Amateur Astronomy

Gregory A. Burnett, AI Specialist, Ford Motor Company, Artificial Intelligence and Operations Research Department, Information Systems Planning, 3184 ROB, phone (313) 84-53586, fax (313) 84-57532, e-mail: usfmc6sh@ibmmail.com

Basic Observing

Greg Burnett
Ford Amateur Astronomy Club

This paper is a compilation of a series of articles originally published in "Star Stuff," the monthly newsletter of the Ford Amateur Astronomy Club. Each article covers one specific segment of amateur observing, and discusses the preferred equipment and basic techniques for that type of observing. The goal is not technical depth, but to provide exposure to a wide range of observing alternatives. This may help a novice get started, or broaden the interest of a more experienced observer.

Solar Observing

The most important watchword for solar observing is safety. This is perhaps the only area of amateur astronomy where there is real danger and potential for serious injury. The necessary precautions are simple, but extremely important. They can be summed up in a single statement: Never observe the sun without proper filtration. This applies to naked eye viewing in addition to telescopic observation. The importance of caution cannot be overemphasized. Even an accidental glance through an unfiltered telescope pointed at the sun will cause immediate, permanent eye damage. You are literally playing with fire; 5000-degree fire!

Excluding specialized telescopes like coronagraphs, there are basically two methods for safely observing the sun: projection and front aperture filtration. Both of these methods are adaptable to most amateur telescopes. Projection involves arranging a projection screen of some sort, a stiff piece of white cardboard for example, at a suitable distance behind the eyepiece. The solar image is then focussed on the screen through the eyepiece. Commercially made mounting brackets are available for this purpose, or they can be homemade. The projection method has the advantage of being relatively inexpensive. It has the disadvantage that fine detail is often difficult to see in a projected image. Also, the full energy from the sun passes through the telescope optics. This can cause heating, particularly in the eyepiece, where cemented lens elements could be damaged. For this reason it is best to use a simple eyepiece for solar projection, like a Huygens or Ramsden type.

Front aperture filtration is accomplished by covering the main objective aperture of the telescope with a filter specially made for solar observing. Such filters may be made of glass or Mylar plastic. Both types rely on a thin coating of metal, usually an alloy of aluminum, to provide the proper filtration. These filters are designed to eliminate all of the ultra-violet and infrared radiation from the sun, and to admit only about a thousandth of a percent of the visible light. An advantage of front filtration is that the operation of the telescope is essentially unaffected. That is, different eyepieces, diagonals, etc. can still be used as usual. Also, the full energy of the sun is kept out of the telescope. The disadvantages are that front filters, particularly glass ones, are somewhat expensive, and they require a certain amount of care.

Another style of solar filter deserves mention because it is not considered safe. Solar filers that attach to the eyepiece are often supplied with "department store" telescopes. These small filters absorb all of the solar energy collected by the telescope objective. They become very hot in just a few minutes and have been known to fracture if over-heated. This could have disastrous consequences for an observer using the telescope at the moment of failure. For a few dollars more, it is better to be safe than sorry.

Space does not allow a more in-depth analysis of the equipment available for solar observing. Those interested in pursuing the subject further would be well advised to obtain one of many books containing detailed information on the subject. Check the book lists in ASTRONOMY or SKY & TELESCOPE magazines.

Once suitable equipment has been arranged, what observing opportunities does the sun offer to the amateur astronomer? Clearly, a solar eclipse is the most dramatic phenomenon associated with the sun. And indeed, except during the few minutes of totality, eclipse observing requires essentially the same equipment as regular solar studies. However, solar eclipses are relatively rare events, and there is quite a number of interesting aspects of solar observing that are present nearly all of the time.

The most obvious features on the sun's surface are sunspots. Sunspots vary in number, size, and location with the eleven year solar cycle, but at least a few are almost always visible. Amateurs with the patience for long term projects can take sunspot counts and compare their counts with the professionals'. Counting sunspots is something of an art; what constitutes a single fragmented sunspot as distinct from a group of multiple spots is often somewhat subjective. Observers with a flair for drawing can record the infinitely varied appearance of sunspots at high magnification, and can note their changes over time. Sunspots sometimes change noticeably over periods of several hours. Often more detail can be captured in a drawing than in a photograph, because the human eye is not as easily confounded by atmospheric seeing conditions as is photographic film. During the day seeing is usually worse than at night. The best solar images will be seen in the mid-morning, after the sun has risen to a moderate height, but before most atmospheric turbulence has time to develop.

In addition to counting, measurements of the latitude of sunspots can be used to construct the so-called "butterfly diagram" as the average spot latitude changes over the 11-year cycle. A graphic plot of spot latitudes over the course of a cycle yields a plot resembling the wings of a butterfly.

During periods of high solar activity, solar flares sometimes erupt on the sun's surface, usually in or very near to large sunspots. These flares produce surges of ultra-violet radiation and high-energy particles that are believed to be associated with shortwave radio blackouts, power surges, and aurorae. Visual detection of flares are useful for predicting these effects (particularly aurorae), which occur after a delay of several hours following the flare event itself. *[Since this article was written, it has been discovered that aurorae are more directly associated with "coronal holes" rather than flares. —G.B.]*

Also visible on the sun are "phlages" or "flocculae", lighter markings that are usually associated with sunspots. New spot groups can sometimes be predicted by observing the formation of flocculae. "Granulation" can be seen over the entire surface of the sun. This pattern, caused by convective movement of the photosphere, can be seen to change in a matter of minutes. Sometimes bright "pores" are seen among the granulations. Pores are often the precursors of sunspots.

The sun is, so far, the only star we are able to study in real detail. For the professional astronomer, the sun is a laboratory for studies in the UV, IR, radio, and X-ray portions of the electromagnetic spectrum. For the amateur, the sun can be a source of many satisfying observations easily within the reach of modest equipment. A number of books are available that contain much more information than I am able to provide here. And, as always, don't neglect your fellow astronomy club members as sources of information and experience.

Observing Asteroids

Asteroids, or "minor planets," are small bodies (by planetary standards) thought to be debris left over from a planet that failed to form due to orbital perturbation resonances. Several thousand asteroids have been identified in orbit around the sun, generally between Mars and Jupiter, forming the so-called "asteroid belt." Many of the orbits are quite eccentric, and there is even a family of asteroids known as the "Earth-Crossers" whose orbits intersect that of Earth. Asteroids range in size from Ceres, the largest with a diameter of 623 miles, down to meteor- and dust-sized particles. There are only about 65 known asteroids with a diameter greater than 100 miles.

As targets for amateur observation, asteroids are generally faint and fast moving. They are too small to show a visible disk, and are difficult to distinguish visually from stars. Their rapid motion usually betrays them, however, and an asteroid can be identified among a field of stars by simply making an accurate sketch of the field, and then checking back, sometimes in only a few hours, to see which "star" moved. More typically, observations on subsequent nights will be required to reveal the asteroid's motion.

There are only 25 asteroids brighter than magnitude 10 at opposition. Vesta, the brightest, reaches magnitude 6 at opposition and can then be seen with the unaided eye under very good sky conditions. Because most are faint, larger telescope apertures are necessary to see them, but there are numerous asteroids within reach of a 6 inch telescope.

The locations of the brighter asteroids are published in the major astronomy magazines from time to time (For example, see "Asteroids Through the Eyepiece" in the June ASTRONOMY, page 53.). More in-depth information on asteroid positions can be obtained from a number of sources, including the Association of Lunar and Planetary Observers and the International Occultation Timing Association.

From time to time an asteroid will occult (eclipse) a visible star. When this occurs, the starlight shadow of the asteroid will sweep a narrow path across the Earth. Anyone in the path at the time will see the star briefly dim or disappear. Because the star is so much farther away than the asteroid, the shadow casts a perfect silhouette and allows the approximate size and shape of the asteroid to be determined from carefully coordinated ground observations. A line of many observers is deployed across the predicted path of the occultation. Each observer accurately (generally +/- 1/10 second) times the beginning and end of the event. From these timings the size and shape of the asteroid are reconstructed. Such observations, by amateur astronomers, are coordinated by the International Occultation Timing Association (IOTA). Occultation timing expeditions offer an exciting and unique opportunity for amateur observing.

Lunar Observing

Even though many amateur astronomers consider the Moon to be a nuisance to "serious" observing, it can be a very interesting target for an informed, open minded, observer. Our Moon is the closest astronomical object (approx. 240,000 miles on average), and the brightest besides the sun. It is also the only one we've actually visited, other than by proxy. The large day to day changes in the Moon make it especially interesting to those of us with short attention spans. It's unfortunate that the moon is so often ignored as an amateur astronomy subject.

Almost any equipment is suitable for some type of lunar observation. In fact, there are many interesting observations that can be made with the unaided eye. Nearly everyone notices the changing phases of the Moon. With only a little extra attention, one can appreciate the geometric relationship among the Sun, Earth, and Moon that gives rise to the particular phase you are seeing, and can note that if you were on the Moon, the phase of the Earth would appear exactly opposite that of the Moon seen from the Earth. Sharp eyed observers can try to spot the earliest crescent Moon following the New Moon. Such observations have great historical significance in establishing the dates of certain religious holidays. Seeing the oldest waning crescent can be equally challenging.

Other phenomena involving the movement and position of the Moon can also be appreciated sans optics. The librational position of the Moon can be seen to vary over the course of each lunation (a complete sequence of phases, i.e. a lunar month). Libration is the apparent tilting or rocking of the Moon, due to its elliptical orbit and other effect, that allows us to actually see more than half of the Moon's surface. Even crude sketches of the naked eye Moon will reveal the librations. It can also be interesting and instructive to follow the rising and setting times and azimuths of the Moon from night to night. On average, the Moon rises about 50 minutes later each night, but this "retardation" varies considerably depending on the position of the moon in its orbit, from as little as 10 minutes to as much as 90 minutes. Some fairly sophisticated mental gymnastics are required to rationalize these variations intuitively. Associated with these variations is the relationship between the Moon's orbit and the ecliptic, which gives rise to variations in the altitude of the culminating Moon. You may have noticed that the Moon is usually higher in the sky during the Winter than during the Summer. There is a reason for this (I'm not going to tell you what it is!). *[The answer to this "exercise for the reader" is as follows: The Moon more-or-less follows the ecliptic during its monthly movements, as the Sun does annually. Thus, the Sun, seen during the day (obviously), is high in the sky during the Summer months and low in the Winter. Since the Moon is usually observed at night (at least it's more often noticed then), the situation is reversed: the Moon, particularly when nearly full, appears generally higher in the sky during the Winter and lower during the Summer. —G.B.]*

Of course eclipses of the Moon are easily observed unaided, but so much has been written on the subject that I'll not belabor it here. A distantly related phenomenon is "Earthshine," which is caused by the light from a nearly "full" Earth illuminating the otherwise dark portion of a crescent Moon. The brightness of the Earthshine is related to a number of factors, not the least of which is the weather on the Earth at the time!

There are a number of lunar features visible to the unaided eye. There are over 25 named maria on the Moon, along with several "lakes," "marshes," and "bays." How many can you see? Can you pick out any of them when illuminated only by Earthshine? How about with binoculars?

There are of course a multitude of interesting lunar feature accessible to amateur telescopes, including craters of every size and description (Do you really believe they're all meteoric and none are volcanic?), crater chains (smart meteors!), mountains and mountain chains, rills, grabens, scarps, clefts, and ray systems. Most features are best seen when they are close to the "terminator," the line that divides the illuminated and unilluminated portions of the visible surface (No, it's got nothing to do with Aaaaarnold!). There the light of the Sun arrives at a low angle and topographic features stand out in striking relief. Some lunar domes, small rises in otherwise level areas of the lunar surface, can only be seen within one or two hours of lunar sunrise or sunset because they are so low. An exception to the foregoing are the ray systems, which are best seen around full phase. Rays are believed to be debris from meteoric impacts. Of course, a good map makes exploring the lunar surface easier and more enjoyable. (See book recommendation below.)

The appearance of most lunar features varies considerably under different lighting conditions. If you sketch a feature near the terminator on a particular night, then locate that feature the next night, you will see drastic changes in its appearance. On later nights you may not even be able to locate the feature because of the lighting differences. Careful sketching can also reveal appearance changes cause by librational variations. If you're not artistically inclined (Actually, sketching features on the Moon requires more patience than skill.), the Moon is an easy target for photography. It is bright enough that good photos can be taken with simple arrangements, and usually no guiding is required. Comparison of photos taken at different times can be very instructive.

Those of us with an inclination to sleuthing can investigate the infamous "TLPs" or Transient Lunar Phenomena. These are suspected occurrences of fogs, outgassings, glows, color changes, and various other questionable events that are claimed to have been observed from time to time. Much has been written about them, but very little definitive evidence has been accumulated. A well documented TLP event could win you fame and fortune in astronomical circles!

Lunar occultations provide interesting observations that relate the Moon to the rest of the sky. When the Moon occults (passes in front of) a bright star, the star disappears from view instantaneously. Through a telescope, the abruptness of the event is startling. This is because the Moon has no atmosphere to fade out the star's light, and the very distant star has no appreciable diameter, so it is obscured all at once. During grazing occultations the star passes behind mountain peaks along the limb (edge) of the Moon, and is seen to blink off and on as the lunar mountains move in front of it. Serious occultation timing groups can produce accurate estimates of mountain heights from carefully recorded grazing occultation observations.

There are many books available on the subject of lunar observing, lunar geology, lunar exploration, and so forth. The one I have and will recommend (I've not really evaluated many) is The Moon Observers Handbook by Fred W. Price (Cambridge University Press, 1988). It contains many excellent maps organized by feature type, and by phase (i.e. terminator position). Another worthwhile book is A Portfolio of Lunar Drawings by Harold Hill (Cambridge University Press, 1991). This book is an absolutely stupendous accumulation of Hill's pen and ink sketches of lunar features. It's great for cloudy night astronomy.

Double Star Observing

In an earlier Star Stuff article (v.2, n.1, January, 1993) I discussed double stars in general, including their classifications (visual, astrometric, spectroscopic, eclipsing, and optical), and some fundamental information on observing. This article will take up several other aspects of double star observing, in an attempt to avoid redundancy. *["Double Stars" is included as an appendix to this paper. —G.B.]*

For serious (but still amateur; read "satisfying") double star observing, your telescope must deliver the goods with respect to resolution. Double stars are often used as test objects to determine the true resolving power of a telescope (See the January article for a table of theoretical resolving powers of telescopes of various apertures.), and that's fine if you're paranoid about the quality of your telescope's optics. The fact is that amateur scopes are always a compromise of several factors, including aperture (i.e. light gathering power), resolution, and portability. Most amateur scopes reflect a compromise that leans toward one particular factor: "Dobs" toward light-gathering, SCTs toward portability, and refractors (and Questars) toward resolution and image quality. For double star observing there is no substitute for crisp, high-resolution images, regardless of aperture. There is a endless range of double stars suitable for telescopes of every size. No matter how much aperture you have, there will still be a zillion doubles beyond your reach. The important thing is that your scope delivers an image that permits observation of doubles with separations down to (and perhaps below) the theoretical limit for its aperture. Otherwise, your double star observations will not be interesting or satisfying.

In response to a point source of light (e.g. a star) a telescope produces an "Airy disk" (named for George Airy, optician and astronomer) that is considerably larger than what the true geometric image of the star would be, typically by a factor of 1000 or more. It is the Airy disk that you see in the eyepiece, not the star. The Airy disk is surrounded by a series of concentric diffraction rings. The Airy disk and its associated diffraction rings represent the best star image your telescope can theoretically produce. If you can see the Airy disk in your telescope, you can make satisfying observations of double stars.

The ability of a telescope to "split" a double simply means that the Airy disks of the two stars are discernibly separate. Below the theoretical limit of separation, the Airy disks will overlap and form a figure "8" or an oval. In this case the star is certainly seen to be double, even though the images of the components are not distinctly separated. Obviously, a high-resolution image is required to make these observations.

Given excellent optics, one remaining obstacle to double star observing is the "seeing" conditions on any particular night. Atmospheric turbulence can prevent your telescope from performing at its best. On nights of poor seeing, doubles that are normally resolvable will be seen as boiling, indistinct knots of glare. On marginal nights, doubles higher above the horizon usually give better results. The nearer your viewing angle is to the zenith, the less air you're looking through.

Double stars can be challenging targets for two reasons: separation and brightness difference. Some of the most difficult doubles for my 6-inch scope are not particularly close, but they exhibit large magnitude differences between the components. For example, Antares has a comfortable 2.7 arcsecond separation, but the 5.4 magnitude secondary can be very difficult to see in the glare of the 1.2 magnitude primary. This difference of over 4 magnitudes makes Antares resolvable only on nights of steady seeing. (Its -17 degree declination doesn't help matters either!) Sirius is an extreme example. The primary is -1.5 magnitude and the secondary is 8.5, giving a difference of 10 magnitudes. Even though the separation is a generous 4 arcseconds, Sirius is impossible to resolve in amateur scopes and is a serious challenge for observatory-class equipment.

There are interesting doubles suitable for any telescope, even binoculars. Most star atlases include lists of popular and interesting double stars. Norton's Star Atlas and volume 1 of the Webb Society Deep-Sky Observer's Handbook are both good sources. Serious observers should consult Sky Catalogue 2000.0, volume 2, which lists over 8,000 double and multiple stars.

Variable Stars

The ancients believed that the sky was perfectly constant, reflecting a notion god-like perpetuity. When they discovered planets, they were naturally uncomfortable, and invented wonderful rationalizations for these "wanderers". The discovery of variable stars put to rest forever the idea of eternally unchanging heavens.

Variable stars fall into four major physical classifications. "Pulsating variables" comprise about a dozen sub-types, including the Cepheid variables that have been so important in measuring the size of the universe. These are stars that exhibit varying brightness due to periodic changes in their internal structure. "Eruptive variables" include a dozen or so sub-types that are considered irregular variables, and also novae and supernovae. Novae are now understood to be members of binary systems that become unstable due to transfer of matter from one star to the other. Supernovae are the explosive results of instabilities in supergiant stars. "Eclipsing binaries" are simply double stars that happen to be oriented so that the stars eclipse on another as they orbit. We observe these eclipses as a variety of possible light curves that can tell us alot about the sizes and other properties of the two stars. "Peculiar variables" include whatever we cannot otherwise classify; there are still some mysteries out there.

The observation of variable stars is one of the last areas where the amateur can contribute observations with real scientific value. There are thousands of variables for which definite light curves and classifications have not yet been established simply because professional observatories cannot devote the time required to monitor them. Likewise, there are numerous irregular and suspected variables that will reveal themselves only if constantly watched. Large organizations of dedicated amateurs provide the only opportunity for sufficient observation of these stars. Similarly, amateurs are often the first discoverers of supernovae, although automated surveys are proving more and more productive.

Almost any equipment can be used to observe variables stars, even binoculars. There are many variables within reach of small telescopes. High quality optics are not a requirement, since resolution and image quality are not important factors. Larger apertures will gain access to fainter stars, including those most lacking regular observation.

Much more important than equipment is observing technique. Overcoming physiological obstacles to "point photometry" with the human eye requires a rigorous adherence to procedure and a great deal of practice to achieve accuracy. Making a variable star observation involves comparing the brightness of the variable to one or more comparison stars. In doing so, the observer must be sure to use the same area of their retina for both stars, since retinal sensitivity varies widely over the retina; averted vision should not be used unless absolutely necessary to see the star. When observing colored stars, the observer must be aware of the eye's non-instantaneous adaptation to red light. Stars with a strong component of red light in their spectrum will seem to become brighter as they are looked at longer. In addition, the "Purkinje effect" will cause red stars to appear brighter than they really are under certain comparison conditions.

There are two fundamental methods for performing magnitude comparisons. To insure accuracy, the observer should adopt a particular method and practice it on known stars until they are adept. One method is called the "step method." This method involves learning to discern magnitude differences of 0.1, 0.2,... all the way to one full magnitude. This must be learned independent of the absolute star brightness; it's the differences that are important. When observing with the step method, the variable is compared with a single comparison star, and the perceived number of 0.1 magnitude steps between the variable and the comparison star are noted. Several separate observations are made using different comparison stars. The observations are later reduced by looking up the catalog brightness of the comparison stars and determining the variable's brightness by adding or subtracting the appropriate multiples of 0.1 magnitude. Clearly, this method requires practice to achieve accurate results.

The second method is called the "fractional method." This method does not rely on learning fixed magnitude steps. It uses two comparison stars simultaneously, instead of just one as in the step method. When observing, the observer determines the ratio of differences between the variable and the two comparison stars. For example, the variable may lie two thirds of the way in brightness from the fainter comparison star to the brighter. The ratio 2:3 would be recorded (along with the identity of the comparison stars, of course). The ratio could vary from 1:1 to 3:5, 2:5, 1:5, etc. Using a denominator greater than 5 becomes difficult. The observations are later reduced by applying the ratio to the cataloged brightnesses of the two comparison stars. This method may at first appear easier than the step method, but appearances are often deceptive.

In addition to a well-trained eye, careful record keeping is required for useful observations. Some variables change brightness slowly over periods of weeks or months. Useful light curves can be built up only from carefully recorded observations that include the observing conditions and the comparison method used. There are several worldwide organizations dedicated to collecting and utilizing amateur observations of variables stars. The most noteworthy are the American Association of Variable Star Observer (A.A.V.S.O.) and the Variable Star Section of the British Astronomical Association. Both of these organizations publish stars charts specifically designed for variable star observing, with comparison stars clearly marked.

Amateurs considering embarking on a variable star observing program would do well to consult one of the many books on the subject. Observational Astronomy for Amateurs by J.B. Sidgwick (Enslow Publishing) contains a chapter on variables that describes the step and fractional observation methods in detail. The Webb Society Deep-Sky Observer's Handbook, vol. 8: Variable Stars by Kenneth Glyn Jones (ed.) is perhaps the standard amateur reference on variables. Serious observers should obtain the AAVSO Variable Star Atlas (2nd ed.) by Charles Scovil. Catalogs of variable stars are included in most listings of popular amateur observing targets, for example Norton's Star Atlas and Sky Catalog 2000.0. All of these books are available from either Willman-Bell or Sky Publishing.

Star Clusters

There are two types of star clusters, "galactic" or "open" clusters, and "globular" clusters. The Pleiades and the Hyades are well known examples of nearby open clusters. M13, the Hercules Cluster, is a prime example of a globular cluster. The two types differ radically, being almost opposites of each other in terms of their defining characteristics. They also call for different observing techniques.

Open clusters generally contain some tens to some hundreds of stars. They occur most often within the spiral arms of our galaxy, hardly ever being found at higher galactic latitudes (i.e. they are all near the plane of the galaxy). As a result, astronomers estimate that there may be as many as 100,000 open clusters that remain undiscovered because they are obscured by dust in the galactic plane. Only about 1200 open clusters have been catalogued. Most open clusters are young, as evidenced by their populations of hot, blue stars of "early" spectral types. Many still contain nebulosity left over from their formative period (e.g. the Pleiades).

The stars in an open cluster are not gravitationally bound to each other. They will eventually disperse into the galaxy due to galactic gravitational tidal forces and other perturbations. But while they remain a cluster, they are useful for computing distances beyond the range of parallax measurements. Because the members of a cluster are travelling in more or less the same direction through space, observations of the convergence (or divergence) of their proper motions, combined with measurements of their radial velocities, allow us to triangulate the distance to the cluster.

Open clusters are comparatively large in angular size, so observing them calls for low powers and wide fields. Many open clusters are admirable, even spectacular, binocular objects, and a few can be easily seen with the naked eye. Generally speaking, open clusters are composed of reasonably bright stars distributed over a generous area, so large telescope apertures and high resolution are not mandatory for satisfying views. The challenge in observing open clusters is often to separate them from the background stars. In this respect great light gathering power can be a hinderance rather than an asset. In a large-aperture scope the cluster can be lost among the many fainter background stars revealed by the large scope. The lowest magnification that provides adequate contrast usually yields the best views of open clusters. Move to higher powers to examine double stars and asterisms within the cluster.

Globular clusters generally contain thousands to hundreds of thousands of stars. They occur throughout a spherical "halo" that encompasses the galaxy, and they are found at all galactic latitudes. Within our galaxy there are 138 known globulars; probably fewer than 100 remain undiscovered. Globulars are among the oldest objects in the galaxy. Some are estimated to be up to 10 billion years old. Most of their stars are poor in "metals" (in astrophysics, any element other than hydrogen or helium is called a "metal"), having formed at a time before much of the heavier elements had been created. The stars of a globular cluster are gravitationally bound to each other. They form a stabile system in which each star orbits the gravitational center of the cluster as a whole. Globulars at high galactic latitudes are sometimes less dense than those closer to the galactic plane. Gravitational tidal forces generated by the galaxy impose a lower limit on the density of globulars close to the plane. Many globular clusters have been identified in other galaxies, and are important "standard candles" used in estimating intergalactic distances. Some 300 have been observed in M31, the Andromeda Galaxy, and a hoard of over 6000 globulars surrounds M87.

Observing globular clusters calls for moderate- to large-aperture telescopes with excellent resolution. Many globulars are somewhat faint, and the best views are those that resolve as many individual stars as possible. Moderate to high magnifications can be used for improved contrast, as globulars are comparatively small in angular diameter.

Star clusters are among the most beautiful objects in the heavens. Most of the best clusters (accessible from the northern hemisphere, at least) are contained in the famous catalogue of Charles Messier. Many additional objects worthy of observation can be found in the NGC and IC listings (New General Catalogue and Index Catalogue). One of the best books about stars clusters for the amateur is the Webb Society Deep-Sky Observer's Handbook, Volume 3: Open and Globular Clusters, which contains a wealth of information about clusters and a very useful catalogue of the best objects of both types.

Meteor Observing

It is estimated that tens of thousands of tons of meteoric material impacts the Earth each day. The vast majority of this material is dust, but some is in lumps of appreciable size, which we call "meteoroids." *[Information recently declassified by the U.S. Government indicates that the entry of large meteors into the Earth's atmosphere is much more frequent than originally thought. The data comes from equipment intended to monitor for nuclear explosions. —G.B.]* When a fast-moving meteoroid encounters the Earth's atmosphere, it is heated to incandescence by air friction at an altitude of 60-80 miles, and we see the phenomenon we call a "meteor." If the object is large enough to survive re-entry, it will arrive at the ground and become a "meteorite."

Most of the meteors we observe in the sky are about the size of sand grains. The very brightest, called "fireballs," and the ones that explode, called "bolides," are generally about the size of marbles. Few of these ever reach the ground. Rarely, a meteor of golf-ball size or larger will arrive and become a meteorite. It is estimated that, on average, one meteorite impacts the Earth's surface per square kilometer per year. Obviously, most fall into the oceans. The rest are lost among the naturally occurring rocks and into the soil. Only when a very large meteoroid is observed arriving, or when one breaks into a shower of fragment, do we have a reasonable chance of recovering any of the material. (Many meteorites are also recovered from Antarctica, where they "float" to the surface of the ice.)

It was once thought that most meteors were following hyperbolic orbits and that they arrived at the Earth from somewhere far beyond the Solar System. We now understand that virtually all meteoric material is debris from comets, and while there are many "sporadic" meteors, most meteors occur as showers associated with a particular comet. In many cases the parent comet is a known periodic comet that is regularly observed. A meteor shower occurs when the Earth passes through the swarm of debris lying along the comet's orbital path. Since the meteoroids of a particular swarm are all moving in the same direction along the comet's orbit, they enter the atmosphere along essentially parallel paths. When we see them from the ground, their paths do not appear parallel, but seem to originate from a particular point in the sky. This point is called the "radiant" of the shower. Because the orbit of the meteor swarm is consistent, the shower will recur each year when the Earth passes through it, and the radiant will appear in a consistent place in the sky. Consequently, most major showers are named after the constellation in which the radiant appears, for example the Perseids each August and the Leonids each November. There are over a hundred known showers, but only about a dozen major showers receive attention from amateur observers.

Meteor observation is important for gaining an understanding of how comets lose material, how it spreads out along the orbit of the comet, the composition of comets, and the relationship between comets and asteroids. Even though most serious meteor observations are now made by radar, the amateur astronomer can still make a contribution. Amateur observations provide important data that helps define meteor swarm orbits and radiant locations, and can help predict major meteor storms. Several organizations collect amateur observations. Two of them are the American Meteor Society (Dept. of Physics and Astronomy, State Univ. of New York, Geneseo, NY, 14454) and the International Meteor Organization (Physics Dept., Univ. of Western Ontario, London, ON, N6A 3K7).

In order for amateur observations to be useful when combined with many others collected from different areas, all must be conducted according to certain guidelines. The most common amateur observation of meteors is simply to count them, but it must be done correctly. Position yourself comfortably where you can view an unobstructed area of sky for at least an hour or so. If some of your view is obstructed by trees or buildings, record how much (e.g. 5%; If it's more than about 20%, choose another location.). Record your viewing period to the nearest minute, including start and stop times, not just the duration. Record the faintest star visible at your location (i.e. the "limiting magnitude"). There are charts available to help with this. The limiting magnitude can change during the night, so check it at least every hour, and record changes if necessary. If clouds temporarily obstruct your view, either record them as obstructions, or if they are more severe, stop your viewing session until they pass. Record the center of your viewing area. You should observe an area between the zenith and 40-50 degrees altitude. If you submit your observations for compilation, include the latitude and longitude of your location.

During your observing session, count the number of meteors seen. You should count sporadics and shower members separately. This requires knowing the location of the radiant in order to distinguish between them. You should also observe whether the shower meteors are fast or slow, faint or bright, whether they leave glowing trails along their path, called "trains", and what colors you observe, if any. Count only the number of meteors within your field of view; do not combine you count with anyone else's or count meteors that you did not actually see (in spite of "ohs" and "ahs" from your fellow observers!). It is also helpful to observe before and after the predicted peak of a shower, in order to help define the extent of the meteor swarm. If these guidelines are followed, your count will be statistically valid when combined with counts of others who followed the same procedure.

There are other, more rigorous methods for meteor observing. Some observers record the actual path of each meteor seen and its brightness by comparing with nearby stars. This requires substantial dedication and practice. Another technique is to coordinate multiple observations from different locations separated by 50-100 miles. In this way the actual path of the meteor can be reconstructed in three dimensions. There have been several projects aimed at meteorite recovery through path triangulation, but none have yet been successful. The best way to obtain a meteorite is to buy one from a collector. You can then hold a piece of the primordial Solar System in your hand.

Comet Observing

To the ancients comets were “hairy stars” (from which the name “comet” derives) and were considered bad omens. We now know that they are debris from the formation of the solar system. Analysis of comets reveals the composition of the original solar nebula. The source of comets is the Oort Cloud (named for Danish astronomer Jan Oort), a spherical shell of some 10^{12} to 10^{13} comets orbiting the Sun at a distance of 50,000 AU (astronomical units; the distance from the Sun to the Earth), about 1000 times the maximum distance of the planet Pluto. From time to time a comet is diverted out of the Oort cloud by close passage of another body, and it travels into the Solar System, perhaps to become an observed comet. If the comet’s orbit is further perturbed by passing close to a planet (Jupiter is usually the culprit), it can become a “short period comet” like Comet Enke, which has an orbital period of 3.3 years. Otherwise it remains a “long period comet” whose orbit may extend almost all the way back out to the Oort cloud, like Comet Kohoutek, which has an estimated period of 80,000 years.

Comets are composed of a conglomeration of rock, dust and ices, including water and methane ice. The prevailing model of comets for many years has been Fred Whipple’s “dirty snowball” model, but that has recently been challenged by observations suggesting that comets may be more closely related to asteroids than previously thought. In any case, as a comet approaches the Sun, the volatile ices begin to evaporate. The resulting gas, combined with dust from the comet, form the “coma” that we observe. The coma usually begins to appear when the comet is about 3 AU from the Sun. The body of the comet itself (referred to as the “nucleus”) may only be 0.1 to 10 km in diameter, while the coma can expand to 10^5 to 10^6 km. The evaporation of ice from the comet can also produce forces that alter the orbit of the comet. Consequently, comet orbits are notoriously difficult to predict accurately.

As the comet gets closer to the Sun, the ejected material may form tails. Often there are two separate tails: The gas or “ion” tail projects from the comet directly away from the Sun, regardless of the true motion of the comet. The gas is driven by the solar wind and more or less ignores the comet’s orbital motion. The dust tail, on the other hand, lies approximately along the orbit of the comet, because the particles of dust respond more to gravitational effects than to the solar wind. Often the tails are distinctly separate, and are usually different colors.

For the amateur astronomer there are essentially two major observational “events” associated with comet observing: recovery of known comets, and discovery of new comets. The predicted return of a known comet is often inaccurate, and being the first to observe a returning periodic comet is still a significant achievement. Over 600 periodic comets are known. Although only a handful attain naked-eye brightness, many become interesting telescopic objects and can be located with the help of positional information published in magazines and ephemerides.

Discovering a comet is still a very real possibility for the amateur, but significant dedication and perseverance are required. Many comets are now discovered by professionals using photographic techniques, but about half are still discovered by amateurs; on average about five per year. Since a newly discovered comet is named for the first person to observe it, there is substantial motivation for comet hunting. Only about 300 to 400 people have discovered comets in all of history, and only 150 or so have found more than one. The record is still held by Jean Louis Pons, the doorkeeper at the Marseille observatory (I don’t know if this makes him a professional?), who discovered 37 comets between 1801 and 1837. More recently, George Alcock in England, Kaoru Ikeya in Japan, and William Bradfield in Australia (among others) have achieved notoriety for their comet discoveries. On average it takes about 300 hours of observing, with good technique, to discover a comet.

Comet hunters typically use telescopes in the 6-inch to 12-inch aperture range, and employ very low magnification. The best technique is to sweep consistent areas of the sky, usually in the early morning. It is important that the observer become familiar with all the non-stellar objects in their sweeping area, lest they be mistaken for comets. Charles Messier was a comet hunter who compiled the Messier Catalog of “M” objects to help others avoid misidentification. If you think you have found a new comet, you must report the find immediately by telegram to the Central Bureau for Astronomical Telegrams at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts. Good hunting!

Planetary Observing

Planetary observing presents a variety of challenges to the amateur astronomer. The planets are constantly changing in appearance and position. With few exceptions (e.g. the Sun and the Moon), this is a unique characteristic among astronomical objects, many of which are the very definition of constancy and changelessness. The continuous movement of the planets requires planning and some ability to navigate in the sky for successful observations. Several of the planets present a level of detail in their appearance that will challenge the resolving ability of the amateur scope and the observing capabilities of the amateur.

Only three of the planets, Mars, Jupiter, and Saturn, are really interesting to "look at." The others are interesting mainly to locate and to follow their movements. However, Mercury and Venus do exhibit interesting phases, similar to the Moon, that add to their attraction even though no surface features may be visible. In what follows, we will look at each planet in turn and discuss its noteworthy features.

Mercury is a difficult planet to observe because it is never very far from the Sun. It is best seen at maximum elongation, and even then it is very small and reveals no surface features in amateur scopes. It does exhibit phases, but is usually observed near half phase because at other times it is just too close to the Sun. It can be challenging even to locate Mercury, and it is worth your while to do so when favorable presentations occur. It is said that Johannes Kepler, who studied planetary motions in great detail, went to his grave without ever seeing Mercury.

Venus is much more easily observed than Mercury, and exhibits very interesting phases and variations in size, which can be followed through nearly a complete cycle. Strangely enough, Venus is seen best during daylight, when its bright glare is suppressed. Through the telescope it looks like a beautiful miniature Moon against the blue of the sky. It is often bright enough to be seen with the naked eye during full daylight, if you know exactly where to look. There have been some claims of seeing surface features on Venus, but such observations are very doubtful in amateur scopes.

Mars provides many interesting surface features and surface activity. Landform markings are easily visible near opposition, and can be compared with the detailed surface maps provided by orbiting spacecraft. The polar caps are visible most of the time, and can bee seen to shrink and grow with the Martian seasons. From time to time huge dust storms will obscure the surface features, and their progress can be followed from night to night. The apparent size of Mars varies greatly with its position, from less than 10" (arc seconds) to almost 24" during a favorable opposition. Due to the relative orbital geometry of the Earth and Mars, some oppositions are much more favorable than others. Mars' apparent diameter at opposition varies from 13.8" to 23.8", almost a 2 to 1 ratio, which can make a significant difference in the amount of visible detail.

Jupiter also presents interesting surface detail, although it's not really a surface we are seeing, but the tops of Jupiter's gas clouds. The appearance of Jupiter is fairly constant, although in the past several years significant changes in the Great Red Spot and one of the major belts have been observed. Some short-lived features can also be observed at times. A major attraction of Jupiter is the set of four ever-changing Galilean moons, which present an almost continuous parade of transits, eclipses and appulses of every sort. The apparent size of Jupiter varies only a little. At opposition it can be from 44.7" to 49.8" in diameter. *[Since this article was written, we have experienced the impact of comet Shoemaker-Levy 9 on Jupiter, creating unprecedented interest in the planet and truly unique observing opportunities. —G.B.]*

Saturn's main attraction is, of course, its famous ring system. The rings show a great deal of detail that will challenge the best telescopes. They also vary their angle to the Earth, disappearing completely as the Earth crosses the ring plane about every twelve years or so. Saturn is probably the most exciting sight for a non-astronomer to see through a telescope. Saturn varies only slightly in size at any time. Several of Saturn's satellites are visible, but they are constantly up-staged by the wonderful rings and consequently are not nearly as popular as Jupiter's four visible moons.

Uranus and Neptune are something of a challenge to locate and identify. They are too small to present any surface detail in amateur scopes, and indeed Neptune is sometimes easy to mistake for a star. Uranus is at times barely visible to the naked eye in very dark skies, reaching a maximum magnitude at opposition of 5.7. Neptune only reaches magnitude 7.8 at opposition. Neptune's moon Triton is visible in scopes of 6 inches of aperture or more.

Pluto is always a challenge to locate, never being brighter than magnitude 13 to 14. At times Pluto is actually closer than Neptune, but since it is so small it is consistently a difficult target. The attraction of observing Pluto is mainly the satisfaction of locating and observing the outermost planet of our Solar System.

Since planets are generally bright (except for Pluto) aperture is not a factor in choosing planetary observing equipment. The name of the game is resolution! This makes refractors, unobstructed reflectors (e.g. trischifspieglers), and specialized long-focus Newtonians highly recommended for planetary observing. Apertures of six to eight inches and less are usually adequate. Larger apertures can suffer more from bad seeing than smaller ones, and owners of large reflectors often stop them down with an off-axis aperture mask for planetary observations.

Choosing the right magnification is important for planetary observing. For a particular set of conditions (i.e. target, scope, and seeing), the observer needs to select a magnification that provides sufficient image size for visibility of available detail, but not so much magnification that seeing effects or resolution limitations begin to dominate the image. Therefore, a wide range of eyepieces is desirable. To assist in seeing surface detail, some observers use colored filters. Their purpose is to enhance certain color contrasts, but their effects are subtle at best and their utility should not be overemphasized.

The planets provided the amateur with an endless variety of observing challenges. While deep-sky objects may hold more romance for some, our neighbors close to home should not be neglected.

Nebula Observing

Nebulae can be divided into three general classifications: bright nebulae, dark nebulae, and planetary nebulae. They are all what we would call "extended objects," and they vary in size from tiny planetaries that are easily mistaken for stars, to gigantic supernova remnants that span many degrees of sky. They are perhaps the most beautiful and certainly the most colorful deep-sky objects.

Bright nebulae comprise two very different types. "Emission" nebula are characterized by bright emission lines in their spectra. They are clouds of gas, mostly hydrogen, that is ionized by the ultra-violet radiation from stars embedded in the cloud. The ionized gas fluoresces as free electrons recombine with ionized atoms. The H-alpha spectral line at 6535 Angstroms predominates in the emitted light, giving emission nebulae their characteristic red color. The nebula gas is very tenuous, having only about 1000 atoms per cubic centimeter (as opposed to around 2.7×10^{19} in normal air) and it is very hot, about 10,000 Kelvins. Well known examples of emission nebulae include M42, the Great Nebula in Orion, and M8, the Lagoon Nebula in Sagittarius.

"Reflection" nebulae are composed mostly of dust rather than gas. The dust particles reflect the light from nearby stars, so the spectrum of a reflection nebula is continuous, with dark absorption lines, characteristic of the illuminating stars. The dust particles are several ten-thousandths of a millimeter in size and therefore tend to scatter blue light more than red, causing the nebula to appear somewhat bluer than the illuminating stars. The dust is composed of various forms of silicon and carbon. Examples of reflection nebulae include M1, the Crab Nebula, which is a supernova remnant, and the nebulosity associated with the Pleaides, M45.

Contrary to what their classification would imply, most 'bright' nebulae are somewhat faint, requiring moderate to large telescope apertures to observe them well. High resolution is not real important, even though many bright nebulae exhibit considerable detail. Several can be seen in binoculars, but most reveal their full extent only in long exposure photographs.

Dark nebulae, the second major class, are composed of the same type of dust as reflection nebulae, but have no nearby stars to illuminate them. They can only be seen in silhouette against a background of stars or bright nebulosity. Usually some stars can be seen through the nebula, and these stars will be reddened due to the blue scattering characteristics of the dust, as mentioned earlier in connection with reflection nebulae. The densest dark nebula will attenuate starlight by as much as five magnitudes. Well known dark nebulae include the Coalsack in Crux (southern hemisphere) and the famous Horsehead Nebula in Orion.

Dark nebulae are not very popular as amateur observing targets because they are usually difficult to see. In general, the same equipment requirements apply as for bright nebulae, but dark nebula are more challenging and reveal themselves clearly only in photographs.

Planetary nebulae are the third major class of nebulae. The name "planetary" was coined by William Herschel based on their visual similarity to the planet Uranus; planetary nebulae actually have nothing at all to do with planets. A planetary nebula is a spherical shell of gas surrounding a hot star, which provides the energy for its light emissions. They often have a circular appearance, and glow in the green light of doubly ionized oxygen, O-III. Perhaps the most famous planetary is the Ring Nebula in Lyra.

The following description of the origin of planetaries comes from Sky Catalog 2000.0, Alan Hirshfeld & Roger W. Sinnott eds., Sky Publishing, 1985.

> "The progenitors of planetary nebulae ("Protoplanetaries") are bloated red-giant Mira variables. Although each starts with one to six times the Sun's mass, it continuously loses material in a slow stellar wind of typically 20 kilometers per second. When the bulk of the atmosphere is gone and the hotter, underlying layers are revealed, the surrounding gas is ionized and begins to glow. The wind increases sharply to perhaps 1,000 kilometers per second and plows the matter into a shell that is typically 0.15 parsec across. (This is about 30,000 times the distance from the Sun to the Earth.) The star then quickly evolves into a white dwarf, and the glowing nebula remains visible for less than 100,000 years. The entire process is described in more detail by Sun Kwok in *Sky and Telescope*, **62**, May 1982, page 449."

Planetary observing has slightly different equipment requirements from other nebula observing. Most planetaries are compact but fairly bright (exceptions being the "Owl" and the "Eskimo" among a few others), so large apertures aren't generally necessary. Good resolution at high magnification is helpful in detecting structural detail. Some planetaries are very small and can be difficult to distinguish from nearby stars. Special filters are available that isolate the unique O-III light from the planetaries to aid in identifying them.

As you can see, there is a wide variety of nebulae available to the amateur astronomer. Most catalogs include lists of the most interesting objects, and many are included in the Messier catalog of "M" objects.

Galaxy Observing

Galaxy! The word itself conjures up a universe of romantic notions: "The Galactic Federation", "Battlestar Galactica", "A Galaxy of Hollywood Stars". These days we take for granted our understanding of galaxies (even though many of us fail to appreciate their scale). Galileo became the first astronomical observer of galaxies when he trained his telescope on our own Milky Way and wrote, “The galaxy is nothing other than a mass of luminous stars gathered together.” For a long time after Galileo galaxies were simply regarded as “spiral nebula.” It was Immanuel Kant who first guessed their true nature in 1755, but his speculations passed unnoticed at the time. The work of Heber Curtis and Edwin Hubble in the early 20-th century finally confirmed their true character. These days the nature of galaxies is largely beyond speculation, even though we continue to work at establishing accurate intergalactic distance measurements.

Galaxies are huge agglomerations of stars, and vast quantities of dust and gas, all bound together by gravity. Galaxies occur in a wide range of sizes; the largest may contain trillions of stars. Our galaxy, the Milky Way, is variously estimated to contain 100 to 200 billion stars. There is a likewise an “astronomical number” of galaxies in the observable universe. As early as 1957, over one million galaxies had been counted on Harvard Observatory photographs. It’s estimated that over a billion are within reach of the 200-inch Hale telescope on Mt. Palomar, and the Hubble Space Telescope promises to reveal many more. Galaxies are very large, with typical diameters of tens of thousands to hundreds of thousands of light years. Given these dimensions, it’s interesting to contemplate one astronomer’s observation that the universe is more densely populated with galaxies than a galaxy is with stars.

Only three galaxies (other than our own Milky Way) are visible to the naked eye: the Andromeda Galaxy (M31), and the Large and Small Magellanic Clouds, but hundreds are within the capabilities of amateur telescopes, perhaps a couple thousand using the larger amateur “light buckets.” They occur in a variety of shapes and sizes. The classifications devised by Hubble in 1926 are still in common use today, and they recognize three categories of galaxies: elliptical, spiral, and irregular.

Elliptical galaxies are disk-like or spheroidal assemblages of stars with little or no internal structure. The class is further divided into subgroups according to their apparent flatness, from E0, the roundest, to E7, the flattest.

Spiral galaxies are those exhibiting an overall spiral structure. Those with tightly wound arms and a prominent central bulge are designated Sa, while loosely coiled systems with inconspicuous nuclei are labeled Sc. The Milky Way is an Sb type with intermediate characteristics. Sometimes stars and gas in the inner regions of a spiral are organized into a straight bar that extends diametrically across the nucleus. These barred spirals are designated SBa, SBb, and SBc. *[Recent observations seem to indicate that almost all spiral galaxies may have bars buried within their nuclei. —G.B.]*

Irregular galaxies are those that show no apparent symmetry at all, and are designated simply Ir. They are sometimes further classified as Ir+ if they are resolvable into individual stars and Ir- if they are not.

For they amateur astronomer, galaxies provide some of the most numerous yet elusive targets. The successful galaxy hunter will use a combination of large aperture and dark skies to stalk his quarry. While there are quite a few galaxies bright enough to be seen in smaller amateur scopes (the famous Messier catalog of “M” objects includes most of the best ones), the vast majority are very faint and are observable only with larger apertures under favorable observing conditions.

Sky Catalog 2000.0, Volume 2 (Sky Publishing) lists over 3000 galaxies with brightness down to about magnitude 15. The “New General Catalog of Nebulae and Clusters of Stars” (NGC) lists almost 8000 objects, most of which are galaxies. A true appreciation of galaxies can only come from observatory photographs. The finest compilation of photos and information about galaxies I have seen is Galaxies by Timothy Ferris (Sierra Club Books). It’s a relatively expensive “coffee table book” but it’s well worth the cost and is suitable for “non-astronomer” types as well.

# # #

APPENDIX I

(Originally published in *Star Stuff*, 2(1), January 1993)

Double Stars

by Greg Burnett

A double star, or binary star, occurs when two stars form a gravitationally bound orbital system. That is, when they are in orbit around each other. It's estimated by some astronomers that 70% of all stars are members of multiple star systems. By that standard our sun is more the exception than the rule (Although some theorists have speculated that our sun may in fact have a small, faint companion, dubbed "Nemesis", that could be responsible for periodic biological extinctions on the Earth. But that's another story...).

Practically everything we know about the masses of stars comes, directly or indirectly, from observations of binary stars. If the distance to a binary can be determined, by parallax or other means, then the masses of the stars can be determined by observing the orbital period. Such observations are extremely valuable in calibrating our knowledge of the relationship between the masses of stars and their spectral classes and temperatures (spectral classes were discussed in a previous issue of "Star Stuff").

Classifications

Binary stars are generally divided into four classes, depending on the manner in which their duplicity is determined. "Visual" binaries are seen telescopically as two stars. They are observed to orbit around each other over periods of tens or hundreds of years, or longer. Sometimes the orbit is so slow that the true duplicity of the system is confirmed only by observing that the two stars share exactly the same proper motion ("proper motion" is the apparent movement of a star across the sky, relative to the other stars, due to its true motion through space. It is usually measured in hundredths of arc seconds per year.). All binaries would appear as visual binaries if they were close enough to us.

"Astrometric" binaries are systems where only one component of the pair is bright enough to be seen. The duplicity of the system is revealed by variations in the proper motion of the visible star. Because the two stars orbit around their common center of gravity (called the "barycenter"), a wobble in the proper motion path of the visible star can betray the presence of an unseen companion.

"Spectroscopic" binaries are identified by observing changes in the radial velocity of a star that indicate orbital motion. The Doppler shift in the spectral lines of the starlight can show that the star is alternately receding and approaching. This phenomenon is not detectable for binary systems whose orbital plane is oriented "face on" since only the radial component of the star's motion can be measured in this manner.

Finally, "eclipsing" binaries can be detected when the orbital plane is presented to us exactly "edge on." When this happens, the stars pass in front of one another as they orbit, and the changes in their combined spectrum can be observed as each star is alternately eclipsed by the other. Depending on the particular combination of size and luminosity of the two stars, an eclipsing binary may also be observed as a variable star, which changes brightness periodically.

There is actually a fifth kind of double star called an "optical" double. This occurs when two unrelated stars just happen to lie close to the same line of sight, but are actually very distant from each other. These doubles are really asterisms, not true binaries.

Observing Double Stars

In addition to their scientific value, binary stars make very interesting targets for amateur observing. The ability of a particular telescope to "spilt" a double star is related to its resolving power as determined by its aperture and the quality of its optics. Many amateurs enjoy testing their telescopes on close double stars. Telescopes with resolving power limited only by their aperture should be able to resolve double stars according to the chart below:

Aperture	Minimum Resolvable Separation
3 inches	1.6 arc seconds
4	1.2
5	0.9
6	0.8
8	0.6
10	0.5

In a telescope with good resolving capability, double stars have an aesthetic appeal that goes beyond their physics. Many doubles show vivid color contrast. Double star present one of the few situations where the colors of stars are readily apparent. Often the perceived colors do not correspond to the spectral classes of the stars in the way one might expect, but come about as a result of contrast between the two individual stars in the absence of any other visual color standard. It is interesting to compare your own visual impressions with those of other observers, including historic observations through observatory telescopes. It is also interesting to note the actual spectral classes of the stars you observe and try to rationalize the contrast effects you see through the eyepiece.

There are many catalogs of binary stars and observing lists that can direct you to the popular seasonal binary targets. I will take the liberty here of mentioning a few of my favorites. Izar (epsilon Bootes) is probably my favorite. It has a yellow primary with a pale blue companion nestled close up against the first diffraction ring of the primary. It can be a difficult object at first, but once you spot the companion, you're sure to return to it again and again. Another favorite of mine is Almach in the constellation Andromeda. Its vivid color contrast is second to none!

There are several very well known stars that most people don't realize are visual binaries. One is Polaris. The second magnitude has a faint ninth magnitude companion at a separation of 18 arc seconds. It can be resolved in most small telescopes. Rigel in Orion is also a binary. Here a brightness difference of seven magnitudes combined with a 9.5 arc second separation makes it a challenging object. One of the most difficult of the popular binaries is Antares, the Red Heart Of The Scorpion. This double is resolvable in my six inch refractor only on the clearest, steadiest nights. But when its can be split, it is really a beauty! The 5.4 magnitude companion is a sparkling sea-green jewel dancing in and out of the glare of the flaming red 1.2 magnitude primary at a separation of only 2.7 arc seconds.

The Romance of Binaries

When observing double stars, you may be looking at someone else's suns. Theorists have shown that many binary star systems could have planets, perhaps like our Earth. A planet might orbit both of the stars simultaneously if they were close together, or a planet could orbit one of the stars, provided the other star was far enough away. Imagine living on such a planet! What would the day/night cycle be like? Perhaps you would experience two sunrises and two sunsets each day. With both suns in the sky, everything would cast two shadows, probably of different colors! What might the seasons be like?

Double stars provide many rewarding targets for the amateur astronomer. Most are relatively easy to find, and there are doubles suitable for nearly any kind of telescope, even binoculars. Their endless variety of colors and configurations can provide many enjoyable hours of observing.

# # #