Introduction	1
About This Book	2
Foolish Assumptions	3
Icons Used in This Book	3
Beyond the Book	4
Where to Go from Here	4
Getting Started with Astrophysics	7
Welcome to the Universe	9
The Science of Astrophysics	10
The start of astronomy	10
A beautiful connection: Physics, astronomy, and astrophysics	11
Let there be light! The electromagnetic spectrum	11
Making waves	13
Tools of the Trade	15
The nitty-gritty of telescopes and astronomical instruments	15
Viewing from above: Space-based telescopes	17
Stars, Galaxies, and Their Cosmological Friends	18
The A to Z of Physics	21
Building Blocks of the Universe: Particles	22
The big three: Protons, neutrons, and electrons	22
Elements and molecules	24
(It's) elementary, particles	26
Light it up with photons	26
What Matters About Matter?	27
The water we drink and the air we breathe, or elements and molecules	28
It's all a state of mind with states of matter	29
But sometimes it just doesn't (anti) matter	30
Let the Force(s) Be With You	30
Getting heavy with gravity	31
Thank Maxwell for the electromagnetic force	33
Strong and weak nuclear forces	34
Store It or Use it, But Don't Waste Energy	35
Fall faster into kinetic and potential energy	35
Transferring thermal energy with conduction, convection, and radiation	36
More than the eye can see: The electromagnetic spectrum	37
Light's unending flexibility as both wave and particle	37
It's the Law! (of Physics)	38
Newton's laws of motion	39
Step it up with velocity, acceleration, and momentum	40
Having a conversation about conservation	40

Einstein and the mass energy equivalence 42
Heat and Energy Unite with Thermodynamics and Statistical Mechanics 42
Learn the laws of thermodynamics 43
Truly being one with the environment: Blackbody radiation 45
Electromagnetic waves do the heavy lifting with radiative transfer 46
When the details matter, zoom in to quantum mechanics 47
Astronomy in a Nutshell 49
Where to Begin … Or, How It All Began 50
Mapping our Solar System, Galaxy, and the Universe 53
A question of scale 53
A planetary survey 55
Experience nature's light show with meteors, asteroids, and comets 58
Galaxies and beyond 58
Observational Astronomy: What are Those Dots in the Sky? 59
Constellations: Mapping the stars 60
The ecliptic, a year-long journey of the Sun 61
How astronomical objects are named 62
Bridging the Gap Between Astronomy and Physics 65
More Than the Sum of Its Parts: The Unique Study of Astrophysics 66
One shift, two shift, redshift, blueshift 67
Don't be late to the party when time matters 68
Celestial mechanics and orbits 70
Diving into the Details of Astrophysics 72
Theoretical astrophysics 72
Observational astrophysics 72
Laboratory astrophysics 72
High-energy astrophysics 73
Running the gamut of the universe with cosmology 73
The Nitty-Gritty of Telescopes and Astronomical Instruments 73
Optical telescopes 74
The night life at optical observatories 76
Other types of telescopes 76
Viewing from above; Space-based telescopes 78
The Sun, the Star of Our Solar System 79
Solar flares, solar wind, and other solar activity 80
Hot or cold? The ins and outs of weather in space 81
Studying the Sun 82
Eclipses, or Throwing Shade in a Scientific Way 83
Red Moon: Lunar eclipses 83
Don't look! Solar eclipses 85

Science of eclipses 88
When You Wish Upon A 89
Star Power: Hydrogen, Helium with a Twist of Nuclear Fusion 91
Happy Birthday! A Star Is Born 92
How do we define stars? 92
Two is better than one: Fusion 92
Protostars, star formation regions, and accretion disks 95
Getting to Know Your Stars: Properties, Types, and Characteristics 98
Don't rely on wishing: Understand the brightness, mass, and more about stars 98
Plotting magnitude with the Hertzsprung-Russell diagram 100
Dwarfs and giants 102
The only constant is change with variable stars 103
All Good Things Must Come to an End 104
From flare ups to full-blown explosions: Novae and supernovae 105
Nucleosynthesis and the creation of new elements 106
The life cycle of a star: Heating, cooling, and everything in between 107
Star reincarnation and the next phase of stellar existence 109
Friends for Life: Star Systems and Dust Clouds 111
The More the Merrier: Binary and Multiple Star Systems 112
The ties that bind: What it means to be gravitationally bound 112
Orbits and the science behind them 114
Formation and evolution of multiple star systems 114
Step into the light; Eclipses in a double star system 116
Binary star orbits and radial velocity 118
Three's not a crowd: Multi-star systems 119
Huddle Up There, Star Clusters 121
Getting sticky with cluster formation 121
Shut the door! Learn about open clusters 121
Get even stickier with globular clusters 122
Pedal to the Metal with Interstellar Gas and Dust 123
The Interstellar medium 123
Dreaming with your head in the (molecular) clouds 124
IR spectroscopy and laboratory astrophysics 124
Adding Structure to That Gas and Dust: Nebulae 125
Diffuse and dark nebulae 126
Who made who? Planetary nebulae and supernova remnants 127
Exoplanets: The Search for Earth 2.0 129
Beyond beyond Earth 130
Exoplanets explained 131
Key to understanding planet formation 132

Exoplanets Come in Many Shapes and Sizes 132
Exoplanet properties (mileage may vary) 133
What's in a name? 134
(Non) Flaming giant balls of gas and Neptunian exoplanets 134
They really are super! Super-Earth exoplanets 135
Look no further than Mother Earth for terrestrial exoplanets 135
Looking Under (or Around) Hidden Rocks: Exoplanet Detection 136
Observational techniques and biases 137
Finding the distance between two points with radial velocity 137
Transiting, TTV, and gravitational lensing 138
Ignore the garbage, but know your debris disk 140
Take a picture! The future of exoplanet detection 140
The Nitty-Gritty of Exoplanet Formation 141
Planetary birthrights: Protoplanetary disks 142
Get moving! The dynamics of exoplanet systems 143
What the Hail … Exoplanet Atmospheres 145
Can Life Be Found on Exoplanets? 146
Goldilocks had it right: The "habitable zone," or conditions for life as we know it 147
Twinning: Why haven't we found Earth 2.0? 148
Smells like life: Searching for biosignatures in exoplanet atmospheres 150
The Drake Equation and the search for intelligent life 150
White Dwarfs, Black Holes, and Neutrinos, Oh My! 153
Snow White and the Seven 154
Pure as the driven snow, but without the snow: White dwarfs 155
So cool and red hot: Red dwarfs 156
Giant stars 157
Evolved Giant Stars 158
There Is No Escape: Black Holes 158
What goes in never comes out: How black holes work 159
The event horizon: The line light cannot cross 160
Seeing the invisible, or the art of detecting black holes 161
Surf's Up! Gravitational Waves 163
A ripple in space-time 163
How to be a wave detective 164
Neutron Stars, or Total Core Collapse 164
Science of the collapse of stars 165
Pulsing radiation from pulsars 165
Quasars, Bursters, and Blazars 166
The XYZ of AGN: Quasars 167
Blazars keep black holes in business 168

Explosions from afar: Burst it out 169
Galaxies: Teamwork Makes the Dream Work 171
From Fuzzy Blobs to Majestic Spirals: The Milky Way and Other Galaxies 173
Where in the World Are We? 174
Galaxy quest 175
Traveling the Milky Way 175
Unraveling the Mystery 177
Galaxies and other fuzzy objects get messier 177
Hubble's puzzle 178
Standard candles and redshifts 178
Galaxy Classification 181
Stars and gas with uncommon beauty: Spiral galaxies 182
Never lose foci: Elliptical galaxies 184
Lenticular galaxies are shaped like … guess what? 185
Last night's leftovers on a universal scale: Irregular galaxies 187
Quantifying the Unknown, or How Galaxies Work 189
Galaxy Formation Helps Unravel the Cosmos 190
Source matter: No EM radiation for you! 190
The trinity: Gravity dominance, instability, collapse 191
Final push: Gravitational torque with a side of angular momentum 192
Mechanics of a Star System 193
Galactic Structure 194
An inventory of the parts 196
Stellar content of galaxies 197
Excuse you! Emissions of active and inactive galaxies 199
Both large and active: Seyfert and radio galaxies 199
Black Holes and Their Role in Galaxies 201
Black holes, the doughnut holes of the galaxy 201
Dynamics and observation 203
The Hubble Deep Field 204
Bigger Than Huge: Galaxy Clusters 207
Making Friends: The Basics of Galaxy Clusters 203
The ins and outs of a galaxy cluster 209
Mass estimation: Virial, Sunyaev-Zel'dovich, and more 210
Galaxy distribution throughout space 212
A Galaxy Cluster of Our Very Own: The Local Group 213
Location, location, location 213
Constituent galaxies 214
Galaxy Cluster Structure and Formation 215
The ever-important role of gravity 216

X-rays and the ICM (Intracluster medium) 216
Physics of Galaxy Clusters 218
The unique interactions of dark matter with baryons 219
Shake it up: Gravitational perturbations and shock waves 220
Always under pressure: Radiative gas physics 221
Galaxy and cluster mergers 222
An involuntary story of acquisition: LMC and SMC 223
Prediction via computer modeling 224
Galaxy cluster collisions 225
What Galaxy Clusters Tell You About the Universe 226
Bigger may be better 226
Chemical emissions as prognosticators 227
Change is hard: Slow rates of change in galaxy clusters 228
Weird and Wacky Galactic Phenomena 231
Not Quite Dinosaurs: Galactic Archaeology 232
What little stars are made of 233
Stellar ages and astroseismology 233
Tracing galactic mergers 234
High Energy Astrophysics 235
Triple E: Extreme energetic events 236
How do we know? ALMA, Hubble, JWST, Chandra, and others 237
Prime examples: Active galactic nuclei, gamma-ray bursts, supernovae 239
Gravitational Lensing 240
The bending of light 241
Strong, weak, and microlensing 244
Heading Down the Wormhole 245
A wormhole by any other name … Einstein-Rosen bridges 246
Making connections between wormholes and string theory 247
Cosmology: The Beginning and the End of Everything 249
The Big Bang: How It All Began 251
What's the Point? A Primer on Cosmology 252
Let's get right to it: The Big Bang 252
Expansion of space, not your grocery bill: Cosmic inflation 254
Creation of fundamental particles 254
Too early to shine or twinkle 255
Scientific Evidence: Why Do We Think There Was a Big Bang? 255
Hubble's Law and the expansion of the universe 256
Not for popcorn: Cosmic microwave background radiation 257
The Big Bang Nucleosynthesis (BBN) era 258
Disproving the steady-state mode! 259

Making Sense of the Unimaginable with the Theory of Inflation 260
The flatness problem 260
CMB and uniform temperature 261
Where galaxy clusters fit in 262
Radiation Dominance in the Radiation Era 262
Nothing Matters More Than Matter in the Matter Era 266
Metric Expansion of Space: The Cosmological Principle 268
We're really not all that special: The Copernican Principle 269
Multi-directional spreading with Hubble universal expansion 269
Big Bang radiation and temperature fluctuation 270
Constant expansion, but of an inconsistent rate 271
The future of direct measurement 272
First Light in the Universe, or How a Star is Born 273
The Cosmic Dark Age 274
The Big Bang cooled the heat 274
Formation of neutral hydrogen atoms and cosmic background radiation 275
A ripple in the universe led to galaxies 276
End of an era: The cosmic dawn 276
Early Star Formation 277
Origins in primordial gas 277
Nuclear fusion to the rescue 278
Star Classification; Population III 278
No room for diets: Very early stars = massive, low metal content 279
Supernova explosions created heavier elements 280
More metal: Next-gen stars had carbon, oxygen, iron, and heavier elements 281
Star Classification: Population II and I 281
Population II: Oldest observed stars formed 1 to 15 billion years ago 282
Population I: Young stars formed 1 million to 10 billion years ago 283
The Epoch of Reionization 284
Energy bubbles and the leaching of ionized radiation 285
Let there be light 286
Formation of the First Galaxies 287
Opposites (or not) attract! 287
Continued evolution and creation of new galaxies 288
And Then St Gets Weirder: Dark Matter, Dark Energy, and Relativity 289
General Facts about General Relativity 290
Keeping it special 290
Einstein's explanation of gravity's interaction with space-time 291
Space-time curvature and total forces 293
The three tests for general relativity 294

Advancing Theories Require Advancing Models 296
Holes and waves 296
First general relativity models: A stable universe and its challengers 297
Einstein's "greatest mistake" and its reinterpretation 298
Galactic Glue: Dark Matter 299
Detecting the darkness 300
Don't be a WiMP(s): Weakly interacting massive particles 302
Some like it hot, some like it cold 302
Dark Energy in Review 304
Why do we need dark energy? 304
A story of accelerating expansion 305
Where Did Dark Energy Come From? 306
Origins of dark energy 1: Einstein (again!) and the Cosmoiogical Constant 307
Origins of dark energy 2: Quantum theory 308
Origins of dark energy 3: Quintessence 308
Origins of dark energy 4: Tachyons moving faster than light 309
Origins of dark energy 5: Questioning Einstein and gravity 310
The standard of cosmology: The Lambda-Cold Dark Matter (ACDM) model 310
The End of It All 313
No Refunds: What Happens When the Sun Explodes 314
Running out of (hydrogen) gas 314
Goodbye, life on Earth 315
Omega Value of the Universe 316
It's critical: The critical density parameter 318
How do we calculate Omega? 319
WMAP and Planck missions 320
Future work on critical density 321
The Big Freeze: An End of the Universe Theory 323
The last stars burn out 323
Over the horizon: Galaxies beyond view 325
Such a degenerate era 326
Heat death of the universe 326
The Big Rip: Another End of the Universe Theory 327
Dynamics: Dark energy changing over time 328
Phantom dark energy 328
The Big Crunch: Yet Another End of the Universe Theory 329
Expanding, then shrinking 329
Spoilers: Dark energy could get in the way 330
Something Before Nothing: Did Anything Come before the Big Bang? 331
Anthropic principle: Why do the laws of physics even allow matter and life? 331

Before and after: The cyclic universe theory 332
Now That We're at the End - How Will It End? 333
Getting Higgy with it: Vacuum decay and the Higgs boson and field 334
Future observations of cosmic microwave background radiation and dark energy 335
Clues from JWST and the earliest galaxies 336
The Part of Tens 337
Ten Scientists Who Paved the Way for Astrophysics 339
Albert Einstein: 1879-1955 339
Edwin Hubble: 1889-1953 340
Cecelia Payne-Gaposchkin: 1900-1979 340
Karl Jansky: 1905-1950 340
Subrahmanyan Chandrasekhar: 1910-1995 341
Vera Rubin: 1928-2016 341
Kip Thorne: 1940- 342
Stephen Hawking: 1942-2018 342
Jocelyn Bell Bunnell: 1943 342
Alan Guth: 1947- 343
Ten Important Space Missions for Astrophysics 345
Hubble Space Telescope (1990-present) 345
James Webb Space Telescope (2021-present) 346
Kepler and TESS (2009-2018 and 2018-present) 347
SOFIA (2010-2022) 348
Chandra X-Ray Observatory (1999-present) 349
Spitzer Space Telescope (2003-2020) 349
Compton Gamma-Ray Observatory (1991-2000) 350
Fermi Gamma-Ray Space Telescope (2008-present) 351
Herschet Space Observatory (2009-2013) 351
Nancy Grace Roman Space Telescope (planned 2027 launch) 352
Glossary 353
Index 359

Table of Contents provided by Blackwell's Book Services and R.R. Bowker. Used with permission.