

Contents

Part I Foundations

1	Astrophysical Information	3
1.1	Carriers of Information	4
1.1.1	Electromagnetic Radiation	4
1.1.2	Matter: From Electrons and Nuclei to Meteorites	5
1.1.3	Neutrinos	6
1.1.4	Gravitational Waves	9
1.1.5	In Situ Observation	10
1.2	Data Acquisition	12
1.2.1	The Main Characteristics of Photons	12
1.2.2	Observing Systems	12
1.2.3	Reaching a Systematic Description of Observation	27
1.3	Global Organisation of Astronomy	28
1.3.1	People	29
1.3.2	Research Policies and Institutions	31
1.3.3	Publications	34
2	The Earth Atmosphere and Space	39
2.1	Physical and Chemical Structure of the Atmosphere	40
2.1.1	Vertical Structure	40
2.1.2	Constituents of the Atmosphere	41
2.2	Absorption of Radiation	45
2.3	Atmospheric Emission	50
2.3.1	Fluorescent Emission	50
2.3.2	Thermal Emission	55
2.3.3	Differential Measurement Techniques	56
2.4	Scattering of Radiation	58
2.5	Atmospheric Refraction and Dispersion	61

2.6	Turbulence Structure of the Earth Atmosphere	62
2.6.1	Turbulence in the Lower and Middle Atmosphere	63
2.6.2	Ionospheric Turbulence	70
2.7	The Atmosphere as Radiation Converter	70
2.7.1	Ground-Based Gamma-Ray Astronomy	70
2.7.2	Air Showers and Cosmic Rays	71
2.8	Terrestrial Observing Sites	71
2.8.1	Visible, Infrared, and Millimetre Observations	72
2.8.2	Centimetre and Metre Wave Radioastronomy	74
2.8.3	Very High Energy Gamma-Ray Astronomy	75
2.8.4	Very High Energy Cosmic Radiation	75
2.8.5	Man-Made Pollution and Interference	75
2.8.6	The Antarctic	76
2.9	Observation from Space	77
2.9.1	The Advantages of Observation from Space	79
2.9.2	Sources of Perturbation	79
2.9.3	Choice of Orbits	86
2.10	The Moon as an Astronomical Site	87
	Problems	89
3	Radiation and Photometry	93
3.1	Radiometry	94
3.2	Aspects of Radiation	99
3.2.1	Blackbody Radiation	99
3.2.2	Coherence	100
3.3	Magnitudes	104
3.4	Photometry Through the Atmosphere	109
3.5	Calibration and Intensity Standards	110
3.5.1	Radiofrequencies	110
3.5.2	Submillimetre, Infrared, and Visible	112
3.5.3	Ultraviolet and X Rays	117
3.5.4	Gamma-Ray Radiation	120
3.5.5	Some Examples of Spectrophotometry	120
3.6	Calibration of Angular Dimensions	123
	Problems	124
4	Space–Time Reference Frames	127
4.1	Spatial Reference Systems	129
4.1.1	Definitions of Spatial Frames	129
4.1.2	Astronomical Reference Frames	131
4.1.3	Change of Frame	138
4.2	Practical Realisation of Spatial Frames	144
4.2.1	Celestial Reference Systems	144
4.2.2	Fundamental Catalogues	145
4.2.3	The Extragalactic System	147

4.2.4	The Hipparcos Frame.....	151
4.2.5	The Near Future: The Gaia Mission	155
4.3	Temporal Reference Systems	157
4.3.1	Time Scales	157
4.3.2	Atomic Time	161
4.3.3	Coordinated Universal Time (CUT or UTC)	164
4.3.4	GPS Time	166
4.3.5	Dynamical Time Scales	167
4.3.6	Dates and Epochs. Dealing with Long Periods.....	169

Part II Data Collection

5	Telescopes and Images	175
5.1	Image and Object in Astronomy	176
5.1.1	The Telescope and Geometrical Optics.....	177
5.1.2	Gravitational Optics	183
5.2	Telescopes	184
5.2.1	Radiotelescopes.....	185
5.2.2	Ground-Based Optical Telescopes: Visible and Near Infrared	189
5.2.3	Space Telescopes, from Ultraviolet to Submillimetre	194
5.2.4	X-Ray Telescopes	199
5.2.5	Gamma-Ray Telescopes.....	201
6	Diffraction and Image Formation	209
6.1	Diffraction by an Arbitrary Aperture	210
6.1.1	The Zernike Theorem	211
6.1.2	Coherence Etendue	214
6.1.3	Diffraction at Infinity	216
6.1.4	Spatial Filtering by a Pupil.....	221
6.2	The Earth Atmosphere and Coherence Losses.....	228
6.2.1	Perturbations of the Wavefront.....	229
6.2.2	The Perturbed Image	232
6.2.3	Effect of the Atmosphere on Interferometry	238
6.3	Adaptive Optics	240
6.3.1	Wavefront Measurement	241
6.3.2	Phase Correction Devices	245
6.3.3	The Final Image	246
6.3.4	Sensitivity and Reference Sources	248
6.3.5	New Concepts	252
6.4	Astronomical Interferometry	256
6.4.1	Obtaining an Interferometer Signal.....	257
6.4.2	Light Transfer	262
6.4.3	Temporal Coherence.....	264
6.4.4	Loss of Spatial Coherence.....	264

6.4.5	Calibrating the Instrumental MTF	268
6.4.6	Phase Closure	271
6.5	Astronomical Interferometers.....	274
6.5.1	Radiotelescope Arrays.....	274
6.5.2	Ground-Based Optical Arrays	286
6.5.3	Space-Based Optical Interferometry.....	294
6.6	High Dynamic Range Imaging (HDRI)	298
6.6.1	Coronagraphy and Apodisation	299
6.6.2	Nulling Interferometry	311
	Problems	316
7	Detectors	323
7.1	General Properties.....	324
7.1.1	Amplitude Detectors. Quadratic Detectors	325
7.1.2	Spatial Structure of Detectors	326
7.1.3	Temporal Response	329
7.1.4	Noise	330
7.1.5	Characterisation of Detectors	331
7.2	Fundamental Fluctuations	332
7.2.1	Quantum Noise	336
7.2.2	Thermal Noise	340
7.3	Physical Principles of the Detection of Electromagnetic Radiation.....	343
7.3.1	Detection of Quanta	344
7.3.2	Detection of the Electromagnetic Field.....	355
7.4	Astronomical Detectors from X Ray to Submillimetre.....	355
7.4.1	Noise Performance	356
7.4.2	Photographic Plates.....	357
7.4.3	Photomultipliers and Classical Cameras: X Ray, UV, and Visible	359
7.4.4	X-Ray Detection (0.1–10 keV)	364
7.4.5	Solid-State Imagers	365
7.4.6	Charge Coupled Device (CCD)	366
7.4.7	The Hybrid CMOS Detector	373
7.4.8	Observing Conditions in the Infrared	380
7.4.9	Development of Solid-State Imaging Arrays.....	381
7.4.10	Bolometers	383
7.5	Astronomical Detectors: Radiofrequencies	387
7.5.1	General Features	388
7.5.2	Heterodyne Detection	393
7.5.3	The Diversity of Radioastronomy	403
7.6	Observing Systems for Gamma-Ray Astronomy	404
7.6.1	Spatial Resolution of Gamma-Ray Sources	407
7.6.2	Spectral Analysis of Gamma-Ray Sources	412

7.7	Neutrino Observing Systems	420
7.7.1	Radiochemical Detection of Solar Neutrinos	421
7.7.2	Neutrino Detection by Cherenkov Radiation	424
7.7.3	High Energy Neutrino Astronomy	425
7.8	Gravitational Wave Detection	431
	Problems	437
8	Spectral Analysis	441
8.1	Astrophysical Spectra	442
8.1.1	Formation of Spectra	442
8.1.2	Information in Spectrometry	448
8.2	Spectrometers and Their Properties	455
8.2.1	Quantities Characterising a Spectrometer	456
8.2.2	Spectral Discrimination	459
8.2.3	The Modes of a Spectrometer	460
8.3	Interferometric Spectrometers	462
8.3.1	General Criteria	462
8.3.2	Interference Filters	463
8.3.3	Grating Spectrometers	463
8.3.4	Fourier Transform Spectrometer	481
8.3.5	The Fabry–Perot Spectrometer	489
8.3.6	The Bragg Crystal Spectrometer (X-Ray Region)	491
8.4	Radiofrequency Spectrometry	494
8.4.1	Spectral Discrimination Methods	495
8.4.2	Submillimetre Spectroscopy	501
8.5	Resonance Spectrometers	503
	Problems	504

Part III Data Analysis

9	The Signal in Astronomy	509
9.1	The Signal and Its Fluctuations	510
9.1.1	Observing System and Signal	510
9.1.2	Signal and Fluctuations. Noise	511
9.1.3	Elementary Signal Processing	519
9.1.4	A Specific Example of Data Processing	528
9.2	Complete Model of an Observing System	529
9.3	Overall Performance of an Observing System	532
9.3.1	Observing with the IRAM Millimetre Interferometer	533
9.3.2	Observing with NAOS Adaptive Optics	536
9.3.3	Observing with the Photometric Satellite COROT	538
9.3.4	Observing with a Coded Mask Gamma-Ray Instrument	541
9.4	Removing Instrumental Signatures	544
9.4.1	Intrinsic Emission from the Instrument	545
9.4.2	Dark Current	545

9.4.3	Non-Linearity Defects	546
9.4.4	Bias	547
9.4.5	Light Interference	547
9.4.6	Flat Field Corrections	548
9.4.7	Defective Pixels	549
9.4.8	Effects of High Energy Particle Impacts	549
9.5	The Problem of Estimation	550
9.5.1	Samples and Statistics	550
9.5.2	Point Estimation	551
9.5.3	Elements of Decision Theory	551
9.5.4	Properties of Estimators	554
9.5.5	Fréchet or Rao–Cramér Inequality	564
9.5.6	Efficient Estimators	566
9.5.7	Efficiency of an Estimator	568
9.5.8	Biased Estimators	568
9.5.9	Minimum Variance Bound and Fisher Information	570
9.5.10	Multidimensional Case	570
9.5.11	Robust Estimators	571
9.5.12	Some Classic Methods	573
9.6	From Data to Object: the Inverse Problem	575
9.6.1	Posing the Problem	576
9.6.2	Well-Posed Problems	579
9.6.3	Conventional Inversion Methods	581
9.6.4	Inversion Methods with Regularisation	587
9.6.5	Application to Adaptive Optics Imaging	592
9.6.6	Application to Nulling Interferometry	595
	Problems	597
10	Sky Surveys and Virtual Observatories	605
10.1	Statistical Astrophysics	605
10.2	Large Sky Surveys	608
10.2.1	Sky Surveys at Visible Wavelengths	610
10.2.2	Infrared Sky Surveys	614
10.3	A Virtual Observatory	615
A	Fourier Transforms	619
A.1	Definitions and Properties	619
A.1.1	Definitions	619
A.1.2	Some Properties	620
A.1.3	Important Special Cases in One Dimension	622
A.1.4	Important Special Cases in Two Dimensions	625
A.1.5	Important Theorems	626
A.2	Physical Quantities and Fourier Transforms	631
A.3	Wavelets	635

B	Random Processes and Variables	637
B.1	Random Variables	637
B.2	Random or Stochastic Processes	644
B.3	Physical Measurements and Estimates	653
B.3.1	An Example of Estimation: The Law of Large Numbers	654
B.3.2	Estimating the Moments of a Process	655
C	Physical and Astronomical Constants	659
D	Tables of Space Missions	661
E	Webography	663
E.1	Main Earth-Based Telescopes	663
E.2	Recent Space Missions	667
E.3	Databases	669
E.4	Journals	672
E.5	Bibliographical Research	673
E.6	Image Sources	673
E.7	Education	675
E.8	Computing and Astronomy	676
E.9	Resources	677
F	Acronyms	679
	Bibliography	687
	Index	705

Observational Astrophysics

Léna, P.; Rouan, D.; Lebrun, F.; Mignard, F.; Pelat, D.

2012, XV, 719 p. 128 illus., 71 illus. in color., Hardcover

ISBN: 978-3-642-21814-9