Chapter-by-Chapter Guide
Part I: Developing Perspective

The remainder of this *Instructor's Guide* goes through the book chapter by chapter. Within each chapter, it is organized as follows:

- A brief introduction with general comments about the chapter.
- "What's New in the Third Edition That Will Affect My Lecture Notes?" This short section is aimed at those who may have notes from teaching with past editions of our book.
- Teaching Notes. Organized section-by-section for the chapter, these are essentially miscellaneous notes that may be of use to you when teaching your course.
- Answers/Discussion Points for Think About It Questions.
- Solutions to End-of-Chapter Problems.

Chapter 1. Our Place in the Universe

The purpose of this first chapter is to provide students with the contextual framework they need to learn the rest of the course material effectively: a general overview of our cosmic address and origins (Section 1.1), an overview of the scale of space and time (Section 1.2), and an overview of motion in the universe (Section 1.3). We often tell students that, after completing this first chapter, they have essentially learned all the major ideas of astronomy, and the rest of their course will be building the detailed scientific case for these general ideas.

As always, when you prepare to teach this chapter, be sure you are familiar with the relevant media resources (see the complete, section-by-section resource grid in Appendix 3 of this Instructor's Guide) and the on-line quizzes and other study resources available on the Astronomy Place website.

What's New in the Third Edition That Will Affect My Lecture Notes?

As everywhere in the book, we have edited to improve the text flow, improved art pieces, and added new illustrations. In addition, those who have taught from previous editions of *The Cosmic Perspective* should be aware of the following organizational or pedagogical changes to this chapter (i.e., changes that will influence the way you teach) in the third edition:

- In the second edition, Section 1.2 included a one-page-per-planet tour of our solar system. This tour has been moved (and updated) to the new Chapter 8 that introduces the solar system. This makes the discussion of scale in Chapter 1 flow more smoothly, leaving the planetary details to the beginning of the planetary chapters.
- We have also moved discussion of seasons and of precession from Section 1.3 of the second edition to new sections in Chapter 2 for the third edition.
- In prior editions, we gave the probable age of the universe as a range from 12–16 billion years. Based on recent results from WMAP and refinements in measurement of Hubble's constant, we now give the age as "approximately 14 billion years."

Teaching Notes (By Section)

Section 1.1 A Modern View of the Universe

This section provides a brief overview of our modern view of the universe, including the hierarchical structure of the universe (our cosmic address) and the history of the universe (our cosmic origins).

- We urge you to pay special attention to the two full-page paintings (Figures 1.1 and 1.3). These pieces should help your students keep our cosmic address and origins in context throughout the course, and you may wish to refer back to them often.
- Note the box on "Basic Astronomical Objects, Units, and Motion": Although some of the terms in this box are not discussed immediately, having them here in the beginning of the book should be helpful to students. All these terms also appear in the glossary, but they are so basic and important that we wanted to emphasize them here in Chapter 1.
- Note that we've chosen to use *light-years* rather than *parsecs* as our primary unit for astronomical distances for the following three reasons:
    1. We have found that light-years are more intuitive than parsecs to most students because light-years require only an understanding of light travel times, and not of the more complex trigonometry of parallax.
    2. Lookback time is one of the most important concepts in astronomy, and use of light-years makes it far easier to think about lookback times (e.g., when a student hears that a star is 100 light-years away, he/she can immediately recognize that we're seeing light that left the star 100 years ago).
    3. Fortuitously, one light-year happens to be very close to 10^{13} kilometers (9.46×10^{12} km), making unit conversions very easy—this helps students remember that light-years are a unit of distance, not of time.

  We introduce parsecs in Chapter 16, by which point students should be sufficiently versed in distance scales to make converting between light-years and parsecs a much simpler task than it would be when they are first learning cosmic distances.
- FYI: The 2.5-million-light-year distance to the Andromeda Galaxy is based on results reported by K. Stanek and P. Garnavich in *Astrophysical Journal Letters*, 20 August 1998 (503, L131). They give the distance to Andromeda as 784 kpc, with a statistical error of $\pm$ 13 and a systematic error of $\pm$ 17. This distance is based on Hipparcos distances of red clump (helium core–burning) stars in the Milky Way and Hubble observations of red clump stars in Andromeda.
- We give the age of the universe as "about 14 billion years" based on the recent WMAP results (http://map.gsfc.nasa.gov/). The WMAP results are consistent with an age of 13.7 billion years with a 1 sigma error bar of 0.2 billion years.

Section 1.2 The Scale of the Universe

We devote this section to the scale of space and time because our teaching experience tells us that this important topic generally is underappreciated by students. Most students enter our course without any realistic view of the true scale of the universe. We believe that it is a disservice to students to teach them all about the content and physics of the universe without first giving them the large-scale context.

- The "walking tour of the solar system" uses the 1-to-10-billion scale of the Voyage scale model solar system in Washington, D.C., a project which was proposed by *The Cosmic Perspective* author Bennett. Voyage replicas are being developed for other science centers; if you are interested in learning more about how to get a Voyage replica in your town, please contact the author. (The same scale is also used in the Colorado Scale Model Solar System in Boulder.)

- With regard to the count to 100 billion, it can be fun in lecture to describe what happens when you ask kids how long it would take. Young children inevitably say they can count much faster than 1 per second. But what happens when they get to, say, "four hundred sixty-two thousand, nine hundred seventy-six… four hundred sixty-two thousand, nine hundred seventy-seven…"? How fast can they count now? And can they remember what comes next?
- Regarding our claim that the number of stars in the observable universe is roughly the same as the number of grains of sand on all the beaches on Earth, here are the assumptions we've made:
  - We are using 10^{22} as the number of stars in the universe. Assuming that grains of sand typically have a volume of 1 mm^3 (correct within a factor of 2 or 3), 10^{22} grains of sand would occupy a volume of 10^{22} mm^3, or 10^{13} m^3.
  - We estimate the depth of sand on a typical beach to be about 2–5 m (based on beaches we've seen eroded by storms) and estimate the width of a typical beach at 20–50 m; thus, the cross-sectional area of a typical beach is roughly 100 m^2.
  - With this 100 m^2 cross-sectional area, it would take a length of 10^{11} m, or 10^8 km, to make a volume of 10^{13} m^3. This is almost certainly greater than the linear extent of sandy beaches on Earth.
- The idea of a "cosmic calendar" was popularized by Carl Sagan. Now that we've calibrated the cosmic calendar to a cosmic age of 14 billion years, note that 1 average month = 1.17 billion years.

Section 1.3 Spaceship Earth

This section completes our overview of the "big picture" of the universe by focusing on motion in the context of the motions of the Earth in space, using R. Buckminster Fuller's idea of *spaceship Earth.*

- There are several different ways to define an average distance between the Earth and the Sun (e.g., averaged over phase, over time, etc.). In defining an AU, we use the term *average* to mean (perihelion + aphelion)/2, which is equivalent to the semimajor axis. This has advantages when it comes to discussing Kepler's third law, as it is much easier for students to think of a in the equation $p^2 = a^3$ as *average* than as *semimajor axis.*
- We use the term *tilt* rather than *obliquity* as part of our continuing effort to limit the use of jargon.
- We note that universal expansion generally is not discussed until very late in other books. However, it's not difficult to understand through the raisin cake analogy, most students have heard about it before (though few know what it means), and it's one of the most important aspects of the universe as we know it today. Given all that, why wait to introduce it?

Section 1.4 The Human Adventure of Astronomy

Although the philosophical implications of astronomical discoveries generally fall outside the realm of science, most students enjoy talking about them. This final section of Chapter 1 is intended to appeal to that student interest, letting them know that philosophical considerations are important to scientists as well.

- FYI: Regarding the Pope's apology to Galileo, the following is a quote from *Time* magazine, 28 Dec 1992:

  Popes rarely apologize. So it was big news in October when John Paul II made a speech vindicating Galileo Galilei. In 1633 the Vatican put the astronomer under house arrest for writing, against church orders, that the earth revolves around the sun. The point of the papal statement was not to concede the obvious fact that Galileo was right about the solar system. Rather, the Pope wanted to restore and honor Galileo's standing as a good Christian. In the 17th century, said the Pope, theologians failed to distinguish between belief in the Bible and *interpretation of it. Galileo contended that the Scriptures cannot err but are often misunderstood. This insight, said John Paul, made the scientist a wiser theologian than his Vatican accusers. More than a millennium before Galileo, St. Augustine had taught that if the Bible seems to conflict with "clear and certain reasoning," the Scriptures obviously need reinterpretation.*

Answers/Discussion Points for Think About It Questions

The Think About It questions are not numbered in the book, so we list them in the order in which they appear, keyed by section number.

Section 1.1

- This question is, of course, very subjective, but can make for a lively in-class debate.
- If people are looking from M31 at the Milky Way, they would see a spiral galaxy looking much like M31 looks to us. They would see it as it looked about 2.5 million years ago (due to light travel time) and thus could not know that our civilization exists here today.

Section 1.2

- This is another very subjective question, but it should get students thinking about the size of Earth in the cosmos. At the least, most students are very surprised at how small our planet seems in relation to the solar system. For most students, it makes Earth seem a little more fragile, and often makes them think more about how we can best take care of our planet.
- This question also can be a great topic of debate. We've found that most students tend to think it is inconceivable that we could be the only intelligent beings. However, some religious students will assume we are alone on grounds of their faith. In both cases, it can generate discussion about how science goes only on evidence. For example, we don't assume there are others because we have no evidence that there are, and we don't assume we are alone for the same reason.
- The logic is that the late appearance of intelligent life suggests: (1) that it is much "harder" to get intelligent life than microbial life, suggesting that "luck" may have been involved; and (2) even if there is an evolutionary imperative toward intelligence, the mere fact that it takes so long to arise would mean that many more worlds already have some life than have intelligent life. Counterarguments include the idea that even if 4 billion years is typical for the time to get intelligent life, there are still plenty of stars that live that long, and that the sheer number of stars might still make intelligent life common. Chapter 24 discusses this issue further.

Section 1.3

- As we understand it, the only real reason that globes are oriented with north on top is because most of the early globe makers lived in the Northern Hemisphere. In any case, it is certainly equally correct to have the globe oriented in any other way.
- This question is easy to discuss if you refer to the 1-to-10-billion scale model developed earlier. On this scale, entire star systems are typically only a few hundred meters in diameter (including all their planets), while they are separated from other systems by thousands of kilometers (at least in our vicinity of the galaxy).

Solutions to End-of-Chapter Problems (Chapter 1)

1. Our solar system is bigger than some galaxies. *This statement does not make sense, because all galaxies are defined as collections of many (a billion or more) star systems, so a single star system cannot be larger than a galaxy.*
2. The universe is about 14 billion light-years old. *This statement does not make sense because it uses the term "light-year" as a time, rather than as a distance.*

3. It will take me light-years to complete this homework assignment. *This statement does not make sense, because it uses the term "light-year" as a time, rather than as a distance.*
4. Someday, we may build spaceships capable of traveling at a speed of one light-minute per hour. *This statement is fine. A light-minute is 18 million kilometers, so it simply says that we'll someday build spaceships that can travel at a speed of 18 million kilometers per hour.*
5. Astronomers recently discovered a moon that does not orbit a planet. *This statement does not make sense, because a moon is defined to be an object that orbits a planet.*
6. NASA soon plans to launch a spaceship that will leave the Milky Way Galaxy to take a photograph of the galaxy from the outside. *This statement does not make sense, because of the size scales involved: even if we could build a spaceship that traveled close to the speed of light, it would take tens of thousands of years before it was high enough above the Milky Way Galaxy to take a picture from the outside, and then tens of thousands of years more for the picture to be transmitted back to Earth.*
7. The observable universe is the same size today as it was a few billion years ago. *This statement does not make sense, because the universe is growing larger as it expands.*
8. Photographs of distant galaxies show them as they were when they were much younger than they are today. *This statement makes sense, because when we look far into space we also see far back in time. Thus, we see distant galaxies as they were in the distant past, when they were younger than they are today.*
9. At a nearby park, I built a scale model of our solar system in which I used a basketball to represent the Earth. *This statement does not make sense. On a scale where Earth is the size of a basketball, we could not fit the rest of the solar system in a local park. (A basketball is roughly 200 times the diameter of Earth in the Voyage model described in the book. Since the Earth–Sun distance is 15 meters in the Voyage model, a basketball-size Earth would require an Earth–Sun distance of about 3 kilometers, and a Sun–Pluto distance of about 120 kilometers.)*
10. Because nearly all galaxies are moving away from us, we must be located at the center of the universe. *This statement does not make sense, as we can tell when we think about the raisin cake model. Every raisin sees every other raisin moving away from it, so in this sense no raisin is any more central than any other. (Equivalently, we could say that every raisin—or galaxy—is the center of its own observable universe, which is true but very different from the idea of an absolute center to the universe.)*
11. A geocentric universe would be a universe with Earth at its center. Many ancient people assumed we live in a geocentric universe. Today, we know that Earth is a tiny planet orbiting a rather average star among several hundred billion stars in our Milky Way Galaxy. Our galaxy, in turn, is just one of billions of galaxies in the observable universe.
12. When we say that the universe is expanding, we mean that average distances between galaxies (or groups of galaxies) are growing with time. This implies that galaxies must have been closer together on average in the past. If we take this idea back far enough, it means there must have been a time when all the matter in galaxies was on top of each other. Since you can't get any closer than that, this time when all matter was together must represent a beginning, which we have named the Big Bang.
13. The observable universe encompasses everything that we could see or study in principle. It is not the same as the entire universe, which is probably far larger (and perhaps even infinite). The extent of the observable universe is determined by the age of the universe: if the universe is 14 billion years old, then we cannot possibly see anything that lies more than 14 billion light-years away.

14. Distances to the stars are far greater than distances within our solar system. Students may put this idea into perspective in many ways. The key idea should be that even the nearest stars are more than 200,000 times farther from us than is the Sun.
15. Again, there are many ways that students can put the galaxy size in perspective, including the two ways suggested in the text: the time needed to count 100 billion star, and the scale model of a galaxy spread out over a football field.
16. There are roughly 100 billion galaxies in the observable universe and typically 100 billion stars per galaxy, giving a total of 10^{22} stars. Students may use the grains of sand analogy from the book, or may find other ways to put this number in perspective.
17. a. The diagrams should be much like Figure 1.19, except that the distances between raisins in the expanded figure will be 4 cm instead of 3 cm.

    b.

Distances and Speeds of Other Raisins as Seen from the Local Raisin

Raisin Number	Distance Before Baking	Distance After Baking (1 hour later)	Speed
1	1 cm	4 cm	3 cm/hr
2	2 cm	8 cm	6 cm/hr
3	3 cm	12 cm	9 cm/hr
4	4 cm	16 cm	12 cm/hr
⋮	⋮	⋮	⋮
10	10 cm	40 cm	30 cm/hr
⋮	⋮	⋮	⋮

    c. As viewed from any location inside the cake, more distant raisins appear to move away at faster speeds. This is much like what we see in our universe, where more distant galaxies appear to be moving away from us at higher speeds. Thus, we conclude that our universe, like the raisin cake, is expanding.
18. a. This problem asks students to draw a sketch. Using the scale of 1 cm = 100,000 light-years, the sketches should show that each of the two galaxies is about 1 cm in diameter and that the Milky Way and M31 are separated by about 25 cm.

    b. The separation between the Milky Way and M31 is only about 25 times their respective diameters—and other galaxies in the Local Group lie in between. In contrast, the model solar system shows that, on a scale where stars are roughly the size of grapefruits, a typical separation is thousands of kilometers (at least in our region of the galaxy). Thus, while galaxies can collide relatively easily, it is highly unlikely that two individual stars will collide. *Note:* Stellar collisions are more likely in places where stars are much closer together, such as in the galactic center or in the centers of globular clusters.
19. A light-second is the distance that light travels in 1 second. We know that light travels at a *speed* of 300,000 km/s, so a light-second is a *distance* of 300,000 km. A light-minute is the speed of light multiplied by 1 minute:

$$\begin{aligned}1 \text{ light-minute } &= (\text{speed of light}) \times (1 \text{ min}) \\ &= \left(300{,}000 \frac{\text{km}}{\text{s}}\right) \times 1 \text{ min} \times \frac{60 \text{ s}}{1 \text{ min}} = 18{,}000{,}000 \text{ km}.\end{aligned}$$

That is, "1 light-minute" is just another way of saying "18 million kilometers." Following a similar procedure, we find that 1 light-hour is 1.08 billion kilometers and 1 light-day is 2.59×10^{10} kilometers, or about 26 billion kilometers.

20. a. The circumference of the Earth is $2\pi \times 6{,}380$ km = 40,087 km. At a speed of 100 km/hr, it would take

$$40{,}087\text{ km} \div 100\text{ km/hr} = 40{,}087\text{ km} \times \frac{1\text{ hr}}{100\text{ km}} \times \frac{1\text{ day}}{24\text{ hr}} = 16.7\text{ days}$$

to drive around the Earth. That is, a trip around the equator at 100 km/hr would take a little under 17 days.

b. We find each time by dividing the distance to the planet from the Sun by the speed of 100 km/hr. It would take about 170 years to reach the Earth and about 6,700 years to reach Pluto (at their mean distances). FYI: The following table shows the driving times from the Sun to each of the planets at a speed of 100 km/hr.

Planet	Driving Time
Mercury	66 years
Venus	123 years
Earth	170 years
Mars	259 years
Jupiter	888 years
Saturn	1,630 years
Uranus	3,300 years
Neptune	5,100 years
Pluto	6,700 years

c. We are given the distance to Proxima Centauri in light-years; converting to kilometers, we get:

$$4.4\text{ light-yr} \times \frac{9.46 \times 10^{12}\text{ km}}{1\text{ light-yr}} = 41.6 \times 10^{12}\text{ km}$$

At a speed of 100 km/hr, the travel time to Proxima Centauri would be about:

$$4.16 \times 10^{13}\text{ km} \div 100\frac{\text{km}}{\text{hr}} = 4.16 \times 10^{13}\text{ km} \times \frac{1\text{ hr}}{100\text{ km}} \times \frac{1\text{ day}}{24\text{ hr}} \times \frac{1\text{ yr}}{365\text{ day}} = 4.7 \times 10^{7}\text{ yr}$$

It would take some 47 million years to reach Proxima Centauri at a speed of 100 km/hr.

21. At *Voyager*'s speed of 50,000 km/hr, the trip to Proxima Centauri would take:

$$4.16 \times 10^{13}\text{ km} \div 50{,}000\frac{\text{km}}{\text{hr}} = 4.16 \times 10^{13}\text{ km} \times \frac{1\text{ hr}}{50{,}000\text{ km}} \times \frac{1\text{ day}}{24\text{ hr}} \times \frac{1\text{ yr}}{365\text{ day}} = 9.5 \times 10^{4}\text{ yr}$$

Even at *Voyager*'s seemingly high speed of 50,000 km/hr, the trip to the nearest star would take some 95,000 years.

22. a. To calculate the average speed of the Earth in its orbit of the Sun, we divide the distance traveled by the Earth in one orbit by the length of time for one orbit. Regarding the orbit as circular with a radius of 1 AU, the circumference of the orbit is:

$$C = 2\pi \times (1\text{AU}) = 2\pi \times (1.50 \times 10^{8}\text{ km}) = 9.40 \times 10^{8}\text{ km}$$

We divide by 1 year to get the speed of the Earth in its orbit of the Sun:

$$v = \frac{9.4 \times 10^8\,\text{km}}{365.25\ \text{day} \times 24\ \text{hr/day}} = 107,000\,\frac{\text{km}}{\text{hr}}$$

As we orbit the Sun, we are traveling through space at an average speed of about 107,000 km/hr, or about 66,000 mi/hr.

b. The average speed of our solar system in its orbit of the Milky Way is the circumference of its orbit divided by the time it takes for one orbit:

$$v = \frac{2\pi(28{,}000\ \text{ly})}{2.3 \times 10^8\,\text{yr}} = \frac{1.76 \times 10^5\ \text{ly} \times 9.46 \times 10^{12}\,\frac{\text{km}}{\text{ly}}}{2.3 \times 10^8\,\text{yr} \times 365\,\frac{\text{day}}{\text{yr}} \times 24\,\frac{\text{hr}}{\text{day}}} \approx 8.3 \times 10^5\,\frac{\text{km}}{\text{hr}}$$

We are racing around the Milky Way Galaxy at about 830,000 km/hr, or about 510,000 mi/hr.

Chapter 2. Discovering the Universe for Yourself

This chapter introduces major phenomena of the sky, with emphasis on:

- The concept of the celestial sphere.
- The basic daily motion of the sky, and how it varies with latitude.
- The cause of seasons.
- Precession and its affects on the sky.
- Phases of the Moon and eclipses.
- The apparent retrograde motion of the planets, and how it posed a problem for ancient observers.

As always, when you prepare to teach this chapter, be sure you are familiar with the relevant media resources (see the complete, section-by-section resource grid in Appendix 3 of this Instructor's Guide) and the on-line quizzes and other study resources available on the Astronomy Place website.

What's New in the Third Edition That Will Affect My Lecture Notes?

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- Section 2.3 on the seasons is new, representing an enhanced version of the material on seasons that appeared in Chapter 1 of the second edition.
- Section 2.4 is also new, though much of its content formerly appeared in Chapter 1. We have added some motivation for why precession occurs.

Teaching Notes (By Section)

Section 2.1 Patterns in the Sky

This section introduces the concepts of constellations and of the celestial sphere, and explains the difference and relationship between the Milky Way in the sky and the Milky Way Galaxy.

- Note that we do not introduce the term *asterism*, instead speaking of *patterns of stars* in the constellations. This decision is simply part of our effort to limit jargon.

- Stars in the daytime: You may be surprised at how many of your students actually believe that stars disappear in the daytime. If you have a campus observatory or can setup a small telescope, it's well worth offering a daytime opportunity to point the telescope at some bright stars, showing the students that they are still there.
- In class, you may wish to take the pancake analogy for the Milky Way somewhat further. Tell your students to imagine being a tiny grain of flour inside a very thin pancake (or crepe!) that bulges in the middle and a little more than halfway toward the outer edge. Ask, "What will you see if you look toward the middle?" The answer should be "dough." Then ask what they will see if they look toward the far edge, and they'll give the same answer. Proceeding similarly, they should soon realize that they'll see a band of dough encircling their location, but that if they look away from the plane, the pancake is thin enough that they can see to the distant universe.

Section 2.2 The Circling Sky

This section introduces horizon-based coordinates and daily and annual sky motions.

- Note that in our jargon reduction efforts, we avoid the term *azimuth* when discussing horizon-based coordinates. Instead, we simply refer to *direction* along the horizon (e.g., south, northwest). The distinction of "along the horizon" should remove potential ambiguity with direction on the celestial sphere (where "north" would mean toward the north celestial pole rather than toward the horizon).
- Angular vs. physical sizes and distances: The conversion between the two is covered in Chapter 7. Here, we focus only on making sure that students understand the difference.
- Sky variation with latitude: Here, the intention is only to give students an overview of the idea and the most basic rules (such as latitude = altitude of NCP). Those instructors who want their students to be able to describe the sky in detail should cover Chapter S1, which covers this same material, but in much more depth.
- The flat Earth: There's a good article about the common misconception holding that medieval Europeans thought the Earth to be flat in *Mercury*, Sept/Oct 2002, page 34.

Section 2.3 The Reason for Seasons

This section focuses on seasons and why they occur.

- Those instructors who wish to spend less time on this topic can concentrate on the misconceptions about the seasons and skip the subsections about when seasons begin and how the distribution of land mass affects the seasons. These topics are arguably secondary in importance for an astronomy class, but are included because students inevitably ask about them.
- In combating misconceptions about the cause of the seasons, we recommend that you follow the logic in the Common Misconceptions box. That is, begin by asking your students what they think causes the seasons. When many of them suggest it is linked to distance from the Sun, ask how seasons differ between the two hemispheres. They should then see for themselves that it can't be distance from the Sun, or seasons would be the same globally rather than opposite in the two hemispheres.
- As a follow-up on the above note: Some students get confused by the fact that seasons diagrams (such as our Figure 2.15) cannot show the Sun–Earth distance and size of the Earth to scale. Thus, unless you emphasize this point (as we do in the figure and caption), it might actually look like the two hemispheres are at significantly different distances from the Sun. This is another reason why we believe it is critical to emphasize ideas of scale throughout your course. In this case, use the scale model solar system as introduced in Section 1.2, and students will quickly see that the two hemispheres are effectively at the same distance from the Sun at all times.

Section 2.4 Precession of Earth's Axis

This section focuses on what we mean by precession and on its observable effects.

- Note that we do *not* go deeply into the physics that causes precession, as even a basic treatment of this topic requires discussing the vector nature of angular momentum. Instead, we include a brief motivation for the cause of precession by analogy to a spinning top.
- FYI regarding Sun signs: Most astrologers have "delinked" the constellations from the Sun signs. Thus, most astrologers would say that the vernal equinox still is in Aries—it's just that Aries is no longer associated with the same pattern of stars as it was in 150 A.D. For a fuller treatment of issues associated with the scientific validity (or, rather, the lack thereof) of astrology, see Section 3.6.

Section 2.5 The Moon, Our Constant Companion

This section discusses the Moon's motion and its observational consequences, including the lunar phases and eclipses.

- For what appears to be an easy concept, many students find it remarkably difficult to understand the phases of the Moon. You may want to do an in-class demonstration of phases by darkening the room, using a lamp to represent the Sun, and giving each student a Styrofoam ball to represent the Moon. If you lamp is bright enough, the students can remain in their seats and watch the phases as they move the ball around their heads.
- When covering the causes of eclipses, it helps to demonstrate the Moon's orbit. Keep a model "Sun" on a table in the center of the lecture area; have your left fist represent the Earth, and hold a ball in the other hand to represent the Moon. Then you can show how the Moon orbits your "fist" at an inclination to the ecliptic plane, explaining the meaning of the nodes. You can also show eclipse seasons by "doing" the Moon's orbit (with fixed nodes) as you walk around your model Sun: the students will see that eclipses are possible only during two periods each year. If you then add in precession of the nodes, students can see why eclipse seasons occur slightly more often than every 6 months.
- The "Moon Pond" painting in Figure 2.21 should also be an effective way to explain what we mean by *nodes* of the Moon's orbit.
- FYI: We've found that even many astronomers are unfamiliar with the saros cycle of eclipses. Hopefully our discussion is clear, but some additional information may help you as an instructor: The nodes of the Moon's orbit precess with an 18.6-year period; note that the close correspondence of this number to the 18 year, 11 day saros has no special meaning (it essentially is a mathematical coincidence). The reason that the same type of eclipse (e.g., partial vs. total) does not recur in each cycle is because the Moon's line of apsides (i.e., a line connecting perigee and apogee) also precesses—but with a different period (8.85 years).
- FYI: The actual saros period is 6585.32 days, which usually means 18 years, 11.32 days, but instead is 18 years, 10.32 days if five leap years occur during this period.

Section 2.6 The Ancient Mystery of the Planets

This section covers the ancient mystery of planetary motion, explaining the motion, how we now understand it, and how the mystery helped lead to the development of modern science.

- We have chosen to refer to the westward movement of planets in our sky as *apparent* retrograde motion, in order to emphasize that planets only appear to go backward but never really reverse their direction of travel in their orbits. This makes it easy to use analogies: e.g., when students try the demonstration in Figure 2.31, they never say that their friend *really* moves backward as they pass by, only that the friend appears to move backward against the background.

- You should emphasize that apparent retrograde motion of planets is noticeable only by comparing planetary positions over many nights. In the past, we've found a tendency for students to misinterpret diagrams of retrograde motion and thereby expect to see planets moving about during the course of a single night.
- It is somewhat rare among astronomy texts to introduce stellar parallax so early. However, it played such an important role in the historical debate over a geocentric universe that we feel it must be included at this point. Note that we do *not* give the formula for finding stellar distances at this point; that comes in Chapter 16.

Answers/Discussion Points for Think About It Questions

The Think About It questions are not numbered in the book, so we list them in the order in which they appear, keyed by section number.

Section 2.1

- Yes, we would still be able to see the Andromeda Galaxy, but it would not be in the constellation Andromeda. You can show your students the first point by, for example, considering the classroom floor as the plane of the Milky Way and an object on the ceiling as Andromeda. They'll see that students on both sides of the room can see the object above the plane. For the second point, remind students of scale and that only very nearby stars in the galaxy make up the constellations we see in the sky. Thus, from the other side of the galaxy, we'd see a completely different set of stars and hence different constellations.

Section 2.2

- This question is designed to make sure students are understanding basic ideas of the sky. Answers are latitude-dependent. Sample answer for latitude 40°N: The north celestial pole is located 40° above the horizon, due north. You can see circumpolar stars by looking toward the north, anywhere between the north horizon and altitude 80°. The lower 40° of the celestial sphere is always below your horizon.
- Depends on the time of year; this question really just checks that students can properly interpret Figure 2.14. Sample answer for Sept. 21: The Sun appears to be in Virgo, which means you'll see the opposite zodiac constellation—Pisces—on your horizon at midnight. After sunset, you'll see Libra setting in the western sky, since it is east of Virgo and therefore follows it around the sky.

Section 2.3

- Jupiter does not have seasons because of its lack of appreciable axis tilt. Saturn, with an axis tilt similar to Earth, does have seasons.

Section 2.4

- Earth's axis precession is an example of gyroscopic motion, but the time scales are very different. The idea that spinning objects tend to keep the same rotation axis means that bicycle wheels tend to remain upright when spinning, but when not spinning they can fall over easily. *Note:* The idea here is only to motivate the ideas, since a complete analysis of gyroscopic motion requires vector analysis that is beyond what we can reasonably expect of students in this course.

Section 2.5

- A quarter-moon visible in the morning must be third-quarter, since third-quarter moon rises around midnight and sets around noon.

Section 2.6

- Opposite ends of the Earth's orbit are about 300 million km apart, or about 30 meters on the 1-to-10-billion scale used in Chapter 1. The nearest stars are tens of trillions of km away, or thousands of km on the 1-to-10-billion scale, and are typically the size of grapefruits or smaller. The challenge of detecting stellar parallax should now be clear.

Solutions to End-of-Chapter Problems (Chapter 2)

1. If you had a very fast spaceship, you could travel to the celestial sphere in about a month. *This statement does not make sense, because the celestial sphere is a concept and not a physical object.*
2. The constellation of Orion didn't exist when my grandfather was a child. *This statement does not make sense, because the constellations don't appear to change on the time scales of human lifetimes.*
3. When I looked into the dark fissure of the Milky Way with my binoculars, I saw what must have been a cluster of distant galaxies. *This statement does not make sense, because we cannot see through the band of light we call the Milky Way to external galaxies; the dark fissure is gas and dust blocking our view.*
4. Last night the Moon was so big that it stretched for a mile across the sky. *This statement does not make sense, because a mile is a physical distance, and we can measure only angular sizes or distances when we observe objects in the sky.*
5. I live in the United States, and during my first trip to Argentina I saw many constellations that I'd never seen before. *This statement makes sense, because the constellations visible in the sky depend on latitude. Since Argentina is in the Southern Hemisphere, the constellations visible there include many that are not visible from the United States.*
6. Last night I saw Jupiter right in the middle of the Big Dipper. (*Hint:* Is the Big Dipper part of the zodiac?) *This statement does not make sense, because Jupiter, like all the planets, is always found very close to the ecliptic in the sky. The ecliptic passes through the constellations of the zodiac, so Jupiter can appear to be only in one of the 12 zodiac constellations—and the Big Dipper (part of the constellation Ursa Major) is not among these constellations.*
7. Last night I saw Mars move westward through the sky in its apparent retrograde motion. (*Hint:* How long does it take to notice apparent retrograde motion?) *This statement does not make sense, because the apparent retrograde motion is noticeable only over many nights, not during a single night. (Of course, like all celestial objects, Mars moves from east to west over the course of EVERY night.)*
8. Although all the known stars appear to rise in the east and set in the west, we might someday discover a star that will appear to rise in the west and set in the east. *This statement does not make sense. The stars aren't really rising and setting, they only appear to rise in the east and set in the west because the EARTH rotates.*
9. If Earth's orbit were a perfect circle, we would not have seasons. *This statement does not make sense. As long as Earth still has its axis tilt, we'll still have seasons.*
10. Because of precession, someday it will be summer everywhere on Earth at the same time. *This statement does not make sense. Precession does not change the tilt of the axis, only its orientation in space. As long as the tilt remains, we will continue to have opposite seasons in the two hemispheres.*
11. The sky looks like a dome because we see half the celestial sphere at any given moment. (The celestial sphere looks like a sphere because space surrounds us in all directions, and our lack of depth perception makes the stars appear to lie on a sphere.) The horizon is the circle marking where the sky appears to touch the ground. The zenith is the point directly overhead. The meridian is a semicircle going from due north, through the zenith, to due south. To describe the location of an object in the local sky, we must state both its altitude above the horizon and its direction along the horizon.

12. When we see an object in the sky, we can directly measure only its angular size, not its physical size, unless we know how far away it is. For example, the Moon and Sun are the same angular size in our sky. We only learned their physical sizes after we developed ways to measure their distances. Arcminutes and arcseconds are measures of angle: 1 arcminute is 1/60 of 1 degree, and 1 arcsecond is 1/60 of 1 arcminute.
13. Without an axis tilt, the Earth would not have seasons because the amount of sunlight striking different places on the Earth would remain essentially constant at all times (with a slight variation due to the fact that the Earth is slightly closer to the Sun at certain times of year).

14. A planet with an axis tilt of 35° should have more extreme seasons than the Earth, because of its more extreme axis tilt.
15. To an observer in M31, the Milky Way Galaxy would look much like M31 does in our sky: a small, fuzzy patch of light, looking much like a small cloud.
16. The Moon goes from new moon through all its phases to the next new moon in approximately a month. The phases are called: new, waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, waning crescent. The Moon goes through phases because of the way we view it as it orbits Earth. Half the Moon is always illuminated (the half facing the Sun), but we generally see some combination of the dark and illuminated portions, which is what makes the phases.
17. We do not see an eclipse at every full and new moon because the Moon's orbit is slightly inclined to the ecliptic. Thus, it is not always directly on the Earth–Sun line at new and full moon. To see an eclipse, the Moon must be near one of the nodes of its orbit (places where its orbit crosses the ecliptic plane) *and* it must be either full moon (for a lunar eclipse) or new moon (for a solar eclipse).
18. Stellar parallax is the slight annual shifting of a star's apparent position in the sky, caused by the fact that we are viewing it from different places in Earth's orbit of the Sun. Although ancient people knew that the existence of stellar parallax would offer direct proof that Earth orbits the Sun, they were unable to measure it. That meant either that the stars must be so far away as to make stellar parallax unmeasurable to the naked eye, or that Earth does not orbit the Sun. Most ancients who thought about it chose the latter explanation, even though we now know the former is correct. (And we now can measure stellar parallax, which proves that Earth really does orbit the Sun.)
19. Answers to all but part (d) will vary with location; the following is a sample answer for Boulder, Colorado.
    a. The latitude in Boulder is 40°N and the longitude is about 105°E.
    b. The north celestial pole appears in Boulder's sky at an altitude of 40°, in the direction due north.
    c. Polaris is circumpolar because it never rises or sets in Boulder's sky. It makes a daily circle, less than 1° in radius, around the north celestial pole.
    d. The meridian is a half-circle that stretches from the due south point on the horizon, through the zenith, to the due north point on the horizon.
    e. In Boulder, the celestial equator is a half-circle that stretches from the due east point on the horizon, through an altitude of 50° due South, to the due west point on the horizon.
20. a. At full moon, you would see new earth from your home on the Moon. It would be daylight at your home, with the Sun on your meridian and about a week until sunset.
    b. If you lived on the Moon, the Earth would remain nearly fixed in the same place in your sky at all times. This occurs because the Moon keeps the same face to Earth at all times. As

the Moon orbits the Earth, you'd see the Earth go through phases at its (nearly) fixed point in your sky. (*Note:* The Earth would not remain perfectly stationary due to the Moon's elliptical orbit, which means we actually see slightly different portions of the Moon's face at different times of month [the effect called *libration*]. Thus, the Earth would trace a small ellipse in the sky each month.)

   c. If you were on the Moon during a total lunar eclipse (as seen from Earth), you would see a total eclipse of the Sun. If you were on the Moon during a total solar eclipse (as seen from Earth), you would see the small circular shadow of the Moon on the full earth.

21. If the Moon were twice as far from the Earth, its angular size would be too small to create a total solar eclipse. It would still be possible to have annular eclipses, though the Moon would cover only a small portion of the solar disk. Lunar eclipses could still occur, as the Earth's shadow would still be big enough to cover the Moon.
22. If the Earth were smaller in size, solar eclipses would still occur in about the same way, since they are determined by the Moon's shadow on the Earth. However, lunar eclipses would be different because the Earth's shadow would be smaller; depending on how small, it might or might not still be able to cover the Moon.
23. This is an observing project that will stretch over several weeks.
24. This is a literary essay that requires reading the Mark Twain novel.
25. a. There are $360 \times 60 = 21{,}600$ arcminutes in a full circle.
    b. There are $360 \times 60 \times 60 = 1{,}296{,}000$ arcseconds in a full circle.
    c. The Moon's angular size of 0.5° is equivalent to 30 arcminutes or $30 \times 60 = 1{,}800$ arcseconds.

Chapter 3. The Science of Astronomy

Most students do not really understand how science works, and our aim in this chapter is to edify them in an interesting and multicultural way. If you are used to teaching from other textbooks, you may be surprised that we have chosen to wait until Chapter 3 to introduce this material. However, we have found that students are better able to appreciate the scientific method and the development of science after they first have some idea of what science has accomplished. Thus, we find that covering the development of science at this point is more effective than introducing it earlier.

- If your course focuses on the solar system, you may wish to emphasize this material heavily in class, and perhaps supplement it with your favorite examples of ancient astronomy.
- If your course focuses on stars, galaxies, or cosmology, you may decide not to devote class time to this chapter at all, or to concentrate only on Section 3.5 on the nature of science. However, you may still wish to have your students read this chapter, as it may prove useful in later discussions about the nature of science.

As always, when you prepare to teach this chapter, be sure you are familiar with the relevant media resources (see the complete, section-by-section resource grid in Appendix 3 of this Instructor's Guide) and the on-line quizzes and other study resources available on the Astronomy Place website.

What's New in the Third Edition That Will Affect My Lecture Notes?

As everywhere in the book, we have edited to improve the text flow, improved art pieces, and added new illustrations. In addition, those who have taught from previous editions of *The Cosmic Perspective* should be aware of the following organizational or pedagogical changes to this chapter (i.e., changes that will influence the way you teach) in the third edition:

- We have completely rewritten Section 3.3 to expand our coverage of ancient Greek modeling. Note the new Figure 3.13, useful as a reference throughout the book.
- Section 3.4 on the Copernican revolution was formerly found in Chapter 5 of the second edition. We moved it here to make a clear historical connection from the Greeks through the Copernican revolution.
- We have completely rewritten Section 3.5 on the nature of science to give a more realistic view of how science works and what distinguishes science from nonscience. In particular, we no longer emphasize the idealized scientific method, instead focusing on what we now call the "hallmarks of science" (summarized in the new Figure 3.26).

Teaching Notes (By Section)

Section 3.1 Everyday Science

This short section is designed to show students that "scientific thinking" is not so different from "everyday thinking," despite the common stereotypes of scientists.

Section 3.2 The Ancient Roots of Science

This section introduces students to the development of astronomy by discussing how ancient observations were made and used by different cultures. We stress that these ancient observations helped lay the groundwork for modern science. The particular examples cited were chosen to give a multicultural perspective on ancient astronomy; instructors may wish to add their own favorite examples of ancient observations. In teaching from this section, you can take one of two basic approaches, depending on how much time you have available: (1) If you have little time to discuss the section in class, you can focus on the examples generally without delving into the observational details; or (2) if you have more time available, you can emphasize the details of how observations allowed determination of the time and date, and of how lunar cycles are used to make lunar calendars.

Section 3.3 Ancient Greek Science

This section focuses on the crucial role of the ancient Greeks in the development of science. We focus on the idea of creating scientific *models* through the example of the gradual development of the Ptolemaic model of the universe. We also try to give context for the timeline of the Greek developments. The section concludes with discussion of the Islamic role in preserving and expanding upon Greek knowledge, setting the stage for discussion of the Copernican revolution in the next section.

Section 3.4 The Copernican Revolution

With the background from the previous two sections, students now are capable of understanding how and why the geocentric model of the universe was abandoned. We therefore use this section to discuss the unfolding of the Copernican revolution by emphasizing the roles of each of the key personalities.

- Note that Kepler's laws are introduced in this section, in their historical context.
- Note that we present Galileo's role by focusing on how he overcame remaining objections to the Copernican model. This is a particularly good example of the working of science, since it shows both that old ideas were NOT ridiculous while also showing how new ideas gained acceptance.

Section 3.5 The Nature of Science

The historical background of the previous sections has students ready to discuss just what science really is. A few notes:

- We distinguish between discovery science and hypothesis-driven science primarily so that students will see that the "scientific method" is not universal. It can be a useful idealization, but science rarely proceeds so linearly.
- The most important part of this section is the "hallmarks of science." We have developed these three hallmarks through extensive discussions with both scientists and philosophers of science, and we believe they represent a concise summary of the distinguishing features of science.
- One of the key reasons that the hallmarks are useful is that they make it relatively easy for students to distinguish between science, nonscience, and pseudoscience.
- We include only a very brief discussion of the idea of scientific paradigms; you may wish to supplement this discussion with your favorite examples of paradigm shifts.

Section 3.6 Astrology

Public confusion between astronomy and astrology is well known. To address this confusion, we end this chapter with a discussion designed to help students distinguish between the two. We have tried to avoid direct criticism of astrology and astrologers even while pointing out that it is clearly not a science. Nevertheless, we suggest that you treat this topic carefully. A fair number of students are hard-core believers in astrology, and an attempt to dissuade them may backfire by making them dislike you and/or your course. If you can at least get such students to ask a few questions of themselves and their beliefs, you will have achieved a great deal.

Answers/Discussion Points for Think About It Questions

The Think About It questions are not numbered in the book, so we list them in the order in which they appear, keyed by section number.

Section 3.1

- This question simply asks students to think about the process of learning by trial and error. If you use this question for in-class discussion, you should encourage students to think about how this process is similar to the process of thinking used in science.

Section 3.2

- This question often generates interesting discussion, particularly if some of your students have read the claims that the Nazca lines have alien origins. We hope students will recognize that such claims shortchange the people who lived there by essentially claiming that they weren't smart enough to have created the lines and patterns themselves. In that way, students usually conclude that the arguments favoring alien origins do not make much sense.

Section 3.3

- The intent of this question is to help students gain appreciation for the accomplishments of ancient Greece. In class, this question can lead to further discussion of how much was lost when the Library of Alexandria was lost and also to discussion of whether the knowledge of our own civilization might suffer a similar fate.

Section 3.4

- Kepler's third law tells us that orbital period depends only on average distance, so the comet with an average distance of 1 AU would orbit the Sun in the same time that Earth orbits the Sun: one year. Kepler's second law tells us that the comet would move fast near its perihelion and slow near its aphelion, so it would spend most of its time far from the Sun, out near the orbit of Mars.

Section 3.5

- When someone says that something is "only a theory," they usually mean that it doesn't have a lot of evidence in its favor. However, according to the scientific definitions, the term "only a theory" is an oxymoron, since a theory must be backed by extensive evidence. Nevertheless, even scientists often use the word in both senses, so you have to analyze the context to decide which sense is meant.
- This question will often generate debate. It is difficult to call claims of UFOs science, since no publicly testable evidence is offered. However, some students may feel uncomfortable saying it is pseudoscience. It's a good discussion topic.

Section 3.6

- This question asks students to think about the type of prediction made by a newspaper horoscope, as opposed to the more specific prediction of a weather forecast. This can lead to an interesting discussion about what constitutes a testable prediction. In class, you may wish to bring examples of more detailed horoscopes or do an experiment to test astrology.

Solutions to End-of-Chapter Problems (Chapter 3)

1. If we defined hours as the ancient Egyptians did, we'd have the longest hours on the summer solstice and the shortest hours on the winter solstice. *This statement is true, because the Egyptians divided the daylight hours into 12 equal parts, regardless of the time of year. Thus, the longer daylight in summer meant the Egyptian hour was longer in summer.*
2. The date of Christmas (December 25) is set each year according to a lunar calendar. *This statement does not make sense, because December 25 is a date on a solar calendar.*
3. When navigating in the South Pacific, the Polynesians found their latitude with the aid of the pointer stars of the Big Dipper. *This statement does not make sense, because the Big Dipper and north celestial pole are not visible from deep in the Southern Hemisphere.*
4. The Ptolemaic model reproduced apparent retrograde motion by having planets move sometimes counterclockwise and sometimes clockwise in their circles. *This statement is false. The Ptolemaic model did not vary the directions in which planets moved; it reproduced apparent retrograde motion by having the planets turn on small circles upon larger circles.*
5. In science, saying that something is a theory means that it is really just a guess. *This statement is false. In science, a theory must be well tested.*
6. Ancient astronomers were convinced of the validity of astrology as a tool for predicting the future. *This statement is false. As demonstrated by the quote from Ptolemy in Section 3.6, ancient astronomers recognized that astrology was less useful as a predictive tool than astronomy.*
7. If the planet Uranus had been identified as a planet in ancient times, we'd probably have eight days in a week. *It's impossible to know whether this would be true or false, but it makes sense based on the origin of the names of the days of our week. With an eighth "planet" visible in the sky, we might well have had eight days in a week.*
8. Upon its publication in 1543, the Copernican model was immediately accepted by most scientists, because its predictions of planetary positions were essentially perfect. *This statement does not make sense, because the original Copernican model did not make particularly accurate predictions.*

9–15. These questions all ask students to briefly restate and explain ideas taken directly from the reading. The key in grading these questions is to make sure that students demonstrate that they *understand* the concepts about which they are writing.

16. Answers will vary depending on the idea chosen. The key in grading is for students to explain themselves clearly and to defend their opinions well.
17. This essay question can generate interesting responses. Of course, the impacts of the Copernican revolution involve opinion, so grade essays based on how well they are written and defended.

18–21. These questions involve independent research. Answers will vary.

22. This problem requires students to devise their own scientific test of astrology. One example of a simple test is to cut up a newspaper horoscope and see whether others can correctly identify the one that applies to them.

Chapter S1. Celestial Timekeeping and Navigation

This is a supplementary chapter, meaning that coverage is optional—nothing in this chapter is prerequisite for the rest of the book. This final chapter of Part 1 fills in details about apparent motions of the sky that have not already been covered in the first three chapters. Note that, although it covers fairly "basic" ideas about the sky, this material is often quite difficult for students. Understanding motions of the sky requires visualizing 3-D geometry, which some students simply cannot grasp in just a week or so. It certainly helps if you have access to a planetarium when covering the motions of the sky.

As always, when you prepare to teach this chapter, be sure you are familiar with the relevant media resources (see the complete, section-by-section resource grid in Appendix 3 of this Instructor's Guide) and the on-line quizzes and other study resources available on the Astronomy Place website.

Teaching Notes (By Section)

Section S1.1 Astronomical Time Periods

This section introduces basic astronomical periods: the solar versus the sidereal day; the synodic versus the sidereal month; the tropical versus the sidereal year; and synodic versus sidereal periods of the planets.

- You may wish to do the demonstration described in the text for showing the difference between a sidereal and a solar day; it's easy for students to watch you rotating as you walk around an object that represents the Sun.
- Technical note: The true rotation period of the Earth differs from the sidereal day by a few thousandths of a second because of the precession of Earth's axis.

Section S1.2 Daily Timekeeping

This section covers our basic modes of daily timekeeping.

- If your campus has a sundial, take a class field trip or ask your students to investigate it on their own.

Section S1.3 The Calendar

This section covers the calendar.

- Many students will find the issues of calendar reform quite interesting from a historical point of view, especially the fact that, for centuries, not all countries agreed on the date, even if they were ostensibly using the same "Christian" calendar.

Section S1.4 Mapping Locations in the Sky

The main purpose of this section is to introduce the celestial coordinates of declination and right ascension. In class, you may want to emphasize that these coordinates are easier to understand if we think of them as "celestial latitude" and "celestial longitude."

Section S1.5 Understanding Local Skies

This section covers the variation in sky motions with latitude.

- If possible, it really helps if you can visit a planetarium to demonstrate the motions described in this section. In that case, you may wish to begin by pointing out how its dome distorts what we see in the real sky. In particular, the point in the planetarium representing the zenith generally is directly over the projector, rather than over any audience member's head. As a result, the planetarium sky looks most distorted above wherever you are sitting. The other major distortion is the smaller angular size of everything viewed in the planetarium compared to the real sky.
- We've found that the order in which sky motions at different latitudes are described is very important in helping students understand what is going on. The order we've chosen begins with the simplest latitudes—the North Pole and then the equator. In class, you should next do your own latitude, then generalize.
- Keep in mind that some otherwise bright students will have difficulty with this 3-D geometry regardless of what you do. Such students may simply have to memorize the rules rather than truly understanding the geometry.

Section S1.6 Principles of Celestial Navigation

This section gives a brief overview of techniques of celestial navigation.

- *Technical note:* Common Misconceptions: Compass Directions. In this box, we say "magnetic north" to mean the magnetic pole located in the Northern Hemisphere. In terms of response to magnetism, the magnetic pole in the Northern Hemisphere is a *south* magnetic pole; that is why the north end of a magnet is attracted in this direction. Similarly, by "south magnetic pole" we really mean the magnetic pole located in the Southern Hemisphere—which is a *north* magnetic pole, according to its magnetic properties.

Answers/Discussion Points for Think About It Questions

The Think About It questions are not numbered in the book, so we list them in the order in which they appear, keyed by section number.

Section S1.1

- At midnight, looking toward the meridian means looking in a direction 180° away from the Sun. Neither Mercury nor Venus ever ventures anywhere close to this far from the Sun as viewed from Earth; neither, therefore, ever appears on the meridian at midnight.

Section S1.2

- 12:01 A.M. is 1 minute after midnight, while 12:01 P.M. is 1 minute after noon.

Section S1.4

- This exercise asks students to continue work with their own model of the celestial sphere, which we explain how to make in the main text (a few paragraphs earlier). On April 21, the Sun is about 1/12 of the way around the ecliptic from the spring equinox. On November 21, it is about 1/12 of the way short of being at the winter solstice.
- This exercise again asks students to continue building their own model of the celestial sphere.

•Again, students will mark their models of the celestial sphere. They should now be able to locate the Sun for any day, including their birthdays.

Section S1.5

•No stars are circumpolar at the equator, and all portions of the celestial sphere become visible over the course of the day.
•At 30°S latitude, the celestial equator crosses the meridian at altitude 90° – 30° = 60° in the northern half of the sky. Stars with positive declinations follow short tracks across the northern sky. Stars with negative declinations follow long tracks across the southern sky (crossing into the north if they have a declination between 0° and –30°). Stars with declinations more negative than –60° are circumpolar.

Solutions to End-of-Chapter Problems (Chapter S1)

1. Last night I saw Venus shining brightly on the meridian at midnight. *This statement does not make sense, because it would require that Venus be at opposition to the Sun in the sky—and, because Venus is closer to the Sun than is Earth, it is never at opposition.*
2. The apparent solar time was noon, but the Sun was just setting. *This statement does not make sense, because apparent solar noon is defined as the time when the Sun is at its highest point on the meridian. If the Sun is at its highest point, it cannot be setting.*
3. My mean solar clock said it was 2:00 P.M., but my friend who lives east of here had a mean solar clock that said it was 2:11 P.M. *Mean solar time is different for every different longitude, so this statement makes sense if the friend lives the equivalent of 11 minutes of longitude east of you.*
4. When the standard time is 3:00 P.M. in Baltimore, it is 3:15 P.M. in Washington, D.C. *This statement does not make sense, because standard time zones must be one hour apart, not 15 minutes apart. (Also, both Baltimore and Washington, D.C., are in the same time zone.)*
5. The Julian calendar differed from the Gregorian calendar because it was based on the sidereal year. *This statement is simply not true; both calendars are based on the tropical year.*
6. Last night around 8 P.M., I saw Jupiter at an altitude of 45° in the south. *This statement makes sense, because it describes the position of Jupiter in your local sky.*
7. The latitude of the stars in Orion's belt is about 5°N. *This statement does not make sense; Orion's belt is not on the Earth, and hence does not have a latitude.*
8. Today the Sun is at an altitude of 10° on the celestial sphere. *This statement does not make sense, because altitude is a coordinate of the local sky, not of the celestial sphere.*
9. Los Angeles is west of New York by about 3 hours of right ascension. *This statement does not make sense, because right ascension is a coordinate of the celestial sphere, not of the Earth.*
10. The summer solstice is east of the vernal equinox by 6 hours of right ascension. *This statement is true at all times.*
11. If it were being named today, the tropic of Cancer would probably be called the tropic of Gemini. *This statement makes sense, because the tropic of Cancer got its name from the constellation (Cancer) in which the Sun appeared on the summer solstice. As a result of precession, today the Sun appears in Gemini rather than in Cancer on the summer solstice.*
12. Even though my UT clock had stopped, I was able to find my longitude by measuring the altitudes of 14 different stars in my local sky. *This statement does not make sense, because longitude determination requires comparing the positions of stars (or the Sun) in your location with their positions in a known location, and the latter requires knowing the time in that location. Thus, without a clock, you can't determine your longitude.*

13–20. These questions all ask students to briefly restate and explain ideas taken directly from the reading. The key in grading these questions is to make sure that students demonstrate that they *understand* the concepts about which they are writing.

21. If the Earth rotated in the opposite direction (with the same period), the solar day would be slightly shorter than the sidereal day, rather than slightly longer.

22. Answers will vary with latitude (except for part (b)); the following is a sample answer for 40°N latitude.
    a. The north celestial pole appears in your sky at an altitude of 40°, in the direction due north.
    b. The meridian is a half-circle that stretches from the point due south on the horizon, through the zenith, to the point due north on the horizon.
    c. The celestial equator is a half-circle that stretches from the point due east on the horizon, through an altitude of 50° due south, to the point due west on the horizon.
    d. The Sun can appear at the zenith only in the tropics. At latitude 40°N, the Sun is never at the zenith.
    e. Because the north celestial pole appears due north at an altitude of 40°, a star is circumpolar if it is *within* 40° of the north celestial pole. The north celestial pole has a declination of +90°, so *within* 40° means declinations *greater than* +50°.
    f. The celestial equator reaches a maximum altitude of 50° in the southern sky. Thus, any star that is more than 50° south of the celestial equator is never visible above the horizon. More than 50° south of the celestial equator means declinations *more negative than* –50°.

23. For Sydney, 34°S latitude:
    a. The south celestial pole appears in your sky at an altitude of 34°, in the direction due south.
    b. The meridian is a half-circle that stretches from the point due south on the horizon, through the zenith, to the point due north on the horizon.
    c. The celestial equator is a half-circle that stretches from the point due east on the horizon, through an altitude of 56° due north, to the point due west on the horizon.
    d. The Sun can appear at the zenith only in the tropics. At latitude 34°S, the Sun is never at the zenith.
    e. Because the south celestial pole appears due south at an altitude of 34°, a star is circumpolar if it is *within* 34° of the south celestial pole. The south celestial pole has a declination of –90°, so *within* 34° means declinations *more negative than* –56°.
    f. The celestial equator reaches a maximum altitude of 56° in the northern sky. Thus, any star that is more than 56° north of the celestial equator is never visible above the horizon. More than 56° north of the celestial equator means declinations *greater than* +56°.

24. Answers will vary with latitude; the following is a sample answer for 40°N latitude.
    a. On the spring or fall equinox, the Sun rises due east, reaches an altitude of 50°S on the meridian, and sets due west.
    b. On the summer solstice, the Sun rises *more than 23.5° north of* due east, reaches an altitude of 50° + 23.5° = 73.5° on the meridian *in the south*, and sets *more than 23.5° north of* due west.
    c. On the winter solstice, the Sun rises *more than 23.5° south of* due east, reaches an altitude of 50° – 23.5° = 26.5° on the meridian *in the south*, and sets *more than 23.5° south of* due west.
    d. Answers depend on the date.

25. In Sydney (lat. 34°S): CE goes due east, through $90° - 34° = 56°$ in the north, to due west.
   a. On the spring or fall equinox, the Sun rises due east, reaches an altitude of 56°N on the meridian, and sets due west.
   b. On the summer solstice, the Sun rises *more than 23.5° north of* due east, reaches an altitude of $56° - 23.5° = 32.5°$ on the meridian *in the north*, and sets *more than 23.5° north of* due west.
   c. On the winter solstice, the Sun rises *more than 23.5° south of* due east, reaches an altitude of $56° + 23.5° = 79.5°$ on the meridian *in the north*, and sets *more than 23.5° south of* due west.
   d. Answers depend on the date.
26. a. Your latitude is 15°N. Because it is the vernal equinox, the Sun follows the path of the celestial equator through the sky. Thus, the Sun's meridian altitude of 75°S tells you that this also is the altitude at which the celestial equator crosses the meridian. Because we know that the celestial equator crosses the meridian at 90°– [your latitude], your latitude is $90° - 75° = 15°$; it is north latitude because the celestial equator is in your southern sky.
   b. Your longitude is 150°W. The Sun is on your meridian, so it is noon for you. The UT clock reads 22:00, or 10 P.M., so Greenwich is 10 hours ahead of you. Each hour represents 15° of longitude, so 10 hours means 150°; you are west of Greenwich because your time is behind.
   c. You are very close to Hawaii.
27. a. You are on the equator. Because it is the summer solstice, the Sun crosses the meridian 23.5° north of the celestial equator. Thus, the Sun's meridian altitude of 67.5°N tells you that the celestial equator is passing through your zenith and hence that you are on the Earth's equator.
   b. Your longitude is 90°E. The Sun is on your meridian, so it is noon for you. The UT clock reads 06:00, or 6 A.M., so Greenwich is 6 hours behind you. Each hour represents 15° of longitude, so 6 hours means 90°; you are east of Greenwich because your time is ahead.
   c. You are in the Indian Ocean, not too far west of the island of Sumatra.
28. a. Your latitude is within 1° of 67°N, which you know because that is the altitude of Polaris in your sky.
   b. Your longitude is 15°W. Your local time is midnight and the UT clock reads 01:00, or 1 A.M., so Greenwich is 1 hour ahead of you. Thus, you are 15° west of Greenwich.
   c. You are just off the northern coast of Iceland.
29. a. Your latitude is 33°S, which you know because that is the altitude of the south celestial pole in your sky.
   b. Your longitude is 75°W. Your local time is 6 a.m. and the UT clock reads 11:00, or 11 A.M., so Greenwich is 5 hours ahead of you. Thus, you are $5 \times 15° = 75°$ west of Greenwich.
   c. You are off the coast of Chile, nearly due west of Santiago.
30. a. On the day of the spring equinox, the Sun is located at the position of the spring equinox in the sky. Thus, at 4 P.M., both the Sun and the spring equinox are 4 hours past the meridian, so the local sidereal time is 4 hours.
   b. Vega has RA = $18^h\,35^m$. Thus, at LST = 19:30, Vega's hour angle is:

$$HA_{Vega} = LST - RA_{Vega} = 19{:}30 - 18{:}35 = 00{:}55$$

   Vega crossed your meridian about 55 minutes ago, which means it will cross again in about 23 hours 5 minutes.

c. We are given HA_{star} = 3 hours and LST = 8:15. Thus, we have the equation:

$$HA_{star} = LST - RA_{star}$$

Solving for the RA of the star, we find:

$$RA_{star} = LST - HA_{star} = 08{:}15 - 03{:}00 = 05{:}15$$

The star has a right ascension of 5 hours 15 minutes.