Dynamic Astronomy

5th Edition

Robert T. Dixon

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Associate Professor of Astronomy
Riverside Community College

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Preface

Like the first four editions of this text, which have been used in over two hundred colleges and universities in the United States and elsewhere, the fifth edition is designed to help the liberal arts student and the general reader to gain an understanding of how the astronomer studies his or her subject and to appreciate the grandeur of the universe in which we live. No prior background in science is presumed. Concepts are developed in the light of common experiences, and what little mathematics is needed is developed as the need arises. Relationships that are usually presented only as mathematical expressions are also stated verbally in order to dispel any anxiety on the part of the reader as to the mysteries of mathematics.

The real beauty of astronomy lies not only in the facts that surround the subject but also in the development of an understanding of relationships within the universe. The background of thought that has brought us to our present view of the cosmos is presented here in conjunction with the methods whereby we make pertinent observations.

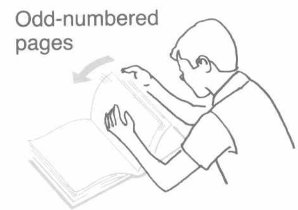
This revision represents not only an updating of information relative to a fast-moving science, but also a move in the direction of a more comprehensive treatment of astronomy. Significant portions of the text have been rewritten to reflect the current state of the art.

While the text is designed primarily for a one-semester course, it lends itself as well to a natural division for the two-quarter or two-semester program. Chapters 1 through 7 emphasize the methods of astronomy and deal with the solar system in particular, while the remaining chapters treat the stars and galaxies.

To a large extent, the astronomy student's understanding is dependent upon his or her ability to visualize the motion of whatever is being discussed in terms of both space and time. To assist the student in visualizing certain rather intricate motions of objects in the universe, a unique kind of illustration is presented in the margins of this text. By flipping the successive pages, the illustrations appear to move.

For their constructive criticism and suggestions, I would like to thank the following reviewers: Dr. Karl Krienke, Seattle Pacific University, Dr. David J. Frantz, McNeese State University, Dr. Alexander K. Dickison, Seminole Community College, Dr. D. O. Van Ostenburg, DePaul University, and Ted Coskey, South Seattle Community College. I would also like to thank the staff of Prentice-Hall, especially Holly Hodder, editor, Maria McColligan, and Debra Wechsler, production editors, and Jayne Conte, designer, for all their assistance and encouragement in the making of this book.

□ KEY TO FLIP PAGES



Right-hand flip pages

Left-hand flip pages

The eight flip-page sequences that occupy the upper margins of the pages of this text are a unique instructional tool dynamically illustrating the basic motions of astronomy. To use the flip pages on the right-hand margins, grasp the desired section with the right hand, bending these pages as illustrated here and allowing the pages to flip, one by one, from beneath your thumb. Left-hand flip pages may be handled in a similar fashion, using the left hand. Remember, flip pages starting on an odd-numbered page (right-hand) are flipped toward higher page numbers; those starting on an even-numbered page (left-hand) are flipped toward lower page numbers. (See the illustrations here in the right margin, which make this clear.)

A brief introduction to each flip sequence follows, together with an indication of its location in the text.

The Ptolemaic system (Right-hand flip pages beginning on page 9) Ptolemy envisioned the earth to be the center of the universe. In order to explain the apparent retrograde (westward) motion of the planets among the stars, he utilized the concept of the epicycle. Each planet was thought to revolve on its epicycle as the epicycle revolved on its primary orbit, called the deferent. By assigning the proper speed to each of these motions, he was able to create a retrograde motion. This motion also explains the fact that at certain times a given planet is closer to the earth. Since it had been observed that Mercury and Venus always remained close to the sun, the centers of their epicycles must always align with the earth and the sun. (This sequence of flip pages will be useful in your study of Chapter 1.)

Retrograde motion of Jupiter (Left-hand flip pages beginning on page 98) This sequence shows Jupiter moving first in a direct (eastward) motion among the stars, then apparently stopping and moving in a retrograde (westward) motion among the stars. Later the planet appears to stop again and resume its direct motion. By careful observation over an extended period of time, this apparent retrograde motion of Jupiter or of any other planet may be observed in the real sky. (This sequence will be helpful in your study of Chapters 1, 5, and 6.)

The Copernican system (Right-hand flip pages beginning on page 99) In this sequence, the planets will be seen to move at their proper speeds in relation to the earth's motion. A period of approximately one year is depicted. The period of revolution of Mercury is 88 days, hence it can make four complete revolutions in one year. Within the period of 116 days, it returns to inferior conjunction with the earth. This is called its synodic period. Venus, on the other hand, makes a complete revolution in 225 days but does not return to inferior conjunction in the period shown. This planet requires 584 days for one synodic revolution. Jupiter needs approximately 12 years for one revolution, hence it is seen to move only about 30° during the period shown. Other configurations such as maximum elongation, superior conjunction, conjunction, quadrature, and opposition may be seen on certain pages individually. See if you can find all possible configurations. (This sequence will be helpful in your study of Chapters 1, 5, and 6.)

A binary system (Left-hand flip pages beginning on page 166) This sequence demonstrates the fact that the earth and the moon form a binary (two-body) system and that it is the barycenter of the system which follows a smooth elliptical orbit. The barycenter of the system is located approximately 3000 miles from the center of the earth. As the moon revolves about this barycenter, the earth also deviates up to

3000 miles on either side of the system's orbit. In a very similar way, two binary stars, stars which lie in each other's gravitational field, orbit around a barycenter. The position of the barycenter is determined by the way in which the material (mass) is distributed in the two stars. (This sequence of flip pages should be helpful in your study of Chapters 4 and 10.)

A comet in motion (Right-hand flip pages beginning on page 219) This sequence depicts Halley's Comet, moving in its highly elongated elliptical orbit about the sun. This comet returns to the region of the sun every 76 years, its next expected return being in 2062. Halley's Comet travels in a retrograde direction that carries it beyond the orbit of Neptune. When a comet is at such a great distance from the sun, it possesses no coma (head) nor tail but exists only as a swarm of frozen gas bodies. As the comet approaches the sun, however, the warmth of the sun vaporizes a portion of the gas, thus producing the coma and tail. The outflow of particles from the sun (the solar wind) continually pushes the gases of the tail in a direction away from the sun. The speed with which the comet travels increases as it approaches the sun, hence only a relatively short time is spent in the vicinity of the sun. (This section of flip pages will be helpful in your study of Chapter 7.)

The proper motion of stars (Left-hand flip pages beginning on page 268) Over a 100,000 year-period, the familiar constellation of the Big Dipper will change in appearance until it no longer resembles a dipper. This change results from the fact that stars are in constant motion. The stars that make up this constellation are moving in different directions. The apparent change in the position of a star in 1 year is very small, perhaps in the order of 1 second of arc per year. This is called the proper motion of the star. (This sequence of flip pages will be helpful in your study of Chapter 9.)

Motion of globular clusters (Right-hand flip pages beginning on page 331) The upper view in this series shows the motion of globular clusters that form the halo of the Milky Way galaxy. Each globular moves along an elliptical path which causes it to periodically "dip" into the nucleus of the Galaxy; however, it spends a relatively short time there. (In this sequence, it is best to choose a particular globular and follow its motion, say, the one marked by the double circle.) *Rotation of the Milky Way galaxy* The lower half of the pages shows the revolution of the Galaxy. The sun participates in this revolution and makes a circuit around the center of the Galaxy in 200 million years. From the sun's position, we see one spiral arm beyond and two arms toward the center of the Galaxy. (This sequence of flip pages will be helpful in your study of Chapter 15.)

An eclipsing binary system (Left-hand flip pages beginning on page 396) The top view in this section shows the motion of a binary system, seen from above. The brighter star (light in color) is about five times as massive as its cooler (darker) component.

The middle view shows the same system, seen from our position on earth. One star is seen periodically to eclipse the other, for the earth lies very nearly in plane of their orbit.

The lower view shows the light curve which is generated as these stars move in their orbit. When the cooler star almost completely eclipses the hot star, the lowest light output is apparent. When the hotter (brighter) star is in front, only a slight dip occurs. While you are seeing the motion of these stars and the light curve generated simultaneously, the astronomer usually observes only the light curve and must infer the actual motion from that curve. (This sequence will be helpful in your study of Chapter 10.)

□ CHAPTER-OPENING ILLUSTRATIONS

Chapter 1 Stonehenge, in England. (Antony Miles)

Chapter 2 The X-ray Sky. (D. McCammon, D.N. Burrows, W. Saunders, and W. Krauschaar)

Chapter 3 The planet earth as seen from Apollo 11. (NASA)

Chapter 4 Apollo 11 astronaut on the moon. (NASA)

Chapter 5 Radar map of Venus. (NASA)

Chapter 6 Saturn (color enhanced). (NASA)

Chapter 7 Comet West. (Cliff Holmes)

Chapter 8 Sun in X-rays. (NASA/American Science and Engineering, Inc.)

Chapter 9 Star field with Lagoon and Trifid nebulae. (Malcolm Ridley)

Chapter 10 Open cluster—Pleiades. (Palomar Observatory)

Chapter 11 Small Magellanic Cloud. (National Optical Astronomy Observatories)

Chapter 12 Orion nebula. (David Malin)

Chapter 13 Monoceros & NGC 2264. (David Malin)

Chapter 14 Eta Carinae nebula. (Cerro Tololo Observatory)

Chapter 15 Milky Way galaxy. (David Malin)

Chapter 16 Spiral galaxy—M 83 in Hydra. (National Optical Astronomy Observatories)

Chapter 17 Gravitational lensing. (National Radio Astronomical Observatory)

Chapter 18 Pioneer plaque. (NASA)

□ NOTE TO THE READER

One of the most productive things you can do as you begin a detailed study of modern astronomy is to relate everything you learn to *your* own "universe." How big is your universe—does it reach beyond your own home, your school, and the city in which you live? Your universe can begin to expand by becoming more aware of things around you. Begin by noticing where the sun appears to rise and set, as viewed from your home. Does the sunrise and sunset occur at the same time everyday? Do the sunrise and sunset points change from week to week? Which way do the sun and moon, the planets and stars seem to move during one day or night? Which way does the moon move in relation to the stars night after night? Can you find the north star—the star that seems always to be in the same location? How do stars appear to move in the region of the sky near the north star? Can you identify any particular constellations (arrangements) of stars using the star maps included in Appendix 13? Can you find a fuzzy spot in the sky (a nebula or star cluster)?

As you study astronomy, you have an opportunity to apply almost everything you learn to the real world about you and in the process you will enlarge your own universe!

R.T. Dixon

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1

History of Astronomy

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  A Megalithic Legacy
  Stonehenge
  Early Concepts of the Universe
  Planets in Motion
  How Good Was Ptolemy's Model?
  Arabic Influence
- Nicolaus Copernicus, Founder of Modern Astronomy
  Tycho Brahe, the Diligent Observer
  Johannes Kepler, the Inventive Mathematician
  Galileo Galilei, Father of Experimental Science
  Isaac Newton, the Young Genius
  The Force of Gravity between Two Objects
  Our Place in the Universe

The history of astronomy is characterized by humans' ever-expanding concept of the cosmos. Through their observations of celestial objects, humans have been able to relate the rhythms of their lives to those of the visible universe. To understand the development of this harmonious relationship, place yourself backward in time about 6000 years and try to imagine what was taking place then. The early humans were nomadic—ever searching for a new supply of food and shelter from the weather and unfriendly animals. The very survival of these early humans demanded that they recognize the cycles of nature: day and night, the monthly phasing of the moon (see Figure 1.1), and the seasonal changes which influenced hunting. These cycles became yet more important when humans turned from nomadic patterns to become farmers—domesticating animals and planting crops. Crops had to be planted in the spring for harvest in the fall.

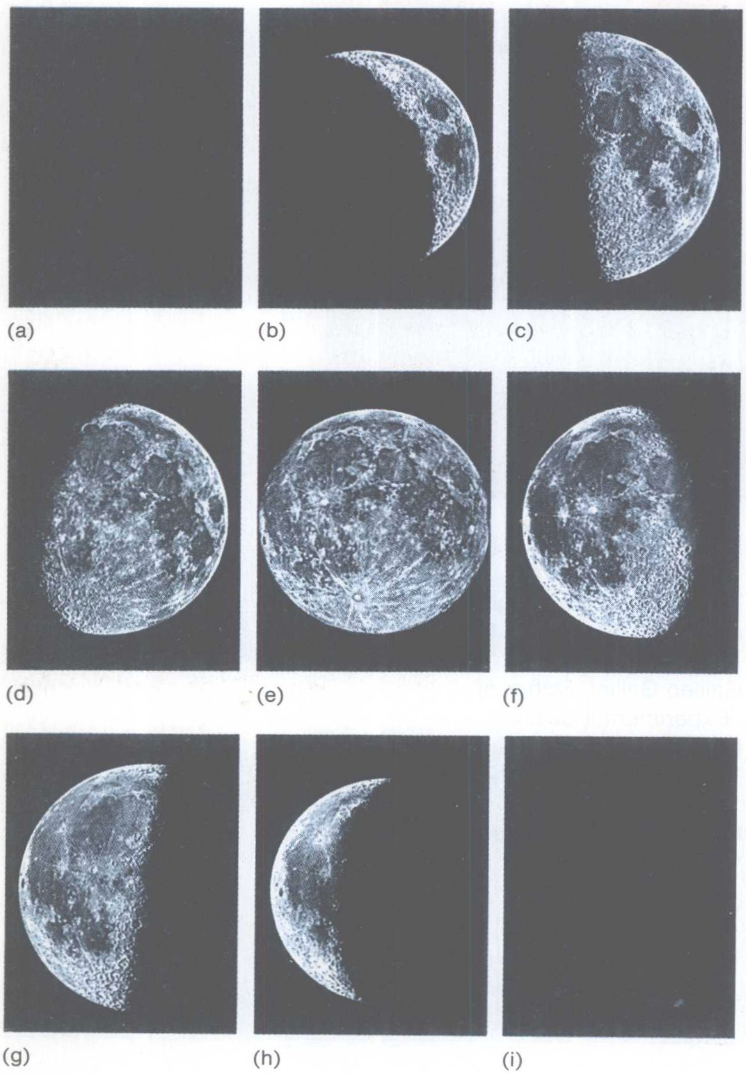

FIGURE 1.1
The phases of the moon: (a) "new moon"; (b) waxing crescent, 4 days old; (c) first quarter, 7 days old; (d) waxing gibbous, 10 days old; (e) full moon; (f) waning gibbous; (g) last quarter; (h) waning crescent; (i) "new moon" again. (Lick Observatory)

The most natural locations for agriculture were along the banks of river valleys, where both fertile soil and water for irrigation were found. As food products were traded with neighboring people, at least four early civilizations arose: China, along the Hwang Ho river; India, along the Indus river; Babylonia and Sumeria, along the Tigris and Euphrates rivers; and Egypt, along the Nile. We have numerous forms of evidence dating from these early cultural beginnings that early humans watched the skies and charted the motion of the sun, moon, and planets among the stars. It is likely that the motion of these objects prompted early people to attach godlike qualities to the celestial bodies, to worship them, and therefore to record their rhythmic motions.

The people of China produced one of the more accurate determinations of the apparent motion of the sun through the constellations, thus establishing the length of the year. In fact, many of their circular objects were divided into 365.25 parts, which corresponds to our present understanding of the number of days contained in a year. What kind of experiment could they have performed in order to determine the number of days in a year so accurately? Visualize yourself standing under the imaginary dome of the sky, facing south. Let an imaginary curved line run on that dome directly north and south over your head. This line is called your *local meridian*. The point directly over your head is called your *zenith*. Choose the time of year when the sun passes closest to your zenith and place a metal rod in a permanent foundation so that it points directly toward the sun as it crosses your meridian. Because the rod is pointed directly toward the sun, it will have no shadow (see Figure 1.2). Note that if the sun is east or west of the meridian, the rod would cast a shadow, and the time would not be noon. You can then easily tell when a full day has passed, because at that moment the rod will cast no shadow again. As the days go by, however, it will become evident that the sun is crossing your meridian farther from your zenith and as a consequence the rod casts a shadow even at noon. But count the number of days until the sun again passes closest to your zenith and the rod casts no shadow at noon and you will have determined the length of a year—approximately 365 days. After several years of counting, your record might look like this:

First year	365 days
Second year	365 days
Third year	366 days

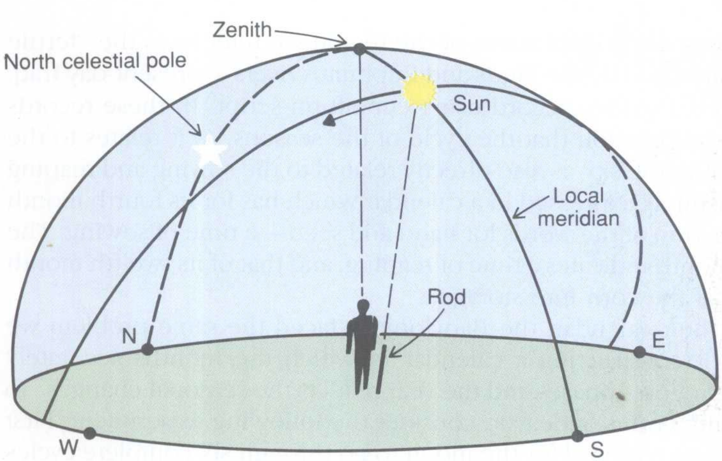

FIGURE 1.2
A rod is placed in the ground so as to cast no shadow when the sun appears highest in the sky.

Fourth year	365 days
Fifth year	365 days
Sixth year	365 days
Seventh year	366 days
Eighth year	365 days
Average	2922 divided by 8 = 365.25 days per year

By averaging the counts of eight consecutive years, we see that a year contains 365.25 days. Even this is not exact and must be corrected periodically, but we will consider this further adjustment later.

As with so many early civilizations, Chinese observers were motivated to follow the motions of the sun, moon, and planets in order to predict human and governmental affairs. Although there is no scientific basis for such a belief, a huge body of observations grew out of such motivations. After many years spent observing the sun and moon, the Chinese were able to predict eclipses—times when the earth, sun, and moon would align so perfectly that the shadow of one object would fall on the other. Because they did not fully understand the cause of eclipses, early observers were superstitious and to a degree fearful of them. A story relates that two Chinese observers named Hi and Ho became lax in their duties and failed to predict a given eclipse which was unexpectedly viewed by the citizens of their province. Because an unheralded eclipse was thought to be a bad omen, the two were beheaded.

Other early civilizations were also interested in the sun. The great temple at Peking is oriented to point toward the rising of the midwinter sun (at the time of the winter solstice). Sun alignments are quite common among the temples and monuments of many cultures. Even today, St. Peter's in Rome is oriented toward the rising sun at the time of the equinox (approximately March 21 and September 21). At these times sunlight floods the entire length of the basilica and illuminates the high altar. At the setting of the sun, a similar phenomenon illuminates the window of the Holy Ghost, producing a spectacular, almost mystical appearance.

Early Indian culture is recorded in a work called the Vedas. Included are hymns to the sun which are at least 3500 years old—hymns which recognize human dependence upon the sun for life and light.

□ BABYLONIAN "ASTRONOMY"

The Sumerians were very early inhabitants of the region we refer to as the "fertile crescent," a region dominated by the Tigris and Euphrates rivers—present-day Iraq. These people produced a written record using cuneiform script. In these records one finds a very early recognition that the cycle of the seasons, as it relates to the sun's apparent position in the sky, is also directly related to the sowing and reaping of crops. This relationship is expressed in a calendar which has for its fourth month a name that is a contraction of the words for hand and seed—a time of sowing. The name of its eleventh month indicates a time of reaping, and that of its twelfth month indicates a gathering of the corn into storage.

In constructing their calendar, the Babylonians faced the same problem we still face today: that of constructing a calendar in which the months accurately reflect the cycle of the moon's phases and the year reflects the seasonal changes. To understand the difficulty of this endeavor, consider the following experiment. First count the number of days required for the moon to go through six complete cycles