Chapter 1 Learning Outcomes

1-1 Describe the daily motions of the sun, moon, stars, and planets relative to the horizon from a midnorthern or midsouthern latitude.

1-2 Describe the seasonal positions of the sun—at sunrise, noon, and sunset—relative to the horizon from a midnorthern or midsouthern latitude.

1-3 Describe the motions of the sun and the moon, as seen from the earth, relative to the stars of the zodiac.

1-4 Describe the motions of the planets, as seen from the earth, relative to the sun and the stars of the zodiac, with special attention to retrograde motions.

1-5 Tell what astronomical events or cycles set the following time intervals: day, month, and year.

1-6 Describe the astronomical conditions necessary for the occurrence of a total solar eclipse and a total lunar eclipse.

1-7 Describe the phases of the moon in terms of the moon's angular position in the sky relative to the sun.

1-8 Define the ecliptic and tell how to find its approximate position in the sky.

1-9 Argue, from naked-eye observations and simple geometry, an order of the sun, moon, and planets from the earth.

1-10 Make use of angular measure to find positions of celestial objects relative to the horizon and relative to one another.

1-11 Define angular speed and angular size and relate angular speed to actual speed and distance and angular size to actual size and distance in verbal, graphical, and analytical form; apply these concepts to astronomical and everyday situations.

Central Concept

The motions of astronomical objects you can see by eye follow distinctive patterns and cycles in the sky over both short and long periods of time. These repeated motions suggest an underlying design to the heavens.

Chapter 2 Learning Outcomes

2-1 Describe and explain the essential aspects of a scientific model.

2-2 Summarize the observations that must be explained in a cosmological/solar system model and evaluate such models in the context of scientific model making.

2-3 Describe the physical basis of Aristotle's geocentric model and tell how it influenced his picture of the cosmos.

2-4 Describe the geometric devices that Aristotle used to explain basic astronomical observations in the context of a geocentric model.

2-5 State the assumptions and physical basis for Ptolemy's geocentric model.

2-6 Sketch a basic geocentric model for the major motions of the moon, sun, and the planets, and show how motions on circles were used to explain retrograde motions and planetary elongations.

2-7 Indicate the geometric devices and physical ideas that Ptolemy used to explain the main celestial motions and any variations in the major cycles.

2-8 Evaluate the essential assets of Ptolemy's geocentric model that led to its wide, long-term acceptance; as part of this appraisal, be able to construct a simplified version of the model.

2-9 Use at least one specific case to show how geometric and aesthetic concepts influenced Greek ideas about the cosmos.

2-10 Describe the difference between a sun-centered model and an earth-centered one with respect to an annual stellar parallax.

Central Concept

Scientific models of the cosmos can explain and predict the motions of celestial bodies, especially those of the planets. Early models of the cosmos were centered on the earth.

Chapter 3 Learning Outcomes

3-1 List the assumptions and arguments that Copernicus used to support his model and refute the Ptolemaic one.

3-2 Explain why Copernicus disliked Ptolemy's use of nonuniform motion and how this bias influenced the development of his heliocentric model.

3-3 Show how the Copernican model explains the major motions in the sky; in particular, use simple diagrams to explain retrograde motions and elongations in the Copernican model.

3-4 Outline how the Copernican model's geometry plus simple observations determine the periods and relative distances of the planets from the sun, and so set a distance scale for the heliocentric model.

3-5 Evaluate the strengths and weaknesses of the Copernican model compared to the Ptolemaic one, including stellar parallax.

3-6 Describe how Copernican ideas influenced the astronomical work of Kepler.

3-7 Argue that Kepler, not Copernicus, properly deserves the title of the "first astrophysicist."

3-8 Describe the important geometric properties of ellipses and apply these to planetary orbits.

3-9 Compare and contrast the Copernican model and the Keplerian one in terms of physics, simplicity, geometry, and prediction.

3-10 State Kepler's three laws of planetary motion and apply them to appropriate astronomical situations.

Central Concept

A heliocentric model of the cosmos was reinvented during the 16th century in Europe, but this break with the geocentric tradition required new physical laws and a revolution of the cosmological views of the time.

Chapter 4 Learning Outcomes

4-1 Describe Galileo's important telescopic discoveries and their impact on the controversy over the Copernican and Ptolemaic models.

4-2 Indicate Galileo's purpose in developing a new science of terrestrial motions, and contrast Galileo's ideas about motion to those of Aristotle.

4-3 Contrast Galileo's astronomy and cosmology to those of Copernicus and Kepler.

4-4 Describe the difference between speed and velocity and between accelerated and unaccelerated motion, giving everyday and astronomical examples of each.

4-5 Cite Newton's three laws of motion, describe each in simple terms, provide concrete examples, and apply them to astronomical and everyday cases.

4-6 Contrast Newton's concept of natural motion to that of Aristotle, especially with regard to celestial motions.

4-7 Describe Newton's Law of Gravitation in simple physical terms, and apply this law to the concept of weight.

4-8 Define and describe the concept of centripetal force and acceleration, and use it in the moon - apple test to support Newton's Law of Gravitation.

4-9 Contrast Newton's astronomy and cosmology with those of Copernicus and Kepler.

4-10 Use Newton's physical ideas to support the Copernican model, and apply these ideas to appropriate astronomical situations, especially to those involving orbits.

4-11 Apply Newton's Law of Gravitation and Newton's revision of Kepler's Third Law in verbal, graphical, or analytical form.

4-12 Describe the physical concept of escape speed and apply it to astronomical situations in verbal, graphical, or analytical form.

Central Concept
Newton's laws of motion and gravitation explain, predict, and unify the motions of the bodies in the solar system. These laws are universal and apply to objects outside of the solar system.

Chapter 5 Learning Outcomes

5-1 Describe the differences in the appearance of continuous, absorption, and emission spectra as seen through a spectroscope.

5-2 Explain how an understanding of spectra made it possible for astronomers to determine the chemical compositions of stars and the physical conditions inside their atmospheres.

5-3 Use Kirchhoff's rules to relate the three basic spectral types to the physical conditions of their production.

5-4 Describe how wavelength, frequency, and speed of light are related.

5-5 Describe the relationship between energy and frequency or wavelength for light and apply it to the spectrum.

5-6 Briefly describe the electromagnetic spectrum with examples from each major region.

5-7 Use an energy-level diagram to explain in general how atoms absorb and emit light.

5-8 Use the energy-level diagram of a hydrogen atom to explain how the Balmer series is produced, both as emission and absorption lines.

5-9 Explain in simple physical terms how absorption lines occur in spectra.

5-10 Describe the concept of the conservation of energy and apply it to ordinary and astrophysical situations.

5-11 Describe the concept of energy and the various types of energy; apply these to light and astrophysical situations.

5-12 Describe, sketch, and explain the three major types of spectra in graphical form.

Central Concept
Matter produces light, and this light carries physical information about the sun, stars, and other celestial objects that emit it. Light comes in discrete units that are emitted and absorbed by atoms.

Chapter 6 Learning Outcomes

6-1 Describe the impact of telescopic observations on scientific models.

6-2 Outline the main functions of a telescope (light-gathering power, resolution, and magnifying power); relate each to specific optical properties of a telescope's design and sketch those relationships in graphical form.

6-3 Compare and contrast a telescope's light-gathering power, resolution, and magnifying power, and discuss the limitations of ground-based telescopes.

6-4 Compare and contrast reflecting and refracting telescopes; include a sketch of the optical layout of each in your comparison.

6-5 Compare a radio telescope to an optical telescope in terms of functions, design, and use.

6-6 Cite a key drawback of a radio telescope compared with an optical telescope and describe how radio astronomers cope with this problem.

6-7 Describe the usefulness of a radio interferometer compared to a single-dish radio telescope.

6-8 Describe what is meant by the term "invisible astronomy."

6-9 Contrast an infrared telescope to an optical telescope in terms of functions, design, and use.

6-10 Discuss at least two important advantages a space telescope in earth orbit has over a ground-based telescope, and the even greater advantages of telescopes on the moon.

6-11 Describe how astronomers make images, and explain the meaning of an intensity map of an astronomical object.

Central Concept

Telescopes extend our perception of the cosmos by revealing faint objects and a wide range of the electromagnetic spectrum. New observations impel the development of new models and often the demise of old ones.

Chapter 7 Learning Outcomes

7-1 State the principle of equivalence and illustrate it with a concrete example.

7-2 Show how the principle of equivalence leads to the local cancellation of gravitational forces and weightlessness.

7-3 Compare and contrast Aristotle's, Newton's, and Einstein's concepts of natural motion for bodies falling near the earth and of the motions of heavenly bodies.

7-4 Describe what is meant by the term *spacetime* and give a common example.

7-5 Argue that concepts of natural motion must be coupled to a notion of the geometry of spacetime, both locally and for the cosmos globally.

7-6 Use the concept of escape speed to relate the future of the universe to its geometry: hyperbolic, spherical (closed), or flat.

7-7 State Einstein's relation between matter and energy, apply it to astrophysical situations, and use it in algebraic form.

7-8 Describe one observational confirmation of Einstein's general theory of relativity.

Central Concept

The general theory of relativity views space and time as unified in four dimensions. The new view of gravity—radically different from that of Newton's—predicts an expanding universe that may be finite or infinite in spacetime.

Chapter 8 Learning Outcomes

8-1 Describe and apply one method for determining the earth's mass and density; apply the concept of escape speed to the earth.

8-2 Sketch the interior structure of the earth, indicating the composition of each general region, and argue that the earth's interior structure implies that it must have been molten at one time.

8-3 Argue from at least two observations that the earth's core probably has a metallic composition.

8-4 State the estimated age of the earth, with a range of uncertainty, and explain the method by which this age is inferred using radioactive decay and half-life.

8-5 Apply the properties of magnetic fields in general to the overall structure of the earth's magnetic field, and present a possible model for the field's source.

8-6 Describe at least two ways in which the earth's atmosphere affects astronomical observations and two ways in which it affects the earth's surface environment.

8-7 Explain how the earth's atmosphere acts like an insulating blanket that keeps the earth's surface warm.

8-8 Outline a possible model for the evolution of the earth's crust and interior, with an emphasis on heat flow.

8-9 Outline a possible model for the evolution of the earth's oceans that ties in with a broader view of the earth's history.

8-10 Outline a possible model for the evolution of the earth's atmosphere; indicate how humankind affects the atmosphere now.

8-11 Summarize the physical processes that affect the evolution of the earth's atmosphere, crust, and interior (especially the outward flow of heat) and serve as a model for planetary evolution.

Central Concept
The dynamic earth is a highly-evolved planet, built over thousands of millions of years by geologic processes that are driven by the slow outflow of internal heat. It serves as the model for understanding other planets.

Chapter 9 Learning Outcomes

9-1 Compare the moon, Mercury, Mars, Venus, and the earth in terms of their general surface and physical properties (such as mass and density), with a special focus on how we know this information.

9-2 Describe each planet's major surface features and indicate a possible formation process for these features.

9-3 Compare and contrast the surface environments (such as temperature, atmosphere, surface features, escape speed) of the terrestrial planets.

9-4 Sketch a model for the structure of the interior of each terrestrial planet and compare them.

9-5 Compare and contrast the magnetic fields (or lack thereof) of the terrestrial planets.

9-6 Compare and contrast the evolution of the terrestrial planets, applying the general processes for evolution, such as cratering, volcanism, and tectonics.

9-7 Compare and contrast the evolutionary lifetimes of the terrestrial planets; argue that the moon is the least evolved, the earth the most.

9-8 Describe the process of cratering of planetary surfaces and tell how craters can be used to infer the relative ages of surfaces.

9-9 Use Newton's law of gravitation to explain the nature of tidal forces, and apply tidal forces to astrophysical situations.

Central Concept

The evolutions of the moon, Mercury, Mars, and Venus have been driven by processes similar to those that have created the earth, but have not operated as long or as vigorously.

Chapter 10 Learning Outcomes

10-1 Compare and contrast the Jovian planets as a group to the terrestrial planets, emphasizing the greatest differences.

10-2 Contrast the Jovian planets to one another in terms of their relative sizes, relative masses, bulk densities, atmospheric compositions, internal structures, and unique features.

10-3 Compare and contrast the interior and composition of Jupiter to those of the earth.

10-4 Compare the rings of Saturn with those of Uranus, Neptune, and Jupiter in terms of size, shape, and possible composition.

10-5 Present the unique characteristics of Pluto that make it neither a Jovian nor a terrestrial planet.

10-6 Describe the general properties of the Pluto - Charon double-planet system.

10-7 Compare and contrast the general characteristics, surface features, and evolution of the Galilean satellites of Jupiter: Io, Europa, Ganymede, and Callisto.

10-8 Compare and contrast the Galilean satellites to the earth's moon and to Pluto and Charon, especially in terms of evolutionary processes.

10-9 Compare the magnetic fields and magnetospheres of Jupiter, Uranus, Neptune, and Saturn to those of the earth, and apply a dynamo model to them.

10-10 Contrast Saturn's largest moon, Titan, with the other moons of Saturn, the Galilean moons of Jupiter, the largest moons of Uranus, and the earth's moon.

10-11 Argue that the Jovian planets have evolved since their formation by heat flow from their interiors, but in contrast with the terrestrial planets, they leave behind no record of their changes.

Central Concept
The Jovian planets, compared to the terrestrial ones, have greater masses and sizes but lower densities. Today they pretty much resemble their early states because they preserve little of the history of their evolution.

Chapter 11 Learning Outcomes

11-1 Identify at least two dynamic and two chemical properties of the solar system that any model of origin must explain.

11-2 Describe and compare the general physical properties of comets, asteroids, meteoroids, and meteorites, and state what the radioactive dating of meteorites implies for the dating of the formation of the solar system.

11-3 Specify what clues asteroids, comets, and meteorites provide about the formation of the solar system, with special emphasis on the composition of each.

11-4 Describe the concepts of angular momentum and the conservation of angular momentum; explain what is meant by the "angular momentum problem" for nebular models.

11-5 Describe one possible way out of the angular momentum problem in modern nebular models.

11-6 Describe briefly the chemical condensation sequence, using one Jovian and one terrestrial planet to illustrate its use.

11-7 Describe the role of accretion in the formation and initial heating of the planets and the role of impacts in the subsequent intense bombardment.

11-8 Compare and contrast a model for the formation of Jovian planets to that of the terrestrial planets.

11-9 Describe the general process of gravitational contraction of a spinning cloud of gas and dust, applying the concepts of the conservation of energy and angular momentum.

11-10 Sketch a modern scenario for the formation of the solar system, and evaluate how well it explains the known chemical and dynamic properties listed for Outcome 11-1.

Central Concept
The planets formed from an interstellar cloud of gas and dust as a natural outgrowth to the formation of the sun. They then evolved by common processes into the planets of today.

Chapter 12 Learning Outcomes

12-1 Outline a contemporary method to find the distance to the sun.

12-2 Describe current methods for finding out the sun's mass, size, density, flux, luminosity, and surface temperature.

12-3 Define a blackbody, describe the characteristics of blackbody radiation, and apply these to the sun and to other appropriate astronomical situations.

12-4 Describe the physical meaning of the term opacity, and explain how this property affects the flow of energy through the sun.

12-5 Describe the appearance of the sun's spectrum and state the atomic processes that produce this spectrum.

12-6 List the sun's two most abundant elements and describe how these and others have been found.

12-7 Briefly, in a sentence or two, explain the source of the sun's energy.

12-8 State the specific thermonuclear reactions that produce the sun's energy and describe the conditions needed for them to take place.

12-9 Discuss the results and possible consequences of solar neutrino experiments.

12-10 Trace the flow of energy from the sun's core to the earth and describe how the features of the quiet sun (photosphere, chromosphere, corona, and solar wind) result from this energy flow.

12-11 Select one feature of the active sun, describe its observed characteristics, and explain the main features in terms of energy flow and magnetic fields.

12-12 Describe the model for an ideal gas and apply this model to the sun, to other stars, and to other appropriate astronomical situations.

Central Concept
The sun produces its life-giving energy by nuclear fusion reactions transforming hydrogen to helium in its hot core. The outward flow of this energy determines the sun's physical structure.

Chapter 13 Learning Outcomes

13-1 Outline the methods astronomers use to find the following physical properties of stars: surface temperature, chemical composition, size (radius or diameter), mass, luminosity, and density.

13-2 Describe the relationship between a star's color and its surface temperature.

13-3 Describe the relationship of a star's luminosity, surface temperature, and radius, assuming that it radiates like a blackbody.

13-4 Explain the difference between flux and luminosity and relate flux, luminosity, and distance.

13-5 Describe what is meant by the inverse-square law for light and apply this relation to astronomical situations.

13-6 Show by a simple diagram the relationship between a star's distance and its parallax, noting the limitations imposed by the earth - sun distance.

13-7 Sketch a Hertzsprung - Russell diagram for stars, indicating the positions of sun, the main sequence, giants, supergiants, and white dwarfs.

13-8 Use the Hertzsprung - Russell diagram to infer the relative luminosities, surface temperatures, and sizes of stars represented on it.

13-9 Outline the steps by which astronomers determine the masses of binary stars, including the application of Kepler's laws, and apply the Doppler shift to binary systems.

13-10 Sketch and make use of the mass - luminosity relation for main-sequence stars; from it, argue that stars have finite lifetimes.

13-11 Use analytical and graphical forms of the inverse-square law for light, stellar parallax, and the mass - luminosity relation.

Central Concept

Astronomers determine the physical properties of stars by finding their distances and analyzing the light received from them. Their properties can be summarized in a mass-luminosity diagram. Like the sun, we find that stars are naturally-controlled thermonuclear reactors.

Chapter 14 Learning Outcomes

14-1 Present observational evidence for the presence of gas and dust between the stars.

14-2 Compare and contrast the different forms in which the interstellar gas is found and tell how each form is observed.

14-3 Describe three observable effects of interstellar dust on starlight.

14-4 Describe possible physical properties of interstellar dust, such as size and chemical composition.

14-5 Indicate how interstellar molecules and dust might be formed and suggest the link between them.

14-6 Describe the basic physical ideas of gravitational collapse and contraction for rotating and nonrotating clouds of material.

14-7 Sketch a scenario for the formation of massive stars from molecular clouds and indicate what observations support this model.

14-8 Outline possible processes for the birth of stars like the sun and provide observational evidence to support them.

14-9 Sketch a model for the formation of massive stars and contrast it to that for solar-mass stars.

14-10 Argue that starbirth is occurring now in our Galaxy, with a focus on infrared and radio observations.

14-11 Describe the environment of star-forming regions, with special attention to outflows of gas as a signature.

14-12 Argue that the general process of gravitational collapse can result in planetary systems and brown dwarfs.

14-13 Explain the observational evidence to date for the existence of extrasolar planets around normal stars.

Central Concept
Stars are born out of the material in the space between the stars. This material consists of gas (in a variety of forms) and dust, mostly collected in clouds.

Chapter 15 Learning Outcomes

15-1 Show how the Hertzsprung - Russell (H - R) diagram for many stars provides clues about the evolution of individual stars.

15-2 Describe the physical basis of a theoretical model of a star, that is, the physical concepts that go into building a star model.

15-3 Trace the evolution of a 1-solar-mass star on a H - R diagram, describing the physical changes of the star that result from changes in the star's core.

15-4 State in one sentence why stars must evolve.

15-5 Compare the evolutionary tracks of a 1-solar-mass star and a 5-solar-mass star on an H - R diagram.

15-6 Describe the evolution, on an H - R diagram, of a cluster of stars of different masses.

15-7 Back up theoretical ideas of stellar evolution with observational evidence, with special emphasis on star clusters and their H - R diagrams.

15-8 List the sequence of thermonuclear energy generation reactions in stars of different masses.

15-9 Compare and contrast galactic (open) star clusters to globular ones in terms of both their physical properties and their H - R diagrams.

15-10 Indicate how mass and chemical composition affect stellar evolution.

15-11 Describe how fusion reactions in stars during their normal lives result in the manufacture of some heavy elements, and indicate how these processed materials may be recycled to the interstellar medium.

15-12 Trace the flow of energy from the core of a star to its surface for stars of different mass and at different stages of evolution.

Central Concept
Stars evolve; their physical properties change as they go through their normal lives. The main agent in how and how fast a star evolves is its mass.

Chapter 16 Learning Outcomes

16-1 Compare the physical natures of white dwarfs and neutron stars; describe the place of each in stellar evolution and observational evidence for them.

16-2 Describe the basic physical properties of a degenerate star in contrast to an ordinary star.

16-3 Argue, with observational support, that pulsars are rapidly rotating, highly magnetic, neutron stars.

16-4 Compare and contrast the observed features of a nova and a supernova.

16-5 Outline a possible model for a nova explosion that involves a binary star system, and connect the model to observations.

16-6 Outline possible models for supernova explosions and describe the effects of the aftermath of such an explosion on the interstellar medium.

16-7 Cite observational evidence that the Crab Nebula is a supernova remnant and describe the effect of the pulsar on the nebula now.

16-8 Describe how synchrotron radiation is emitted, identify its observed properties, and apply this concept to appropriate astrophysical situations.

16-9 Describe a black hole in terms of escape speed and the speed of light, and tell what happens to an observer falling into a black hole from the viewpoints of the infalling observer and an outside observer far from the black hole.

16-10 Describe how nucleosynthesis can occur in a supernova and identify possible products of such nuclear reactions.

16-11 State an important consequence for cosmic evolution if black holes do exist.

16-12 State and evaluate the observational evidence for the existence of black holes.

16-13 Outline a model for x-ray and gamma-ray bursters, and compare these to models for novas and supernovas.

Central Concept
Stars finally lose their struggle with gravity. Most stars die violently and leave behind strange corpses: white dwarfs, neutron stars, and black holes.

Chapter 17 Learning Outcomes

17-1 Explain at least one astronomical difficulty in trying to figure out the structure of the Galaxy from our location in it.

17-2 Name the important spiral-arm tracers and state generally how they are used to map spiral structure.

17-3 Present the observational evidence for the Galaxy's having a spiral structure; that is, describe what specific methods astronomers use to work out the positions of spiral arms.

17-4 Sketch the rotation curve of the Galaxy, describe how to find from it the approximate mass of the Galaxy, and argue that a significant amount of the Galaxy's mass must exist in the halo in an unseen form.

17-5 Describe the sun's orbit around the galactic center and explain the techniques used to find the distance and speed of this orbit.

17-6 Explain how radio astronomers used 21-cm-line and millimeter-line observations to trace spiral arms; indicate the limitations of their method and explain its advantage over optical observations.

17-7 Describe the contents of a typical spiral arm and explain how these evolve.

17-8 Describe the evolution of spiral arms in terms of the density-wave model for spiral structure.

17-9 Outline a model for the evolution of the disk of the Galaxy.

17-10 Outline a model for the evolution of the halo of the Galaxy.

17-11 Make two rough sketches of the entire Galaxy, from a top and a side view, labeling the disk, spiral arms, halo, globular clusters, and nucleus, and indicating the sun's position.

17-12 Describe what information radio, infrared, and x-ray observations provide about the nucleus of the Galaxy and make a case for the possible existence there of a supermassive black hole.

17-13 Speculate on the future of the Galaxy from current information and models.

Central Concept
The evolution of the Milky Way, a spiral galaxy, is driven primarily by the evolution of the parts that make up its disk.

Chapter 18 Learning Outcomes

18-1 Describe the general physical characteristics of disk (spiral), elliptical, and irregular galaxies, including their differences in size, shape, mass, color, stellar types, and amount of interstellar gas and dust.

18-2 Outline specific methods used to find the bulk physical properties of galaxies.

18-3 Describe how to use the criteria "brightness means nearness" and "smallness means farness" to estimate the relative distances to galaxies.

18-4 Indicate what observation clinched the idea that the spiral nebulas are actually other galaxies.

18-5 Describe briefly the general techniques to find distances to galaxies.

18-6 Outline a contemporary method of finding distances to distant galaxies, starting with nearby objects and ending with Hubble's constant.

18-7 Evaluate the weaknesses in the procedure you outlined in Outcomes 18-3 and 18-6 so that you can estimate the possible errors in distances to galaxies.

18-8 Show how (graphically or analytically) getting distances and radial velocities for galaxies results in a value for Hubble's constant, and use this value to estimate distances to galaxies.

18-9 State the range of uncertainty in the value of Hubble's constant, and give the implications of this uncertainty.

18-10 Define the term "cluster of galaxies" and describe the layout of a cluster in space.

18-11 Evaluate the evidence for intergalactic medium between and/or within clusters of galaxies.

18-12 Define supercluster and describe the general layout of superclusters in space and the voids between them.

18-13 Discuss the evidence, direct or indirect, for dark matter in clusters and superclusters of galaxies.

Central Concept
Galaxies make up the visible universe; how are they distributed throughout space and time gives us clues about the origin of the cosmos.

Chapter 19 Learning Outcomes

19-1 Outline the observational evidence for violent activity in our Galaxy and other galaxies, with special emphasis on synchrotron radiation, and an overall view of their spectra.

19-2 Compare and contrast the nuclei of active galaxies to ordinary ones (such as the Milky Way Galaxy).

19-3 List at least four important observational characteristics of quasars.

19-4 Sketch a physical model that could account for the observed characteristics of quasars.

19-5 Discuss the significance of redshifts for quasars for both their emission and absorption lines.

19-6 Summarize the evidence for quasars as the active nuclei of distant galaxies.

19-7 Compare and contrast the nucleus of the Milky Way Galaxy, active galactic nuclei (AGNs), and quasars.

19-8 Outline a method used to estimate distances to quasars and discuss its uncertainties.

19-9 Outline a generic model for AGNs and quasars, using a supermassive black hole as the power source.

19-10 Describe the observational properties of jets in the nuclei of galaxies and outline a possible model for them.

Central Concept

Observations, especially at radio wavelengths, show violent activity in peculiar objects beyond the Milky Way Galaxy. These may be powered by supermassive black holes.

Chapter 20 Learning Outcomes

20-1 State the basic assumptions of scientific cosmology about the physical universe.

20-2 Present, in a short paragraph, key observations that have cosmological import.

20-3 Describe briefly the Big Bang model, focusing on its assumptions and ability to explain key cosmological observations.

20-4 Describe briefly the observed properties of the cosmic background radiation.

20-5 Present at least one argument for ascribing a cosmic origin to the background radiation and explain how it is a natural consequence of a Big Bang model.

20-6 Discuss the importance and the impact of cosmic radiation for the Big Bang model.

20-7 Outline the process of element formation in the standard Big Bang model and cite at least one observation that supports theoretical ideas.

20-8 Describe a physical basis for particle production from light in the young, hot universe.

20-9 Outline a history of matter and radiation from the time they stopped interacting strongly to the present.

20-10 Describe a model of galaxy formation from the Big Bang and pinpoint problems with this model, especially in light of observations of the cosmic background radiation.

20-11 Identify at least two problems associated with the standard Big Bang model and explain how an inflationary model attempts to cope with them.

20-12 Specify the nature of the "dark matter problem" for the cosmic geometry and future of the universe.

Central Concept
The universe originated at a finite time in the past and has evolved to its present state guided by fundamental physical laws. The beginning of the universe was branded by the Big Bang, the relic radiation that we detect today.