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Chapter one

Background

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1.1 The cosmic backdrop

Being an amateur astronomer is a lot of fun. There are so many different and interesting areas. But before we *do* astronomy, let's learn a little about what we're going to be observing by taking a little tour. We will start right here on Earth. (Note: Experienced observers can proceed beyond this section.)

Earth

The Earth is a planet. Planets are different from stars because they do not give off their own light (although large planets like Jupiter may radiate some energy). Planets are also generally much smaller than stars, so they seem to orbit stars (although technically both the star and the planet are orbiting a common point known as the center of mass). For our purposes, we will be referring to planets as objects which are orbiting the Sun.

The Earth is the third planet out from the Sun. Closest to the Sun is Mercury, then Venus. These are known as the inner or inferior planets. Further than the Earth are the planets (in order) Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. These are the outer or superior planets. Four planets (Jupiter, Saturn, Uranus, Neptune) are larger than the Earth and the other four are smaller. The four larger planets are also different

Gil Machin, of Kansas City, Missouri, with his superb homemade 400 mm Newtonian. Gil ground the mirror as well and the views must be experienced to be believed. (Photo by the author)

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The Moon. (Photo by Robert Kuberek of Valencia, California)

in that they are mainly composed of gas, with relatively small rocky or metallic cores deep within. And although Pluto may be mainly composed of frozen gases, the other three small planets are much more Earth-like in composition.

Moon

The first stop out from the Earth is the Moon. The Moon is about one-quarter of the diameter of our Earth, but much less massive. It orbits the Earth every 27 1/3 days, approximately. However, since the Earth is also moving through space (as it orbits the Sun) the Moon takes about 29 1/2 days to go through a complete cycle of phases. The lunar cycle begins at New Moon (which cannot be seen from Earth). New Moon occurs when the Moon is between the Sun and the Earth.

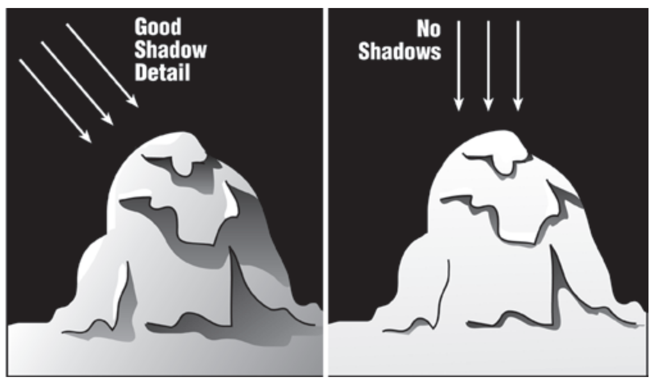
Eclipses

Once in a while, we see the Moon pass in front of the Sun. This is called a solar eclipse. Eclipses can be total, if the Moon covers the Sun entirely, or partial, if the Moon covers only part of the Sun, or annular, if the Moon is far from Earth and (although it passes directly in front of the Sun) does not cover the entire disk of the Sun but leaves a ring of the Sun's surface visible. Eclipses do not occur every 29 1/2 days because the Moon's orbit is tilted to the orbit of the Earth around the Sun. So at times it is above the Sun at New Moon and at other times it is below.

The two intersections of the orbit of the Moon and the apparent path of the Sun (the ecliptic) are known as nodes. Only when the Full Moon is at one of the nodes is an eclipse possible. When the Sun is at the same node, the eclipse will be solar. When the Sun and Moon lie at opposite nodes, the eclipse will be lunar. (Illustration by Holley Y. Bakich)

There are also eclipses of the Moon (lunar eclipses). These events happen at Full Moon, when the Earth is between the Moon and the Sun. Lunar eclipses can be total or partial. Also, since the Earth's shadow has two parts, a dark inner part (called the umbra) and a lighter outer part (the penumbra), there are times when the Moon does not enter the umbra. Such an eclipse is called a penumbral eclipse. All total or partial eclipses of the Moon occur when the Moon passes through the umbra of the Earth's shadow.

Observers who are not interested in the Moon generally schedule their observing sessions around the time of New Moon. Actually, during the roughly two weeks between Last Quarter and First Quarter, the light of the Moon is diminished and many good observations may be obtained. Also, a Quarter Moon is in the sky only half the night (First Quarter from sunset to midnight and Last Quarter from midnight to sunrise). One further point. Due to the angle of the Sun's light striking the Moon's surface, Quarter Moons are only 10% as bright as the Full Moon.



Full Moon (when the Sun's rays are perpendicular to the surface) is the worst time to observe the Moon, as the detail is reduced. (Illustration by Holley Y. Bakich)

Angle of sunlight is also the reason why those interested in observing the Moon do not generally observe at Full Moon. During that phase, the Sun is directly behind the observer. Thus, as seen from the Moon, it would be overhead and any shadows would be at their shortest. The best location on the lunar surface for observing detail is where the sunlit part of the Moon meets the dark portion. This line is the point of sunrise (when the phase is between New Moon and Full Moon) or sunset (when the phase is between Full Moon and New Moon) and is called the terminator.

Mercury and Venus

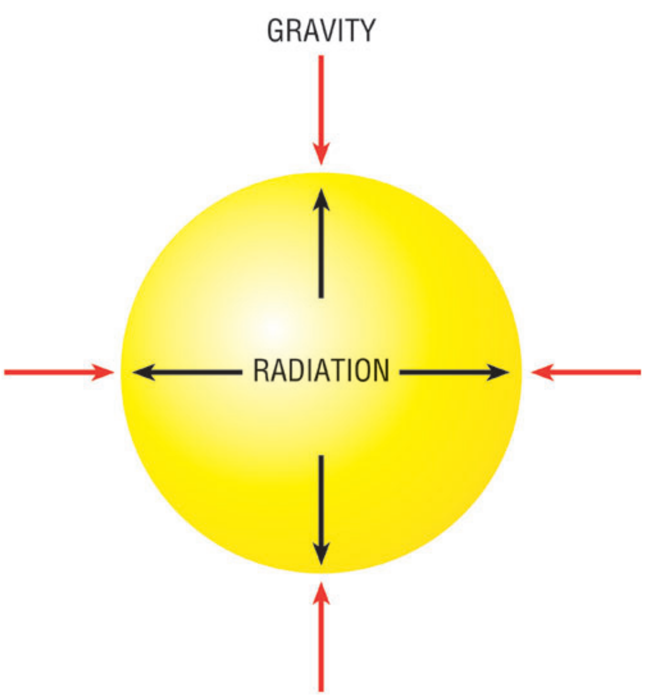
As we move outward from the Moon (in the direction of the Sun), we encounter the planets. Mercury and Venus, because their orbits are smaller than the orbit of the Earth, are never seen very far from the Sun. At most, Mercury can be 28° from the Sun and Venus 47°. A degree, by the way, is a unit of measuring distance across the sky. This type of distance is called angular distance, as you are really measuring the angle observed, and not the true distance in miles or kilometers. To get an idea of degree measurement, make a fist and hold it at arm's length. From the top to the bottom of your fist is roughly 10°. If you extend one finger, that's approximately 2°. (Rough measurements in the sky include the distance between the two stars in the bowl of the Big Dipper (called the Pointer Stars). They are a little over 5° apart. From the tip of the bowl to the end of the handle the distance is a little over 25°. Other distance "helpers" will be discussed later.)

Mercury is small and essentially no detail has ever been seen on it by amateur observers. Venus is larger and closer, but its surface is totally obscured by a thick layer of cloud. Occasionally, and by employing the right equipment, cloud structure can be seen when observing Venus. This will be discussed in more detail in the section on observing Venus.

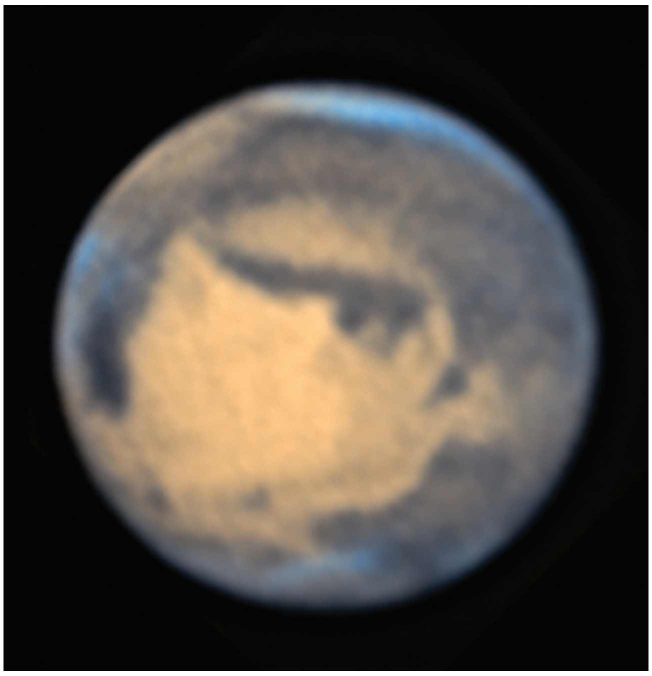
Mercury and Venus can line up with the Earth and Sun in two ways. Each can be between the Sun and Earth (this is called inferior conjunction) or on the opposite side of the Sun from the Earth (superior conjunction). Just like eclipses, usually the three bodies are not directly in line. However, if either Mercury or Venus is directly in line with the Earth, the disk of the planet will appear as a black dot on the face of the Sun. This is called a transit. Transits of Mercury are infrequent, but much more common than transits of Venus (which occur in pairs separated by more than 100 years).

Sun

Since we've been moving in the direction of the inferior planets, let me say a few introductory words about the Sun. The Sun is a star, similar to those that we see at night. It is an average star. About half the stars in space are larger, half are smaller. Half the stars are hotter, half are cooler. Half the stars are more massive, half are less massive. But more importantly than being average, the Sun is also a *stable* star.



In a stable star such as the Sun, the forces of gravity and radiation are in balance. (Illustration by Holley Y. Bakich)



Mars. Tan Wei Leong, of Singapore, took this image at 16:18 UT on 20 Jun 2001. (Celestron C11 and an SBIG ST7E CCD camera)

Two major forces are at work within the Sun. The first is gravity. Gravity causes the material of the Sun (and that of all other celestial objects) to remain a single body. But gravity wants to pull all the mass of the Sun to its center. Opposing the force of gravity is the force created by the energy being produced in the Sun's core. There, at temperatures of 15 million degrees Celsius, the centers of hydrogen atoms are being smashed into one another with such force that a helium atom (at least its center, called the nucleus) can form. In this process, some mass is lost as energy is released. This is the reason the Sun shines. All of us have probably at least heard of Albert Einstein's famous equation $E = mc^2$. This is a simple way of stating how mass (m in the equation) can be transformed into energy (E).

Mars

Continuing our journey outward, we come to Mars. Of all the planets, Mars most resembles Earth. Its day is just over 24 hours long. The tilt of its axis (that is, how much the poles point from straight up – the Earth's tilt is 23½ degrees) is similar to that of the Earth. This means that, like the Earth, Mars has four distinct seasons. Mars' temperature range is also closer to that of Earth than any of the other planets, although it still is very cold there on average. Mars is also the only planet where the telescopes of amateur astronomers can resolve details on its surface.

Asteroid belt

Between Mars and the next planet, Jupiter, lies the asteroid belt. Asteroids (also called minor planets) are rocky bodies which also orbit the Sun, taking from three to six years to do so. Hundreds of thousands of asteroids inhabit this region. The largest of these, Ceres, has a diameter of only 930 km. Some asteroids do not lie within this area of the solar system, but range far and wide. Those few that approach our region of space are called NEOs, or Near-Earth Objects.

Jupiter, Saturn, Uranus, and Neptune

The planets Jupiter, Saturn, Uranus, and Neptune are called either the Jovian planets (for their resemblance to Jove, that is, Jupiter) or the gas giants. In composition, these planets are much more like the Sun than they are like the Earth. They are made mostly of hydrogen and helium, with other gases in smaller amounts. When we observe these planets, we are viewing only the tops of their atmospheres. Uranus and Neptune reveal little detail (except for color) in amateur telescopes. Jupiter and Saturn are showpieces.

Even through small telescopes, Jupiter reveals several belts and four bright moons. Jupiter also rotates (spins) quickly, so features on it change a lot. Saturn is best known for its magnificent system of rings. However, Saturn is not the only planet with rings. The other three gas giants also have ring systems. In contrast, their rings are thin and composed of dark material which makes them impossible to observe directly from Earth. Saturn's rings, on the other hand, are big and bright, being composed mainly of ice crystals and ice-covered rock.

Pluto

The last planet in our journey out from the Sun is Pluto. Pluto has successfully been observed through medium-sized amateur telescopes. It looks just like a star, however, and a faint one at that. You also need a good star chart to find it.

Kuiper Belt

After Pluto, there is still plenty of solar system left. A disk of comets called the Kuiper Belt extends from the area of Pluto out to a distance of several thousand times as far as the Earth is from the Sun. By the way, the average Earth–Sun distance has a name. Astronomers call it the astronomical unit; it is often abbreviated AU.

Oort Cloud

The extent of our solar system is defined by the Oort Cloud. This is a much larger group of comets lying much further from the Sun. The Oort Cloud lies between 30 000 and 100 000 astronomical units from the Sun. This places the furthest comets in the Oort Cloud slightly over one-third the distance to the next nearest star.

Comets

The previous two paragraphs have discussed comets, but only as icy objects lying far from the Sun. Often, however, comets approach the Sun and we find them in our region of space. When this happens, heat from the Sun begins to evaporate the ice of which the comet is mostly made. (The other main ingredient of comets is dust.) At this point the comet may develop a coma (a cloud of gas surrounding the central body of the comet; once the coma forms, that central body is called the nucleus) and it may even develop a tail. Here is where observers start getting excited. The large area of glowing gas makes the comet much easier to observe. How bright any comet gets depends on three factors: (1) the composition of the comet itself; (2) distance from the Sun; and (3) distance from the Earth. The closer a comet gets to the Sun, the brighter it becomes. However, if the comet is on the other side of the Sun from the Earth at that time, it will not look as bright as if it were also near the Earth. This is the reason that Halley's Comet (among others) sometimes appears brilliant while at other times it is barely visible.

Halley's Comet, 4 Jan 1986, Naco, Arizona. (8" f/1.5 Celestron Schmidt camera, 5 minutes on hypered TP 2415 film. Image by David Healy, Sierra Vista, Arizona)

Stars

Moving out from our solar system, we encounter the stars. The stars are so far away that a new scale of distance is now required. An example will help. The brightest star in the night sky is Sirius. Sirius is easy to see from late fall to mid-

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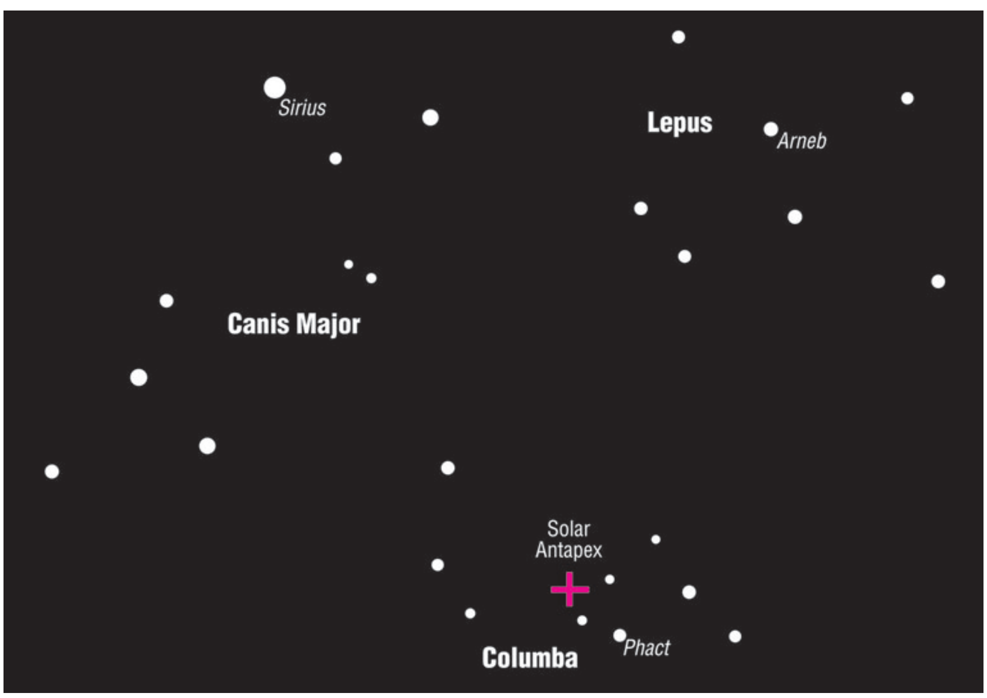
The constellation Canis Major, featuring the brilliant star Sirius. On the original slide, no less than five Messier objects are visible: M41, M46, M47, M50, and M93. Messier objects are discussed later in the text. (Photo by the author)

spring and can be located by using the belt of the constellation Orion by simply drawing a line down from the belt to brilliant Sirius. When astronomers describe the distance to this star they do not use kilometers but rather light years or parsecs.

A light year may sound like a unit of time but it is actually a unit of distance. It is the distance that light (moving at the approximate speed of 300 000 km/s) travels in one year. After performing a little math, we discover that a light year corresponds to nearly 9.5 trillion kilometers! Sirius, lies 8.65 light years distant.

Parsecs are slightly more difficult to understand as they are more of a mathematical construction. One parsec is defined as the distance of an object if its parallax equals one second of arc. Parallax is defined as one-half the angle that an object makes when measured from both sides of the Earth's orbit (see diagram). A second of arc is 1/3600 of a degree (a very tiny angle). When you are looking at the sky, it is impossible to measure kilometers from one object to another, so astronomers use angular measurements. There are 360 degrees in a circle, 60 minutes of arc in each degree and 60 seconds of arc in each minute of arc. Thus, the distance of any object lying at one parsec is a little over three and one-quarter light years (3.2616 to be exact).

Stars come in different varieties. All stars, however, go through the same stages of "birth," "life" and "death." (Describing it like this is an easy way to picture the various parts of a star's existence.) Stars are born in vast clouds of gas, almost entirely composed of hydrogen and helium. Such clouds are found within galaxies. Gravity causes areas of the gas to collapse inward, raising the temperature and pressure. This contraction continues until the temperature of the star reaches about 10 000 000°C. At this point, a process called nuclear fusion can occur. Lighter atoms, sped up by the tremendous energy available, collide with one another, "fusing" into heavier elements. The most common transformation happens when hydrogen atoms collide and combine, finally fusing to become helium. As this happens, a



The solar antapex lies to the south and west of Sirius, within Columba. This is the point away from which our solar system is moving, due to the rotation of the Milky Way. (Illustration by Holley Y. Bakich)

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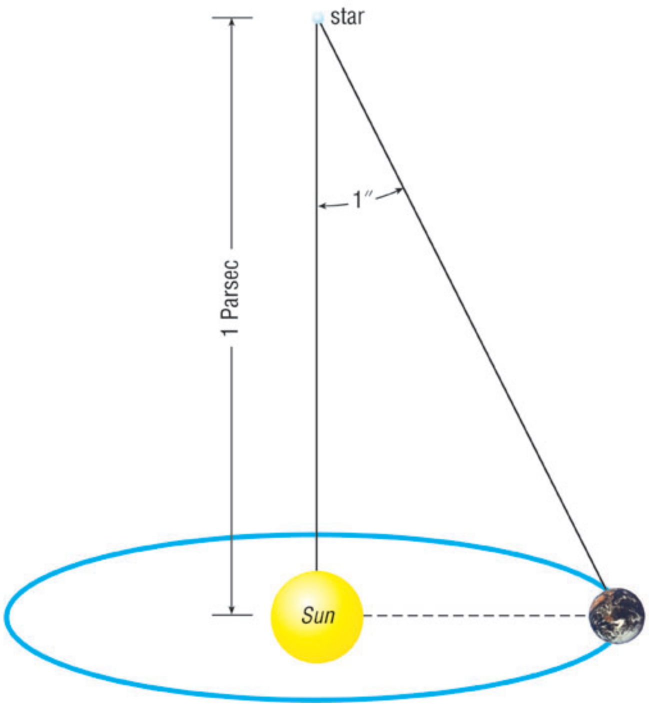


No star is as near as on parsec, where its parallax would be one second of arc. Not to scale. (Illustration by Holley Y. Bakich)

small part of the mass of the hydrogen is converted into energy. We have to thank Albert Einstein for helping us understand this process. $E = mc^2$ is his famous formula. Simply, it says that energy equals mass multiplied by a large number, the speed of light squared. This explains why a little mass can produce a large amount of energy. Nuclear fusion, then, is what makes the Sun and most of the other stars shine.

When a star begins to fuse hydrogen (and this only happens in its center, or core) it quickly achieves a balance between two forces. One is the force of the energy (flowing outward) and the other is the force of gravity (pulling inward). When these are in balance, a star is said to be stable. This is by far the most important attribute of our Sun – it is stable. If there were fluctuations in its temperature, size, etc., well, you can easily imagine that life on Earth would be impossible.

The middle part of a star's life (sometimes called the hydrogen-burning stage because that is what the star is using for fuel) is where most visible stars are. How long a star stays in this stage depends only on its mass. Massive, hot stars, with very high temperatures in their cores, use up their hydrogen fuel quickly (at least quickly in astronomical terms). Less massive stars, like our Sun, may be in this stage for billions of years. (The Sun's estimated middle lifespan is 10 billion years. It has been in this stage for approximately half that time so far.)

Massive (notice that I'm not saying "big" because it is mass, not size, that is the important factor) stars are very

The Pleiades, a very young open star cluster in Taurus. SBIG ST7e NABG camera with the SBIG CLA Nikon lens adapter on a Vixen GP-DX EQ mount. 80 mm Nikon lens, 10-minute exposure. A set of 2" RGB filters were manually switched between shots. (Image by Chris Woodruff, of Valencia, California)

M27. (Tri-color image with SBIG ST-8 CCD camera, R: 20 minutes, G: 30 minutes, B: 60 minutes, full resolution, Meade 16" LX200 @ f/6, 18 Jul 1998, Sierra Vista, Arizona. Image by David Healy)

The apex of the Sun's way, or solar apex, lies approximately 3° from the star θ Her. The nearest bright star is Vega. The solar apex is the direction in space toward which the Sun and our solar system are heading, due to our rotation in the Milky Way galaxy. (Illustration by Holley Y. Bakich)

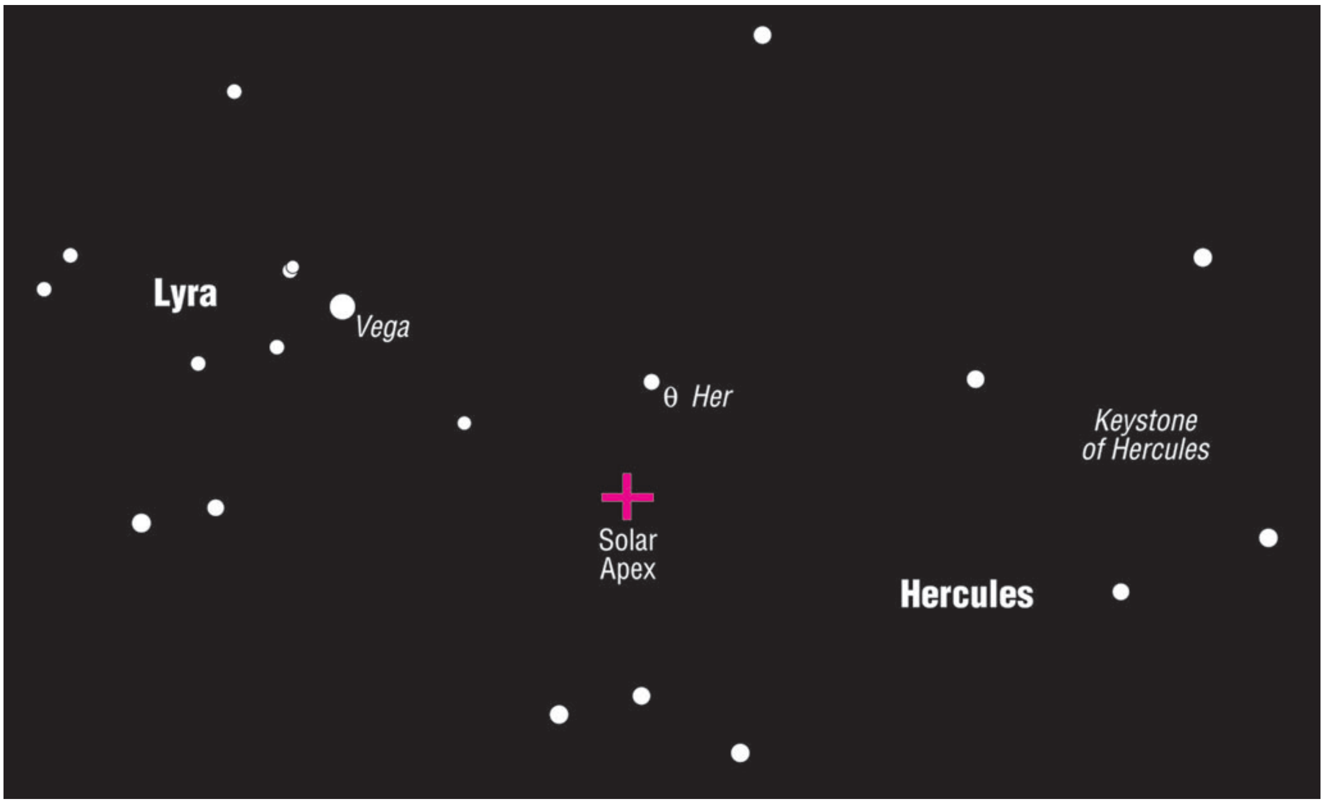
bright, but due to the extremely high temperatures in their cores they only live for a short time. Once the energy output starts to diminish, the force of gravity begins to win the "tug-of-war" with energy and the star begins to contract, but this only causes a new change to come about. The temperature and pressure in the core increase and soon helium becomes the fuel used to produce energy. Because helium fuses at a much higher temperature than hydrogen, more energy is released and the star's outer layers expand until the balance is once again restored between energy and gravity. The star has now become a red giant. Other, heavier elements may be fused at higher temperatures to turn the star into a red supergiant, but this process soon ends. Different things can happen to the star now.

Planetary nebulae

One scenario is that the star will continue to make energy by using hydrogen and helium outside of the core; its surface will rise and fall and the star will become a variable star. When out of control, the layers of gas will pull away, forming a shell of gas known as a planetary nebula. As an amateur astronomer, you will have lots of opportunities to observe planetary nebulae. Many of these objects are reasonably bright and easy to observe.

White dwarf

As the outer layers are puffed away, the core contracts to roughly Earth-like size. The star is now known as a white dwarf. Further contraction is prevented because the star



doesn't have enough mass to overcome the force caused by the repulsion of electrons in its matter. Probably the most famous white dwarf star is the first to be discovered, Sirius B. As the name implies, it is a companion to the brightest nighttime star, Sirius. It was discovered in 1862 by a famous American telescope maker named Alvan Clark. The overwhelming glare of Sirius makes this companion difficult to observe unless it lies far enough away in its orbit. The section on double stars later in this book has a diagram showing when Sirius B is best for observation.

Supernova

Very massive stars will continue to fuse heavy elements in order to produce more energy. However, once iron is formed, more fusion cannot occur since iron is very stable and its fusion would require more energy than even the largest stars have available. Rather quickly after the formation of iron the core will collapse under its own gravity and huge amounts of gas on the surface of the star will explode out. The star has become a supernova. Supernovae are the largest explosions in the universe and really bright ones often outshine the entire galaxy in which they are located!

Neutron star

During a supernova explosion, tremendous amounts of energy are available. The core of the star is crushed to such a degree that protons and electrons are made to combine, leaving only neutrons, and those with very little of the original space that separated them. Neutron stars consist of matter that is 100 million times denser than white dwarf matter. I once heard it put this way: a teaspoonful of neutron star material would weigh more than every automobile ever produced on Earth!

Pulsars

If the original star which became a supernova and produced a neutron star was rotating, the law of "conservation of angular momentum" insures that the neutron star is

The constellation Lyra, the Harp. Just to the upper left of brilliant Vega you can see the Double-Double resolved into "two" stars. (Kodak Elite Chrome 200, pushed 1 stop. Nikon F2 with a 50 mm Nikkor lens. Photo by Ulrich Beinert of Kronberg, Germany) spinning very fast. The usual analogy given here is that of a skater whose arms are pulled close to their body while spinning, increasing the speed of the spin. Hot spots, caused by magnetic fields, may form on the neutron star. If these brighter spots pass by our field of view, the star will appear to blink on and off, or pulse. Such a star is known as a pulsar. Pulsars cannot be observed with equipment available to amateur astronomers.

Black holes

If the original star was massive – say, six to eight times the mass of our Sun or more – an object even stranger than a neutron star will be produced. Astronomers have coined the term "black hole" for such an object, but "invisible star" would be equally descriptive. Black holes are produced by the most powerful supernova explosions which force the matter within the star's core to an incredible, no, unbelievable density. In the tug-of-war between gravity and energy, a black hole represents the ultimate victory for gravity. Such an object has a gravitational field so strong that nothing – not even light – can escape. Black holes are not observed directly even by professional astronomers using the largest telescopes. They simply cannot be seen. Their presence is revealed by the effect they have upon nearby stars, or upon gas which they are consuming.

Constellations

All visible stars are grouped into constellations. There are 88 constellations that cover the sky. (For a complete list, see Appendix A.) There is no overlap among constellations and no gaps between them. The boundaries of the constellations were officialized in 1928 (published in 1930). Today, when we talk about celestial objects being "in" a particular constellation, this means that the object is to be found within the official boundary established long ago.

I think that all amateur astronomers should be familiar with at least the most prominent constellations. At gatherings, questions of location are common as are answers such as, "It is in Bootes." You still are clueless if you don't know where Bootes is. Also, it is good to know which are the "constellations of the seasons," usually defined as the constellations visible after sunset during the middle of each season.

While you take a little time to learn the locations and general figures of the constellations in the sky, also take a look at their correct pronunciations (see Appendix A). Oh, and while I'm on this subject, there are two constellations of the zodiac whose names are often butchered. They are Scorpius and Capricornus. If you are heard to say "Scorpio" or "Capricorn," prepare yourself for some abuse, because that's how *astrologers* refer to those star groups.

In addition to the 88 "official" constellations, there are a number of unofficial groups of stars, or *asterisms* in the sky. Two examples are the Big Dipper in Ursa Major and the Teapot in Sagittarius. Often, asterisms are made of stars which come from more than a single constellation. One example is the Summer Triangle, composed of three stars, one each from the constellations Lyra, Aquila and Cygnus.

The Eta Carinae Nebula. Truly one of the wonders of the sky. (This 20-minute exposure was on hypered Fuji HG 400 through a Celestron 5 at f/6.3. Image by Steven Juchnowski, Balliang East in the State of Victoria, Australia)

Nebulae

The word "nebula" comes from the Latin for "cloud." So when I speak of a nebula I mean a cloud of gas and dust in space. Two main types of nebulae exist: emission and reflection. In an emission nebula, the atoms are giving off light because they are being excited by massive, hot stars within the nebula itself. These nebulae are generally red in color because they are made almost entirely of hydrogen. When hydrogen is excited it gives off light, red light being the strongest color. Emission nebulae often have dark areas caused by clouds of dust which block the light. The combination of "red" hydrogen gas and dust gives us some very interesting objects. A great example of this is the North American Nebula, in the constellation Cygnus.

The other main type of nebula is known as a reflection nebula. Such an object is produced when dust in a cloud of gas reflects light from stars not within the cloud itself. Reflection nebulae are often blue since the blue light is scattered throughout the cloud by dust particles. Scattering of blue light is the same phenomenon that gives us a blue daytime sky. Some nebulae are made up of both reflection and emission components. A good example of this is the Trifid Nebula in the constellation Sagittarius.

Star clusters

Many stars occur in groups called star clusters. Astronomers divide star clusters into three main types: associations, open clusters and globular clusters. Associations are the loosest groupings of stars, usually containing a few stars to a few