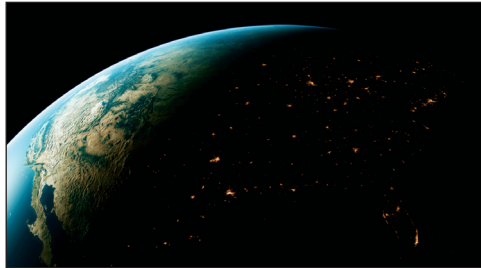


Contents

Foreword, *v*
Preface, *vi*



Part 1 The Journey Begins

chapter 1

Journey's Start, 3

Evening, 4
The Moving Sky, 5
The Terrestrial Coordinate System, 6
The Celestial Sphere, 8
Angles, 8
The Horizon System, 9
Circumpolar Motion, 11



chapter 2

Patterns in the Sky, 17

The Daily Motion of the Sky, 18
The Apparent Motion of the Sun, 22
 The Seasons, 23
 Time, 26
The Phases of the Moon, 28
The Motion of the Moon, 30
The Motions of the Planets, 31



chapter 3

Ancient Astronomy, 37

Mesopotamian Astronomy, 38
Egyptian Astronomy, 40
Early Greek Astronomy, 40
 The Astronomers of Miletus, 40
 Pythagoras and His Students, 42
 Eudoxus, 42
 Aristotle, 43
Later Greek Astronomy, 45
 Aristarchus, 45
 Eratosthenes, 48
 Hipparchus, 49
 Ptolemy, 50
Chinese and Mesoamerican Astronomy, 52
 Chinese Astronomy, 52
 Mesoamerican Astronomy, 53



chapter 4

Renaissance Astronomy, 57

Astronomy After Ptolemy, 58
 Islamic Astronomy, 58

The Rebirth of Astronomy in Europe, 58
 Copernicus, 60
 The Heliocentric Model, 61
 Tycho Brahe—The Great Observer, 66
 Kepler and Planetary Orbits, 68
 Kepler’s First Law, 69
 Kepler’s Second Law, 69
 Kepler’s Third Law, 70
 Galileo and the Telescope, 71
 The Observations, 71
 The *Dialogue*, 74



chapter 5

Gravity and Motion, 79

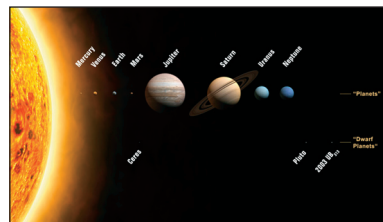
Force and Motion Before Newton, 80
 Galileo’s Experiments, 80
 Descartes and Inertial Motion, 81
 Planetary Motion Before Newton, 81
 Kepler’s Explanation, 82
 Robert Hooke, 82
 Isaac Newton, 83
 The Laws of Motion, 83
 Gravity, 86
 Newton’s Analysis, 86
 The Apple and the Moon, 86
 The Law of Gravitation, 87
 Elliptical Orbits, 89
 Force at a Distance, 91
 Orbital Energy and Speed, 91
 Orbital Speed, 91
 Escape Velocity, 92
 The Four Kinds of Trajectories, 93
 Tides, 94
 Differences in Gravity, 94
 Solid Earth Tides, 95
 Ocean Tides, 95



chapter 6

Light and Telescopes, 101

Waves, 102
 Electromagnetic Waves, 102
 The Spectrum, 103
 The Doppler Effect, 105
 Photons, 106
 Reflection and Refraction, 108
 Reflection, 108
 Refraction, 108
 Dispersion, 109
 Optical Telescopes, 110
 Refractors, 110
 Reflectors, 110
 Forming an Image, 111
 Detectors, 113
 Notable Optical Telescopes, 115
 Optical Observatories, 117
 Modern Observatories, 118
 Space Observatories, 121
 Optical Observations, 121
 Infrared and Ultraviolet Observations, 122
 X-Ray and Gamma-Ray Observations, 122
 Radio Telescopes, 123
 Radio Interferometry, 123



Part 2 Journey Through the Solar System

chapter 7

Overview of the Solar System, 131

Solar System Inventory, 132
 The Abundance of the Elements, 132

- Gases, 133
 - Atoms in Motion, 133
 - Density and Pressure, 135
- Radiation and Matter, 137
 - Blackbody Radiation, 138
 - Thermal Equilibrium, 140
 - Temperatures in the Solar System, 140
- Nuclear Reactions and Radioactivity, 142
 - Nuclei and Nuclear Particles, 142
 - Nuclear Reactions, 143
 - Radioactivity, 144
- Internal Heat In Planets, 145
 - Radioactive Heating, 145
 - Accretional Heating, 145
 - Flow of Heat, 146
- Planetology, 147

- Magnetosphere, 172
 - Van Allen Belts, 172
 - Structure of Magnetosphere, 172
- Evolution of the Earth, 175
 - Development of the Core, 175
 - Oceans, 175
 - Atmosphere, 175



chapter 9

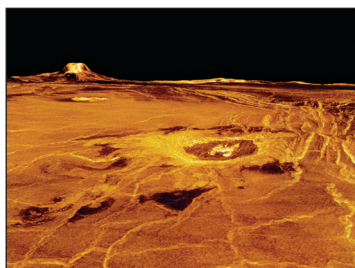
The Moon, 181

- Revolution and Rotation, 182
 - The Month, 182
 - Synchronous Rotation, 182
 - The Orbit and Size of the Moon, 183
- Eclipses, 184
 - Eclipses as Omens, 186
 - Eclipses and Shadows, 186
 - Predicting Eclipses, 189
- Tides, 191
 - Tides and the Earth's Rotation, 192
 - Tides and the Moon's Orbit, 193
- The Moon's Surface, 193
 - Observations from the Earth, 193
 - Exploration of the Moon, 194
 - Lunar Craters, 194
 - Volcanic Features, 196
- Lunar Samples, 197
 - Chemical Composition, 197
 - Ages of Lunar Samples, 197
 - Ages and Cratering, 198
- The Moon's Atmosphere, 199
 - Density, 199
 - Gain and Loss of Gases, 200
- The Moon's Interior, 200
 - Mass, 200
 - The Density of the Moon, 200
 - Lunar Seismology and Internal Structure, 201
- The Origin of the Moon, 201
 - Fission, Accretion, Capture, 201
 - The Giant Impact Theory, 202

chapter 8

The Earth, 153

- Rotation and Revolution, 154
 - Aberration, 154
 - The Foucault Pendulum, 155
 - "Centrifugal Force," 155
 - Coriolis Effect, 156
- Surface, 158
 - The Age of the Earth and its Rocks, 158
 - Minerals and Rocks, 159
 - Oceans and Continents, 160
- Interior, 160
 - Probing the Interior, 160
 - Internal Structure, 163
 - Plate Tectonics, 164
- Atmosphere, 168
 - Composition, 168
 - Thermal Structure, 169
 - Human Changes, 170



chapter 10

Mercury and Venus, 207

Mercury, 208

Mercury's Orbit, 208

Surface, 210

Mercury's Interior, 214

Venus, 215

Rotation and Revolution, 216

Venus's Hostile Atmosphere, 217

Surface, 219

Interior, 226

Evolution of Venus, 227



chapter 11

Mars, 233

The Exploration of Mars, 235

The Surface of Mars, 236

Martian Craters, 237

Meteorites from Mars, 237

Volcanic Activity, 238

Volcanos of the Tharsis Region, 238

Other Volcanos, 240

Volcanic History, 240

Crustal Motion, 241

The Martian Channels, 243

River Systems, 243

Ancient Floods, 243

The Polar Regions, 246

Seasonal Caps, 246

Residual Caps, 246

Layered Deposits, 246

The Exploration of Mars's Surface, 247

The *Viking* Landers, 247

Pathfinder, 249

Spirit and *Opportunity*, 250

Phoenix, 252

The Atmosphere of Mars, 254

Weather on Mars, 254

Atmospheric Dust, 255

Clouds, 256

The Interior and Evolution of Mars, 257

Internal Structure, 257

Thermal History, 258

Water on Mars, 258

Where Is Mars's Water?, 258

Climate History, 259

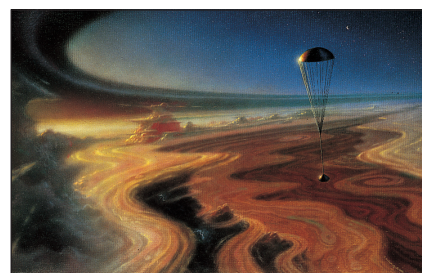
Life on Mars, 260

Viking Search for Life, 260

Molecular Analysis, 260

Biology Experiments, 260

The Evolution of the Terrestrial Planets, 261



chapter 12

Jupiter and Saturn, 267

Jupiter and Saturn, 269

Basic Properties, 269

Diameter, Mass, and Density, 269

Visual Appearance, 270

Rotation and Winds, 271

Atmospheres, 272

Chemical Composition, 273

Vertical Structure, 273

Cloud Features—Jupiter, 273

Cloud Features—Saturn, 274

Infrared and Radio Appearance, 275

Temperature, Depth, and Convection, 276

Atmospheric Coloration, 277

Interiors, 279

Metallic Hydrogen, 279

Internal Structure, 279

Internal Energy, 280

The Internal Energy of Jupiter and Saturn, 280

Energy from Gravitational Contraction, 281

Saturn's Internal Energy, 281

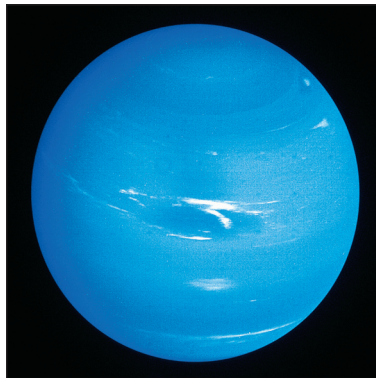
Magnetospheres, 281

Rings, 283

Ring Dimensions, 284

Structure of Saturn's Rings, 285

- Resonances, 286
- Spokes, 287
- The Formation and Evolution of Planetary Rings, 288



chapter 13

The Outer Solar System, 293

- Discoveries, 294
 - Uranus, 294
 - Neptune, 294
- Uranus and Neptune, 295
 - Basic Properties, 295
 - Atmospheres, 296
 - Internal Structure, 298
 - Magnetic Fields and Magnetospheres, 300
 - Rings, 301
- Trans-Neptunian Objects, 304
 - Pluto, 305
 - Other TNOs, 309
 - TNOs and the History of the Solar System, 310



chapter 14

Satellites, 315

- Kinds of Satellites, 316
 - Regular Satellites, 316
 - Collision Fragments, 316

- Captured Asteroids, 316
 - Other Satellites, 316
- General Properties of Satellites, 316
 - Density and Composition, 316
 - Internal Activity, 317
- The Satellites of Mars, 319
- The Galilean Satellites, 320
 - Io, 321
 - Europa, 323
 - Ganymede, 325
 - Callisto, 327
- The Icy Moons of Saturn, 328
 - Hyperion, 328
 - Rhea and Mimas, 329
 - Dione and Tethys, 329
 - Iapetus, 330
 - Enceladus, 331
- Titan, 332
 - Origin of Titan's Atmosphere, 332
 - Atmospheric Structure, 332
 - At the Surface of Titan, 333
- Satellites of Uranus, 335
 - Oberon, Titania, Umbriel, and Ariel, 335
 - Miranda, 337
- Satellites of Neptune, 338
 - Triton, 338

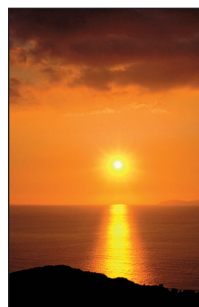


chapter 15

Small Solar System Bodies, 345

- Meteors, 346
 - The Meteor Phenomenon, 346
 - Sizes of Meteoroids, 347
 - Meteor Showers, 347
 - Micrometeorites, 349
- Meteorites, 349
 - How Often Do They Fall?, 350
 - Kinds of Meteorites, 350
 - Ages of Meteorites, 352
 - Parent Bodies of Meteorites, 352
- Asteroids, 353
 - Discovery of Asteroids, 353
 - Orbits of Asteroids, 354
 - Classes of Asteroids, 358
 - Asteroids and Meteorites, 358

- Comets, 359
 - Anatomy of a Comet, 359
 - Comet Orbits, 362
 - What Happens to Comets?, 364
- Where did Comets Form?, 367
- Collisions with Earth, 367
 - How Often Do Collisions Occur?, 367
 - Record of Impacts, 367
 - Consequences of an Impact, 368
 - Has This Ever Happened?, 369



Part 3 Journey to the Stars

chapter 16

Basic Properties of Stars, 375

- Star Names, 376
- The Distances of Stars, 376
 - Pretelescopic Estimates, 376
 - Later Estimates, 376
 - Parallax, 376
- The Motions of the Stars, 378
 - Proper Motions, 378
 - The Motion of the Sun, 378
- The Brightnesses of Stars, 380
 - Stellar Magnitudes, 380
 - Absolute Magnitude, 381
 - Luminosity Functions, 383
- Stellar Spectra, 383
 - Atoms and Spectral Lines, 383
 - Spectral Classification, 386
 - The Role of Temperature, 387
 - Luminosity Class, 388
 - Chemical Abundances, 389
 - The Doppler Effect and Stellar Spectra, 389
- H-R Diagrams, 391
- Stellar Masses, 393
 - Masses of Binary Stars, 393
 - The Range of Stellar Masses, 393
 - The Mass-Luminosity Relation, 393

chapter 17

The Sun, 399

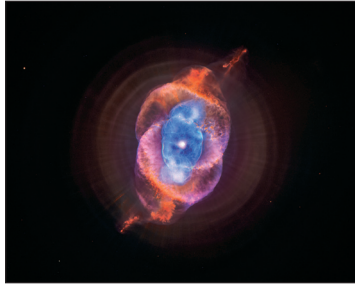
- The Internal Structure of the Sun, 400
- The Sun's Energy, 401
 - Some Wrong Answers, 401
 - Nuclear Reactions, 401
 - Flow of Energy to the Surface, 403
- The Outer Layers of the Sun, 406
 - The Photosphere, 406
 - The Chromosphere, 412
 - The Corona, 413
 - The Solar Wind, 417
- The Sunspot Cycle, 418
 - A Model of the Sunspot Cycle, 419
- Solar Mysteries, 421



chapter 18

The Formation of Stars and Planets, 425

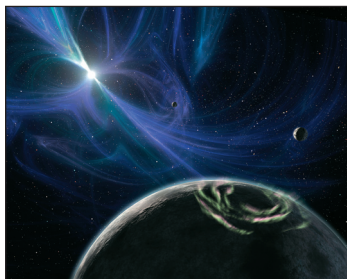
- Some Important Clues, 426
 - Clues from Stars, 426
 - Clues from the Solar System, 426
- Star Formation, 426
 - Giant Molecular Clouds, 426
 - Cores and Star Formation, 427
- Protostars, 429
 - The Evolution of a Protostar, 429
 - Rotation and Disks, 430
- Young Stars, 431
 - H-R Diagrams for Young Stars, 431
 - Winds and Disks, 432
- Planetary Systems, 435
 - The Solar Nebula, 435



chapter 19

The Evolution of Stars, 443

- Why Do Stars Evolve?, 444
 - Energy Generation, 444
 - Opacity, 446
 - Equation of State, 446
 - The Vogt-Russell Theorem, 447
 - Models of Stars, 447
- Evolutionary Tracks and Star Clusters, 447
 - Changing Appearance in the H-R Diagram, 447
 - H-R Diagrams of Star Clusters, 448
- Main Sequence Stars, 450
 - The Variety of Main Sequence Stars, 450
 - Main Sequence Lifetime, 452
 - Evolution on the Main Sequence, 453
- After the Main Sequence, 454
 - Red Giant Stars, 455
 - Core Helium Burning, 456
 - The Asymptotic Giant Branch, 459
 - Very Massive Stars, 463
 - The Formation of Heavy Elements in Stars, 464

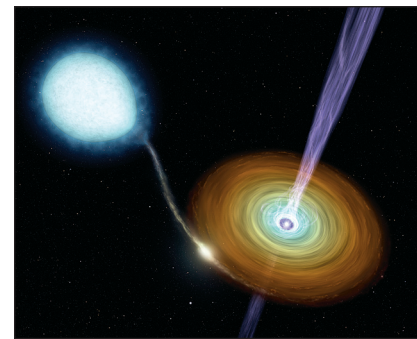


chapter 20

White Dwarfs, Neutron Stars, and Black Holes, 469

- White Dwarf Stars, 470
 - White Dwarfs and Electron Degeneracy, 470
 - Evolution of White Dwarf Stars, 471
 - What Is the Origin of White Dwarf Stars?, 472
- Neutron Stars, 473
 - Supernovae, 473
 - Gamma Ray Bursts, 477
 - Supernova Remnants, 478

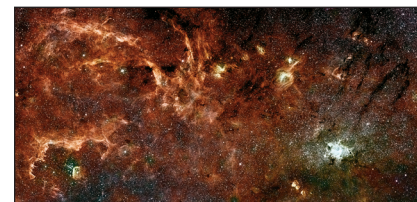
- Properties of Neutron Stars, 480
- Pulsars, 481
- Black Holes, 484
 - Spacetime, 484
 - The Formation of a Black Hole, 489
 - Detecting Black Holes, 490



chapter 21

Binary Star Systems, 495

- The Kinds of Binary Stars, 496
 - Detecting Binary Stars, 496
 - Multiple Star Systems, 502
- The Formation of Binary Systems, 502
 - Wide Binaries, 503
 - Close Binaries, 503
- Evolution of Close Binaries, 503
 - Evidence for Interaction: The Algol Paradox, 503
 - Equipotentials, 503
- Binaries with Compact Objects, 511
 - Accretion Disks, 511
 - Binaries with White Dwarfs, 512
 - Binaries with Neutron Stars or Black Holes, 513



Part 4 Journey to the Cosmic Frontier

chapter 22

The Milky Way, 521

- Interstellar Matter, 522
 - Interstellar Gas, 523
 - Interstellar Dust, 527

- The Shape and Size of the Galaxy, 531
 - Star Counting, 532
 - The Modern View of the Galaxy, 533
- The Rotation of the Milky Way, 535
 - The Orbit of the Sun, 535
 - The Rotation Curve of the Galaxy, 536
- The Spiral Structure of the Galaxy, 539
 - Observations of Spiral Structure, 539
 - Why Is There Spiral Structure?, 541
- The Center of the Galaxy, 543
 - Crowded Stars, 544
- The History of the Galaxy, 546
 - Stellar Populations, 546
 - Galactic Evolution, 546



chapter 24

Quasars and Other Active Galaxies, 573

- Quasars, 574
 - The Meaning of Quasar Redshifts, 574
 - Properties of Quasars, 575
- The Active Galaxy Zoo, 581
 - Seyfert Galaxies, 581
 - Radio Galaxies, 582
 - Blazars, 585
 - IRAS Galaxies, 585
- Massive Black Holes and Active Galaxies, 586
 - Massive Black Holes, 586
 - Accretion Disks, 587
 - The Host Galaxy, 590
- Evolution of Quasars, 592
 - Evidence for Evolution, 592
 - Where Are the Dead Quasars?, 594
- Quasars as Probes of the Universe, 594
 - Absorption Lines, 594
 - Gravitational Lenses, 595

chapter 23

Galaxies, 553

- The Discovery of Galaxies, 554
 - Island Universes, 554
 - Hubble Proves Nebulae Are Galaxies, 555
- The Kinds of Galaxies, 555
 - Elliptical Galaxies, 555
 - Spiral Galaxies, 557
 - Irregular Galaxies, 559
 - Why Are There Different Kinds of Galaxies?, 560
 - The Rotation of Galaxies, 563
- The Cosmic Distance Scale, 565
 - Primary Distance Indicators, 565
 - Secondary Distance Indicators, 566
 - Tertiary Distance Indicators, 566
 - Hubble's Law, 567



chapter 25

Galaxy Clusters and the Structure of the Universe, 601

- Clusters of Galaxies, 602
 - Classifying Clusters, 602
 - Galaxies in Clusters, 608
 - Other Matter in Clusters, 610

- Superclusters and Voids, 613
 - The Local Supercluster, 613
 - Other Superclusters, 613
 - Voids, 614
 - Why Are There Voids and Sheets?, 615
 - The Great Attractor, 615



chapter 26

Cosmology, 619

- Hubble's Law Revisited, 620
 - The Expansion Age of the Universe, 620
- Cosmological Models, 621
 - Curvature of Space, 621
 - Testing Curvature, 624
 - Three-Dimensional Universes, 625
 - Distant Supernovae, 628
- The Big Bang, 629
 - When Did the Big Bang Occur?, 630
 - What Happened?, 630
 - The Cosmic Microwave Background, 634
- Inflation, 636
 - Problems with the Standard Big Bang, 636
 - How Inflation Solves the Problems, 637
 - Why Inflation?, 638
- The Fate of the Universe, 639
 - The Choices, 639
 - Contraction and Beyond, 639
 - Continued Expansion, 640
 - Which Will It Be?, 640



Part 5 The Journey in Search of Life

chapter 27

Life in the Universe, 645

- Life, 646
 - What Is Life?, 646

- Life on Earth, 646
 - Other Possibilities, 647
- The Origin and Evolution of Life on Earth, 647
- Life Elsewhere in the Solar System, 648
- Life in Other Planetary Systems, 649
 - Finding Other Planetary Systems, 650
 - Habitable Planets, 654
 - Intelligent Life, 655
- Interstellar Communication, 656
 - Travel, 656
 - Radio Communication, 657

Appendixes, A-1

- 1 Mathematical and Physical Constants, A-1
- 2 Astronomical Constants, A-1
- 3 Conversion Factors, A-1
- 4 Periodic Table of the Elements, A-2
- 5 Orbital Properties of the Planets and Dwarf Planets, A-3
- 6 Physical Properties of the Planets and Dwarf Planets, A-3
- 7 Properties of the Major Satellites of the Planets and Dwarf Planets, A-4
- 8 Orbital Properties of Selected Asteroids, A-6
- 9 Orbital Properties of Selected Comets, A-6
- 10 Properties of Selected Meteor Showers, A-7
- 11 The Constellations, A-7
- 12 Stars Nearer Than Four Parsecs, A-10
- 13 The Brightest Stars, A-11
- 14 Principal Members of the Local Group of Galaxies, A-11
- 15 The Brightest Galaxies Beyond the Local Group, A-12
- 16 Properties of Selected Clusters of Galaxies, A-12
- 17 Logarithmic Graphs, A-13
- 18 Answers to Odd-Numbered Questions, A-14

Glossary, G-1

References, R-1

Credits, C-1

Index, I-1