

# Contents

<b>Preface</b>	<b>xiii</b>
<b>I THE TOOLS OF ASTRONOMY</b>	<b>1</b>
<b>1 ■ The Celestial Sphere</b>	<b>2</b>
1.1 The Greek Tradition	2
1.2 The Copernican Revolution	5
1.3 Positions on the Celestial Sphere	8
1.4 Physics and Astronomy	19
<b>2 ■ Celestial Mechanics</b>	<b>23</b>
2.1 Elliptical Orbits	23
2.2 Newtonian Mechanics	29
2.3 Kepler's Laws Derived	39
2.4 The Virial Theorem	50
<b>3 ■ The Continuous Spectrum of Light</b>	<b>57</b>
3.1 Stellar Parallax	57
3.2 The Magnitude Scale	60
3.3 The Wave Nature of Light	63
3.4 Blackbody Radiation	68
3.5 The Quantization of Energy	71
3.6 The Color Index	75
<b>4 ■ The Theory of Special Relativity</b>	<b>84</b>
4.1 The Failure of the Galilean Transformations	84
4.2 The Lorentz Transformations	87
4.3 Time and Space in Special Relativity	92
4.4 Relativistic Momentum and Energy	102

viii	Contents	
<b>5</b>	<b>■ The Interaction of Light and Matter</b>	<b>111</b>
5.1	Spectral Lines	111
5.2	Photons	116
5.3	The Bohr Model of the Atom	119
5.4	Quantum Mechanics and Wave–Particle Duality	127
<b>6</b>	<b>■ Telescopes</b>	<b>141</b>
6.1	Basic Optics	141
6.2	Optical Telescopes	154
6.3	Radio Telescopes	161
6.4	Infrared, Ultraviolet, X-ray, and Gamma-Ray Astronomy	167
6.5	All-Sky Surveys and Virtual Observatories	170
	<b>II THE NATURE OF STARS</b>	<b>179</b>
<b>7</b>	<b>■ Binary Systems and Stellar Parameters</b>	<b>180</b>
7.1	The Classification of Binary Stars	180
7.2	Mass Determination Using Visual Binaries	183
7.3	Eclipsing, Spectroscopic Binaries	186
7.4	The Search for Extrasolar Planets	195
<b>8</b>	<b>■ The Classification of Stellar Spectra</b>	<b>202</b>
8.1	The Formation of Spectral Lines	202
8.2	The Hertzsprung–Russell Diagram	219
<b>9</b>	<b>■ Stellar Atmospheres</b>	<b>231</b>
9.1	The Description of the Radiation Field	231
9.2	Stellar Opacity	238
9.3	Radiative Transfer	251
9.4	The Transfer Equation	255
9.5	The Profiles of Spectral Lines	267
<b>10</b>	<b>■ The Interiors of Stars</b>	<b>284</b>
10.1	Hydrostatic Equilibrium	284
10.2	Pressure Equation of State	288
10.3	Stellar Energy Sources	296
10.4	Energy Transport and Thermodynamics	315
10.5	Stellar Model Building	329
10.6	The Main Sequence	340

Contents	ix
<b>11 ■ The Sun</b>	<b>349</b>
11.1 The Solar Interior	349
11.2 The Solar Atmosphere	360
11.3 The Solar Cycle	381
<b>12 ■ The Interstellar Medium and Star Formation</b>	<b>398</b>
12.1 Interstellar Dust and Gas	398
12.2 The Formation of Protostars	412
12.3 Pre-Main-Sequence Evolution	425
<b>13 ■ Main Sequence and Post-Main-Sequence Stellar Evolution</b>	<b>446</b>
13.1 Evolution on the Main Sequence	446
13.2 Late Stages of Stellar Evolution	457
13.3 Stellar Clusters	474
<b>14 ■ Stellar Pulsation</b>	<b>483</b>
14.1 Observations of Pulsating Stars	483
14.2 The Physics of Stellar Pulsation	491
14.3 Modeling Stellar Pulsation	499
14.4 Nonradial Stellar Pulsation	503
14.5 Helioseismology and Asteroseismology	509
<b>15 ■ The Fate of Massive Stars</b>	<b>518</b>
15.1 Post-Main-Sequence Evolution of Massive Stars	518
15.2 The Classification of Supernovae	524
15.3 Core-Collapse Supernovae	529
15.4 Gamma-Ray Bursts	543
15.5 Cosmic Rays	550
<b>16 ■ The Degenerate Remnants of Stars</b>	<b>557</b>
16.1 The Discovery of Sirius B	557
16.2 White Dwarfs	559
16.3 The Physics of Degenerate Matter	563
16.4 The Chandrasekhar Limit	569
16.5 The Cooling of White Dwarfs	572
16.6 Neutron Stars	578
16.7 Pulsars	586

x	Contents	
<b>17</b>	<b>■ General Relativity and Black Holes</b>	<b>609</b>
17.1	The General Theory of Relativity	609
17.2	Intervals and Geodesics	622
17.3	Black Holes	633
<b>18</b>	<b>■ Close Binary Star Systems</b>	<b>653</b>
18.1	Gravity in a Close Binary Star System	653
18.2	Accretion Disks	661
18.3	A Survey of Interacting Binary Systems	668
18.4	White Dwarfs in Semidetached Binaries	673
18.5	Type Ia Supernovae	686
18.6	Neutron Stars and Black Holes in Binaries	689
<b>III</b>	<b>THE SOLAR SYSTEM</b>	<b>713</b>
<b>19</b>	<b>■ Physical Processes in the Solar System</b>	<b>714</b>
19.1	A Brief Survey	714
19.2	Tidal Forces	719
19.3	The Physics of Atmospheres	724
<b>20</b>	<b>■ The Terrestrial Planets</b>	<b>737</b>
20.1	Mercury	737
20.2	Venus	740
20.3	Earth	745
20.4	The Moon	754
20.5	Mars	762
<b>21</b>	<b>■ The Realms of the Giant Planets</b>	<b>775</b>
21.1	The Giant Worlds	775
21.2	The Moons of the Giants	790
21.3	Planetary Ring Systems	801
<b>22</b>	<b>■ Minor Bodies of the Solar System</b>	<b>813</b>
22.1	Pluto and Charon	813
22.2	Comets and Kuiper Belt Objects	816
22.3	Asteroids	830
22.4	Meteorites	838

Contents	xi
<b>23 ■ Formation of Planetary Systems</b>	<b>848</b>
23.1 Characteristics of Extrasolar Planetary Systems	848
23.2 Planetary System Formation and Evolution	857
<b>IV GALAXIES AND THE UNIVERSE</b>	<b>873</b>
<b>24 ■ The Milky Way Galaxy</b>	<b>874</b>
24.1 Counting the Stars in the Sky	874
24.2 The Morphology of the Galaxy	881
24.3 The Kinematics of the Milky Way	898
24.4 The Galactic Center	922
<b>25 ■ The Nature of Galaxies</b>	<b>940</b>
25.1 The Hubble Sequence	940
25.2 Spiral and Irregular Galaxies	948
25.3 Spiral Structure	964
25.4 Elliptical Galaxies	983
<b>26 ■ Galactic Evolution</b>	<b>999</b>
26.1 Interactions of Galaxies	999
26.2 The Formation of Galaxies	1016
<b>27 ■ The Structure of the Universe</b>	<b>1038</b>
27.1 The Extragalactic Distance Scale	1038
27.2 The Expansion of the Universe	1052
27.3 Clusters of Galaxies	1058
<b>28 ■ Active Galaxies</b>	<b>1085</b>
28.1 Observations of Active Galaxies	1085
28.2 A Unified Model of Active Galactic Nuclei	1108
28.3 Radio Lobes and Jets	1122
28.4 Using Quasars to Probe the Universe	1130
<b>29 ■ Cosmology</b>	<b>1144</b>
29.1 Newtonian Cosmology	1144
29.2 The Cosmic Microwave Background	1162
29.3 Relativistic Cosmology	1183
29.4 Observational Cosmology	1199

xii	Contents	
<b>30</b>	<b>■ The Early Universe</b>	<b>1230</b>
	30.1 The Very Early Universe and Inflation	1230
	30.2 The Origin of Structure	1247
<b>A</b>	<b>■ Astronomical and Physical Constants</b>	<b>Inside Front Cover</b>
<b>B</b>	<b>■ Unit Conversions</b>	<b>Inside Back Cover</b>
<b>C</b>	<b>■ Solar System Data</b>	<b>A-1</b>
<b>D</b>	<b>■ The Constellations</b>	<b>A-3</b>
<b>E</b>	<b>■ The Brightest Stars</b>	<b>A-5</b>
<b>F</b>	<b>■ The Nearest Stars</b>	<b>A-7</b>
<b>G</b>	<b>■ Stellar Data</b>	<b>A-9</b>
<b>H</b>	<b>■ The Messier Catalog</b>	<b>A-13</b>
<b>I</b>	<b>■ Constants, A Programming Module</b>	<b>A-16</b>
<b>J</b>	<b>■ Orbit, A Planetary Orbit Code</b>	<b>A-17</b>
<b>K</b>	<b>■ TwoStars, A Binary Star Code</b>	<b>A-18</b>
<b>L</b>	<b>■ StatStar, A Stellar Structure Code</b>	<b>A-23</b>
<b>M</b>	<b>■ Galaxy, A Tidal Interaction Code</b>	<b>A-26</b>
<b>N</b>	<b>■ WMAP Data</b>	<b>A-29</b>
	<b>Suggested Reading</b>	<b>A-30</b>
	<b>Index</b>	<b>I-1</b>