

KAUFMANN

UNIVERSE

SECOND EDITION

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SECOND EDITION

William J. Kaufmann, III



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To Elayne R., with love

Front cover image

A giant luminous arc in a cluster of galaxies In 1987, Roger Lynds at Kitt Peak National Observatory and Vahe Petrosian of Stanford University announced their discovery of the huge luminous arc shown on the cover of this book. This arc is more than 300,000 light years long and is located in a remote cluster of galaxies. Many of the fuzzy spots on the cover photograph are galaxies in this cluster, which is roughly 5 billion light years from Earth. A giant elliptical galaxy is located near the center of curvature of the arc. For a sense of scale, you should know that a typical galaxy like our Milky Way measures about 80,000 light years in diameter. Astronomers are at a loss to explain this enormous glowing arc. (Courtesy of NAO)

Back cover images

Top: The Horsehead Nebula This nebulosity is part of a large region of active star formation in the constellation of Orion. Radiation from newborn, massive stars causes the interstellar hydrogen gas to glow with a characteristic reddish hue. The dark features are produced by clouds of interstellar dust grains silhouetted against the background nebulosity. This nebula is about 1600 light years from Earth. (Anglo-Australian Observatory)

Middle: An annular eclipse of the Sun This composite of six images shows the progress of a solar eclipse that occurred on December 24, 1974, as viewed from Costa Rica. At the time of this eclipse, the Moon was near apogee, its farthest distance from Earth. The Moon's disk was therefore too small to cover the Sun completely and a ring, or annulus, of light was seen around the Moon at mid-eclipse. (Courtesy of Dennis di Cicco)

Bottom: A spiral galaxy Vigorous star formation in this galaxy is occurring along graceful spiral arms which are outlined by numerous glowing nebulae and bright, newborn stars. Various processes can compress interstellar gases and trigger such star formation. This galaxy, called NGC 4303 or M61, is located in the constellation of Virgo at a distance of about 50 million light years from Earth. (Palomar Observatory)

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Preface

The popularity of astronomy as a general science course is due in large measure to the inherent intrigue of its subject matter. Since earliest times people have been fascinated by topics that astronomers explore today: the creation of the universe, the formation of the Earth and other planets, the motions of the stars, the structure of space and time. Armed with the powers of observation, the laws of physics, and the resourcefulness of the human mind, astronomers survey alien worlds, follow the life cycles of stars, and probe the dim and distant reaches of the cosmos.

Astronomy raises our consciousness because it investigates phenomena and explores realms far removed from our daily experience. Many of the objects that astronomers study are far too vast, distant, or intangible to ever sample directly; indeed, many of the phenomena that are observed today occurred very long ago. When viewed in the context of the evolution of the universe, even the dimensions of space and time take on new meaning.

I have tried, however, to convey more than the intriguing nature of our physical universe. I also describe how astronomers have come to know what they know. To show students how scientists reason must be an objective of any first science course. By studying the methods that astronomers have used in exploring the universe, we can learn something about the nature of scientific inquiry.

Organization

This text is designed for both one- and two-term courses. The level of coverage here is generally more comprehensive and contains a little more mathematics than that found in the sister text *Discovering the Universe*. While comprehensive, this second edition of *Universe* has a flexible, modular structure.

The book's twenty-nine chapters are easily divided into two nearly equal parts, the first half dealing with introductory material and planetary astronomy, and the second half treating stars, galaxies, and cosmology. Instructors may emphasize either half of the book according to preference, covering more or less of the detail as time and the preparation of the students permit.

The traditional Earth-outward organization of this text emphasizes how our understanding of the universe developed and invites the reader to share in the excitement of astronomical discovery. The first celestial objects to be examined are those that were observed by the ancient astronomers. Moving outward from the planets to the stars and galaxies, older Earth-based observations and the questions that they provoke are augmented or even supplanted by newer observations, including those from outside the visible range and those made from space. These new observations in turn raise new questions, which draw the reader on to the outer limits of our universe and our understanding.

The first six chapters introduce the foundations of astronomy, including descriptions of such naked-eye observations as eclipses and planetary motions and such basic tools as Kepler's laws, the fundamental properties of light, and the optics of telescopes. A discussion of the formation of the solar system in Chapter 7 prepares the reader for the next ten chapters, which cover the planets in outward order from the Sun. One of these chapters deals with the Galilean satellites, which are terrestrial worlds in their own right.

Chapter 18 introduces stellar astronomy by describing stars in general, and in Chapter 19 one particular star, the Sun, is examined in detail. In Chapters 20 through 24, stellar evolution is described chronologically from birth to death. Molecular clouds, star clusters, nebulae, neutron stars, black holes, and various other phenomena are presented in the sequence in which they naturally occur in the life of a star, thus unifying the wide variety of objects that astronomers find scattered about the heavens.

A survey of the Milky Way introduces galactic astronomy in Chapter 25; this is followed by two chapters on galaxies and quasars. The final two chapters, on cosmology, emphasize exciting recent developments in our understanding of the physics of the early universe.

Major changes in this edition

The first step in planning the second edition of *Universe* was to compile and examine reactions to the first edition. A questionnaire sent to hundreds of instructors who had used *Universe* in both the United States and Canada, provided a most enlightening and inspiring impetus for this revision. Many of the improvements made in the second edition reflect the good judgment and class experience of numerous text users, reviewers, and friends.

Two major organizational changes were made in this edition. The first involves the treatment of light. Virtually all topics relating to the physics of electromagnetic radiation, from Wien's law to atomic structure, are now consolidated in one chapter near the beginning of the book. This chapter, entitled "The Nature of Light and Matter," provides a complete and satisfying orientation to this critical yet basic topic, and increases the text's flexibility as well. For instance, a course on stellar astronomy could begin with the introductory chapters on gravitation and light (Chapters 4 and 5) and proceed directly to Chapter 18 without any loss of continuity.

A second significant organization change concerns the treatment of cosmology. In this second edition, virtually all of the more "standard" cosmological issues are discussed in Chapter 28. It would thus be quite appropriate to end an astronomy course with that chapter. Chapter 29 was created for those who wish to go on to consider the interface between cosmology and particle physics. Entitled "Physics of the Early Universe," Chapter 29 introduces several unifying theories and deals with such speculative and exciting ideas as cosmic strings and eleven-dimensional spacetime. This challenging, optional chapter explores topics in which research is today proceeding at a fevered pitch. The student will learn that physicists are at the brink of tackling questions like: Why is there only one dimension of time, yet three dimensions of space?

Many smaller, yet equally important, revisions enhance the rest of the text. The text was, of course, updated throughout. The planets chapters have been streamlined and strengthened through the deletion of extraneous details. Coverage of Uranus and Comet Halley reflects our latest findings. A discussion of mass-transfer in close binary systems has been added. In light of SN 1987A, the treatment of supernovae was enlarged and now includes some details about exploding white dwarfs. Explanations for spiral structure in galaxies now include stochastic, self-propagating star formation. And, finally, the discussion of galactic evolution has been greatly amplified. With these changes, I have ventured to create a comprehensive yet entertaining text that gives a fair and accurate picture of the full scope of astronomy.

Pedagogical emphasis

The student's ease in understanding astronomy continues to be a major objective of this text. Each chapter begins with a brief, one-paragraph abstract that gives the reader a clear idea of the chapter's contents. The chapter headings, in the form of declarative sentences, highlight main concepts. A formal summary outlines the essential facts addressed in each chapter. Each chapter concludes with a series of questions grouped into three categories: review, advanced, and discussion. Answers to questions that require computation (marked by an asterisk) appear at the end of the book. Care has been taken to include some questions whose answers require reasoning rather than just memorization. Roger Culver of Colorado State University deserves special recognition for his many contributions here.

Boxed inserts set aside the text's more technical and/or mathematical material. Many review key formulas and the calculations that lead to astounding discoveries. Others contain technical reference information, such as the orbital and physical data for each planet. Still others present arguments, taking an idea raised in the text a step further. Boxes may be omitted without loss of continuity. This segregation permits greater flexibility in an instructor's use of the text and allows students to easily locate and review topics to which they may wish to refer again.

Illustrations

Color illustrations greatly enhance the effectiveness of this book. Most astronomy texts contain only a sampling of color photographs, usually segregated from the corresponding narrative. In this text, however, color photographs are integral to the text and are incorporated throughout. Color pictures are indispensable to a truly modern view of astronomy. Color is now routinely used by astronomers in a wide variety of circumstances. One glance at a color photograph of a planet's cloudtops or of the glowing gases of a nebula reveals significant details about the object that cannot be gleaned from a black-and-white view. X-ray, infrared, and radio views of the sky are now very comprehensibly displayed in extraordinary computer-generated false-color images. The incorporation of color pictures in the main body of the text not only makes reading and learning easier, but reflects how astronomy is practiced today.

Essays

It is again a great pleasure to include the essays of six renowned astronomers, who offer their personal views on topics of especially current interest. These exceptional essays round out the book and give it a depth and quality that could not have otherwise been possible:

Astrology and astronomy	Owen Gingerich
Extraterrestrial life	Frank D. Drake
The outlook for space science	Peter B. Boyce
Supercomputers in astronomy	Larry L. Smarr
The Hubble Space Telescope:	
A bridge into time and space	Riccardo Giacconi
The edge of spacetime	Stephen W. Hawking

Ancillaries

It is a pleasure to announce the availability of the following outstanding ancillaries to the second edition of *Universe*:

A *Computerized Test Bank* has been prepared by T. Alan Clark, The University of Calgary, Alberta, Canada. Included on this IBM-PC-based testing program are multiple-choice questions, indexed by chapter and topic category, and a flexible edit feature which allows instructors to include their own questions.

A set of slides is available to accompany *Universe*. The 60 slides contain a selection of line illustrations reproduced directly from the text. Both the *Computerized Test Bank* and *Slide Set* are free to adopters of 100 or more copies of the text.

An *Instructors Manual* has been prepared by Thomas H. Robertson, Ball State University and Andrew Franknoi, Astronomical Society of the Pacific. It contains chapter synopses, hints for teaching and discussion, and a current list of resources for teaching.

Andrew Fraknoi's very successful *Universe in the Classroom: A Resource Guide for Teaching Astronomy* is an invaluable book for teaching ideas, resources, experiments, and other related activities.

For more information and to request copies of these supplements please contact:

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Finally, I thank Dwight Nicholson at the University of Iowa as well as Jack Connors and Beth Avery, who hunted down typos and errors in the first edition. Although we have made a valiant effort to make this an error-free edition, some mistakes may have crept in. I would appreciate hearing from anyone who finds an error or who wishes to comment on the text. You may write to me in care of the publisher. I will respond personally to all correspondence.

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Contents overview

1	Chapter 1	Astronomy and the universe
16	Chapter 2	Knowing the heavens
33	Chapter 3	Eclipses and the astronomy of antiquity
54	Chapter 4	Gravitation and the motions of the planets
76	Chapter 5	The nature of light and matter
101	Chapter 6	Optics and telescopes
124	Chapter 7	Our solar system
144	Chapter 8	Sun-scorched Mercury
162	Chapter 9	Cloud-covered Venus
180	Chapter 10	Our living Earth
202	Chapter 11	Our barren Moon
221	Chapter 12	The Martian invasions
243	Chapter 13	Jupiter: Lord of the planets
261	Chapter 14	The Galilean satellites of Jupiter
279	Chapter 15	The spectacular Saturnian system
301	Chapter 16	The outer worlds
320	Chapter 17	Interplanetary vagabonds

344	Chapter 18	The nature of the stars
368	Chapter 19	Our star
393	Chapter 20	The birth of stars
412	Chapter 21	Stellar maturity and old age
429	Chapter 22	The deaths of stars
448	Chapter 23	Neutron stars
468	Chapter 24	Black holes
483	Chapter 25	Our galaxy
502	Chapter 26	Galaxies
526	Chapter 27	Quasars and active galaxies
549	Chapter 28	Cosmology: The creation and fate of the universe
576	Chapter 29	The physics of the early universe

Contents

xv Preface

1 Chapter 1 **Astronomy and the universe**

- | | | | |
|---|---|----|--|
| 2 | Astronomers use angles to denote the apparent sizes and positions of objects in the sky | 7 | Astronomical distances are often measured in AUs, parsecs, or light years |
| 3 | Powers-of-ten notation is a useful shorthand system of writing numbers | 8 | By studying stars and nebulae, astronomers discover how stars are born, grow old, and eventually die |
| 4 | <i>Box 1-1 The small-angle formula</i> | 9 | <i>Box 1-3 Units of length, time, speed, and mass</i> |
| 5 | <i>Box 1-2 Arithmetic with exponents</i> | 11 | By observing galaxies, astronomers learn about the creation and fate of the universe |
| 5 | Astronomers use the laws of physics to understand the universe | 13 | <i>Box 1-4 Astronomy as a profession</i> |
| 6 | By exploring the planets, astronomers uncover clues about the formation of the solar system | | |

16 Chapter 2 **Knowing the heavens**

- | | | | |
|----|--|----|---|
| 18 | <i>Box 2-1 Star names and catalogues</i> | 24 | <i>Box 2-2 Tropics and circles</i> |
| 19 | It is often convenient to imagine that the stars are located on the celestial sphere | 26 | Keeping track of time is traditionally a responsibility of astronomers |
| 21 | The seasons are caused by the tilt of the Earth's axis of rotation | 28 | <i>Box 2-3 Sidereal time</i> |
| 23 | Precession is a slow, conical motion of the Earth's axis of rotation | 29 | Astronomical observations led to the development of the modern calendar |

33 Chapter 3 **Eclipses and the astronomy of antiquity**

- | | | | |
|----|---|----|---|
| 35 | Lunar phases are caused by the Moon's orbital motion | 41 | <i>Box 3-1 Some details of the Moon's orbit</i> |
| 37 | Ancient astronomers measured the size of the Earth and attempted to determine distances to the Sun and Moon | 46 | Ancient astronomers achieved a limited ability to predict eclipses |
| 39 | Eclipses occur only when the Sun and Moon are both on the line of nodes | 47 | Ancient astronomers established traditions and invented systems that are still used |
| 40 | Solar and lunar eclipses can be either partial or total, depending on the alignment of the Sun, Earth, and Moon | | |

52 Essay **Owen Gingerich: Astrology and astronomy**

54	Chapter 4 Gravitation and the motions of the planets	
55	Ancient astronomers invented a geocentric cosmology to explain planetary motions	63
57	Nicolaus Copernicus devised the first comprehensive heliocentric cosmology	64
59	<i>Box 4-1 Synodic and sidereal periods</i>	
60	<i>Box 4-2 Copernicus's method of determining the sizes of orbits</i>	68
61	Johannes Kepler proposed elliptical paths for the planets about the Sun	70
		Galileo's discoveries with a telescope strongly supported a heliocentric cosmology
		Isaac Newton formulated a description of gravity that accounts for Kepler's laws and almost explains the motions of the planets
		Albert Einstein's theory states that gravity affects the shape of space and the flow of time
76	Chapter 5 The nature of light and matter	
77	Light travels through empty space at a speed of 300,000 km/sec	89
78	Light is electromagnetic radiation and is characterized by its wavelength	90
82	An object emits electromagnetic radiation with intensity and wavelengths related to the temperature of the object	92
83	<i>Box 5-1 Temperatures and temperature scales</i>	
86	<i>Box 5-2 The Sun's luminosity and surface temperature</i>	94
86	A full explanation of blackbody radiation requires assuming that light has particlelike properties	96
		Each chemical element produces its own unique set of spectral lines
		<i>Box 5-3 Photon energy and the electron volt</i>
		An atom consists of a small, dense nucleus surrounded by electrons
		Spectral lines are produced when an electron jumps from one energy level to another within an atom
		The wavelength of a spectral line is affected by the relative motion between the source and the observer
101	Chapter 6 Optics and telescopes	
102	A refracting telescope uses a lens to concentrate incoming starlight at a focus	110
104	A reflecting telescope uses a mirror to concentrate incoming starlight at a focus	112
105	<i>Box 6-1 Major refracting telescopes</i>	113
107	<i>Box 6-2 Major reflecting telescopes</i>	
110	An electronic device is often used to record the image at a telescope's focus	116
		Spectrographs record the spectra of astronomical objects
		Photometers measure the intensity of light from astronomical objects
		A radio telescope uses a large concave dish to reflect radio waves to a focus
		Telescopes in orbit around the Earth detect radiation that does not penetrate the atmosphere
124	Chapter 7 Our solar system	
125	The planets are classified as terrestrial or Jovian by their physical attributes	131
129	Seven large satellites can also be classified as terrestrial planets	133
		Spectroscopy reveals the chemical composition of the Sun, planets, and stars
		<i>Box 7-1 Atoms and isotopes</i>

134	The relative abundances of the elements are the result of cosmic processes	138	Computer simulations help us understand details of the formation of the planets
135	The planets were formed by accumulation of material in the solar nebula during the birth of the Sun		
144	Chapter 8 Sun-scorched Mercury		
145	Earth-based optical observations of Mercury are difficult to make and often prove disappointing	152	Photographs from <i>Mariner 10</i> revealed Mercury's heavily cratered, lunarlike surface
146	<i>Box 8-1 Mercury data</i>	156	Like the Earth, Mercury has an iron core and a magnetic field
148	Radio and radar observations of Mercury revealed its rotation rate	158	Mercury's magnetic field shields the planet from the solar wind
150	<i>Box 8-2 Thermal motion and the retention of an atmosphere</i>		
162	Chapter 9 Cloud-covered Venus		
163	The surface of Venus is hidden beneath a very thick, highly reflective cloud cover	170	Spacecraft provided detailed information about the chemical composition and weather in Venus's corrosive atmosphere
164	<i>Box 9-1 Venus data</i>	172	Volcanoes probably created the atmospheres of the terrestrial planets
165	Venus's rotation is slow and retrograde	172	Active volcanoes are probably responsible for Venus's clouds
167	The surface of Venus is very warm because of the greenhouse effect	174	Radar maps of Venus reveal gently rolling hills, two continents, and large volcanoes
168	Space flights to Venus discovered neither a magnetic field nor a magnetosphere		
168	Spacecraft descending into the clouds provided detailed information about cloud layers in Venus's dense atmosphere		
180	Chapter 10 Our living Earth		
181	Absorption of sunlight and the Earth's rotation govern the behavior of our nitrogen–oxygen atmosphere	189	The Earth's magnetic field produces a magnetosphere that captures particles from the solar wind
182	<i>Box 10-1 Earth data</i>	191	The process of plate tectonics is responsible for many phenomena and features of the Earth's surface, including earthquakes, mountain ranges, and volcanoes
184	<i>Box 10-2 Atmospheric pressure</i>	194	The abundance of life on Earth inspires us to speculate about the possibility of extraterrestrial biology
184	The Earth's crust contains clues about the processes that shape our planet's surface		
186	Studying earthquake waves reveals the interior structure of the Earth		
200	Essay Frank D. Drake: Extraterrestrial life		

202	Chapter 11 Our barren Moon		
203	<i>Box 11-1 Lunar data</i>	211	Lunar rocks were formed 3 to 4.5 billion years ago
203	The Moon's early history can be deduced from the craters, maria, and mountains visible on its surface	213	The Moon probably formed by the accretion of material that orbited the primordial Earth
207	Measurements on the lunar surface show that the Moon has no magnetic field but may have a small, solid core	214	<i>Box 11-2 Radioactive age dating</i>
209	Gravitational interactions produce significant tidal effects in the Earth–Moon system		
221	Chapter 12 The Martian invasions		
222	Earth-based observations suggested that Mars might have some form of extraterrestrial life	234	Instruments on the <i>Viking</i> landers sent back detailed information about the Martian climate
223	<i>Box 12-1 Mars data</i>	236	Geological analysis by the <i>Viking</i> landers showed that the Martian regolith contains abundant iron
225	<i>Box 12-2 Martian oppositions: 1980–2000</i>	237	The two Martian moons resemble asteroids
225	Space probes to Mars found craters, volcanoes, and canyons—but no canals	238	Biological experiments failed to detect any conclusive evidence of life on Mars
229	Surface features indicate that water once flowed on Mars	239	More Martian probes are needed to answer important questions about Mars and about Earth
231	Earth and Mars began with similar atmospheres that evolved very differently		
233	The <i>Viking</i> landers sent back close-up views of the Martian surface		
243	Chapter 13 Jupiter: Lord of the planets		
244	<i>Box 13-1 Jupiter data</i>	251	Pictures taken during flybys show many details in Jupiter's clouds
245	Huge, massive Jupiter is composed largely of lightweight gases	253	Infrared observations probed the vertical structure of Jupiter's atmosphere
246	Details of Jupiter's rotation give clues about the planet's internal structure	254	Studies using computers explain some of the phenomena we see in the Jovian clouds
247	<i>Box 13-2 Oppositions of Jupiter</i>	258	Many aspects of Jupiter's clouds, such as their colors, are still poorly understood
248	Radio observations suggested Jupiter's magnetic field and metallic hydrogen interior		
249	Spacecraft mapped details of Jupiter's enormous magnetosphere		
261	Chapter 14 The Galilean satellites of Jupiter		
262	The Galilean satellites are easily seen with Earth-based telescopes	264	The formation of the Galilean satellites probably mimicked the formation of our solar system
263	<i>Box 14-1 The Galilean satellites</i>	265	Calculations and observations prior to the <i>Voyager</i> flybys suggested that Io might be volcanically active
263	Data from spacecraft have greatly improved our knowledge of the Galilean satellites	266	<i>Box 14-2 The Voyager flybys</i>

266	The <i>Voyager</i> spacecraft discovered several small moons and a ring around Jupiter	272	Europa is covered with a smooth layer of ice that is crisscrossed with numerous cracks
267	Io is covered with colorful deposits of sulfur compounds ejected from numerous active volcanoes	273	Ganymede and Callisto have heavily cratered, icy surfaces
268	<i>Box 14-3 Jupiter's family of moons</i>		
<hr/>			
279	Chapter 15 The spectacular Saturnian system		
280	Earth-based observations reveal gaps in Saturn's rings as well as faint markings on the planet	289	The sizes and densities of particles in the rings were deduced from studies of scattered sunlight
281	<i>Box 15-1 Saturn data</i>	290	Saturn's innermost satellites affect the appearance and structure of its rings
282	Saturn's rings are composed of numerous fragments of ice and ice-coated rock	292	Titan has a thick, opaque atmosphere rich in methane, nitrogen, and hydrocarbons
284	The internal structure of Saturn was deduced from measurements of its flattened shape	293	<i>Box 15-2 Saturn's rings</i>
285	Like Jupiter, Saturn emits more radiation than it receives from the Sun	294	The features of the icy surfaces of Saturn's six moderate-sized moons provide clues to their histories
286	Saturn's atmosphere extends to a greater depth and has higher wind speeds than Jupiter's atmosphere	295	<i>Box 15-3 Saturn's satellites</i>
287	Saturn's rings consist of thousands of narrow, closely spaced ringlets		
<hr/>			
301	Chapter 16 The outer worlds		
302	Uranus was discovered by chance, but Neptune's existence was predicted with Newtonian mechanics	311	<i>Box 16-3 Uranus's satellites</i>
303	Uranus and Neptune are similar to each other but different from Jupiter and Saturn	311	Neptune's two largest moons, Triton and Nereid, follow unusual orbits
305	<i>Box 16-1 Uranus data</i>	312	Pluto was discovered after a laborious search of the heavens
305	<i>Box 16-2 Neptune data</i>	313	<i>Box 16-4 Uranus's rings</i>
306	Uranus is nearly featureless and its magnetic field is oriented at an unusual angle	314	Pluto and its moon Charon are roughly comparable in size
307	Uranus is orbited by satellites that bear the scars of many shattering collisions	315	<i>Box 16-5 Pluto data</i>
309	Uranus is circled by a system of thin, dark rings	316	Pluto may once have been a satellite of Neptune
<hr/>			
320	Chapter 17 Interplanetary vagabonds		
321	Bode's law led astronomers to search for a planet between the orbits of Mars and Jupiter	326	<i>Box 17-1 Lagrange points and the restricted three-body problem</i>
322	Numerous small objects orbit the Sun between the orbits of Mars and Jupiter	327	Asteroids occasionally collide with each other and with the inner planets
324	Jupiter's gravity affects the structure of the asteroid belt and captures asteroids along its orbit	330	Meteorites are classified as stones, stony irons, or irons, depending on their composition

332	Meteorites provide significant information about the formation of the solar system	337	Cometary dust and debris rain down on the Earth during meteor showers
334	A comet is a dusty chunk of ice that becomes partly vaporized as it passes near the Sun	339	<i>Box 17-2 Meteor showers</i>
342	Essay Peter B. Boyce: The outlook for space science		
344	Chapter 18 The nature of the stars		
345	Distances to nearby stars are determined by parallax	354	<i>Box 18-2 Bolometric magnitude and luminosity</i>
347	A star's luminosity can be determined from its apparent magnitude and distance	356	<i>Box 18-3 Stellar radii</i>
348	A star's color reveals its surface temperature	358	Binary stars provide information about stellar masses
349	<i>Box 18-1 Magnitude and brightness</i>	361	Binary systems that cannot be examined visually can still be detected and analyzed
351	A star's spectrum also reveals the star's surface temperature	363	Light curves of eclipsing binaries provide detailed information about the two stars
353	Hertzsprung–Russell diagrams demonstrate that there are different kinds of stars		
368	Chapter 19 Our star		
369	The Sun's energy is produced by thermonuclear reactions in the core of the Sun	378	The chromosphere is located between the photosphere and the Sun's outermost atmosphere
370	<i>Box 19-1 Solar data</i>	380	The corona is the outermost layer of the Sun's atmosphere
371	A theoretical model of the Sun shows how energy gets from the Sun's center to its surface	382	Sunspots are one of many phenomena associated with a 22-year solar cycle
374	The mystery of the missing neutrinos inspires speculation about the Sun's interior	386	<i>Box 19-3 The Zeeman effect</i>
375	<i>Box 19-2 The proton–proton chain and the CNO cycle</i>	389	Solar seismology and new satellites are among the latest tools for solar research
377	The photosphere is the lowest of three main layers in the Sun's atmosphere		
393	Chapter 20 The birth of stars		
394	Protostars form in cold, dark nebulae	401	Star birth begins in giant molecular clouds
394	Protostars evolve into young main-sequence stars	402	<i>Box 20-1 Famous H II regions</i>
397	A vigorous ejection of matter often accompanies the birth of a star	405	<i>Box 20-2 Interstellar molecules</i>
398	Young star clusters are found in H II regions	407	Supernova explosions also compress the interstellar medium and thereby trigger star birth
412	Chapter 21 Stellar maturity and old age		
413	When core hydrogen burning ceases, a main-sequence star becomes a red giant	416	<i>Box 21-1 Main-sequence lifetimes</i>
415	Helium burning begins at the center of a red giant	418	Evolutionary tracks on the H–R diagram reveal the ages of star clusters

421	Supergiants and red giants typically show mass loss	424	Many mature stars pulsate
422	Mass transfer in close binary systems can produce unusual double stars		
429	Chapter 22 The deaths of stars		
430	Low-mass stars die by gently ejecting their outer layers, creating planetary nebulae	439	Accreting white dwarfs in close binary systems can also become supernovae
432	The burned-out core of a low-mass star cools and contracts until it becomes a white dwarf	441	<i>Box 22-3 The supernova 1987A</i>
434	High-mass stars die violently by blowing themselves apart in supernova explosions	442	A supernova remnant is detectable at many wavelengths for many years after a supernova explosion
435	<i>Box 22-1 Famous planetary nebulae</i>	443	Neutrinos and gravity waves emanate from supernovae
436	<i>Box 22-2 The s and r processes</i>		
448	Chapter 23 Neutron stars		
449	Pulsars are rapidly rotating neutron stars with intense magnetic fields	460	High-speed jets of matter can be ejected from an accreting neutron star
453	Superfluidity and superconductivity are among the strange properties of neutron stars	461	Explosive thermonuclear processes on white dwarfs and neutron stars produce novae and bursters
456	<i>Box 23-1 The conservation of angular momentum</i>		
457	Pulsating X-ray sources are neutron stars in close binary systems		
466	Essay Larry L. Smarr: Supercomputers in astronomy		
468	Chapter 24 Black holes		
469	The general theory of relativity describes gravity in terms of the geometry of space and time	476	<i>Box 24-2 Gravitational radiation</i>
470	<i>Box 24-1 Some comments on special relativity</i>	477	A black hole distorts the images of background stars and galaxies
472	A black hole is a simple object that has only a "center" and a "surface"	478	Black holes have been discovered in binary-star systems
474	The structure of a black hole is completely described with only three numbers		
483	Chapter 25 Our galaxy		
484	The Sun is located in the disk of the galaxy about 25,000 light years from the galactic center	493	Self-sustaining star formation can produce spiral arms
488	The spiral structure of our galaxy has been plotted from radio and optical observations of star-forming regions	494	Spiral arms are caused by density waves that sweep around the galaxy
490	Moving at half a million miles per hour, the Sun takes 200 million years to complete one orbit of our galaxy	497	Infrared and radio observations are used to probe the galactic nucleus whose nature is poorly understood