Astronomy and the Universe 1

This chapter contains a preview of the major topics and astronomical objects to be discussed in subsequent chapters. A brief introduction to the tools, such as angular sizes and angular separations and scientific notation, used by astronomers to describe and investigate astronomical objects is also included. The last section presents astronomy as an adventure of the human mind.

1-1 To understand the universe, astronomers use the laws of physics to construct testable theories and models
Hypotheses, models, theories, and laws are essential parts of the scientific way of knowing.

1-2 By exploring the planets, astronomers uncover clues about the formation of the solar system
Studying planetary science gives us a better perspective on our own unique Earth.

1-3 By studying stars and nebulae, astronomers discover how stars are born, grow old, and die
Studying the life cycles of stars is crucial for understanding our own origins.

1-4 By observing galaxies, astronomers learn about the origin and fate of the universe
The motions of distant galaxies motivate the ideas of the expanding universe and the Big Bang.

1-5 Astronomers use angles to denote the positions and apparent sizes of objects in the sky
Angular measure is a tool that we will use throughout our study of astronomy.

Box 1-1 The Small-Angle Formula
The conversion of angular sizes and angular separations into linear distances is described and an example is solved using data for the planet Jupiter.

1-6 Powers-of-ten notation is a useful shorthand system of writing numbers
Learning powers-of-ten notation will help students deal with very large and very small numbers.

Box 1-2 Arithmetic with Powers-of-Ten Notation
The rules for multiplying and dividing two numbers expressed as powers of ten are explained and examples are solved.

1-7 Astronomical distances are often measured in astronomical units, parsecs or light-years
Specialized units make it easier to comprehend immense cosmic distances.

Box 1-3 Units of Length, Time, and Mass
A review is provided of the basic units of measure used by scientists to express mass, time, speed, and length. Metric and English equivalents are provided. The SI system is introduced.

1-8 Astronomy is an adventure of the human mind
Studying the universe benefits our lives on Earth.

Why Astronomy? by Sandra Faber

This essay focuses on four main points of interest that might enhance student appreciation of astronomy. (1) The study of astronomy is described as an expansion of the standard general educational goal of developing a historical perspective of the place of man in the cosmic timescale. (2) The study of astronomy is viewed as a challenge to many of the belief systems commonly held by college students. (3) The cosmic timescale is noted in the context of evolution and the reality of perpetual change in the universe. (4) Astronomy is viewed as providing a new perspective on the nature of human existence in philosophical and religious terms.

This is an excellent opportunity to provide some incentive for students to develop an additional sense of value for the subject matter of the course. Students who take astronomy because it fulfills a general education science requirement often fail to see why they should make more than a minimal effort in a course that seems to be far removed from practical applications. Although faculty consider issues like those raised in this essay to be central to general education, students view them in relative importance far below the selection of a major and mastery of basic skills.

Teaching Hints and Strategies

The foundation of modern astronomy is based on our understanding of the laws of physical science (Section 1-1). Astronomers generally can't do controlled experiments and we must assume that physical laws applicable on Earth must also be valid elsewhere in the universe. If we did not assume that the same laws of nature apply in the far reaches of the universe, then we could not hope to make any progress in our investigations. Our assumptions about the universal applicability of these basic laws have been carefully examined and shown to be consistent with our observations.

The introduction of terminology associated with scientific methods (Section 1-1) provides an excellent opportunity to call attention to some confusion about the use of the words "hypothesis," "theory" and "law" in scientific contexts. Point out that the words "theory" and "hypothesis" can be used interchangeably in common usage, but that Einstein's theory of relativity is much more than just one man's guess. It can be helpful to ask students to think in terms of theories with a lowercase "t" and with an uppercase "T." The difference is that a Theory has been successfully tested and found to be accurate in its ability to predict additional applications and has been verified. This distinction is helpful in combating the public impression that the "Theory of Relativity" and the "Theory of Evolution" are of diminished value because they are "just theories." Also try to emphasize the similarities of "laws" and "Theories." It can be misleading for students to try to comprehend the relative merits of Newton's laws of motion and Einstein's theories of relativity.

Although an understanding of the formation of the solar system (Section 1-2) might be important for astronomers, it has little direct appeal for more practical students. Emphasize the need to understand better the changes currently taking place in our atmosphere such as the increases in carbon dioxide levels and resulting climatic temperature changes. These changes will certainly have a direct impact on all inhabitants of our planet in our lifetimes. Our attempts to understand the current nature and evolution of planetary atmospheres are a logical step in learning to manage our own environment.

An attempt should be made to demonstrate that modern astronomers are trying to determine the physical nature of celestial objects and the relationships between them in the context of stellar evolution (Section 1-3). Because our Sun is a star, it is in our direct interest to know how it will change with time and when it will change. The fact that it must change is very difficult for some students to accept. If a student accepts that the Sun is constantly losing energy in the form of light and heat and that the finite Sun cannot contain an infinite store of energy, then the ultimate death of the Sun is the only logical conclusion.

The investigation of stellar systems and the universe (Section 1-4) is difficult to present in a practical context because of the staggering distances and times involved. It does provide an opportunity to discuss the differences between applied and basic science. Much of the modern technology we enjoy can be traced to advances in our understanding of the basic laws of nature. Our understanding of such fundamental laws would probably not advance rapidly if all scientists engaged in applied science.

The review of angles (Section 1-5) is an excellent opportunity to emphasize that astronomy is an observational rather than an experimental science, principally because of the vast distances between celestial objects. Although the space program is very important in the advance of modern astronomy, humans have visited only one other celestial object (the Moon) and have landed spacecraft on four others (Mars, Venus, Titan, and Eros). Much of the space program has been devoted to using remote observatories, which are still passive observers and which do not conduct active experiments beyond the solar system. Due to the vast distances between astronomical objects, their true sizes and distances are very frequently unknown.

Application of the small-angle formula (Box 1-1) to objects having the same angular size but vastly different distances will reinforce the limitations of angular size and angular separation data.

The introduction of scientific notation (Section 1-6) can be justified by noting that astronomy is the science of not only the big but also the small. Call attention to the left end of Figure 1-13. It is helpful to remind the students that the observational (passive) nature of astronomical investigations means that all the information about the physical conditions existing on celestial objects and about their past and future conditions must be extracted from an understanding of the nature of atoms and the constituent parts of atoms, the smallest entities of the universe.

Most students have basic scientific calculators. Scientific calculators are cheap enough that it would not be an imposition to ask students who do not own one to purchase one. The warning in the "Caution" box of Section 1-6 about entering numbers in scientific notation should be stressed. Instead of the "**EXP**" key, students will invariably want to use the multiply key or **10^x**. You might tell your students to think "**EXP**" when they see the symbols "$\times 10^n$." For example, when entering "1.5×10^4" in a calculator, think "1.5 **EXP** 4." Some calculators may have a key labeled **EE** for entering exponents of 10.

The use of different systems of distance units in astronomy (Section 1-7) can serve to emphasize the role of units in general in the physical sciences and to illustrate the justification of establishing different systems of units for a simple quantity such as length. Many students fail to associate units with numbers. They have dealt with numbers in mathematics courses but have had little experience in the measuring activities that lie at the heart of the physical sciences. A brief discussion of how units give meaning to numbers can be helpful in making students aware of the units. The value of using different units of length in astronomy is that it permits the use of simple fractions and whole numbers in comparing sizes and distances that are of comparable magnitude. Although any system of units can be used with powers-of-ten notation, it is not as easy to visualize the relative magnitudes of two numbers having very large or very small values. Comparisons of the sizes of and distances between objects of vastly different dimensions are more readily accomplished in powers-of-ten notation. It is useful to encourage students to view the differences between exponents in the context of order-of-magnitude comparisons. It is always a good idea to emphasize that light-years are units of length, not units of time.

It is a good idea to review what is meant by the word "size." Usually the word is used in the context of length measurement. Many students confuse the basic concepts of size, area, volume, mass, weight, and density. A clear presentation at this point might avoid much confusion in the future. Be sure to identify radius and diameter as length measurements related to circles and spheres that represent their sizes. Be specific when preparing test questions that ask "how big."

Units (Box 1-3) can be emphasized by having students identify the type of quantity expressed by dimensional analysis. The units used in *Universe* are generally from the SI system rather than cgs units used in astrophysics and often used in some older textbooks.

The concept of the adventure of the human mind (Section 1-8) is clearly appropriate in modern astronomy. If modern astronomers are less immediately connected with applied science than were astronomers of the past, we certainly are engaged in one of the most intriguing intellectual exercises of all time. It is part of the challenge of modern astronomy education to convey to students the fact that the science of modern astronomy is involved in understanding and explaining objects as interesting as the most innovative science fiction writers can imagine. The exploration of the universe with the mind as well as with manned or unmanned spacecraft is the next logical step in the journeys of exploration that have always driven people to expand beyond their boundaries since before recorded history.

The *Cosmic Connections* diagram, *Sizes in the Universe*, can help students visualize the vast scale of the universe. Ask them if they think it would be possible to make a scale model of the universe *without* powers-of-ten notation.

Although the subjects of creationism or intelligent design may not surface until the end of the course, some students may inquire about their professor's thoughts on these topics. A valuable resource is *An Ancient Universe: How Astronomers Know the Vast Scale of Cosmic Time.* Published by the American Astronomical Society, this booklet is a guide for teachers, students and the public. The booklet was written by a subcommittee of the American Astronomical Society's Astronomy Education Board, and was published in 2004 by the American Astronomical Society with the Astronomical Society of the Pacific. The document may be downloaded in PDF format free of charge: aas.org/files/resources/An_Ancient_Universe.pdf.

Another helpful resource is *Science and Creationism: A View from the National Academy of Sciences*, Second Edition*,* Steering Committee on Science and Creationism, National Academy of Sciences, (1999). This booklet considers the science that supports the Theory of Evolution, focusing on three categories of scientific evidence:

- Evidence for the origins of the universe, Earth, and life
- Evidence for biological evolution, including findings from paleontology, comparative anatomy, biogeography, embryology, and molecular biology
- Evidence for human evolution

At the end of each of these sections, the positions held by advocates of "creation science" are briefly presented and analyzed as well. Ordering information at: www.nap.edu/catalog/6024.html.

Review Questions

1. A scientist trying to understand some observed phenomenon proposes a hypothesis, which is a collection of ideas that seems to explain what is observed. A body of related hypotheses can be pieced together into a self-consistent description of nature called a theory. In science a good theory is one that explains reality very well and that can be applied to explain new observations. An excellent example is the theory of gravitation (Chapter 4).

2. Laws are general truths. Theories are our best current description of the truth. Since the complete absolute truth can never be known, even the so-called laws are just theories. Mathematics is used by both.

3. Theories are tested with experiments. The ability of a theory to make predictions is another test.

4. Without skepticism, any wild claim would be accepted as valid. Skepticism is the demand for proof or evidence.

5. The Earth's atmosphere blocks some portions of the electromagnetic spectrum and also causes distortions of optical wavelengths.

6. Craters on the Moon were caused by impacts of rocky bodies striking the Moon's surface.

7. Meteorites are small rocky debris left over from the formation of the solar system. They tell us something about the chemical composition of the early solar system.

8. The Sun and stars shine because of thermonuclear fusion in their cores.

9. Nebulae are the raw materials out of which stars form.

10. A solar system is a star (Sun) and its retinue of planets and other orbiting objects. A galaxy is an enormous grouping of gravitationally bound stars and other objects.

11. Degrees, arcminutes, and arcseconds are units of angular measure. They are related as follows:

60 arcmin = 1 degree

60 arcsec = 1 arcmin

360 degrees = 1 full circle.

12. There are $60 \times 60 = 3600$ arcsec in 1°.

13. A full circle around the sky is 360°. When we say that the Moon subtends an angle of 1/2°, we mean that the angular width of the Moon is 1/720 of the circle.

14. An exponent is the superscript on the ten in powers-of-ten notation. Exponents keep track of the location of the decimal point.

15. Powers-of-ten notation makes arithmetic easier when using very large and very small numbers.

16. (a) 1×10^{7}, (b) 6×10^{4}, (c) 4×10^{-3}, (d) 3.8×10^{10}

17. One AU is the average Earth–Sun distance. This unit is convenient when expressing interplanetary distances.

18. Using the light-year as a unit of distance tells the astronomer the age of the information conveyed by the light.

19. A parsec is a unit of distance defined as the distance where 1 AU would subtend an angle of 1 arcsec. A kiloparsec is 1000 parsecs and a megaparsec is 1,000,000 parsecs.

20. (a) kilometer, (b) centimeter, (c) second, (d) kilometers per second, (e) miles per hour, (f) meters, (g) meters per second, (h) hours, (i) years, (j) grams, (k) kilograms. The units of speed are (d), (e), and (g).

21. The context of the sentence suggests that a *time* be specified. The parsec is a unit of *distance*, not time. Keeping a log of scientific errors in the media—fiction or real life—can be an interesting activity!

22. A light-year is the distance that light travels in one year.

Advanced Questions

23. The letters RIVUXG stand for R = radio; I = infrared; V = visible; U = ultraviolet; X = X rays; G = gamma rays. The highlighted or reversed-type letter indicates which one of these radiations was used to take the image in the figure.

24. Set up a proportion, but be sure that you express all the distances in the same units (e.g., centimeters). The diameter of the Sun is to the size of a basketball as the distance to Proxima Centauri is to the unknown distance (x), so $\frac{1.4\times10^{11}\text{cm}}{30\text{ cm}}=\frac{(4.2\text{ ly})(9.46\times10^{17}\text{cm/ly})}{x}$. Rearranging terms, we get $x=\frac{(4.2)(9.46\times10^{17})(30\text{ cm})}{1.4\times10^{11}}=8.51\times10^{8}\text{ cm}=8.51\times10^{3}\text{ km}$. In other words, if the Sun were the size of a 30-cm ball, the nearest star would be 8510 km away, which is roughly the distance from Los Angeles to Tokyo.

25. Using the information given in the previous question, you first convert the distance to Proxima Centauri to the same unit of length as the Sun's diameter. You then form a ratio by dividing the distance to Proxima Centauri by the Sun's diameter: $\frac{(4.2\text{ ly})(9.46\times10^{17}\text{cm/ly})}{1.4\times10^{11}\text{cm}}=2.84\times10^{7}$

Thus, 28.4 million Suns placed side by side would reach to the nearest star.

26. You must first express the radius of the observable universe in the same units of length as the radius of the hydrogen atom: $(14\times10^{9}\text{ly})(9.46\times10^{12}\text{km/ly})(10^{5}\text{cm/km})=1.32\times10^{28}\text{cm}$. Dividing the radius of the observable universe by the radius of a hydrogen atom, we get:

$\frac{1.32\times10^{28}}{5\times10^{-9}}=2.65\times10^{36}$. The universe is about 3×10^{36} times bigger than a hydrogen atom.

27. Divide the Sun's hydrogen mass by the mass of one atom: $\frac{3}{4}(1.99\times10^{30}\text{ kg})=1.49\times10^{30}\text{ kg}$. The Sun therefore contains $\frac{1.49\times10^{30}\text{ kg}}{1.67\times10^{-27}\text{ kg/atom}}=8.92\times10^{56}$ hydrogen atoms.

28. (a) $d=1.496\times10^{8}\text{ km}\times\frac{1\text{ ly}}{9.46\times10^{12}\text{ km}}=1.58\times10^{-5}\text{ ly}$

(b) $d=1.496\times10^{8}\text{ km}\times\frac{1\text{ pc}}{3.09\times10^{13}\text{ km}}=4.84\times10^{-6}\text{ pc}$ (c) Light-years or parsecs are not appropriate because of the extreme smallness of the resulting numbers.

29. The distance from the Sun to the Earth is 1 AU = 1.496 × 10^8 km. If you express the Sun-Earth distance in kilometers, you must express the speed of light in km/s. The light-travel time is 1 AU divided by the speed of light: $d = vt$. Solve for t: $t = \frac{d}{v} = \frac{1.496\times10^8\ \text{km}}{3\times10^5\ \text{km/s}} = 499\ \text{s} = 8.3\ \text{min.}$

30. Calculate how far light travels in 4 hours as follows: (3 × 10^5 km/s)(4 hr)(3600 s/hr) = 4.3 × 10^9 km.

31. $d = 5.15\ \text{pc}\times\frac{3.09\times10^{13}\ \text{km}}{1\ \text{pc}} = 1.59\times10^{14}\ \text{km}$ $d = 5.15\ \text{pc}\times\frac{3.26\ \text{ly}}{1\ \text{pc}} = 16.8\ \text{ly},$ so the time required is 16.8 years.

32. Convert 13.7 billion years into seconds as follows: (1.37 × 10^{10} yr)(3.16 × 10^7 s/yr) = 4.33 × 10^{17} s.

33. From geometry, the relation between arc length (D), radius (d), and angle (α) is: $D = \alpha d,$ where α is in radians and D and d are in the same units. If we wanted to express α in arcsec we would use

$$\alpha(\text{arcsec}) = \alpha(\text{rad})\times\frac{360°}{2\pi(\text{rad})}\times\frac{60'}{1°}\times\frac{60''}{1'}$$

$$\alpha(\text{arcsec}) = \alpha(\text{rad})\times 206,265$$

$$\alpha(\text{rad}) = \frac{\alpha(\text{arc sec})d}{206,265}$$

$$D = \frac{\alpha(\text{arc sec})d}{206,265} = \frac{\alpha d}{206,265}$$

34. These three questions require you rewrite the small-angle formula as $d = 206,265\left(\frac{D}{\alpha}\right).$

(a) α = 1 degree = 3600 arcsec and D = 2.6 cm

$$d = 206,265\left(\frac{2.6}{3600}\right) = 149\ \text{cm} = 1.5\ \text{m}$$

(b) α = 1 arcmin = 60 arcsec and D = 2.6 cm

$$d = 206,265\left(\frac{2.6}{60}\right) = 8938\ \text{cm} = 89\ \text{m}$$

(c) α = 1 arcsec = 60 arcsec and D = 2.0 cm

$$d = 206,265\left(\frac{2.6}{1}\right) = 536,289\ \text{cm} = 5363\ \text{m}$$

35. D = 2 mm × 1 m/1000 mm = 0.002 m; α = 1 arcmin × 60 arcsec/1 arcmin = 60 arcsec;

d = (206,265)(0.002)/60 = 6.9 m.

36. You must first express the Moon's diameter in seconds of arc:

Moon's diameter = 1/2° = 30′ = (30 × 60)″ = 1800″. Now you can use the small-angle formula in Box 1-1: $D = \frac{\alpha d}{206,265} = \frac{(1800)(384,000 \text{ km})}{206,265} = 3350 \text{ km}$. NOTE**:** If you had used the more accurate observation that the Moon's angular diameter is 31′05″, you would have calculated the lunar diameter to be 3472 km, which is quite close to the value given in Appendix 3 in the textbook.

37. *d* = 384,400 km (from Appendix 3), α = 2 arcsec

$$D = \frac{\alpha d}{206,265} = \frac{(2)(384,000 \text{ km})}{206,265} = 3.7 \text{ km}$$

38. Use the small-angle formula given in Box 1-1 with *d* = 0.869 AU and *D* = 12,104 km

$$\alpha = \frac{D(206,265)}{d} = \frac{(12,104 \text{ km})(206,265)}{(0.869 \text{ AU})(1.496 \times 10^8 \text{ km/AU})} = 19.2 \text{ arcsec} = 0.32 \text{ arcmin}$$

39. Use the same method as the previous question. *D* = 30 ly, d = 1500 ly

$\alpha = \frac{D(206,265)}{d} = \frac{(30 \text{ ly})(206,265)}{1500 \text{ ly}} = 4125 \text{ arcsec} = 1.1 \text{ degrees}$. The moon is less than half this angular diameter.

Discussion Questions

40. Einstein had a similar idea when he said, “God does not play dice with the universe.”

41. The work of Newton and Einstein are examples of how science operates. Some students may think that Einstein proved Newton to be wrong. Rather, Einstein extended Newton’s ideas to the very small, very large, and very fast.

42. Astronomers can only collect the EM radiation that comes to them from the universe. They cannot manipulate their subjects or control the experiment. They do, however, use large numbers of objects to arrive at a conclusion.

Web/eBook Questions

43. If your course meets in the wintertime, when Orion is visible, look at the Orion Nebula with binoculars. Use *Starry Night* to visualize Orion from Australia. He stands on his head Down Under!

44. The history of modern astronomy could be divided into two eras—pre-Crab and post-Crab—as far as understanding this object as a supernova remnant. There is some evidence that Native Americans in the U.S. Southwest observed this supernova near the waning crescent moon on the morning of 5 July 1054. Simulate this event with *Starry Night*. If your college or university has a dark sky observing site, and if you have a good telescope, students might be able to see the Crab.

Become familiar with *Sky & Telescope* magazine’s This Week’s Sky at a Glance: www.skyandtelescope.com/observing/ataglance. It provides a wealth of information on the latest astronomy news as well as observing tools that can supplement *Starry Night.*

EarthSky,(earthsky.org/) is another good source of night sky information.

Astro Bob (astrobob.areavoices.com/) discusses celestial happenings students can see from their own backyard or campus. This astronomy blog is written by chief photographer Bob King of the *Duluth News Tribune* in Duluth, Minnesota.

Observing Projects

48. Answers are dependent upon date and time of observation

49. a) Angle between Merak and Dubhe is 5° 22'.
b) Angle between Dubhe and the Pole Star is 28° 42'
c) Number of pointer-star spacings between Dubhe and the pole is about 5.4
d) Angle between NCP and Pole Star is about 40'
e) Angle between the pole and the horizon, (the Altitude of the pole star) is about 51°. This angle is equal to the latitude of the observer at Calgary.
f) Angle between Dubhe and Alkaid is 25° 42' and the angle between Dubhe and Caph is 58° 26'.
g) Angle between Gacrux and Acrux is 6°.
h) Angle between Acrux and the S Pole is 26° 40'.
i) Number of pointer-star spacings between Acrux and the S pole is approximately 4.4.
j) Angle between the pole and the horizon is about 27°. This angle is equal to the latitude of the observer at Brisbane.

Collaborative Exercises

50. Discuss this question in small groups of three students each. After each group has had some time to develop the lists, a member of each group can share the group's list with the entire class. Ask students to explain and elaborate when necessary, and defend any position they take.

51. An art professor or art major may discuss how art relies on angular size to suggest a distance. Ask students to think about how the angular size of an object in a work of art reveal the artist's distance from the object.

52. Watch the classic video *Powers of Ten*. *Powers of Ten* takes us on an adventure starting by the lakeside in Chicago, and ending at outer edges of the universe. Every 10 seconds we view the starting point from 10 times farther out. Returning to Earth with breathtaking speed, we move inward with ten times more magnification every 1 second. Our journey ends inside a carbon atom. Relate this video to the *Cosmic Connections* diagram in this chapter.