

Contents

<i>Preface</i>	<i>page</i> xi
<i>List of contributors</i>	xiv
1 Introduction	1
2 A guide to modern cosmology	9
2.1 The expanding universe	10
2.2 The thermal cosmic microwave background radiation	16
2.3 What is the universe made of?	18
3 Origins of the cosmology of the 1960s	23
3.1 Nucleosynthesis in a hot big bang	23
3.2 Nucleosynthesis in alternative cosmologies	34
3.3 Thermal radiation from a bouncing universe	40
3.4 Interstellar molecules and the sea of microwave radiation	42
3.5 Direct detection of the microwave radiation	44
3.6 Cosmology in the early 1960s	51
3.6.1 The steady state cosmology and the cosmological tests	53
3.6.2 Light elements from the big bang	58
3.6.3 Radiation from the big bang	60
3.6.4 Galaxy formation	66
3.6.5 The situation in the early 1960s	67
4 Recollections of the 1960s	69
4.1 Precursor evidence from communications experiments	70
4.1.1 <i>David C. Hogg</i> : Early low-noise and related studies at Bell Laboratories, Holmdel, NJ	70
4.2 Precursor evidence from interstellar molecules	74
4.2.1 <i>Neville J. Woolf</i> : Conversations with Dicke	74
4.2.2 <i>George B. Field</i> : Cyanogen and the CMBR	75

viii	<i>Contents</i>	
	4.2.3 <i>Patrick Thaddeus</i> : Measuring the cosmic microwave background with interstellar molecules	78
4.3	Precursor evidence from element abundances	86
	4.3.1 <i>Donald E. Osterbrock</i> : The helium content of the universe	86
4.4	The path to the hot big bang in the Soviet Union	92
	4.4.1 <i>Yuri Nikolaevich Smirnov</i> : Unforgettable Yakov Zel'dovich	92
	4.4.2 <i>Igor Dmitriyevich Novikov</i> : Cosmology in the Soviet Union in the 1960s	99
	4.4.3 <i>Andrei Georgievich Doroshkevich</i> : Cosmology in the 1960s	107
	4.4.4 <i>Rashid Sunyaev</i> : When we were young ...	108
	4.4.5 <i>Malcolm S. Longair</i> : Moscow 1968–1969	132
4.5	Detection at Bell Laboratories	144
	4.5.1 <i>Arno Penzias</i> : Encountering cosmology	144
	4.5.2 <i>Robert W. Wilson</i> : Two astronomical discoveries	157
4.6	The Bell Laboratories–Princeton connection	176
	4.6.1 <i>Bernard F. Burke</i> : Radio astronomy from first contacts to the CMBR	176
	4.6.2 <i>Kenneth C. Turner</i> : Spreading the word – or how the news went from Princeton to Holmdel	184
4.7	Developments at Princeton	185
	4.7.1 <i>P. James E. Peebles</i> : How I learned physical cosmology	185
	4.7.2 <i>David T. Wilkinson</i> : Measuring the cosmic microwave background radiation	200
	4.7.3 <i>Peter G. Roll</i> : Recollections of the second measurement of the CMBR at Princeton University in 1965	213
	4.7.4 <i>R. Bruce Partridge</i> : Early days of the primeval fireball	221
4.8	Developments at Cambridge	238
	4.8.1 <i>Malcolm S. Longair</i> : Cambridge cosmology in the 1960s	238
	4.8.2 <i>John Faulkner</i> : The day Fred Hoyle thought he had disproved the big bang theory	244
	4.8.3 <i>Robert V. Wagoner</i> : An initial impact of the CMBR on nucleosynthesis in big and little bangs	258

	<i>Contents</i>	ix
4.8.4	<i>Martin Rees</i> : Cosmology and relativistic astrophysics in Cambridge	261
4.9	Critical reactions to the hot big bang interpretation	267
4.9.1	<i>Geoffrey R. Burbidge</i> and <i>Jayant V. Narlikar</i> : Some comments on the early history of the CMBR	267
4.9.2	<i>David Layzer</i> : My reaction to the discovery of the CMBR	275
4.9.3	<i>Michele Kaufman</i> : Not the correct explanation for the CMBR	279
4.10	Measuring the CMBR energy spectrum	280
4.10.1	<i>Jasper V. Wall</i> : The CMB – how to observe and not see	280
4.10.2	<i>John R. Shakeshaft</i> : Early CMBR observations at the Mullard Radio Astronomy Observatory	288
4.10.3	<i>William “Jack” Welch</i> : Experiments with the CMBR	293
4.10.4	<i>Kazimir S. Stankevich</i> : Investigation of the background radiation in the early years of its discovery	296
4.10.5	<i>Paul Boynton</i> : Testing the fireball hypothesis	302
4.10.6	<i>Robert A. Stokes</i> : Early spectral measurements of the cosmic microwave background radiation	323
4.10.7	<i>Martin Harwit</i> : An attempt at detecting the cosmic background radiation in the early 1960s	329
4.10.8	<i>Judith L. Pipher</i> : Being a young graduate student in interesting times – Ignoring the forest for the trees	339
4.10.9	<i>Kandiah Shivanandan</i> : The big bang, brighter than a thousand suns	340
4.10.10	<i>Rainer Weiss</i> : CMBR research at MIT shortly after the discovery – is there a blackbody peak?	342
4.11	Structure in the distributions of matter and radiation	361
4.11.1	<i>Yu Jer-tsang</i> : Clusters and superclusters of galaxies	361
4.11.2	<i>Rainer K. Sachs</i> : The synergy of mathematics and physics	364
4.11.3	<i>Arthur M. Wolfe</i> : CMBR reminiscences	368
4.11.4	<i>Joe Silk</i> : A journey through time	371
4.11.5	<i>George F. R. Ellis</i> : The cosmic background radiation and the initial singularity	379

x	<i>Contents</i>	
4.12	Measuring the CMBR anisotropy	385
4.12.1	<i>Ronald N. Bracewell</i> and <i>Edward K. Conklin</i> : Early cosmic background studies at Stanford Radio Astronomy Institute	385
4.12.2	<i>Stephen Boughn</i> : The early days of the CMBR – An undergraduate’s perspective	393
4.12.3	<i>Karl C. Davis</i> : Going the “easy” direction – and finding a lot of the wrong thing	397
4.12.4	<i>Paul S. Henry</i> : Driven to drink – pursuit of the cosmic microwave background radiation	401
5	Cosmology and the CMBR since the 1960s	408
5.1	The CMBR energy spectrum	412
5.2	The aether drift	424
5.3	The CMBR intrinsic anisotropy spectrum	434
5.3.1	Theoretical concepts	434
5.3.2	Advances in the anisotropy measurements and analysis	447
5.4	The cosmological tests	465
5.5	Lessons	475
	<i>Appendix</i>	478
	<i>Glossary</i>	510
	<i>References</i>	531
	<i>Index</i>	561