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ABSTRACT This guide provides the interested student with a wide range of astronomical investigations that require a minimum of equipment. Activities focus on analysis and understanding of numerous celestial events which are observable every day. The guide is intended to lead the amateur through initial steps in the understanding of some of the functions of the universe.
 (Author/RE)

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field
guide
to

ASTRONOMY Without a TELESCOPE

William A. Dexter

SE 089 282

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The first effort to understand the universe must begin with the amateur. Every day we witness a panorama of celestial events, many of which could be understood more clearly by performing some of the activities suggested in this pamphlet. This guide provides the interested student with a wide range of investigations that require a minimum of equipment.

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FIELD GUIDE TO

Astronomy

Without a

Telescope

William A. Dexter

Series Editor: Robert E. Boyer

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Astronomy Without a Telescope

INTRODUCTION

Have you ever wondered how we know the earth's place in space, the distances to the stars, when eclipses of the sun and moon will occur, or how stars produce light?

Answering these and many other questions is the work of professional astronomers, but getting out at night and looking for yourself is fascinating. Hundreds of thousands of people all over the world pursue astronomy as a hobby, and some gather information that is essential to the professional astronomer.

Perhaps you have wondered how high the sky is and how many stars it contains. This depends on your interpretation of what is meant by the sky. To meteorologists, the sky may be limited to the space in which all atmospheric phenomena take place. To astronomers, there is no limit. The sky appears to continue to infinity, and space has no edge. Our universe consists of everything that ever was and still is. Because most of this universe is empty, one might say that the universe has no boundaries. It is like an imaginary endless sea of night with stars and galaxies strung out like beacons of light, many at fantastic distances, and some distant stars that are rushing away from us at nearly the speed of light. Some stars are billions of light-years away; others are close neighbors of our sun.

Probably more stars exist in our heavens than grains of sand on all the beaches on earth. These countless billions of stars are certainly not all visible to us, but some in our immediate vicinity are within the reach of the unaided eye. How many can you see on a clear night away from the smog and lights of the city? The light-gathering power of the human eye is limited, and an average observer can probably see no more than three thousand stars even under ideal conditions.

Astronomy is a science in which the amateur is respected, and in which he can make a contribution. There simply are not enough full-time astronomers to keep track of many of the things that are happening. In fact, well over 200 amateur astronomical societies and clubs are scattered over the United States; you may be interested in joining the group nearest you. Ask an astronomy or earth science instructor for the name of the local club, or write to *Sky and Telescope* (in References) for a free list of all the astronomical societies in the United States.

Most amateur astronomers, however, watch the skies just for their own pleasure. While doing so, they may be the first to sight an unknown bright comet or a *nova*, an exploding star that appears to be "new." If you are the first to find a comet, it will be named after you. During the past few years, two Japanese amateur astronomers, a guitar player (Ikaya) and a piano tuner (Seki), have discovered several comets. One, which they both discovered the same night, now has the name Ikaya-Seki.

This guide is intended to acquaint you with astronomical objects—their nature, positions, and movement. It requires no equipment other than your eyes and perhaps a pair of binoculars. It can be used profitably in your own back yard or for organized field trips in astronomy.

You do not have to travel far to appreciate the sky; wherever you are you see a constantly changing panorama of celestial events. The farther away from city lights, however, the better.

OBSERVING THE SKY

Constellations

Constellations are arrangements of stars, long imagined to outline the shapes of objects or beings. Each season is announced by its display of these imaginary inhabitants of the sky. Today astronomers recognize 88 constellations whose boundaries are well defined. Depending on your latitude, you can see 40 to 50 percent of them at a time.

Bright stars within constellations are known by Arabic names and are also assigned letters from the Greek alphabet: Alpha generally indicates the brightest, Beta the next brightest, and so on.

On star maps, the constellation *Ursa Major* (The Big Dipper) is a key for finding stars and constellations in the Northern Hemisphere. A star map is found on pages 26-29. The following methods, illustrated in Figure 1, are a few examples:

- 1) Draw a straight line from the "pointer stars" at the Big Dipper's end in the direction of the open side; this line will point directly to *Polaris*, the North Star, and on to the constellation *Cepheus* (The King).
- 2) Draw a straight line following the pointer stars in the opposite direction toward the closed side of the Dipper; it will point directly to the constellations *Leo Minor* (The Little Lion) and *Leo Major* (The Big Lion).
- 3) Along the handle of the Dipper, draw a curved line following the arc of the handle off its back end; it will curve to the constellation *Boötes* (The Herdsman) and the bright star *Arcturus*.
- 4) Following the curvature of the Dipper's handle across the bowl points to the constellation *Gemini* (The Twins).
- 5) The two stars of the open top of the Dipper's bowl away from the handle point to the constellation *Auriga* (The Charioteer) with its bright star *Capella*.

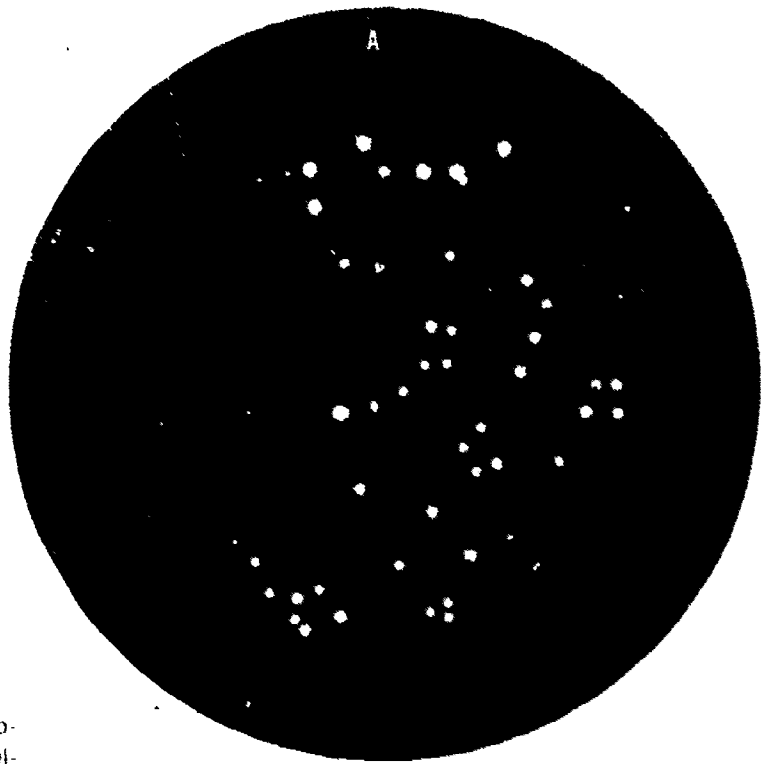
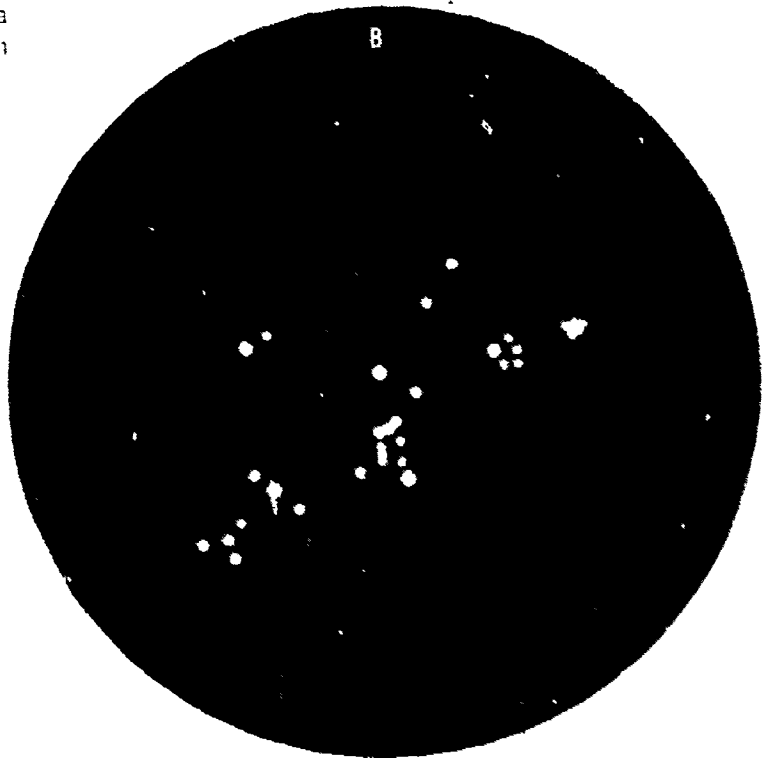


Figure 1 How to locate stars and constellations using the constellations (A) Ursa Major and (B) Orion as keys





On star maps *Orion* (The Hunter), a familiar winter constellation, is used as a guide for finding other winter groups:

- 1) Follow the belt of Orion toward the east to *Canis Major* (The Big Dog) and the brightest star in the sky, *Sirius*.
- 2) Well above Sirius is the bright star *Procyon*, in the constellation *Canis Minor* (The Small Dog).
- 3) In a line to the west of Orion's belt lie the constellation *Taurus* (The Bull) and the star clusters *Hyades* and *Pleiades*. This straight line passes just beneath the bright star *Aldebaran*.

You can find several other ways to locate constellations using star charts. Imagination is the key to successful constellation study. Use it. See if you can locate each of the constellations mentioned in this section in the sky.

The Sky

The sky is the limit, and in it are the stars, moon, sun, and planets; this darkened dome above our heads seems to extend "forever." In fact, at this moment there is a star in the sky that is exactly overhead for each person on earth. It is at his *zenith*, or overhead point. Every place has its own zenith. If you walk a block from where you are now standing, your zenith will have changed (Figure 2).

Figure 2 Your zenith changes with your motion and the motion of the earth

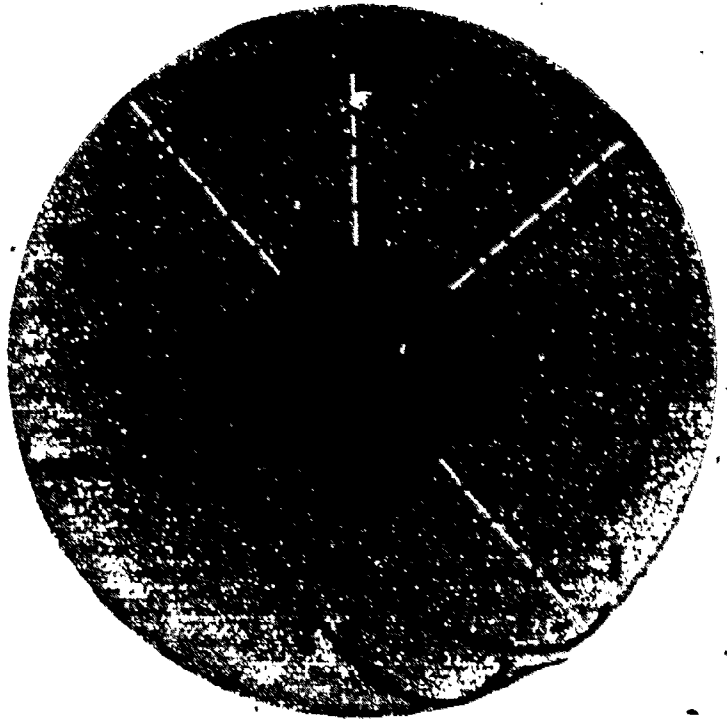


Figure 3 Important points and lines on the sky. The ecliptic is the path along which the sun appears to move among the stars.

Since ancient times the sky has been regarded as an inverted bowl or dome. Because of this illusion, for centuries astronomers have spoken of the *celestial sphere*. Stars appear fixed on this celestial dome, and the earth's rotation gives us the impression that the entire dome of the sky turns while we stand still. Whether a star is far or near, it has a definite position on the celestial sphere. For example, both the distant Andromeda Galaxy and the nearby star Sirius have precise locations on the celestial sphere. In contrast, the planets, sun, and moon change their positions; for this reason no star map can indicate their positions for very long.

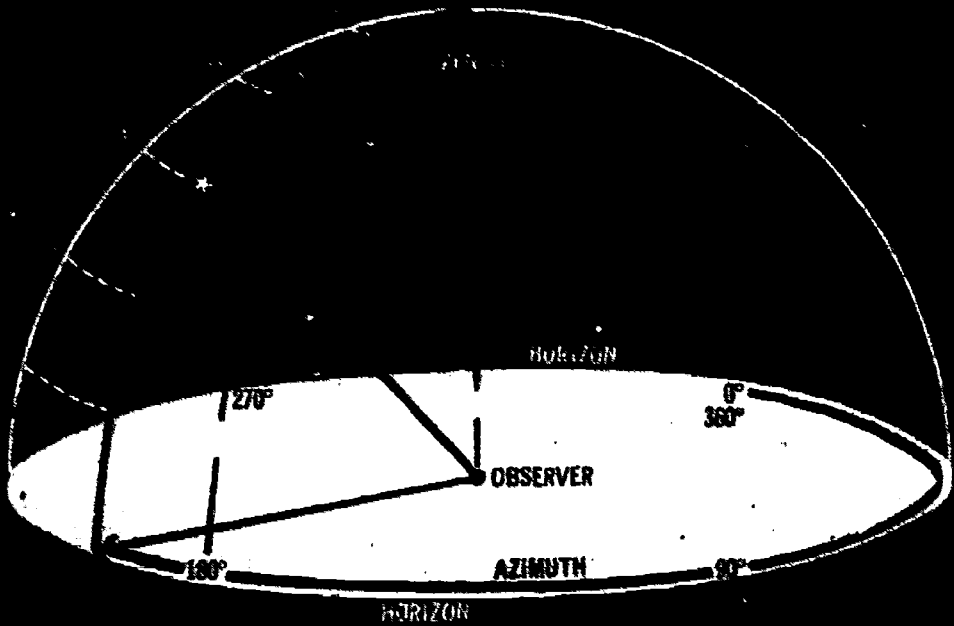
Finding Celestial Objects

The first step in observing the sky is to orient yourself in relation to the celestial sphere. Imagine the earth as a balloon that can be blown up until it "touches the sky." The line where the equator of the earth would then touch the sky is the *celestial*

equator (Figure 3). The point where the north pole touches the sky becomes the *north celestial pole* (NCP). The celestial sphere appears to turn around its poles in the same manner that the earth turns around its axis, but in the opposite direction, the same way that trees and houses seem to be going by when you are in a moving car.

The observer's *meridian* is an important imaginary line (Figure 3), extending from the horizon in the north through the north celestial pole, then through the zenith, and on down to the horizon in the south. Once you have established the meridian and remember that east is on the right as you look north, you have enough information to record positions in the sky. This method, called the *horizon system*, uses the coordinates azimuth and altitude (Figure 4). *Azimuth* is the angle measured around the horizon (in degrees); *altitude* is the angle from the horizon up to that object (also in degrees). Azimuth is measured eastward from north; altitude is measured from 0° on the horizon to 90° at the

Figure 4. Describing the position of a star by the horizon system.



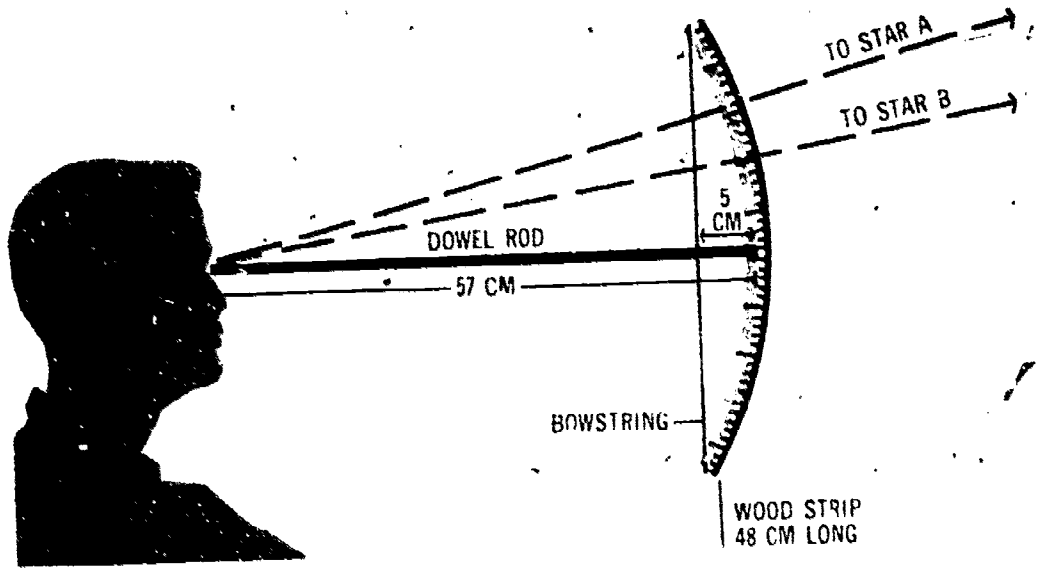


Figure 5 Building the ancestor of the modern sextant

zenith. Remembering the daily motion of the earth, can you see the disadvantage of the horizon system?

The ancestor of the modern sextant (Figure 5) can help find positions of objects by the horizon system. This instrument can be easily made from a thin strip of wood 48 centimeters long, marked off in centimeters. Bend it so that it bows five centimeters from the center and attach a string tacked to a dowel 57 centimeters long. Every centimeter on the bent strip of wood measures one degree from the end of the dowel which you hold up to your eye.

Directions on the sky are the same as directions on earth. Traveling north on earth means traveling toward the earth's north pole; the same is true on the sky. On earth we travel northward to higher latitudes; on the sky we do the same thing, except that latitude on the sky is called *declination*. Parallels of latitude thus become parallels of declination, two different names for the same thing. The altitude of Polaris equals your latitude on earth, as shown in Figure 6.

East and west directions on the sky are also given different names. On earth we measure angular distances (*longitude*) east or west of the Prime Meridian at Greenwich, England. For example, St. Louis is 90° west of Greenwich; Tokyo is 140°

east of Greenwich. The circles like meridians of longitude on earth are called *hour circles* on the sky. It would have been simpler if the terms "latitude" and "longitude" were also used on the sky. However, through centuries of tradition, what corresponds to latitude is called *declination* on the sky, and what corresponds to longitude is called *right ascension* on the sky.

Star Time

Right ascension is measured in hours, minutes, and seconds, rather than in degrees. The position of a star on the celestial sphere, for example Arcturus, is given as 14 hours 14 minutes right ascension, $+19^\circ$ declination. It would seem that we are mixing apples and oranges (time and degrees), but this method is logical if the celestial sphere is likened to a clock. Unlike familiar clocks in which the face remains stationary and the hands move, the clock of the sky has a single hand, the meridian, which seems to remain stationary. Instead the clock face (the celestial sphere) moves. When the earth turns eastward once around its axis, the sky seems to turn westward once around us. It takes 24 hours for one such turn, and since a full turn is 360° , 360° equals 24 hours; so one hour equals 15° , and one degree equals four minutes of time.

Start at some arbitrary zero point on the sky: one hour later the sky will apparently have turned westward through 15° . This is the first hour circle. Similarly, 3, 10, and 15 hours later the earth (and therefore to us the sky) will have turned through 45° , 150° , and 225° , respectively, and the 3rd, 10th, and 15th hour circles will have come to our meridian. It takes "time" for the earth to turn (rotate) out from under the stars. This is why the west-east direction of the sky is measured in hours rather than in degrees, although one could say that a star whose right ascension is 15 hours (the star is on the 15th hour circle of the sky) has a right ascension of 225° .

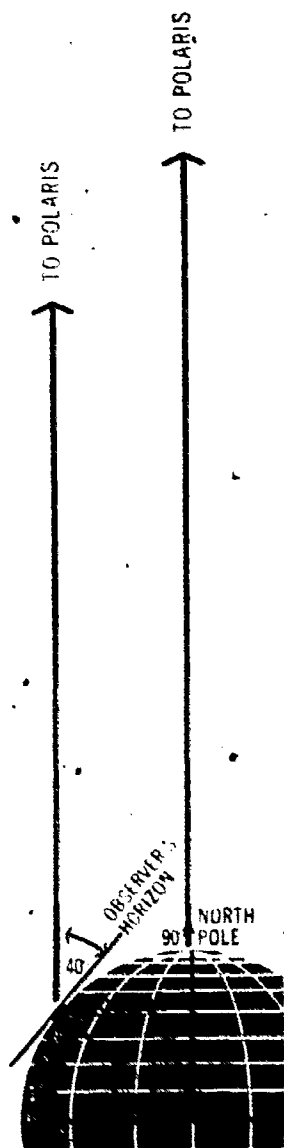


Figure 6 Geometrical proof that the altitude of Polaris equals the observer's latitude. What would the altitude of Polaris be if you were at the North Pole? If you were on the equator?

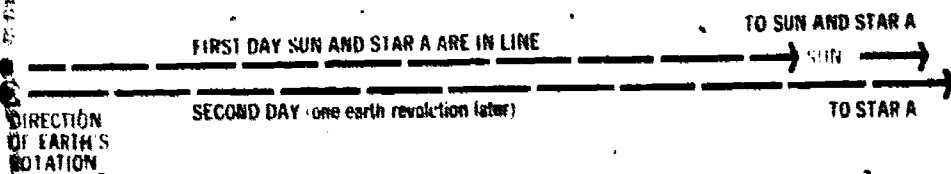
All we need to know is the location of the zero hour circle on the sky. On the earth longitude starts with the Greenwich Meridian, but on the sky there is no Greenwich. Any arbitrary point on the equator of the sky could be designated zero, but nature has provided a convenient starting point. The zero of the celestial clock is the meridian along which is located that point on the sky where the sun is on March 21. This point is called the *vernal equinox*; technically it is where the apparent path of the sun on the sky (the *ecliptic*) crosses the celestial equator going from south to north (Figure 3). The celestial equator is inclined $23\frac{1}{2}^\circ$ from the ecliptic because the earth is tilted $23\frac{1}{2}^\circ$ with respect to the plane of the solar system.

The location of this reference-point can be estimated if you know the date, location of the sun during the time of observation (time of day), and the rate of the sun's apparent eastward movement. This rate is four minutes or one degree per day.

Activity 1—Suppose the sun were at the noon position (midway between rising and setting), and the date were April 15. Where would you find the vernal equinox? (Activity discussions and answers are in the Appendix, page 46.)

When this zero hour is on the meridian, the *star time* is zero. One hour later, star time is one hour; ten hours later, ten hours. Star time is used to denote a star's position on the sky because if a star has a right ascension of eight hours, it will be on the meridian when the star time is eight hours.

At what time of the day do the zero hour circle and vernal equinox cross the meridian? It would be convenient if this occurred at the same time every day. But it does not, and for a good reason. Suppose the sun and a star are both on the meridian one day (at noon). Do you think the sun and that star would get back to the meridian at the same time the following day? They would not, but why? Because the



EARTH'S ORBIT AROUND SUN

earth is revolving about the sun while it rotates on its axis. As seen in Figure 7, if the sun and a star start together, when the earth has completed one full rotation about its axis the star—but not the sun—will be back on the meridian. Because of the earth's revolution around the sun, the sun appears to move slowly eastward among the stars. Consequently, it takes longer for the sun to get back to the meridian each day than it does for a star. Every day the sun will seem to lag behind the star. Why? The earth has moved $1/365$ of its journey about the sun. Consequently, the sun will reach the meridian about $1/365 \times 24$ hours, or about four minutes, later each day. The sun day is therefore approximately four minutes longer than a star day.

Constellations near the meridian early one evening will be seen two hours west of the meridian one month later (4 minutes or $1/15$ hour \times 30 days). This is because the stars advance westward $1/12$ of the earth's entire revolution per month, and $1/12$ of 24 hours is 2 hours. Thus, the sky can be considered both a clock and a calendar. To orient most star maps properly, you must know the local star time, or the sun time and the date.

A handy rule of thumb for calculating star time so that you can orient a star chart properly is to take the number of months past March 21, multiply by two, and add the number of hours past noon. Try this for 9 P.M. today and see if it works.

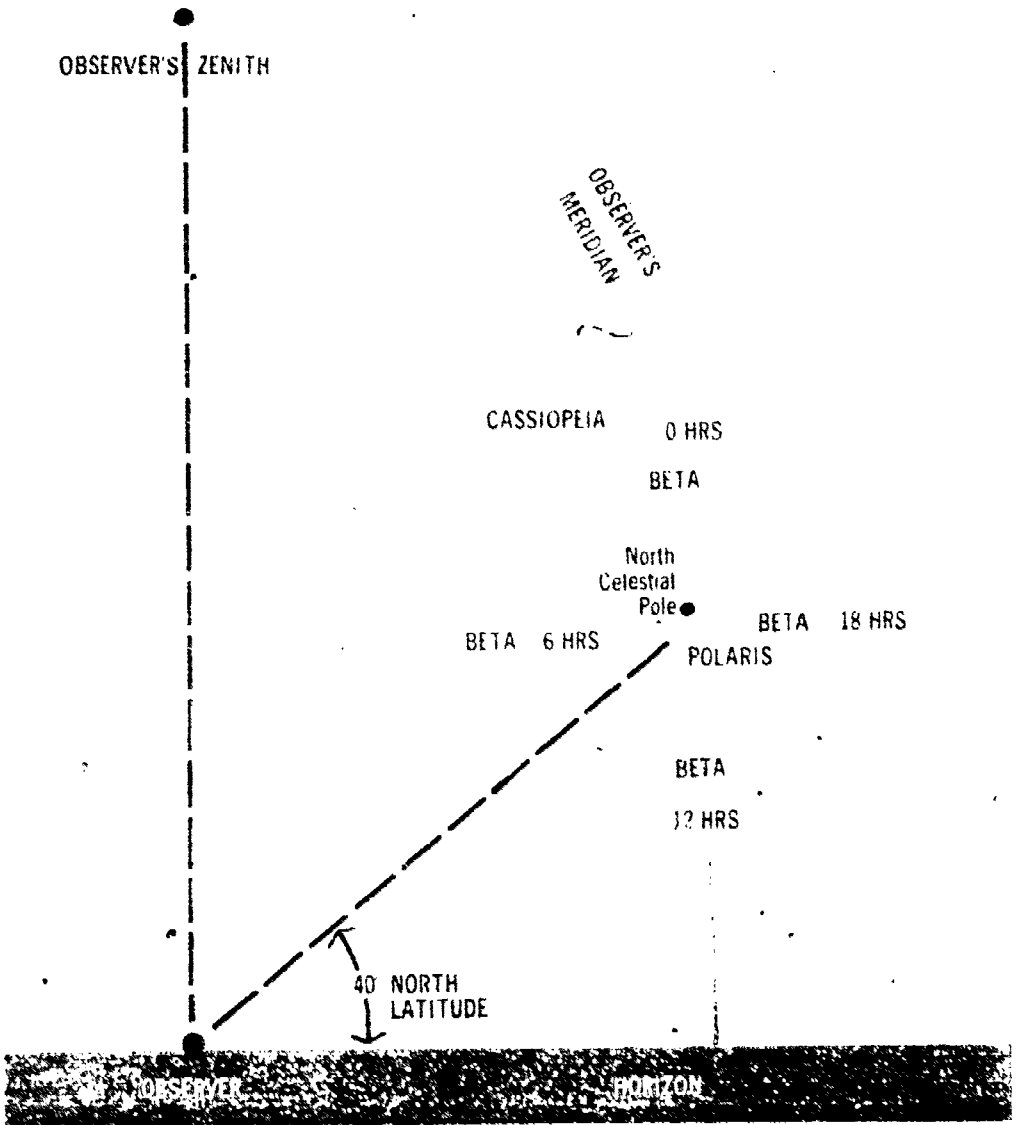
Figure 7. Sun time versus star time. After the earth makes a complete rotation on its axis according to the stars, it must rotate four extra minutes to turn the same face toward the sun because of its revolution around the sun. What would happen if the earth rotated in the opposite direction?

Activity II—How can you find out if the difference between a sun day and a star day is really four minutes? Some evening select a star, preferably one of the brightest, and record its exact position in reference to your observing position. Sit or stand firmly and sight on that star in reference to a fence post, branch or tree, or some other convenient marking device. At the instant the star is in line with your marker, check your watch (which reads sun time at a standard meridian near you). The following night, at exactly the same watch time, make this sighting again. What do you observe? Continue to repeat this observation on successive nights.

The sky itself offers a quick, rough way of telling star time if you observe the position of the star Beta Cassiopeia in reference to the star Polaris. Remember that the meridian is a line that extends from the north celestial pole, through the zenith, to the south celestial pole. Look north at the meridian (in its northerly position). With the help of the star chart on pages 26-29, find the constellation Cassiopeia and the star Beta Cassiopeia, which has right ascension zero hours. Where is Beta Cassiopeia in relation to the meridian and to Polaris? Its location relative to Polaris is shown in Figure 8. When it is directly above Polaris, on the meridian, the local star time is approximately zero hours; the vernal equinox, the zero point on the celestial equator, is then behind you, also on the meridian. This establishes an approximate star clock in the northern sky.

Building a Star Finder

You can easily construct a simple device for quickly locating any particular object in the sky. A star finder is a useful tool, and you will soon become acquainted with the coordinates (right ascen-



sion and declination of many celestial objects. The basic principles used with the star finder are essentially those used in more accurate telescopes. To build a star finder of mine 90° you will need the following materials:

Tripod or metal base plate, approximately 10 cm x 15 cm

Rectangular wooden block, 10 cm x 8 cm x 2 cm

Triangular block, approximately 15 cm high with 10 cm base, whose upper angle equals the latitude of the observer.

Construction of the star finder is shown in the accompanying illustration. The star finder is used by placing it on a level surface and adjusting the tripod or base plate so that the star finder is level. The star finder is then used to find the position of a star in the sky.

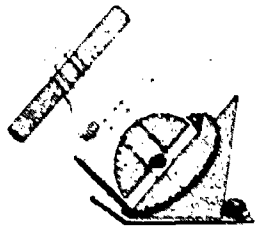
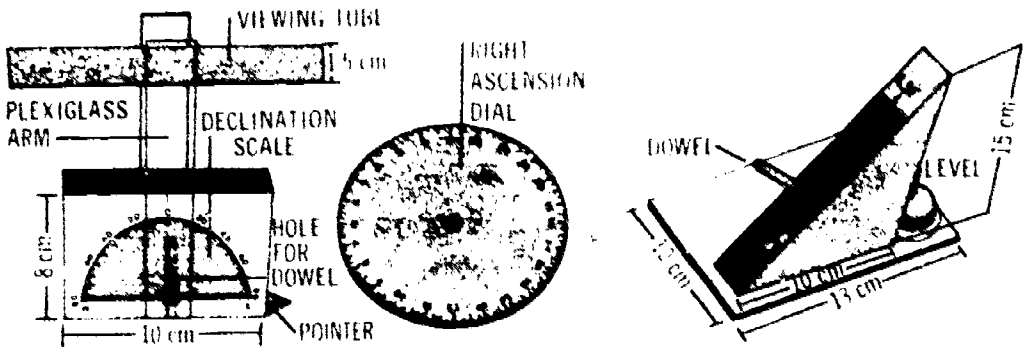


Figure 8. Directions for building a star finder.

Paper rolled into tube 1.5 cm in diameter
 2 thin strips of plexiglass, approximately 13 cm
 x 2 cm

Thin dowel pin, glue, straight pin

Use a half-circle scale (a plastic protractor will do) as a declination scale. Attach the declination scale to one side of the rectangular block. Drill a hole the size of the dowel pin perpendicular to the hypotenuse of the triangular block 5 centimeters from the base of the triangular block. Insert the dowel pin into the hole and glue it firmly. Draw a full circle 13 centimeters in diameter, calibrated in hours and minutes, to represent the right ascension dial, as seen in Figure 9. Be sure that this circle is calibrated counterclockwise from zero hours to 24 hours, with its smallest subdivision four minutes of time. Place the completed right ascension dial on the dowel pin so that it will turn freely. Drill another hole, the same size as the first one, into the middle of the base of the rectangular block. Sand down the exposed dowel pin so that the rectangular block will swing freely. Then place the rectangular block on the dowel pin. Screw the plexiglass to the rectangular block so that it turns freely. Scratch a line lengthwise along the center of this plexiglass to coincide with the markings on the declination scale. Glue the paper tube on the block side of the plexiglass arm, parallel to the top of the rectangular block. Inscribe a line or draw an arrow on the upper

part of the longest side (hypotenuse) of the triangular block and mark this LST (local star time). At the base of the upper end of the rectangular block, mount a straight pin in a bent position (right angles) in the upper face of the rectangular block. This is a pointer to indicate the right ascension of the object being located.

Mount the completed star finder on a tripod or rigid base; be sure that this base is level. Remove the entire upper assembly (rectangular block, plexiglass, and viewing tube). Point the exposed dowel pin north. At night, point it directly at the North Star. Carefully put the upper assembly back on the dowel pin. Locate a familiar star in the sky and set its coordinates (right ascension and declination) as given from a handbook or star chart. Lock the star finder in position and locate other stars from the known star's position. Remember that the stars advance one degree every four minutes, and adjust local star time to take this motion into account.

With a little practice you will be able to find stars in a matter of seconds; when you become really proficient with the star finder, you may want to precalculate local star time and thereby also find celestial objects without using your known star.

Observation of Magnitudes

How bright is bright? Are stars brighter than planets? Brighter than the moon? Why are some stars bright and others dim? Just as we can see differences in colors of some stars, like Betelgeuse and Rigel in Orion, we can also see that some stars are brighter than others. Brightness is related to luminosity (the amount of energy produced) and distance. Some stars are close to us; others are far away. Some are large and some are small. Suppose you were in a dark room with a flashlight shining at a friend. The friend may say, "Back up, your light is too bright." What happens to the intensity of light when distance is increased?

Activity III—Go to your school football field with several friends some evening. (Get permission first.) Take four flashlights, preferably all the same kind and with new batteries. Stand on one goal line and ask one friend to stand at the other goal line. Have the others stand at the far 20-yard line, at midfield, and at the near 10-yard line. At a signal from you, have each person turn on his flashlight, directing the light beam at you. What observation can you make about the brightness of the four flashlights?

Light appears dimmer as the distance from the source increases. Moving a light source twice as far from you makes it only one-fourth as bright; three times as far away it is one-ninth as bright. Brightness, therefore, varies inversely as the square of the distance from the observer. Hence two stars of the same real brightness will have different apparent brightnesses if they are at different distances from you.

The apparent brightness of a star is its *apparent magnitude*. Each magnitude is approximately 2.5 times as bright as the next higher magnitude number (Table 1). The brighter the star, the lower the magnitude number. Our unaided eyes are generally able to see stars only as faint as fifth magnitude (+5).

You will undoubtedly find references to *absolute magnitude*, or *luminosity*, of stars. This is the real or actual brightness of stars independent of their distance from us, and is not a type of brightness you can observe. Astronomers use the distance 32.6 light-years as the standard for finding absolute magnitude. It then becomes clear that nearby stars look considerably brighter to us than they are in terms of the amount of light they actually give off. For example, our sun, viewed from 32.6 light-years away, would have absolute magnitude +4.8; this would make it barely visible to you on a clear night.

Some objects in the sky are brighter than apparent magnitude +1. Sirius, our brightest star, has an apparent magnitude of -1.42 . Venus averages -3.5 , the full moon -12.7 , and the sun -26.7 .

Activity IV—Try a simple problem with magnitudes. If star A has an apparent magnitude of $+1.5$ and star B an apparent magnitude of $+4.5$, how many times brighter is star A than star B? Use Table 1 to find the answer. How many times brighter is the sun than the full moon?

Some stars vary in magnitude. Algol in the constellation Perseus seems to fade in brightness from second magnitude to fourth magnitude in less than two days. On the other hand, Mira in the constellation Cetus takes 11 months to fade about eight magnitudes and return to its maximum brightness. The star map on pages 26-29 will help you find these two stars; observe their changes in brightness by comparing them with nearby steady stars.

Table 1. Stellar Magnitude Scale

Magnitude Difference	means	Brightness Ratio
0.00		1.00
0.50		1.6
1.0		2.5
1.5		4.0
2.0		6.3
2.5		10.0
3.0		16.0
3.5		25.0
4.0		40.0
4.5		63.0
5.0		100.0

Note: In comparing the brightness of two stars, remember to take magnitude differences. Magnitude is not proportional to brightness.

The northern circumpolar constellation Draco (The Dragon) provides us with an interesting but easy way to compare the magnitudes of stars. The head of Draco is made up of four stars that form a regular quadrilateral, or four-sided figure. Using the star map on pages 26-29, find the constellation Draco in the sky and observe the position of the stars in its head region. How do the four stars compare in brightness? As it happens, the brightest of the four stars is second magnitude; the second brightest, third magnitude; the third, fourth magnitude; and the faintest, fifth magnitude. Therefore, Draco is an excellent gauge because it is always visible on a clear night from most places in North America.

Spectral Classes

Astronomers have attempted to classify stars into categories based on color and temperature. The categories are designated by letters: O, B, A, F, G, K, M, R, N, and S. This chaotic mass of letters was originally intended to be alphabetical but, as knowledge developed and exceptions were discovered, this scheme had to be changed. Blue-white stars are O and B. White stars are A, yellowish stars are F and G, orange stars are K, and the redder stars are in the remaining M, R, N, and S groups. Temperature and color are directly related, too; the redder the stars, the cooler they are. To help you remember this spectral sequence, think of the following expression: *Oh, Be A Fine Girl, Kiss Me Right Now, Sol.*

You can do an interesting, unaided eye exercise using Table 2. Choose several stars from Table 2 which you can find in the sky using the star chart. Look for these stars; compare their apparent magnitudes, and note their distances. What can you infer about their luminosities, or absolute magnitudes? Locate as many of the bright stars as possible, noting their apparent magnitudes and colors. Can you detect the color differences between stars?

Compare, for example, the stars Betelgeuse and Rigel in the constellation Orion.

WATCHING PLANETS AND THEIR SATELLITES

The earth is our observing station in space. Like the other planets, it travels around the sun. Several centuries ago the German astronomer, Kepler, discovered that the time it takes a planet to revolve around the sun, called its *period*, is related to its distance from the sun. The closer a planet is to the sun, the shorter its period and the faster it travels in its orbit. The earth travels around the sun at

Table 2. The Brightest Stars

Name	Apparent Magnitude	Distance (Lt. Yrs.)	Spectral Class	Color	Right Ascension	Declination 1970
Sirius	- 1.42	8.7	A	white	6h 44m	- 16° 40'
Canopus	- 0.72	98	F	yellow-white	6h 23m	- 52° 41'
α Centauri (Rigel Kentaurus)	- 0.26	4.3	G	yellow	14h 38m	- 60° 43'
Vega	0.04	26.5	A	white	18h 36m	+ 38° 45'
Capella	0.05	45	G	yellow	5h 14m	+ 45° 58'
Arcturus	0.06	36	K	orange	14h 14m	+ 19° 20'
Rigel	0.14	900	B	blue-white	5h 13m	- 8° 14'
Procyon	0.37	11.3	F	yellow-white	7h 38m	+ 5° 18'
Betelgeuse	0.41	520	M	red	5h 53m	+ 7° 24'
Achernar	0.51	118	B	blue-white	1h 37m	- 57° 23'
β Centauri	0.63	490	B	blue-white	14h 02m	- 60° 14'
α Crucis (Acrux)	0.75	370	B	blue-white	12h 25m	- 62° 56'
Altair	0.77	16.5	A	white	19h 47m	+ 8° 47'
Aldebaran	0.86	68	K	orange	4h 34m	+ 16° 27'
Spica	0.91	220	B	blue-white	13h 24m	- 11° 00'
Antares	0.92	520	M	red	16h 28m	- 26° 22'
Pollux	1.16	35	K	orange	7h 43m	+ 28° 06'
Fomalhaut	1.19	22.6	A	white	22h 56m	- 29° 47'
Deneb	1.26	1600	A	white	20h 40m	+ 45° 10'
β Crucis	1.28	490	B	blue-white	12h 46m	- 59° 32'
Regulus	1.36	84	B	blue-white	10h 07m	+ 12° 07'
Adhara	1.48	680	B	blue-white	6h 57m	- 28° 56'
Castor	1.6	45	A	white	7h 33m	+ 31° 57'

about 30 kilometers per second, or 100,000 kilometers per hour. Mercury, the planet closest to the sun, travels at 470 kilometers per second, while Pluto moves only about five kilometers per second.

We view the planets as we view everything else on the celestial sphere, from our traveling, spinning observing station—the earth. Because the other planets are themselves moving, their positions among the stars seem to change slowly night after night. They appear to wander among the stars. In fact the name "planet" comes from the Greek word "planetos," meaning wanderer. Before artificial satellites were put into orbit around the earth, planets were the only starlike objects that wandered among the stars in the sky.

Planets can also be distinguished from stars because planets rarely twinkle. Stars are so far away that they appear almost as true points of light. Rays of starlight must pass through the earth's atmosphere, which is like an ocean with waves and ripples. These bend the rays in a zigzag fashion so that when you look at a star you see rays that have been deflected slightly. The changing deflection produces the familiar twinkling of starlight. A planet, on the other hand, is close enough to the earth to show through a telescope as a tiny disk. Therefore it appears as many points of light. The atmospheric distortions that would produce twinkling cancel out, and the planet shines steadily. Even a planet, however, when close to the horizon, can twinkle because its light must then pass along a much longer path through the earth's atmosphere. For this reason the planet Mercury is commonly mistaken for a star low in the western sky.

Because they wander among the stars, planets are not placed on star maps. You would need a new

Activity V—Move your head in a circle while looking through a pair of opera glasses or binoculars at a bright twinkling star near the horizon. What do you observe?

star map every few evenings. The *World Almanac* and other popular almanacs tell you where to look for planets in the sky. Exact positions can be found from an observer's handbook or the *American Ephemeris and Nautical Almanac* for the year of observation. (See References.)

All planets change somewhat in brightness as their distance from the earth changes. Venus, for example, varies a great deal, from magnitude -4.4 to -3.3 . At its brightest, Venus is so bright that it can be seen easily in the daytime sky if its exact location is known. At that time, Venus is visible as a thin crescent, when it is nearly between the earth and the sun.

Mars varies in magnitude from -1.0 to $+1.4$, while Jupiter and Saturn vary only a few tenths of a magnitude in a year. This is because the orbits of Saturn and Jupiter are so much larger than Earth's orbit that their distances from Earth do not appear to change significantly and we always see them fully lighted.

Imagine Jupiter as a sun and its moons as planets. Then watch the moons of Jupiter change their positions evening by evening, and you can see roughly what the solar system would look like from far outside. Four of Jupiter's 12 satellites are giant moons, two of them considerably larger than the earth's moon (Figure 10). These four satellites could be seen with the unaided eye if they were not so close to the much brighter Jupiter. You can see them through binoculars if you hold the binoculars steady by propping them firmly against a fence post or other solid object. The four major moons, Io, Europa, Ganymede, and Callisto, travel around



Figure 10 Jupiter and its four largest satellites. Their motions may be followed with binoculars.

Jupiter in periods of $1\frac{3}{4}$, $3\frac{1}{2}$, $7\frac{1}{2}$, and $16\frac{3}{4}$ days, respectively.

Saturn can be observed with the naked eye, but its rings are not visible without a telescope. Uranus becomes barely visible to the unaided eye for a month or so each year when it is on the side of the earth opposite the sun; it then rises at sunset. Neptune and Pluto are never visible with the unaided eye.

THE MOON

The moon, although small (Figure 11), is a prime target of the space effort. It is relatively near compared to other bodies in the solar system. On a scaled-down model of the solar system that is twice as large as a football field, the moon is just one centimeter from the earth.

Even without a telescope the moon provides many fine opportunities in field astronomy. Watching its motion among the stars from night to night, or even during one night, can tell us much about its orbit, its actual speed, and even something about its physical condition. We often take the moon for granted, but have you ever thought about the following questions:

- 1) Why does the moon appear to be the same size as the sun in the sky?
- 2) Would total eclipses of the sun be possible if the moon did not seem as large or larger than the more distant sun?
- 3) Does the moon move eastward or westward among the stars?
- 4) Does the moon rise every day? Table 3 gives the rising and setting times of the moon in its successive *phases*, or stages of appearance.
- 5) Can you see the moon in bright daylight?
- 6) Can the moon ever be seen in the northern part of the sky?
- 7) Does the moon appear larger when it is near the horizon?

8) What is the angular size of the moon in the sky?

Table 3. Time of Moon's Rising and Setting for Successive Phases

Phase	Rise	*South	Set	**North
new	6 A. M.	noon	6 P. M.	midnight
first quarter	noon	6 P. M.	midnight	6 A. M.
full	6 P. M.	midnight	6 A. M.	noon
last quarter	midnight	6 A. M.	noon	6 P. M.

* Refers to the position between rising and setting.
 ** Refers to the position between setting and rising.

Figure 11. Although small compared to the earth, the moon has enough surface to explore.

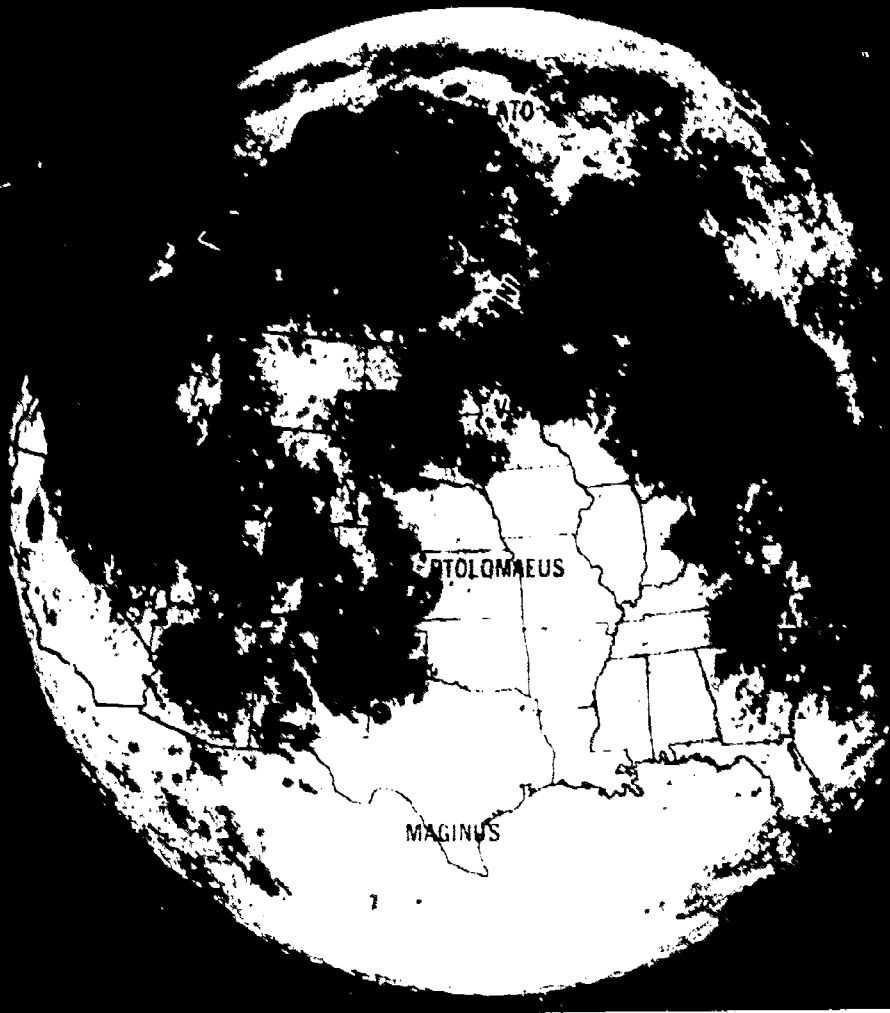


Figure 12. The moon moves westward around the earth as its phases change, but it appears to move eastward compared to the stars

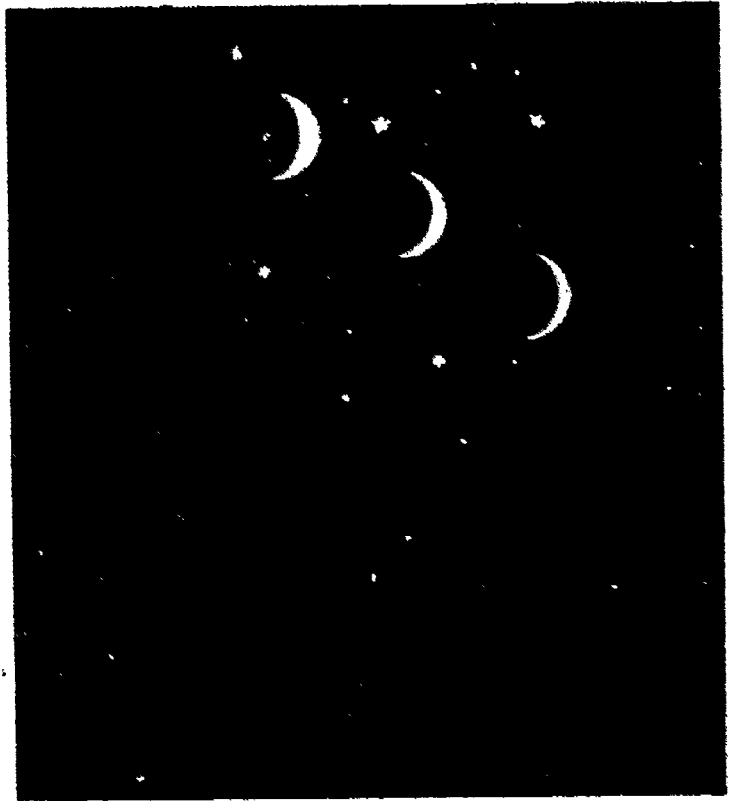
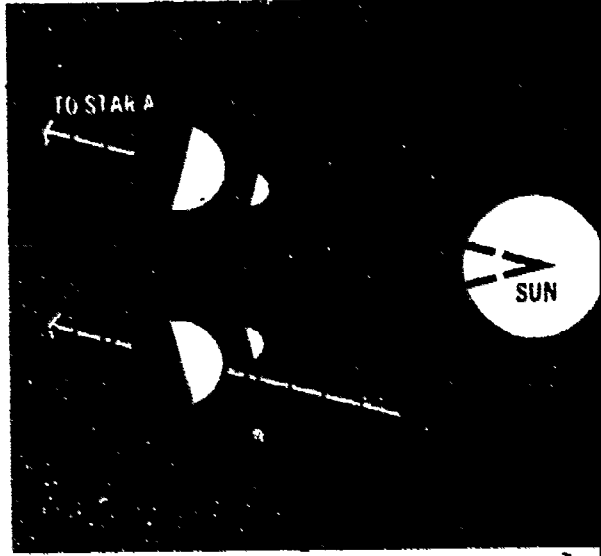
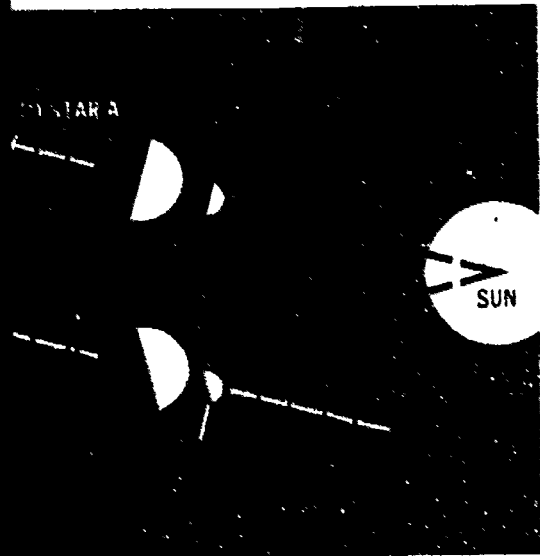


Figure 13 Comparison of the sidereal month or star month, and the synodic month, the month of the phases of the moon.

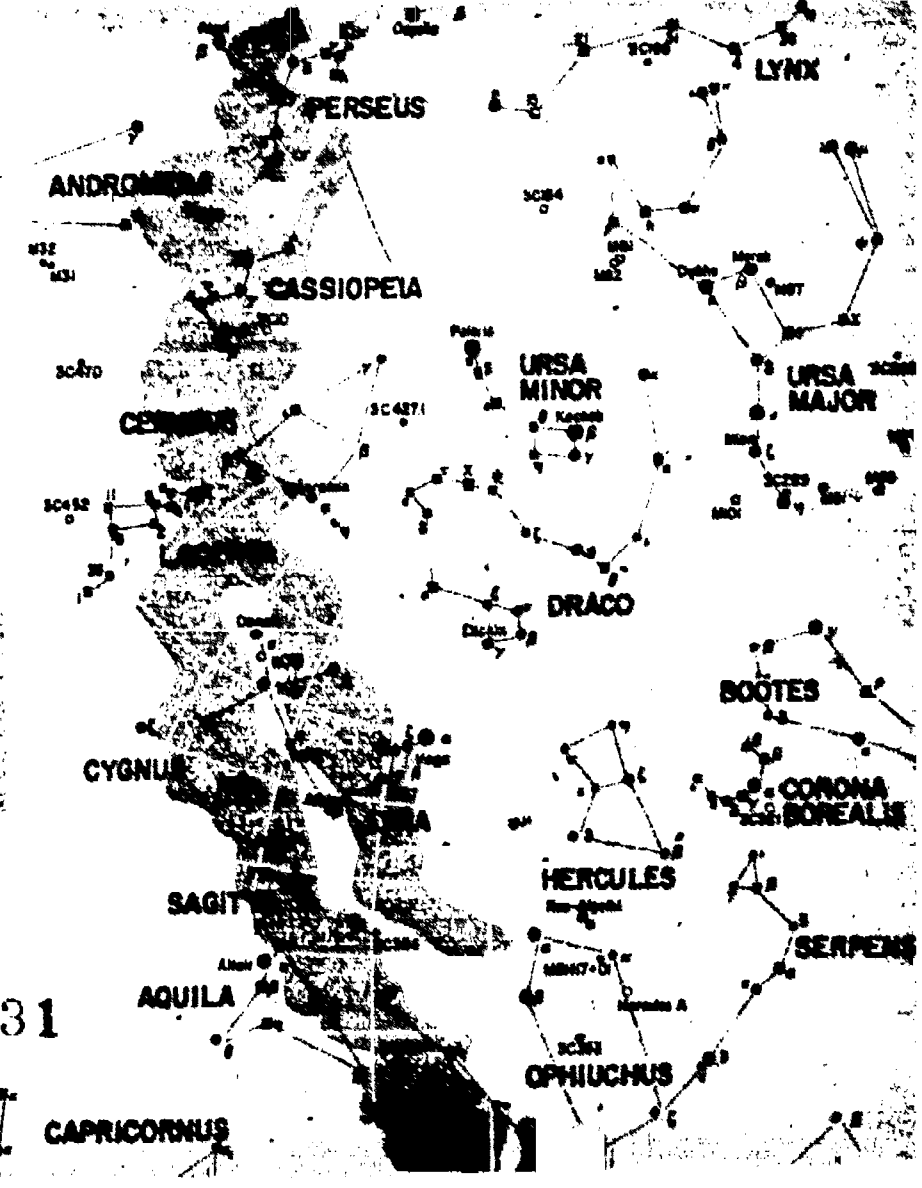
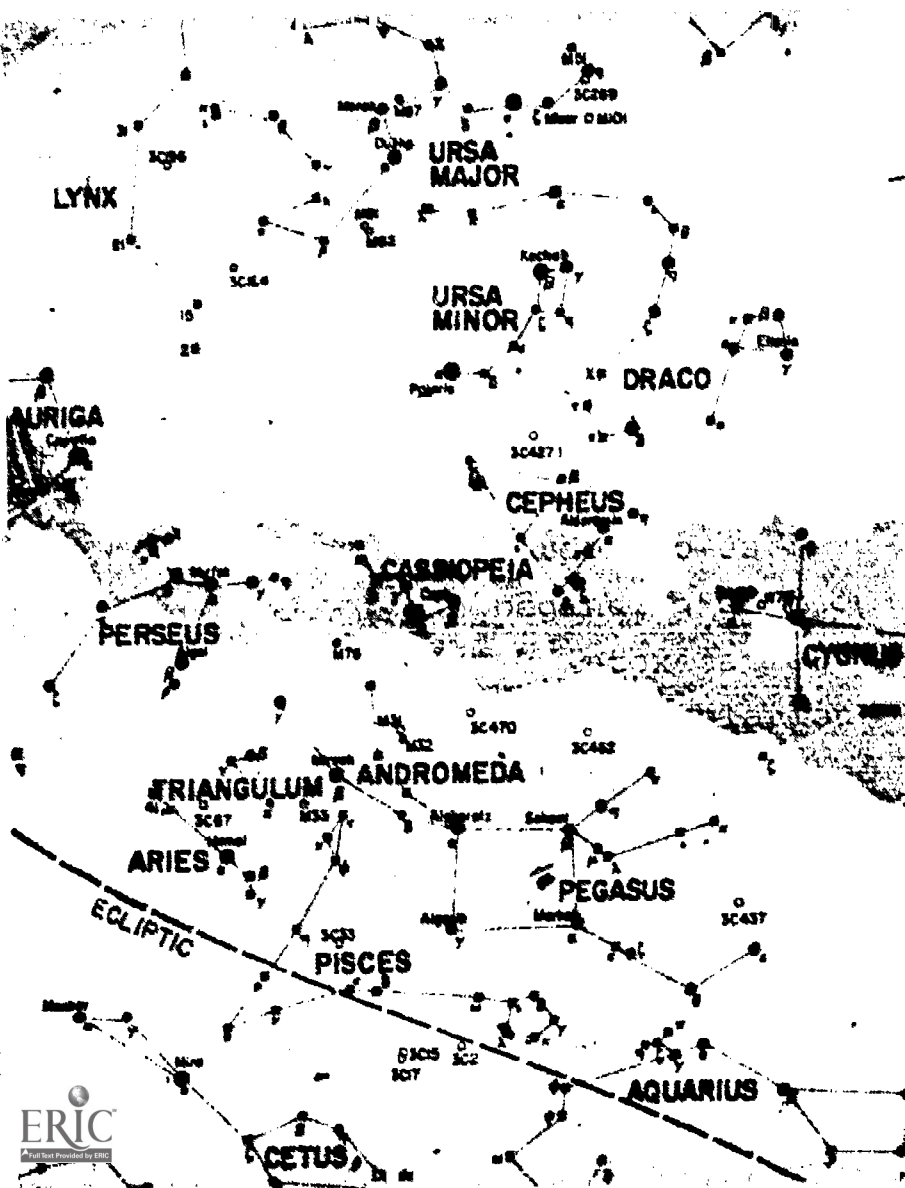


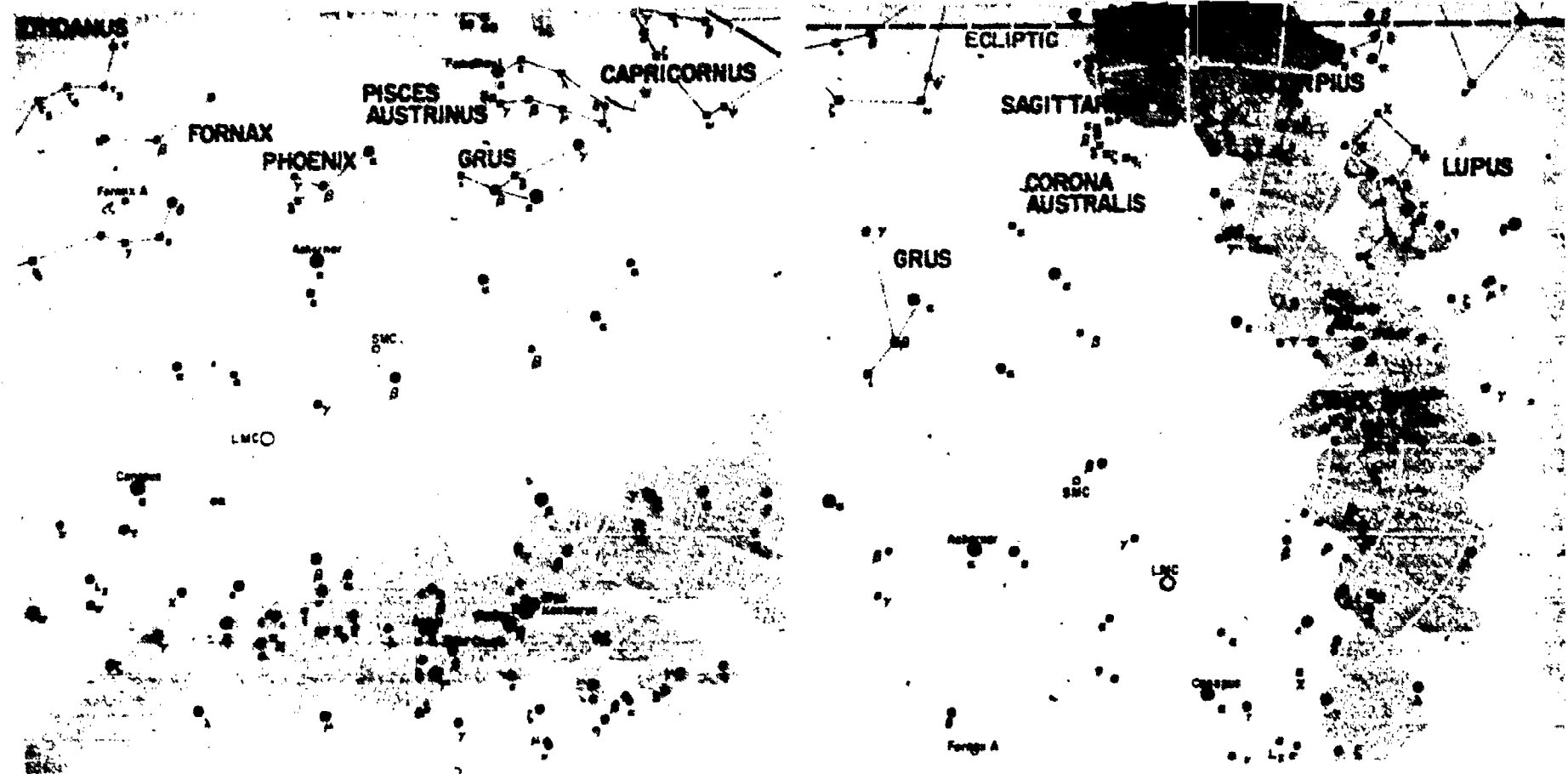
Activity VI—Using a ruler (or the type of sextant discussed on page 8) held at arm's length, measure the size of the moon. Two centimeters on a ruler held at arm's length cover 1° . What is the angular size of the moon? How many full moons could be placed on the sky, like beads on a string, from horizon to horizon? Guess the angular size of the sun. (Remember not to look directly at the sun, as you can severely damage your eyes.) The moon seems larger when it is rising or setting. Is this really the case? With your ruler, measure the moon near the horizon and again when it is high in the sky. Compare the measurements.

Activity VII—How is the moon's motion *among the stars* determined? As the evening progresses, the moon and stars seem to move westward because of the earth's rotation (Figure 12). But the moon does not move westward as fast as the stars appear to. In the early evening, line up the moon with a nearby star. Three or four hours later, make the same observation. Has the moon changed its position with reference to the star? How many moon diameters has it moved in that length of time? How many hours would it take the moon to get back to the same star? How many days is this?

It takes the moon $27\frac{1}{3}$ days to return to the same star in the sky. This is called the *sidereal month*, or star month. A quick glance at the calendar shows us, however, that full moon to full moon takes $29\frac{1}{2}$ days, not $27\frac{1}{3}$ days. The difference is caused by the fact that during the time the moon has been going around the earth once, the earth has been moving around the sun, so that the sun too has appeared to move eastward among the stars. It takes the moon a little more than two days of extra travel to catch up with the sun (Figure 13).

The star map on the next four pages covers the entire sky as seen from all parts of the world. The observer only has to find a constellation in the sky to orient the map. Then he can locate other stars. The shapes of the constellations are accurate even near the edges of the map. The four parts of the map are centered on right ascensions 0, 18, 12, and 6 hours. Objects with declinations above 40° or below -40° appear on all four parts. The Milky Way is grayish. The ecliptic is a dashed purple line. The constellations are labeled in capital letters. The names of the major stars are given. The apparent magnitude and spectral class of a star are indicated by the size, color, and shape of the dot representing it. (See Key.) Messier objects (nebulae, star clusters, and galaxies) and radio and X-ray sources are shown. Their catalog numbers are on the map, and their apparent magnitudes are coded in the Key.





KEY

MILKY WAY

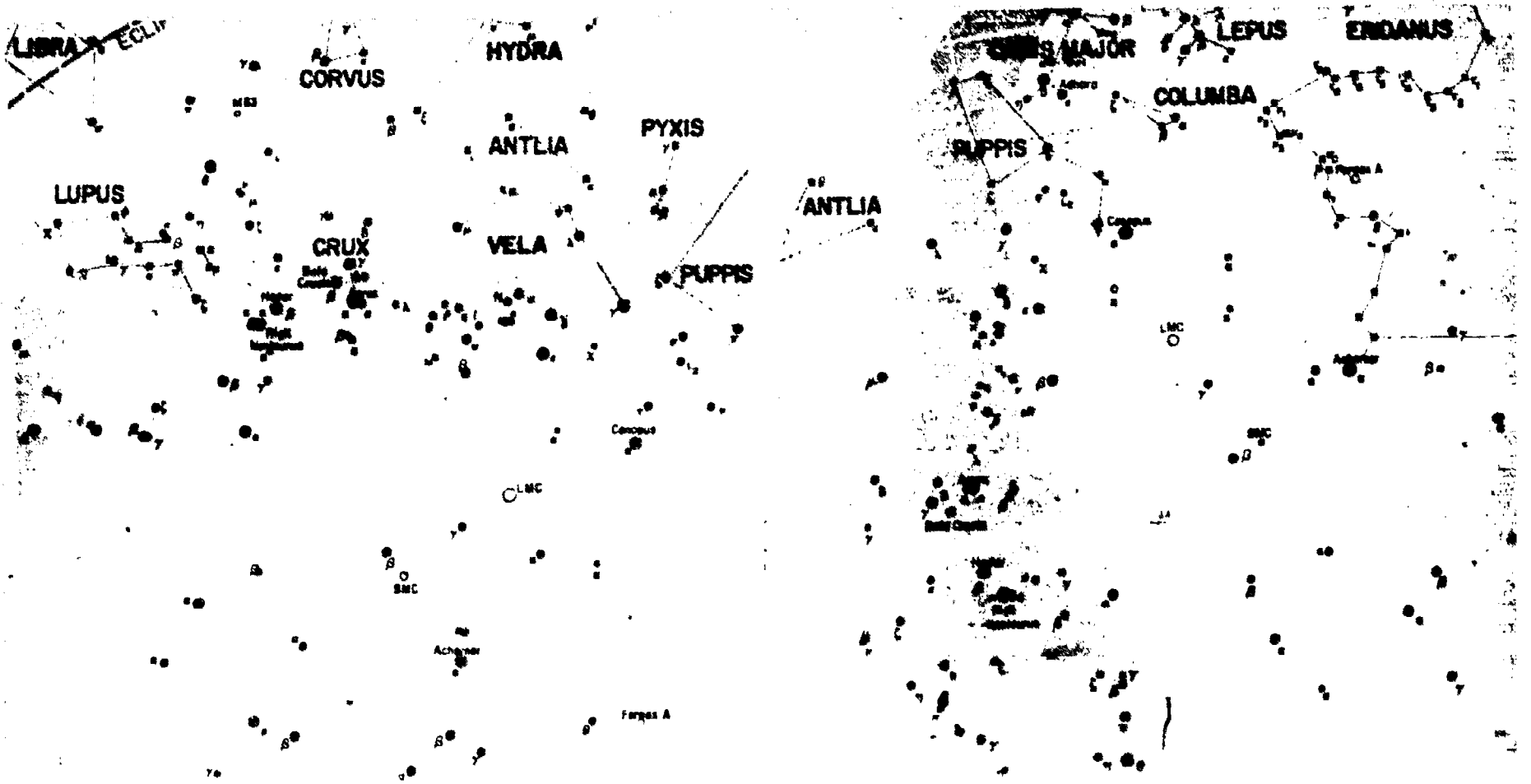
MAGNITUDE

SPECTRAL CLASS	MAGNITUDE				
	LESS THAN 1.05	1.05 2.05	2.05 3.05	3.05 4.05	MORE THAN 4.05
O, B, A, F	●	●	●	●	●
G, K, M, R, N, S	●	●	●	●	●
UNCLASSIFIED	■	■	■	■	■

MAGNITUDE

OTHER	MAGNITUDE				
	LESS THAN 1.05	1.05 2.05	2.05 3.05	3.05 4.05	MORE THAN 4.05
MESSIER OBJECT	○	○	○	○	○
X-RAY OR RADIO SOURCE					

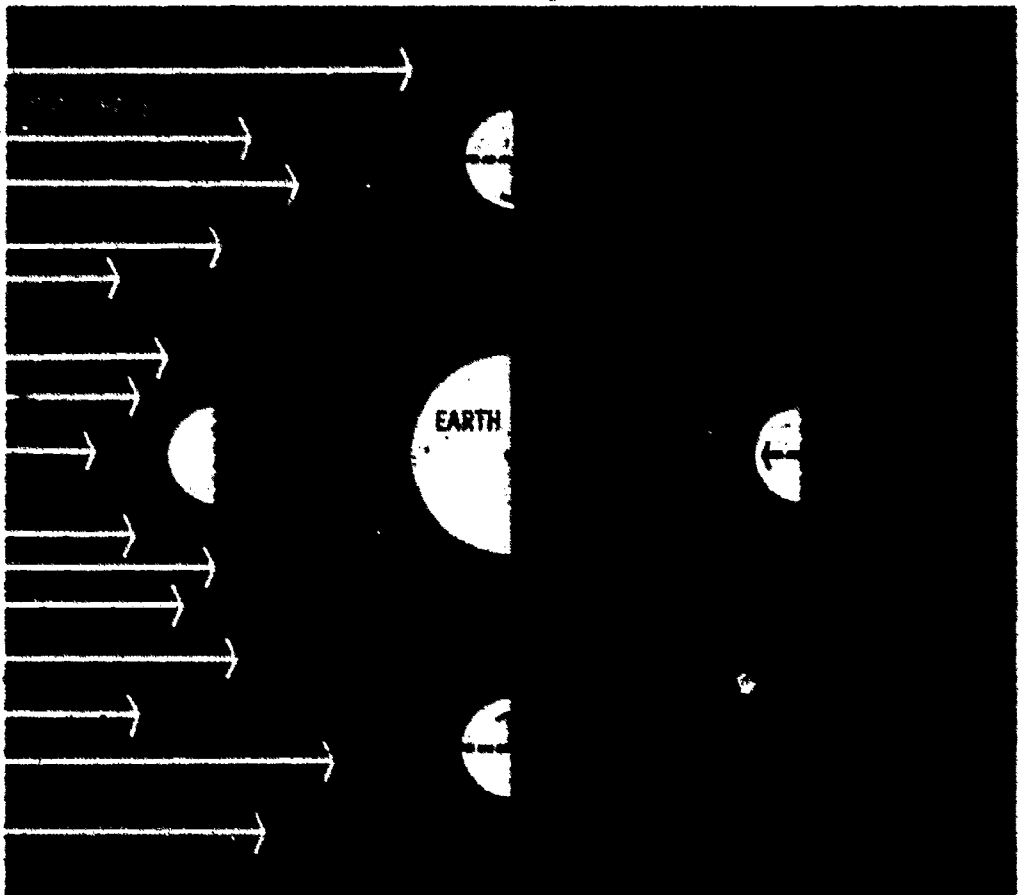


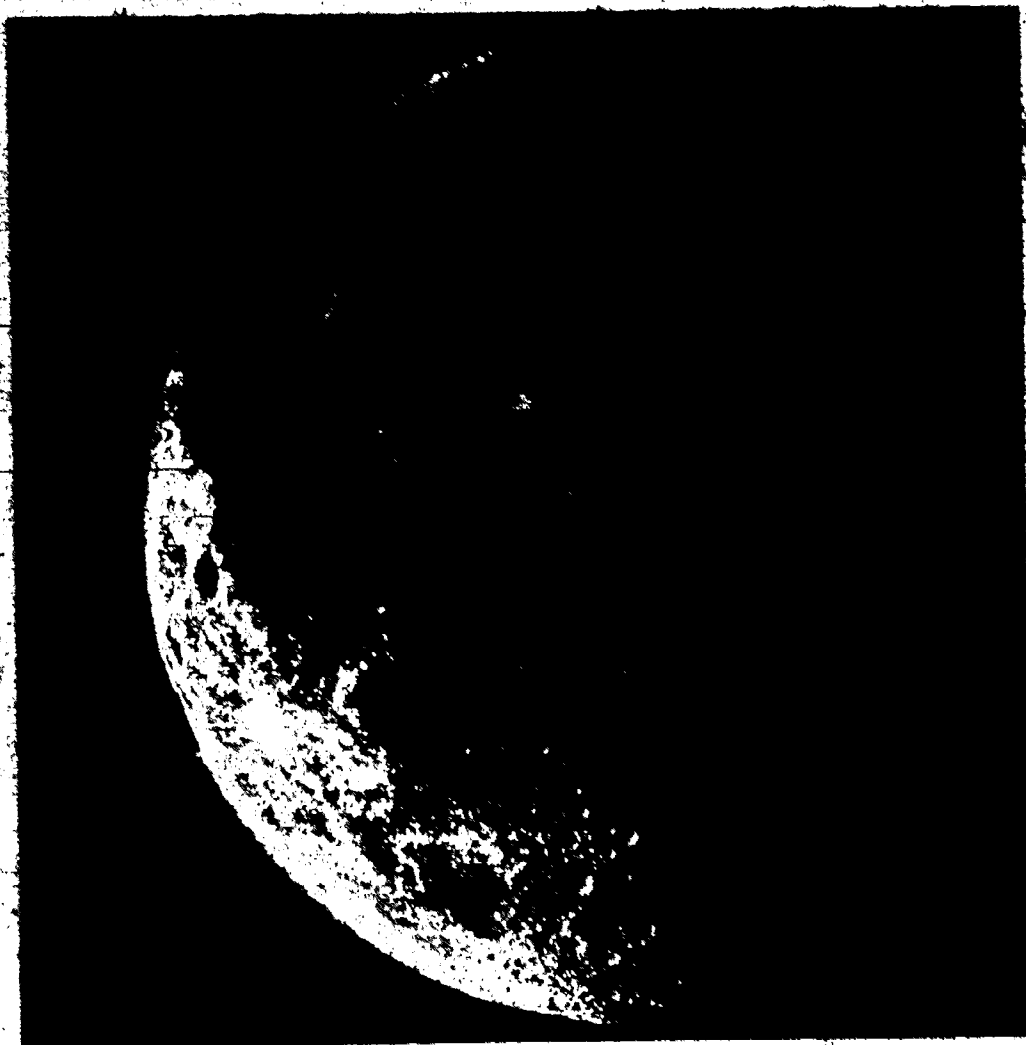


The month of the phases of the moon is called the *synodic month*. It is still somewhat shorter than our average calendar month. However, the name month is derived from it, and was originally "moonth."

As the moon goes around the earth, different portions of the side facing the earth are illuminated. When the moon is opposite the sun, the side facing the earth receives full sunlight; this is the *full moon*. About seven days later the moon has completed a quarter of its journey around the earth and, as shown in Figure 14, is then at *last quarter*. Why is it called last quarter rather than last half? Half of the side facing the earth is illuminated, but that is only one-quarter of the moon's revolution around the earth; hence, it is called last quarter (Figure 15). After seven more days, the moon has gone halfway

Figure 14. Phases of the moon. The moon rotates on its axis in the same period of time it revolves around the earth, so it always keeps the same face toward the earth.





around the earth and is in line with the sun. This phase is called the *new moon*. How much of the moon is visible at this time? The permanently hidden side of the moon is fully illuminated at the new phase. Observe the crescent moon a few days after new moon. Can the crescent moon ever be seen at midnight?

Do not confuse the hidden side of the moon with the dark side. The moon always keeps the same face toward the earth, with the other side truly hidden from our view (Figure 14). At new moon it is the hidden side that is lighted; at full moon the side turned toward the earth is lighted.

Figure 15. The moon at last quarter. Compare this photograph with Figure 14. Which way is north?

You have heard of sunshine and possibly of moonshine, but maybe not of "earthshine." When the crescent moon is above the western horizon, shortly after new moon, you may see the rest of the moon barely illuminated by the sunlight reflected from the earth back to the moon (Figure 16). This situation is sometimes called "the old moon in the new moon's arms." What do you think this means?

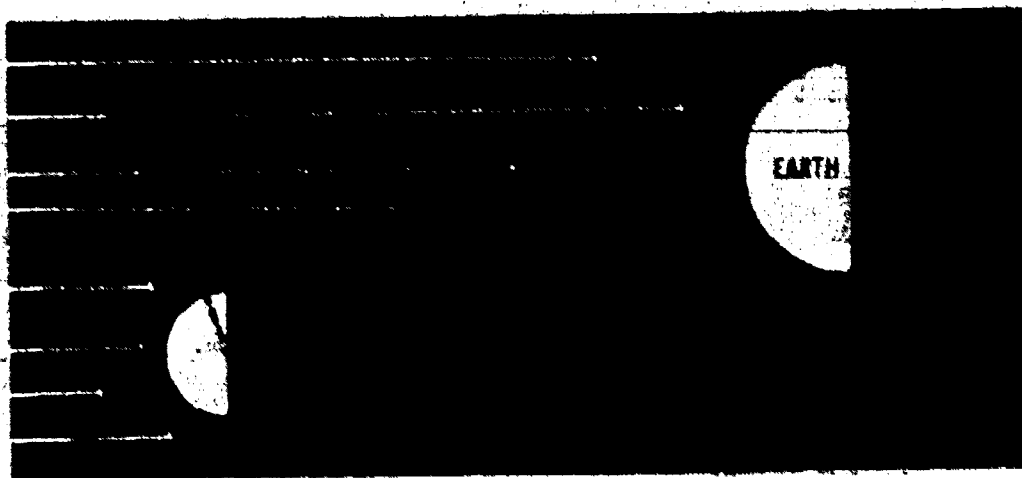


Figure 16. Earthshine on the moon. The earth and moon reflect light in all directions because their surfaces are rough.

The moon wanders among the stars much more rapidly than do the planets. Just how far north and south of the celestial equator can you see the moon? Can it ever get as far north as the Big Dipper? The best way to answer these questions is to see for yourself. Use your star finder to sight on the moon on successive nights. Record its right ascension and declination. When you have a dozen or more observations, plot them on graph paper or on a star chart. How far north and south has the moon wandered? As the moon changes phases, the lighted portion grows or *waxes* and then decreases in size or *wanes*. The division between the lighted and dark part of the side facing us is called the *terminator*. Draw a circle about 12 cm in diameter on a piece of paper. Lightly pencil the terminator on the circle on successive nights in order to measure the changing phases. Label each line with the date.

Activity VIII—Continue your observations of the moon, plotting its path in the sky throughout the year. What do you observe? You will find quite a difference as to how far north the moon appears in winter and summer. How much does it differ and why? Do you think that a connection exists between this and the fact that the sun appears higher in the sky in summer than in winter?

As the moon travels through the sky on its monthly journey around the earth, it frequently passes between the earth and a star or planet. This is called a *lunar occultation* (Figure 17). Do you think that watching an occultation could tell anything about whether the moon has an atmosphere? Unless the star being occulted is very bright, it is easiest to observe an occultation through a pair of binoculars or a telescope.

Activity IX—Observe an occultation. How quickly did the star disappear? Did it disappear on the right or left edge of the moon? How long was it occulted? What did you observe that might tell you whether the moon has an atmosphere?

Figure 17. Lunar occultation.



A *lunar eclipse*, or eclipse of the moon, occurs when the moon passes into the earth's shadow. For such an eclipse to occur, the moon must be in full phase; only then can the sun, earth, and moon be aligned, with the moon on the side of the earth opposite the sun (Figure 18). If the moon's orbit were in the same plane as the earth's orbit, a lunar eclipse would occur at every full moon. This is not the case, however, since the moon's orbit is inclined by about 5° . Only when the moon is close to the plane of the earth's orbit can there be a total lunar eclipse. A whole year can go by without the moon passing into the earth's shadow even once. Consult an almanac or other reference book to find when the next lunar eclipse will be visible at night in your area. (See References.)

Figure 18. Geometry of a lunar eclipse.



Activity X—Which side of the moon, right or left, will enter the earth's shadow first in a lunar eclipse? Time how long it takes the moon to go completely through the earth's shadow.

If you could hold a field trip on the moon, what would the earth look like during a lunar eclipse? Would you see the night side or the day side of the earth? Would there be any meaning to the term "new earth"?

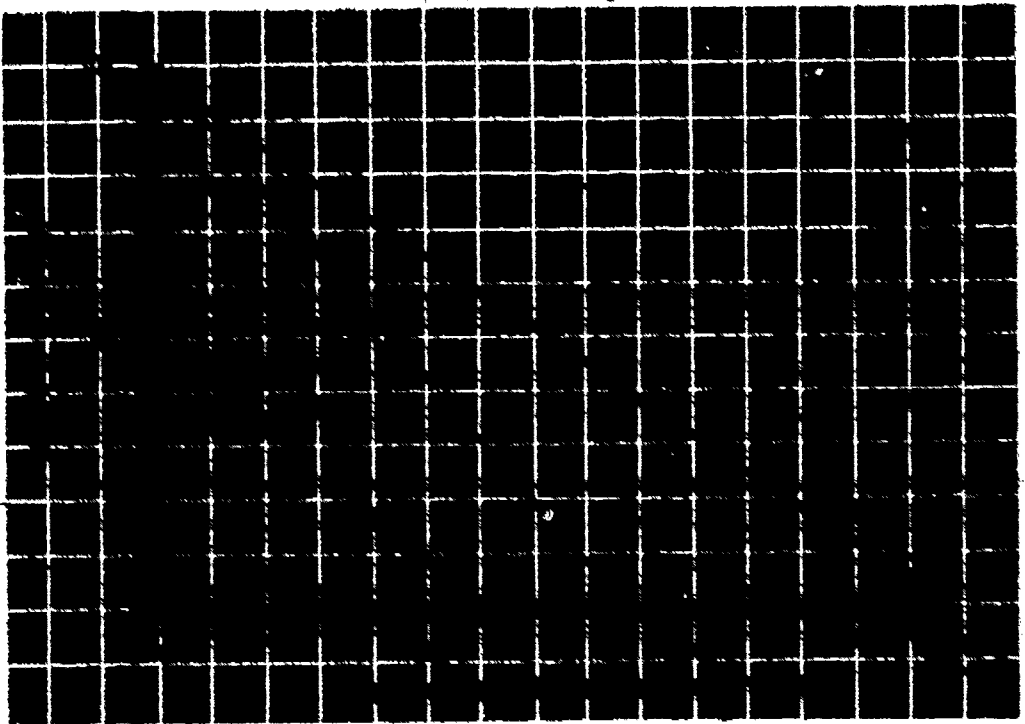
From what parts of the earth can a lunar eclipse be seen? Because the earth is preventing the sun's light from reaching the moon, a lunar eclipse can be seen from the entire hemisphere of the earth facing the moon.

THE SUN—THE NEAREST STAR

The sun is the nearest star, and the only one whose surface we can see. Ancients of many lands expressed their appreciation for the warmth and light given them by the sun. It is not hard to understand why sun worship was prominent in many religions. No wonder man is interested in the well-being of this stable star—his existence depends on it.

Because of the sun's great glare we can rarely observe it directly with our unprotected eyes. Only when it is setting and its light is dimmed greatly, or when seen through a heavy veil of clouds or a smoked glass (solar filter) can the sun really be glimpsed. Use great care when observing the sun. The safest way is to project the image, as will be discussed later. The glare of the sun creates the impression that it is much larger than it really is; when seen high in the sky, through clouds, it looks approximately the same size as the moon. Because

Figure 19. Graph of the length of the shortest shadow of a sundial on June 21 and on December 21, showing how to determine the observer's latitude from these measurements.



we can never directly look at the unobstructed sun with our unaided eyes, we must observe it by indirect means. Astronomers use heavy filters or project the sun's image onto a white screen, or they observe particular features of the sun with specialized instruments.

Activity XI—How can you establish the seasonal vertical motion of the sun? You will need to make observations over a period of several months including June 21, when the sun is farthest north, and December 21, when it is farthest south. For a sundial, use a long straight stick such as an old broomstick. Drive it firmly and vertically into the ground in a sunny area with not much traffic. An existing clothesline pole or a TV antenna on a flat roof can also be used. Measure the height of the stick in centimeters. Each day, measure the length of the shortest shadow. What time of day is the shadow shortest? Keep a record of the length of the shortest shadow each day. On a large sheet of graph paper, draw the stick and plot the lengths of these shadows (Figure 19). After all the observations have been made and the results plotted, use a protractor to measure the angle on the graph between the line to the longest of these shadows and the line to the shortest. Draw a line that divides this angle in half. The angle between this dividing line (the dotted line in Figure 19) and the vertical stick is equal to your latitude. Why? Check your result on a map.

A *solar eclipse*, or eclipse of the sun, is quite different from an eclipse of the moon. Whereas the lunar eclipse occurs at full moon, a solar eclipse must occur at new moon, for it is at new moon that the moon's shadow may fall upon the earth. A solar eclipse, like a lunar eclipse, does not occur every month because of the 5° inclination of the moon's orbit. More often than not, at new moon the moon's shadow passes above or below the earth instead.

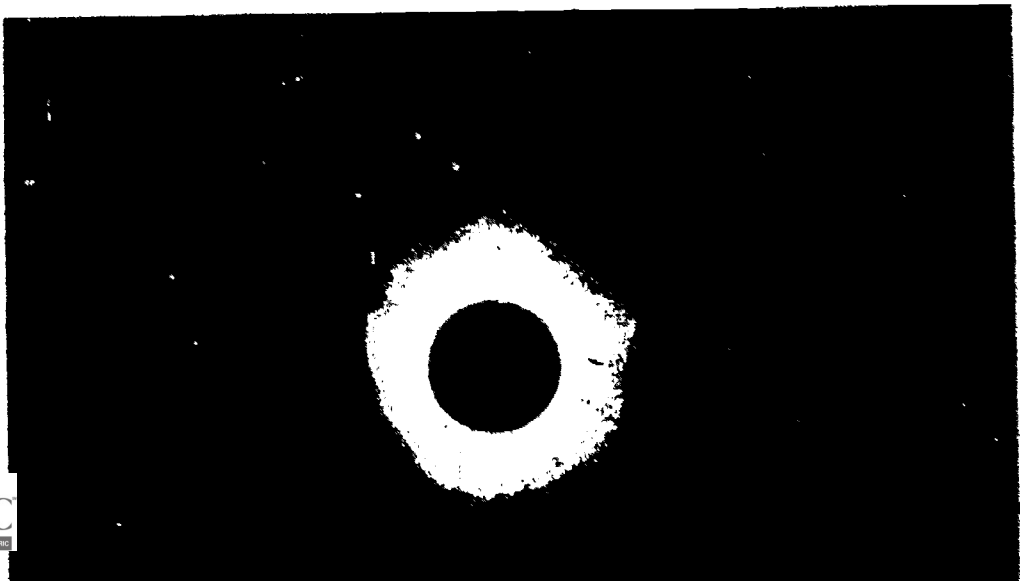


Total eclipses of the sun are seen in a relatively small area because the tip of the moon's shadow cuts a very narrow swath across the earth's surface (Figure 20). Only observers directly in the path of the moon's shadow will see the sun completely covered. They observe the glorious spectacle of the total solar eclipse during which the full light of the sun is blocked out, the sky becomes dark, birds come home to roost, and the stars are visible. Although the main body of the sun is hidden, its extensive atmosphere, the *corona*, is not (Figure 21). This is the only time the corona can be seen in its entirety without using an instrument.

Over a much wider area of the earth's surface, the moon only partially blocks the sun's light: this is the area of the partial eclipse. Every total eclipse of the sun over one part of the earth is also a partial eclipse in nearby areas. Some eclipses of the sun are only partial everywhere. In such a case, the direct shadow of the moon misses the earth, but the moon still blocks some of the sun's light from the earth.

Figure 20 Geometry of a solar eclipse. Compare this with Figure 18. Why are you more likely to see a lunar eclipse?

Figure 21 The total solar eclipse of March 7, 1970. Note the size of the corona.



Only one total eclipse of the sun will be seen in the United States between now and the year 2000. It will occur on February 26, 1979, in the state of Washington. Many partial eclipses of the sun will be visible in the United States; a world almanac will tell you on what days they will occur and whether they will be visible from your locality.

Under no circumstances should you attempt to observe an eclipse of the sun with unprotected eyes. There are safe ways of observing solar eclipses, but no matter what device is used, stop the observation immediately if you experience any eye discomfort. And *never* look at the sun through binoculars or a telescope. Tests have shown that you can observe an eclipse of the sun through one or more pieces of heavily fogged photographic film or heavy smoked glass, through which the sun should appear even dimmer than it does when you see it occasionally shining through heavy clouds.

An indirect method of observing an eclipse is to make a small but clean-cut pinhole in a piece of cardboard and project the sun's image through it onto a second piece of cardboard. Better yet make a pinhole in the side of a cardboard box and put the box over your head. With the pinhole behind your head, the image of the sun is projected as shown in Figure 22.

Figure 22 Projecting the sun's image to observe an eclipse safely



Total solar eclipses are possible because of a remarkable coincidence: Both the sun and the moon appear about the same angular size in the sky. This is the case because the sun is approximately 400 times greater in diameter than the moon, but is also about 400 times as far away. An aspirin tablet held at arm's length will cover the moon or the sun. Although the aspirin tablet is billions of times smaller than the sun, it is also billions of times closer to us and thus covers an angle of about the same size.

OTHER CELESTIAL OBJECTS

Observing Meteors

It is almost impossible to observe the sky on a clear dark night for half an hour or so without seeing a *meteor*, a bright streak of light flashing across the sky. Meteors have been called "shooting stars," and almost every nation in the past has had its legends concerning them. Even today, some people say, "Oh, there goes a shooting star. Make a wish." Of course these are not stars. A meteor is actually the light given off when a piece of stone or iron, called a *meteoroid*, zips into the earth's atmosphere and almost immediately burns up through friction with the air, usually 80 to 120 kilometers above the earth's surface. When a meteoroid is large enough to survive a journey through the atmosphere and reach the earth's surface it is called a *meteorite*. (See *Meteorites*, in References.)

When you are riding in a car, do the bugs get splattered on the windshield or the rear window? The same principle applies to meteoroids. The "windshield" side of the earth (side A in Figure 23) faces in the direction of the earth's motion around the sun and naturally collides with more meteoroid particles than side B, the "rear window" side of the earth. What are these sides? As Figure 23 shows, the part of the earth that is having sunrise faces the same direction as the earth is traveling. Any time

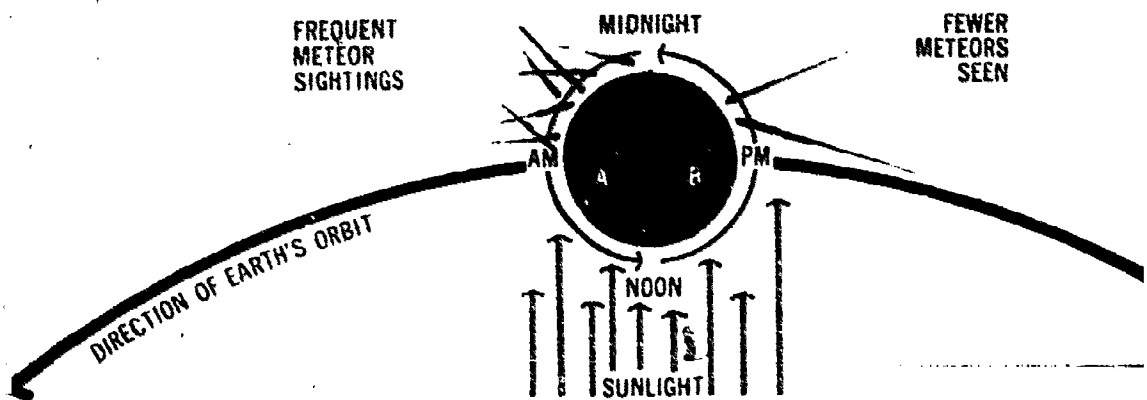


Figure 23. Because of the earth's motion, you can see the most meteors at sunrise

between noon and midnight you are on the "following" side of the earth. Therefore you see fewer meteors in the early evening than after midnight, and the ones you do see make much slower and longer streaks across the sky.

Many meteoroid particles travel in swarms around the sun. Such swarms are commonly associated with comet orbits and with material spread all along the comet's orbit. When cometary debris comes very near the earth, the earth will collide with a great many meteoric particles. The result is a "meteor shower." One of the useful observations during a meteor shower is plotting the meteor trails on a star chart and finding the *radiant*, or point on a chart from which most of the meteor tracks extend. Plotting trails on a chart and locating the radiant allows you to find which meteors observed belong to that specific shower. Usually a few are observed which are not part of the shower. The name of the shower signifies which constellation is in the same direction as the radiant (Table 4).

Artificial Earth Satellites

An ever-increasing number of artificial earth satellites can now be observed with the unaided eye. A few hours spent observing the skies can hardly pass without one or more of these satellites passing slowly across the sky. How can you tell a satellite when you see one? Satellites look like

Table 4. Observable Meteor Showers

Shower	Approximate Date	Radiant		Hourly Sighting Rate
		R.A.	Dec.	
Quadrantids	Jan. 3	15 h 28 m	+ 50°	40
Lyrids	April 22	18 h 16 m	+ 34°	15
Aquarids	May 5	22 h 24 m	00°	20
Aquarids	July 29	22 h 36 m	- 17°	20
Perseids	Aug. 12	03 h 04 m	+ 58°	50
Orionids	Oct. 20	06 h 20 m	+ 15°	25
Taurids	Nov. 5	03 h 32 m	+ 14°	15
Leonids	Nov. 16	10 h 08 m	+ 22°	25
Geminids	Dec. 13	07 h 32 m	+ 32°	50
Ursids	Dec. 22	14 h 28 m	+ 76°	15

stars and generally twinkle. They may also vary in brightness when they tumble as they proceed in their orbits. Satellites always appear to move fastest when high in the sky, near the zenith, because then they are moving across your line of sight instead of toward or away from you.

Satellites shine by reflected sunlight; because they are generally fairly close to the earth, they are best seen in the evening and morning twilight hours. When a satellite goes into the earth's shadow, it disappears like a candle being slowly snuffed out.

Double Stars

Nearly half of the "stars" visible in the sky are actually two stars rather than one, but this can be discovered only with the aid of a telescope. A few of these *double stars* are visible to the unaided eye and serve as interesting tests of your vision. The Arabs used the pair Alcor and Mizar, the so-called Horse and Rider, which together make up the second star in the handle of the Big Dipper. Alcor and Mizar appear to lie in almost the same direction from us. Can you distinguish them?

A much better eye test, requiring above average vision, is the double star Epsilon Lyrae. With the help of your star chart, locate Epsilon Lyrae by

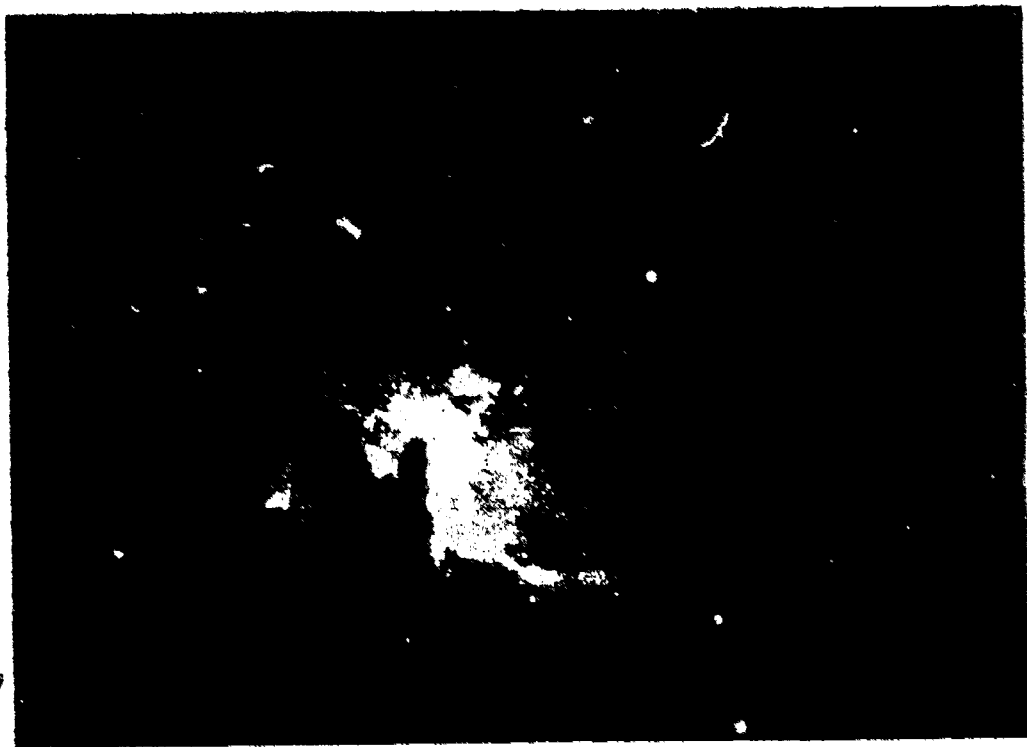
first looking at the bright star Vega, which itself is the apex of a small triangle of stars. The two other stars of the triangle are almost the same brightness. One of these is a double star. Can you tell which one?

Clusters and Nebulae

Clusters or groups of stars, some of which can be seen with the unaided eye, can be fascinating features of the sky. Clusters fall into two basic categories: the open (galactic) and the closed (globular) clusters. "Deep-sky" bodies like these are assigned numbers by the Messier catalog or the New General Catalog and are commonly referred to by this assigned number, such as M13 or NGC 6205 in the constellation Hercules. The Hercules cluster M13 is a globular cluster containing some 50,000 stars about 25,000 light-years away (Figure 24).

Figure 24. The globular cluster M13 in Hercules. It contains about 50,000 stars





The most conspicuous clusters are the open clusters (not so dense and not as far away). The Pleiades and the Hyades in the constellation Taurus are easy to find. The unaided eye reveals six or eight stars in the Pleiades and five in the Hyades. High magnification, however, shows several hundred stars in each of these groups, several hundred light-years away. Many other clusters are worth viewing. Consult the star map on pages 26-29 for their positions.

The interstellar gaseous clouds of space are called *nebulae*. Most are beyond the reaches of the unaided eye. However, some like M42, the great Orion nebula shown in Figure 25, can be easily found in the sword region of Orion. Find M42 and other visible nebulae on the star map.

Beyond the Milky Way

All the objects discussed so far are relatively close. Even the stars are still in the neighborhood

Figure 25 The great nebula M42 in Orion. On clear winter nights it can be seen with the naked eye.

of the sun—within our own galaxy, the Milky Way. However, it is possible to see another galaxy, without a powerful telescope. Two galaxies, really satellite galaxies of our own Milky Way galaxy, are easily visible in the Southern Hemisphere. These are the famous clouds of Magellan, first reported in the logbook of Magellan's journey around the world. They appear as two wispy cloud-like objects. Light from them takes nearly 200,000 years to reach us.

In the Northern Hemisphere you can, with the unaided eye, see light that is 2 million years old. This "fossil light" comes from the Andromeda galaxy M31 (Figure 26). The Andromeda galaxy is so called because it lies in the general direction of the constellation Andromeda. (The stars that make up the constellation Andromeda are, of course, much closer to us.) It is impossible to see the Andromeda galaxy if there are city lights nearby, if the moon is shining, or if the sky is even

Figure 26 The Andromeda galaxy M31. The light that made this photograph left the galaxy before the beginning of mankind.



slightly hazy. And even on a clear night it is not easy to pick out. The Andromeda galaxy can be spotted by using "averted vision" instead. Don't look directly at the spot where it is, but a little to one side of it. The eye is somewhat more sensitive to faint, hazy objects when they are not viewed directly.

Observing the moon, planets, and the stars even with the unaided eye can be exciting. A new kind of excitement starts when you get or build a telescope, view the deep reaches of space, and see double stars, planets, and the moon in detail that is impossible with the eye alone.

DISCUSSION QUESTIONS

- 1) Show with a sketch that you can use both the Big Dipper and Orion as a key for finding other familiar constellations.
- 2) The stars, sun, moon, and planets appear to move across the sky from east to west. How can you account for the motion? Why do the sun and moon appear to move from west to east among the stars?
- 3) Why cannot the real positions of celestial objects be found by the horizon, or altitude and azimuth, system?
- 4) How is the vernal equinox used as a reference position on the sky for locating celestial objects?
- 5) Why is there a difference between sun time and star time?
- 6) Compare the brightness of star A, apparent magnitude +1, with star B, apparent magnitude +6. Which is brighter? How many times brighter?
- 7) How do you account for the changing brightness of Venus as observed at different times of the year?
- 8) Describe the conditions necessary for an eclipse of the moon to occur.

- 9) Explain why the interval of revolution of the moon about the earth does not equal the interval between successive phases of the moon.
- 10) Why are meteors more common on some nights of the year than on others?

APPENDIX

Activities: Discussions and Answers

- ACTIVITY I** The sun would apparently have moved eastward through 25 days from the zero point at the rate of four minutes or one degree per day. The vernal equinox is therefore 25 degrees west of the sun, or 1 hour and 40 minutes west of the sun ($25 \text{ days} \times 4 \text{ min/day} = 100 \text{ min}$). Choose another date and find the approximate location of the vernal equinox on that date.
- ACTIVITY II** The star will be slightly farther west than it was the day before. The difference becomes marked as you repeat the sighting on successive nights. Stars, then, cross the meridian four minutes earlier every night according to sun time, but at exactly the same star time.
- ACTIVITY III** The lights vary in brightness. The nearest one appears considerably brighter than the ones farther away. The one at midfield appears about four times as bright as the one at the far goal line. The lights at

ACTIVITY IV

other distances will vary inversely with the squares of the distances from you. Subtract the magnitude of star A from that of star B; the difference is +3 magnitudes. On the magnitude-brightness ratio scale (Table 1), a magnitude difference of 3 equals a brightness ratio of 16. Star A is 16 times brighter than star B. Since the moon has an apparent magnitude of -12.7 and the sun -26.7 , the difference is 14 magnitudes. Each magnitude represents a ratio of brightness of 2.5. Therefore the sun is 2.5^{14} , or 400,000, times brighter than the full moon.

ACTIVITY V

You will observe an interesting fourth-of-July sparkler effect. The star not only twinkles, but it changes color because the beams of different colors are bent to different degrees.

ACTIVITY VI

The angular size of the moon is about $\frac{1}{2}^\circ$. This is slightly larger than the diameter of an aspirin tablet held at arm's length. The distance from horizon to horizon equals 180° , so 360 moons strung together would fit into this space. The angular size of the sun and moon are nearly the same. If the sun were larger, or the moon were farther away, one of the most spectacular celestial events could never happen—the total solar eclipse.

When near the horizon the moon appears larger because it can be compared to some object, as perhaps a house, tree, or car. However, its angular size is the same when it is near the horizon as when it is high in the sky. You can prove this with photography, or try to cover the moon with an aspirin held at arm's length. The tablet will nearly cover it at any elevation.

ACTIVITY VII

The moon moves eastward among the stars its own apparent diameter in an hour. Since this means that the moon moves eastward with respect to the stars almost $\frac{1}{2}^\circ$ each hour, it will take about 720 hours (actually 656) to make the complete circuit of 360° and return to its initial spot. The journey takes $27\frac{1}{3}$ days.

ACTIVITY VIII

Throughout the year the elevation of the moon changes. It does not always rise due east and set due west, for it deviates from the plane of the sun by only about five degrees.

In winter the full moon is higher in the sky than in summer. In a way, the full moon and the sun are opposites, for the moon will be in the sun's position the opposite season. The elevation of the moon at any time relates directly to the latitude of the observer. The moon is highest in the sky when it is viewed from a low latitude.

ACTIVITY IX

Because the moon has no atmosphere, the occulted star disappears instantly. If the moon had an atmosphere, the star would be slowly snuffed out. The star being occulted will disappear on the left (east side) and reappear on the right (west side). This occurs because the moon revolves around the earth in an eastward direction.

ACTIVITY X

Since the moon is traveling around the earth from west to east, the east or left edge of the moon will encounter the earth's shadow first. Generally the moon does not get completely dark. The earth's atmosphere bends some of the sunlight into the shadow, causing the moon to appear with a ruddy glow (Figure 18). Occasionally, when the weather is very cloudy along the terminator of the earth, the edge of the shadow will appear diffuse. The time it takes the moon to pass through the earth's shadow depends on whether the moon passes centrally through the earth's shadow. When it does, the full moon can virtually disappear from sight for about an hour.

ACTIVITY XI

The shadow cast by the stick will be shortest near the noon position and on the day with the most daylight hours during summer; at that time the sun will be shining most nearly vertically downward.

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Glossary

absolute magnitude—the brightness a star would have if it were at a standard distance of 32.6 light-years or 10 parsecs.

angular diameter—a measurement or calculation of the angle that an object covers in the sky.

apparent magnitude—the brightness of a star directly visible to the naked eye.

celestial equator—the great circle halfway between the celestial poles, corresponding to the equator of the earth on the celestial sphere.

celestial sphere—the whole sky visible from the earth over a period of one day. The earth is in the center.

corona—an irregular pearly ring of light surrounding the sun and visible only during a total solar eclipse, or with a special instrument.

declination—imaginary division markers on the celestial sphere which correspond to latitude on earth, parallel to the celestial equator.

double star—two or more stars either physically connected or in the same line of sight, which may appear to the naked eye as a single star.

eclipse—a linear alignment of three celestial bodies which obscure one body from another.

ecliptic—the path through the celestial sphere which the sun appears to follow in the course of a year.

galactic cluster—a number of stars in the same area of the sky moving toward the same point on the celestial sphere.

globular cluster—a globe-shaped, densely-packed mass of stars which thins out at the edges.

hour circles—graduated great circles which divide the celestial sphere into 24 equal parts called "hours," perpendicular to the celestial equator.

luminosity—a measure of the actual amount of light emitted by a star.

magnitude—a relative scale of brightness. The lower the number, the greater the brightness; the higher the number, the lower the brightness. The brightest bodies have negative magnitudes.

nebula—a very faint, luminous patch of dust and gas which either emits or reflects light.

north celestial pole (NCP)—the point in the Northern Hemisphere about which the celestial sphere appears to revolve; the zenith at the North Pole on the earth.

occultation—the disappearance of a star or other celestial body behind the moon or a planet.

radiant—the point in the sky from which meteors in a meteor shower appear to come.

right ascension—imaginary division markers on the celestial sphere which correspond to longitude on the earth.

sidereal month—the time it takes the moon to make one complete revolution around the earth and return to the same position relative to the stars (27.3 days).

sidereal time or star time—a time used for measuring right ascension which corresponds to the movement of the stars across the meridian.

south celestial pole (SCP)—the point in the Southern Hemisphere about which the celestial sphere appears to revolve; the zenith at the South Pole on the earth.

star cluster—a small group of stars that appear to be more or less closely packed together.

synodic month—the time it takes the moon to revolve completely around the earth and to return to its same position relative to the earth-sun system. A synodic month, the time from new moon to new moon, takes 29.5 days.

terminator—the line between shadow and light created by the sun shining on the moon.

vernal equinox—the zero point for celestial measurement of right ascension, where the sun appears to be in the sky about March 21.

waning—the decreasing of the area of the moon that is illuminated (approaching new moon).

waxing—the increasing of the area of the moon that is illuminated (approaching full moon).

zenith—the point in the sky directly over the observer's head.

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