

Contents

5 Special types of stars

5.1	5.5 see Subvolume b, p. 197ff.	
5.6	Compact Objects	
5.6.1	Neutron stars (M. GREWING)	1
5.6.1.1	General properties	1
5.6.1.2	Results from model calculations	2
5.6.1.2.1	Masses, radii and moments of inertia	2
5.6.1.2.2	Maximum-mass considerations	6
5.6.1.2.3	Magnetic fields	6
5.6.1.2.4	Cooling calculations for neutron stars	7
5.6.1.3	Observational results	7
5.6.1.3.1	Masses, radii and moments of inertia	7
5.6.1.3.2	Magnetic fields	8
5.6.1.3.3	Surface temperatures	8
5.6.1.4	References for 5.6.1	9
5.6.2	Radiopulsars (M. GREWING)	10
5.6.2.1	General properties	10
5.6.2.2	Surveys	10
5.6.2.3	Radiopulsar positions, periods, period changes, and dispersion measures	11
5.6.2.4	Distance estimates	18
5.6.2.5	Proper motions and space velocities	18
5.6.2.6	Statistical properties	19
5.6.2.6.1	Galactic distribution	19
5.6.2.6.2	Period distribution	20
5.6.2.6.3	Characteristic pulsar ages	20
5.6.2.6.4	Characteristic surface magnetic fields	21
5.6.2.7	Radiopulsars in binary systems	22
5.6.2.8	Theoretical models of the magnetosphere of radiopulsars	22
5.6.2.9	References for 5.6.2	22
5.6.3	Pulsating X-ray sources (J. TRÜMPER/H. H. FINK)	24
5.6.3.1	General properties	24
5.6.3.2	Determination of binary-system parameters	26
5.6.3.3	Neutron star properties as derived from observations of pulsating X-ray sources	28
5.6.3.4	References for 5.6.3	28
5.6.4	X-ray bursters (J. TRÜMPER/H. H. FINK)	30
References for 5.6.4		31
5.6.5	Black holes (J. TRÜMPER/H. H. FINK)	32
References for 5.6.5		33
5.7	X-ray and γ-ray sources (H. H. FINK/J. TRÜMPER)	33
5.7.1	X-ray sources	33
5.7.1.1	Overview	33
5.7.1.2	Sky surveys	36
5.7.1.3	X-ray emission processes	36
5.7.1.3.1	Bremsstrahlung from a hot plasma	36
5.7.1.3.2	Recombination radiation from a hot plasma	37
5.7.1.3.3	Line emission from a hot plasma	37
5.7.1.3.4	Synchrotron radiation	39
5.7.1.3.5	Inverse Compton effect	39

5.7.2 γ -ray sources	40
5.7.2.1 Overview	40
5.7.2.2 γ -radiation processes	42
5.7.3 References for 5.7	43

6 Double stars and star clusters

see Subvolume b, p. 381ff.

7 Interstellar matter

7.1 Phenomena of the generally distributed medium (H. SCHEFFLER)	45
7.1.1 General references	45
7.1.2 Interstellar extinction	45
7.1.2.1 Mean values and fluctuations	45
7.1.2.2 Interstellar reddening law	46
7.1.2.3 Ratio of total to selective extinction	47
7.1.2.4 Visual extinction or colour excess as a function of position (l, b) and distance r	47
7.1.2.5 References for 7.1.2	48
7.1.3 Interstellar polarization of starlight	49
7.1.3.1 Symbols and definitions	49
7.1.3.2 Degree and angle of linear polarization	49
7.1.3.3 Wavelength-dependence of linear polarization	50
7.1.3.4 Interdependence of linear polarization and extinction	51
7.1.3.5 Circular polarization	51
7.1.3.6 References for 7.1.3	51
7.1.4 Scattering of starlight by interstellar dust	52
7.1.4.1 Reflection nebulae	52
7.1.4.2 Diffuse galactic light	54
7.1.4.3 References for 7.1.4	54
7.1.5 Interstellar absorption lines and bands in stellar spectra	55
7.1.5.1 Lines of the spectral region 3000–8000 Å (groundbased observations)	55
7.1.5.2 Lines of the UV region $\lambda < 3000$ Å	57
7.1.5.3 Diffuse interstellar absorption bands	60
7.1.5.4 References for 7.1.5	60
7.1.6 Radio line emission and absorption	61
7.1.6.1 21-cm line of neutral hydrogen	61
7.1.6.2 Diffuse (“weak”) recombination line emission	63
7.1.6.3 References for 7.1.6	64
7.1.7 Continuous radio emission of interstellar origin: nonthermal background	64
References for 7.1.7	66
7.1.8 UV and visual interstellar radiation field	66
References for 7.1.8	66
7.2 Cool interstellar clouds (H. SCHEFFLER)	67
7.2.1 General references	67
7.2.2 Dark nebulae and globules	67
7.2.3 Statistical description of interstellar cloud structure	69
7.2.4 Molecular clouds	72
7.2.5 References for 7.2	86
7.3 H II regions (H. SCHEFFLER)	88
7.3.1 General references	88
7.3.2 Catalogues, surveys, statistical data	88
7.3.3 Classification	91
7.3.4 The individual H II regions	91
7.3.4.1 Properties of selected objects	91
7.3.4.2 Infrared brightness distribution	96

7.3.4.3 Spectrum of H II regions	96
7.3.4.4 Molecular masers associated with H II regions	101
7.3.5 References for 7.3	102
7.4 Physics of interstellar dust (H. SCHEFFLER)	106
7.4.1 Optical properties of the grains	106
7.4.1.1 Definitions	106
7.4.1.2 Efficiency factors	106
7.4.1.3 Albedo and asymmetry factor derived from observations	106
7.4.1.4 Grain models	107
7.4.1.5 Extinction coefficient per unit mass and total amount of dust; dust-to-gas ratio	109
7.4.1.6 References for 7.4.1	110
7.4.2 Grain temperatures	111
7.4.2.1 Introduction	111
7.4.2.2 H I regions and cool dense clouds	111
7.4.2.3 H II regions	114
7.4.2.4 References for 7.4.2	114
7.5 Physics of the interstellar gas (J. SCHMID-BURGK)	115
7.5.1 List of symbols and definitions	115
7.5.2 Components of the interstellar gas	115
7.5.2.1 Atoms and atomic ions	115
7.5.2.2 Molecules	115
7.5.2.3 Chemical abundances in the interstellar medium	117
7.5.3 Particle processes	117
7.5.3.1 Interaction with photon fields: radiation	117
7.5.3.2 Photoionization	118
7.5.3.2.1 Photoionization of atoms	118
7.5.3.2.2 Photoionization and photodissociation of molecules	118
7.5.3.3 Interaction with cosmic rays and X-ray photoelectrons	118
7.5.3.4 Recombination of atomic ions	118
7.5.3.4.1 Radiative recombination	118
7.5.3.4.2 Dielectronic recombination	120
7.5.3.5 Radiative and dissociative recombination of molecules	120
7.5.3.6 Charge exchange	120
7.5.3.6.1 Charge exchange: atomic ions	122
7.5.3.6.2 Charge exchange: molecules	122
7.5.3.7 Collisional excitation and de-excitation	122
7.5.3.8 Chemical reactions in interstellar clouds	123
7.5.4 Phases, bulk properties and processes of the interstellar gas	124
7.5.5 References for 7.5	126
7.5.5.1 General references	126
7.5.5.2 Special references	127
7.6 Cosmic rays (M. GREWING)	134
7.6.1 Solar cosmic rays	134
7.6.2 Galactic cosmic rays (GCR)	134
7.6.2.1 The total flux of GCR	134
7.6.2.2 Galactic cosmic-ray nuclei	135
7.6.2.2.1 Observed energy spectra of individual nuclei	135
7.6.2.2.2 The isotopic composition of GCR nuclei	136
7.6.2.2.3 GCR with energies above 10^{13} eV	137
7.6.2.2.4 Source composition of GCR nuclei	137
7.6.2.3 The lepton component of GCR	140
7.6.2.4 The origin of GCR	141
7.6.3 The anomalous component	141
7.6.4 High-energy particles in extragalactic systems	141
7.6.5 References for 7.6	142

7.7 Interstellar magnetic field (J. SCHMID-BURGK)	143
7.7.1 Symbols and units	143
7.7.2 Methods of determination	143
7.7.3 Observational results	143
7.7.4 Theoretical aspects	145
7.7.5 References for 7.7	145
 8 Our Galaxy	
8.1 Positions, motions, parallaxes of stars (W. GLIESE)	147
8.1.1 Star positions	147
8.1.1.1 Introduction	147
8.1.1.2 Constellations	147
8.1.1.3 Star lists and nomenclature of stars	147
8.1.1.4 Sky charts and atlases	149
8.1.1.5 Catalogues of star positions	150
8.1.1.6 Precession tables	153
8.1.1.7 References for 8.1.1	154
8.1.2 Proper motions	155
8.1.2.1 Definition	155
8.1.2.2 Components	155
8.1.2.3 Determination of proper motions	156
8.1.2.4 Numerical values and error estimates	156
8.1.2.5 Catalogues containing proper motions	157
8.1.2.6 References for 8.1.2	158
8.1.3 Radial velocities	159
8.1.3.1 Definitions	159
8.1.3.2 Methods of observation	159
8.1.3.3 Accuracy	160
8.1.3.4 Standard-velocity stars	160
8.1.3.5 Standard wavelengths for v_r determinations	161
8.1.3.6 Catalogues of stellar radial velocities	162
8.1.3.7 Some statistical results	162
8.1.3.8 References for 8.1.3	163
8.1.4 Parallaxes	163
8.1.4.1 Introduction	163
8.1.4.2 Determination of stellar parallaxes	164
8.1.4.2.1 Trigonometric parallaxes	164
8.1.4.2.2 Dynamical parallaxes	164
8.1.4.2.3 Cluster parallaxes	165
8.1.4.2.4 Statistical parallaxes	165
8.1.4.2.5 Spectroscopic and photometric parallaxes	165
8.1.4.3 Parallax catalogues and lists	166
8.1.4.4 References for 8.1.4	167
8.2 The nearest stars (W. GLIESE)	168
8.2.1 Introduction and data	168
8.2.2 Luminosity function in the solar neighbourhood	168
8.2.3 Star number density and density of matter in the solar neighbourhood	169
8.2.4 Colour-luminosity diagram of the nearest stars	170
8.2.5 Stars within 5 pc	171
8.2.6 References for 8.2	174
8.3 Structure of the Galaxy (H. SCHEFFLER)	175
8.3.1 Apparent distribution of galactic objects on the celestial sphere	175
8.3.1.1 Galactic coordinates	175
8.3.1.2 Distribution of surface brightness	175

8.3.1.3 Apparent distribution of the different types of galactic objects	178
8.3.1.4 References for 8.3.1	180
8.3.2 The local star field	180
8.3.2.1 Luminosity function	180
8.3.2.2 Star densities in the solar neighbourhood	182
8.3.2.3 Distribution of common stars near the galactic plane	182
8.3.2.4 Distribution of common stars perpendicular to the galactic plane	188
8.3.2.5 References for 8.3.2	188
8.3.3 Large-scale distribution of the stars	189
8.3.3.1 Subsystems of the Galaxy, stellar populations	189
8.3.3.2 Distribution of stars in the galactic disk	190
8.3.3.3 Distribution of stars in the galactic halo	194
8.3.3.4 References for 8.3.3	195
8.3.4 Large-scale distribution of interstellar matter	196
8.3.4.1 General remarks	196
8.3.4.2 Interstellar dust	197
8.3.4.3 Interstellar gas in the galactic disk	197
8.3.4.4 References for 8.3.4	200
8.3.5 The galactic center	201
8.3.5.1 Position and distance of the nucleus	201
8.3.5.2 Gas distribution in the central region	201
8.3.5.3 Central stellar bulge and nucleus	204
8.3.5.4 References for 8.3.5	205
8.3.6 Properties of the Galaxy as a whole	207
References for 8.3.6	207
8.4 Kinematics and dynamics (R. WIELEN)	208
8.4.0 Notation	208
8.4.1 Kinematics	209
8.4.1.1 Base concepts of galactic kinematics	209
8.4.1.2 Velocities	209
8.4.1.2.1 Space velocities	209
8.4.1.2.2 Solar motions	210
8.4.1.2.3 Local standard of rest	212
8.4.1.2.4 Velocity dispersions	213
8.4.1.2.5 Representative nearby stars	213
8.4.1.2.6 Moving groups	215
8.4.1.3 Galactic rotation	216
8.4.1.3.1 Constants of galactic rotation	216
8.4.1.3.2 Galactic rotation curve	217
8.4.1.3.3 Deviations from circular motion	218
8.4.2 Dynamics	219
8.4.2.1 Basic concepts of galactic dynamics	219
8.4.2.2 Mass models and gravitational forces	219
8.4.2.2.1 Mass models	219
8.4.2.2.2 Galactic gravitational force K_R	220
8.4.2.2.3 Galactic gravitational force K_z	222
8.4.2.2.4 Local mass density	223
8.4.2.2.5 Galactic center	224
8.4.2.3 Stellar orbits	224
8.4.2.3.1 Unrestricted orbits	224
8.4.2.3.2 Epicyclic orbits	225
8.4.2.3.3 Relaxation and diffusion	227
8.4.2.3.4 Density-wave theory of the spiral structure	228
8.4.3 References for 8.4	229

9 Galaxies and universe

9.1 General information and integral properties of galaxies	232
9.1.1 Catalogues, atlases, positions (B. F. MADORE)	232
9.1.1.1 General catalogues of non-stellar objects	232
9.1.1.2 Galaxy catalogues	232
9.1.1.3 Optical identification	233
9.1.1.3.1 Pictures and photographic atlases	233
9.1.1.3.2 Positional identification	233
9.1.1.4 Named galaxies	234
9.1.1.5 References for 9.1.1	235
9.1.2 Apparent integral properties of galaxies (B. F. MADORE)	237
9.1.2.1 Magnitudes	237
9.1.2.2 Dimensions of galaxies	238
9.1.2.3 Colours	238
9.1.2.4 Redshifts	238
9.1.2.5 References for 9.1.2	239
9.1.3 Qualitative classification of galaxies (B. F. MADORE)	240
9.1.3.1 The classical Hubble-Sandage classification	240
9.1.3.2 Alternate systems and modifications	242
9.1.3.2.1 The Yerkes classification	242
9.1.3.2.2 Spiral varieties	242
9.1.3.2.3 Dwarf galaxies	242
9.1.3.2.4 Luminosity classification	243
9.1.3.2.5 Byurakan nuclear types, bright nuclei galaxies, and Seyfert galaxies	243
9.1.3.2.6 Compact galaxies	244
9.1.3.2.7 The numerical code t of the morphological types	244
9.1.3.3 Spectroscopic criteria	244
9.1.3.4 Peculiar and interacting galaxies	245
9.1.3.5 References for 9.1.3	246
9.1.4 Intrinsic integral properties of galaxies (H. H. VOIGT)	247
9.1.4.1 Linear dimensions	247
9.1.4.2 Luminosity, absolute magnitude	247
9.1.4.3 Surface brightness	249
9.1.4.4 Masses	250
9.1.4.5 Mass-to-luminosity ratio	252
9.1.4.6 Colours	252
9.1.4.7 References for 9.1.4	253
9.2 Internal structure and dynamics of galaxies (H. H. VOIGT, W. K. HUCHTMEIER)	254
9.2.1 Stellar and gaseous content of normal galaxies	254
9.2.2 The ellipticity of galaxies	256
9.2.3 Luminosity distribution	257
9.2.4 Spiral structure	260
9.2.5 Radio radiation of normal galaxies	261
9.2.5.1 Radio-continuum structure	261
9.2.5.2 Neutral hydrogen (HI) in galaxies	261
9.2.6 Rotation, kinematics, dynamics	263
9.2.7 References for 9.2	268
9.3 Galaxies with special peculiarities; pairs, groups and clusters of galaxies (P. BIERMANN)	271
9.3.1 Galaxies with special peculiarities	271
9.3.2 Pairs of galaxies	272
9.3.2.1 Observations	272
9.3.2.2 Theoretical concepts	273
9.3.3 Groups of galaxies	274
9.3.3.1 Definition	274
9.3.3.2 Structure	275
9.3.3.3 The Local Group	275

9.3.4 Clusters of galaxies	277
9.3.5 Superclusters	278
9.3.6 References for 9.3	279
9.4 Evolution of galaxies	288
9.4.1 Formation of galaxies (H. H. VOIGT)	288
9.4.2 Evolution of galaxies (H. H. VOIGT)	289
9.4.3 References for 9.4.1 and 9.4.2 (H. H. VOIGT)	290
9.4.4 Star-formation activity in normal galaxies (P. BIERMANN)	292
9.4.4.1 Tracers of star formation	292
9.4.4.2 Star formation in the nuclear regions of observed galaxies	293
9.4.4.3 Theoretical interpretation	295
9.4.4.4 References for 9.4.4	296
9.5 Quasars and active galactic nuclei (H. NETZER)	300
9.5.0 Abbreviations	300
9.5.1 Definition and classification	300
9.5.1.1 Active galactic nuclei	300
9.5.1.2 Quasars	300
9.5.1.3 Seyfert galaxies	302
9.5.1.4 Radio galaxies with active nuclei	303
9.5.1.5 Liners	304
9.5.1.6 BL Lac objects	304
9.5.2 Continuum radiation	305
9.5.2.1 Optical and ultraviolet radiation	305
9.5.2.2 Infrared radiation	305
9.5.2.3 Radio emission	306
9.5.2.4 X and γ radiation	306
9.5.2.5 Variability	306
9.5.2.6 Polarization	307
9.5.3 Spectral lines	307
9.5.3.1 Emission lines	307
9.5.3.2 Photoionization models	310
9.5.3.3 Absorption lines	311
9.5.4 Theoretical models for AGNs	311
9.5.5 References for 9.5	312
9.6 Extragalactic radio sources (K. J. FRICKE, A. WITZEL)	315
9.6.1 Observational methods	315
9.6.2 Surveys	315
9.6.2.1 Radioastronomical sky surveys	316
9.6.2.2 Surveys for specific classes and properties of sources	318
9.6.2.3 Radio spectra	321
9.6.3 Basic relations	323
9.6.3.0 List of symbols	323
9.6.3.1 Synchrotron radiation	325
9.6.3.1.1 Emission by a single electron	325
9.6.3.1.2 Radiation from an ensemble of electrons	326
9.6.3.2 Absorption mechanisms and plasma effects	326
9.6.3.3 Energy losses and evolution of source spectra	328
9.6.3.3.1 Energy loss rates and time scales	328
9.6.3.3.2 Equilibrium spectra	330
9.6.3.3.3 Synchrotron and Compton losses	330
9.6.3.3.4 Inverse Compton limit	331
9.6.3.3.5 Inverse Compton effect and X-ray observations	331
9.6.3.3.6 Adiabatic expansion	332
9.6.3.4 Energy considerations	332

9.6.4 Extended sources	334
9.6.4.1 Structure of extended sources	334
9.6.4.2 Structure of lobes	336
9.6.4.3 “Jets”	336
9.6.4.4 Properties of extended radio sources	336
9.6.4.5 Alignments on large scale	337
9.6.5 Compact sources	339
9.6.5.1 Structure of compact sources	339
9.6.5.2 Variability of compact sources	339
9.6.5.3 Correlations of radiospectra with other properties	341
9.6.6 Interpretation of extended and compact radio sources (K. J. FRICKE)	396
9.6.6.1 Extended sources	396
9.6.6.1.1 Ejection of massive objects	396
9.6.6.1.2 Ejection of plasmoids	396
9.6.6.1.3 Continuous flow or beam models	397
9.6.6.2 Large-scale jets and beams	397
9.6.6.3 Compact radio nuclei	399
9.6.6.3.1 Optical objects	399
9.6.6.3.2 The canonical model, sizes and energetics	399
9.6.6.3.3 Coherent models	400
9.6.6.3.4 Interpretation of radio spectra of compact sources	400
9.6.6.3.5 Correlations between radio, optical and X-ray fluxes	401
9.6.6.3.6 Models for optical, UV, and X-ray emission from compact sources	401
9.6.6.4 Compact radio jets	402
9.6.6.4.1 Angular structure	402
9.6.6.4.2 Superluminal motions	402
9.6.6.4.3 The Scheuer-Readhead hypothesis	403
9.6.6.4.4 Relativistic bulk motions	404
9.6.6.4.5 In-situ acceleration	404
9.6.6.4.6 Origin of compact jets	405
9.6.6.5 The central engine	405
9.6.6.5.1 Gravitation as ultimate source of energy	405
9.6.6.5.2 Dense star clusters	405
9.6.6.5.3 Supermassive stars, rotators, spinars or magnetoids	406
9.6.6.5.4 Massive black holes	406
9.6.6.6 Large-scale distribution of radio sources and cosmological evolution	407
9.6.6.7 References for 9.6.6	407
9.6.7 References for 9.6.1–9.6.5	341
9.7 Cosmology (G. A. TAMMANN)	346
9.7.1 List of symbols	346
9.7.2 Friedmann cosmologies	346
9.7.2.1 Basic assumptions	346
9.7.2.2 Basic equations	347
9.7.2.2.1 Line element	347
9.7.2.2.2 Einstein field equations	347
9.7.2.2.3 The general Friedmann equation	347
9.7.2.2.4 Distances	348
9.7.2.2.5 The magnitude–redshift relation	348
9.7.2.2.6 The count–magnitude relation	349
9.7.2.2.7 Angular diameter–redshift relation	350
9.7.3 Observations supporting basic assumptions	351
9.7.3.1 Support for general relativity (GR)	351
9.7.3.2 Limits of the annual variation of some physical constants	351
9.7.3.3 Evidence for cosmic evolution	351
9.7.3.4 Observational evidence for a Big Bang	352
9.7.3.5 Isotropy	353

9.7.4 Redshifts	354
9.7.4.1 Definition of Doppler shift	354
9.7.4.2 Corrections	354
9.7.4.3 Peculiar motions of galaxies	355
9.7.4.3.1 Random peculiar motions	355
9.7.4.3.2 Streaming motions	355
9.7.4.4 The nature of extragalactic redshifts	356
9.7.5 The determination of the Hubble constant H_0	356
9.7.6 The determination of the deceleration constant q_0	358
9.7.6.1 The classical tests for q_0	358
9.7.6.1.1 The magnitude-redshift relation	358
9.7.6.1.2 The count-magnitude relation	358
9.7.6.1.3 The angular diameter-redshift relation	358
9.7.6.1.4 Other methods	359
9.7.6.2 The determination of the mean matter density	359
9.7.6.2.1 Ω_0 from the mean luminosity density	359
9.7.6.2.2 Ω_0 from the Virgocentric flow model	360
9.7.6.2.3 Ω_0 from galaxy correlations	360
9.7.6.2.4 Ω_0 from the primordial nucleosynthesis	360
9.7.7 Constituents of the universe	361
9.7.8 The time scale of the universe	362
9.7.8.1 The Friedmann time	362
9.7.8.2 The look-back time	362
9.7.8.3 The age of the universe	363
9.7.8.4 The history of the Canonical Big Bang	363
9.7.9 Other cosmologies	365
9.7.9.1 Other pressure-free, uniform world models of general relativity	365
9.7.9.2 Models with variable mass and/or variable physical constants	365
9.7.9.2.1 Steady-state model	365
9.7.9.2.2 Dirac-Jordan cosmology	366
9.7.9.2.3 Scalar-tensor theory	366
9.7.9.2.4 Hoyle-Narlikar theory	366
9.7.9.3 Matter-antimatter cosmologies	366
9.7.9.4 Tired-light models	366
9.7.10 References for 9.7	366
9.7.10.1 General references	366
9.7.10.2 Special references	368
 3.3.3 Comets, Appendix (J. RAHE)	375
3.3.3.10 Comet Halley	375
3.3.3.10.1 Orbital calculations, historical apparitions	375
3.3.3.10.2 The 1910 apparition	377
3.3.3.10.3 The 1985/86 apparition	379
3.3.3.10.3.1 Ephemerides and orbital data	379
3.3.3.10.3.2 Ground-based data	382
3.3.3.10.3.3 Expected physical data; models	384
3.3.3.10.4 Comet Halley missions	385
3.3.3.10.5 Other future comets	387
3.3.3.10.6 References for 3.3.3.10	394
Comprehensive index (L. D. SCHMADEL, G. ZECH)	417

