

Contents

Part 1: Finding Our Place in Space 1

1 Naked Sky, Naked Eye: Finding Your Way in the Dark 3

Sun Days	3
Flat Earth, Big Bowl	4
<i>Man in the Moon</i>	5
<i>Lights and Wanderers</i>	7
<i>Celestial Coordinates</i>	7
<i>Measuring the Sky</i>	9
<i>The Size of Things, or "I Am Crushing Your Head!"</i>	9
Celestial Portraits.....	11
<i>The Dippers First</i>	12
<i>The Stars of Spring</i>	13
<i>Summer Nights</i>	13
<i>Fall Constellations</i>	14
<i>Winter Skies</i>	15
Who Cares?	16

2 Ancient Evenings: The First Watchers 17

A Dragon Eats the Sun: Ancient Chinese Astronomy	18
<i>Why the Emperor Executed Hsi and Ho</i>	18
<i>Time, Space, Harmony</i>	19
Babylon Revisited	20
<i>The Venus Tablet</i>	20
<i>Draftsmen of the Constellations?</i>	21
Egypt Looks	22
<i>Celestial Pyramids</i>	22
<i>The Universe-in-a-Box</i>	23
Stonehenge and the New World	23
Grecian Formula	24
<i>Anaximander Puts Earth in Space</i>	24
<i>Anaximenes Says Stars Burn</i>	25
<i>Pythagoras Calls Earth a Globe</i>	25
<i>Anaxagoras Explains Eclipses</i>	26
<i>Aristarchus Sets the Sun in the Middle and Us in Motion</i>	26
<i>Eratosthenes Sizes Up the Earth</i>	26

3 The Unexplained Motions of the Heavens 31

Time on Our Hands.....	32
<i>What Really Happens in a Day?</i>	32
<i>A Month of Moons</i>	34
<i>Another Wrinkle in Time</i>	37
<i>To Everything a Season</i>	38
The Sun Goes Dark, the Moon Becomes Blood	41
Aristotle Lays Down the Law	41
Ptolemy's Picture	43
Night Falls	44

4 Astronomy Reborn: 1543–1687 47

Arabian Nights.....	48
Heresy of a Polish Priest	49
<i>"More Pleasing to the Mind"</i>	50
<i>A Revolution of Revolutions</i>	52
The Man with the Golden Nose	53
Kepler Makes Sense of It	54
<i>Three Laws</i>	55
Galileo's Eye.....	57
Holding It All Together	58
<i>Newton's Three Laws of Motion</i>	59
<i>Weighty Matters</i>	60
<i>It's Not Just a Good Idea</i>	60

Part 2: Now You See It (Now You Don't) 63

5 The Art of Collecting Light (with a Telescope) 65

Slice of Light	66
<i>The Whole Spectrum</i>	67
Buckets of Light.....	69
<i>The Telescope Is Born</i>	69
<i>Refraction</i>	70
... or Reflection?	71
<i>Variations on an Optical Theme</i>	73
Size Matters	74
<i>The Power to Gather Light</i>	75
<i>The Power to Resolve an Image</i>	75
Twinkle, Twinkle	75
<i>Computer Assist</i>	76
<i>Fun House Mirrors</i>	77
<i>Observatory in Space: The Hubble Space Telescope</i>	78

6 You and Your Telescope 81

Do I Really Need a Telescope?	82
Science Aside, What Will It Cost?	87
Decisions, Decisions	89
<i>Refractors: Virtues and Vices</i>	89
<i>Reflectors: Newton's Favorite</i>	90
<i>Rich-Field Telescopes: Increasing in Popularity</i>	90
<i>Schmidt-Cassegrain: High-Performance Hybrid</i>	90
<i>Maksutov-Cassegrain: New Market Leader</i>	91
<i>Dobsonians: More for Your Money?</i>	92
The Go-To Revolution	93
I've Bought My Telescope, Now What?	94
<i>Grab a Piece of Sky</i>	94
<i>Become an Astrophotographer</i>	95
<i>Light Pollution and What to Do About It</i>	96
<i>Finding What You're Looking For</i>	97
Learning to See	98
<i>Low-Light Adjustment</i>	98
<i>Don't Look Too Hard</i>	99

7 Over the Rainbow 101

Making Waves	102
<i>Anatomy of a Wave</i>	102
<i>New Wave</i>	104
<i>Big News from Little Places</i>	104
Full Spectrum	105
<i>The Long and the Short of It</i>	106
<i>What Makes Color?</i>	107
Heavenly Scoop	108
<i>Atmospheric Ceilings and Skylights</i>	109
<i>The Black-Body Spectrum</i>	110
<i>Watch Your Head, Here Comes an Equation</i>	111
<i>Read Any Good Spectral Lines Lately?</i>	112

8 Seeing in the Dark 117

Dark Doesn't Mean You Can't See	118
<i>A Telephone Man Tunes In</i>	118
<i>Anatomy of a Radio Telescope</i>	121
<i>Bigger Is Better: The Green Bank Telescope</i>	121
<i>Interference Can Be a Good Thing</i>	123
What Radio Astronomers "See"	124

You Can Do This, Too!	125
<i>Amateur Radio Astronomy: No-Cost and Low-Cost Approaches</i> ..	126
<i>Solar Flares and Meteor Events</i>	127
<i>ET Phone Home</i>	128
The Rest of the Spectrum	128
<i>New Infrared and Ultraviolet Observations</i>	129
<i>Chandrasekhar and the X-Ray Revolution</i>	129
<i>Capturing the Full Spectrum</i>	130

9 Space Race: From *Sputnik* to the International Space Station **131**

This Really Is Rocket Science.....	132
<i>From Scientific Tool to Weapon and Back Again</i>	133
<i>Playing with Balloons</i>	134
<i>The Battle Cry of Sputnik</i>	134
Early Human Missions	135
Satellites and Probes	136
<i>The Explorers</i>	136
<i>Observatories in Space</i>	137
JFK's Challenge	137
<i>Lunar Probes</i>	137
<i>The Apollo Missions</i>	138
Planetary Probes	140
<i>Mariners and Vikings</i>	140
<i>Pioneers and Voyagers</i>	141
<i>Magellan, Galileo, and Ulysses</i>	141
<i>Mars Observer, Surveyor, and Pathfinder</i>	142
<i>A More Distant Voyager</i>	143
Space Shuttles and Space Stations.....	144
<i>Skylab</i>	145
<i>The Demise of Mir</i>	145
International Space Station: The Latest	145

Part 3: A Walk Around the Block **147**

10 The Moon: Our Closest Neighbor **149**

What If We Had No Moon?	150
Lunar Looking	150
<i>What Galileo Saw</i>	151
<i>What You Can See</i>	152
It's a Moon!	154
<i>A Daughter?</i>	154
<i>A Sister?</i>	154

<i>A Captive?</i>	154
<i>A Fender Bender?</i>	155
<i>Give and Take</i>	155
<i>Green Cheese?</i>	157
<i>A Pocked Face</i>	158
<i>And What's Inside?</i>	159
11 Solar System Home Movie	161
Solar System History	162
<i>The Biggest Problem: We Weren't There</i>	162
<i>What Do We Really Know About the Solar System?</i>	163
From Contraction to Condensation	165
<i>Angular Momentum Explained</i>	165
<i>Pearls the Size of Worlds</i>	166
<i>Birth of the Planets</i>	166
<i>Accretion and Fragmentation</i>	168
Whipping Up the Recipe	168
<i>Out of the Frying Pan</i>	169
<i>Into the Fire</i>	169
<i>Do the Pieces Fit?</i>	170
Ashes to Ashes, Dust to Dust	171
12 Solar System Family Snapshot	173
A Beautiful Day in the Neighborhood: Let's Take a Stroll	174
<i>Some Points of Interest</i>	175
<i>More or Less at the Center of It All</i>	176
<i>Planetary Report Card</i>	176
The Inner and Outer Circles	177
<i>Snapshot of the Terrestrial Planets</i>	177
<i>Snapshot of the Jovian Planets</i>	177
Serving Up the Leftovers	178
<i>The Asteroid Belt</i>	178
<i>Landing on Eros—The Love Boat</i>	178
<i>Rocks and Hard Places</i>	179
<i>Impact? The Earth-Crossing Asteroids</i>	180
Anatomy of a Comet	181
<i>A Tale of Two Tails</i>	182
<i>"Mommy, Where Do Comets Come From?"</i>	182
<i>A-Hunting We Will Go</i>	184
Catch a Falling Star	185
<i>Meteors, Meteoroids, and Meteorites</i>	186
<i>News from NEAT</i>	186
<i>April Showers (or the Lyrids)</i>	187

13 So Close and Yet So Far: The Inner Planets 189

The Terrestrial Roster	190
Mercury: The Moon's Twin	192
<i>Lashed to the Sun</i>	193
<i>"I Can't Breathe!"</i>	194
Forecast for Venus: "Hot, Overcast, and Dense"	194
<i>The Sun Sets on Venus (in the East)</i>	195
<i>Venusian Atmosphere</i>	196
The Earth: Just Right	197
Mars: "That Looks Like New Mexico!"	198
<i>Martian Weather Report: Cold and Thin Skies</i>	198
<i>The Martian Chronicles</i>	199
<i>Why Mars Is Red</i>	200
<i>Volcanoes, Craters, and a "Grand Canyon"</i>	201
<i>Water, Water Anywhere?</i>	202
<i>Martian Moons</i>	203
Where to Next?	203

14 Great Balls of Gas! The Outer Planets 205

The Jovian Line-Up	206
<i>Planetary Stats</i>	206
<i>Latecomers: Uranus and Neptune</i>	209
<i>Earthbound Views: Uranus and Neptune</i>	211
<i>Earthbound Views: Jupiter and Saturn</i>	212
<i>Views from the Voyagers and Galileo</i>	214
Rotation: A New Twist	215
Stormy Weather	216
<i>The Great Red Spot</i>	216
<i>Bands of Atmosphere</i>	217
<i>Layers of Gas</i>	217
Saturnine Atmosphere	218
The Atmospheres of Uranus and Neptune	218
Inside the Jovians	219
The Jovian Magnetospheres	219

15 The Far End of the Block 221

Lord of the Rings	222
<i>Looking from Earth</i>	222
<i>Looking with Voyager</i>	224
<i>More Rings on the Far Planets</i>	225
On the Shoulders of Giants	225
Faraway Moons	226
<i>Jupiter's Four Galilean Moons</i>	226
<i>Titan: Saturn's Highly Atmospheric Moon</i>	228

<i>Triton, Neptune's Large Moon</i>	229
<i>A Dozen More Moons in the Outer Solar System</i>	230
<i>Pluto Found</i>	232
<i>A "New" Moon</i>	233
<i>Where Did Pluto Come From?</i>	233

Part 4: To the Stars 235

16 Our Star 237

<i>The Solar Furnace</i>	238
<i>A Very Special Theory</i>	239
<i>What's It Made Of?</i>	239
<i>A Spectacular, Mediocre Star</i>	239
<i>Four Trillion Trillion Light Bulbs</i>	240
<i>The Solar Atmosphere</i>	240
<i>Not That Kind of Chrome</i>	241
<i>A Luminous Crown</i>	241
<i>Solar Wind</i>	243
<i>Fun in the Sun</i>	244
<i>A Granulated Surface</i>	244
<i>Galileo Sees Spots Before His Eyes</i>	244
<i>Sunspots: What They Are</i>	244
<i>Sunspot Cycles</i>	246
<i>Coronal Fireworks</i>	247
<i>At the Core</i>	247
<i>Gone Fission</i>	248
<i>Chain Reactions</i>	248
<i>Your Standard Solar Model</i>	249

17 Of Giants and Dwarfs: Stepping Out into the Stars 251

<i>Sizing Them Up</i>	252
<i>Radius, Luminosity, Temperature: A Key Relationship</i>	252
<i>The Parallax Principle</i>	253
<i>How Far Away Are the Stars?</i>	255
<i>Nearest and Farthest</i>	256
<i>Do Stars Move?</i>	257
<i>How Bright Is Bright?</i>	259
<i>Luminosity Versus Apparent Brightness</i>	259
<i>Creating a Scale of Magnitude</i>	259
<i>How Hot Is Hot?</i>	260
<i>Stellar Pigeonholes</i>	262
<i>Using the Spectrum</i>	262

From Giants to Dwarfs: Sorting the Stars by Size.....	262
Making the Main Sequence.....	263
<i>Off the Beaten Track</i>	264
<i>Stellar Mass</i>	264
<i>The Life Expectancy of a Star</i>	265
18 Stellar Careers	267
A Star Evolves	268
<i>The Main Sequence—Again</i>	268
<i>From Here to Eternity</i>	268
<i>Swelling and Shrinking</i>	269
Stellar Nursing Homes.....	269
<i>Red Giant</i>	269
<i>A Flash in the Pan</i>	270
<i>Red Giant Revisited</i>	270
<i>Core and Nebula</i>	271
<i>White Dwarf</i>	272
<i>Going Nova</i>	273
The Life and Death of a High-Mass Star.....	273
<i>Fusion Beyond Carbon</i>	274
<i>Over the Edge</i>	274
Supernova: So Long, See You in the Next Star	275
<i>Types of Supernovae</i>	275
<i>The Supernova as Creator</i>	276
Neutron Stars.....	276
<i>In Theory</i>	277
<i>What the Pulsars Tell Us</i>	277
<i>A Stellar Lighthouse</i>	278
I Can't Stop!.....	278
19 Black Holes: One-Way Tickets to Eternity	279
Is There No End to This Pressure?	280
<i>Black Holes: The Ultimate End</i>	280
<i>What's That on the Event Horizon?</i>	281
<i>Where's the Surface?</i>	282
Relativity	282
<i>What Is Curved Space?</i>	283
<i>No Escape</i>	283
<i>The Black-Hole Neighborhood</i>	284
Thought Experiments	284
<i>Postcards from the Edge</i>	284
<i>Into the Abyss</i>	285
Black-Hole Evidence	285

20 Stellar Nurseries 289

An Interstellar Atlas	290
<i>Blocking Light</i>	291
<i>Dusty Ingredients</i>	292
<i>Flipping Out</i>	293
Star Light, Star Bright	294
<i>A Matter of Perspective</i>	295
The Interstellar Medium: One Big Fuel Tank	297
<i>Tripping the Switch</i>	297
<i>Letting It All Out</i>	297
<i>Not Quite a Star</i>	298
<i>The "On" Switch</i>	299
<i>A Collapsed Souffle</i>	299
Multiple Births	299
In the Delivery Room	299

Part 5: Way Out of This World 301

21 The Milky Way: Much More Than a Candy Bar 303

Where Is the Center and Where Are We?	304
Home Sweet Galaxy	304
<i>A Thumbnail Sketch</i>	305
<i>Keeping up with the Joneses</i>	306
<i>Take a Picture, It'll Last Longer</i>	307
Measuring the Milky Way	307
<i>Where Do We Fit In?</i>	310
Milky Way Portrait	311
<i>A Monster at the Center?</i>	312
<i>The Birth of the Milky Way</i>	313
Dark Matters	314
<i>In the Arms of the Galaxy</i>	315

22 A Galaxy of Galaxies 317

Sorting Out the Galaxies	318
<i>Spirals: Catch a Density Wave</i>	319
<i>Ellipticals: Stellar Footballs</i>	319
<i>Are These Reduced? They're All Marked "Irregular"</i>	321
Galactic Embrace	322
<i>Catch the Wave</i>	323
How to "Weigh" a Galaxy	323
<i>A Big Job</i>	324
<i>"It's Dark Out Here"</i>	324

Let's Get Organized	325
<i>Measuring Very Great Distances</i>	325
<i>The Local Group and Other Galaxy Clusters</i>	326
<i>Superclusters</i>	327
Where Does It All Go?	327
<i>Hubble's Law and Hubble's Constant</i>	327
<i>The Big Picture</i>	329

23 Moving Out of Town 331

A Long Time Ago in a Galaxy Far, Far Away	332
Quasars: Looks Can Be Deceiving	332
<i>Small and Bright</i>	333
Quasars and the Evolution of Galaxies	334
A Piece of the Action	335
<i>The Violent Galaxies of Seyfert</i>	335
<i>Cores, Jets, and Lobes: Radio Galaxy Anatomy</i>	336
Where It All Starts	338
<i>Generating Energy</i>	338

Part 6: The Big Questions 341

24 Table for One? 343

What Do You Mean by "Alone"?	344
... <i>If You Call This Living</i>	344
<i>Is Earth Rare?</i>	345
<i>The Chemistry of Life</i>	346
The Odds for Life on Mars	347
<i>The Face on Mars</i>	348
Hello! Is Anybody Out There?	349
<i>You Just Love the Drake Equation</i>	350
A Closer Look at the Equation	351
<i>Galaxy Productivity</i>	352
<i>Do They All Have Planets?</i>	352
<i>Welcome to the Habitable Zone</i>	352
<i>Let There Be Life</i>	352
<i>Who Are You Calling Intelligent?</i>	352
<i>The Life Span of a Civilization</i>	353
Where Are the Little Green Men?	354
<i>What We Look For</i>	354
<i>Later, on Oprah</i>	354
<i>Down at the Old Water Hole</i>	356
<i>Should We Reach Out?</i>	356

25 What About the Big Bang? 359

The Work of the Cosmologist	359
I'll Give You Two Clues	360
Redshifting Away.....	360
Pigeon Droppings and the Big Bang	361
Same Old Same Old	363
The Cosmological Principle	363
So What Was the Big Bang?	363
Big Bang Overview.....	364
A Long Way from Nowhere	365
How Was the Universe Made?	365
How Were Atoms Made?	366
Stretching the Waves	366

26 (How) Will It End? 369

What the Redshift Means	369
Limited Options.....	370
A Matter of Density	370
A Surprising Boomerang.....	371
Run Away! Run Away!.....	372
What Does It All Mean?	373
What's the Point?	373
The Universe: Closed, Open, or Flat?	374
Saddle Up the Horses: Into the Wide-Open Universe	374
We Have a Problem	375
Down to Earth.....	376
Blow It Up	376
Looks Flat to Me	377
Coming Full Circle	378

Appendixes

A Star Words Glossary 379

B Upcoming Eclipses 395

C The Constellations 397

D The Messier Catalog 401

E Sources for Astronomers 407

Index 413