Chapter 0: Charting the Heavens
The Foundations of Astronomy

Outline

0.1 The “Obvious” View
0.2 Earth’s Orbital Motion
0.3 The Motion of the Moon
0.4 The Measurement of Distance
0.5 Science and the Scientific Method

Summary

This chapter covers the view from Earth, including constellations, the celestial sphere, and the apparent motions of the Sun and stars. The actual motions of Earth that give rise to those apparent motions are then discussed. The motion and appearance of the Moon are addressed in the third section. The chapter concludes with distance determinations and a discussion of the scientific method.

Major Concepts

- The view from Earth
  - Constellations
  - The celestial sphere
- Earth’s orbital motion
  - Rotation
  - Revolution
  - Angular measurement
  - Precession
- Motion of the Moon
  - Lunar phases
  - Eclipses
- Measuring distance
  - Triangulation
  - Parallax
- Scientific theory and the scientific method
  - Observation
  - Theory
  - Prediction

Teaching Suggestions and Demonstrations

One of the challenges in studying astronomy is developing the ability to view the universe from different perspectives, primarily the perspective we have from Earth, where we see the Sun and stars rise in the east and set in the west, and the perspective from outside, where we see Earth spinning on its axis and orbiting the Sun. Use plenty of models and diagrams in teaching this introductory material in order to help your students practice shifting viewpoints. Lots of new vocabulary is introduced in this chapter; take the time to define new terms.
There has been an emphasis among the astronomy educational research community that teaching approaches in college astronomy classes should be more learner-centered. An easy way to start to incorporate this approach is the book *Lecture-Tutorials for Introductory Astronomy* 3/E by Prather, Slater, Adams, and Brissenden. This book contains many in-class exercises that students work on in small groups. There are exercises on positional *astronomy*, *solar vs. sidereal day*, *seasonal stars*, the *ecliptic*, and *phases of the Moon* as well as additional topics that will be mentioned throughout this book. It takes a lot of consideration to decide how to use such materials, but research shows that it will benefit most students for the classroom to be more learner-centered.

**Section 0.1**

Your students will all have heard of *constellations* and will probably be able to name at least a few. Emphasize that the stars in a given constellation are probably not physically close to each other in space; they just appear close to each other as seen from Earth. The stars in each constellation were grouped together by observers in ancient times, and we continue to use nearly the same groupings today. You can pass out or project a sky chart without constellations drawn in and challenge students to make up their own.

Asking students what their zodiacal sign is can be a good way for the students to feel connected to the sky, even though very few might actually follow astrology. Consider using *Starry Night College* to demonstrate how the zodiacal constellations lie across or near the ecliptic line. Show how the sky view will change during the year. Be sure to let students know that their zodiacal constellation is associated with where the Sun was located when they were born, but it’s about a month off due to precession of the equinoxes. This is illustrated in Figure 0.8.

It is also interesting to compare names of northern and southern constellations. The northern constellations are typically named for animals and mythological characters. The Southern Hemisphere sky includes constellations such as the telescope, the microscope, and the octant. Ask your students if they can explain the difference. The *constellation names* we have inherited today derive from northern observers. The northern constellation names, therefore, date from ancient times, but the southern ones date from the early travels made by northern explorers to the Southern Hemisphere.

If you have time, explain a few of the *myths* that involve whole families of constellations. The story of Orion, Taurus, and the Pleiades is a good one, as is the story of Cassiopeia, Cepheus, Andromeda, Cetus, and Perseus. These are all constellations your students can find in the night sky, depending on the time of year you are teaching the course. Provide star charts and encourage your students to find major constellations in the night sky throughout the course.

The concept of the *celestial sphere* is an important one. We are missing *depth perception* when we look out at the night sky. If you have one, bring in a transparent model of the celestial sphere with Earth inside and point out the *north and south celestial poles* and the *celestial equator*. This is a good time to discuss Polaris and clear up any misconceptions; often, introductory astronomy students believe the North Star must be the brightest star in the sky.

Introduce students to *right ascension* and *declination* by comparing these to latitude and longitude. Emphasize that the celestial coordinates are attached to the sky. Over the course of a night, stars move from east to west and the coordinate system moves with them. Look up the coordinates of a few well-known stars (including Polaris) and help students determine their positions. Ask students to compare the two different methods of describing star locations, by coordinates and by constellation, and discuss the advantages of each.
Section 0.2

Students usually know the terms rotation and revolution but often confuse them, so take a few moments to define these terms. Consider using the word “orbit” instead of “revolution” to help avoid confusion. Students will also probably know that Earth takes a day to turn on its axis and a year to orbit the Sun, but will not know the difference between a solar day and a sidereal day, or a tropical year and a sidereal year. Use lots of diagrams, such as Figure 0.7, to help explain. Models also help. Demonstrate rotation and revolution with globes, or bring students to the front of the class to model Earth’s motions. For instance, one student can spin around (slowly) while also orbiting another. Ask the class to concentrate on one point on the Earth, say, the spinning student’s nose, and imagine when it is lit and when it is dark. Use this model to explain day and night, sidereal vs. solar days, and why different constellations are visible in the night sky during different months.

Figure 0.9 is also an important one. Make sure students understand that it shows the apparent path of the Sun on the celestial sphere. Use models of Earth and the Sun (or just two spheres) to help explain how Earth’s tilt changes the position of the Sun in the sky as Earth orbits the Sun. Emphasize that the terms solstice and equinox can each refer to both a point in time and a point in space. The summer solstice, for instance, is the point on the ecliptic where the Sun is at its northernmost position, but we also use the term to refer to the time and day when the Sun is at that point. Students will be most familiar with the latter meaning, and know that the summer solstice occurs around June 21.

Begin your discussion of seasons with an informal, multiple-choice pre-quiz. If you’d like to make this pre-assessment a bit more formal, author Paul Green discusses more ideas in his book Peer Instruction for Astronomy starting on page 11. He also includes “concept tests” for the seasons as well as the celestial sphere and time conventions used in astronomy that can be used throughout the lecture. These can be used in conjunction with additional “clicker questions” that are provided with the instructor materials. During your lecture, ask students what causes the seasons, and include in the answer choices both the correct response, namely, Earth’s tilt, and a common misconception, the distance from Earth to the Sun. If significant numbers of students choose the distance answer, make sure you address this misconception and explain why the different distances from Earth to the Sun do not affect the seasons. Many students are surprised to find that, in fact, the Earth is farthest from the Sun during the Northern Hemisphere summer. Bring in a flashlight and shine it directly down on a tabletop or on the floor, and then shine it at an angle to show how the angle of the Sun’s rays affects solar heating. Go back to your model of Earth orbiting the Sun to show how the length of time the Sun is up in the sky also changes as the seasons change.

A gyroscope or top makes a good demonstration of precession. Find Vega on a star chart and point it out to students to help them get a sense of the scale of the change. Precession is also responsible for the fact that the zodiac constellations no longer correspond to their astrological dates. The heliacal rising of Sirius, in the constellation Canis Major, was an important date in the ancient agricultural calendar, but this no longer occurs on the same date today.

Angular measure is very important to astronomy. Discuss More Precisely 0-1 carefully. Demonstrate angular measure by holding up a penny. At a distance of about 1 meter, a penny subtends an angle of about 1 degree. Students can hold up a penny and see what objects at different distances in the classroom have an angular size of about 1 degree. Also have students try this at night and estimate the angular size of the Moon, half a degree. Go over angular measurements and then try several examples. Many problems throughout the text use the equations in this section, so it is worth spending some time with them to ensure student understanding.

Section 0.3
Demonstrate the **Moon’s phases** by shining a flashlight on a ball. You can also paint one half of a Ping-Pong ball black and have students hold it at arm’s length with different amounts of the black side facing them. For different positions of the Moon, ask students how much of the surface of the Moon is lit, and how much of the lit surface can be seen from Earth. Emphasize that half the surface is always receiving light, but we just do not see it all. Before showing Figure 0.13, demonstrate and discuss with students when one particular phase, first quarter, say, will rise and set. Then ask them to predict rising and setting times of the other phases. This exercise provides an excellent opportunity for students to practice changing viewpoints as discussed in the previous sections. For best results, you should do this demo in a very dark room. Even with all the lights turned out, there will still be a lot of light reflected from the walls. It’s best to use a classroom with dark walls, but this might be a difficult task. You should always try out a demo in the room where you’ll be teaching before you do the demo in front of a class.

Consider assigning students a project to track the Moon’s phases. For instance, you can ask them to look for the Moon each (clear) night for a month, sketch its shape, and note the time and position in the sky. At the end of the month, they can compare this view from Earth with a diagram showing the perspective from outside the Earth.

Once your students have a good grasp of phases, they should have no trouble understanding the causes of **eclipses**. Some points that you may need to clarify include why we do not have a solar eclipse every new Moon and a lunar eclipse every full Moon, and why a lunar eclipse lasts a while and can be seen from about half Earth’s surface, but a solar eclipse can be seen only from a narrow band and lasts only a short time for any particular observer. A scale model using two spheres (for Earth and the Moon) and a strong light source (for the Sun) can help clarify points about lunar eclipses. Show pictures of the Sun during a solar eclipse and try to convey some of the excitement and awe inspired by eclipses. In addition to being spectacular events to watch, solar eclipses provide Earth-bound astronomers a rare opportunity to study the Sun’s corona.

**Section 0.4**

Figure 0.21 illustrates an excellent demonstration of **parallax** that you can have your students try in class. Instruct them to hold up a finger (or pencil), close one eye, and line their finger up with some object on the far wall of the classroom. When they sight on their finger with the *other* eye open instead, it lines up at a different position. Ask students to try the exercise several times with their finger at different distances from their eyes to determine the relationship between the distance and the amount of shift. Figure 0.20 shows this method applied to astronomy using Earth’s diameter as a baseline. Challenge students to come up with a method where observers restricted to the surface of Earth can create an even longer baseline in order to measure parallaxes of more distant stars. (Observations can be made at different points in Earth’s orbit around the Sun.) Even with the diameter of Earth’s orbit as a baseline, the parallax method only works for the stars in the solar neighborhood.

**Section 0.5**

Since many of your students are likely to have had minimal exposure to science, this section is worthwhile focusing on for class discussions. In introducing the **scientific method**, refer to Figure 0.22 now as well as throughout the semester. Remind the students that science is a cyclic process rather than some fixed set of ideas or laws. This is a **STRENGTH**, not a weakness. Sometimes those that might challenge the validity of science using non-scientific arguments often try to exploit the tentative nature of science. The strength of science rests on the fact that it does not rely on the authority of political or religious systems nor on the interpretation of texts, ancient or otherwise. Ask the students to provide examples of ideas in their own minds that have changed once additional data or knowledge had become...
known to them. In my own opinion, I think science is a way that we (as humans) can sense the world around us and make predictions that can be tested and verified. At the heart of this process is the fact that the universe is inherently knowable. When discussing the nature of science, it is easy to fall into the philosophy of science. This can become a very exhaustive discussion, so make sure to have certain specific goals in mind so that you can move on to other topics when you’ve completed them.

**Student Writing Questions**

1. What was the tiniest object you have ever seen? The largest? The longest distance you have ever traveled? What is the largest number of objects you have ever knowingly encountered? (You may encounter lots of bacteria but not knowingly.) What was the longest you ever spent doing one activity? How do the largest and the smallest of these compare? How do the distances compare to the size of Earth? To the distance to the Moon? How does your time spent in one class compare to your lifetime?

2. Describe in metric units the room in which you do most of your studying. How big is it? What is the size of your desk? The TV or radio? How heavy are your books? The dimensions of your bed? Choose objects that have a range in sizes.

3. Test your horoscope. Each day, write two or three sentences about the most significant events that occurred to you that day. Cut out or copy your horoscope for that day and save. Continue this daily for about three weeks and make sure you write down your daily events before you read the horoscope. After three weeks, check what you wrote and your horoscope for each day to see whether there is a match. Count the number of hits and misses. Discuss the results and whether there is any significance to the number of hits. Are horoscopes truly predictive?

4. Find a location to view the night sky with as little interference as possible. Do this on as clear a night as possible. What do you see? Look all over and make note of the brightest stars. Are there any planets? How can you tell? Is the Moon out? What does it look like? What sort of details can you see on its surface?

5. What would it be like to live with only one functional eye? How would this change your perception of everything around you? What would pose the greatest difficulty to you? The least? You might actually try this first and then write about it. Did you get used to not having both eyes? Is parallax the only effect you miss with only one eye?

6. Describe an ordinary situation in which people regularly apply the scientific method, even though they are not aware they are doing so. Relate the situation to the three basic steps in the scientific method: gather data, form theory, and test theory.

7. Compare and contrast science as a way of knowing with some other way of knowing, such as social science, art, philosophy, or religion. How do these disciplines differ, and how might they be similar?

**Answers to End of Chapter Exercises**

**Review and Discussion**

1. The Earth’s diameter is about $110^{\text{th}}$ that of the Sun. The Earth is about $10^{14}$ times smaller than the Milky Way Galaxy and about $10^{18}$ times smaller than the Universe.
2. A constellation is a pattern of stars that appear together in the sky although they are generally not close together in space. Many constellations are named after mythological figures or animals. Each constellation covers a specific area on the celestial sphere, and stars are designated by the constellation to which they belong.

3. Earth’s rotation makes the Sun, the Moon and the stars appear to rise in the east and set in the west.

4. A solar day (measured by the Sun) is about 3.9 minutes longer than a sidereal day (measured by the stars). As Earth rotates on its axis, it also moves forward in its orbit so it has to rotate a little farther than one full turn to bring the Sun back to the same position in the sky.

5. One orbit of the Sun corresponds to one year, so a person’s age in years equals the number of times he or she has orbited the Sun.

6. Because Earth revolves around the Sun, Earth’s dark side (away from the Sun) faces a different direction at different times in Earth’s orbit. The stars visible in the winter night sky are behind the Sun in the summer and therefore not visible.

7. Seasons are caused by the tilt of Earth’s axis with respect to the plane of its orbit. The hemisphere tilted toward the Sun has summer, because the Sun appears higher in the sky and therefore the Sun is up longer and its rays are more direct. Both the length of time the Sun is in the sky and the angle of the rays contribute to increased heating.

8. Precession is the slow shift in the orientation of Earth’s rotation axis. It is caused by the combined gravitational pulls of the Moon and the Sun.

9. Only a portion of the hemisphere of the Moon that is lit by the Sun may be facing Earth. For instance, during a full Moon, the entire lit portion faces Earth, but during a new Moon, the entire lit hemisphere is facing away from Earth, so we see none of it.

10. A lunar eclipse occurs when Earth’s shadow falls on the Moon. A solar eclipse occurs when the Moon passes directly in front of the Sun, blocking its light so that shadow of the Moon falls on Earth. The Moon’s orbit is slightly inclined with respect to the ecliptic, so Earth, the Moon, and the Sun are not precisely lined up every full and new Moon.

11. Since neither Mercury nor Venus have moons, it would have to be Mars or other outer planets. However the moons of Mars are too small to cover the solar disc as seen from the surface of Mars, as shown in problem #10 of Chapter 6. Eclipses as seen from the cloud tops of Jupiter is the topic for problem #5 in Chapter 8.

12. Parallax is the apparent shift in position of a foreground object with respect to the background as the observer’s position changes. For example, as you drive down the road, a telephone pole along the road will line up with different points in the distant landscape.

13. When using triangulation, the longer the baseline, the greater the shift in position, or the greater the parallax angle. Objects in space are so far away that their shifts are very small. A long baseline will increase the chance that the shift will at least be measurable.

14. The diameter of an object can be determined if both the distance to the object and its angular diameter are known.
15. The scientific method obtains truths that rely on empirical data obtained in a naturalistic way using our senses. Religion, on the other hand, relies on truths that are divinely revealed.

**Conceptual Self-Test**


*Multiple Choice* 8. b 9. b 10. c 11. a 12. c 13. d 14. b 15. a

**Problems**

1. The year 10,000 A.D. is about 8000 years from now, which is about 0.3 of the total precessional period of 26,000 years. Because there are 12 constellations in the zodiac, this corresponds to about 3½ constellations. If the vernal equinox is just now entering Aquarius, then it will be in the latter half of Scorpio in 10,000 A.D. (See Figure 0.8.)

2. The distance Earth moves in a year is the circumference of its orbit:

\[ C = 2\pi r = 2\pi(1.5 \times 10^8 \text{ km}) = 9.42 \times 10^8 \text{ km}. \]

A day is 1/365 of a year, so the distance Earth moves in a day is:

\[ 9.42 \times 10^8 \text{ km} / 365 = 2.58 \times 10^6 \text{ km}. \]

An hour is 1/24 of this, so the distance Earth moves in an hour is:

\[ 2.58 \times 10^6 \text{ km} / 24 = 1.08 \times 10^5 \text{ km}. \]

Finally, in a second, the Earth moves: \(1.08 \times 10^5 \text{ km} / 3600 = 29.9 \text{ km}\).

3. The sidereal day would be the same, but the solar day would change in length because the Earth is still orbiting the Sun at roughly 1 degree per day. Normally the Earth must rotate an extra 1 degree after it reaches an entire sidereal day as shown in Figure 0.7. This means that it takes about 3.9 extra minutes for the Earth to reach the position for a solar day, so a solar day is 3.9 minutes longer than a sidereal day. If the direction of rotation is changed, then it will take ~3.9 minutes less to reach a solar day than it would a sidereal day. In this case, the solar day will be ~3.9 minutes shorter than the sidereal day, which remains the same. The difference in the solar day would be: \(3.9 \text{ min} \times 2 = 8 \text{ min}\)

4. Let’s assume that the Moon is in a circular orbit with an orbital period of 27.3, which is the sidereal period. We’ll assume that it moves through 360 degrees in these 27.3 days. Convert 27.3 days to seconds: 27.3 days = 2358720 seconds. The calculations should be done using ratios.

\[ \begin{align*}
(a) \quad \frac{360^\circ}{2358720 \text{ sec}} &= \frac{X^\circ}{3600 \text{ sec}} \Rightarrow X^\circ = 0.5^\circ = 33'/\text{hour} \\
(b) \quad \frac{360^\circ}{2358720 \text{ sec}} &= \frac{X^\circ}{60 \text{ sec}} \Rightarrow X^\circ = 0.01^\circ = 0.55' = 33''/\text{min} \\
(c) \quad \frac{360^\circ}{2358720 \text{ sec}} &= \frac{X^\circ}{1 \text{ sec}} \Rightarrow X^\circ = 0.00015^\circ = 0.01' = 0.55''/\text{sec}
\end{align*} \]
5. Calculate the circumference of the lunar orbit, then divide by the sidereal period (27.3 days) converted to seconds. 27.3 days = 2358720 seconds.

\[
\frac{3.14 \times 2 \times 384,000 \text{ km}}{2358720 \text{ sec}} = 1.0 \text{ km/s}
\]

6. Sidereal month = 27.32 days

\[
\frac{27.3 \times 0.986^\circ}{27.3^\circ} = 26.92^\circ \quad (\text{The Moon must travel this extra angle for a synodic month})
\]

\[
\text{synodic month} = \frac{386.92^\circ}{27.32^\circ} = 1.075 \times 27.32 = 29.4 \text{ days (synodic month)}
\]

7. \(\tan 60^\circ = \frac{\text{distance}}{100 \text{ m}}\) (Drawing the triangle to scale will result in a similar answer.)

173 m = \(d\)

8. Use the relationship:

\[
dist. = \text{baseline} \times \frac{(360^\circ/2\pi)}{\text{parallax}}
\]

(a) \(dist. = 1000 \text{ km} \times \frac{(360^\circ/2\pi)}{1^\circ} = 57,300 \text{ km}\)

(b) \(dist. = 1000 \text{ km} \times \frac{(360^\circ/2\pi)}{(1/60)^\circ} = 3.44 \times 10^6 \text{ km}\)

(c) \(dist. = 1000 \text{ km} \times \frac{(360^\circ/2\pi)}{(1/3600)^\circ} = 2.06 \times 10^8 \text{ km.}\)

9. \(\text{Angle} = 360^\circ \times \frac{780 \text{ km}}{100,000 \text{ km}} = 2.8^\circ\)

10. Using Discovery 0-1, if the Earth was flat, the angle with respect to the shaft of the well would always be zero, as long as the Sun is far enough away so that the Sun’s rays are parallel when they reach the Earth. In Discovery 0-1, the angle is caused by the roundness of the Earth.

**Resource Information**

**MasteringAstronomy Media Resources**

**Self-Guided Tutorials for Students**
Phases of the Moon
Stellar Parallax

**Animations/Videos**
Summer Solstice
Winter Solstice
The Equinoxes
Solar Eclipse in Indiana

**Interactive Figures**
- Figure 0.2 Constellation Orion
- Figure 0.4 The Celestial Sphere
- Figure 0.5 The Northern Sky
- Figure 0.8 The Zodiac
- Figure 0.10 Seasons
- Figure 0.12 Precession
- Figure 0.14 Lunar Eclipse
- Figure 0.16 Solar Eclipse Types
- Figure 0.20 Parallax

**Materials**

Some basic materials helpful for demonstrations in this chapter include a globe (showing the tilt of Earth’s axis), a strong flashlight, a gyroscope, and at least two different-size balls. (Styrofoam balls work well; you can use toothpicks stuck in the poles to show the axes.)

“Star wheels” or “star finders” are adjustable circular star charts that enable you to show the stars for any particular night and time. These are very helpful for explaining the apparent motions of the stars during the course of a night or the course of a year because you can rotate the wheel to represent passing time. Edmund Scientific has inexpensive cardboard ones sold in bulk packs.

*Starry Night Pro* software is very helpful for illustrating positions and motions of objects on the celestial sphere.

**Suggested Readings**


Cordell, John. “Non-mathematical explanation of precession.” *The Physics Teacher* (Dec 2011). p. 572. Good conceptual explanation of a motion that is often hard for students to understand.

Dunlop, S., and Tirion, W. *How to Identify the Night Sky*. Collins. 2004. I particularly like this reference because the star maps include an adjacent star field image which is good for practicing constellation identification.


Kuhn, T.S. *The Structure of Scientific Revolutions 3rd edition*. University of Chicago Press, Chicago, 1996. This is a reprinting of the classic 1962 work which discusses the philosophy and nature of science. This is a must for those who want to delve deeper into the philosophy of science.


Rey, H. A. *The Stars: A New Way to See Them*. Houghton Mifflin, Boston, 1962. One of my favorite books for introducing constellations. Rey uses diagrams that make the groupings of stars actually look like what they are supposed to represent!


Schaaf, Fred. “Celebrating the longest night.” *Sky & Telescope* (Dec 2002). p. 90. Addresses the winter solstice and sidereal time.

Schulz, Teresa M. “Mask of the black god: the Pleiades in Navajo cosmology.” *Journal of College Science Teaching* (Oct. 2005). p. 30. Describes a case study in which students learn about the role of a constellation in Navajo cosmology and also practice their observational and star map skills.


**Notes and Ideas**

*Class time spent on material: Estimated:___________  Actual:___________*

*Demonstration and activity materials:*

*Notes for next time:*