THE Stargazer's GUIDE TO THE Night Sky

Dr. Jason Lisle

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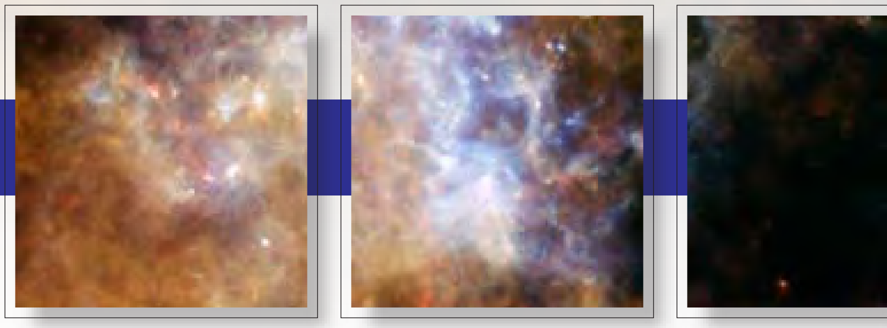
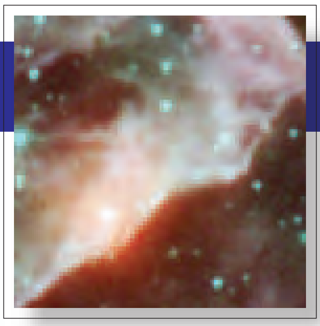
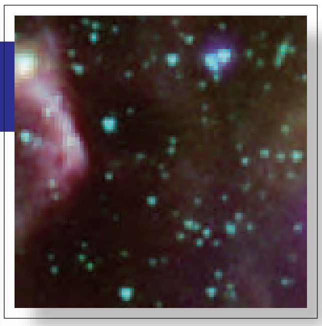
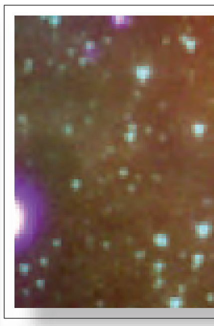


The heavens declare the glory of God; and the firmament sheweth his handywork.

—Psalm 19:1







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Introduction

There is something about the night sky that captures our imagination and evokes a sense of awe and wonder. And our appreciation of the magnificence of creation is enhanced as we learn more about the cosmos. As one example, the bright red star Betelgeuse is beautiful, whether you know anything about it or not. But when you consider that Betelgeuse is over 60,000 times the diameter of the Earth and lies at a distance of 3,000 trillion miles, somehow that just makes it all the more impressive.

We have all seen beautiful images of the universe obtained by professional astronomers. But what many people do not realize is that many of these celestial wonders are within the range of a small telescope. You just have to know where to look. In fact, there are many heavenly gems (such as star clusters) that look beautiful in binoculars. Even without any optical aid, there are countless celestial treasures that can be seen with the eye — if you know where and how to look for them.

This book is written for the person who has no experience in astronomy, but wants to learn how to best enjoy the night sky. If you have a small telescope, the star charts in this book will help you find the most spectacular celestial objects visible in such a telescope. If you are considering buying a small telescope at some point, this book will show you what things to consider. But even if you have no intention of ever owning a telescope, there are many cosmic wonders that can be seen by the unaided eye — or with low-power binoculars. And this book will show you how to find them. If you have ever looked up into the night sky and wanted to know more about what you are seeing, this book is for you.

I love astronomy. I always have. When I was very young, I would read all the astronomy books I could find. But what was really exciting to me was when I learned to find astronomical objects in a small telescope. My dad had a six-inch Newtonian reflector telescope — nothing fancy. But it is amazing what you can see with such a telescope, if you know the night sky. During the summer, when school was not in session, I could often be found outside on clear evenings, peering through that telescope. There is something very different about seeing an astronomical object with your own eyes. It just makes it so much more "real" than a textbook photograph. And it is this experience that I want to share with others.

I have worked at a number of observatories, and have led more telescope observing sessions than I can count. Through my education in astrophysics and through many years of experience, I have learned how to better enjoy the night sky. There are some simple tips and tricks that can make an observing session go from mediocre to spectacular. Whether you have a telescope, binoculars, or just your eyes, everyone can benefit from these guidelines.

This book is particularly helpful for observers in the Northern Hemisphere, especially those at mid-northern latitudes such as in the United States and Europe. However, Southern Hemisphere observers will still benefit from this book, and I have included several star charts for them as well. In fact, the general principles in chapters 1, 2, 3, 5, 6, 7, 9, and 12 apply equally well in either hemisphere. But the star charts in chapter 4, for example, apply mainly to the Northern Hemisphere (though they will still be somewhat useful for the Southern Hemisphere). This bias is due to the simple fact that I have lived entirely at mid-northern latitudes, and thus my experience is primarily with the portion of the sky visible from northern latitudes.

To maximize our enjoyment of the night sky, it is necessary to know how things move in the night sky. This is important so that we know when and where to look for a given target. To that end, chapter 1 is a basic introduction to celestial motions. Chapter 2 continues this theme with more advanced topics in celestial motions.

Stargazing is great for all ages!

The basics of celestial motions are not difficult at all, once you have a mental picture of how things move in space.

Chapter 3 is all about the human eye. By understanding how the eye works, it is possible to greatly enhance your views of stellar objects. Whether you are looking through a telescope or viewing something with the unaided eye, chapter 3 will have some very helpful tips.

Chapter 4 is all about what you can see with the unaided eye. If you have ever wanted to know the names of constellations or bright stars, the charts in this chapter will make that easy to do. The chapter is organized by the time of year in which the various objects are visible. So if you are observing in mid-summer, you can skip to that section of the chapter. Chapter 5 is about celestial events, such as eclipses and meteor showers. It will tell you when and where to watch for these things.

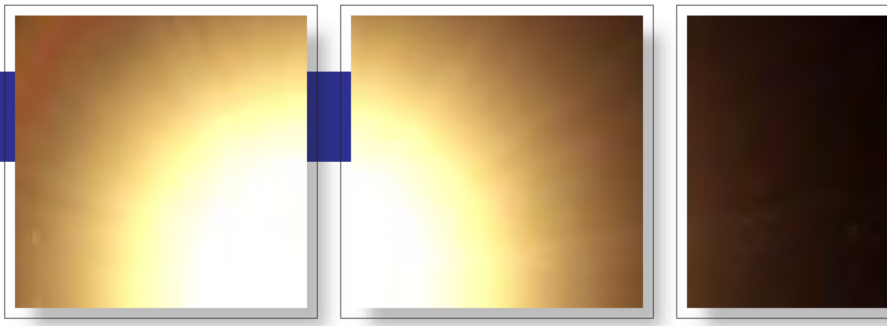
Chapter 6 is an introduction to telescopes. In it, we discuss the various types of telescopes and the advantages and disadvantages of each. This chapter will be particularly helpful for people who wish to purchase a small telescope. In chapter 7 we then discuss tips on setting up and using a telescope to get the most out of it.

Chapter 8 is about the two largest celestial objects: the moon and the sun. This will be a great chapter whether you view the moon by eye, with binoculars or with a small telescope. We also discuss how to safely view the sun. Chapter 10 is about stars — how they are classified and what to look for. Telescope users will find instructions on locating the best binary stars.

Chapters 9, 11, and 12 are particularly useful for people who have (or who are going to get) a small backyard telescope. (However, the information may be very interesting even to those who do not have a telescope). In these chapters we discuss how to get the best telescopic views of planets (chapter 9), and deep sky objects (chapter 11). Chapter 12 is for those who wish to take photos using their telescope.

It is my hope that this book will help readers to appreciate and enjoy the wonders of the night sky.

Chapter 1



Motions in the Sky—Basic

One of the most useful skills of the amateur astronomer involves a basic understanding of how things move in the sky. If you are going to really enjoy the night sky, it is important to know when various objects will be visible and where to look. So in this chapter we will explore the movement of celestial objects. We will answer questions like: Is Saturn visible this time of year? What constellations are visible at 10:00 tonight? What is the best time of night to see the constellation Orion? What phase will the moon be in next week? Why does the sun rise and set at different times during different seasons? When will the moon rise tonight? What is my current latitude? How do the stars change positions if I go from the Northern Hemisphere to the Southern? If the bright star Sirius is high in the sky directly in front of me, what direction am I facing?

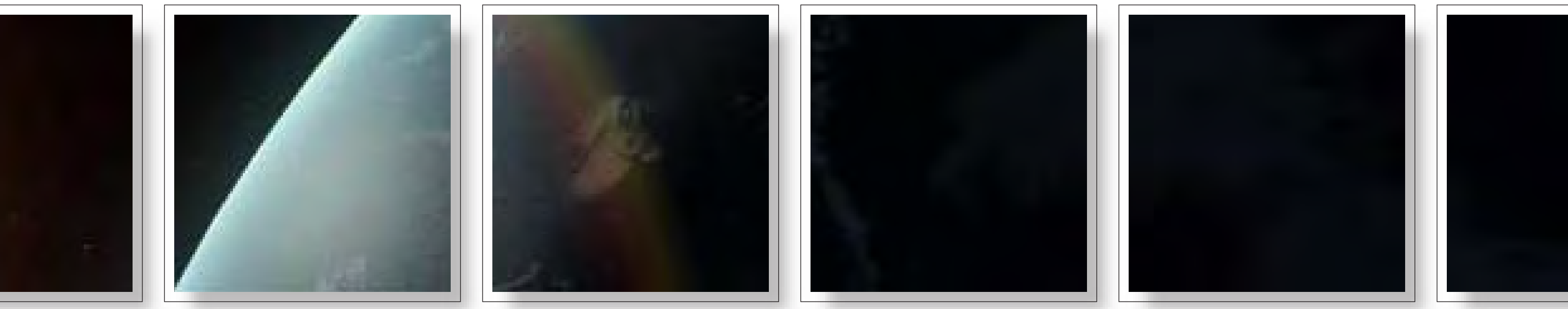
All these questions are easy to answer when a person has a basic knowledge of motions in the sky. In fact, these questions can easily be solved "in your head" without a calculator. All that is needed is a basic mental picture of how the Earth, moon, and planets move in relation to the sun and stars. (A little bit of practice helps, too.) We will examine how the spinning of the Earth on its axis and the motion of the Earth around the sun affect the apparent position of objects in our sky. We will also explore the motion of the moon and the planets.

Celestial motions are not only interesting, they are very practical. As long as the sky is clear, I always know what direction I'm facing because of the position of the sun or stars. It's a useful skill to have when driving to somewhere new, or going for a long hike. This directional awareness is second nature; I don't have to think about it. I can even tell the approximate time by the position of the sun, moon, or stars. And anyone can learn to do this. It's not hard at all.

When we understand celestial motions, it is very enjoyable to see the universe operate with the clockwork precision with which it was designed. It is fun to think, "Well, it's 7:00, so the moon should be low in the southwest right now" and then step outside and say, "Yes. Right where I expected." However, it is also very important to know about these motions if you want to look for something specific. If you want to look at Saturn tonight, you had better know when it is going to rise and set — or whether it's visible at all this time of year. Will your telescopic view of the Orion Nebula or your naked-eye view of the Milky Way be hampered by bright moonlight? You'd better know what phase the moon is in, and when it will rise and set.

◇Diurnal Motion

We begin by studying the most basic motion of objects



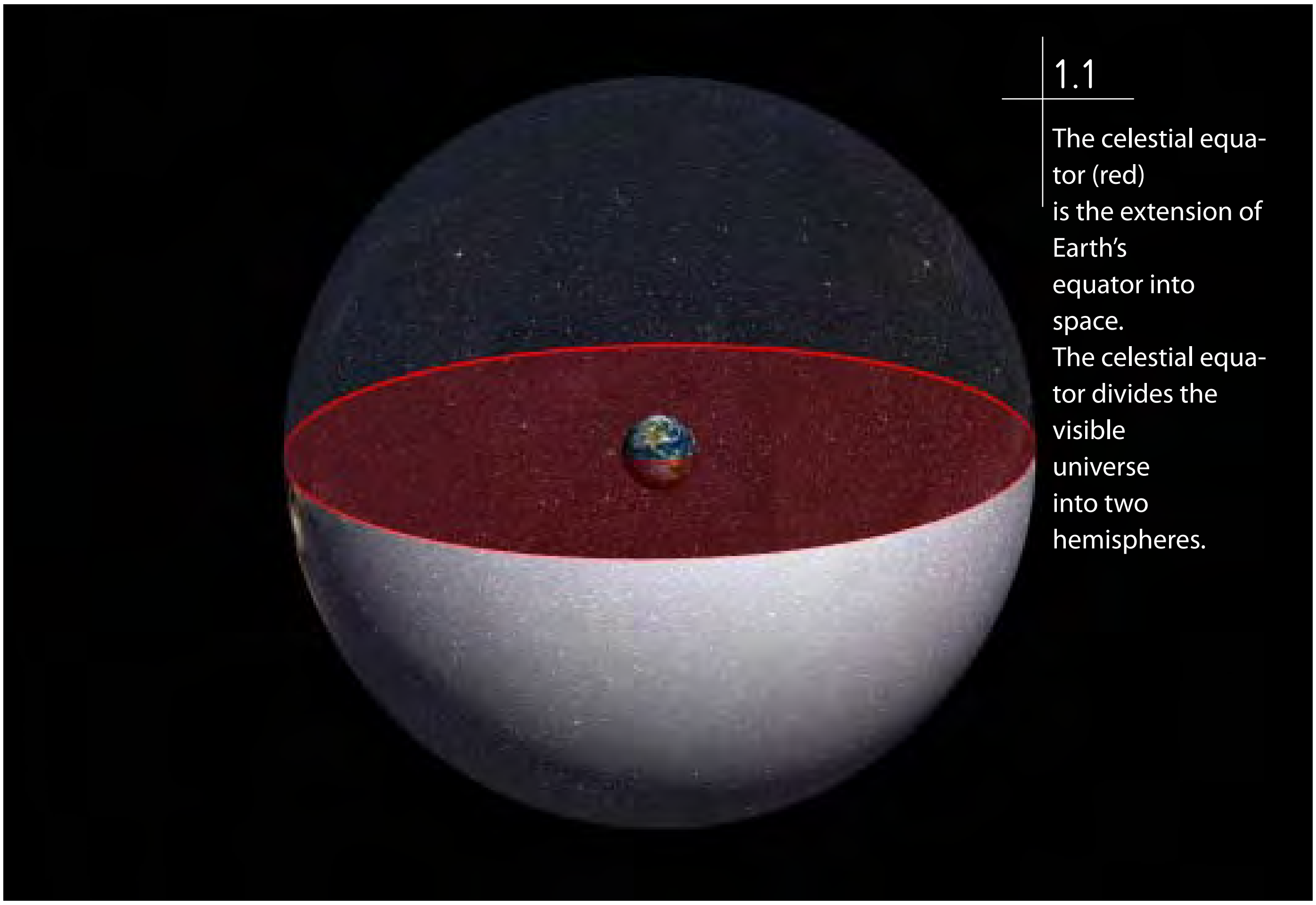
in our sky. It is common knowledge that the sun always rises in the east and sets in the west. However, the moon, stars, and planets also adhere to this pattern. This basic trend of east-to-west motion is due to Earth's rotation on its axis; things seem to go from east to west simply because the Earth is spinning in the opposite direction. This is called "diurnal motion." It is no different than someone spinning in a revolving chair; the world seems to be spinning the opposite way.

The Earth takes approximately 24 hours to rotate on its axis. Therefore, any object in the sky will take approximately 24 hours to make a complete circuit. If you see a bright star rising in the east, that star will be high in the sky 6 hours later, and will set in the west after an additional 6 hours; the star will then be below the horizon (and thus not visible) for an additional 12 hours. These numbers are approximations only — we'll see why later. One application of this principle is that if you see a star (or planet) in a particular section of the sky tonight, rest assured that you will see it in almost the same spot in the sky the following night at the same time (24 hours later).

◇The Celestial Sphere

A very useful concept for understanding the positions and motions of stars is called the "celestial sphere." Ancient astronomers imagined that the stars were all pinned to the surface of a gigantic invisible sphere,

One hour timelapse photography



1.1

The celestial equator (red) is the extension of Earth's equator into space. The celestial equator divides the visible universe into two hemispheres.

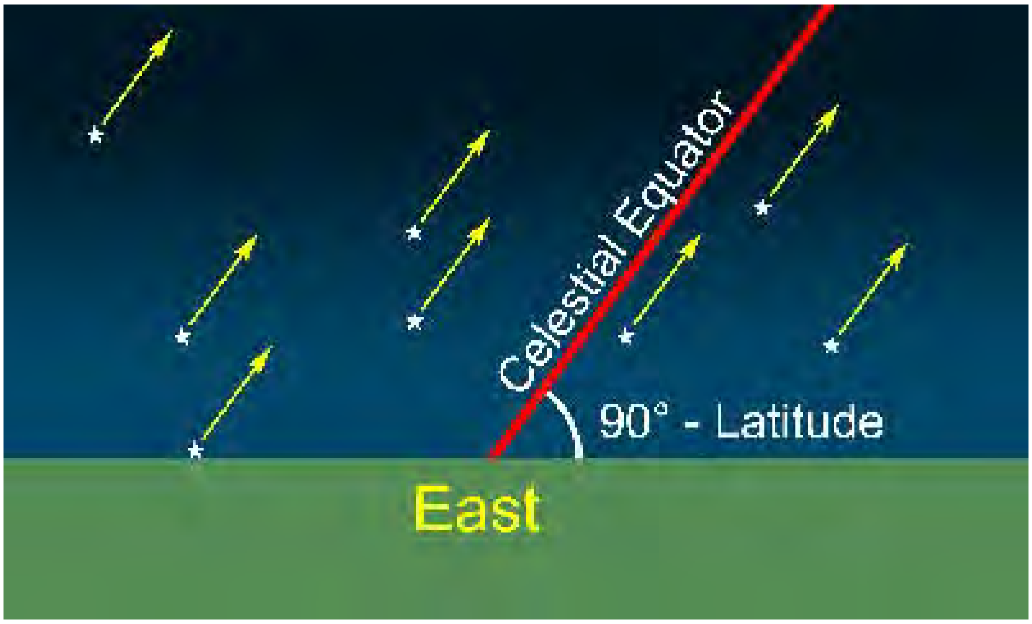
with Earth at its center. This sphere seems to rotate (east to west) relative to us, since the Earth is in fact rotating in the opposite direction. Of course, we now know that the stars are not on the two-dimensional surface of a sphere, but are at various distances throughout space. Nonetheless, the celestial sphere is a useful mental construct for understanding apparent stellar motion. There is no need to know the distance to different stars to understand their motion. Just imagine that they are all pinned to a giant, invisible sphere that spins around the Earth.

The celestial sphere has an equator and a North and South Pole – just like the Earth. By construction, the celestial poles and equator are perfectly aligned with Earth's. Imagine expanding Earth's equator out into space, so that it divides the universe into two hemispheres FIGURE 1.1. That dividing circle would represent the "celestial equator." Likewise, imagine standing on the North Pole of Earth and looking straight up. That spot in the sky is the "North Celestial Pole" (NCP). It so happens that there is a star extremely close to the NCP; it's called the North Star or "Polaris." So, conveniently, the North Star is a nice physical representation of the NCP. A person standing on Earth's South Pole looking directly overhead would see the South Celestial Pole (SCP). But there is not a bright star at that location.

The celestial equator may be difficult to visualize as we stand on Earth's surface. However, if you lived on Earth's equator, the celestial equator would go right overhead. It would extend from due east to directly overhead to due west. Since the United States is north of the Earth's equator, the celestial equator appears shifted southward. In the USA, the celestial equator extends from due east, to a point somewhat south of

1.2

The celestial equator intersects the horizon at due east at an angle that is related to the observer's latitude. For this reason, stars rise in the east at an angle.



overhead, to due west. In fact, the angle at which the celestial equator intersects the horizon is exactly 90° minus the latitude FIGURE 1.2. At the North or South Pole, the celestial equator would be the same as the horizon.

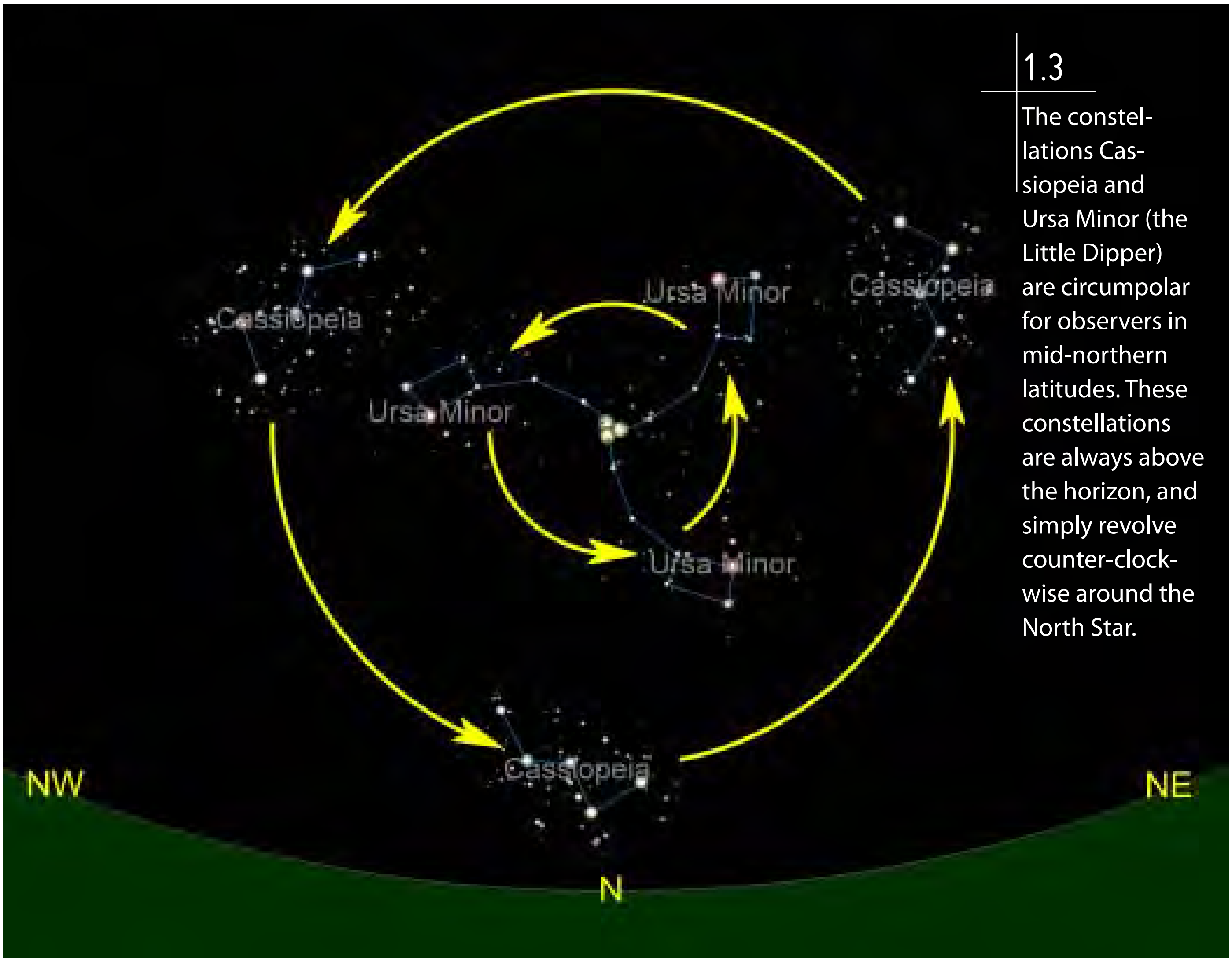
Since we live on a rotating planet, from our point of view the celestial sphere rotates counterclockwise around the NCP. Thus, stars rise in the east and set in the west. Stars very close to the NCP never go below the horizon (so they do not rise or set), but they still circle in the same direction — counterclockwise around Polaris. The celestial poles themselves always appear in exactly the same location in space, as seen from a given location on Earth. However, since the celestial poles are at exactly opposite points on the celestial sphere, only one of them can be seen from any given location on Earth (except at the equator where both poles are barely visible, just touching the horizon). In the Northern Hemisphere, we can always see the NCP (i.e., the North Star is always visible in exactly the same spot), but we can never see the SCP since it is permanently below the horizon for us. Conversely, people living south of the Earth's equator can never see the North Star.

Some constellations are close enough to the celestial pole that they are visible all night, year-round, like Cassiopeia and Ursa Minor (for the USA). These are called "circumpolar" constellations FIGURE 1.3. Likewise, some stars (like Alpha Centauri) and constellations (such as Crux) can never be seen from mid-northern latitudes because they are too close to the SCP, and thus never get above the horizon.

◇The Greater Light to Rule the Day

For any given location on Earth, the local time is based on where the sun is in the sky. When the sun has reached its highest point in the sky, we set our clocks to noon. (To be precise, it's a bit more complicated than this. Time zones, daylight savings time, and the uneven speed of Earth's orbit around the sun all cause the sun to be not exactly at its highest point at noon. But it's close enough for our purposes here.) On average, the sun rises at approximately 6 a.m., sets at approximately 6 p.m., and is farthest below the horizon at midnight. (Again, this is simplified.) We have defined time in such a way that it takes exactly 24 hours (on average) for the sun to make a complete circuit in the sky. Most of the sun's apparent motion is due to Earth's rotation on its axis, but not all.

The Earth actually takes 23 hours and 56 minutes to rotate on its axis once. For that reason, from our point of view all stars take 23 hours 56 minutes to revolve around Polaris and return to their original position. All stars do this except one — the sun. The sun takes 24 hours (on average) to return to a given location in the sky. The reason for the four-minute difference is that the Earth is orbiting the sun (and not the distant stars). It takes a full year for the Earth to orbit the sun once;



1.3

The constellations Cassiopeia and Ursa Minor (the Little Dipper) are circumpolar for observers in mid-northern latitudes. These constellations are always above the horizon, and simply revolve counter-clockwise around the North Star.

but it moved a small fraction of that orbit in one day. So, whereas the Earth takes only 23 hours and 56 minutes to rotate completely, the sun is no longer in the same position it was one day ago since the Earth has moved around it just a bit. It takes an extra 4 minutes to "make up the difference." See FIGURE 1.4.

Since the 23 hours and 56 minutes period is how long it takes the Earth to turn as seen from a distant star, this is called a "sidereal day"; this represents the true rotation of the Earth on its axis. The 24-hour day is called a "solar day" (also called a "synodic day") since it is in relation to the position of the sun. From Earth's point of view, the sun travels eastward relative to the stars on a path called the "ecliptic." The ecliptic is actually the plane of the Earth's orbit around the sun, and therefore appears to be the sun's annual path around the Earth as well. It is this slow motion along the ecliptic that causes the sun to rise 4 minutes later relative to the stars every day, or alternatively the stars appear to rise 4 minutes earlier relative to the sun.

Since we find it convenient to work by daylight, we have chosen to set our clocks by the sun, so there are 24 hours in one solar day. However, astronomers often prefer to set their time by the stars — sidereal time. There are 24 sidereal hours in one sidereal day. This is extremely convenient in astronomy, since a given star is always at the same location at a given sidereal time; we don't have to subtract 4 minutes off of every day.

But, in our standard solar time, the stars rise 4 minutes earlier every night, and the sun takes 24 hours to make a circuit. Conversely, in sidereal time, stars rise at exactly the same time every night; and the sun rises later by (an average of) 4 minutes per day. One minute of sidereal time is therefore slightly shorter than one minute of solar time. Since virtually all cultures of the world use solar time, this is what we will use throughout this book. But keep in mind that a sidereal day is 4 minutes shorter than a solar day; so stars take 23 hours 56 minutes to complete their circuit in the heavens — just 4 minutes short of a day.

The "4 minute" number is an approximation; but how does the number come about? The Earth takes one year to orbit the sun — that's about 365.25 (solar) days. Therefore, from the viewpoint of the Earth, the sun makes one complete revolution around the celestial sphere in one year. The Earth orbits the sun in the same direction the Earth rotates. This means, the sun "sees" one less Earth rotation every year than the stars do. So, whereas there are 365.25 solar days in a year, there are 366.25 sidereal days (the Earth has actually rotated 366.25 times in one year). So the stars are effectively rising 24 hours (one full day) earlier after a period of 12 months. This means that stars rise 2 hours earlier per month, which works out to about 28 minutes per week, or just a bit less than 4 minutes per day.

remember

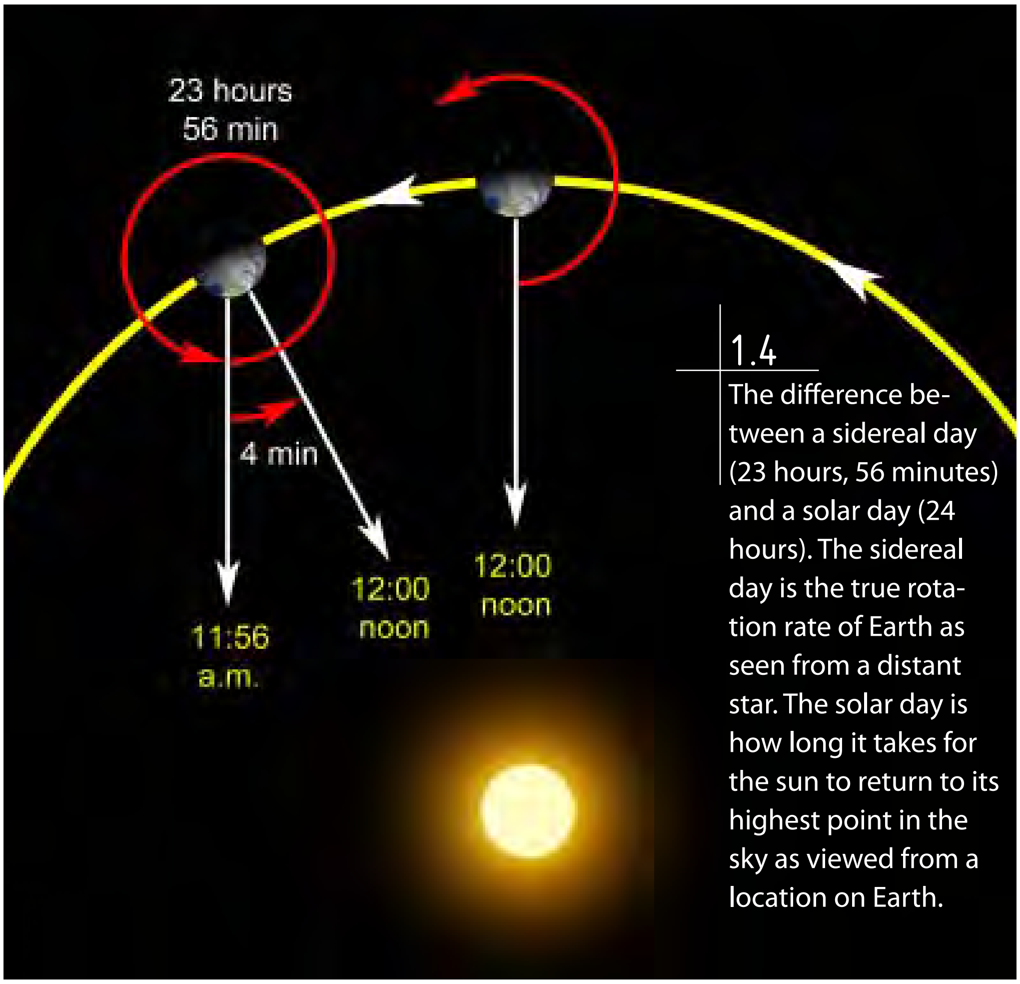
Stars rise about 4 minutes earlier every night.

They rise about a half-hour earlier every week.

They rise about 2 hours earlier every month.

In one year, they have returned to their original positions.

If we understand the basic motion of the Earth on its axis, and the motion of the Earth around the sun, and if we gain a bit of familiarity with the constellations and bright stars, it is very easy to tell when an object of interest will be visible. Suppose you see a bright star high in the sky at midnight in the middle of December. You automatically know that it will be in that same position at 10:00 p.m. in January, and at 8:00 p.m. in February. You can also conclude that the star will not be easily visible in July, since it will be lost in the glare of the sun. If you see a star that is fairly close to the North Star, you can easily conclude that it will be visible year-round, at any time of night.



1.4
The difference between a sidereal day (23 hours, 56 minutes) and a solar day (24 hours). The sidereal day is the true rotation rate of Earth as seen from a distant star. The solar day is how long it takes for the sun to return to its highest point in the sky as viewed from a location on Earth.

Here are some practical results of the above discussion. Since stars rise 2 hours earlier every month, they rise 12 hours earlier after 6 months — half a year. This makes sense since the Earth would then be on the opposite side of the sun. Therefore, stars and constellations that are visible in the evening sky in the summer are visible in the morning sky in winter (i.e., 12 hours later). Constellations that are high in the sky at midnight in spring cannot be seen in fall. If a constellation is low in the west just after sunset today, you know it probably won't be visible at all next month — it will set two hours earlier and will be lost in the sun's glare. These simple guidelines allow you to know where and when to look for the desired star or constellation.

Experience is the key. To someone who has never thought about motions in the night sky, the above discussion may seem abstract or confusing. But a little experience will make it very obvious what is going on. Simply try it. Go outside tonight, find a bright star, and make an estimation of its position. A week later, go out one half-hour earlier, and you will see the same star in the same position. Go out an hour or two later and see how that star has shifted to the west. It doesn't take long before these motions are very intuitive.

◇The Lesser Light to Rule the Night

In order to really get the most out of an astronomy observing session, it is crucially important to know the phase of the moon and approximately when the moon will rise and set. The rise and set times are determined primarily by the phase, so if you know one bit of information, you can estimate the others. It's important to know where the moon is for two reasons. First, the moon is beautiful (particularly in the first and third quarter phases) and makes a wonderful object to view in its own right. Second, and most importantly, when the moon is visible it tends to "wash out" anything else in the night sky. The moon is immensely brighter than any other nighttime object — it "rules" the night. The effect is particularly bad when the moon is near its full phase. The full moon is actually about nine times brighter than the first quarter moon. This effect will not significantly degrade your viewing of the planets, or bright stars. But globular clusters and nebulae are virtually destroyed by bright moonlight. Galaxies that are easy binocular objects under dark skies suddenly become almost impossible to find when the full moon is out, even with the aid of a good telescope. It is astonishing how severe this effect is.

The moon orbits the Earth in the same direction the

Earth spins — counterclockwise looking down over the Earth's North Pole. However, the moon orbits much slower than the Earth turns — taking 27.5 days to orbit once. So, although the moon orbits from west to east relative to the background stars, it "loses" to the Earth's rotation and thus appears to move from east to west, just like the sun and stars. However, it appears to do this slightly slower than the sun and stars since its true motion through space is west to east. For this reason, the moon rises (on average) about 50 minutes later each day. So if you know when the moon was out last night, you know it will be about 50 minutes later tonight. Stars rise 4 minutes earlier every night, and the moon rises 50 minutes later. Alternatively, keeping time the same, the moon will be farther east (by about 12 degrees) than it was last night at the same time.

Many people are under the impression that the moon


Earth's Moon: Photographed by the Expedition 28 crew aboard the International Space Station, this image shows the moon, the Earth's only natural satellite, at center with the limb of Earth near the bottom transitioning into the orange-colored troposphere, the lowest and most dense portion of the Earth's atmosphere. The troposphere ends abruptly at the tropopause, which appears in the image as the sharp boundary between the orange- and blue-colored atmosphere. The silvery-blue noctilucent clouds extend far above the Earth's troposphere.

does not rotate since we always see the same side of the moon. But the moon does rotate; it simply rotates at the same rate that it revolves around the Earth — that's why we always see the same side. In fact, if the moon did not rotate, we would see the other side of the moon when it was on the other side of the Earth. The fact that the moon rotates at the same rate it revolves is not uncommon. Virtually all large moons do this; they are "tidally locked." Such a condition is very stable; if the moons were not tidally locked to begin with, they would eventually come to such a condition in time anyway. Since the moon rotates, it experiences day and night just like the Earth does. But since the moon rotates slowly, it takes nearly a month to go from one sunrise to the next.

Once when I was speaking at a university, an individual came up to me afterward and suggested that the moon and Earth should really be considered co-orbital planets. He suggested that the moon really shouldn't be considered a moon since the gravitational pull of the sun on the moon is about twice the pull of the Earth on the moon. This is in fact true. Effectively, the moon belongs more to the sun than the Earth as far as gravity is concerned. In essence, both the Earth and the moon orbit the sun directly; however, the close proximity between the Earth and moon causes each of their orbits to be strongly perturbed by the other body. As far as I know, the Earth's moon is the only "moon" for which this is the case. It is ironic that the only "moon" that isn't truly a moon is called "the moon."

◇Phases of the Moon

As the moon orbits the Earth it goes through phases. A lot of people are under the impression that phases have something to do with Earth's shadow, but this is not so. Phases have to do with the percentage of the day side of the moon we can see from our position. The moon has a day side and a night side, just like the Earth. As the moon orbits the Earth (and rotates accordingly) we see different amounts of illumination from the sun, due to the changing angle of the sunlight. When the moon is closer to the sun than the Earth is (sort of "in between" the Earth and the sun), we see mostly the night side of the moon (the crescent and new phases); when the moon is farther away from the sun than the Earth is, we see mostly the day side

The moon is a great choice for a stargazer to begin

1.5 Lunar Phases and Time. As the moon moves from west to east (right to left), it goes through phases as we see varying fractions of the sun's illumination.

of the moon (the gibbous and full phases). In between these two cases, when the sun is at a 90-degree angle relative to the moon, we see exactly half of the day side, and half of the night side of the moon (1st or 3rd quarter).

Phases are called "waxing" if we are seeing increasing percentages of the day side of the moon as time goes forward day after day; they are called "waning" if we see decreasing portions of the day side. The phases go in this order: new moon, waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, and waning crescent. The moon is illuminated on is right side when in waxing phases; it is illuminated on the left when in waning phases (as viewed from the Northern Hemisphere of Earth). The practical application is this: if the moon is illuminated on its right side, it will be even brighter and fuller tomorrow night. If it is illuminated on its left side, it will be less illuminated tomorrow night.

It takes 29.3 days for the moon to go through all its phases. Note that this is slightly different than the orbital period of the moon (27.5 days). The difference is exactly analogous to the difference between sidereal and solar days on Earth. The moon takes 27.5 days to come back to its original position as seen by a star, but 29.3 days to come back to its original position as seen by the sun. The difference is because the Earth (and therefore the moon as well) has made a fraction of its orbit around the sun in one month. Since we usually prefer to use solar time, the 29.3 days period is the more useful figure. This is where we get the idea of a month, and the word month is indeed derived from "moon."

Since it takes about one month for the moon to go through all its phases, it takes roughly one week to go through one-fourth of the cycle. If the moon is "new" today, it will be in first quarter phase in one week, full the week after that, third quarter the week after that, and then back to new the week after that. This is another one of those useful tidbits to keep in mind.

◇Phases and Times

It is very easy to tell roughly when and where the moon will be in the sky once you know its phase. A simple trick is to remember that the first quarter moon follows the sun by 6 hours (that is, it is now where the sun was 6 hours ago). The full moon follows (or leads) the sun by 12 hours — and is always opposite the sun in the sky. The third quarter moon leads the sun by 6 hours (or trails by 18 hours if you prefer). When the moon is new, it is roughly where the sun is; but, of course, you won't see it anyway FIGURE 1.5. Now let's go through some practical examples.

Suppose you want to look for some galaxies around 10:00 p.m. and don't want to be bothered by bright moonlight. If the moon is in "new" phase, that's great because you won't see it at all that night. But third quarter phase, or a waning crescent phase would also work — because the moon won't rise until after midnight. A

(thin) waxing crescent phase would probably also be okay, because the moon will set before 10:00 p.m.

Suppose you do want to look at the moon itself; probably the best phase would be first quarter. Here the moon is half illuminated from our perspective and the craters look the most vivid and beautiful. The first quarter moon would be high in the sky right after sunset and so you could start observing right away. If you are a morning person, then maybe third quarter phase would be your preference. The moon would be high in the sky just before sunrise, and would be beautifully "half" illuminated, though now on the left side instead of the right.

Suppose you remember seeing the moon in its first quarter phase last week, and want to know when it will rise tonight and what it will look like. Since it is one week later, the moon will be in its full phase. It will rise as the sun sets, and will set when the sun rises; so, you will be able to see the moon at any time of the night.

As one last example, let's imagine that it is 9:00 in the morning, and you want to know if the moon is visible. Your calendar tells you that the moon was full 6 days ago. That means it is in the waning gibbous phase today — almost at 3rd quarter. It is therefore ahead of the sun by a little over 6 hours. So the moon is where the sun will be at around 3:50 p.m.; this is above the horizon in the southwestern sky. So, yes, you can see the moon at this time. Many people don't think to look for the moon in broad daylight, but it really can be seen if you know when (and where) to look.

◇Planets

The motion of planets is more complicated because their apparent motion in the sky is the combination of their true motion around the sun, plus the apparent shift in position due to Earth's motion around the sun. Fortunately, all the planets orbit in approximately the same plane: the ecliptic. For this reason the planets always form a nearly straight line along with the sun and the moon, and move along this line. Since the planets orbit the sun rather slowly, (especially the outer planets) their motion is similar to that of the stars, at least for short time intervals (i.e. Saturn rises roughly 4 minutes earlier every evening, just like the stars). The planets generally move eastward relative to the background stars; however, they occasionally move in the opposite direction. We will see why this is in a later section.

◇Seasons

The Earth's rotation axis is tilted relative to its orbit around the sun by 23.4 degrees. It is this tilt that is responsible for seasons on Earth. We notice two effects as a result of this tilt. In the summer, the sun is high in the sky and remains out for more than 12 hours per day. In the winter, the sun is low in the sky and remains out for less than 12 hours. Only at the equator is the sun out for 12 hours a day regardless of the season.

The height of the sun is directly connected with the amount of time it is visible per day. When the sun is higher in the sky as it is during summer, more than 50 percent of the sun's daily path is above the horizon. The sun is above the celestial equator in the summer. Therefore the sun remains up longer than 12 hours; in fact, it could be up as long as 24 hours for locations near the North Pole. When the sun is out longer, we receive more energy from the sun, and consequently have warmer temperatures. Also, since the sun is higher in the sky in summer, a given section of the ground receives more energy per unit area, and is thus warmer than in winter.

Although the Earth's tilt does not change (at least not significantly over the course of one year), the Earth is orbiting the sun. So, whereas the northern hemisphere is tipped toward the sun in summer, one-half year later it is tipped away from the sun FIGURE 1.6. It's not that the tilt has changed; rather the relative position of the sun has changed. Since the Northern Hemisphere is tilted toward the sun in summer, the Southern Hemisphere would necessarily be tilted away from the sun at this same time. This is why the Southern Hemisphere experiences the opposite season as the Northern Hemisphere for a given date.

It is a common misconception that seasons are caused by the changing distance from the Earth to the sun; many people suppose that we are closer to the sun in summer and farther away in winter. Although the Earth's orbit is slightly elliptical, the effect is fairly small and thus cannot account for seasons. Moreover, the Earth is actually closer to the sun in the (Northern Hemisphere) winter. So the changing Earth-sun distance cannot be responsible for seasons, even though this is very commonly believed.

◇Celestial Coordinate Systems

At this point we've explored how to estimate roughly where the sun, moon, and stars will be for a given time of night and a given time of year. It is now useful to discuss celestial coordinate systems, and some other terms relating to astronomical positions. These will allow us to understand and describe the position of the sun, moon, and stars with greater precision and will enable us to explore the motion of the planets and other celestial bodies as well.

1.6 The seasons are caused by the tilt of Earth's rotation axis relative to its orbit around the sun

Two coordinate systems are widely used in astronomy. The first is based on our local horizon. The second is based on the celestial sphere. The local horizon coordinate system describes the position of an object in the sky with two coordinates: altitude and azimuth. If we wanted to, we could use a third coordinate to specify the distance; however, in most cases we don't need to know the distance. Two coordinates will do. These two coordinates are angular; they measure a separation in angle, not linear distance.

"Altitude" describes how high above the horizon an object is (in angle). A star that is touching the horizon has an altitude of 0°, whereas an object that is directly overhead has an altitude of 90°. An altitude could be negative — this would mean that the object is below the horizon and thus cannot be seen. The altitude of any object must always be between -90° and 90°.

Azimuth describes how far along the horizon an object is to the right of due north. So the North Star has an azimuth of (approximately) 0° because it is due north. A star that is directly east has an azimuth of 90°. A star that is due south has an azimuth of 180°, and a star that is due west has an azimuth of 270°. So, the azimuth of an object is always less than 360° and is always greater than or equal to 0°.

There are two other useful guides based on horizon coordinates. "Zenith" is defined to be the position directly overhead. So the zenith has an altitude of exactly 90°. The "meridian" is the great circle that runs through due north through the zenith, to due south[1] FIGURE 1.7. All stars reach their highest altitude when they cross the meridian, which marks the halfway point of a star's diurnal path.

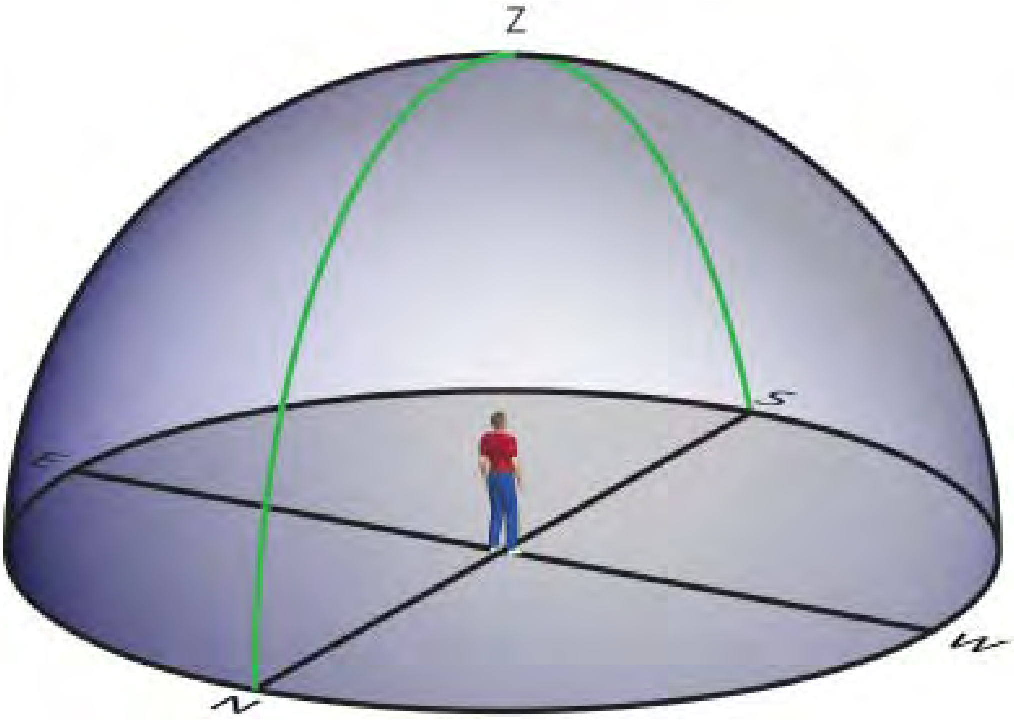
It so happens that the width of your hand held out at arm's length (with your fingers and thumb together, not spread out) happens to cover about ten degrees of angle. This works for nearly everyone because people that have larger hands usually have longer arms as well. You can test this by holding your hand at arm's length "sideways" so that the side just touches the horizon. Then place your other hand above it — just touching it, and place the first hand above it and so on, "walking" hand after hand until you reach the spot directly overhead. This should take nine hand widths — which is 90°. The altitude of the North Star is equal to your latitude on Earth. So if you live at latitude 40°, the North Star will be 40° in altitude — about four handwidths above the horizon FIGURE 1.8.

You can also use this method to measure angular separation. You might estimate that Jupiter is 20 degrees to the left of a particular star. This is a quick and easy way to describe to other observers exactly where you are looking.

Likewise, you can estimate the azimuth of an object by lining up hand after hand along the horizon starting from due north (due north is always easy to find because it is always directly below the North Star). Remember that azimuth is measured in angle along the horizon — not at any other altitude. The reason for this is that the angular separation of two different azimuths decreases as the altitude increases. For example, consider two stars on the horizon, one at azimuth 0° (due north), the other at 90° (due east). Their angular separation would be 90°.

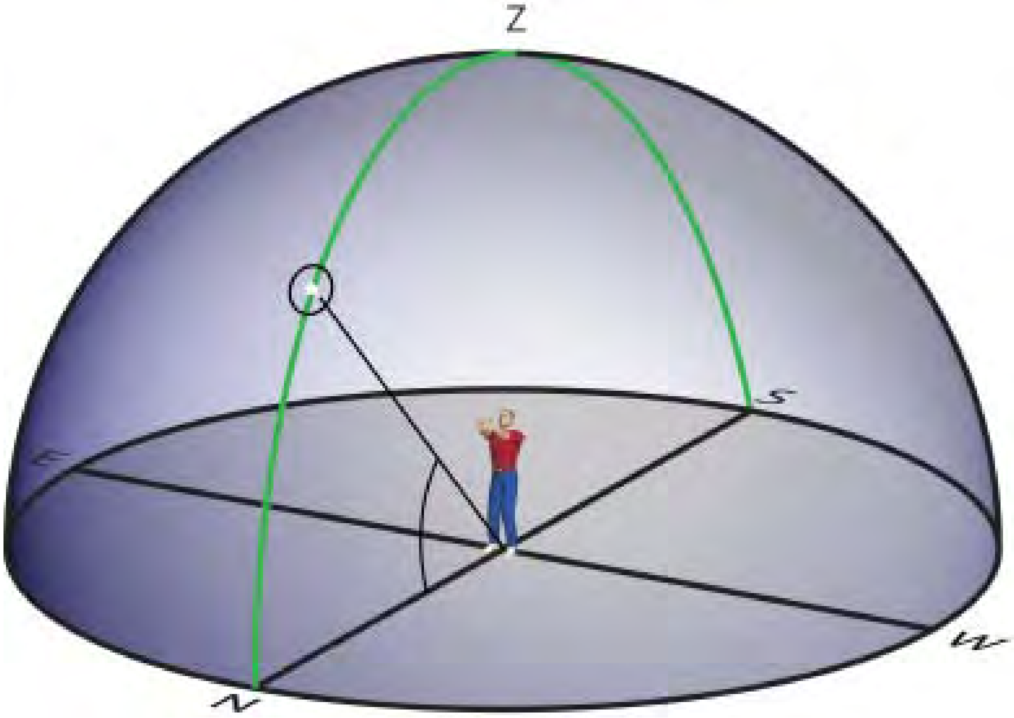
However, suppose instead that the two stars are not on the horizon but instead have an altitude of 89° — almost directly overhead. Those two stars would be extremely close together — their angular separation would be less than 2° even though one has an azimuth of 0° and the other has an azimuth of 90°. One lesson to learn here is that you cannot easily (i.e., "in your head") estimate the angular separation of two objects from their azimuths and altitudes (except for some special cases). The branch of mathematics that deals with computing such angular separations is called "spherical trigonometry." It is a useful tool in astronomy, but is beyond the scope of this book.

It is customary in astronomy to use "degrees" to measure large angles. If an angle is smaller than one degree, it is measured in "minutes of arc" or "arcminutes" (or sometimes just "minutes" for short). One



1.7

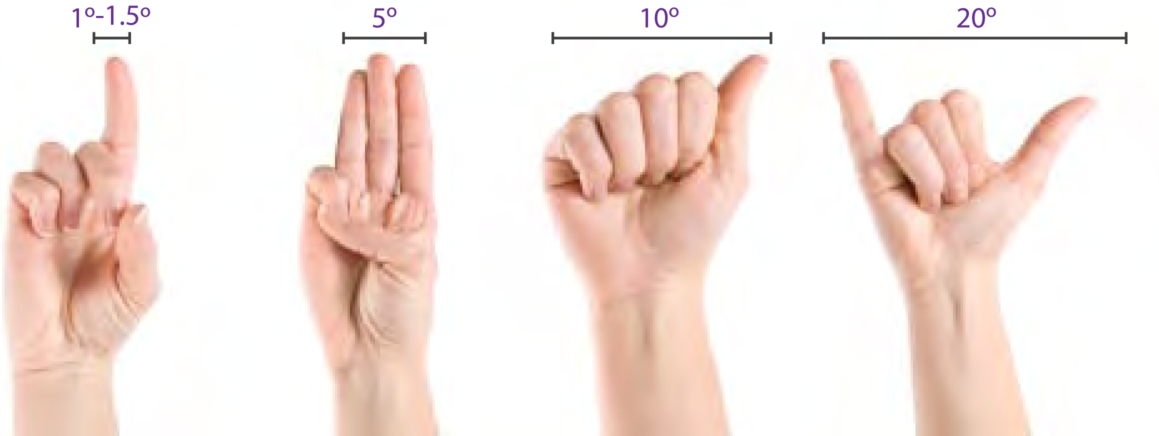
The meridian (green) passes from due north to the zenith (Z) to due south.



1.8

The altitude of the North Star is equal to the observer's latitude on Earth. This number can be estimated by noting how many hand widths (held at arm's length) it takes to go from the north horizon to the North Star. Each hand width is about 10 degrees.

Quick Method for Stargazing Measurements

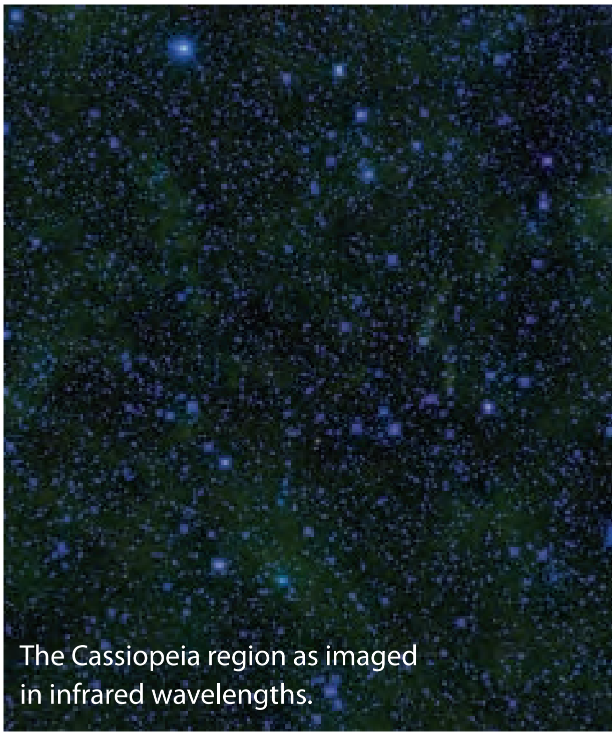


degree is equal to 60 arc-minutes. Furthermore, 1 arc-minute is composed of 60 "seconds of arc" or "arc-seconds." The symbol for 1 arc-minute is a single quotation mark or apostrophe; the symbol for arc-second is a double quotation mark. So 37 degrees, 46 arc-minutes, 56 arc-seconds is written as 37° 46′ 56″. Of course, it's no crime to write an angle as a decimal expression as well. We could write 37° 46′ 56″ as 37.78222°. Even though these two numbers are the same, note that the decimal expression is not .4656. You must divide by 60 to get the expansion. So be careful not to confuse arc-minutes with fractions of a degree. This can be a problem when people do not write down the symbols — especially in computer programs. For example, does 36 06 mean 36.06° or 36°06′? These are different quantities for the same reason that 0.7 hours is not the same as 70 minutes.

Another very useful tidbit is to know that the sun covers one-half of a degree — or 30 arc-minutes. The moon also covers roughly one-half of a degree. So the sun and the moon have approximately the same angular size. Your finger held at arm's length covers a little more than one degree — so it will appear twice as large as the sun or moon. This may seem surprising; psychologically, we "feel" that the sun and moon should be larger than this, but they're not. You will find that you can easily block the moon with your finger at arm's length (with one eye closed).

◇Equatorial Coordinates

The horizon coordinate system discussed above is very useful for describing the position of a celestial object to other observers who are present. However, it is not useful for describing such positions to observers who are at a remote location. Suppose you are talking on the phone with your friend who lives in a different state, telling him how to find Mars. It's no good giving him an altitude and azimuth, because the object will appear at a different altitude and azimuth for him. Horizon coordinates are based on the local horizon, but different parts of the world have a different horizon. (Though, horizon coordinates may be "close enough" if the remote observer is within a few hundred miles). Furthermore, as the Earth rotates, the horizon coordinates of a star change. It would be nice if we had a coordinate system where a star's position is relatively permanent.


The Cassiopeia region as imaged in infrared wavelengths.

The "equatorial coordinate system" overcomes these two problems. Equatorial coordinates are the same for everyone on Earth, and they do not change with time; that is, a star's equatorial coordinates remain the same throughout the night, even though its altitude and azimuth change. Otherwise, equatorial coordinates are very similar to horizon coordinates.

Equatorial coordinates are based on the celestial sphere. In particular, they are based on the celestial equator — hence the name. The angular distance of a star above the celestial equator is called its "declination." If the star is below the celestial equator, its declination is negative. Declination is exactly analogous to altitude except it is based on the celestial equator instead of the local horizon. The NCP has a declination of exactly 90°, whereas the SCP has a declination of -90°. The North Star would thus have a declination of almost 90°.

For Northern Hemisphere observers, it is very easy to estimate the declination of an object. Simply use your hands at arm's length (as described above) to measure the angular separation of the object from the North Star, then subtract this number from 90°. Interestingly, at the Earth's North Pole, declination and altitude are the same for all objects; the North Star would be at the zenith — directly above the observer.

Declination is also analogous to latitude. If you are located at latitude 40°, and you know of a star that has a declination of 40°, that star will pass directly overhead when it crosses the meridian. Stars with a declination that is less than your latitude will pass south of zenith when they cross the meridian; and stars with a greater declination will pass north of zenith.

Stars or constellations whose declination is greater than the quantity of 90° minus your latitude will never go below the horizon. These are the "circumpolar" stars and constellations that we mentioned previously. Circumpolar stars or constellation never rise nor set because they never reach the horizon. Rather, they simply revolve counterclockwise around the North Star. Observers in the continental United States can always see the Little Dipper as well as the constellation Cassiopeia on a clear night since these constellations have a high declination. They are close to Polaris, and never set. The downside of this is that stars or constellations with a declination less than your latitude minus 90° can never be seen. For mid-northern latitude observers, this would include the Southern Cross (Crux) and Eta Carina.

For every patch of sky that is circumpolar, there is an equal and opposite patch of sky that can never be seen from the same latitude. At the North Pole, or South Pole, all the visible stars and constellations are circumpolar, but half of the sky is forever hidden. At the equator, all of the sky can be seen (throughout the course of a day), but no constellations are circumpolar.

Right ascension (RA) is the other equatorial coordinate. This coordinate describes how far along the celestial equator an object is. So it is analogous to azimuth; but there are some differences. The first difference is that (unlike all other celestial coordinates) RA is measured in hours — not degrees. A complete circle in RA would consist of 24 "hours" rather than 360°. These are "hours" of angle not of time. I know it's confusing. I wouldn't have set it up that way; but that's just the convention. (And despite the confusion, there really are some good reasons for it.)

A second difference is the starting point. Whereas the starting point (0°) for azimuth is due north, the starting point (0h) for right ascension is the position of the sun at the vernal equinox. Unfortunately, this is a bit hard to picture. I find that RA is the most difficult coordinate to estimate by eye for this reason. It may help to know that the zero point is below the great square of Pegasus.

A third difference is that RA increases as you go left (to the east), whereas azimuth increases to the right. So if star A is to the left of star B, then star A has the greater RA (unless we passed 24h along the way). A fourth difference is that the RA coordinate moves with the stars — not the Earth. Think of the equatorial coordinate system as being "attached" to the celestial sphere as the Earth rotates inside it. So as a star rises, passes the meridian, and sets, its RA remains constant. Therefore, which RA coordinates can be seen depends on the time of day and the time of year FIGURE 1.9.

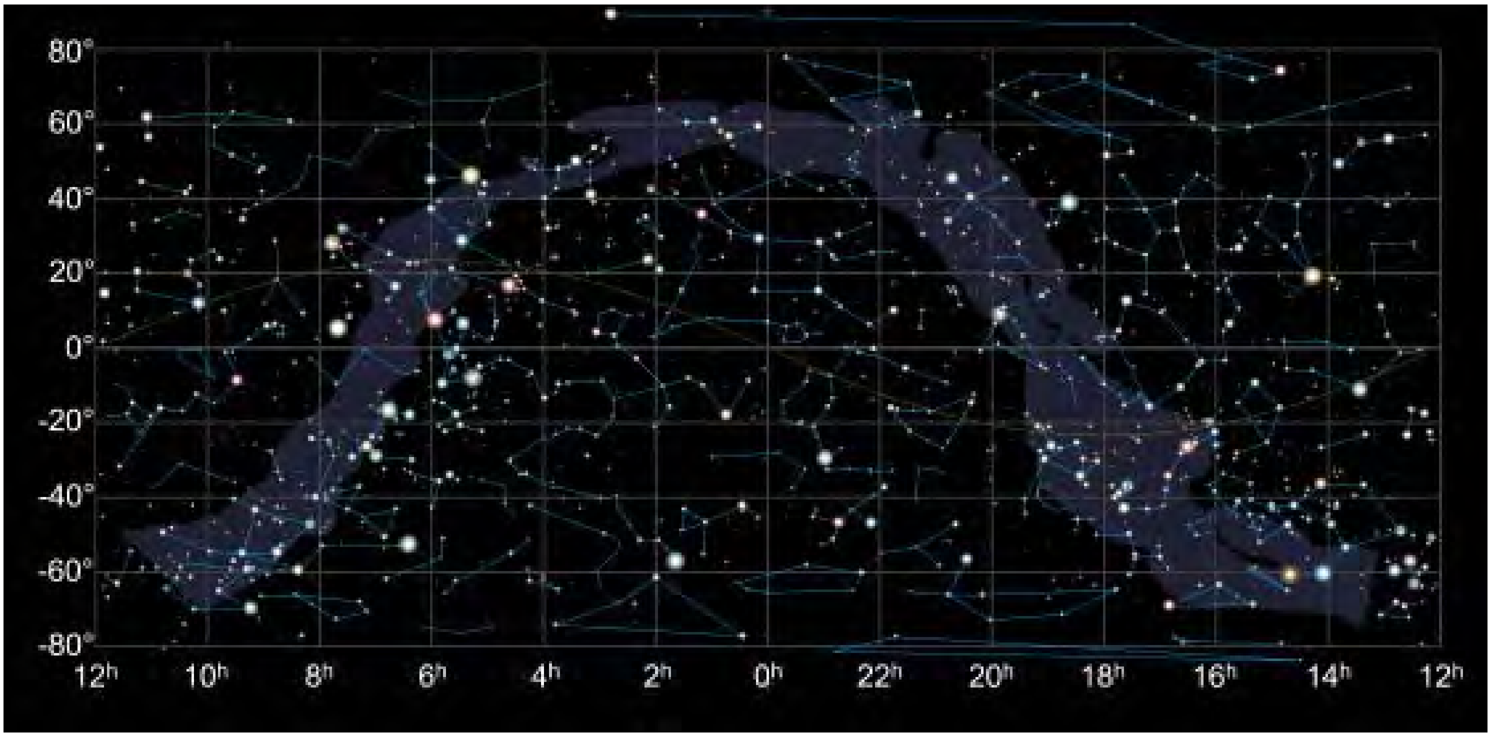
Suppose that it is the vernal equinox; this means the sun has an RA of exactly 0h. Also, suppose that we see the moon rise three hours after the sun does. Then the moon would have an RA of 3h. So now we can see why the RA coordinate is measured in hours, and why it increases as you go left.

You can roughly estimate the RA of an object by measuring its angular distance along the Celestial Equator (going to the left) from Pegasus (zero hours) — (or another object for which you already know the RA), and then divide the angle by 15 to convert to hours (since 360°/15 = 24 hr). This is similar to measuring the azimuth by estimating the angle along the horizon, but it's a bit harder because the celestial equator is not visible as the horizon is, and also because the starting point isn't as obvious (as due north is). You will probably never have to estimate RA and Dec by eye to find an object; there are several other ways in which they are useful.

◇Using RA and Dec Coordinates

Often, astronomical publications such as *Sky & Telescope* magazine will give the equatorial coordinates of an object of interest, such as a newly discovered comet. There are several ways in which you could use the listed RA and Dec coordinates to find the object. First, if the object is fairly bright, you may not need to know its position very precisely. In this case, you could simply estimate the position in the sky by eye — finding the declination by the distance from the North Star, and the RA by the distance to the left of Pegasus as previously discussed.

Alternatively, many computer programs can display the RA and Dec as a grid, or as labels for various objects. You could use such a program, or any map of the



1.9 The equatorial coordinate system. The vertical axis shows the declination; the horizontal axis shows the right ascension.

night sky that shows equatorial coordinates to locate your object. You can use FIGURE 1.9 in this way. You may find, for example, that the coordinates point you to a spot 2 degrees above Orion's central Belt star (Alnilam). You'll know exactly where to look.

Some telescopes have "setting circles." Once calibrated on an object whose RA and Dec you know, you can use these circles to find any other RA or Dec. This method requires that the telescope is properly aligned with the NCP. Moreover, this method does require a bit of practice, and a bit of patience. Note that some setting circles use "hour-angle" instead of RA. This coordinate is related to RA by the sidereal time. This isn't used very often these days and so it won't be discussed further here.

Additionally, many telescopes now have built-in computer controls which (once calibrated) will automatically point to the correct RA and Dec. This is probably the most useful purpose you will have for equatorial coordinates. Simply punch in these numbers and the telescope will move to the correct location. One disadvantage of this method is that you do not get a "feel" for where the object is actually found in the heavens when the telescope does all the work for you. So it can be a little "too easy." Also, most telescopes I've used do not calibrate perfectly. They'll get you close to the object, but it's best if you have a pretty good idea where the object is anyway.

◇Experience: Both Real and Virtual

The best way to get a feel for motions in the sky is to get outside and watch. Whenever you are outside, take a moment to look up and note the position of celestial objects. Even before you get into your car on the way to work, take the time to notice the position of the sun, and think about whether or not the moon is above the horizon. If it is, try to see it. It is really amazing what you can see when you take just a moment to look.

Another great way to get a feel for stellar motions is with the virtual experience provided by computer software. There are a number of fantastic planetarium-style programs — many of them free. Try one of these programs and watch what happens when you speed up time. Try watching the diurnal pattern of the stars over the course of a night. Or try skipping ahead from one day to the next to notice how the stars and moon change positions from night to night. It's like traveling through time, and it will quickly give you a feel for how the night sky works.

Another useful tool is a planisphere, also called a "star wheel." At the writing of this book, the best plansisphere available is called a "Miller Plansiphere" and should cost less than $10. Some (like the Miller version) are made of plastic, others of paper. These star wheels make use of the fact that the stars appear to rotate once around the Earth each night, and also make one complete rotation each year (by virtue of rising four minutes earlier each night). By lining up the date with the time on the planisphere, you can see what the stars will look like at any given date and time. It won't do planets or the moon, since their motion is more complex. But the planisphere is a great instrument to quickly find out which constellations will be visible at a given time on a given date.

◇A Review of Celestial Motions

The above sections are all you really need to know about motions in the sky to find anything you want to find. By noting the time, you can estimate in your head where the sun is. By looking at a calendar you can check the phase of the moon and estimate when it will rise and set. By looking up the coordinates of an object, or finding it on a star chart, you can estimate very roughly when it will rise and set. A computer program or an astronomy magazine such as *Sky and Telescope* can give you the current location of the planets, or any bright comets. You could at this point skip to another chapter to learn about what interesting things to find, and how specifically to find them.

But if you would like to learn a bit more detail about estimating when and where things will rise and set, read on. You may have noticed for example, that the sun does not always rise exactly at the same time, or in the same location. Sometimes the full moon is high in the sky, and other times it is lower. These issues are also something that you can learn to estimate "in your head" without the use of a computer or calculator. The next chapter is designed to clarify and reinforce the information we've already discussed, and enhance the precision of our estimations of celestial motions.