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Observational Astrophysics

Translated by S. Lyle

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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 coronography, 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 Hélène 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 Michèle 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.

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