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» Weighing in on gravity

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Chapter 1
Seeing the Light: The Art and Science of Astronomy

Step outside on a clear night and look at the sky. If you're a city dweller or live in a cramped suburb, you see dozens, maybe hundreds, of twinkling stars. Depending on the time of the month, you may also see a full Moon and up to five of the eight planets that revolve around the Sun.

A shooting star, or "meteor," may appear overhead. What you actually see is the flash of light caused by a tiny piece of space dust streaking through Earth's upper atmosphere.

Another pinpoint of light moves slowly and steadily across the sky. Is it an artificial satellite, such as the Hubble Space Telescope or International Space Station, or is it just a high-altitude airliner? If you have binoculars, you may be able to see the difference. Airliners have flashing lights, and their shapes may be perceptible.

If you live in the country — on the seashore away from resorts and developments, on the plains, or in the mountains far from any floodlit ski slope — you can see thousands of stars on a clear night. The Milky Way appears as a beautiful pearly swath across the heavens. What you're seeing is the cumulative glow from millions of faint stars, individually indistinguishable with the naked eye. At a great observation place, such as Cerro Tololo in the Chilean Andes, you can see even more stars. They hang like brilliant lamps in a coal black sky, often not even twinkling, like in Vincent van Gogh's *Starry Night* painting.

When you look at the sky, you practice astronomy — you observe the universe that surrounds you and try to make sense of what you see. For thousands of years, everything people knew about the heavens they deduced by simply observing the sky. Everything that astronomy deals with

- Is seen from a distance
- Falls from afar like a meteorite, or is collected and brought to Earth with a spacecraft like a Moon rock
- Is discovered by studying light and particles of matter that come from objects in space
- Moves through space under the influence of gravity

This chapter introduces you to these concepts (and more).

Astronomy: The Science of Observation

Astronomy is the study of the sky, the science of cosmic objects and celestial happenings, and the investigation of the nature of the universe we live in. Professional astronomers carry out the business of astronomy by observing with telescopes that capture visible light from the stars or by tuning in to radio waves that come from space. They use backyard telescopes, huge observatory instruments, and satellites that orbit Earth collecting forms of light (such as ultraviolet radiation) that the atmosphere blocks from reaching the ground. They send up telescopes in sounding rockets (equipped with instruments for making high-altitude scientific observations) and on unmanned balloons. And they send some instruments into the solar system aboard deep-space probes.

Astronomers also use telescopes positioned in certain regions about 1 million miles from Earth, including the James Webb Space Telescope and the Solar and Heliospheric Observatory.

Professional astronomers study the Sun and the solar system, the Milky Way, and the universe beyond. They teach in universities, design satellites in government labs, and operate planetariums. They also write books (like us, your personal cosmic tour guides). Most have completed years of schooling to earn PhDs. Many study advanced physics, work with automated, robotic telescopes, or use supercomputers to simulate the history of the universe. They may never have studied the *constellations* (star patterns, such as Ursa Major, the Great Bear, named by ancient stargazers) that amateur or hobbyist astronomers first explore.

You may already be familiar with the Big Dipper, an asterism in Ursa Major. An *asterism* is a named star pattern that's not identical to one of the 88 recognized constellations. An asterism may be wholly within a single constellation or may include stars from more than one constellation. For example, the four corners of the Great Square of Pegasus, a large asterism, are marked by three stars of the constellation Pegasus and a fourth from Andromeda. Figure 1-1 shows the Big Dipper in the night sky. (In the United Kingdom, some people call the Big Dipper the Plough.)

FIGURE 1-1: The Big Dipper, one of the most familiar asterisms (star patterns) in the night sky, comprises the brightest stars in the constellation Ursa Major, the Great Bear.

Courtesy of Richard Tresch Fienberg

Amateur astronomers, who vastly outnumber professionals, usually know the constellations and use them as guideposts when exploring the sky by eye, with binoculars, and with telescopes. Many amateurs also make useful scientific contributions. They monitor the changing brightness of variable stars; discover asteroids, comets, and exploding stars; and crisscross Earth to enjoy total eclipses of the Sun or catch the shadows cast as asteroids pass in front of bright stars (thereby helping astronomers map the asteroids' shapes). They even join in professional research efforts with their home computers and smartphones (or with telescopes) through Citizen Science projects, which we describe in Chapter 2 and elsewhere throughout the book.

Many amateur astronomers do educational outreach in their communities, explaining astronomy to school groups and public gatherings.

In this and the next two chapters, we provide you with information on how to observe the skies effectively and enjoyably.

What You See: The Language of Light

Light brings us information about the planets, moons, and comets in our solar system; the stars, star clusters, and nebulas in our galaxy; and the objects beyond.

In ancient times, skygazers didn't think about the physics and chemistry of the stars; they absorbed and passed down folk tales and myths: the Great Bear, the Demon star, the Man in the Moon, the dragon eating the Sun during a solar eclipse, and more. The tales varied from culture to culture. But many people did discover the patterns of the stars. In Polynesia, skilled navigators sailed across hundreds of miles of open ocean with no landmarks in view, no compass, and certainly no GPS. They navigated by the stars, the Sun, and their knowledge of prevailing winds and currents.

Gazing at the light from a star, the ancients noted its brightness, position in the sky, and color. This information helps people distinguish one sky object from another, and the ancients got to know them like old friends. Now you can, too. Some basics of recognizing and describing what you see in the sky are

- Distinguishing planets from stars
- Identifying constellations, individual stars, and other sky objects by name
- Observing brightness (measured in *magnitudes*)
- Understanding the concept of a light-year
- Charting sky positions (measured in special units called *RA* and *Dec*)

They wondered as they wandered: Understanding planets versus stars

The term *planet* comes from the ancient Greek word *planetes*, meaning "wanderer." The Greeks (and other ancient people) noticed that five spots of light move with respect to the stars in the sky. Sometimes they go steadily in one direction; at other times they loop back on their own paths. Nobody knew why. And these spots of light don't twinkle like stars do; no one understood that difference, either. Every culture had a name for those five spots of light — what we now call planets. Their English names are Mercury, Venus, Mars, Jupiter, and Saturn. These celestial bodies aren't wandering among the stars; they orbit around the Sun, our solar system's central star.

Today astronomers know that planets can be smaller or bigger than Earth, but they all are much smaller than the Sun. The planets in our solar system are so close to Earth that they have perceptible disks — at least, when viewed through a telescope — so we can see their shapes and sizes. The stars are so far away that even if you view them through a powerful telescope, they show up only as points of light. (For more about the planets in the solar system, flip to Part 2. We cover the planets of stars beyond the Sun in Chapter 14.)

The essential physical difference between stars and planets is that stars are made of gas all the way through and shine by their own light, whereas planets have rock and perhaps ice inside and shine by reflecting light from their host star (in our solar system, that's the Sun). You can read about the planets of our solar system in Chapters 6, 8, and 9; about the Sun in Chapter 10; about other stars in Chapter 11; and about planets around other stars (*exoplanets*) in Chapter 14.

So, why *do* the planets in our solar system sometimes appear to change direction in the sky as they wander across the starry background? They orbit the Sun in concentric circles (actually in slightly out-of-round ellipses), like the lanes of a running track, going counterclockwise if we treat north as "up." Here on Earth, we're in lane 3; Mercury and Venus run in lanes 1 and 2, whereas Mars, Jupiter, and Saturn scoot along in lanes 4, 5, and 6. Unlike the runners on a track, any of whom might win the race, in the solar system the planets closer to the Sun always orbit faster than the ones farther out, because they're pulled harder by the Sun's gravity (as we explain later in this chapter).

Now, imagine running a race in which the fastest competitor is in lane 1, you're in lane 3, and the slowest runner is in lane 6. If you look at faster runners (analogous to inner planets) as they lap you, or at slower runners (outer planets) as you lap them, they appear to move from your left to your right. But if you look at them when they're on the opposite side of the track (or Sun) from you, they appear to go from right to left as seen against the bleachers in the background (analogous to the stars). Their apparent change of direction is simply a consequence of your changing perspective as everybody runs around the track at different speeds. To see this in action, play around with the University of New Mexico's online simulator at `physics.unm.edu/Courses/Rand/applets/retrograde.html`.

And why *don't* planets twinkle like stars? Twinkling arises from atmospheric turbulence, which causes rays of light from space to zigzag slightly as they make their way to Earth's surface. The zigs and zags are minuscule, but since stars appear to us as mere points, those tiny diversions cause rapid, erratic variations in a star's apparent position, which we perceive as twinkling. Even though we can't see planets' disks without a telescope, those disks are bigger than the distortions caused by air turbulence. So the zigs and zags of light rays coming from different parts of the disk overlap and cancel each other, and a planet appears to shine steadily.

If you see a Great Bear, start worrying: Naming stars and constellations

We used to tell planetarium audiences who craned their necks to look at stars projected above them, "If you can't see a Great Bear up there, don't worry. Maybe those who *do* see a Great Bear should worry."

Ancient astronomers divided the sky into imaginary figures, such as Ursa Major (Latin for "Great Bear"); Cygnus, the Swan; Andromeda, the Chained Lady; and Perseus, the Hero. The ancients identified each figure with a pattern of stars. The truth is, to most people, Andromeda doesn't look much like a chained lady at all (see Figure 1-2).

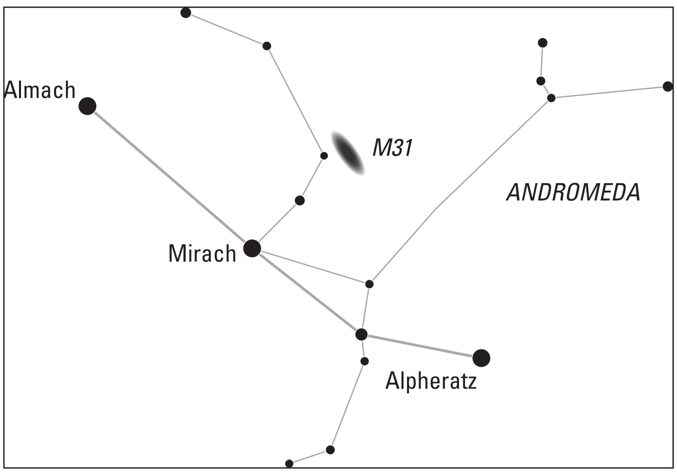

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FIGURE 1-2: It takes some imagination to see the constellation Andromeda, the Chained Lady, as a chained lady. The oval marks the position of the Andromeda galaxy (see page 22 and Chapter 12).

Today astronomers have divided the sky into 88 constellations, which contain all the stars you can see. The International Astronomical Union, which governs the science, set boundaries for the constellations so astronomers can agree on which star is in which constellation. Previously, sky maps drawn by different astronomers often disagreed. Now when you read that the Tarantula nebula is in Dorado (see Chapter 12), you know that, to see this nebula, you must seek it in the Southern Hemisphere constellation Dorado, the Goldfish.

The largest constellation is Hydra, the Water Snake. The smallest is Crux, the Cross, which most people call the Southern Cross. You can see a Northern Cross, too, but you can't find it in a list of constellations; it's an asterism within Cygnus, the Swan. Although astronomers generally agree on the names of the constellations, they don't have a consensus on what each name means. For example, some astronomers call Dorado the Swordfish, but we'd like to skewer that name. One constellation, Serpens, the Serpent, is broken into two sections that aren't connected. The two sections, located on either side of Ophiuchus, the Serpent Bearer, are Serpens Caput (the Serpent's Head) and Serpens Cauda (the Serpent's Tail).

The individual stars in a constellation often have no relation to each other except for their proximity in the sky as visible from Earth. In space, the stars that make up a constellation may be completely unrelated to one another, with some located relatively near Earth and others located at much greater distances in space. But they make a simple pattern for observers on Earth to enjoy.

The brighter stars in a constellation were assigned Greek letters by German astronomer Johann Bayer, who included them in his *Uranometria* star atlas in 1603. In each constellation, the brightest star was (usually) labeled alpha, the first letter of the Greek alphabet. The next brightest star was beta, the second Greek letter, and so on down to omega, the final letter of the 24-character Greek alphabet. (The astronomers used only lowercase Greek letters, so you see them written as α, β, . . . ω.)

So Sirius, the brightest star in the night sky — in Canis Major, the Great Dog — is called Alpha Canis Majoris. (Astronomers traditionally add a suffix to put star names in the Latin genitive case.) Table 1-1 shows the lowercase Greek alphabet, in order, with the names of the letters and their corresponding symbols. (You can see star names with their Latin genitive suffixes in the fourth column of Table 1-2.)

TIP

When you look at a star atlas, you discover that the individual stars in a constellation aren't marked α Canis Majoris, β Canis Majoris, and so on. Usually, the creator of the atlas marks the area of the whole constellation as Canis Major and labels the individual stars α, β, and so on. When you read about a star in a list of objects to observe, say, in an astronomy magazine (see Chapter 2), you probably won't see it listed in the style of Alpha Canis Majoris or even α Canis Majoris. Instead, to save space, the magazine prints it as α CMa; *CMa* is the three-letter abbreviation for Canis Majoris (and also the abbreviation for Canis Major). We give the abbreviation for each of the constellations in Table 1-2.

TABLE 1-1

The Greek Alphabet

Letter	Name
α	Alpha
β	Beta
γ	Gamma
δ	Delta
ε	Epsilon
ζ	Zeta
η	Eta
θ	Theta
ι	Iota
κ	Kappa
λ	Lambda
μ	Mu
ν	Nu
ξ	Xi
ο	Omicron
π	Pi
ρ	Rho
σ	Sigma
τ	Tau
υ	Upsilon
φ	Phi
χ	Chi
ψ	Psi
ω	Omega

TABLE 1-2 The Constellations and Their Brightest Stars

Name	Abbreviation	Meaning	Brightest Star	Magnitude
Andromeda	And	Chained Lady	Alpheratz	2.1
Antlia	Ant	Air Pump	Alpha Antliae	4.3
Apus	Aps	Bird of Paradise	Alpha Apodis	3.8
Aquarius	Aqr	Water Bearer	Sadalsuud (Beta Aquarii)	2.9
Aquila	Aql	Eagle	Altair	0.8
Ara	Ara	Altar	Beta Arae	2.9
Aries	Ari	Ram	Hamal	2.0
Auriga	Aur	Charioteer	Capella	0.1
Boötes	Boo	Herdsman	Arcturus	0.0
Caelum	Cae	Chisel	Alpha Caeli	4.5
Camelopardalis	Cam	Giraffe	Beta Camelopardalis	4.0
Cancer	Cnc	Crab	Tarf (Beta Cancri)	3.5
Canes Venatici	CVn	Hunting Dogs	Cor Caroli	2.9
Canis Major	CMa	Great Dog	Sirius	–1.5
Canis Minor	CMi	Little Dog	Procyon	0.4
Capricornus	Cap	Sea Goat	Deneb Algedi (Delta Capricorni)	2.9
Carina	Car	Ship's Keel	Canopus	–0.7
Cassiopeia	Cas	Queen	Schedar	2.2
Centaurus	Cen	Centaur	Rigil Kentaurus	0.0
Cepheus	Cep	King	Alderamin	2.4
Cetus	Cet	Whale	Diphda (Beta Ceti)	2.0
Chamaeleon	Cha	Chameleon	Alpha Chamaeleontis	4.1
Circinus	Cir	Compasses	Alpha Circini	3.2
Columba	Col	Dove	Phact	2.6
Coma Berenices	Com	Berenice's Hair	Beta Comae Berenices	4.3
Corona Australis	CrA	Southern Crown	Meridiana	4.1
Corona Borealis	CrB	Northern Crown	Alphecca	2.2

(continued)

TABLE 1-2 ***(continued)***

Name	Abbreviation	Meaning	Brightest Star	Magnitude
Corvus	Crv	Crow	Gienah (Gamma Corvi)	2.6
Crater	Crt	Cup	Delta Crateris	3.6
Crux	Cru	(Southern) Cross	Acrux	0.8
Cygnus	Cyg	Swan	Deneb	1.3
Delphinus	Del	Dolphin	Rotanev (Beta Delphini)	3.6
Dorado	Dor	Goldfish	Alpha Doradus	3.3
Draco	Dra	Dragon	Eltanin (Gamma Draconis)	2.2
Equuleus	Equ	Little Horse	Kitalpha	3.9
Eridanus	Eri	River	Achernar	0.5
Fornax	For	Furnace	Dalim	3.9
Gemini	Gem	Twins	Pollux (Beta Geminorum)	1.1
Grus	Gru	Crane	Alnair	1.7
Hercules	Her	Hercules	Kornephoros (Beta Herculis)	2.8
Horologium	Hor	Clock	Alpha Horologii	3.9
Hydra	Hya	Water Snake	Alphard	2.0
Hydrus	Hyi	Little Water Snake	Beta Hydri	2.8
Indus	Ind	Indian	Alpha Indi	3.1
Lacerta	Lac	Lizard	Alpha Lacertae	3.8
Leo	Leo	Lion	Regulus	1.4
Leo Minor	LMi	Little Lion	Praecipua (46 Leonis Minoris)	3.8
Lepus	Lep	Hare	Arneb	2.6
Libra	Lib	Scales	Zubeneschamali (Beta Librae)	2.6
Lupus	Lup	Wolf	Alpha Lupi	2.3
Lynx	Lyn	Lynx	Alpha Lyncis	3.1
Lyra	Lyr	Lyre	Vega	0.0
Mensa	Men	Table	Alpha Mensae	5.1
Microscopium	Mic	Microscope	Gamma Microscopii	4.7
Monoceros	Mon	Unicorn	Beta Monocerotis	3.7

Name	Abbreviation	Meaning	Brightest Star	Magnitude
Musca	Mus	Fly	Alpha Muscae	2.7
Norma	Nor	Level and Square	Gamma Normae	4.0
Octans	Oct	Octant	Nu Octantis	3.8
Ophiuchus	Oph	Serpent Bearer	Rasalhague	2.1
Orion	Ori	Hunter	Rigel (Beta Orionis)	0.1
Pavo	Pav	Peacock	Peacock	1.9
Pegasus	Peg	Winged Horse	Enif (Epsilon Pegasi)	2.4
Perseus	Per	Hero	Mirfak	1.8
Phoenix	Phe	Phoenix	Ankaa	2.4
Pictor	Pic	Easel	Alpha Pictoris	3.2
Pisces	Psc	Fishes	Kullat Nunu (Eta Piscium)	3.6
Pisces Austrinus	PsA	Southern Fish	Fomalhaut	1.2
Puppis	Pup	Ship's Stern	Naos (Zeta Puppis)	2.3
Pyxis	Pyx	Compass	Alpha Pyxidis	3.7
Reticulum	Ret	Reticle	Alpha Reticuli	3.4
Sagitta	Sge	Arrow	Gamma Sagittae	3.5
Sagittarius	Sgr	Archer	Kaus Australis (Epsilon Sagittarii)	1.9
Scorpius	Sco	Scorpion	Antares	1.0
Sculptor	Scl	Sculptor	Alpha Sculptoris	4.3
Scutum	Sct	Shield	Alpha Scuti	3.9
Serpens	Ser	Serpent	Unukalhai	2.7
Sextans	Sex	Sextant	Alpha Sextantis	4.5
Taurus	Tau	Bull	Aldebaran	0.9
Telescopium	Tel	Telescope	Alpha Telescopii	3.5
Triangulum	Tri	Triangle	Beta Trianguli	3.0
Triangulum Australe	TrA	Southern Triangle	Atria	1.9
Tucana	Tuc	Toucan	Alpha Tucanae	2.9

(continued)

TABLE 1-2 ***(continued)***

Name	Abbreviation	Meaning	Brightest Star	Magnitude
Ursa Major	UMa	Great Bear	Alioth (Epsilon Ursae Majoris)	1.8
Ursa Minor	UMi	Little Bear	Polaris	2.0
Vela	Vel	Sails	Suhail al Muhlif (Gamma Velorum)	1.8
Virgo	Vir	Virgin	Spica	1.0
Volans	Vol	Flying Fish	Gamma Volantis	3.8
Vulpecula	Vul	Fox	Anser	4.4

Astronomers didn't coin special names such as Sirius for every star in Canis Major, so they named them with Greek letters or other symbols. In fact, some constellations don't have a single named star. (Don't fall for those advertisements that offer to name a star for a fee. The International Astronomical Union doesn't recognize purchased star names.) In other constellations, astronomers assigned Greek letters, but they could see more stars than the 24 Greek letters. Therefore, astronomers gave some stars Arabic numbers or letters from the Roman alphabet, or numbers in professional catalogs. So you see star names such as 61 Cygni, b Vulpeculae, HR 1516, and even RU Lupi. (We're not making this up.) But as with any other stars, you can recognize them by their positions in the sky (as tabulated in star catalogs), their brightness, their color, or other properties, if not their names.

When you look at the constellations today, you see many exceptions to the rule that the Greek-letter star names correspond to the respective brightness of the stars in a constellation. The exceptions exist because

- The letter names were based on inaccurate naked-eye observations of brightness.
- Over the centuries, star atlas authors changed constellation boundaries, moving some stars from one constellation into another that included previously named stars.
- Some astronomers mapped out small and Southern Hemisphere constellations long after the Greek period, and they didn't always follow the lettering practice.
- The brightness of some stars has changed over the centuries since the ancient Greeks charted them.

A good (or bad) example is the constellation Vulpecula, the Fox, in which only one of the stars (alpha) has a Greek letter.

Because alpha isn't always the brightest star in a constellation, astronomers needed another term to describe that exalted status, and *lucida* is the word (from the Latin word *lucidus,* meaning "bright" or "shining"). The lucida of Canis Major is Sirius, the alpha star, but the lucida of Orion, the Hunter, is Rigel, which is Beta Orionis. The lucida of Leo Minor, the Little Lion (a particularly inconspicuous constellation), is Praecipua, or 46 Leonis Minoris.

Table 1-2 lists the 88 constellations, the brightest star in each, and the magnitude of that star. *Magnitude* is a measure of a star's brightness. (We talk about magnitudes in the later section "The smaller, the brighter: Getting to the root of magnitudes.") When the lucida of a constellation also is the alpha star and has a name, we list only the name. For example, in Auriga, the Charioteer, the brightest star (Alpha Aurigae) is Capella. But when the lucida isn't an alpha, we give its Greek letter or other designation in parentheses. Thus, the lucida of Cancer, the Crab, is Tarf, also known as Beta Cancri.

TIP

Some star names that you see in Table 1-2 may differ from those in other books that might not be up to date. In 2016, the International Astronomical Union issued a list of official names for bright stars, and they've approved more names since then. Eight stars in Table 1-2 have been affected, with minor changes in spelling or a whole new name. In one case, a star was named after its constellation: Alpha Pavonis, in Pavo the Peacock, was itself named Peacock.

Identifying stars would be much easier if they had little name tags that you could see through your telescope. If you have a smartphone, you can download an app to identify the stars for you. Just download a sky map or planetarium app (such as we recommend in Chapter 2) and aim the phone toward the sky. The app generates a map of the constellations in the general direction your phone is facing. With some apps, when you touch the image of a star, its name appears. (We describe the various types of stars, their "life cycles," physical properties, and more in Chapter 11.)

The smaller, the brighter: Getting to the root of magnitudes

A star map, constellation drawing, or list of stars almost always indicates each star's magnitude. The *magnitudes* represent the brightness of the stars. One of the ancient Greeks, Hipparchos (also spelled Hipparchus, but he wrote it in Greek), divided all the stars he could see into six classes. He called the brightest stars magnitude 1 or *1st magnitude,* the next brightest bunch the *2nd magnitude* stars, and on down to the dimmest ones, which were *6th magnitude.*

Notice that, contrary to most common measurement scales and units, the brighter the star, the smaller the magnitude. The Greeks weren't perfect, however; even Hipparchos had an Achilles' heel: He didn't leave room in his system for the very brightest stars, when accurately measured.

So today we recognize a few stars with a zero magnitude or a negative magnitude. Sirius, for example, is magnitude −1.5. And the brightest planet, Venus, is sometimes magnitude −4 (the exact value differs, depending on the distance Venus is from Earth at the time and its direction with respect to the Sun).

Another omission: Hipparchos didn't have a magnitude class for stars that were too dim to be seen with the naked eye. This didn't seem like an oversight at the time because nobody knew about these stars before the invention of the telescope. But today astronomers know that billions of stars exist beyond our naked-eye view. Their magnitudes are larger numbers: 7 or 8 for stars easily seen through binoculars, and 10 or 11 for stars easily seen through a small telescope. The magnitudes reach as high (and as dim) as 21 for the faintest stars in the Palomar Observatory Sky Survey, about 31 for the Hubble Space Telescope, and even fainter for the James Webb Space Telescope.

What do I spy? Spotting the Messier Catalog and other sky objects

Naming stars was easy enough for astronomers. But what about all those other objects in the night sky — galaxies, nebulas, star clusters, and the like (which we cover in Chapters 11 to 13)? Charles Messier (1730–1817), a French astronomer, created a numbered list of about 100 fuzzy sky objects. His list is known as the *Messier Catalog,* and now when you hear the Andromeda galaxy called by its scientific name, M31, you know that it stands for number 31 in that catalog. Today 110 objects make up the standard Messier Catalog. It's a neat list.

TIP

You can find pictures and a complete list of the Messier objects at the Messier Catalog website of Students for the Exploration and Development of Space at `messier.seds.org`. And you can find out how to earn a certificate for viewing Messier objects from the Astronomical League Messier Program website at `www.astroleague.org/al/obsclubs/messier/mess.html`.

Experienced amateur astronomers often engage in Messier marathons, in which each person tries to observe every object in the Messier Catalog during a single long night (which is possible only in March at northern temperate latitudes). But in a marathon, you don't have time to enjoy an individual nebula, star cluster, or galaxy. Our advice is to take it slow and savor their individual visual delights. A wonderful book on the Messier objects, which includes hints on how to observe each object, is Stephen James O'Meara's *Deep-Sky Companions: The Messier Objects*, 2nd Edition (Cambridge University Press).

Since Messier's time, astronomers have confirmed the existence of thousands of other *deep sky objects*, the term amateurs use for star clusters, nebulas, and galaxies to distinguish them from stars and planets. Because Messier didn't list them, astronomers refer to these objects by their numbers as given in other catalogues. You can find many of these objects listed in viewing guides and sky maps by their NGC *(New General Catalogue)* and IC *(Index Catalogue)* numbers. For example, the bright double cluster in Perseus, the Hero, consists of NGC 869 and NGC 884. The NGC is more than 130 years old, but it was new when they named it.

BY THE NUMBERS: THE MATHEMATICS OF BRIGHTNESS

The 1st magnitude stars are about 100 times brighter than the 6th magnitude stars. In particular, the 1st magnitude stars are about 2.512 times brighter than the 2nd magnitude stars, which are about 2.512 times brighter than the 3rd magnitude stars, and so on. You mathematicians out there will recognize this as a *geometric progression.* Each magnitude is the 5th root of 100 (meaning that when you multiply a number by itself four times — for example, $2.512 \times 2.512 \times 2.512 \times 2.512 \times 2.512$ — the result is 100). If you doubt our word and do this calculation on your own, you'll get a slightly different answer because we left off some decimal places.

Thus, you can calculate how faint a star is — compared to some other star — from its magnitude. If two stars are 5 magnitudes apart (such as the 1st magnitude star and the 6th magnitude star), they differ by a factor of 2.512^5 (2.512 to the fifth power), and a good pocket calculator shows you that one star is 100 times brighter. If two stars are 6 magnitudes apart, one is about 250 times brighter than the other. And if you want to compare, say, a 1st magnitude star with an 11th magnitude star, you compute a 2.512^{10} difference in brightness, meaning a factor of 100^2, or 10,000.

The faintest object visible with the Hubble Space Telescope is about 25 magnitudes fainter than the faintest star you can see with the naked eye (assuming normal vision and viewing skills — some experts and a certain number of liars and braggarts say that they can see 7th magnitude stars). Speaking of dim stars, 25 magnitudes are 5 times 5 magnitudes, which corresponds to a brightness difference of a factor of 100^5. So the Hubble can see $100 \times 100 \times 100 \times 100 \times 100$, or 10 billion times fainter than the human eye. The James Webb Space Telescope can see even fainter.

The Hubble and Webb telescopes cost billions of dollars. But you can get a good telescope for well under $1,000, as we explain in Chapter 3.

Looking back on light-years

The distances to the stars and other objects beyond the planets of our solar system are measured in *light-years.* As a measurement of actual length, a light-year is about 5.9 trillion miles long.

People confuse a light-year with a length of time because the term contains the word *year.* But a light-year is really a *distance* measurement — the length that light travels, zipping through space at 186,000 miles per second, over the course of a year.

When you view an object in space, you see it as it appeared when the light left the object. Consider these examples:

- When astronomers spot an explosion on the Sun, we don't see it in real time; the light from the explosion takes about 8 minutes to get to Earth.
- The nearest star beyond the Sun, Proxima Centauri, is about 4 light-years away. Astronomers can't see Proxima as it is now — only as it was four years ago.
- Look up at the Andromeda galaxy, the most distant object that you can readily see with the unaided eye, on a clear, dark night in the fall. The light your eye receives left that galaxy about 2.5 million years ago. If there was a big change in Andromeda tomorrow, we wouldn't know that it happened for more than 2 million years. (See Chapter 12 for hints on viewing the Andromeda galaxy and other prominent galaxies.)

Here's the bottom line:

- When you look out into space, you're looking back in time.
- Astronomers don't have a way to know exactly what an object out in space looks like right now.

When you look at some big, bright stars in a faraway galaxy, you must entertain the possibility that those particular stars don't even exist anymore. As we explain in Chapter 11, some massive stars live for only 10 million or 20 million years. If you see them in a galaxy that is 50 million light-years away, you're looking at lame duck stars. They aren't shining in that galaxy anymore; they're now dead.

If astronomers were to send a flash of light toward one of the very distant galaxies found with the Hubble, Webb, or other major telescopes, the light would take billions of years to arrive. Astronomers, however, calculate that the Sun will swell up and destroy all life on Earth a few billion years from now, so the light would be a futile advertisement of our civilization's existence — a flash in the celestial pan.

HEY, YOU! NO, NO, I MEAN AU

Earth is about 93 million miles from the Sun, or 1 *astronomical unit* (AU). The distances between objects in the solar system are usually given in AU. Its plural is also AU. (Don't confuse AU with "Hey, you!")

In public announcements, press releases, and popular books, astronomers often state how far the stars and galaxies that they study are "from Earth." But among themselves and in technical journals, they always give the distances from the Sun, the center of our solar system. This discrepancy rarely matters because astronomers can't measure the distances of the stars precisely enough for 1 AU more or less to make a difference, but they do it this way for consistency.

Keep on moving: Figuring the positions of the stars

Astronomers used to call stars "fixed stars," to distinguish them from the wandering planets. But in fact, stars are in constant motion as well, both real and apparent. The whole sky rotates overhead because Earth is turning. The stars rise and set, like the Sun and the Moon, but they stay in formation. The stars that make up the Great Bear don't swing over to the Little Dog or Aquarius, the Water Bearer. Different constellations rise at different times and on different dates, as seen from different places around the globe.

Actually, the stars in Ursa Major (and every other constellation) do move with respect to one another — and at breathtaking speeds, measured in hundreds of miles per second. But those stars are so far away that scientists need precise measurements to detect their motions across the sky. Those observations tell us that 20,000 years from now, the stars in Ursa Major will form a different pattern in the sky. (Maybe they will even look like a Great Bear.)

In the meantime, astronomers have measured the positions of billions of stars, and many of them are tabulated in catalogs and marked on star maps. The positions are listed in a system called *right ascension* and *declination* — known to all astronomers, amateur and pro, as *RA* and *Dec:*

- RA is the position of a star measured in the east–west direction on the sky (like longitude, which is the position of a place on Earth measured east or west of the prime meridian at Greenwich, England).

- Dec is the position of the star measured in the north–south direction, like the latitude of a city, which is measured north or south of the equator. Dec is measured north or south of the celestial equator (see Figure 1-3).

Astronomers usually list RA in units of hours, minutes, and seconds, like time. We list Dec in degrees, minutes, and seconds of arc. Ninety degrees make up a right angle, 60 minutes of arc make up a degree, and 60 seconds of arc equal a minute of arc. A minute or second of arc is also often called an "arc minute" or an "arc second," respectively.

REMEMBER

A few simple rules may help you remember how RA and Dec work and how to read a star map (see Figure 1-3):

- The North Celestial Pole (NCP) is the place to which the axis of Earth points in the north direction. If you stand at the geographic North Pole, the NCP is right overhead. (If you stand there, say "Hi" to Santa from us, but beware: You may be on thin ice because there's no land at the geographic North Pole.)
- The South Celestial Pole (SCP) is the place to which the axis of Earth points in the south direction. If you stand at the geographic South Pole, the SCP is right overhead. We hope you dressed warmly: You're in Antarctica!
- The imaginary lines of RA run through the NCP and SCP as semicircles centered on the center of Earth. They may be imaginary, but they appear marked on most sky maps to help people find the stars at particular RAs.
- The imaginary lines of Dec, like the line in the sky that marks Dec of 30° north, pass overhead at the corresponding geographic latitudes. So if you stand in New York City, latitude 41° north, the point overhead is always at Dec 41° north (astronomers write it as +41°), although its RA changes constantly as Earth turns. These imaginary lines appear on star maps, too, as *declination circles.* If you live in Cape Town, South Africa, latitude 33.9 degrees south, the point overhead is written as Dec –33.9°.

Suppose you want to find the NCP as visible from your backyard. Face due north and look at an altitude of x degrees, where x is your geographic latitude. We're assuming that you live in North America, Europe, or somewhere in the Northern Hemisphere. If you live in the Southern Hemisphere, you can't see the NCP. You can, however, look for the SCP. Look for the spot due south whose altitude in the sky, measured in degrees above the horizon, is equal to your geographic latitude.

In almost every astronomy book, the symbol ″ means seconds of arc, not inches. But there's often one student in an astronomy class who misses that definition and writes about a sky measurement "in inches."

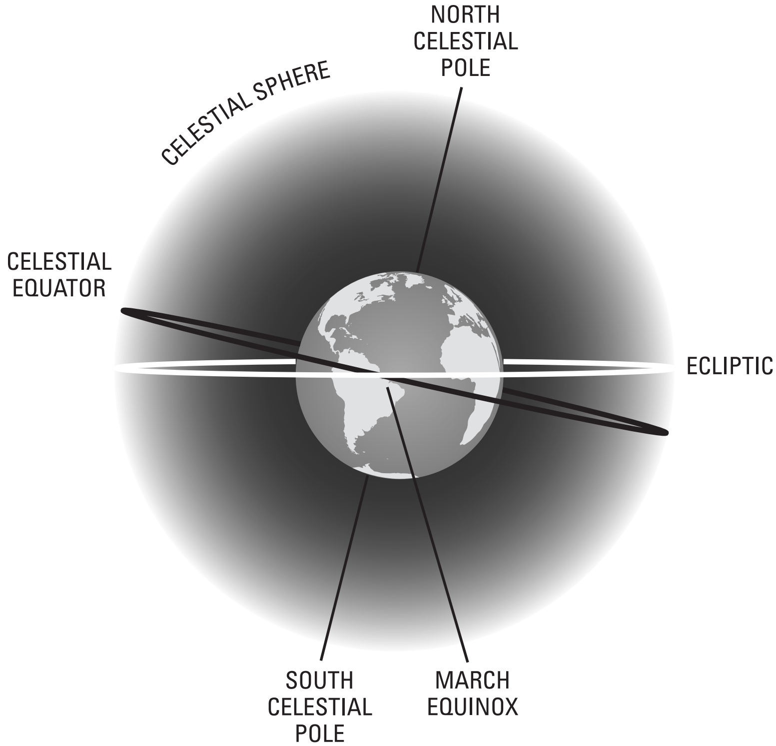

FIGURE 1-3: Decoding the celestial sphere to find directions in space. The celestial equator is Earth's equator projected onto the sky. The Sun, Moon, and planets always hug the ecliptic (see Chapter 3). On the March equinox, the Sun appears to cross the celestial equator heading north.

Here's the good news: If you just want to spot the constellations and the planets, you don't have to know how to use RA and Dec. Just consult a star map drawn for the current week or month (you can find these on the website of *Sky & Telescope* or one of the other magazines that we mention in Chapter 2, in the magazines themselves, or using a desktop planetarium program for your home computer or a planetarium app for your smartphone or tablet; we recommend programs, websites, and apps in Chapter 2 as well). But if you want to learn how star catalogs and maps work and how to zero in on faint galaxies with your telescope, understanding the system helps.

And if you purchase one of those snazzy and surprisingly affordable telescopes with computer control (see Chapter 3), you can punch in the RA and Dec of a recently discovered comet, and the scope points right at it. (A little table called an *ephemeris* comes with every announcement of a new comet. It gives the predicted RA and Dec of the comet on successive nights as it sweeps across the sky.)

Gravity: A Force to Be Reckoned With

Ever since the work of Sir Isaac Newton, the English scientist (1642–1727), everything in astronomy has revolved around gravity. Newton explained gravity as a force between any two objects. The force depends on mass and separation. The more massive the object, the more powerful its pull. The greater the distance, the weaker the gravitational attraction. Newton sure was a smart cookie!

Albert Einstein developed an improved theory of gravity, which passes experimental tests that Newton's theory flunks. Newton's theory was good enough for commonly experienced gravity, like the force that made an apple fall on his head (if one really did). But in other respects, Newton's theory was hit or miss. Einstein's theory is better because it predicts everything that Newton got right, but also predicts effects that happen close to massive objects, where gravity is very strong. Einstein didn't think of gravity as a force; he considered it the bending of space and time by the very presence of a massive object, such as a star. We get all bent out of shape just thinking about it.

Newton's concept of gravity explains the following:

- Why the Moon orbits Earth, why Earth orbits the Sun, why the Sun orbits the center of the Milky Way, and why many other objects orbit one object or another out there in space
- Why a star or a planet is round
- Why gas and dust in space may clump together to form new stars

Einstein's theory of gravity, called the general theory of relativity, explains everything that Newton's theory does plus the following:

- Why stars visible near the Sun during a total eclipse seem slightly out of position
- Why black holes exist
- Why gravitational lensing is found when we observe deep space
- Why Earth drags warped space and time around with it as it turns, an effect that scientists have verified with the help of satellites orbiting Earth
- How a collision of two black holes produces gravitational waves that shake things up even billions of light-years away

You find out about black holes in Chapters 11 and 13, and you can read up on gravitational lensing in Chapters 11, 14, and 15 without mastering the general theory of relativity.

You'll get smarter if you read every chapter in this book, but your friends won't call you Einstein unless you let your hair grow, parade around in a messy old sweater, and stick out your tongue when they take your picture. He did all that.

Space: A Commotion of Motion

Everything in space is moving and turning. Objects can't sit still. Thanks to gravity, other celestial bodies are always pulling on a star, planet, galaxy, or spacecraft. Some of us are self-centered, but the universe has no center.

For example, Earth

- Turns on its axis — what astronomers call *rotating* — and takes one day to turn all the way around.
- Orbits around the Sun — what astronomers call *revolving* — with one complete orbit taking one year.
- Travels with the Sun in a huge orbit around the center of the Milky Way. The trip takes about 226 million years to complete once, and the duration of the trip is called the *galactic year.*
- Moves with the Milky Way in a trajectory around the center of the *Local Group of galaxies,* consisting of about 80 (mostly small) galaxies in our neck of the universe.
- Moves through the universe with the Local Group as part of the *Hubble flow,* the general expansion of space caused by the *Big Bang.* The Big Bang is the event that gave rise to the universe and set space itself expanding at a furious rate. Detailed theories about the Big Bang explain many observed phenomena and have successfully predicted some that hadn't been observed before the theories were circulated. (For more about the Big Bang and other aspects of the universe, check out Chapter 16.)

Remember Ginger Rogers? She did everything Fred Astaire did when they danced in the movies, and she did it all backward and in heels. Like Ginger and Fred, the Moon follows all the motions of Earth (though not backward), except for Earth's rotation; the Moon rotates more slowly, about once a month. And it performs its tasks while also revolving around Earth (which it also does about once a month).

And you, as a person on Earth, participate in the motions of rotation, revolution, galactic orbiting, Local Group cruising, and cosmic expansion. You do all that while you walk, bicycle, drive, or take public transportation to work. Ask your boss for a little consideration the next time you arrive a few minutes late.