

# Contents

*Preface* *page xv*

<b>1 The Hipparcos and Tycho Catalogues</b>	<b>1</b>
1.1 Overview	1
1.2 Observation principles	1
1.3 Hipparcos Input Catalogue	4
1.4 Hipparcos Catalogue and Annexes	5
1.4.1 Hipparcos astrometry	5
1.4.2 Hipparcos photometry	11
1.4.3 Hipparcos double and multiple systems	12
1.4.4 Intermediate astrometric and transit data	12
1.4.5 Transformation of astrometric data	14
1.5 Tycho Catalogue and Annexes	15
1.5.1 Tycho astrometry	16
1.5.2 Tycho photometry	17
1.5.3 Tycho double and multiple systems	18
1.6 Post-publication Hipparcos reductions	18
1.7 Post-publication Tycho reductions	19
1.8 Catalogue products	20
1.8.1 Organisation	20
1.8.2 Availability	20
1.9 Recommended catalogues	22
1.10 Catalogue investigations post-publication	22
1.10.1 Error assessment: Internal	22
1.10.2 Error assessment: External	24
1.11 Catalogue combinations to reveal long-period binaries	27
1.12 Reference frame studies: Optical, radio and infrared	30
1.13 Radial velocities	32
1.13.1 Data to complement the Hipparcos Catalogue	32
1.13.2 Astrometric radial velocities	35
1.14 Cross-identifications	38
1.15 Relativity and astrometry	38
1.16 Astrometry beyond Hipparcos	43
<b>2 Derived catalogues and applications</b>	<b>54</b>
2.1 Introduction	54
2.2 Reference system for meridian circles	56
2.3 Reference system for astrolabes	59
2.4 Reference system for the Astrographic Catalogue and Carte du Ciel	60
2.5 Reference system for Schmidt plates	62
2.5.1 Guide Star Catalogue	64
2.5.2 USNO A1, A2, B1	65

2.5.3	SuperCOSMOS Sky Survey	65
2.6	Other photographic surveys	69
2.6.1	Re-reduction of the AGK2	69
2.6.2	Re-reduction of the CPC2	69
2.6.3	Re-reduction of the NPM and SPM	69
2.6.4	Other photographic surveys	71
2.7	Reference system for CCD surveys	72
2.7.1	USNO catalogues: UCAC 1/2 and NOMAD	72
2.7.2	FASTT	74
2.7.3	Sloan Digital Sky Survey	74
2.7.4	Other CCD imaging systems	75
2.8	Infrared reference frame	75
2.9	Atmospheric attenuation and refraction	75
2.10	Proper motion surveys	76
2.10.1	High proper motion surveys	76
2.10.2	Other proper motions surveys	78
2.11	Parallaxes	79
2.11.1	Ground-based parallaxes	79
2.11.2	Common proper motion systems	80
2.12	Other applications	80
2.12.1	Celestial cartography	80
2.12.2	Handbooks and related compilations	82
2.12.3	Satellite and telescope operations	83
2.12.4	Education and outreach	83
<b>3</b>	<b>Double and multiple stars</b>	<b>91</b>
3.1	Introduction	91
3.2	Double and multiple stars in the Hipparcos Catalogue	91
3.2.1	Observational effects of multiplicity	93
3.2.2	Classification of solutions	94
3.2.3	Accuracy verification	96
3.3	Tycho Catalogue double stars	97
3.4	Subsequent investigations of double and multiple stars	99
3.4.1	Improved solutions	99
3.4.2	Single stars showing evidence for binarity: The $\Delta\mu$ binaries	101
3.4.3	Statistical properties	103
3.5	Orbital systems	111
3.5.1	General properties	111
3.5.2	Individual orbital systems	120
3.6	Eclipsing binaries	125
3.7	Contact binaries: W UMa, symbiotic, and RS CVn systems	130
3.8	Ground-based follow-up observations	133
3.8.1	Astrometry	133
3.8.2	Radial velocity and spectroscopy	134
3.8.3	Photometry	134
3.8.4	Speckle interferometry	134
3.8.5	Adaptive optics	138
3.8.6	Long-baseline interferometry	139
<b>4</b>	<b>Photometry and variability</b>	<b>153</b>
4.1	Hipparcos and Tycho photometric data	153
4.1.1	Magnitudes and photometric systems	153
4.1.2	Hipparcos and Tycho photometric systems	154
4.1.3	Main mission photometric reductions	154
4.1.4	Tycho photometric reductions	156

**Contents****ix**

4.1.5	Variability analysis	156
4.1.6	Data products	157
4.2	Photometric properties and validation	158
4.3	Photometric calibration in the optical	161
4.4	Photometric calibration in the infrared	165
4.5	Photometric calibration in the ultraviolet	165
4.6	Variability	167
4.6.1	Variability detection methods	167
4.6.2	Tycho variables	170
4.6.3	Contribution of amateur astronomers	171
4.7	Variability over the HR diagram	172
4.8	Main instability strip	173
4.8.1	Cepheid variables	173
4.8.2	W Virginis variables	174
4.8.3	RR Lyrae variables	174
4.9	Pulsators on or near the main sequence	174
4.9.1	$\delta$ Scuti variables	175
4.9.2	Rapidly-oscillating Ap (roAp) stars	181
4.9.3	$\gamma$ Doradus variables	184
4.9.4	$\beta$ Cephei variables	185
4.9.5	Supergiants: Pulsating O and $\alpha$ Cyg variables	186
4.9.6	Slowly-pulsating B stars	186
4.9.7	Maia variables	189
4.10	Red variables: Long-period, Mira, and semi-regular	189
4.11	Individual objects	197
<b>5</b>	<b>Luminosity calibration and distance scale</b>	<b>207</b>
5.1	Introduction	207
5.2	Statistical biases	208
5.2.1	Malmquist bias	209
5.2.2	Lutz–Kelker bias	209
5.2.3	Maximum likelihood techniques	211
5.2.4	Astrometry-based luminosity, or reduced parallax	211
5.2.5	Reduced proper motions	212
5.3	Secular and statistical parallaxes	212
5.4	Absolute magnitude versus spectral type	212
5.5	Luminosity indicators using spectral lines	219
5.5.1	Wilson–Bappu effect	220
5.5.2	Equivalent width of O I	222
5.5.3	Interstellar lines	222
5.6	Use of standard candles	223
5.7	Population I distance indicators	224
5.7.1	Classical Cepheids	224
5.7.2	Red clump giants	230
5.7.3	Mira and semi-regular variables	236
5.7.4	Other Population I distance indicators	239
5.8	Population II distance indicators	239
5.8.1	Subdwarf main-sequence fitting	239
5.8.2	RR Lyrae and horizontal branch stars	246
5.8.3	Other Population II distance indicators	251
5.9	The Magellanic Clouds	253
5.9.1	Distance to the Large Magellanic Cloud	253
5.9.2	Dynamics of the Magellanic Clouds	253
5.10	Other galaxies	255
5.11	Supernovae	258

<b>6 Open clusters, groups and associations</b>	<b>273</b>
6.1 Introduction	273
6.2 Detection methods	274
6.2.1 General considerations	274
6.2.2 Convergent-point method	275
6.2.3 Other search methods	276
6.3 The Hyades	279
6.3.1 Introduction	279
6.3.2 Convergent-point analyses	279
6.3.3 Hipparcos results	280
6.3.4 Chemical composition and theoretical models	280
6.3.5 Secular parallaxes	283
6.3.6 Further complications	285
6.3.7 <i>N</i> -body analyses	286
6.3.8 Summary of uncertainties	287
6.4 The Pleiades	287
6.4.1 Introduction	287
6.4.2 Hipparcos distance estimates	288
6.4.3 Main-sequence fitting post-Hipparcos	290
6.4.4 Other distance estimates	292
6.4.5 Summary of the Pleiades distance	295
6.5 Distances to other nearby clusters	296
6.6 Other astrophysical applications	297
6.7 Searches for new clusters and members	298
6.8 Specific clusters	300
6.9 Kinematic groups	302
6.9.1 Introduction	302
6.9.2 Detection of kinematic groups	304
6.9.3 Origin of kinematic groups	310
6.10 Associations	311
6.10.1 Introduction	311
6.10.2 Large-scale studies	312
6.10.3 Individual associations	318
6.10.4 Young nearby streams, associations or moving groups	319
6.10.5 The Gould Belt	324
<b>7 Stellar structure and evolution</b>	<b>339</b>
7.1 Introduction	339
7.2 Observational framework and the HR diagram	340
7.2.1 Bolometric magnitudes	341
7.2.2 Effective temperatures	341
7.2.3 Surface gravities	342
7.2.4 Abundances	343
7.3 Theoretical framework	343
7.3.1 Equation-of-state and opacities	343
7.3.2 Atmospheres	345
7.3.3 Transport processes	345
7.3.4 Evolutionary tracks and isochrones	346
7.4 Fundamental parameters from Hipparcos	349
7.4.1 Bolometric magnitudes	349
7.4.2 Effective temperatures	349
7.4.3 Surface gravities	353
7.4.4 Stellar radii	355

**Contents****xi**

<b>7.5</b>	Hipparcos results on stellar evolution	361
7.5.1	Nearby stars	361
7.5.2	Zero-age main sequence	365
7.5.3	Subdwarfs and other Population II stars	366
7.5.4	Subgiants	369
7.5.5	Giants	370
7.5.6	Horizontal branch	371
7.5.7	Asymptotic giant branch	373
7.5.8	Mass loss	373
7.5.9	Binary systems	375
7.5.10	Other results	377
<b>7.6</b>	Abundances	377
7.6.1	[Fe/H]	377
7.6.2	$\alpha$ -elements	378
7.6.3	Helium	379
7.6.4	Lithium	380
7.6.5	Metal-poor stars	383
7.6.6	Super metal-rich stars	385
7.6.7	Chemical enrichment of the Galaxy	386
<b>7.7</b>	Other stellar properties	389
7.7.1	Rotation	389
7.7.2	Magnetic field	392
7.7.3	Imaging of surface structure	395
<b>7.8</b>	Asteroseismology	395
<b>8</b>	<b>Specific stellar types and the ISM</b>	413
<b>8.1</b>	Pre-main-sequence stars	413
8.1.1	Introduction	413
8.1.2	T Tauri stars	413
8.1.3	Herbig Ae/Be stars	419
<b>8.2</b>	Main-sequence evolutionary phases	421
8.2.1	Be stars	421
8.2.2	Shell stars	426
8.2.3	Chemically peculiar (Ap/Bp/Am stars)	426
8.2.4	Flare stars	427
8.2.5	$\lambda$ Bootis stars	428
<b>8.3</b>	X-ray sources	430
<b>8.4</b>	Late stages of stellar evolution	438
8.4.1	Wolf-Rayet stars	438
8.4.2	Runaway stars	440
8.4.3	Carbon stars	449
8.4.4	Hydrogen-deficient carbon-rich stars	452
8.4.5	Technetium stars	452
8.4.6	Barium stars	453
8.4.7	Planetary nebulae	453
8.4.8	White dwarfs	455
8.4.9	Supernovae, pulsars, and neutron stars	464
<b>8.5</b>	Local interstellar medium	464
8.5.1	Local bubble	464
8.5.2	Extinction and reddening	469
8.5.3	Polarisation	474
8.5.4	Interstellar radiation field	475
<b>9</b>	<b>Structure of the Galaxy</b>	490
<b>9.1</b>	Introduction	490

9.1.1	Overall structure of the Galaxy	490
9.1.2	Hipparcos contributions	491
9.1.3	Concepts and definitions	491
9.2	The Sun within the Galaxy	495
9.2.1	Distance to the Galactic centre	495
9.2.2	Distance from the Galactic plane	496
9.2.3	Velocity dispersion and vertex deviation	497
9.2.4	Solar motion with respect to the local standard of rest	497
9.2.5	Rotation speed of the disk	499
9.2.6	Stellar kinematics in the Oort–Lindblad model	501
9.2.7	Stellar kinematics in the Ogorodnikov–Milne model	503
9.2.8	Stellar kinematics and vector harmonics	508
9.3	Census of nearby stars	509
9.4	Derived characteristics	510
9.4.1	Mass density in the solar neighbourhood	510
9.4.2	Escape velocity	514
9.4.3	Initial mass function	515
9.4.4	Star-formation rate	517
9.5	Properties of the disk	519
9.6	Properties of the bar	527
9.7	Properties of the spiral arms	530
9.8	Properties of the stellar warp	535
9.9	The stellar halo	538
9.9.1	Mass and extent	538
9.9.2	Rotation, shape and velocity dispersion	539
9.9.3	Formation	540
9.9.4	Halo substructure	542
9.10	Models of the various Galaxy components	544
9.11	Globular clusters	545
9.11.1	Introduction	545
9.11.2	Ages	547
9.11.3	Independent age estimates of the oldest halo objects	548
9.11.4	Consequences of globular cluster ages	548
9.11.5	Kinematics and dynamics	550
9.11.6	Cluster disruption	553
9.11.7	Tidal streams and the mass of the Galaxy	554
9.11.8	Individual globular clusters	555
<b>10</b>	<b>Solar System and exoplanets</b>	<b>566</b>
10.1	Hipparcos Solar System objects	566
10.2	Asteroids: Masses and orbits	568
10.2.1	Mass determination	568
10.2.2	Orbits and photometry	570
10.3	Planets, satellites, occultations and appulses	571
10.4	Dynamical reference system	575
10.4.1	Constraining precession	575
10.4.2	Earth rotation and polar motion	578
10.5	Passage of nearby stars	583
10.6	Earth's climate	586
10.6.1	Maunder minimum	586
10.6.2	Sun's orbit and the spiral arms	586
10.6.3	Sun's orbit and Galactic plane passages	589
10.7	Exoplanets, brown dwarfs and disks	590
10.7.1	Introduction	590
10.7.2	Astrometric detection	591

**Contents****xiii**

---

10.7.3 Photometric transits	598
10.7.4 Host star properties	601
10.7.5 Proto-planetary disks	604
10.7.6 Habitability and related issues	606
10.7.7 Solar twins and solar analogues	607
10.7.8 Search for extraterrestrial intelligence	609
<i>Appendix A Numerical quantities</i>	619
<i>Appendix B Acronyms</i>	623
<i>Appendix C Author gallery</i>	628
<i>Index of first authors</i>	639
<i>Subject index</i>	658