

Chapter-by-Chapter Guide

Part I: Developing Perspective

The remainder of this Instructor Guide goes through the book chapter by chapter. Each chapter is organized as follows:

- A brief introduction with general comments about the chapter.
- 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 and See It for Yourself Questions.
- Solutions to End-of-Chapter Problems.

Chapter 1. A Modern View of 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 the scale of the universe (Section 1.1), the history of the universe and the scale of 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 online quizzes, interactive figures and tutorials, assignable homework, and other resources available on the MasteringAstronomy Web site.

Key Changes for the 8th Edition: For those who have used earlier editions of our textbook, please note the following significant changes in this chapter:

- Updated definition of galaxies to reflect recent discoveries.
- Added emphasis on dark matter and dark energy, so students will be prepared for the fact that we will now be making more use of these ideas in our discussion of galaxy evolution (which comes before we discuss the mysterious natures of dark matter and dark energy in Chapter 23).
- Updated Figure 1.1 to show Milky Way with bar and more realistic background universe.
- Updated Special Topic on Pluto and planet definition.
- New Figure 1.8 to match up with the foldout in front of book.

Teaching Notes (by Section)

Section 1.1 The Scale of the Universe

This section provides a brief overview of our place in the universe, including the hierarchical structure of the universe (our cosmic address) and the scale of the universe.

- Our emphasis on scale may seem unusual to those who have not taught from our book previously. However, we believe it is an extraordinarily important topic that generally is underappreciated by students. Most students enter our course without any realistic view of the true scale of the universe, and without the context of scale, they are likely to misinterpret much of the rest of the content and detail in an astronomy course. That is why, in addition to the discussion of scale in this section and throughout the book, we have also included the foldout “You Are Here in Space” in the front of the book, so students can refer to ideas of scale at any time.
- Note that the section begins with a brief discussion of the Hubble eXtreme Deep Field, which helps set the context for an overview of our place in the universe.
- Note the box on “Basic Astronomical Definitions”: 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 want to emphasize them here in Chapter 1.
- This section introduces astronomical distance measurements in AU and light-years. A couple of notes on our choices and definitions:
 - There are several different ways to define an average distance between Earth and the Sun (e.g., averaged over phase, over time, etc.). In defining an astronomical unit (AU) as the *average* distance between Earth and the Sun, we are using the term *average* to mean $(\text{perihelion} + \text{aphelion})/2$, 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*.
 - Note that we’ve chosen to use *light-years* rather than *parsecs* as our primary unit for stellar and galactic distances for 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, 1 light-year happens to be very close to 10^{13} kilometers (9.46×10^{12} kilometers), making unit conversions very easy—this helps students remember that light-years are a unit of distance, not of time.

- Note that in discussing distances to very distant galaxies, we give distances in terms of lookback times; for example, when we say “7 billion light-years,” we mean a lookback time of 7 billion years. With this definition, the radius of the observable universe is about 14 billion light-years, corresponding to the age of the universe. Unfortunately, some media reports instead quote distances as they would be today with the ongoing expansion, hence saying that the universe is 40+ billion light-years in radius. As a result, some students may be confused about which is the “real” radius of the observable universe. To alleviate this confusion, in Chapter 20 we explain that
 - “Distance” is ambiguous in an expanding universe; e.g., do you mean an object’s distance at the time the light left, or now, or some time in between? The choice is arbitrary, with no particular choice (such as “now”) being any better than any other (such as “at the time the light left”).
 - In contrast, “lookback time” is unambiguous—it is the actual amount of time that the light has been traveling to reach us. For this reason, we feel that lookback time is a much better way to describe distances.
- For our discussion of scale, we begin by making use of the 1-to-10-billion scale of the Voyage scale model solar system in Washington, D.C., a project that was proposed by *The Cosmic Perspective* author Jeff Bennett. Voyage replicas are being developed for other science centers and universities; if you are interested in learning more about how to get a Voyage replica in your town, please contact Jeff by e-mail (jeff@bigkidsscience.com).
- With regard to the count to 100 billion, it can be fun in lecture to describe what happens when you ask children how long it would take. Young children inevitably say they can count much faster than one per second. But what happens when they get to, say, “twenty-four billion, six hundred ninety-seven million, five 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 meters (based on beaches we’ve seen eroded by storms) and estimate the width of a typical beach at 20–50 meters; 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} meters, or 10^8 kilometers, to make a volume of 10^{13} m^3 . This is almost certainly greater than the linear extent of sandy beaches on Earth.

Section 1.2 The History of the Universe

This section provides a brief overview of our place in time, including an overview of the history of the universe (our cosmic origins) and the scale of time.

- As in the first section, we include a major emphasis on scale—in this case, the scale of time. Be sure to point out the backside of the foldout in the front of the book, which is called “You Are Here in Time” and is in some sense a summary of this section.
- We give the age of the universe as “about 14 billion years”; we feel this rounding to two significant digits makes it easier for students to understand, given that the current best estimate age (from the Planck mission) is 13.82 billion years, with a 1 sigma error bar of about 0.1 billion years.
- 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 Earth in space, using R. Buckminster Fuller’s idea of *Spaceship Earth*.

- Note that the summary figure for this section comes at its end, in Figure 1.17.
- 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 (although 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?
- Similarly, we briefly introduce the ideas of dark matter and dark energy, since students have almost undoubtedly heard of them in the media.
- With regard to our solar system’s distance from the center of the galaxy, the literature offers values over a fairly wide range; for example:
 - 27,200 \pm 1,100 lt-yr (Gilessen et al. 2009 – from stellar orbits around central BH)
 - 25,400 \pm 2,000 lt-yr (Majaess et al. 2009 – from Cepheids)
 - 25,700 \pm 2,600 lt-yr (Reid et al. 2009 – VLBI of water masers near GC)

Based on this range, we have chosen to go with 27,000 light-years, which is the result above with the smallest error bars and which is consistent with all three ranges.

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 quotation from *Time* magazine (Richard N. Ostling, John Moody, Rome and Amanv Radwan), December 28, 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 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/See It for Yourself Questions

The Think About It and See It for Yourself 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

- (p. 2) This question is, of course, very subjective, but can make for a lively in-class debate.
- (p. 4, SIFY) The main goal of this activity is for students to go out and look for the Andromeda Galaxy and contemplate seeing light that has been traveling through space for 2.5 million years. If people in the Andromeda Galaxy were looking at the Milky Way, they would see a spiral galaxy looking much like their galaxy looks to us. They would see our galaxy as it was about 2.5 million years ago (due to light travel time) and thus could not know that our civilization exists here today.

- (p. 10) This question 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, the question 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.
- (p. 11) This is another very subjective question, but it should get students thinking about the size of Earth in the cosmos. (It should also get them to study the scale foldout in the front of the book.) At the least, most students are very surprised at how small our planet seems in relation to the solar system. For most students, its small size makes Earth seem a little more fragile, and often makes them think more about how we can best take care of our planet.

Section 1.2

- (p. 14) This is another very subjective question, similar to the one at the end of Section 1.1 but focused on our place in time rather than in space.

Section 1.3

- (p. 15) As we authors 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.
- (p. 16) 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).
- (p. 18) This question just checks student understanding of the raisin cake figure. For a raisin that starts out at 10 cm, after one hour it is 30 cm away, which means it appears to be moving away from the Local Raisin at a speed of 20 cm/hr.

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

Visual Skills Check

1. b
2. c
3. c
4. No, the nearest stars would not fit on Earth with this scale.

Review Questions

1. The largest scale is the universe itself, which is the sum total of all matter and energy. The largest known organized structures are superclusters of galaxies, then clusters and groups of galaxies, and then the roughly 100 billion individual galaxies, most of which are many thousands of light-years across. Each galaxy contains billions of stars, and many or most stars may be orbited by planets.
2. Astronomical unit: the average distance between Earth and Sun, which is about 1.496×10^8 kilometers. Light-year: the distance that light travels in 1 year, which is about 9.46 trillion kilometers.
3. Because light travels at a fixed speed, it takes time for it to go between two points in space. Although light travels very quickly, the distances in the universe are so large that the time for light to travel between stars is years or longer. The farther away we look, the longer it takes light to have traveled to us from the objects. So the light we see from more distant objects started its journey longer ago. This means that what we see when we look at more distant objects is how they looked longer ago in time. So, looking farther away means looking further back in time.
4. The observable universe is the portion of the entire universe that we can in principle see; it is about 14 billion light-years in radius, because light from more than 14 billion light-years away could not yet have reached us during the 14 billion years since the Big Bang. Scientists currently think that the entire universe is larger than the observable universe.
5. Solar system: On the 1-to-10-billion scale, the Sun is about the size of a grapefruit and the planets are the sizes of marbles or smaller. The distances between the planets are a few meters for the inner solar system to many tens of meters in the outer solar system. Distances to nearby stars: On the same scale, the nearest stars are thousands of kilometers away. The Milky Way Galaxy: One way to understand the size of our galaxy is to note that if the Milky Way were the size of a football field, then the distance to the nearest star would be about 4 millimeters. The number of stars in the galaxy is more than 100 billion, so many that it would take thousands of years to count them out loud. The observable universe: One way to get a sense of the size of the observable universe is to note that the number of stars in it is comparable to the number of grains of sand on all of the beaches on Earth.
6. When we say that the universe is expanding, we mean that the average distance between galaxies is increasing with time. If the universe is expanding, then if we imagine playing time backward, we'd see the universe shrinking. Eventually, if we went far enough back in time, the universe would be compressed until everything was on top of everything else. This suggests that the universe may have been very tiny and dense at some point in the distant past and has been expanding ever since. This beginning is what we call the Big Bang. Based on observations of the expansion rate, the Big Bang must have occurred about 14 billion years ago.

7. We are “star stuff” because most of the atoms in our bodies (all the elements except for hydrogen, since our bodies generally do not contain helium) were made by stars that died long ago. These elements were released into space when the stars died, where they were then incorporated into new generations of stars. This is how our solar system obtained those elements, which became part of Earth and ultimately part of us.
8. There are numerous ways to describe how humanity fits into cosmic time, but here is one straight from the cosmic calendar: If the entire history of the universe were compressed into a single year, modern humans would have evolved only 2 minutes ago and the pyramids would have been built only 11 seconds ago.
9. Earth rotates once each day on its axis and orbits the Sun once each year. The ecliptic plane is the plane defined by Earth’s orbit around the Sun. Most of the other planets orbit nearly in this same plane. Axis tilt is the amount that a planet’s rotation axis is tipped relative to a line *perpendicular* to the ecliptic plane.
10. The Milky Way Galaxy is a spiral galaxy, which means that it is disk-shaped with a large bulge in the center. The galactic disk includes a few large spiral arms. Our solar system is located about 27,000 light-years from the center of the galaxy, or about halfway out to the edge of the galaxy. Our solar system orbits about the galactic center in a nearly circular orbit, making one trip around every 230 million years.
11. Dark matter is matter that does not emit light and is therefore invisible to our telescopes, but that we can detect because it has gravity that affects other objects we *can* see. Most dark matter resides in the halo of the galaxy, which is the large, spherical region that surrounds the galaxy’s flat disk. Dark energy is the name given to whatever is causing the expansion of the universe to accelerate with time. Dark matter and dark energy are mysterious because we don’t know exactly what they are, and they are important because they make up the majority of the total energy content of the universe.
12. Edwin Hubble discovered that most galaxies are moving away from our galaxy, and the farther away they are located, the faster they are moving away. While at first this might seem to suggest that we are at the center of the universe, a little more reflection indicates that this is not the case. If we imagine a raisin cake rising, we can see that every raisin will move away from every other raisin. So each raisin will see all of the others moving away from it, with more distant ones moving faster—just as Hubble observed galaxies to be moving. Thus, just as the raisin observations can be explained by the fact that the raisin cake is expanding, Hubble’s galaxy observations tell us that our universe is expanding.

Does It Make Sense?

13. *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.
14. *The universe is billions of light-years in age.* This statement does not make sense, because it uses the term “light-years” as a time, rather than as a distance.

15. *It will take me light-years to complete this homework assignment.* This statement does not make sense, because it uses the term “light-years” as a time, rather than as a distance.
16. *Someday we may build spaceships capable of traveling a light-year in only a decade.* This statement is fine. A light-year is the distance that light can travel in 1 year, so traveling this distance in a decade would require a speed of 10% of the speed of light.
17. *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.
18. *NASA will soon launch a spaceship that will photograph our Milky Way Galaxy from beyond its halo.* 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 to get high enough into the halo to photograph the disk, and then tens of thousands of years more for the picture to be transmitted back to Earth.
19. *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.
20. *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.
21. *At a nearby park, I built a scale model of our solar system in which I used a basketball to represent 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.)
22. *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.)

Quick Quiz

23. a
24. b
25. c
26. b

- 27. a
- 28. b
- 29. c
- 30. b
- 31. a
- 32. a

Process of Science

- 33. Major changes in scientific views are possible because science relies on physical evidence. Science must be backed by evidence from observations or experiments, and when the evidence does not back up the scientific story, the story is changed. That is what happened, for example, when belief in an Earth-centered universe gave way to the idea that Earth orbits the Sun. (In contrast, religious or cultural beliefs generally are less subject to change, because they are based on faith or scriptures rather than on a search for physical evidence.)
- 34. Using the Voyage model scale (1 to 10 billion), Earth is barely 1 mm across but is located 15 meters from the Sun. In other words, Earth's distance from the Sun is some 15,000 times as great as Earth's diameter. Given that fact, the difference in distance of the day and night sides of Earth is negligible, so it would be difficult to see how it could explain day and night temperature differences. If we had no other explanation for the temperature difference, then we might still be forced to consider whether there is some missing piece to our understanding. In this case, however, we have a much simpler alternative explanation: the day side is warm because it faces the Sun, and the night side is cooler because it faces away from the Sun.
- 35. Answers will vary. This question is designed to get students thinking about the nature of evidence and what it might take to get them to accept some scientific idea.

Group Work Exercise (no solution provided)

Short Answer/Essay Questions

- 37. This is a short essay question. Key points should include discussion of the difference in scale between interstellar travel and travel about our own world, so that students recognize that alien technology would have to be far more advanced than our own to allow them to visit us with ease.
- 38. a. The diagrams should be much like Figure 1.16, except that the distances between raisins in the expanded figure will be 4 centimeters instead of 3 centimeters.

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.
39. a. This problem asks students to draw a sketch. Using the scale of 1 centimeter = 100,000 light-years, the sketches should show that each of the two galaxies is about 1 centimeter in diameter and that the Milky Way and M31 are separated by about 25 centimeters.
- 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.
40. This is a subjective essay question. Grade should be based on clarity of the essay.

Quantitative Problems

41. a. A light-second is the distance that light travels in 1 second. We know that light travels at a speed of 300,000 kilometers per second, so a light-second is a distance of 300,000 kilometers.
- b. A light-minute is the speed of light multiplied by 1 minute:

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

That is, “1 light-minute” is just another way of saying “18 million kilometers.”

- c. Following a similar procedure, we find that 1 light-hour is 1.08 billion kilometers; and
 - d. 1 light-day is 2.59×10^{10} kilometers, or about 26 billion kilometers.
42. Recall that

$$\text{speed} = \frac{\text{distance traveled}}{\text{time of travel}}$$

We can solve for time by multiplying both sides by “time of travel” and dividing both sides by distance:

$$\text{time of travel} = \frac{\text{distance traveled}}{\text{speed}}$$

The speed of light is 3×10^5 kilometers per second. (We choose the value in kilometers per second rather than meters per second because we are given distances in kilometers.)

- a. Mars at its nearest is 56 million kilometers away, so the light travel time is

$$\text{time of travel} = \frac{5.6 \times 10^7 \cancel{\text{ km}}}{3.00 \times 10^5 \cancel{\text{ km}}/\text{s}} = 187 \text{ s}$$

We would prefer this answer in minutes, so converting:

$$187 \cancel{\text{ s}} \times \frac{1 \text{ min}}{60 \cancel{\text{ s}}} = 3.11 \text{ min}$$

It takes a little over 3 minutes each way to communicate with a spacecraft on Mars at closest approach.

- b. At the most distant, Mars is 400 million kilometers from Earth, so we can compute the travel time for light:

$$\text{time of travel} = \frac{4 \times 10^8 \cancel{\text{ km}}}{3.00 \times 10^5 \cancel{\text{ km}}/\text{s}} = 1330 \text{ s}$$

We would again prefer this in minutes, so we convert:

$$1330 \cancel{\text{ s}} \times \frac{1 \text{ min}}{60 \cancel{\text{ s}}} = 22.2 \text{ min}$$

It takes a little over 22 minutes each way to communicate with a spacecraft on Mars when Mars is at its farthest from Earth.

- c. We will again use the speed-time-distance relationship:

$$\text{time of travel} = \frac{\text{distance traveled}}{\text{speed}}$$

In this case, we seek the time it takes light to travel from Earth to Pluto. Earth's average distance from the Sun is 1.496×10^8 kilometers and Pluto's average distance is 5.916×10^9 kilometers. If we assume the two bodies are lined up on the same side of the Sun at their average distances, the distance between them is

$$\begin{aligned}\text{Earth to Pluto distance} &= 5.916 \times 10^9 \text{ km} - 1.496 \times 10^8 \text{ km} \\ &= 5.766 \times 10^9 \text{ km}\end{aligned}$$

Using this value, the light travel time is:

$$\text{time of travel} = \frac{5.766 \times 10^9 \cancel{\text{ km}}}{3.00 \times 10^8 \cancel{\text{ km}}/\text{s}} = 1.922 \times 10^4 \text{ s}$$

This is nearly 20,000 seconds, so let's try changing to more comprehensible units. We'll start by converting to minutes:

$$1.922 \times 10^4 \cancel{\text{ s}} \times \frac{1 \text{ min}}{60 \cancel{\text{ s}}} = 320 \text{ min}$$

That's a lot better, but it's still a lot more than 1 hour, so let's convert to hours:

$$320 \cancel{\text{ min}} \times \frac{1 \text{ hr}}{60 \cancel{\text{ min}}} = 5.33 \text{ hr}$$

It would take light 5.33 hours, or 5 hours and 20 minutes, to travel from Earth to Pluto under the alignment conditions and average distances we've assumed.

43. We are asked to find how many times larger the Milky Way Galaxy is than the planet Saturn's rings. We are told that Saturn's rings are about 270,000 kilometers across and that the Milky Way is 100,000 light-years in diameter. Clearly, we'll have to convert one set of units or the other. Let's change light-years to kilometers. In Appendix A we find that $1 \text{ light-year} = 9.46 \times 10^{12}$ kilometers, so we can convert:

$$100,000 \cancel{\text{ light-years}} \times \frac{9.46 \times 10^{12} \text{ km}}{1 \cancel{\text{ light-year}}} = 9.46 \times 10^{17} \text{ km}$$

We can now find the ratio of the two diameters:

$$\begin{aligned}\text{ratio} &= \frac{\text{diameter of Milky Way}}{\text{diameter of Saturn's rings}} \\ &= \frac{9.46 \times 10^{17} \cancel{\text{ km}}}{2.7 \times 10^5 \cancel{\text{ km}}} = 3.5 \times 10^{12}\end{aligned}$$

The diameter of the Milky Way Galaxy is about 3.5 trillion times as large as the diameter of Saturn's rings!

44. We are given the distance to Alpha Centauri as 4.4 light-years, but those units aren't very useful to us. So let's convert to kilometers. From Appendix A we see that 1 light-year = 9.46×10^{12} kilometers. So the distance to Alpha Centauri is

$$4.4 \cancel{\text{light-years}} \times \frac{9.46 \times 10^{12} \text{ km}}{1 \cancel{\text{light-year}}} = 4.2 \times 10^{13} \text{ km}$$

At a scale of 1 to 10^{19} , the distance to Alpha Centauri is

$$\frac{4.2 \times 10^{13} \text{ km}}{10^{19}} = 4.2 \times 10^{-6} \text{ km}$$

As numbers go, that one's not very easy to picture. So let's convert it to some smaller units. Since there are a thousand (10^3) meters to a kilometer and a thousand (10^3) millimeters to a meter, there are (10^6) millimeters to a kilometer. Those units seem about right for this distance, so let's convert:

$$4.2 \times 10^{-6} \cancel{\text{km}} \times \frac{10^6 \text{ mm}}{1 \cancel{\text{km}}} = 4.2 \text{ mm}$$

From Appendix E, the Sun is 7.0×10^5 kilometers in radius, so the diameter is twice this, or 1.4×10^6 kilometers. On the 1-to- 10^{19} scale, this is

$$\frac{1.4 \times 10^6 \text{ km}}{10^{19}} = 1.4 \times 10^{-13} \text{ km}$$

We're asked to compare this to the size of an atom, 10^{-10} meter, so we had better convert one of the numbers. We'll convert from kilometers to meters:

$$1.4 \times 10^{-13} \cancel{\text{km}} \times \frac{1000 \text{ m}}{1 \cancel{\text{km}}} = 1.4 \times 10^{-10} \text{ m}$$

Note that this is about the same size as a typical atom. In summary, we've found that on a scale on which the Milky Way Galaxy would fit on a football field, the distance from the Sun to Alpha Centauri is only about 4.2 millimeters—smaller than the width of a finger—and the Sun itself becomes as small as an atom.

45. a. First, we need to work out the conversion factor to use to go between the real universe and our model. We are told that the Milky Way Galaxy is to be about 1 centimeter in the new model. We know from this chapter that the Milky Way Galaxy is about 10^5 light-years across. We could convert this to kilometers, but looking at what we're asked to convert, it appears that all the numbers we'll be using will be given in light-years anyway. So our conversion factor is

$$1 \text{ cm} = 10^5 \text{ light-years}$$

So for the first part, we need to figure out how far the Andromeda Galaxy (also known as M31) is from the Milky Way. The chapter tells us that their actual separation is 2.5 million light-years. So the distance on our scale is

$$2.5 \times 10^6 \text{ light-years} \times \frac{1 \text{ cm}}{10^5 \text{ light-years}} = 25 \text{ cm}$$

The Andromeda Galaxy would be 25 centimeters away from our galaxy on this scale.

- b. From Appendix F, we learn that Alpha Centauri is 4.4 light-years from the Sun. So using the conversion factor we developed in part (a), we convert this to the scale model distance:

$$4.4 \text{ light-years} \times \frac{1 \text{ cm}}{10^5 \text{ light-years}} = 4.4 \times 10^{-5} \text{ cm}$$

The separation between Alpha Centauri and our Sun is about 4.4×10^{-5} centimeter on this scale. As we will see in Chapter 5, this is comparable to the wavelength of blue light.

- c. The observable universe is about 14 billion light-years in radius, so let's use that distance as an approximation to the distance of the most distant observable galaxies. Converting this distance to our model's scale:

$$14 \times 10^9 \text{ light-years} \times \frac{1 \text{ cm}}{10^5 \text{ light-years}} = 1.4 \times 10^6 \text{ cm}$$

That's more than a million centimeters, but it's difficult to visualize how far that is offhand. Let's convert that number to kilometers. We'll convert to meters first since we know how to go from centimeters to meters and meters to kilometers, but it's difficult to remember how to go straight from centimeters to kilometers:

$$1.4 \times 10^6 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} \times \frac{1 \text{ km}}{1000 \text{ m}} = 14 \text{ km}$$

On a scale where our entire Milky Way Galaxy is the size of a marble, the most distant galaxies in our observable universe would be located some 14 kilometers away.

46. a. The circumference of Earth is $2\pi \times 6380 \text{ km} = 40,087 \text{ km}$. At a speed of 100 kilometers per hour, 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 Earth. That is, a trip around the equator at 100 kilometers per hour would take a little under 17 days.

- b. We find the time by dividing the distance to Earth from the Sun by the speed of 100 kilometers per hour. It would take about 170 years to reach Earth and about 6700 years to reach Pluto (at their mean distances).
- c. Similarly, it would take 6700 years to drive from the Sun to Pluto at 100 kilometers per hour. FYI: The following table shows the driving times from the Sun to each of the planets at a speed of 100 kilometers per hour.

Planet	Driving Time
Mercury	66 yr
Venus	123 yr
Earth	170 yr
Mars	259 yr
Jupiter	888 yr
Saturn	1630 yr
Uranus	3300 yr
Neptune	5100 yr
Pluto	6700 yr

- d. Appendix F gives the distance to Alpha Centauri in light-years; converting to kilometers, we get

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

At a speed of 100 kilometers per hour, the travel time to Alpha 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 Alpha Centauri at a speed of 100 kilometers per hour.

47. a. To reach Alpha Centauri in 100 years, you would have to travel at $4.4/100 = 0.044$ of the speed of light, which is about 13,200 kilometers per second or nearly 50 million kilometers per hour.
- b. This is about 1000 times the speed of our fastest current spacecraft.

48. 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:

$$v = \frac{2\pi(27,000 \text{ lt-yr})}{2.3 \times 10^8 \text{ yr}} = \frac{1.70 \times 10^5 \cancel{\text{ lt-yr}} \times 9.46 \times 10^{12} \frac{\text{km}}{\cancel{\text{ lt-yr}}}}{2.3 \times 10^8 \cancel{\text{ yr}} \times 365 \frac{\cancel{\text{ day}}}{\text{yr}} \times 24 \frac{\text{hr}}{\cancel{\text{ day}}}} \approx 7.9 \times 10^5 \frac{\text{km}}{\text{hr}}$$

We are racing around the Milky Way Galaxy at nearly 800,000 kilometers per hour.

49. We'll use the relationship that says that

$$\text{speed} = \frac{\text{distance traveled}}{\text{time}}$$

To compute each speed, we'll find the distance a person travels around Earth's axis in 1 day (24 hours). Using the hint from the problem, we can find that the radius of the circle that a person at a given latitude travels is $R_{\text{Earth}} \times \cos(\text{latitude})$, where $R_{\text{Earth}} = 6378 \text{ km}$ from Appendix E.

- a. The radius of the circle that a person at latitude 30° travels is

$$(6378 \text{ km}) \times \cos(30^\circ) = 5524 \text{ km}$$

To get the distance traveled, we use the fact that a circle's circumference is given by $c = 2\pi r$, so in this case:

$$\text{distance} = 2\pi(5524 \text{ km}) = 34,700 \text{ km}$$

Using the relationship between speed, time, and distance given above, the speed is

$$\text{speed} = \frac{34,700 \text{ km}}{24 \text{ hr}} = 1446 \text{ km/hr}$$

A person at 30° latitude would be traveling at 1446 kilometers per hour around Earth's axis because of Earth's rotation.

- b. The radius of the circle that a person at 60° latitude travels is

$$(6378 \text{ km}) \times \cos(60^\circ) = 3189 \text{ km}$$

The distance traveled is

$$\text{distance} = 2\pi(3189 \text{ km}) = 20,040 \text{ km}$$

The speed is

$$\text{speed} = \frac{20,040 \text{ km}}{24 \text{ hr}} = 834 \text{ km/hr}$$

A person at 60° latitude travels around the axis at 834 kilometers per hour due to Earth's rotation.

- c. Answers will vary depending on location.