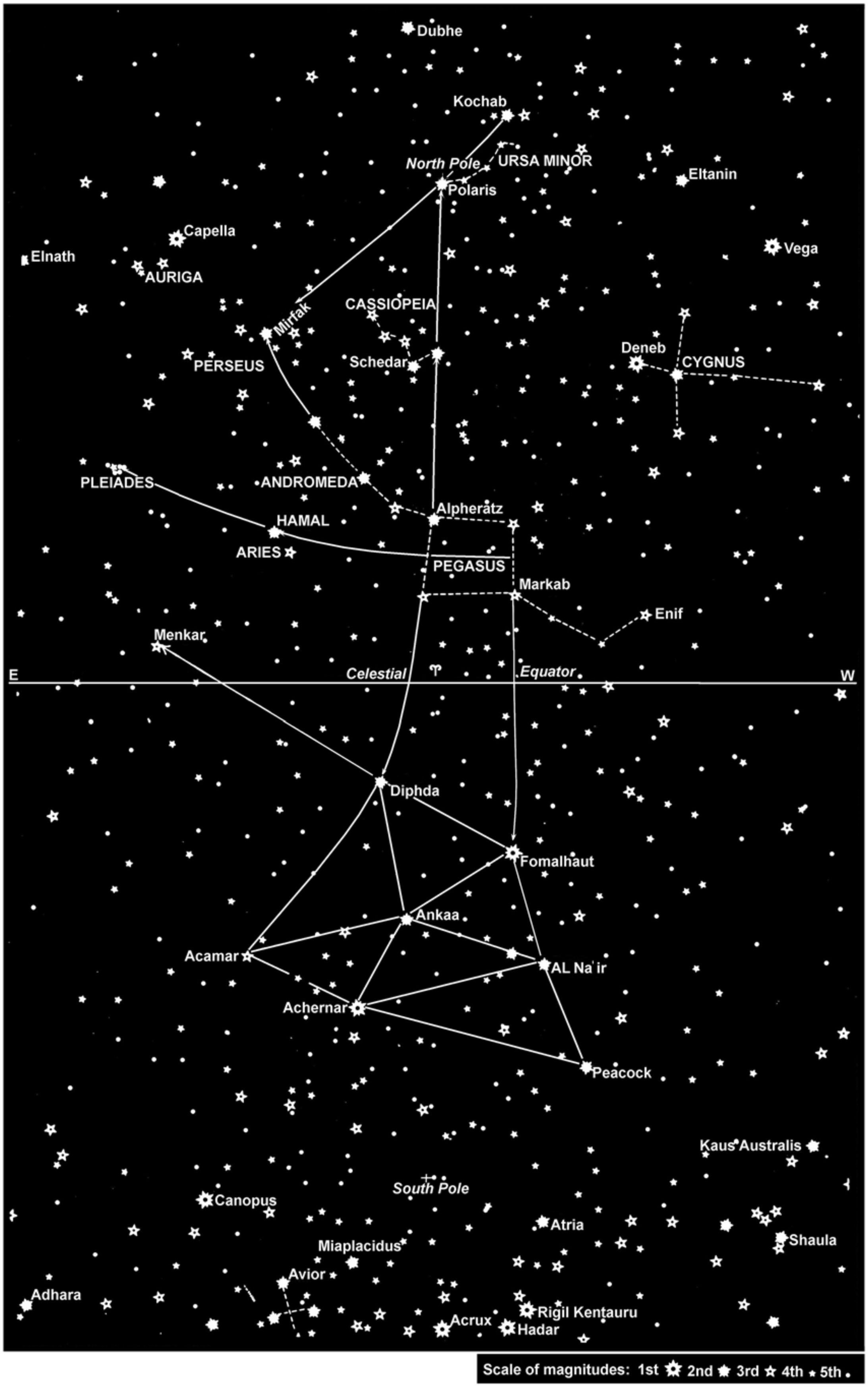


Figure 1335. Stars in the vicinity of Pegasus.

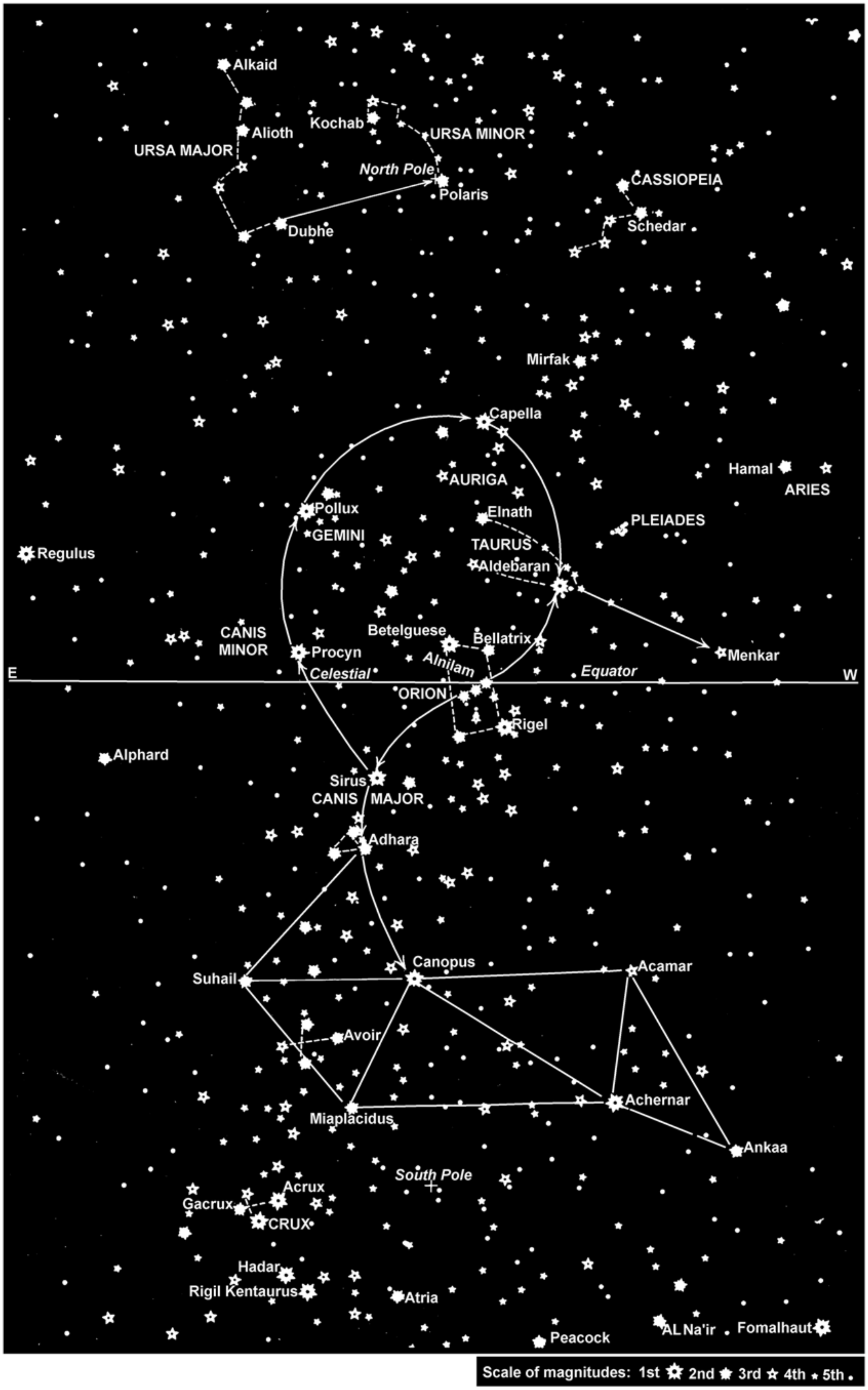


Figure 1336. Stars in the vicinity of Orion.

Mars and Jupiter at or near their greatest brilliance, the Sun, Moon, and Venus are brighter than Sirius. Sirius is part of the constellation Canis Major, the large hunting dog of Orion. Starting at Sirius a curved line extends northward through first magnitude Procyon, in Canis Minor, the small hunting dog; first magnitude Pollux and second magnitude Castor (not listed on the daily pages of the *Nautical Almanac*), the twins of Gemini; brilliant Capella in Auriga, the charioteer; and back down to first magnitude Aldebaran, the follower, which trails the Pleiades, the seven sisters. Aldebaran, brightest star in the head of Taurus, the bull, may also be found by a curved line extending northwestward from the belt of Orion. The V-shaped figure forming the outline of the head and horns of Taurus points toward third magnitude Menkar. At the summer solstice the Sun is between Pollux and Aldebaran.

If the curved line from Orion's belt southeastward to Sirius is continued, it leads to a conspicuous, small, nearly equilateral triangle of three bright second magnitude stars of nearly equal brilliancy. This is part of Canis Major. Only Adhara, the westernmost of the three stars, is listed on the daily pages of the *Nautical Almanac*. Continuing on with somewhat less curvature, the line leads to Canopus, second brightest star in the heavens and one of the two stars having a negative magnitude (–0.9). With Suhail and Miaplacidus, Canopus forms a large, equilateral triangle which partly encloses the group of stars often mistaken for Crux. The brightest star within this triangle is Avior, near its center. Canopus is also at one apex of a triangle formed with Adhara to the north and Suhail to the east, another triangle with Acamar to the west and Achernar to the southwest, and another with Achernar and Miaplacidus. Acamar, Achernar, and Ankaa form still another triangle toward the west. Because of chart distortion, these triangles do not appear in the sky in exactly the relationship shown on the star chart. Other daily-page almanac stars near the bottom of Figure 1336 are discussed in succeeding articles.

In the winter evening sky, Ursa Major is east of Polaris, Ursa Minor is nearly below it, and Cassiopeia is west of it. Mirfak is northwest of Capella, nearly midway between it and Cassiopeia. Hamal is in the western sky. Regulus and Alphard are low in the eastern sky, heralding the approach of the configurations associated with the evening skies of spring.

1337. Stars in the Vicinity of Ursa Major

As if to enhance the splendor of the sky in the vicinity of Orion, the region toward the east, like that toward the west, has few bright stars, except in the vicinity of the south celestial pole. However, as Orion sets in the west, leaving Capella and Pollux in the northwestern sky, a number of good navigational stars move into favorable positions for observation.

Ursa Major, the great bear, appears prominently above the north celestial pole, directly opposite Cassiopeia, which appears as a "W" just above the northern horizon of most observers in latitudes of the United States. Of the seven stars forming Ursa Major, only Dubhe, Alioth, and Alkaid are in the list of selected stars in *Nautical Almanac*. See Figure 1337.

The two second magnitude stars forming the outer part of the bowl of Ursa Major are often called the pointers because a line extending northward (down in spring evenings) through them points to Polaris. Ursa Minor, the Little Bear, contains Polaris at one end and Kochab at the other. Relative to its bowl, the handle of Ursa Minor curves in the opposite direction to that of Ursa Major.

A line extending southward through the pointers, and curving somewhat toward the west, leads to first magnitude Regulus, brightest star in Leo, the lion. The head, shoulders, and front legs of this constellation form a sickle, with Regulus at the end of the handle. Toward the east is second magnitude Denebola, the tail of the lion. On toward the southwest from Regulus is second magnitude Alphard, brightest star in Hydra, the sea serpent. A dark sky and considerable imagination are needed to trace the long, winding body of this figure.

A curved line extending the arc of the handle of Ursa Major leads to first magnitude Arcturus. With Alkaid and Alphecca, brightest star in Corona Borealis, the Northern Crown, Arcturus forms a large, inconspicuous triangle. If the arc through Arcturus is continued, it leads next to first magnitude Spica and then to Corvus, the crow. The brightest star in this constellation is Gienah, but three others are nearly as bright. At autumnal equinox, the Sun is on the celestial equator, about midway between Regulus and Spica.

A long, slightly curved line from Regulus, east-southeasterly through Spica, leads to Zubenelgenubi at the southwestern corner of an inconspicuous box-like figure called Libra, the scales.

Returning to Corvus, a line from Gienah, extending diagonally across the figure and then curving somewhat toward the east, leads to Menkent, just beyond Hydra.

Far to the south, below the horizon of most northern hemisphere observers, a group of bright stars is a prominent feature of the spring sky of the Southern Hemisphere. This is Crux, the Southern Cross. Crux is about 40° south of Corvus. The "false cross" to the west is often mistaken for Crux. Acrux at the southern end of Crux and Gacrux at the northern end are selected stars, listed on the daily pages of the *Nautical Almanac*.

The triangles formed by Suhail, Miaplacidus, and Canopus, and by Suhail, Adhara, and Canopus, are west of Crux. Suhail is in line with the horizontal arm of Crux. A line from Canopus, through Miaplacidus, curved slightly toward the north, leads to Acrux. A line through the east-west arm of Crux, eastward and then curving toward the south, leads first to Hadar and then to Rigil Kentaurus, both very bright stars. Continuing on, the curved line leads to small Triangulum Australe, the Southern Triangle, the easternmost star of which is Atria.

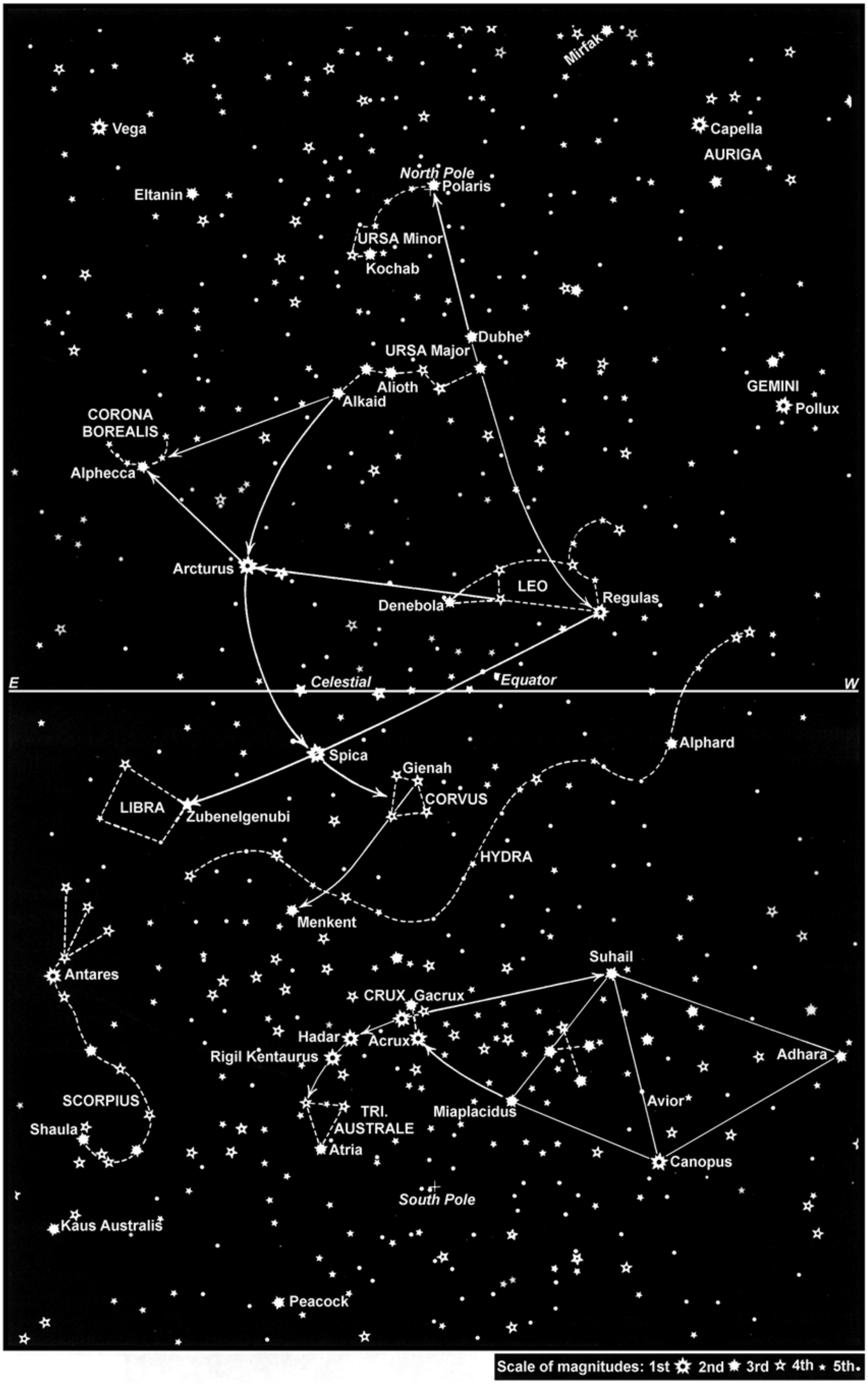


Figure 1337. Stars in the vicinity of Ursa Major.

1338. Stars in the Vicinity of Cygnus

As the celestial sphere continues in its apparent westward rotation, the stars familiar to a spring evening observer sink low in the western sky. By midsummer, Ursa Major has moved to a position to the left of the north celestial pole, and the line from the pointers to Polaris is nearly horizontal. Ursa Minor, is standing on its handle, with Kochab above and to the left of the celestial pole. Cassiopeia is at the right of Polaris, opposite the handle of Ursa Major. See Figure 1338.

The only first magnitude star in the western sky is Arcturus, which forms a large, inconspicuous triangle with Alkaid, the end of the handle of Ursa Major, and Alphecca, the brightest star in Corona Borealis, the Northern Crown.

The eastern sky is dominated by three very bright stars. The westernmost of these is Vega, the brightest star north of the celestial equator, and third brightest star in the heavens, with a magnitude of 0.1. With a declination of a little less than 39°N, Vega passes through the zenith along a path across the central part of the United States, from Washington in the east to San Francisco on the Pacific coast. Vega forms a large but conspicuous triangle with its two bright neighbors, Deneb to the northeast and Altair to the southeast. The angle at Vega is nearly a right angle. Deneb is at the end of the tail of Cygnus, the swan. This configuration is sometimes called the Northern Cross, with Deneb at the head. To modern youth it more nearly resembles a dive bomber, while it is still well toward the east, with Deneb at the nose of the fuselage. Altair has two fainter stars close by, on opposite sides. The line formed by Altair and its two fainter companions, if extended in a northwesterly direction, passes through Vega, and on to second magnitude Eltanin. The angular distance from Vega to Eltanin is about half that from Altair to Vega. Vega and Altair, with second magnitude Rasalhague to the west, form a large equilateral triangle. This is less conspicuous than the Vega-Deneb-Altair triangle because the brilliance of Rasalhague is much less than that of the three first magnitude stars, and the triangle is overshadowed by the brighter one.

Far to the south of Rasalhague, and a little toward the west, is a striking configuration called Scorpius, the scorpion. The brightest star, forming the head, is red Antares. At the tail is Shaula.

Antares is at the southwestern corner of an approximate parallelogram formed by Antares, Sabik, Nunki, and Kaus Australis. With the exception of Antares, these stars are only slightly brighter than a number of others nearby, and so this parallelogram is not a striking figure. At winter solstice the Sun is a short distance northwest of Nunki.

Northwest of Scorpius is the box-like Libra, the scales, of which Zubenelgenubi marks the southwest corner.

With Menkent and Rigil Kentaurus to the southwest, Antares forms a large but unimpressive triangle. For most observers in the latitudes of the United States, Antares is low in the southern sky, and the other two stars of the triangle are below the horizon. To an observer in the Southern Hemisphere Crux is to the right of the south celestial pole, which is not marked by a conspicuous star. A long, curved line, starting with the now-vertical arm of Crux and extending northward and then eastward, passes successively through Hadar, Rigil Kentaurus, Peacock, and Al Na'ir.

Fomalhaut is low in the southeastern sky of the southern hemisphere observer, and Enif is low in the eastern sky at nearly any latitude. With the appearance of these stars it is not long before Pegasus will appear over the eastern horizon during the evening, and as the winged horse climbs evening by evening to a position higher in the sky, a new annual cycle approaches.

1339. Planet Diagram

The planet diagram, on page 9 of the *Nautical Almanac* shows, for any date, the Local Mean Time (LMT) of meridian passage of the Sun, for the five planets Mercury, Venus, Mars, Jupiter, and Saturn, and of each 30° of SHA (Figure 1339). The diagram provides a general picture of the availability of planets and stars for observation, and thus shows:

1. Whether a planet or star is too close to the Sun for observation.
2. Whether a planet is a morning or evening star.
3. Some indication of the planet's position during twilight.
4. The proximity of other planets.
5. Whether a planet is visible from evening to morning twilight.

A band 45 minutes wide is shaded on each side of the curve marking the LMT of meridian passage of the Sun. Planets and stars lying within the shaded area are too close to the Sun for observation.

When the meridian passage occurs at midnight, the body is in opposition to the Sun and is visible all night; planets may be observable in both morning and evening twilights. When meridian passage is between 12h and 24h (that is, after the Sun's meridian passage), the object is visible in the evening sky, after sunset. When meridian passage is between 0 and 12 hours (that is, before the Sun's meridian passage) the object is visible in the morning sky, before sunrise. Graphically, if the curve for a planet intersects the vertical line connecting the date graduations below the shaded area, the planet is a morning "star"; if the intersection is above the shaded area, the planet is an evening "star".

Only about one-half the region of the sky along the ecliptic, as shown on the diagram, is above the horizon at one time. At sunrise (LMT about 6^h) the Sun and, hence, the

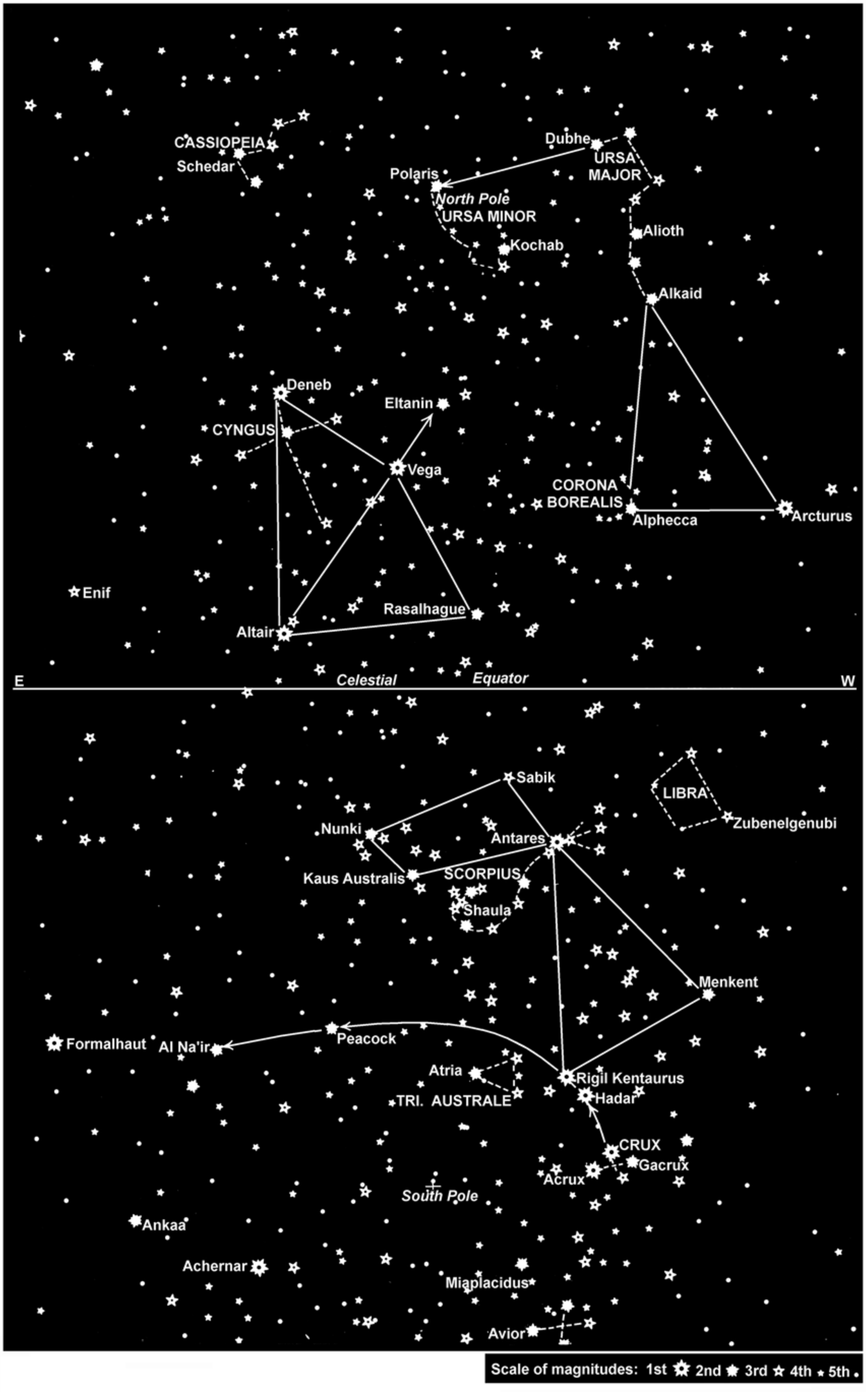


Figure 1338. Stars in the vicinity of Cygnus.

region near the middle of the diagram, are rising in the east; the region at the bottom of the diagram is setting in the west. The region half way between is on the meridian. At sunset (LMT about 18^h) the Sun is setting in the west; the region at the top of the diagram is rising in the east. Marking the planet diagram of the *Nautical Almanac* so that east is at the top of the diagram and west is at the bottom can be useful to interpretation.

A similar planet location diagram in the *Air Almanac* (pages A122-A123) represents the region of the sky along the ecliptic. It shows, for each date, the Sun in the center and the relative positions of the Moon, the five planets Mercury, Venus, Mars, Jupiter, Saturn and the four first magnitude stars Aldebaran, Antares, Spica, and Regulus, and also the position on the ecliptic which is north of Sirius (i.e. Sirius is 40° south of this point). The first point of Aries is also shown for reference. The magnitudes of the planets are given at suitable intervals along the curves. The Moon symbol shows the correct phase. A straight line joining the date on the left-hand side with the same date of the right-hand side represents a complete circle around the sky, the two ends of the line representing the point 180° from the Sun; the intersections with the curves show the spacing of the bodies along the ecliptic on the date. The time scale indicates roughly the local mean time at which an object will be on the observer's meridian.

At any time only about half the region on the diagram is above the horizon. At sunrise the Sun (and hence the region near the middle of the diagram), is rising in the east and the region at the end marked "West" is setting in the west; the region half-way between these extremes is on the meridian, as will be indicated by the local time (about 6^h). At the time of sunset (local time about 18^h) the Sun is setting in the west, and the region at the end marked "East" is rising in the east. The diagram should be used in conjunction with the Sky Diagrams.

1340. Finding Stars for a Fix

Various devices have been invented to help an observer find individual stars. The most widely used is the **Star Finder and Identifier**, also known as a **Rude Star Finder** and formerly published by the U.S. Navy Hydrographic Office as **No. 2102D**. It is no longer issued, but it is still available commercially. A navigational calculator or computer program, like the U.S. Navy STELLA program is much quicker, more accurate, and less tedious. A navigational calculator can be used to predict the best stars to observe for a fix. See Section 1900 - Computer Sight Reduction for a more thorough discussion.

HO Publication 249, (Rapid Sight Reduction Tables for Navigation), Volume 1, identifies the best three and seven stars for a navigational fix given an observer's latitude and LHA of Aries. This publication is also known as AP 3270.

The navigational program also solves for the LOP's for each object observed, combines them into the best fix, and displays the lat./long. position. Most navigational programs also print out a plotted fix, just as the navigator might have drawn by hand.

Computer sight reduction programs can also automatically predict twilight on a moving vessel and create a plot of the sky at the vessel's twilight location (or any location, at any time). This plot will be free of the distortion inherent in the mechanical star finders and will show all bodies, even planets, Sun, and Moon, in their correct relative orientation centered on the observer's zenith. It will also indicate which stars provide the best geometry for a fix.

Computer sight reduction programs or celestial navigation calculators, or apps are especially useful when the sky is only briefly visible thorough broken cloud cover.

1341. Identification by Computation

If the altitude and azimuth of the celestial body, and the approximate latitude of the observer, are known, the navigational triangle can be solved for meridian angle and declination. The meridian angle can be converted to LHA, and this to GHA. With this and GHA ♈ at the time of observation, the SHA of the body can be determined. With SHA and declination, one can identify the body by reference to an almanac. Any method of solving a spherical triangle, with two sides and the included angle being given, is suitable for this purpose.

Although no formal star identification tables are included in *Pub. No. 229*, a simple approach to star identification is to scan the pages of the appropriate latitudes, and observe the combination of arguments which give the altitude and azimuth angle of the observation. Thus the declination and LHA H are determined directly. The star's SHA is found from SHA H = LHA H – LHA ♈ . From these quantities the star can be identified from the *Nautical Almanac*.

Another solution is available through an interchange of arguments using the nearest integral values. The procedure consists of entering *Pub. No. 229* with the observer's latitude (same name as declination), with the observed azimuth angle (converted from observed true azimuth as required) as LHA and the observed altitude as declination, and extracting from the tables the altitude and azimuth angle respondents. The extracted altitude becomes the body's declination; the extracted azimuth angle (or its supplement) is the meridian angle of the body. Note that the tables are always entered with latitude of same name as declination. In north latitudes the tables can be entered with true azimuth as LHA.

If the respondents are extracted from above the C-S Line on a right-hand page, the name of the latitude is actually contrary to the declination. Otherwise, the declination of the body has the same name as the latitude. If the azimuth angle respondent is extracted from above the C-S Line, the supplement of the tabular value is the meridian angle, t, of the body. If the body is east of the observer's meridian, LHA = 360° – t; if the body is west of the meridian, LHA = t.

PLANETS, 2016

LOCAL MEAN TIME OF MERIDIAN PASSAGE

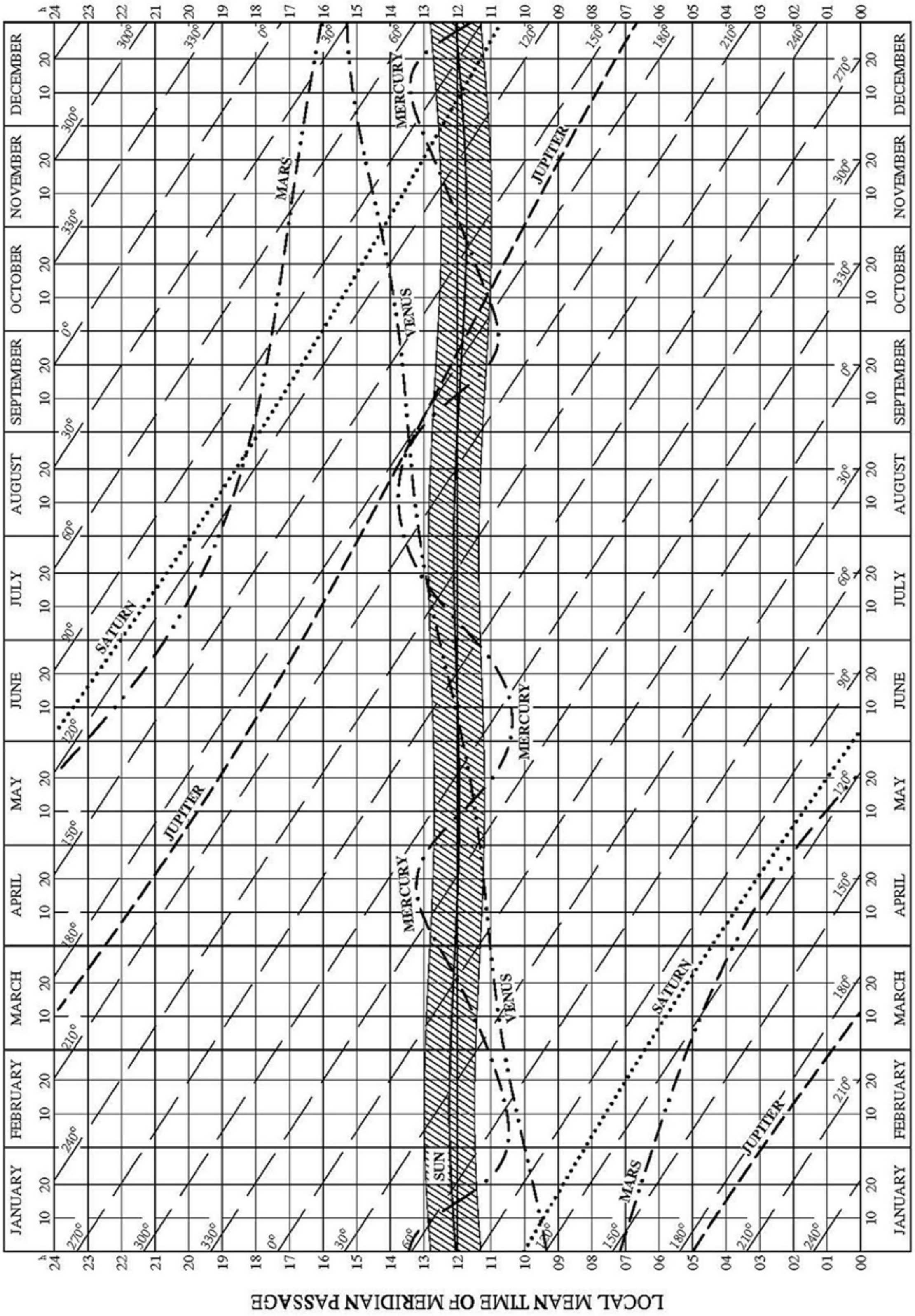


Figure 1339. Reproduction of Nautical Almanac Page 9.

Figure 1341. The Ghost of Cassiopeia. Image Credits: NASA, ESA and STScl; Acknowledgment: H. Arab (University of Strasbourg). Powerful gushers of energy from seething stars can sculpt eerie-looking figures with long, flowing veils of gas and dust. One striking example is "the Ghost of Cassiopeia" officially known as IC 63, located 550 light-years away in the constellation Cassiopeia the Queen.The constellation Cassiopeia is visible every clear night from mid-northern and higher latitudes. Its distinctive "W" asterism, which forms the queen's throne, is best seen high in the sky on autumn and winter evenings. Gamma Cassiopeiae, the middle star in the W, is visible to the unaided eye, but a large telescope is needed to see IC 63. Hubble photographed IC 63 in August 2016.