First Light

It was his first look ever through a telescope and he could hardly contain his excitement as he swung the tube on its alt-azimuth mount and pointed it in the direction of the first quarter moon. He locked the axis screws and peered through the finder scope. (He had spent part of the afternoon aligning it on a church steeple a mile away.) There, just a little below and to the left of the cross hairs, was the quarter moon! He unlocked the set screws and clumsily centered the cross hairs on the target and then— with the expectancy of a child at Christmas— he looked into the eyepiece.

Words could not describe how that fourteen year old boy felt! There were craters, just like his astronomy book showed! And mountains, and maria! The jagged rip of the terminator was a source of incredible fascination to him.

After several minutes of absorbing his first telescopic views of the moon, he decided to try to conquer more ambitious targets. Being the spring of the year, the youngster loosened the set screws and slewed the tube to the vicinity of the Keystone in Hercules. He wanted to look at the great globular star cluster, M13. (He was not sure what the M stood for, but the pictures of M13 in his astronomy book were breathtaking.) He pointed the tube at the spot on the western side of the Keystone where his little star chart said M13 was, and used his finder scope to fine tune his aim. When he thought he was in the right area, he went to the eyepiece and—no M13! Patiently, he worked his way back and forth in the field until suddenly a fuzzy ball of light popped into view. “Is **that** it?” he mused to himself. “That’s not how it looks in my book,” he thought. Where were the myriad dots of light his picture showed? This was not much at all—just a big, round patch of ill-defined fog!

He then spent twenty minutes in a fruitless effort to find M87 in Virgo. He then took several minutes to get Alcor and Mizar in the Big Dipper’s handle in the eyepiece before he could enjoy the first of over 21,000 “double stars.”

And so it went, the rest of the evening (although not very late—the next day was a school day), trying to locate things he had seen in his astronomy book and looking where the star charts said to look, as often as not failing to locate the object, but nonetheless not finding his enthusiasm dampened one bit by his failures.

It was the start of a rich and rewarding hobby.

APERTURE FEVER

That youngster was me, and the year was 1965. I had just bought my first telescope, a 60mm refractor on an alt-azimuth mount, from a high school senior who sold it to me for a hefty $15 (which I had to scrape together from several months of allowances and chores), and it included a Barlow lens, a solar projection screen, and two 0.925” eyepieces, giving me magnifications of 30x and 100x (60x and 200x with the Barlow). The alt-azimuth mount was smooth, even if it could not be used to locate objects by their sky coordinates, and the tripod was a fairly sturdy one. Such a telescope today would probably cost around $300.

For the next four years, I used my little f-15 refractor to explore first the easy things (the moon, the planets, bright galaxies, star clusters, and easy double stars). Then, as my skills improved, I went for more and more difficult targets, eventually pushing the modest optics of my scope to their limits. I saw the polar caps of Mars, the Red Spot on mighty Jupiter (at that time, a light brick red, not the salmon of today), the Cassini Division in the rings of Saturn, the moon’s Straight Wall and Alpine Valley. I spent many nights in awe gazing at the Pleiades or M11. I strained to make out the Crab Nebula and several faint galaxies. I even spent one bitterly cold winter night watching the moons of Jupiter go through their majestic and formal dance.

In my junior year at high school, I gave the refractor to a younger neighbor and bought my first “serious” scope—a 4.5” Tasco reflector with an equatorial mount. And thus began a new era of beginner’s frustration!

I had never used an equatorial mount before, but knew from my readings that if I ever hoped to easily locate the sky’s more difficult (a euphemism for “faint”) objects, I would find one helpful. The frustration came in learning what the sky’s coordinates were all about, and then learning how to accurately “polar align” the thing so I could find those faint fuzzies the books all talked about. I’ll cover in later pages how I now accurately polar align, but suffice it to say for now that my last years of high school were times when I had a love-hate relationship with my reflector!

WHAT I ASSUME YOU KNOW

At this point, I assume you already have a fairly good *basic* understanding of the elements of visual astronomy. This means that I assume you:

- Know the difference between a refracting telescope and a reflecting telescope
- Know what is meant (roughly) by “polar aligning”
- Know the difference between an alt-azimuth and an equatorial mount

- Understand how to use an equatorial mount and that you are conversant with astronomy's system of longitude (Right Ascension) and latitude (Declination)
- Have a fundamental grasp of the magnitude scale
- Know the basic types of things that there are to see in the sky with a telescope
- Know what is meant by "aperture"
- Know how to compute the magnification of a telescope given the focal lengths of the objective and the oculars

If these assumptions are above your present skill level, I suggest you first read any of the several excellent manuals on these topics for beginners, such as Phil Harrington's *Stare Ware*, or David Eicher's *Beginner's Guide to Amateur Astronomy*, or Sam Brown's *All About Telescopes*. If you own a 20-cm (8-inch) Schmidt-Catadioptic telescope, as I do, you might also enjoy Peter Manly's *The 20-cm Schmidt-Cassegrain Telescope.*

LIGHT GATHERING POWER

The 4.5" Tasco reflector offered me one great advantage over the 60mm refractor—light gathering power, or in the vernacular of the amateurs, light grasp. I had learned that a manufacturer's claims about a telescope's magnifying power were secondary, and in most cases grossly exaggerated. The main thing an astronomer needs a telescope for is to gather photons, and for that the diameter of the *objective* is the governing factor. My 4.5" reflector had over 3.6 times the photon grasp of my refractor. Since each step of the Pogson or *magnitude* scale represents an increase of 2.54 times the light of the next level, this meant I could extend my reach a little over one full magnitude! Theoretically, my 4.5" reflector could reach magnitude 12.5 while the refractor could only reach down to 11.3. This meant, according to one of my astronomy books, an increase in the number of objects visible to me from about 870,000 with the refractor to 3,500,000 with the reflector.

Wow! In one fell swoop (at the cash register), I had almost quadrupled my visible universe!

I also knew that with increasing objective diameter came an increase in a telescope's ability to show detail—what astronomers call *resolving power*, or resolution. The simplified astronomy text I was using at the time gave a formula that I have since learned was a great simplification of the original *Rayleigh Formula*[1], and it expressed a telescope's resolving power as its ability to discern details expressed in seconds of arc. The formula, in its simplest form, says to divide 4.5 by the telescope's objective diameter in inches. In the case of my old refractor, this would have meant 4.5 / 2.36 or 1.9 seconds of arc. In other words, I should have just been able to resolve (or, in the amateur's lingo, "split") a double star whose members were about 2 arc seconds apart or see details in planets and extended objects about 2 seconds in size. With my new reflector, the resolving power dropped to 1.1 seconds of arc, almost twice as good as the old refractor.

Until I learned what a reflector's secondary mirror and mounting system can do to the light path and resulting resolution. The secondary mount and mirror create ripples in the incoming light that opticians call interference. The net result is that the telescope cannot resolve quite as finely as the formula predicts. For me this meant that reflector had more light grasp than my old refractor, but not a whole lot better resolution. (With my 8-inch and 11-inch SCTs, the large central obstructions caused by the secondaries plays havoc with stellar images under certain conditions.)

But all is not lost! The Rayleigh limit and Dawes's research show the *theoretical* boundaries for a telescope. In actual practice, most *good* telescopes can go surprisingly *beyond* the Rayleigh limit! My 8-inch SCT has a theoretical resolving limit of 0.57 seconds of arc, but after careful collimation (setting the optical path for perfect alignment), I have split stars that were closer than this. In fact, Paul Couteau, the prolific French double star observe, developed an empirical rule about how close pairs would look in a good telescope. Using "r" as the theoretical limit of resolution (the "Rayleigh limit", Couteau's rules can be summarized in a table:

"r"	Effect
1.00	stars separated
0.98 r	stars touching tangentially
0.90 r	stars form a figure "8"
0.85 r	flattened figure "8" (corresponds to the Dawes limit)
0.80 r	stars form a narrow rod
0.75 r	stars form a rod
0.70 r	stars form a rod
0.60 r	stars form an egg or olive shape
0.50 r	stars form a slightly oval image

Recent experiments by a number of seasoned double star observers around the globe suggest that Couteau might be onto something with his "rules".

At any rate, for the next four years, I explored the heavens with my reflector and honed my skills with the equatorial mount. This in turn allowed me to locate many objects that I had always wanted to see but never could locate. It was one of the most rewarding times in my life as an amateur.

During my freshman year at college, I decided to sell the reflector and start saving up for a really good telescope—something in the 10- to 12-inch range! But a series of unforeseen events forestalled the purchase of my dream scope until I was well out of college. And then I made a mistake—I bought another 60mm refractor. At least, it had an equatorial mount.

I kept the second refractor for a couple of years and sold it too. This time I vowed to earnestly pursue my dream scope.

But it was to be five years before the opportunity to acquire it presented itself, and it involved an agreement I struck with my wife—we would split our income tax refund and each of us get something we really wanted. (She knew what that meant in my case.) I had picked out either an 8-inch SCT or a 10-inch Newtonian and was about to place my order when, through an unlikely chain of events that does not make a good story line, I obtained my 8-inch SCT for a fraction of the cost of a new one, buying it second-hand from a fellow only forty miles from my home.

I have had that Celestron Classic C-8 for over 17 years now and have seen wonders that I thought I would never see. I also had to learn a whole new way to observe the heavens, since so many things were available to me, and so little time.

Then, in 2000, I added a Celestron C-11 to my arsenal, and, in 2001, housed it in an observatory in my back yard. The observatory is a roll-off roof type, and this set-up has allowed me to observe more in the last few years than all my observing time up to 2000!

MODIFIED STAR HOPPING

As you probably already know, the equatorial mount consists of two axes set at right angles to each other. One axis—the *polar* axis—points to the *north celestial pole* or that point in the sky where the earth's rotational axis seems to point. The other axis—the *declination* axis—is allowed to rotate around the polar axis and permits pointing the telescope north and south. The beauty of this system is that once the polar axis is accurately aligned with the north celestial pole (that is, parallel to the earth's axis), the user only needs to rotate the telescope around the polar axis using a motorized drive system to compensate for earth's rotation and thus keep objects centered in the eyepiece.

Attached to each axis is a round graduated plate or collar known as a *setting circle*. Since there are two axes on an equatorial mount, there are two setting circles. Setting circles derive their names from the fact that because they are graduated with numbered scales, they can be used to "set" the telescope's aim by using the stellar coordinate system. Thus by turning the two axes until a certain Right Ascension (RA) and Declination (dec) appear, the telescope should be pointing at that coordinate's position in the sky. If that coordinate is for a galaxy or a double star, when the observer goes to the eyepiece, that object should be more or less centered and ready to view.

Setting circles are movable. Depending on the manufacturer, they will either be snugly held in place by friction, or they will be locked in place by set screws. In either case, their movability is meant to allow the observer to (1) get a star of known coordinates in view in the eyepiece, and then (2) go to the setting circles and turn them until the pointers on the axes line up with the RA and declination coordinates for the star. Then, (3) the telescope may be aimed at a point in the sky by unlocking the RA and declination axis brakes and turning the telescope until the new coordinates are under the pointers. The axis brakes can then be locked and—hopefully—the target will be in view when the user goes to the eyepiece.

Thus, using setting circles is a modified version of "star hopping." But it is far easier and more accurate than traditional star hopping. But beware of this: if you ever attend a star party, you'll probably run into someone who sneers at you with disdain because you use setting circles instead of star hopping. "Why, you'll *never* learn the sky that way," they'll say. Each to his own. With my limited supply of observing time, I **don't** want to waste it hopping around in the sky in search of faint targets. I want to drive right up to the front door and get down to a visit!

POLAR ALIGNMENT

The effective use of setting circles demands an accurate alignment of the telescope's polar axis with the earth's axis. Polaris, the "Pole Star", does not sit exactly at the north celestial pole. It is about 40 minutes or so from the true pole, so if one were to align on Polaris, he or she would be off by almost a degree near the pole, and even more in other parts of the sky. And this error is more than the width of the field of view of most general purpose eyepieces.

There are a number of gadgets on the market to help you make an accurate alignment on the north celestial pole. (I purchased one of these wonders for $200 several years ago and am sorry I did. I never could get an accurate fix on the north celestial pole. I gave it to a hunter who loaned me his rifle one deer season. Pity *his* aim with that scope!)

I found a simple method of polar alignment that costs nothing other than a few minutes of time. I learned it from the technical experts at Orion Telescope Company of California.

To understand this method, look at a high quality star chart. You'll notice that Polaris lies just east of the 2-hour meridian (2 hours, 45 minutes to be exact).[2]

This fact is the key to the Orion method. As it turns out, a good sampling of bright and easily accessible stars also lie on or near 0245, as well as 1445 (the same meridian extended through the north celestial pole and down the opposite side of the sky). We can use these stars and Polaris to walk a telescope mount's polar axis onto the north celestial pole.

Good target stars on the same side of the Pole as Polaris (that is, on or near 0245) include ε Cassiopeia (at 0154+6346), γ Andromeda (0204+4222), and α Aries (0207+2331).

On the opposite side of the sky, you could use Arcturus (α Bootes, at 1416+4222), α Draco (1404+6420), or β Ursa Minor (1451+7413). As a rule, the farther from the north celestial pole, the better.

My personal favorites are Arcturus (for early spring/summer) and γ Andromeda (the rest of the year). Both stars are fairly distant from the north celestial pole and are also easy to identify in spotter scopes.

To align the polar axis on the north celestial pole, begin by setting up the telescope so that the tripod head is as level as possible. (I use a good quality bubble level for this.)

Next, if you have a clock drive, turn it on.

Now, find the reference star you want to use and center it in your eyepiece. Set the telescope's setting circles for the coordinates of this reference star. If the declination is off, loosen the declination scale plate and rotate it to the star's declination and secure it.

Unlock the axis brakes and slew the telescope to Polaris's *coordinates* (not Polaris) and lock the brakes. If Polaris is not in the eyepiece, loosen the azimuth and altitude locks on the mount and rotate the mount east or west, north or south, or both, to center Polaris.

Next, go back to the reference star again and center it in the eyepiece and reset the setting circles to read the star's coordinates. Again, aim to Polaris's *coordinates* and see if it is centered in the eyepiece. If it is not, repeat the mount adjustment, then repeat the entire process until Polaris is centered and no more adjustments are necessary.[3]

ACCURATE SETTING CIRCLES

Many of the objects you will find in this book are incredibly faint or get lost in stunningly rich fields of the Milky Way. You will find your enjoyment of the sky greatly enhanced if you have accurate polar alignment and accurate setting circles.

To be as accurate as possible, the setting circles should be as large as possible. For instance, my C-8 has a large diameter RA scale that is easy to aim to within 1 minute of arc. But the Declination scales on the Celestron C-8 are woefully too small to be accurate. So I removed the Declination circle from the right side of the fork and replaced it with an 8-inch diameter scale I obtained from the Oregon Rule Company in Portland, Oregon (www.oregonruleco.com). If you have the money, digital setting circles are even more accurate, and the ultimate would be the computer assisted telescope! (My C-11 uses digital circles, and I can also connect it to my laptop computer and use it in conjunction with Software Bisque's powerful program, ***TheSky***.)

If you go the high-tech route, be prepared for scoffers who will jab at you for "cheating" and not learning the sky. All I can say is that I own a telescope to see the sky, and I don't care how I get there as long as the wonders of the heavens can be found and I can have a nice visit once I arrive.

(For the purist, I do, in fact, do a considerable amount of classical "star hopping", but my preferred way to find targets is by setting circles.)

THE EYES HAVE IT

Let's discuss observing techniques. If you are a seasoned observer, this section may be boring to you, so feel free to skip it.

The goal in astronomy is to gather photons. The aperture of the telescope is the chief factor in this process, but the eye of the observer is the other. A 400-inch telescope is useless if the observer is blind. I have known observers who could see more with a four-inch telescope than those who owned twelve-inch models. The secret is in how you use your eyes.

The human eye is not very efficient at gathering light. As a sensory receptor, it is designed to work well in daylight, not darkness. Also, the eye's sensitivity to light varies greatly from one person to the next.

If you have inherited poor night vision, there is not much you can do about it except compensate for it with aperture. (This is a costly cure!) But there are things you can do to help your night vision no matter how your genes are programmed.

For instance, it takes the average eye about thirty minutes to adapt to darkness, so begin your observing sessions by letting your eyes thoroughly "dark adapt."

This implies that the selection of observing sites is critical. A street light 50 meters away could make one as blind as the proverbial bat as far as seeing galaxies is concerned. Find as dark a site as possible. If you can afford it, build an observatory so you can totally block off stray ground-level light.

Another factor in site selection is the clarity of the sky. There is not much you can do about this if your area, like mine, is normally full of wind-blown dust and pollen, water vapor and aerosols. Airborne contaminants reflect light from ground sources, giving the sky a ghostly glow. This glow very effectively blocks out the feeble light of galaxies and nebulae.

One partial remedy for sky glow is to use a light pollution reducing filter. There are many on the market, and they go by a confusing array of names. Some are better than others. Good filters can eliminate a lot of the sky glow and often let a feeble galaxy punch through the haze and become detectable by the eye. (I have about 200 observations that would have been impossible without my $100

Orion Sky Glow filter.) But beware—no filter will make galaxies *brighter* to see. There are special filters (like the O-III) that actually enhance the detail you can see in gaseous emission nebulae, but they have little impact on most galaxies, which are composed not of narrow-band emission spectra, but of brand-band stellar spectra. Also, the use of almost any filter will rob the system of almost one magnitude of light and cause false colors to be seen in stars. When you consider that the purpose of most broad band filters is to enhance contrast, one can usually afford a magnitude loss in galaxies if the sky behind them gets dark enough to let the weakened light punch through. For general sky glow, consider a broad band filter that cuts out the wavelengths associated with mercury vapor and high pressure sodium lights. Metal halide lights are a different problem, as they emit a richer spectrum than the rather narrow bands of mercury vapor and high pressure sodium lights. Low pressure sodium lights are monochromatic and hence of no serious threat to sky glow. Narrow band filters, like the O-III, have special tasks behind their design, and although they can make the sky background velvety black, they can also filter out much of the light of stars and galaxies.

Related to sky glow is the sky's general transparency. For this purpose, I use a scale of 1 (cloud cover) to 5 (as clear as it gets from the surface of the earth).

One must also contend with the turbulence of the air, a factor astronomers generally call "seeing." A large instrument with poor seeing is no better off than a small one with good seeing in many cases. (In fact, larger telescopes often suffer more from bad "seeing" than smaller ones since there is more air in the column represented by the telescope's objective as the base of a cylinder of air that reaches from ground level to the top of the atmosphere. Within this column of air, the air will have thousands of small eddy currents or pockets that each refract light a tiny amount. The combined effect of hundreds or thousands of such minute refractions is a boiling image that never holds steady.) I generally rate seeing from 1 (dismal) to 5 (perfect).

OTHER TRICKS OF THE TRADE

While observing, use a filtered light for reading sky charts, making notes, sketches, and so on. The best color, of course, is red, as red lacks the quantum power to harm night vision. (However, I have also experimented with dimmable green LED lights and found no degradation in night vision with dim green light.) Personally, I use a small variable output flashlight with two red LEDs and, for other purposes, two white LEDs. If you use a computer at scope side, be sure the software has a "night vision mode". ***TheSky***, from Software Bisque of Golden, Colorado, is my program of choice, and it has a good night vision mode. (It is also the program that I used to generate all the star charts in this book. These charts were generated with the permission of Software Bisque.) As an added protection to my night vision, I also use a red Plexiglas cover for my laptop's screen. This added layer of filtering further reduces the intensity of light coming off the laptop's display.

Another visual acuity trick is to use a black cloth to cover your head and eyepiece region (similar to the old photographer's camera drape). I use a 3-foot square piece of black muslin for this and find it is a help when the moon is in the sky.

You will also enjoy greater light sensitivity if you don't fatigue your eyes. One of the greatest causes of fatigue is squinting the unused eye while you are at the eyepiece. I have learned over the years how to keep both eyes open while at the eyepiece and ignore what the unused eye is seeing. Until you can get to that level of visual discipline, feel free to use an eye patch (available at most pharmacies).

While at the eyepiece, there are a few things you can do to sharpen your eye's sensitivity as well. The retina is composed of rods and cones. Rods pick up light and contrast; the cones detect color. Since our eyes are so color sensitive, the center of the retina is made mostly of cones. The rods lie on the periphery. If you want to see more at the eyepiece, learn how to look to the *side* of the target, not directly at it. Looking to the side (using what is called *averted vision*) lets the photons fall on the rod-rich part of the retina. Often, I have seen a galaxy with averted vision that disappears when I look directly at it.

The eye is also very sensitive to movement. I have found that at times when averted vision fails to detect a faint galaxy that moving the telescope slightly in declination or even tapping the tube to induce a little vibration will allow me to detect the object.

Still another way to heighten your visual acuity is to train your eye the way an artist trains his or her eye. Start drawing eggs. Keep drawing them until the drawing actually *looks* like an egg! When you reach that level of skill, your eye will see detail in galaxies, nebulae, and the like that you missed earlier.

Consider keeping a sketch book of your observations. Draw what you see (even a dense open cluster or rich globular). It does not have to be perfect or of museum quality. But you will find that drawing what you see forces your eye to concentrate on what is really there. I use good quality drawing paper (you can get artist's sketch pads at any art store) and a soft pencil and paper smudging stick. (The smudging stick helps to blur out details and results in a realistic rendering of galaxies and nebulae.)

In viewing the many extremely faint and tiny galaxies listed in this book, bear in mind that all that can be seen of many galaxies is the bright nucleus (especially when observing from light-polluted sites, like my suburban observatory). The arms of spiral galaxies are often so faint as to be undetectable in small telescopes. This means that for many galaxies, you'll be searching for only the tiny nucleus. Such nuclei look like fuzzy stars in the eyepiece—they don't seem to focus quite as sharply as the stars in the field. Such "fuzzy stars" are what you will be looking for. When you have what you suspect to be a galactic nucleus in the field, run the magnification up to as high as the conditions will allow (I have used 700x before). If the object really is a galaxy, you will not be able to focus it no matter what you do. If it is a star, you'll know soon enough.

A BAD RULE OF THUMB

An old rule of thumb in astronomy is that the practical magnification you can use with a telescope is 50 times its aperture in inches (or 20 per cm). But how many people have the same size thumb?

I have learned through experience that when the sky is clear enough and transparent enough, I have run my C-8 up to 700x (88 times the aperture). I even ran the C-11 up to 1,450x on night—some 132 times the aperture! Don't let someone tell you that 50x per inch is your limit. Push your scope as far as the seeing will allow, and you may be amazed at what you see!

WHO WAS THAT MASKED DOUBLE STAR?

Here is a technique that will help you split difficult double stars and see greater detail in planets. A difficult double star can be one in which there is a great difference between the brightness of the main star (primary) and its companion, or where two bright stars are very close together. The glare of a bright primary can often drown a feeble companion. Also, when two stars are very close together, the image of the fainter star may actually lie on one of the diffraction rings of the primary.

This is where an *objective mask* can help. An objective mask induces interference in the light path of the telescope and can turn the Airy disc and diffraction rings of a normal view into a sharp Airy disc with no rings. In my case, I built a *hexagonal* mask out of thin plywood. Placing it over the business end of my C-8 results in stellar images that are sharp Airy discs with six spikes radiating outward from the Airy disc. If a faint companion lies on the primary's diffraction rings, the mask often removes the diffracting rings and lets the faint companion pop into view. If the spike sits on the companion, rotating the mask a few degrees often brings the companion into view.

This technique is mostly of value to centrally-obstructed telescopes, such as Newtonians and SCTs. Experimentation by some colleagues who have refractors shows that the mask is of little value.

It was by the use of such a mask that I detected the illusive companion of Sirius and the notoriously difficult *blue*[4] companion of Antares.

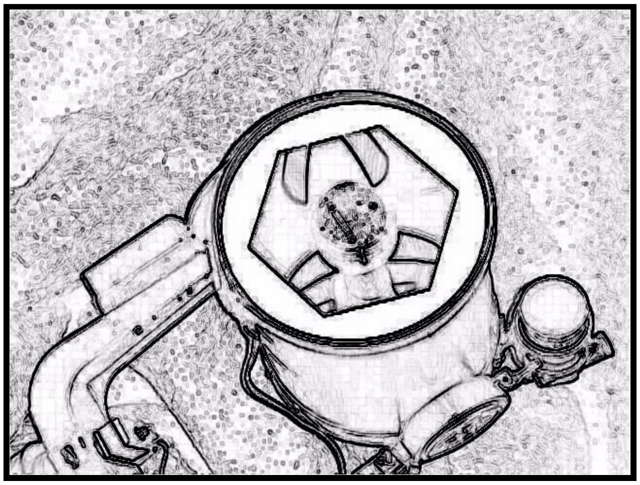

Figure 1: Objective mask on the C8

DOUBLE JEOPARDY

Observing double and multiple stars can be at the same time one of the easiest and yet most challenging activities for an amateur astronomer. It can also be a very rewarding area of study from an aesthetic sense. If you have the instrumentation for it and the required skill, you can even make measurements that can contribute to orbital solutions that help us refine our models of stellar evolution and development.

Double and multiple stars consist of a main star (called the primary, or in the case of multiples, A) and a companion (sometimes called *comes*, or B) or companions (*comites*, or B, C, D, etc.). Double and multiple stars are stars that are truly gravitationally bound and traveling through space together. Sometimes, two stars will happen to line up along the same line of sight and *appear* to be a double star system. However, they are not gravitationally bound at all and represent a chance alignment. Such a pair is called an *optical double* to distinguish it from a true double, which is often also called a *binary system*. I have made every attempt to point out which double stars in my list are (or may be) opticals.

Most binaries have members that are visible in a telescope, but a large number of what appear to be single stars are actually very close binaries. They are so close together in space that they appear as one star from earth. The fact that they are two stars instead of one is revealed by the spectroscope as the emission lines of both stars show up in the combined spectrum and these lines shift left and right as the stars approach or recede from earth as they orbit one another (the Doppler shift). These ultra-close pairs, not resolvable in any amateur telescope (and only a few of which can be resolved by huge instruments) are called *spectroscopic bina-*

ries. In a few rare cases, these pairs have been resolved using a technique called *speckle interferometry*, a complex process that I need not describe here. A small list of others have been "resolved" by lunar occultations as the light output of the system drops in steps rather than the dramatic "on / off" of a single star occultation. These stars are often called *occultation binaries*.

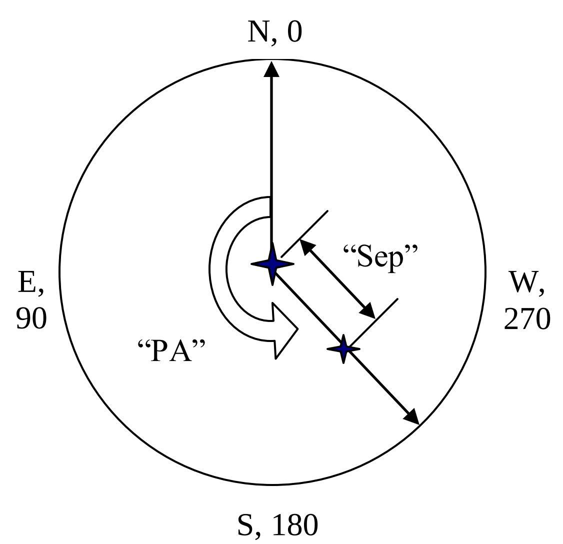

Figure 2: Position Angle (PA) and Separation (Sep) in Double Stars

In this book, you will be observing normal binaries and optical pairs. For these stars, there are two measurements that are crucial: *position angle* and *separation*. Position angle (or PA is it is normally abbreviated) refers to the angle between the A and B stars measured counterclockwise from north, using the A star as the center of the circle. In this method, north is 0°, east is 90°, south is 180°, and west is 270°. So a PA of 225 indicates that the star in question is southwest of A. But before you can know what to expect at the eyepiece, you need to know how your telescope presents the image.

With both of my SCTs, I use a right-angle "star diagonal", which produces an upright but mirror image of the star field. So for my purposes, the PA scale runs clockwise from the top of the field, making east the right side of my field, west the left, north at the top and south at the bottom. Other telescopes, however, produce inverted and mirror images, or inverted but normal images, and so on. The easiest way to find out how your scope presents the field is to center a bright star in the field of view and turn the declination slow motion control back and forth and note which way the star moves. If you turn your declination knob so as to move the telescope north and the star drops to the bottom of the field, your scope does not invert the image; if it rises, it does invert the image. For mirroring, re-center the star and turn off the clock drive (if you have one) and let the star begin to drift. It will drift towards the west, so whichever side of the field the star drifts to is west. If the scope makes a mirror image (like mine), the star will drift to the left; if it does not make a mirror image, the star will drift to the right.

Separation is the angular distance between the stars. A separation of 30 seconds (30") would mean that the two stars are half a minute (or 1/120th of a degree) apart. Combining separation with the PA gives an accurate idea of what you can expect when you look into the eyepiece. For instance, if the components of a double star are listed as being 8” apart in PA 40, you should look for a close pair with the B star lying about midway between north and east.

HOW LARGE IS THE FIELD OF VIEW?

To fully appreciate the separation measurement, you need to know how large a field of view each of your eyepieces gives. There is an easy way to do this. You’ll need a stopwatch. Put one of your eyepieces in the telescope and center a fairly bright star in the field of view. The closer to the celestial equator, the better, but any star will do. Next, unlock the RA brake and use the slow motion controls to move the star so that it is just off the field of view on the east side of the field and lock the brake. Turn off the clock drive. As soon as the star creeps into view, start the stopwatch. Watch the star as it traverses the field, and when it exits the west side of the field, stop the stopwatch. Divide the transit time in seconds by 4 and multiply that result by the cosine of the declination to get the field width in minutes of arc. Do this about six times for each eyepiece and average the results. You’ll find a form for this calculation on the CD-ROM that comes with the book.

> **EXAMPLE**: Suppose you use δ Orionis (the west-most star of Orion’s “belt”) to test your eyepieces. With the first eyepiece, you get an average transit time of 180 seconds. Dividing 180 by 4 gives 45 minutes of arc. Since δ Ori’s declination is –0018, the cosine is 0.9999863, so for all practical purposes, the field is 45 minutes in diameter. Suppose that for your next eyepiece, your average transit time is 118 seconds. The field of view would then be 29.5 minutes of arc. A third eyepiece, with an average transit time of 54 seconds, would have a field of view of 13.5 minutes.
>
> Had you used ε Persei (declination of +4000) for the transits, the transit times would have been longer—235 seconds, 154 seconds, and 70 seconds respectively. The cosine of 40^o is 0.7660444. Dividing the transit time for the first eyepiece by 4 produces 58.75, which when multiplied by the cosine of 40^o, is 45 minutes, the same result we obtained using δ Ori (but in substantially less time).

STARLIGHT, STAR BRIGHT, WHAT COLOR ARE YOU?

The other details necessary for double star observations are their magnitudes and spectra or colors. The magnitudes are straightforward enough (although you should be aware that some of the double star discoverers of the 19th century were notorious for mis-stating the magnitudes of their stars[5]). The main difficulty you will encounter with magnitudes is where two stars of great magnitude difference are close to each other, in which case the objective mask I described earlier will be a useful tool.

The color issue is more subtle. All stars have color, but most of the hues are so subtle that to the casual observer, they all look white. A star's color is a function of its surface temperature, which in turn is tied to its spectral class. The old Morgan-Keenan-Kellman spectral class system runs OBAFGKM (often remembered by the mnemonic, "Oh, be a fine girl: kiss me."). Recent discoveries have added a few more classes (W, which has been dropped, and RNSLT[6]). The temperatures run in the same sequence. O stars are the hottest of all (surface temperatures of 70,000° K or hotter) and have a definite bluish to violet tint. B stars are a little cooler and also appear bluish. A stars are cooler yet and appear bluish-white. F stars are cooler, and look white to most observers. G stars (like the Sun) are yellowish. K stars look orange, while M are red. But remember—these colors are subtle, and differences in eyes and atmospheric conditions can alter the colors any one observer might perceive. When I say that I saw a pair of stars as blue and orange, that is my assessment of the colors, based on subtle shades of color; the colors you perceive may very well be different.

You should also be aware that the eye tends to see fainter and fainter stars as more and more bluish in tint. This is a peculiar effect of the eye, and not a true case of faint stars being blue.

Spectral subclasses run 0 to 9, where 0 is at the "hot" end of the class and 9 at the "cool" end. Thus a G0 star is just a little cooler than an F9. Other sub-codes include "comp" for composite spectrum (usually due to an unresolved binary); "e" for emission lines; "m" for metallic; "n" for broad lines (usually caused by rapid rotation); "p" for peculiar; "s" for sharp lines; "shell" for shell star (main sequence star embedded in a gaseous shell); "Si" for strong silicon lines (or other metals, using the chemical symbol for those metals); and "v" for variable.

In the color taxonomy I use for this book, colors are represented by letters. Here is the taxonomy:

R = red
O = orange
Y = yellow
G = green (rare in star colors; some—including this author— argue it does not exist at all)
W = white

B = blue
V = violet
L = lilac
D = gold

In addition, the code can be modified by preceding the capital color letter with a lowercase modifier. A “p” should be read as “pale”, while “d” is read “deep”. Thus, pB is pale blue and dR is deep red. In addition, using a lowercase color letter before an uppercase color letter indicates a blend of colors, as rO would be read as reddish-orange.

Intense colors will be indicated by the addition of an exclamation point at the end of the code, and very intense colors by two exclamation points. Thus R! would suggest a very strong red, while D!! indicates a stunning gold hue. A question mark indicates that the color is at best questionable—B? would be read as “blue, maybe”. If all you see in the color field is a question mark, that means the star was too faint to get a reliable color estimate. Finally, if I could not detect the star, you will see “No” in the color field.

PUTTING IT ALL TOGETHER

The double star STF 541 (STF being the code for Friedrich Struve; this star is number 541 in his Dorpat Catalog of 1827) lies in Canis Major and consists of a K0 primary accompanied by an F class secondary 23” away in PA 44, with magnitudes of 8.0 and 9.0. What should you expect to see in the eyepiece?

You should see a moderately bright orange star and, 23” away in the northeast direction, a fainter white companion.

WHOSE DOUBLE IS IT, ANYWAY?

The double stars in this book will be listed by the name (or code) of their discoverer and the number that pair occupies on his or her list. Whenever possible, the earliest known discoverer will be given the honors of top billing, with subsequent discoverers (or those who found later companions) listed under the “Other Names” field. When available, I will also list the star’s position in Robert Aitken’s master list of ADS numbers. The code for discoverers is as follows:

A. G. = Astronomische Gesellschaft Katalog of 1875

A = **Robert Aitken**, 1864-1951, American astronomer and astronomer at Lick Observatory. Aitken brought order to the non-systematic observations of Sherburne Burnham and others by using a rigorous program at Lick to confirm and/or discover 17,000 binaries down to magnitude 9.0. (This catalog was published in 1932.) After completing his massive catalog, he spent many years computing binary orbits.

Abetti = Giorgio Abetti, 1882-1982.

AC = Alvan Clark, 1804-1887.

Alden = H. L. Alden

Algiers Obs = Algiers Observatory

Ali = Alaaeldin Ali.

Aller = Ramon Maria Aller. (1878-1966)

Anderson = J. A. Anderson

Aravamudan = S. Aravamudan

Argelander = F. W. A. Argelander, 1799-1875.

Bur = **Sherburne W. Burnham**, 1838-1921. One of the most prolific and keen-eyed binary star discoverers, S. W. Burnham was not a professional astronomer but was highly esteemed by the professional community nonetheless. He became interested in astronomy as a Confederate soldier in New Orleans during the American Civil War, but continued his career as a reporter and clerk. After the Civil War, he settled in Chicago, only a few hundred yards from the Dearborn Observatory. In 1869, he met Alvan Clark, from whom he ordered the 6" refractor with which he would discover hundreds of new double stars. He found his first new pair, B40, on April 27, 1870. When he had a list of 81 new pairs, he sent the list off to the Monthly Notices of the Royal Astronomical Society. This was followed a year later by two more lists. For these first lists, Burnham had no filar micrometer, so the measurements were made by the Italian astronomer Dembowski. While on a vacation in 1874, he got to use a 9.4-inch telescope at Dartmouth College Observatory and even got to use the 26-inch refractor at Washington one night. During this 10-day period, he added 14 stars to his list. From that time forward, he was able to use many of the larger American telescopes, including the 36-inch Lick and 40-inch Yerkes instruments. From 1888 to 1892, he was officially on the staff at Lick, although he kept his day job and would commute to Williams Bay, Wisconsin on weekends to use the Yerkes instruments. During his career, he discovered 1,274 new doubles, many of which are true binaries. In 1894, he received the Gold Medal of the Royal Astronomical Society for his work, and in 1904, the Lalande Prize from the Paris Academy of Sciences, as well as honorary degrees from Yale and Northwestern Universities. Not bad for an amateur!

Baillaud = Rene Baillaud. 1885-1977.

Baize = **Paul Baize**, 1901-1995. Trained as a medical doctor and receiving his degree in 1924, Paul has practiced most of his life as a pediatrician. His astronomical work, of prodigious quantity, has been purely amateur. He began double star work in 1925 with a 10.8 cm refractor with a micrometer he built himself. Between 1925 and 1932, he made 3,834 measurements that were published in "Les Journal des Observateurs". Starting in 1933, he used the 30.5cm equatorial refractor in the West Tower of the Paris Observatory and completed 11,332 measurements by 1949. From 1949 to 1971, he used the 38cm telescope in the East Tower and produced an additional 8,878 measurements. He has also calculated the orbits of some 200 binaries and published numerous articles for astronomical journals.

Ball = R. S. Ball, 1840-1913.

Barnard = E. E. Barnard, 1857-1923.

Barton = S. G. Barton. 1958 -

Bemporad = A. Bemporad, 1875-1945.

Bergh = S. van den Bergh

Bhaskaran = T. P. Bhaskaran, 1889 -

Bigourdan = G. Bigourdan, 1851-1932.

Bird = F. Bird.

Bos = **Willem H. van den Bos**, 1896-1974. Born in Rotterdam on September 25, van den Bos was attracted to astronomy and double stars at an early age. He started studying astronomy at Leiden in 1913 and was taught by such men as Hertzsprung and deSitter. He earned his PhD in 1925 (Physics/Mathematics) and traveled that year to South Africa to serve as a guest observer at the Union (Republic) Observatory of Johannesburg. In 1930 he joined the staff at Union Observatory and remained there until his retirement in 1956. He continued double star research on a private basis until ill health forced him to stop in 1966. By that time, he had made 74,000 visual measurements, discovered some 2,900 new pairs, and computed 150 orbits. Known for great speed (he could make 20 measures per hour), he was also a very keen observer.

Bottger = G. van Bottger.

Bowyer = W. M Bowyer.

Bpm = Burnham's proper motion pairs.

Brisbane Obs = Brisbane (Australia) Observatory

Burton = C. E. Burton.

Chevalier = P. S. Chevalier, 1930-

Cogshall = W. A. Cogshall.

Cordoba = Cordoba Observatory (Argentina).

Courtot = J. F. Courtot.

Couteau = **Paul Couteau**, 1923 - . A Frenchman, Paul Couteau knew he wanted to be an astronomer by age 11. In 1949, he earned his PhD from the Astrophysical Institute of Paris (thesis on white dwarfs), and began his observing career professionally at Nice (1951-1967), making some 12,000 measurements. He also spent time at Yerkes Observatory (5 months in 1961). Since 1965, he has systematically measured the stars of the BD Catalog zone +17 to +53 (some 170,000 stars are in this band). He had observed 102,000 stars by 1984 and discovered 2,200 pairs, half of which are closer than 0.5" of arc.

CPO = Cape Observatory (South Africa).

Dawes = **William Rutter Dawes**, 1799-1868. A doctor and clergyman, Dawes was always in poor health. The bulk of his work is contained in the "Catalog of Micrometrical Measures of Double Stars", which is part of volume 35 of the Transactions of the Astronomical Society of London.

Dawson = B. H. Dawson.

Dembowski = **Baron Ercole Dembowski**, 1812-1881. Born in Milan on January12, he was of noble ancestry on his father's side. His early life was in the military and only turned to astronomy after meeting an astronomer (Antonio Nobile) sometime after 1843. He published his first list of pairs in 1851, which consisted of accurate measurements of 127 of F. G. Struve's list. Beginning in 1858, he made a thorough update to Struve's Dorpat Catalog.

Doberck = W. A. Doberck.

Donner = H. F. Donner.

Doolittle = **Eric Doolittle**, 1869-1920. An American, Eric graduated from Lehigh University in 1891 as a civil engineer and became an instructor of mathematics at Lehigh and later Iowa University. From 1896 to the end of his life, Eric worked at the University of Pennsylvania's Flower Observatory where he used the new 18-inch Brashear refractor to create four large volumes of measurements.

Dorpat Obs = Dorpat Observatory.

Duner = N. C. Duner.

Dunlop = J. Dunlop.

Egbert = H. V. Egbert.

Engelmann = R. Engelmann.

Espin = **Thomas Henry Espinall Compton Espin**, 1858-1934, was a cleric and Vicar of Town Law in County Durham, England. He became interested in astronomy after 1874. His first work was a catalog of 3,800 red stars (1885-1899). In 1900, he started double star work with the 17-inch Calver reflector, finding 2,575 pairs, most of them wide ones. He also discovered Nova Lacertae on December 30, 1910.

F Brown = F. Brown

Fender = F. G. Fender.

Filipov = M. L. Filipov.

Finsen = **William Steven Finsen**, 1905-1979. An Icelander (though born in Johannesburg) and a nephew of a Nobel Prize winner, Finsen assisted van den Bos at the Union Observatory. Later, using instrumentation of his own design, he made 13,000 measurements of 8,117 stars between -75 degrees and +20 degrees declination. From this work, 73 new pairs were found, 11 of which have orbital periods of less than 21 years. He also made 6,000 measures that were too close for the micrometer.

Fox = Philip Fox, 1878-1944.

Franks = W. S. Franks, 1851-1935.

G Struve = G. Struve.

Gallo = J. Gallo, 1882-1965.

GAn = George Anderson.

Gauchet = P. L. Gauchet.

Giacobini = M. Giacobini.

Giclas =

Gilliss = J. M. Gilliss.

Glaisher = J. Glaisher, 1848-1928.

Glasenapp = S. de Glasenapp, 1848-1937.

Goyal = A. N. Goyal.

H = **William Herschel**, 1739-1822. Herschel's first double star work was to find good candidates for parallax measurements. His first list had 269 stars on it, only 42 of which had been known previously. His painstaking measurements of these stars convinced him that the changes he saw were not due to parallax after all, but to tiny changes as the stars seemed to orbit one another (a radical concept at the time). Herschel sub-classes include I (difficult), II (close but measurable), III (5" to 15"), IV (15" to 30"), V (30" to 60"), VI (1' to 2'), and N (the 1821 catalog).

h = **John Herschel**, 1792-1871. John's early work was to remeasure his father's lists to confirm the elder Herschel's binary star theory. Later, he teamed up with James South and together they published some 380 new pairs. John's expedition to the Cape of Good Hope (1834-1838) was a milestone for astronomy, the younger Herschel cataloging some 1,202 new pairs.

Harvard = Harvard Observatory.

Hastings = C. S. Hastings, 1848-1932.

Haupt = H. Haupt.

H Wilson = H. C. Wilson.

Heintz = Wulff Heintz.

Hernandez = S. Hernandez.

Hertzsprung = Ejnar Hertzsprung, 1873-1967.

Hh = An obscure index catalog produced by William Herschel.

Hipparcos = Hipparcos space astronometry mission (ESA, 1992)

Holden = Frank Holden, 1917-1992.

Holmes = E. Holmes, 1919 - .

Hough = G. W. Hough, 1836-1909.

Howe = H. A. Howe, 1858-1926.

H Struve = H. Struve.

Hussey = **William Joseph Hussey**, 1862-1926. Originally a professor of mathematics at the University of Michigan, Hussey went to Palo Alto, California where he was a professor of astronomy at the Leland Stanford Junior University. While there, he made frequent visits to Lick Observatory, joining the staff in 1896. Working with Robert Aitken, he discovered 1,327 new pairs in six years. In 1905, he returned to the University of Michigan and, in 1911, became director of the

LaPlata Observatory in Argentina. His great ambition was to see a great telescope for southern hemisphere double star observations to be built.

Innes = **Robert Thorburn Ayton Innes**, 1861-1933. A Scotsman by birth and education, all of Innes's amateur astronomical career was in the southern hemisphere. His capstone work, the "Southern Double Star Catalog", was published in 1927 and contains 1,613 of his discoveries plus thousands of other pairs.

Jacob = W. S. Jacob.

Jessup = M. K. Jessup.

Jonckheere = **Robert Jonckheere**, 1889-1974. Robert began his career as a double star observer in 1905. His first published list (1908) contained 40 pairs. In 1962, he published his major work, "General Catalog", which contains 3,355 new pairs he discovered since 1906.

Kazeza = S. M. Kazeza.

Knott = G. Knott.

A Krueger = A. Krueger.

Kruger = E. C. Kruger.

Kuiper = Gerard P. Kuiper, 1905-1973.

Kustner = F. Kustner.

Lamont = J. von Lamont.

LaPlata = La Plata Observatory, Argentina.

Lalande = F. de Lalande.

Larink = J. Larink

Lau = H. E. Lau, 1879-1918.

Leavenworth = F. P. Leavenworth, 1858-1928.

Leonard = F. C. Leonard, 1896-1960.

Lewis = **Thomas Lewis**, 1856-1927. Lewis joined the staff of the Royal Observatory in 1881. His major achievement is the book "Measures of the Double Stars contained in the Mensurae Micrometricae of F. G. W. Struve" (1906).

Lhose = O. Lohse.

LDS = W. J. Luyten, 1899-1994.

Lyndsay =

Madler = J. Madler.

Mason = H. C. Mason, 1813-1936.

Milburn = W. Milburn.

Miller = J. A. Miller, 1859-1946.

Mitchell = S. A. Mitchell.

Morgan = H. R. Morgan.

Motherwell = R. M. Motherwell.

P Muller = **Paul Muller**, 1910- . Paul joined the staff of the Observatory of Strassbourg in 1931. He has measured pairs with an instrument of his own design, the double image micrometer. He has made over 11,000 measurements and calculated 90 orbits.

Olivier = C. P. Olivier, - 1975.

Opik = E. Opik.

OS = **Otto Struve**, 1819-1905. At 18 years of age, Otto became his father's assistant at Dorpat. His double star work includes the discovery of 547 pairs. The OS stars are his original Pulkovo catalog of 1843.

OSS = Otto Struve Index Catalog, 1843, containing wide pairs.

Osvalds = V. Osvalds.

Paloque = E. Paloque.

Panjaitan =

Pannuzzio =

Perrine =

Perth Obs = Perth Observatory (Australia).

Pettitt = Edison Pettit, 1889-1962.

Pocock = R. J. Pocock, 1889-1918.

Popovic = C. Popovic, 1910-1977.

Pourteau = A. Pourteau.

Pritchett = H. S. Pritchett.

Pulkovo = Pulkovo Observatory.

Przbylloc = E. Przbylloc.

Rabe = W. Rabe.

Roe = E. D. Roe, Jr, 1929-

Rossiter = **Richard Alfred Rossiter**, 1886-1977. The dean of southern hemisphere double star astronomy, Richard was born in New York but moved to South Africa in 1926. (During the trip, William Hussey, who was accompanying Rossiter, died suddenly in London.) His work produced a list of 7,368 southern pairs, of which 5,534 were his own discoveries, still a record.

Rousseau =

Russell = H. C. Russell, 1836-1907.

STF = **Freidrich Wilhelm Struve,** 1793-1864. The STF stars are his Dorpat Catalog of 1827. The "rej" that appears on some of the stars (as it does also in the OS stars) means that Freidrich rejected the pair from his original catalog because he thought it was too far apart to merit further study. In a two-year project, Struve made 10,448 measurements and produced a list of 3,112 pairs of which 2,343 were new.

Scardia = M. Scardia.

Scheiner = J. Scheiner, 1858-1913.

Schjellerup = H. C. F. C. Schjellerup.

Secchi = **Father Angelo Secchi**, 1818-1878. Best known for his work in stellar spectra, Secchi also made contributions to double star work, producing a catalog of 1,321 doubles in 1860.

See = Thomas J. J. See, 1866-1962.

Sh = James South, John Herschel joint catalog of 1824.

SI = F. W. Struve's First Index Catalog.

SII = F. W. Struve's Second Index Catalog.

Skinner = A. N. Skinner, -1918.
Smart = W. M. Smart, - 1975.
Sola = J. Comas Sola.
Soulie = G. Soulie.
South = **James South**, 1785-1867. South was a surgeon who later became interested in astronomy. Marrying into great wealth made the pursuit of his hobby an amateur's dream.
Stein = J. Stein, 1871-1951.
Stone = Ormond Stone, -1933.
Swift =
Tarrant = K. J. Tarrant.
Torino Obs = Torino Observatory.
Tucker =
Tycho = Tycho astronometric mission (ESA, 1992)
Upton = W. Upton.
USNO = U. S. Naval Observatory, Washington, D. C.
Van Biesbroeck = **George van Biesbroeck**, 1880-1974. One of the greatest double star observers of all time, he was active for over 70 years. George is best known for his painstaking measurements and rechecking of earlier catalogs for orbital changes, not so much for discovering new pairs. (He made 35,915 measures during his life.)
van de Kamp = Peter van de Kamp.
Vatican Obs = Vatican Observatory.
Vilkki = E. Vilkki.
Voute = **John George Erardus Voute**, 1879-1963. Voute began his astronomical career at Leiden Observatory in 1908, publishing a double star orbit in his first year. He spent most of his career at the Cape Observatory. He made 26,126 measures over his lifetime.
Walker = R. L. Walker.
Ward =I. W. Ward.
Webb = T. W. Webb, 1807-1885.
Weisse = M. Weisse.
Winnecke = F. A. Winnecke.
Wirtz = Carl Wirtz, -1939.
Worley = Carl Worley. –1997.

DOUBLE STARS MOVE OVER TIME!

Double stars are dynamic systems—that is, they move over time even as the earth and other planets revolve around the Sun. Thus, the characteristics of a double star at one time may be different from a later time. I try to show this by two cues in this book. One is the “Year” field. This information tells you the year of the double star measurement I use in this book. Unless otherwise stated, all data is from the 2001 edition of the Washington Double Star Catalog (or WDS), the “Bible” of double star research.

If there is only one measurement on record, you will see the separation and position angle data without modifiers.

But if there is more than one measurement, I will usually tell the first measurement (in the Notes area) and the most recent measurement in the double star data table. If the latest measurement is the same as the first one, I will follow the data with an equal sign (=). If the later data is greater than the first data, a plus sign (+) will be used; and if the later data is less than the first data, a minus sign (-) will be used.

Perhaps a couple of examples will help. Suppose that the measures for a particular double star in 1844 were 36.2” of separation at a position angle of 121 degrees. Suppose also that the WDS shows a 1994 measure of 36.2” at 121 degrees. In this case, you would simply see 36.2 in the separation field and 121 in the position angle field.

But if the WDS had shown 1994 measures of 38.3” at 126 degrees, you would see 38.3 + and 126 + in the separation and position angle fields respectively.

And if the WDS had shown 1994 measures of 38.3” at 112 degrees, you would see 38.3 + and 112 -.

If the measures have changed significantly from the first ones, a single exclamation point (!) will be used. If the measures have changed greatly, two points will be used (!!).

Finally, be careful that you don’t make the assumption that a + sign means a measure is currently increasing (or a – sign indicate it is decreasing). The + and – signs are only relative to the first measure. If a pair is a true binary and the pair has recently passed apastron, there is a very good chance that recent measures will be greater than the original ones, yet still smaller than the measures when the pair was at maximum separation.

ABOUT THE "MODELS"

Whenever possible, I will include a "scale model" of the object in question. These scale models deserve some cautions.

First, it is only possible to build scale models of stellar systems (binaries, star clusters, etc.) when we know the distance (with some degree of accuracy) and the angular size as measured in a telescope. In the early 1990's, the European Space Agency (ESA) conducted a milestone mission named "Hipparcos" (and a secondary mission named "Tycho"), using orbiting observatories to collect positional data on millions of stars with unprecedented accuracy. A spin-off of this research was the discovery of thousands of new (and much more accurate) parallaxes to nearby stars.

The Hipparcos and Tycho data on parallaxes is very good out to about 500 light years from earth; beyond that range and the accuracy begins to drop off rather quickly. So for double stars within that range, the models that I put forth are probably fairly accurate; beyond that distance, the model should be taken with a healthy allowance for variance.

There are virtually no deep-sky objects within 500 light years of earth, so the distances to deep-sky objects (open clusters, globular clusters, planetary nebulae, and so on) are often just good estimates. In a few cases, Cepheid variable stars are present in these objects that allow us get a rather accurate fix on their distances, but for the most part, distances to deep-sky objects are, at best, educated estimates.

I have chosen to let the Sun be represented by a 3-inch (7.62 cm) sphere—roughly, the size of an American baseball. On this scale, the earth would be 0.0274 inches (0.6 mm) in diameter—about the size of a ball point pen's roller ball. This ball would be almost 27 feet (8.19 m) away from the baseball. Pluto would lie about 1,062 feet (324 m) away. A light year, at this scale, would be about 322 miles (518 km).

Astronomers generally agree that for binary stars in the galactic disc, if the stars are more than a light year apart, they are probably not truly binary as the local tugs on the pair will pull them from each other's grasp in less than one galactic orbit, so when my models show a component to be more than 322 miles (518 km) away from its primary, more than likely, we are not looking at a true binary star system. But the final verdict may take centuries to reach (in some cases) as enough of the companion's motion can be measured to decide if it is on an orbital path or a passing (hyperbolic) path.

Also in modeling double stars, the separation between components is at best the *minimum* separation, as we usually do not know the binary system's true orientation to earth with regards to its orbital plane. If the orbital plane is highly inclined to our line of sight, the angular separation we measure with the telescope may be a shortened "projection" of the true line separating the two stars. Thus, if we know the distance to the system and the angular dimensions, we can project the linear size of the projection, but must bear in mind that the size we compute must be for the two-dimension projection of the actual distance against the sphere of the sky.

Finally, in modeling double stars, I use one of two methods to determine the size(s) of the stars for the model. If the complete spectral class is known (Morgan-Keenan type plus luminosity class, such as G5V), I make the assumption that the star is a typical representative of any star of that class. We have a fairly good idea of how large different stars are based on their spectral types, so this is a reasonable approach to take. However, it is not 100% accurate, for the same reason that we cannot always say that a 45-year old American male with a height of 6 feet will weigh exactly 168 pounds. Some males of that age and size *will* weigh 168 pounds, but most will not. So when considering the size of the stars in a model based on spectral class, know that the model is at best a statistical average and not necessarily a precise representation.

The other method to determine stellar sizes is to use the relationship between surface temperature and apparent magnitude. If we know the surface temperature (which is a direct function of the spectral class) and magnitude, along with distance, we can compute the star's luminosity. This is also a rough approach, as allowances must be made for interstellar absorption of light (which is not always known), as well as the *effective* temperature of the star (roughly, it's "black body" temperature—the temperature it would be if it were a perfect radiator of light, which no star is).

WHAT ABOUT OTHER STUFF?

This book is not about double stars and double stars only (although they make up the bulk of the work). There are plenty of other objects in the sky to draw the attention of an amateur observer!

The so-called "deep sky objects" (as if double stars aren't deep enough in the sky!) consist of nebulae, star clusters (both open and globular), planetary nebulae, supernova remnants, and galaxies.

There are several fields of information supplied for every deep sky object in this book. First, of course, is the magnitude of the object. But be careful—this can be deceptive. The magnitude for an extended deep sky object is its "point source" magnitude. In other words, if all the light emitted by the object came from a single star-sized point, how bright would that point be? Many times I have searched for a 9th magnitude star cluster to find that I was dealing with a small but very faint grouping of stars, none of which were 9th magnitude themselves. In fact, if you wanted to get a rough idea of what to expect on some of the nebulous or galactic objects, find a star that is the magnitude of the object and defocus it until its bloated image is the size of the deep sky object. That is what you'll be looking for! (Try bloating a 10th magnitude star into a 30” diameter blob to simulate a faint elliptical galaxy. It is not an easy thing to see!)

Related to this is the concept of surface brightness. This is a more reliable indicator of how difficult it will be to see the object, but surface brightness is only useful for nebulae and galaxies, as it indicates the approximate magnitude of any point on the surface of the object.

The types of deep sky objects follow this code: GAL = galaxy; PN = planetary nebula; GC = globular cluster; OC = open cluster; GN = bright galactic nebula; DN = dark nebula; QSO = quasi-stellar object; SNR = supernova remnant

The size of a deep sky object will be shown in minutes of arc without the (‘) symbol. If the object is sub-minute in size, the seconds marks (“) will be shown. So, no marks means the size is given in minutes; with marks the size is given in seconds. Also, if the object is oblong, the PA of the major axis will be shown.

The class of deep sky object will also be shown.

For galaxies, two classification schemes are used— the classical Hubble Scheme, in which S is spiral, SB is barred spiral, SO is spheroidal, E is elliptical and Irr is irregular. Sub-classes designate the amount of arm winding (for spirals, barred spirals) or oblateness (ellipticals and spheroidals); and the newer de Vaucouleurs scheme in which the following complex taxonomy is used:

- Ellipticals (Hubble E)
  - Compact types (Hubble E6 = cE; Hubble E5 = E0; Hubble E5 intermediate = E0-1; Hubble E4 = E+)
- Lenticulars (Hubble S0)
  - Non-barred = SA0
  - Barred = SB0
  - Mixed = SAB0
    - Inner ring = S(r)0
    - S-shaped = S(s)0
    - Mixed = S(rs)0
      - Early (Hubble S03) = S0-
      - Intermediate (Hubble S02) = S0*
      - Late (Hubble S01) = S0+
- Spirals (Hubble S)
  - Non-barred = SA
  - Barred = SB
  - Mixed = SAB
    - Inner ring = S(r)
    - S-shaped = S(s)
    - Mixed = S(rs)
  - Stages
    - Hubble S0 = SO/a
    - Hubble S1 = Sa
    - Hubble S2 = Sab

- Hubble S3 = Sb
- Hubble S4 = Sbc
- Hubble S5 = Sc
- Hubble S6 = Scd
- Hubble S7 = Sd
- Hubble S8 = Sdm
- Hubble S9 = Sm

Irregulars (Hubble Irr)
- Non-barred = IA
- Barred = IB
- Mixed = IAB
  - S-shaped = I(s)
    - Non-Magellanic = I0
    - Magellanic = Im
  - Compact = cI

Peculiars = Pec

For all types, the following addends apply:
- : = uncertain
- ? = doubtful
- s = spindle
- (R) = outer ring
- (R') = pseudo-outer ring

The David Dunlop Observatory Spiral Luminosity type is then attached as a Roman numeral: I = thick, well-developed arms down to V = anemic, poorly-developed arms.

For open clusters, I use the Trumpler taxonomy as described in the Lick Observatory Bulletin, #14, page 154, 1930 issue. A Roman numeral (I to IV) indicates the concentration of the cluster from I (very concentrated) to IV (not well detached from the surrounding star field). A numeral from 1 to 3 indicates the range in brightness, with 1 being a small range and 3 a large range. Finally, a lower case letter indicates richness, with p being poor (fewer than 50 stars), m being moderately rich (50-100 stars), and r being rich (over 100 stars). In addition, a suffix of "n" means nebulosity is present.

For globular clusters, I use the taxonomy developed by Harlow Shapley and Helen Sawyer in the Harvard Observatory Bulletin, No. 824, 1927. Values range from 1 to 12 with the smaller the number indicating the more highly concentrated the stars are toward the center.

For planetary nebulae, I use the Vorontsov-Velyaminov scheme (1934), where the types range from I (stellar) to IIa (oval, evenly bright, concentrated), IIb (oval, evenly bright, not concentrated), IIIa (oval, unevenly bright), IIIb (oval, unevenly bright, brighter edges), IV (annular), V (irregular), and VI (anomalous).

In some cases, I will also show the old (obsolete) Herschel numbers for double stars and deep-sky objects. William Herschel developed a rather elaborate catalog system. For double stars, the catalog had these classes: I (difficult), II (close but measurable), III (5" to 15"), IV (15" to 30"), V (30" to 60"), VI (1' to 2'), and N (the 1821 catalog).

For deep-sky objects, Herschel's catalog used a similar system, but with different definitions for the codes: I (bright nebulae), II (faint nebulae), III (very faint nebulae), IV (planetary nebulae), V (very large nebulae), VI (very compressed rich clusters of stars), VII (compressed clusters of stars) and VIII (coarse clusters of stars).

Herschel numbers are no longer used by astronomers, but are included for those who are pursuing their Herschel 400 and Herschel II awards from the Astronomical League.

THE DEEP SKY NOMENCLATURE

The deep sky object nomenclature follows this code:

3C = Third Cambridge Catalog of Radio Sources (nebulae, galaxies)
Barnard = E. E. Barnard (various objections)
Basel = (open clusters)
Berkeley = (open clusters)
Biurakan = (galaxies)
Blanco = (open clusters)
Bochum = (open clusters)
Cederblad = (nebulae)
Collinder = (open clusters)
Czernik = (open clusters)
Dolidze = (open clusters)
Frolov = (open clusters)
Haffner = (open clusters)
Herschel = William Herschel (various objects)
King = (open clusters)
M = Charles Messier (various objects)
Markarian = (galaxies)
MCG = Morphological Catalog of Galaxies
Melotte = (open clusters)
NGC = New General Catalog (Dreyer), 1895, 1908 (various objects)
Palomar = (globular clusters)
PK = Perez-Kohoutek (planetary nebulae)

Roslund = (open clusters)
Ruprecht = (open clusters)
Stephenson = (open clusters)
Stock = (open clusters)
Tombaugh = Clyde Tombaugh (globular clusters)
Trumpler = (open clusters)
UGC = Uppsala General Catalog, 1973 (galaxies)

A NOTE ABOUT MAP SCALES

There are many different scales of map used in this book. The largest scale is for an entire zone and is approximately ten degrees square.. The faintest stars plotted on this map are magnitude 9.0.

The detail maps come in two versions— a normal view (as the sky would look to the eye without inversion or reversal) and a mirror image view (upright but mirrored). Between these two chart options, you can have an eyepiece view for any telescope (by either using the charts as printed or by rotating the page). These detailed charts show stars to 12.5 magnitude and deep-sky objects to 15.0 magnitude.

IT'S ALL ABOUT ZONES

The entire book is set up using Zones. A zone is one hour angle wide and ten degrees tall (except near the poles, where the zone may span 3 hour angles).

Each **zone file** will open with a full zone map, showing the orientation and numbering of the detailed finder charts. The finder charts will then be displayed after the zone map in both normal and mirror modes.

Each zone file also has a **zone catalog** that describes all the objects I have observed in that zone.

The object descriptions will bet set up in two areas. The first area will be the description of the double stars on the finder chart. The second section will be a description of the deep-sky objects on the chart.

In each section, the objects will be presented in order of increasing difficulty and decreasing “rating”. I use three difficulty levels—easy, moderate, and difficult. These are only my way of telling you what you can expect under ordinary seeing conditions[7]. Bear in mind that most of my observations have been made from a suburban location, not the darkest or cleanest skies in America. So when I say a particular galaxy is moderate in difficulty, that is my rating from my light-polluted location (unless otherwise noted). If you are lucky enough to live in an area with darker skies, my “moderate” may be your “easy” and so on.

The rating is a scale I developed early in my observing career when I began logging my observations in a database on my computer. I wanted some way to rapidly query the database for various types of objects that I could show a guest on short notice. Let’s face it—you and I, as experienced observers, would have fun observing almost anything with our telescopes. But to the layman who has not spent any time at a telescope, dim and difficult double stars or BARFS (big and really faint stuff) would probably be boring beyond belief. So I began rating each object with a scale of 1 to 5, where 1 is a stunning and wonderful view and 5 is a view that is hardly worth the effort to get.

So combining the difficult and rating scales, you will have an idea of what you might expect of any object before you see it. A double star, for instance, rated a 5E, would very easy but awfully boring. Likewise, a galaxy rated 5D would be boring but awfully difficult. (That’s not to say that seeing ancient light is boring, but after viewing thousands of galaxies, I can say that many of them are just about as exciting to watch as drying paint.)

SOURCES AND ACKNOWLEDGEMENTS

All the star charts in this book were generated with ***TheSky*** astronomy software, version 5.0 by Software Bisque, located at 912 Twelfth Street, Suite A, Golden, Colorado 80401. Charts are used with permission.

"Star Notes", featured in some of the Notes fields, area are from James B. Kaler, Professor of Astronomy at the University of Illinois and downloaded from his web page (http://www.astro.uiuc.edu/~kaler/sow/), and used with permission. Sources he credits are:

Allen, R. H., "Star Names: Their Lore and Meaning," Dover, New York, reprint, 1963.

The Astronomical Journal

The Astronomical Society of the Pacific Conference Series

Astronomy and Astrophysics: A European Journal

Astronomy and Astrophysics Abstracts, Springer, Heidelberg

Astronomy and Astrophysics Supplement Series

The Astrophysical Journal

The Astrophysical Journal Supplement Series

Berry, A., "A Short History of Astronomy," Dover, New York, reprint, 1961

Burnham, R., Jr., Burnham's Celestial Handbook, Dover, New York, 1978.

Hoffleit, D. and Jaschek, C., The Bright Star Catalogue, Fourth Revised Ed., Yale University Observatory, 1982

The Hipparcos and Tycho Catalogues, European Space Agency, 1998

Kaler, J. B., "Astronomy!," HarperCollins, New York, 1994

Kaler, J. B., "Stars and their Spectra," Cambridge U. Press, 1989

Kunitzsch, P. and Smart, T., "Short Guide to Modern Star Names/Derivations," Harrassowitz, Berlin, 1986

Monthly Notices of the Royal Astronomical Society

The Observatory

Observer's Handbook, Royal Astron. Soc. Canada, R. Bishop, ed, Toronto, U. Toronto Press

Publications of the Astronomical Society of the Pacific

SIMBAD on the Web, CDS, University of Strasbourg

Tirion, T., Sky Atlas 2000, Sky Publishing Corp., Cambridge, 1981

Other public domain sources include:

Astronomy Magazine, numerous issues from 1975 to 1996.

Burnham's Celestial Handbook (volumes 1 to 3), by Robert Burnham. © 1968, 1978 by Dover Publications, Inc. New York, NY.

Catalogue of Open Cluster Data, downloaded from CompuServe's Astronomy Forum in the early 1990's.

The Centre de Données stronomiques de Strasbourg, which runs an awesome web site (http://simbad.u-strasbg.fr/sim-fid.pl).

Celestial Objects for Common Telescopes, by The Reverend T. W. Webb. © 1962 by Dover Publications, Inc. New York, NY. Webb's original book was published in 1917.

A Concise Dictionary of Astronomy, by Jacqueline Mitton. © 1191 by Oxford University Press, Oxford, England.

The Facts on File Dictionary of Astronomy, Third Edition, edited by Valerie Illingworth. © 1979, 1985, 1994 by Market House Books, Ltd. Published by Facts on File, Inc. New York, NY.

The Deep Sky Field Guide to Uranometria 2000.0, by Murray Cragin, James Lucyk, and Barry Rappaport. © 1993 by Willmann-Bell, Inc. Richmond, VA.

The New General Program, a computer database and record-keeping system for deep sky observations by G. Dean Williams. Downloaded in 1994 from CompuServe's Astronomy Forum, along with observational notes uploaded by Dean Williams, Barbara Wilson, Eric Greene, Steve Coe, and Geoff Chester, as well as files from The Morphological Catalog of Galaxies, the Lynds Catalog of Bright Nebulae, and The Lynga Catalog of Open Clusters.

RealSky, the Palomar Observatory Sky Survey on CD-ROM, with the Equatorial and Southern Sky Surveys of the Siding Spring Observatory, Australia. Joint project of the Astronomical Society of the Pacific and the Space Telescope

Science Institute, co-sponsored by The Association of Universities for Research in Astronomy, Inc. (AURA).

Reprint No. 181, “Redshifts and Magnitudes of Extragalactic Nebulae” by M. Humason, N. Mayall, and A. Sandage; *The Astrophysical Journal,* Vol 61, pp. 97-162; 1956.

The Saguaro Astronomy Club (SAC) Database, by members of the Saguaro Astronomy Club of Phoenix, Arizona. A special thanks to Steve Coe for all his help and assistance!

Sky Catalog 2000.0 (Volumes 1 and 2), by Alan Hirshfeld, Roger W. Sinnott, and Francois Ochsenbein. © 1991 by Sky Publishing Corporation, Cambridge, MA, and Cambridge University Press, Cambridge, MA.

Sky and Telescope Magazine, numerous issues from 1994 to the present.

Star Names, Their Lore and Meaning by Richard H. Allen. © 1963 by Dover Publications, Inc. New York, NY.

The Webb Society's Deep Sky Observer's Handbooks (Volumes 1 to 8), compiled by members of The Webb Society, Kenneth G. Jones, Editor. © 1975 by The Webb Society. Published by Enslow Publishers, Inc. Hants, UK.

The Washington Double Star Catalog, compiled by Brian Mason, and downloaded from the U. S. Naval Observatory's web page.

The Yale Bright Star Catalog, downloaded from:

http://www.pomona.claremont.edu.

All Hubble Space Telescope pictures used for the CD Menus are used with the permission of NASA and the STScI.

Main Menu: Hubble Deep Field. Image credit: NASA, ESA, F. Summers (STScI)

Maps and Catalogs, 00h – 05h: NGC 1850. Image credit: NASA, ESA, Martino Romaniello (ESO)

Maps and Catalogs, 06h –11h: Orion Nebula. Image credit: NASA, ESA, The Hubble Heritage Team (STScI/AURA)

Maps and Catalogs, 12h – 17h: M104. Image credit: NASA and the Hubble Heritage Team (STScI/AURA)

Maps and Catalogs, 18h – 23h: M17. Image credit: NASA, ESA and J. Hester (ASU)

Support Files Menu: Supernova Remnant N 63A. Image credit: NASA, ESA, HEIC, The Hubble Heritage Team (STScI/AURA)

Index Menu: Supergiant V838 Mon. Image credit: NASA, ESA, H. E. Bond (STScI)

Sky Albums Menu: Quintuplet Cluster. Image credit: NASA, ESA, STScI.

End Notes

[1] The Rayleigh limit formula for the resolving power of a telescope is given by

$$2.5 \times 10^5 (\lambda / d)$$

where λ and d are expressed in meters. For optical values of λ, the formula approximates to 0.13 / d arc seconds. The Dawes Limit, determined by empirical measurements, yields 0.12 / d arc seconds. Converting these to English units of measurement shows that where Dawes shows 4.5 / d, Rayleigh shows 4.87 / d.

[2] For the remainder of this book, I'll abbreviate coordinates like this: HHMM+DDMM or HHMM-DDMM, where the HH and MM are hours and minutes of RA and the DD and MM are degrees and minutes of Declination, + being north of the celestial equator, - being south. Thus Polaris's RA would be 0245. Its declination is +8918, so its full position using this shorthand would be 0245+8918.

[3] This process is superb for visual astronomy, but if you want to do astrophotography or want greater aiming accuracy, you will need to amore accurate alignment. For such accuracy, you'll need an *illuminated reticule eyepiece*. Such an eyepiece has a graduated scale etched into it that can be illuminated softly by a red light emitting diode (LED). Once the Orion method of alignment has been performed, insert the illuminated reticule into the eyepiece holder. If the eyepiece gives less than 150x of magnification, use a Barlow to get it above 150x. Find a star as close to the celestial equator as possible and as close to the meridian as you can (no more than 5° from the equator or the meridian). Center this star on the reticule's scale and watch the star for several minutes. If the image drifts *south*, the telescope points too far to the *east*. Loosen the mount's set screws and tap it lightly towards the west. Repeat the process until the drift stops. Conversely, if the star drifts *north*, the mount points too far to the west.

The final step in this extra-precise alignment method requires that you select a star within 5° of the celestial equator and as close to the eastern horizon as you can get and watch the drift again. This time, if the star drifts *south*, the polar axis points *below* the pole—raise it. Repeat the process until the drift stops. (Conversely, if the drift is *north*, you need to lower the polar axis.)

[4] Some observers claim the companion is green, but there are no green stars. The green hue described by some is probably a "contrast effect" of the blue being set against the deep orange-red of Antares.

[5] For example, The Reverend T. W. Webb, in his classic handbook *Celestial Objects for Common Telescopes*, Volume Two, presents a chart showing how the magnitude scales used by Smyth (a 19th century double star fanatic) compared to Friedrich Struve (the dean of double star discoverers), John Herschel, and Argelander. As an example of the wild variation in those days, a Smyth 10.0 magnitude is equivalent to a Struve 9.3, a Herschel 10.4, and an Argelander 9.4!

[6] When WRNS was added to the MKK taxonomy, the mnemonic was changed to, "Oh, be a fine girl: kiss me. Well, right now, sweetheart!" With the dropping of W and the addition of L and T, one can only imagine how someone will modify the mnemonic!

[7] About 95% of the objects in this work have been observed from urban settings; about half of them with a C-8 from the outskirts of Columbia, Missouri form 1987 to 1990, and the other half from suburban north Kansas City, Missouri, from 1990 to the present, using the C-8 (up to 2002) and the C-11 since 2002. In the few cases where I could only observe an object from extra dark skies or with different instruments, this will be noted in the catalog description. My point is that there is a great deal of observational astronomy that can be done even from a moderately light-polluted area if you are patient and develop your skills.