

Contents

Preface to First Edition	xi
Preface to Second Edition	xix
PART 1 Cosmological Models	1
1 First Principles	3
1.1 The Cosmological Principle	3
1.2 Fundamentals of General Relativity	6
1.3 The Robertson-Walker Metric	9
1.4 The Hubble Law	13
1.5 Redshift	16
1.6 The Deceleration Parameter	17
1.7 Cosmological Distances	18
1.8 The m - z and N - z Relations	20
1.9 Olbers' Paradox	22
1.10 The Friedmann Equations	23
1.11 A Newtonian Approach	24
1.12 The Cosmological Constant	26
1.13 Friedmann Models	29
2 The Friedmann Models	33
2.1 Perfect Fluid Models	33
2.2 Flat Models	36
2.3 Curved Models: General Properties	38
2.3.1 Open models	39
2.3.2 Closed models	40
2.4 Dust Models	40
2.4.1 Open models	41
2.4.2 Closed models	41
2.4.3 General properties	42
2.5 Radiative Models	43
2.5.1 Open models	43
2.5.2 Closed models	44
2.5.3 General properties	44
2.6 Evolution of the Density Parameter	44
2.7 Cosmological Horizons	45
2.8 Models with a Cosmological Constant	49

3	Alternative Cosmologies	51
3.1	Anisotropic and Inhomogeneous Cosmologies	52
3.1.1	The Bianchi models	52
3.1.2	Inhomogeneous models	55
3.2	The Steady-State Model	57
3.3	The Dirac Theory	59
3.4	Brans-Dicke Theory	61
3.5	Variable Constants	63
3.6	Hoyle-Narlikar (Conformal) Gravity	64
4	Observational Properties of the Universe	67
4.1	Introduction	67
4.1.1	Units	67
4.1.2	Galaxies	69
4.1.3	Active galaxies and quasars	70
4.1.4	Galaxy clustering	72
4.2	The Hubble Constant	75
4.3	The Distance Ladder	79
4.4	The Age of the Universe	83
4.4.1	Theory	83
4.4.2	Stellar and galactic ages	84
4.4.3	Nucleocosmochronology	84
4.5	The Density of the Universe	86
4.5.1	Contributions to the density parameter	86
4.5.2	Galaxies	88
4.5.3	Clusters of galaxies	89
4.6	Deviations from the Hubble Expansion	92
4.7	Classical Cosmology	94
4.7.1	Standard candles	95
4.7.2	Angular sizes	97
4.7.3	Number-counts	99
4.7.4	Summary	100
4.8	The Cosmic Microwave Background	100
PART 2	The Hot Big Bang Model	107
5	Thermal History of the Hot Big Bang Model	109
5.1	The Standard Hot Big Bang	109
5.2	Recombination and Decoupling	111
5.3	Matter-Radiation Equivalence	112
5.4	Thermal History of the Universe	113
5.5	Radiation Entropy per Baryon	115
5.6	Timescales in the Standard Model	116
6	The Very Early Universe	119
6.1	The Big Bang Singularity	119
6.2	The Planck Time	122
6.3	The Planck Era	123
6.4	Quantum Cosmology	126
6.5	String Cosmology	128
7	Phase Transitions and Inflation	131
7.1	The Hot Big Bang	131
7.2	Fundamental Interactions	133
7.3	Physics of Phase Transitions	136
7.4	Cosmological Phase Transitions	138

7.5	Problems of the Standard Model	141
7.6	The Monopole Problem	143
7.7	The Cosmological Constant Problem	145
7.8	The Cosmological Horizon Problem	147
	7.8.1 The problem	147
	7.8.2 The inflationary solution	149
7.9	The Cosmological Flatness Problem	152
	7.9.1 The problem	152
	7.9.2 The inflationary solution	154
7.10	The Inflationary Universe	156
7.11	Types of Inflation	160
	7.11.1 Old inflation	160
	7.11.2 New inflation	161
	7.11.3 Chaotic inflation	161
	7.11.4 Stochastic inflation	162
	7.11.5 Open inflation	162
	7.11.6 Other models	163
7.12	Successes and Problems of Inflation	163
7.13	The Anthropic Cosmological Principle	164

8 The Lepton Era 167

8.1	The Quark–Hadron Transition	167
8.2	Chemical Potentials	168
8.3	The Lepton Era	171
8.4	Neutrino Decoupling	172
8.5	The Cosmic Neutrino Background	173
8.6	Cosmological Nucleosynthesis	176
	8.6.1 General considerations	176
	8.6.2 The standard nucleosynthesis model	177
	8.6.3 The neutron-proton ratio	178
	8.6.4 Nucleosynthesis of Helium	179
	8.6.5 Other elements	181
	8.6.6 Observations: Helium 4	182
	8.6.7 Observations: Deuterium	183
	8.6.8 Helium 3	184
	8.6.9 Lithium 7	185
	8.6.10 Observations versus theory	185
8.7	Non-standard Nucleosynthesis	186

9 The Plasma Era 191

9.1	The Radiative Era	191
9.2	The Plasma Epoch	192
9.3	Hydrogen Recombination	194
9.4	The Matter Era	195
9.5	Evolution of the CMB Spectrum	197

PART 3 Theory of Structure Formation 203

10 Introduction to Jeans Theory 205

10.1	Gravitational Instability	205
10.2	Jeans Theory for Collisional Fluids	206
10.3	Jeans Instability in Collisionless Fluids	210
10.4	History of Jeans Theory in Cosmology	212
10.5	The Effect of Expansion: an Approximate Analysis	213
10.6	Newtonian Theory in a Dust Universe	215
10.7	Solutions for the Flat Dust Case	218
10.8	The Growth Factor	219

10.9	Solution for Radiation-Dominated Universes	221
10.10	The Method of Autosolution	223
10.11	The Meszaros Effect	225
10.12	Relativistic Solutions	227
11	Gravitational Instability of Baryonic Matter	229
11.1	Introduction	229
11.2	Adiabatic and Isothermal Perturbations	230
11.3	Evolution of the Sound Speed and Jeans Mass	231
11.4	Evolution of the Horizon Mass	233
11.5	Dissipation of Acoustic Waves	234
11.6	Dissipation of Adiabatic Perturbations	237
11.7	Radiation Drag	240
11.8	A Two-Fluid Model	241
11.9	The Kinetic Approach	244
11.10	Summary	248
12	Non-baryonic Matter	251
12.1	Introduction	251
12.2	The Boltzmann Equation for Cosmic Relics	252
12.3	Hot Thermal Relics	253
12.4	Cold Thermal Relics	255
12.5	The Jeans Mass	256
12.6	Implications	259
	12.6.1 Hot Dark Matter	260
	12.6.2 Cold Dark Matter	261
	12.6.3 Summary	262
13	Cosmological Perturbations	263
13.1	Introduction	263
13.2	The Perturbation Spectrum	264
13.3	The Mass Variance	266
	13.3.1 Mass scales and filtering	266
	13.3.2 Properties of the filtered field	268
	13.3.3 Problems with filters	270
13.4	Types of Primordial Spectra	271
13.5	Spectra at Horizon Crossing	275
13.6	Fluctuations from Inflation	276
13.7	Gaussian Density Perturbations	279
13.8	Covariance Functions	281
13.9	Non-Gaussian Fluctuations?	284
14	Nonlinear Evolution	287
14.1	The Spherical 'Top-Hat' Collapse	287
14.2	The Zel'dovich Approximation	290
14.3	The Adhesion Model	294
14.4	Self-similar Evolution	296
	14.4.1 A simple model	296
	14.4.2 Stable clustering	299
	14.4.3 Scaling of the power spectrum	300
	14.4.4 Comments	301
14.5	The Mass Function	301
14.6	<i>N</i> -Body Simulations	304
	14.6.1 Direct summation	305
	14.6.2 Particle-mesh techniques	306
	14.6.3 Tree codes	309
	14.6.4 Initial conditions and boundary effects	309

14.7	Gas Physics	310
	14.7.1 Cooling	310
	14.7.2 Numerical hydrodynamics	312
14.8	Biased Galaxy Formation	314
14.9	Galaxy Formation	318
14.10	Comments	321

15 Models of Structure Formation 323

15.1	Introduction	323
15.2	Historical Prelude	324
15.3	Gravitational Instability in Brief	326
15.4	Primordial Density Fluctuations	327
15.5	The Transfer Function	328
15.6	Beyond Linear Theory	330
15.7	Recipes for Structure Formation	331
15.8	Comments	334

PART 4 Observational Tests 335

16 Statistics of Galaxy Clustering 337

16.1	Introduction	337
16.2	Correlation Functions	339
16.3	The Limber Equation	342
16.4	Correlation Functions: Results	344
	16.4.1 Two-point correlations	344
16.5	The Hierarchical Model	346
	16.5.1 Comments	348
16.6	Cluster Correlations and Biasing	350
16.7	Counts in Cells	352
16.8	The Power Spectrum	355
16.9	Polyspectra	356
16.10	Percolation Analysis	359
16.11	Topology	361
16.12	Comments	365

17 The Cosmic Microwave Background 367

17.1	Introduction	367
17.2	The Angular Power Spectrum	368
17.3	The CMB Dipole	371
17.4	Large Angular Scales	374
	17.4.1 The Sachs-Wolfe effect	374
	17.4.2 The COBE DMR experiment	377
	17.4.3 Interpretation of the COBE results	379
17.5	Intermediate Scales	380
17.6	Smaller Scales: Extrinsic Effects	385
17.7	The Sunyaev-Zel'dovich Effect	389
17.8	Current Status	391

18 Peculiar Motions of Galaxies 393

18.1	Velocity Perturbations	393
18.2	Velocity Correlations	396
18.3	Bulk Flows	398
18.4	Velocity-Density Reconstruction	400
18.5	Redshift-Space Distortions	402
18.6	Implications for Ω_0	405

19 Gravitational Lensing	409
19.1 Historical Prelude	409
19.2 Basic Gravitational Optics	412
19.3 More Complicated Systems	415
19.4 Applications	418
19.4.1 Microlensing	418
19.4.2 Multiple images	419
19.4.3 Arcs, arclets and cluster masses	420
19.4.4 Weak lensing by large-scale structure	421
19.4.5 The Hubble constant	422
19.5 Comments	423
20 The High-Redshift Universe	425
20.1 Introduction	425
20.2 Quasars	426
20.3 The Intergalactic Medium (IGM)	428
20.3.1 Quasar spectra	428
20.3.2 The Gunn–Peterson test	428
20.3.3 Absorption line systems	430
20.3.4 X-ray gas in clusters	432
20.3.5 Spectral distortions of the CMB	432
20.3.6 The X-ray background	433
20.4 The Infrared Background and Dust	434
20.5 Number-counts Revisited	437
20.6 Star and Galaxy Formation	438
20.7 Concluding Remarks	444
21 A Forward Look	447
21.1 Introduction	447
21.2 General Observations	448
21.3 X-rays and the Hot Universe	449
21.4 The Apotheosis of Astrometry: GAIA	450
21.5 The Next Generation Space Telescope: NGST	452
21.6 Extremely Large Telescopes	453
21.7 Far-IR and Submillimetre Views of the Early Universe	454
21.8 The Cosmic Microwave Background	456
21.9 The Square Kilometre Array	456
21.10 Gravitational Waves	458
21.11 Sociology, Politics and Economics	460
21.12 Conclusions	461
Appendix A. Physical Constants	463
Appendix B. Useful Astronomical Quantities	465
Appendix C. Particle Properties	467
References	469
Index	485