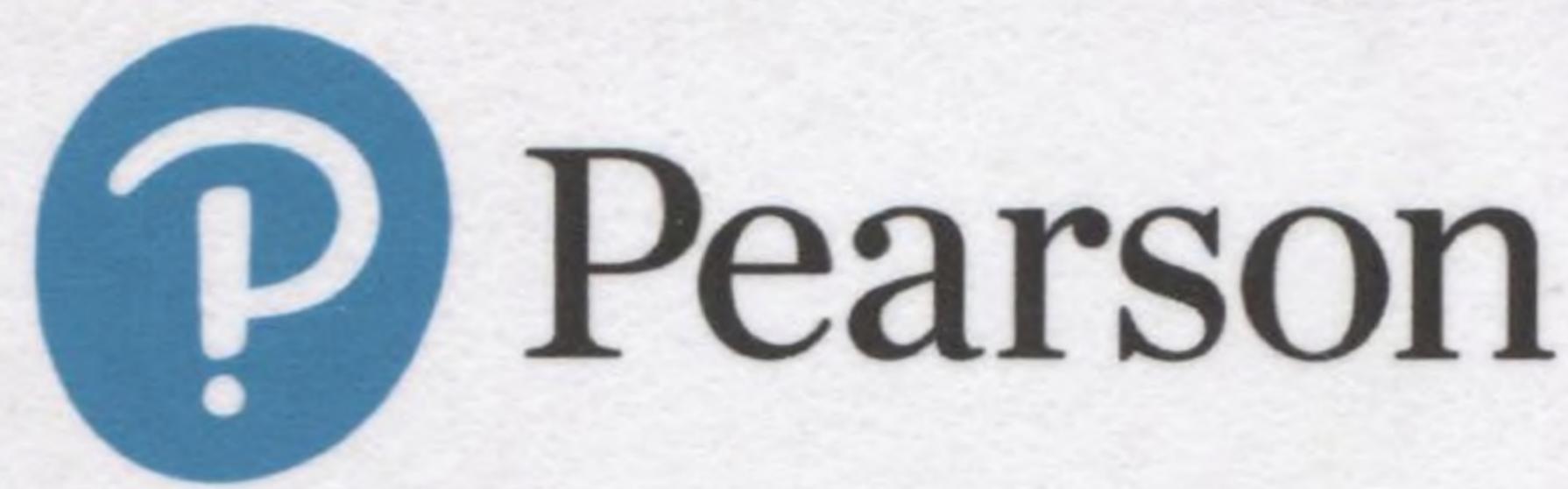


## ABOUT THE COVER

On the cover, the center of our Milky Way Galaxy is rising over the island of Rapa Nui, also known as Easter Island. In the foreground are silhouettes of moai, the ancient stone carvings left on the island by Polynesian people who expertly used the stars to navigate the South Pacific seas. They are reminders that the night sky belongs to everyone and that many different cultures have contributed to our understanding of astronomy.



Now for  
the good  
stuff!  
< Scan me  
Pearson

INTERCEPTAG



Please visit us at [www.pearson.com](http://www.pearson.com) for more information. To order any of our products, contact our customer service department at (800) 824-7799, or (201) 767-5021 outside of the U.S., or visit your campus bookstore.

[www.pearson.com](http://www.pearson.com)

ISBN-13: 978-0-13-487436-4  
ISBN-10: 0-13-487436-6

EAN



9 780134 874364

# Detailed Contents

|   |       |
|---|-------|
| Preface                                 | xx    |
| About the Authors                       | xxx   |
| How to Succeed in Your Astronomy Course | xxxii |
| Foreword by Neil deGrasse Tyson         | xxxiv |

## PART I DEVELOPING PERSPECTIVE

### 1 A MODERN VIEW OF THE UNIVERSE

|                                      |    |
|--------------------------------------|----|
| 1.1 The Scale of the Universe        | 2  |
| 1.2 The History of the Universe      | 11 |
| 1.3 Spaceship Earth                  | 14 |
| 1.4 The Human Adventure of Astronomy | 19 |
| <i>Exercises and Problems</i>        | 21 |

**COMMON MISCONCEPTIONS:** The Meaning of a Light-Year 6

**Mathematical Insight 1.1:** How Far Is a Light-Year? An Introduction to Astronomical Problem Solving 6

**Special Topic:** How Many Planets Are There in Our Solar System? 8

**Mathematical Insight 1.2:** The Scale of Space and Time 9

**Mathematical Insight 1.3:** Order of Magnitude Estimation 10

**COMMON MISCONCEPTIONS:** Confusing Very Different Things 11

**COSMIC CONTEXT FIGURE 1.10:** Our Cosmic Origins 12

**Mathematical Insight 1.4:** Speeds of Rotation and Orbit 16

### 2 DISCOVERING THE UNIVERSE FOR YOURSELF

|  |    |
|--|----|
| 2.1 Patterns in the Night Sky          | 25 |
| 2.2 The Reason for Seasons             | 32 |
| 2.3 The Moon, Our Constant Companion   | 38 |
| 2.4 The Ancient Mystery of the Planets | 45 |
| <i>Exercises and Problems</i>          | 50 |

**Mathematical Insight 2.1:** Angular Size, Physical Size, and Distance 28

**COMMON MISCONCEPTIONS:** The Moon Illusion 29

**COMMON MISCONCEPTIONS:** Stars in the Daytime 30

**COMMON MISCONCEPTIONS:** What Makes the North Star Special? 31

**COMMON MISCONCEPTIONS:** The Cause of Seasons 32

**COMMON MISCONCEPTIONS:** High Noon 33

**COSMIC CONTEXT FIGURE 2.15:** The Cause of Seasons 34

**COMMON MISCONCEPTIONS:** Sun Signs 38

**COMMON MISCONCEPTIONS:** Shadows and the Moon 40

**COMMON MISCONCEPTIONS:** The “Dark Side” of the Moon 40

**COMMON MISCONCEPTIONS:** Moon in the Daytime and Stars on the Moon 41

**Special Topic:** Does the Moon Influence Human Behavior? 44

**Special Topic:** Who First Proposed a Sun-Centered Solar System? 48

### 3 THE SCIENCE OF ASTRONOMY

|                                  |    |
|----------------------------------|----|
| 3.1 The Ancient Roots of Science | 54 |
| 3.2 Ancient Greek Science        | 59 |
| 3.3 The Copernican Revolution    | 63 |
| 3.4 The Nature of Science        | 69 |
| 3.5 Astrology                    | 77 |

*Exercises and Problems* 81

**Special Topic:** Aristotle 61

**COMMON MISCONCEPTIONS:** Columbus and a Flat Earth 62

**Special Topic:** Eratosthenes Measures Earth 62

**Mathematical Insight 3.1:** Eccentricity and Planetary Orbits 68

**Mathematical Insight 3.2:** Kepler’s Third Law 70

**COSMIC CONTEXT FIGURE 3.25:** The Copernican Revolution 72

**Special Topic:** And Yet It Moves 74

**COMMON MISCONCEPTIONS:** Eggs on the Equinox 75

**Special Topic:** Logic and Science 75

**Extraordinary Claims:** Earth Orbits the Sun 77

### S1 CELESTIAL TIMEKEEPING AND NAVIGATION

|  |     |
|--|-----|
| S1.1 Astronomical Time Periods                   | 85  |
| S1.2 Celestial Coordinates and Motion in the Sky | 91  |
| S1.3 Principles of Celestial Navigation          | 101 |

*Exercises and Problems* 105

**Mathematical Insight S1.1:** The Copernican Layout of the Solar System 88

**Special Topic:** Solar Days and the Analemma 94

**Mathematical Insight S1.2:** Time by the Stars 97

**COMMON MISCONCEPTIONS:** Compass Directions 102

**COSMIC CONTEXT PART I:** Our Expanding Perspective 108

## PART II KEY CONCEPTS FOR ASTRONOMY

### 4 MAKING SENSE OF THE UNIVERSE: UNDERSTANDING MOTION, ENERGY, AND GRAVITY

|     |  |     |
|-----|--|-----|
| 4.1 | Describing Motion: Examples from Daily Life    | 111 |
| 4.2 | Newton's Laws of Motion                        | 114 |
| 4.3 | Conservation Laws in Astronomy                 | 117 |
| 4.4 | The Universal Law of Gravitation               | 123 |
| 4.5 | Orbits, Tides, and the Acceleration of Gravity | 125 |
|     | Exercises and Problems                         | 134 |

**COMMON MISCONCEPTIONS:** No Gravity in Space? 114

**Mathematical Insight 4.1:** Units of Force, Mass, and Weight 116

**COMMON MISCONCEPTIONS:** What Makes a Rocket Launch? 117

**Mathematical Insight 4.2:** Mass-Energy 122

**Mathematical Insight 4.3:** Newton's Version of Kepler's Third Law 126

**Mathematical Insight 4.4:** Escape Velocity 128

**COMMON MISCONCEPTIONS:** The Origin of Tides 128

**Mathematical Insight 4.5:** The Acceleration of Gravity 131

### 5 LIGHT AND MATTER: READING MESSAGES FROM THE COSMOS

|     |                        |     |
|-----|------------------------|-----|
| 5.1 | Light in Everyday Life | 138 |
| 5.2 | Properties of Light    | 140 |
| 5.3 | Properties of Matter   | 143 |
| 5.4 | Learning from Light    | 150 |
|     | Exercises and Problems | 162 |

**COMMON MISCONCEPTIONS:** Light Paths, Lasers, and Shadows 140

**COMMON MISCONCEPTIONS:** Is Radiation Dangerous? 142

**COMMON MISCONCEPTIONS:** Can You Hear Radio Waves or See an X-Ray? 142

**Mathematical Insight 5.1:** Wavelength, Frequency, and Energy 144

**Special Topic:** What Do Polarized Sunglasses Have to Do with Astronomy 145

**COMMON MISCONCEPTIONS:** The Illusion of Solidity 146

**COMMON MISCONCEPTIONS:** One Phase at a Time? 147

**Extraordinary Claims:** We Can Never Learn the Composition of Stars 154

**Mathematical Insight 5.2:** Laws of Thermal Radiation 155

**COSMIC CONTEXT FIGURE 5.25:** Interpreting a Spectrum 158

**Mathematical Insight 5.3:** The Doppler Shift 160

### 6 TELESCOPES: PORTALS OF DISCOVERY

|     |  |     |
|-----|--|-----|
| 6.1 | Eyes and Cameras: Everyday Light Sensors | 166 |
| 6.2 | Telescopes: Giant Eyes                   | 168 |
| 6.3 | Telescopes and the Atmosphere            | 175 |
| 6.4 | Telescopes Across the Spectrum           | 179 |

Exercises and Problems 185

**COMMON MISCONCEPTIONS:** Magnification and Telescopes 169

**Mathematical Insight 6.1:** Angular Resolution 170

**Mathematical Insight 6.2:** The Diffraction Limit 171

**COMMON MISCONCEPTIONS:** Twinkle, Twinkle, Little Star 176

**COMMON MISCONCEPTIONS:** Closer to the Stars? 177

**Special Topic:** Would You Like Your Own Telescope? 177

**COSMIC CONTEXT PART II:** The Universality of Physics 188

## PART III LEARNING FROM OTHER WORLDS

### 7 OUR PLANETARY SYSTEM

|     |  |     |
|-----|--|-----|
| 7.1 | Studying the Solar System                  | 191 |
| 7.2 | Patterns in the Solar System               | 205 |
| 7.3 | Spacecraft Exploration of the Solar System | 207 |

Exercises and Problems 212

**COSMIC CONTEXT FIGURE 7.1:** The Solar System 192

**Special Topic:** How Did We Learn the Scale of the Solar System? 207

### 8 FORMATION OF THE SOLAR SYSTEM

|     |   |     |
|-----|---|-----|
| 8.1 | The Search for Origins                            | 215 |
| 8.2 | Explaining the Major Features of the Solar System | 217 |
| 8.3 | The Age of the Solar System                       | 226 |

Exercises and Problems 230

**COMMON MISCONCEPTIONS:** Solar Gravity and the Density of Planets 220

**Extraordinary Claims:** A Giant Impact Made Our Moon 226

**Mathematical Insight 8.1:** Radiometric Dating 227

**Special Topic:** What Started the Collapse of the Solar Nebula? 228

### 9 PLANETARY GEOLOGY: EARTH AND THE OTHER TERRESTRIAL WORLDS

|     |   |     |
|-----|---|-----|
| 9.1 | Connecting Planetary Interiors and Surfaces | 234 |
| 9.2 | Shaping Planetary Surfaces                  | 240 |
| 9.3 | Geology of the Moon and Mercury             | 246 |
| 9.4 | Geology of Mars                             | 250 |
| 9.5 | Geology of Venus                            | 257 |
| 9.6 | The Unique Geology of Earth                 | 259 |

Exercises and Problems 267

|   |     |   |     |
|---|-----|---|-----|
| <b>COMMON MISCONCEPTIONS:</b> Earth Is Not Full of Molten Lava                    | 236 | <b>COMMON MISCONCEPTIONS:</b> Dodge Those Asteroids!                                  | 352 |
| <b>Special Topic:</b> How Do We Know What's Inside Earth?                         | 237 | <b>Special Topic:</b> A Visitor from the Stars  | 353 |
| <b>COMMON MISCONCEPTIONS:</b> Pressure and Temperature                            | 238 | <b>Extraordinary Claims:</b> The Death of the Dinosaurs Was Catastrophic, Not Gradual | 364 |
| <b>Mathematical Insight 9.1:</b> The Surface Area-to-Volume Ratio                 | 239 |   |     |
| <b>Extraordinary Claims:</b> Martians!  | 251 |   |     |
| <b>10 PLANETARY ATMOSPHERES: EARTH AND THE OTHER TERRESTRIAL WORLDS</b>           | 270 | <b>13 OTHER PLANETARY SYSTEMS: THE NEW SCIENCE OF DISTANT WORLDS</b>                  | 372 |
| 10.1 Atmospheric Basics   | 271 | 13.1 Detecting Planets Around Other Stars   | 373 |
| 10.2 Weather and Climate  | 280 | 13.2 The Nature of Planets Around Other Stars   | 379 |
| 10.3 Atmospheres of the Moon and Mercury  | 286 | 13.3 The Formation of Other Solar Systems   | 391 |
| 10.4 The Atmospheric History of Mars  | 288 | 13.4 The Future of Extrasolar Planetary Science                                       | 393 |
| 10.5 The Atmospheric History of Venus   | 293 | <i>Exercises and Problems</i>   | 397 |
| 10.6 Earth's Unique Atmosphere  | 296 | <b>Special Topic:</b> How Did We Learn That Other Stars Are Suns?                     | 375 |
| <i>Exercises and Problems</i>   | 308 | <b>Special Topic:</b> The Names of Extrasolar Planets                                 | 378 |
| <b>Mathematical Insight 10.1:</b> "No Greenhouse" Temperatures                    | 275 | <b>COSMIC CONTEXT FIGURE 13.6:</b> Detecting Extrasolar Planets                       | 380 |
| <b>COMMON MISCONCEPTIONS:</b> Temperatures at High Altitude                       | 277 | <b>Mathematical Insight 13.1:</b> Finding Orbital Distances for Extrasolar Planets    | 382 |
| <b>COMMON MISCONCEPTIONS:</b> Why Is the Sky Blue?                                | 278 | <b>Mathematical Insight 13.2:</b> Finding Masses of Extrasolar Planets                | 384 |
| <b>COMMON MISCONCEPTIONS:</b> Toilets in the Southern Hemisphere                  | 281 | <b>Mathematical Insight 13.3:</b> Finding Sizes of Extrasolar Planets                 | 386 |
| <b>Special Topic:</b> Weather and Chaos   | 283 | <b>COSMIC CONTEXT PART III:</b> Learning from Other Worlds                            | 400 |
| <b>Mathematical Insight 10.2:</b> Thermal Escape from an Atmosphere               | 287 |   |     |
| <b>COMMON MISCONCEPTIONS:</b> Ozone—Good or Bad?                                  | 297 |   |     |
| <b>COMMON MISCONCEPTIONS:</b> The Greenhouse Effect Is Bad                        | 300 |   |     |
| <b>Extraordinary Claims:</b> Human Activity Can Change the Climate                | 303 |   |     |
| <b>COSMIC CONTEXT FIGURE 10.43:</b> Global Warming                                | 304 |   |     |
| <b>11 JOVIAN PLANET SYSTEMS</b>   | 311 | <b>S2 SPACE AND TIME</b>  | 402 |
| 11.1 A Different Kind of Planet   | 312 | S2.1 Einstein's Revolution  | 403 |
| 11.2 A Wealth of Worlds: Satellites of Ice and Rock                               | 323 | S2.2 Relative Motion  | 406 |
| 11.3 Jovian Planet Rings  | 333 | S2.3 The Reality of Space and Time  | 410 |
| <i>Exercises and Problems</i>   | 339 | S2.4 Toward a New Common Sense  | 418 |
| <i>Exercises and Problems</i>   | 339 | <i>Exercises and Problems</i>   | 421 |
| <b>Special Topic:</b> How Were Uranus, Neptune, and Pluto Discovered?             | 315 | <b>Special Topic:</b> What If Light Can't Catch You?                                  | 409 |
| <b>12 ASTEROIDS, COMETS, AND DWARF PLANETS: THEIR NATURE, ORBITS, AND IMPACTS</b> | 342 | <b>Mathematical Insight S2.1:</b> The Time Dilation Formula                           | 412 |
| 12.1 Classifying Small Bodies   | 343 | <b>Mathematical Insight S2.2:</b> Formulas of Special Relativity                      | 415 |
| 12.2 Asteroids  | 347 | <b>Special Topic:</b> Measuring the Speed of Light                                    | 416 |
| 12.3 Comets   | 352 | <b>Mathematical Insight S2.3:</b> Deriving $E = mc^2$                                 | 417 |
| 12.4 Pluto and the Kuiper Belt  | 358 |   |     |
| 12.5 Cosmic Collisions: Small Bodies versus the Planets                           | 361 |   |     |
| <i>Exercises and Problems</i>   | 369 |   |     |
| <i>Exercises and Problems</i>   | 369 |   |     |
| <b>S3 SPACETIME AND GRAVITY</b>   | 424 |   |     |
| S3.1 Einstein's Second Revolution   | 425 |   |     |
| S3.2 Understanding Spacetime  | 428 |   |     |
| S3.3 A New View of Gravity  | 433 |   |     |
| S3.4 Testing General Relativity   | 437 |   |     |
| S3.5 Hyperspace, Wormholes, and Warp Drive  | 440 |   |     |
| S3.6 The Last Word  | 441 |   |     |
| <i>Exercises and Problems</i>   | 444 |   |     |
| <b>Special Topic:</b> Einstein's Leap   | 427 |   |     |

## PART IV A DEEPER LOOK AT NATURE

|   |            |   |   |            |
|---|------------|---|---|------------|
| <b>Mathematical Insight S3.1:</b> Spacetime Geometry                        | 428        | 16.3  | Masses of Newborn Stars                                   | 527        |
| <b>Special Topic:</b> The Twin Paradox                                      | 441        |   | <i>Exercises and Problems</i>                             | 532        |
| <b>S4 BUILDING BLOCKS OF THE UNIVERSE</b>                                   | <b>447</b> |   | <b>Mathematical Insight 16.1:</b> Gravity versus Pressure | 520        |
| S4.1 The Quantum Revolution   | 448        | <b>17 STAR STUFF</b>  |   | <b>535</b> |
| S4.2 Fundamental Particles and Forces                                       | 448        | 17.1 Lives in the Balance   | 536   |            |
| S4.3 Uncertainty and Exclusion in the Quantum Realm                         | 453        | 17.2 Life as a Low-Mass Star  | 537   |            |
| S4.4 Key Quantum Effects in Astronomy                                       | 458        | 17.3 Life as a High-Mass Star   | 543   |            |
| <i>Exercises and Problems</i>   | 463        | 17.4 The Roles of Mass and Mass Exchange  | 549   |            |
| <b>Extraordinary Claims:</b> Faster-Than-Light Neutrinos                    | 452        | <i>Exercises and Problems</i>   | 554   |            |
| <b>Special Topic:</b> A String Theory of Everything?                        | 454        | <b>Special Topic:</b> How Long Is 5 Billion Years?                              | 544   |            |
| <b>Special Topic:</b> Does God Play Dice?                                   | 456        | <b>COSMIC CONTEXT FIGURE 17.19:</b> Summary of Stellar Lives                    | 550   |            |
| <b>Mathematical Insight S4.1:</b> Electron Waves in Atoms                   | 457        |   |   |            |
| <b>COSMIC CONTEXT PART IV:</b> A Deeper Look at Nature                      | 466        | <b>18 THE BIZARRE STELLAR GRAVEYARD</b>   | <b>557</b>  |            |
| <b>PART V STARS</b>   |            | 18.1 White Dwarfs   | 558   |            |
| <b>14 OUR STAR</b>  | <b>468</b> | 18.2 Neutron Stars  | 561   |            |
| 14.1 A Closer Look at the Sun   | 469        | 18.3 Black Holes: Gravity's Ultimate Victory                                    | 565   |            |
| 14.2 Nuclear Fusion in the Sun  | 472        | 18.4 Extreme Events   | 570   |            |
| 14.3 The Sun-Earth Connection   | 480        | <i>Exercises and Problems</i>   | 575   |            |
| <i>Exercises and Problems</i>   | 487        | <b>Mathematical Insight 18.1:</b> The Schwarzschild Radius                      | 567   |            |
| <b>COMMON MISCONCEPTIONS:</b> The Sun Is Not on Fire                        | 472        | <b>COMMON MISCONCEPTIONS:</b> Black Holes Don't Suck                            | 568   |            |
| <b>Mathematical Insight 14.1:</b> Mass-Energy Conversion in Hydrogen Fusion | 476        | <b>Extraordinary Claims:</b> Neutron Stars and Black Holes Are Real             | 569   |            |
| <b>Mathematical Insight 14.2:</b> Pressure in the Sun: The Ideal Gas Law    | 478        | <b>COSMIC CONTEXT PART V:</b> Balancing Pressure and Gravity                    | 578   |            |
| <b>15 SURVEYING THE STARS</b>   | <b>490</b> |   |   |            |
| 15.1 Properties of Stars  | 491        | <b>PART VI GALAXIES AND BEYOND</b>  |   |            |
| 15.2 Patterns Among Stars   | 499        |   |   |            |
| 15.3 Star Clusters  | 506        | <b>19 OUR GALAXY</b>  | <b>580</b>  |            |
| <i>Exercises and Problems</i>   | 511        | 19.1 The Milky Way Revealed   | 581   |            |
| <b>Mathematical Insight 15.1:</b> The Inverse Square Law for Light          | 492        | 19.2 Galactic Recycling   | 585   |            |
| <b>Mathematical Insight 15.2:</b> The Parallax Formula                      | 494        | 19.3 The History of the Milky Way   | 594   |            |
| <b>Mathematical Insight 15.3:</b> The Modern Magnitude System               | 495        | 19.4 The Galactic Center  | 596   |            |
| <b>COMMON MISCONCEPTIONS:</b> Photos of Stars                               | 496        | <i>Exercises and Problems</i>   | 601   |            |
| <b>Mathematical Insight 15.4:</b> Measuring Stellar Masses                  | 500        | <b>COMMON MISCONCEPTIONS:</b> The Halo of a Galaxy                              | 582   |            |
| <b>Mathematical Insight 15.5:</b> Calculating Stellar Radii                 | 501        | <b>Special Topic:</b> How Did We Learn the Structure of the Milky Way?          | 582   |            |
| <b>COSMIC CONTEXT FIGURE 15.10:</b> Reading an H-R Diagram                  | 502        | <b>Special Topic:</b> How Do We Determine Stellar Orbits?                       | 583   |            |
| <b>16 STAR BIRTH</b>  | <b>514</b> | <b>Mathematical Insight 19.1:</b> Using Stellar Orbits to Measure Galactic Mass | 584   |            |
| 16.1 Stellar Nurseries  | 515        | <b>COMMON MISCONCEPTIONS:</b> The Sound of Space                                | 587   |            |
| 16.2 Stages of Star Birth   | 523        | <b>COMMON MISCONCEPTIONS:</b> What Is a Nebula?                                 | 593   |            |
|   |            | <b>COSMIC CONTEXT FIGURE 19.22:</b> The Galactic Center                         | 598   |            |
| <b>20 GALAXIES AND THE FOUNDATION OF MODERN COSMOLOGY</b>                   |            |   |   |            |
|   |            | 20.1 Islands of Stars   | 605   |            |
|   |            | 20.2 Measuring Galactic Distances   | 611   |            |

|  |            |  |            |
|--|------------|--|------------|
| 20.3 The Age of the Universe   | 617        | COSMIC CONTEXT FIGURE 23.20: Dark Matter and Dark Energy       | 688        |
| Exercises and Problems   | 624        | COSMIC CONTEXT PART VI: Galaxy Evolution                       | 696        |
| <b>Mathematical Insight 20.1:</b> Standard Candles                                   | 612        |  |            |
| <b>Special Topic:</b> Who Discovered the Expanding Universe?                         | 615        |  |            |
| <b>Mathematical Insight 20.2:</b> Redshift   | 618        |  |            |
| <b>Mathematical Insight 20.3:</b> Understanding Hubble's Law                         | 619        |  |            |
| <b>COMMON MISCONCEPTIONS:</b> What Is the Universe Expanding Into?                   | 620        |  |            |
| <b>Mathematical Insight 20.4:</b> Age from Hubble's Constant                         | 620        |  |            |
| <b>COMMON MISCONCEPTIONS:</b> Beyond the Horizon                                     | 622        |  |            |
| <b>Mathematical Insight 20.5:</b> Cosmological Redshift and the Stretching of Light  | 622        |  |            |
| <b>21 GALAXY EVOLUTION</b>   | <b>627</b> | <b>24 LIFE IN THE UNIVERSE</b>                                 | <b>698</b> |
| 21.1 Looking Back Through Time   | 628        | 24.1 Life on Earth   | 699        |
| 21.2 The Lives of Galaxies   | 630        | 24.2 Life in the Solar System                                  | 708        |
| 21.3 The Role of Supermassive Black Holes  | 636        | 24.3 Life Around Other Stars                                   | 712        |
| 21.4 Gas Beyond the Stars  | 642        | 24.4 The Search for Extraterrestrial Intelligence              | 715        |
| Exercises and Problems   | 645        | 24.5 Interstellar Travel and Its Implications for Civilization | 719        |
| <b>Mathematical Insight 21.1:</b> Feeding a Black Hole                               | 638        | Exercises and Problems   | 725        |
| <b>Mathematical Insight 21.2:</b> Weighing Supermassive Black Holes                  | 639        | <b>Special Topic:</b> Evolution and the Schools                | 707        |
| <b>22 THE BIRTH OF THE UNIVERSE</b>  | <b>648</b> | <b>Special Topic:</b> What Is Life?                            | 708        |
| 22.1 The Big Bang Theory   | 649        | <b>Extraordinary Claims:</b> Aliens Are Visiting Earth in UFOs | 717        |
| 22.2 Evidence for the Big Bang   | 653        | <b>COSMIC CONTEXT PART VII:</b> A Universe of Life?            | 728        |
| 22.3 The Big Bang and Inflation  | 659        |  |            |
| 22.4 Observing the Big Bang for Yourself   | 663        |  |            |
| Exercises and Problems   | 666        | <b>CREDITS</b>   | <b>C-1</b> |
| <b>COSMIC CONTEXT FIGURE 22.5:</b> The Early Universe                                | 654        |  |            |
| <b>Extraordinary Claims:</b> The Universe Doesn't Change with Time                   | 657        | <b>APPENDICES</b>  | <b>A-1</b> |
| <b>Mathematical Insight 22.1:</b> Temperature and Wavelength of Background Radiation | 659        | A Useful Numbers   | A-2        |
| <b>23 DARK MATTER, DARK ENERGY, AND THE FATE OF THE UNIVERSE</b>                     | <b>670</b> | B Useful Formulas  | A-3        |
| 23.1 Unseen Influences in the Cosmos   | 671        | C A Few Mathematical Skills                                    | A-4        |
| 23.2 Evidence for Dark Matter  | 672        | D The Periodic Table of the Elements                           | A-10       |
| 23.3 Structure Formation   | 681        | E Solar System Data  | A-11       |
| 23.4 Dark Energy and the Fate of the Universe  | 684        | F Stellar Data   | A-14       |
| Exercises and Problems   | 693        | G Galaxy Data  | A-16       |
| <b>Mathematical Insight 23.1:</b> Mass-to-Light Ratio                                | 674        | H The 88 Constellations  | A-19       |
| <b>Mathematical Insight 23.2:</b> Finding Cluster Masses from Galaxy Orbits          | 675        | I Star Charts  | A-21       |
| <b>Mathematical Insight 23.3:</b> Finding Cluster Masses from Gas Temperature        | 678        | J Key to Icons on Figures                                      | A-26       |
| <b>Extraordinary Claims:</b> Most of the Universe's Matter Is Dark                   | 679        | <b>GLOSSARY</b>  | <b>G-1</b> |
| <b>Special Topic:</b> Einstein's "Greatest Blunder"                                  | 685        | <b>INDEX</b>   | <b>I-1</b> |

## PART VII LIFE ON EARTH AND BEYOND