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Observational Astrophysics

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Cover figure: The mobile auxiliary telescopes (1.8-m in diameter) of the European *Very Large Telescope* (VLT), contributing to the interferometric mode (VLTI) of the VLT (see Chap. 6). The sky background is added from a real photograph.

Credit: Pierre Kervella, Observatoire de Paris

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Preface

Up until the end of World War II, almost the only tools available for astronomical observation were telescopes, spectrometers, and photographic plates, limited to the visible range of the electromagnetic spectrum. This was a relatively simple technology, but carried to a high level of performance by the combined efforts of opticians and astronomers. Then in the 1950s came radioastronomy, followed by infrared, ultraviolet, X-ray, and γ -ray astronomy, the birth and growth of space-based observation, *in situ* observation of the Solar System, and the advent of computing with the massive improvement in data processing capacity that resulted from it, so many factors leading to an unprecedented explosion in astrophysical activity. The first French edition of this book appeared in 1986, after three decades of new observational developments, followed in 1988 by the English translation *Observational Astrophysics*, published by Springer. And yet, ten years later, this first edition had already given way to a second: CCD detectors had replaced photography and a new generation of giant optical telescopes was coming into being on the Earth's surface, while the first cosmic neutrinos had been detected and the existence of gravitational waves indirectly demonstrated. The world astronomical community had also evolved since, apart from the English translation of the second edition in 1998, a slightly updated Chinese version appeared in Taiwan in 2004.

But after a further decade of astonishing developments in astronomical observation, the book must yet again be reworked. Adaptive optics has opened up entirely novel prospects for Earth-based optical telescopes, while interferometry can achieve angular resolutions on the ground today, and soon in space, that were previously only obtained at radiofrequencies. Meanwhile an assortment of new Earth- and space-based instruments are being developed today to explore the submillimeter range, still virtually uncharted, to observe objects with very high spectral shifts and the cosmological background radiation. The discovery of an ever-increasing number of exoplanets has led to many refinements of older techniques, such as coronagraphy, while opening a new and fascinating chapter in the history of astronomy — the search for life in the Universe — in which physics, chemistry, and biology each play their role. There are new and more refined neutrino telescopes, while those developed to seek out gravitational waves are gradually being brought

into service. And space exploration of the Solar System is still an issue, as more and more probes and *in situ* experiments go out to Mars, Titan, and cometary nuclei. The temporal and spatial reference frames used by astronomers, but others too, e.g., for detailed study of continental drift, are becoming increasingly accurate.

With the help of several new authors, we have therefore rewritten the book, reorganising and extending the material used in the previous editions. The work started out as lecture notes for a course one of us (PL) delivered to graduate students of astrophysics at the Denis Diderot University (Paris VII). The original section on methodology has been maintained. Apart from surveying the broad range of techniques specific to each wavelength, the details of which can be found in more specialised sources, our aim has been to present the *physical* foundations for the various types of instrumentation: telescopes gathering data, spectrometers analysing it, and detectors converting it into a signal. After the first four chapters, which deal with information carriers (Chap. 1), the effects of the Earth atmosphere (Chap. 2), basic photometry (Chap. 3), and spatial and temporal reference systems (Chap. 4), there follow a chapter each on telescopes, detectors, and spectrometers (Chaps. 5–8), with some emphasis of course on image formation.

The idea has been to bring out the main principles, describing levels of performance or the ultimate limits allowed by the laws of physics. So the guiding thread here lies in the properties of the photon (or the electromagnetic wave), since this remains the main information carrier in astrophysics. Acquisition, measurement, and quantitative techniques for analysing data constitute the theme of this book, and the choices made here reflect this objective. Such an approach necessarily limits what can be covered, and we make no pretence to exhaust all observational methods, nor to provide a complete and systematic presentation of the corresponding tools.

The increasing complexity, development timescales, and costs involved in today's instrumentation have radically changed the way this kind of work is now organised, and indeed the whole profession. Very often, too often perhaps, those who design and build an instrument are not the same as those who use it and who interpret the observations. The present book will have achieved its aim if it provides some with the means to advance the pursuit of data, and others with the lights to understand the 'black boxes' that constitute contemporary observational equipment.

There have been two major additions to the new edition. One is a more detailed discussion of signal processing in Chap. 9, stressing the universal digitization of data and the power of computational tools which have revolutionized the way information is processed. This chapter is inevitably rather mathematical and stands out from the rest of the book, but we have no doubt that it will be of great interest to readers. Apart from this, Chap. 10 is entirely new, describing the way modern instruments gather huge volumes of data, making them available to all in data banks. This leads to the idea of the *virtual observatory*, something that has transformed the everyday life of the astrophysicist. Finally, the essential mathematical tools, such as the Fourier transform and an introduction to probability and statistics, can be found in the appendices. We have kept the exercises included in the earlier editions without modification or addition. Despite their sometimes rather simple or even dated nature, students have found them of some use, at least at the elementary level.

The rich supply of information, images, and up-to-date news available on the Internet might make it seem pointless to try to catch all this knowledge in long-lasting written form. Naturally, the book includes a detailed webography, wherein the reader may find updates for all the subjects treated here. However, efficient use of the web can only be achieved within the kind of framework we hope to provide through this book. This has been the underlying idea that guided us while we were writing it.

Since the aim has been to produce a reference book, we have chosen to remove bibliographical references from the text as far as possible. We have simply put together a short bibliography at the end, not intended to be exhaustive. The reference books that seem to us to be potentially the most useful to the student, researcher, or teacher have been organised according to theme.

We could not possibly name or thank all colleagues or students, often later to become colleagues, who have contributed to the two first editions and provided illustrations. We would just like to thank Mme Claude Audy, who prepared the final version of the manuscript, and Mme H el ene de Castilla of InterEditions (Paris), together with Eric Gendron, who carefully copy-edited. The current edition is indebted to Laurent Mugnier, who wrote part of Chap. 9, and Marc Huertas, who put together the webography. We are also grateful to Laurent Pagani for radiofrequencies, Michel Cribier for neutrinos, Philippe Laurent for gravitational waves, Jean Ballet for X-ray astronomy, Philippe Goret for ground-based γ -ray astronomy, and Claude Pigot, who accepted to write or proofread parts of the text. The *Fondation des Treilles* generously hosted one of us (PL) in Provence (France) while the book was being finalised. We thank them for that, and also Mich ele Leduc for her tireless supervision of the *Savoirs actuels* series.

We have not forgotten that the two previous editions of this book were dedicated to the memory of the astronomer and physicist Philippe Delache (1937–1996). We hope that the present edition, following his example, will excite the enthusiasm of many new generations of students, attracted into this most wonderful of sciences — astronomy.

Paris

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A detailed bibliography is given at the end of the book. Only a few specific references are given in the course of the chapters, in the text or in footnote. Beside the classical names of journals, some specific abbreviations are used for frequent quotations of documents detailed in the bibliography, namely:

- AF for the book *Astrophysical Formulae*.
- AQ for the book *Astrophysical Quantities*
- ARAA for *Annual Review of Astronomy and Astrophysics*.

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