MEASURING THE UNIVERSE

Astronomy is an observational science, renewed and even revolutionized by new developments in instrumentation. With the resulting growth of multiwavelength investigation as an engine of discovery, it is increasingly important for astronomers to understand the underlying physical principles and operational characteristics for a broad range of instruments.

This comprehensive text is ideal for graduate students, active researchers, and instrument developers. It is a thorough review of how astronomers obtain their data, covering current approaches to astronomical measurements from radio to gamma rays. The focus is on current technology rather than the history of the field, allowing each topic to be discussed in depth. Areas covered include telescopes, detectors, photometry, spectroscopy, adaptive optics and high-contrast imaging, millimeter-wave and radio receivers, radio and optical/infrared interferometry, and X-ray and gamma-ray astronomy, all at a level that bridges the gap between the basic principles of optics and the subject's abundant specialist literature.

Color versions of figures and solutions to selected problems are available online at www.cambridge.org/9780521762298.

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A Multiwavelength Perspective

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To Foster Rieke (my father),
Trevor Weekes, and Frank Low,
who introduced me to the
challenge and fun of
scientific instrumentation

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Preface

Progress in astronomy is fueled by new technical opportunities (Harwit, 1984). For a long time, steady and overall spectacular advances in the optical were made in telescopes and, more recently, in detectors. In the last 60 years, continued progress has been fueled by opening new spectral windows: radio, X-ray, infrared (IR), gamma ray. We haven't run out of possibilities: submillimeter, hard X-ray/ gamma ray, cold IR telescopes, multi-conjugate adaptive optics, neutrinos, and gravitational waves are some of the remaining frontiers. To stay at the forefront requires that you be knowledgeable about new technical possibilities.

You will also need to maintain a broad perspective, an increasingly difficult challenge with the ongoing explosion of information. Much of the future progress in astronomy will come from combining insights in different spectral regions. Astronomy has become panchromatic. This is behind much of the push for Virtual Observatories and the development of data archives of many kinds. To make optimum use of all this information requires you to understand the capabilities and limitations of a broad range of instruments so you know the strengths and limitations of the data you are working with.

As Harwit (1984) shows, before about 1950, discoveries were driven by other factors as much as by technology, but since then technology has had a discovery shelf life of only about five years! Most of the physics we use is more than 50 years old, and a lot of it is more than 100 years old. You can do good astronomy without being totally current in physics (but you need to know physics very well). The relevant technology, in comparison, changes rapidly and you absolutely must be up to date on it, or you will rapidly fall behind in the field.

There are many specialist texts and conferences on specific measurement techniques. However, treatments designed to bridge from simple principles of optics to these materials are rare. It is also uncommon to provide such a bridge across the entire electromagnetic spectrum so it can provide an overview at an appropriate level for anyone approaching astronomy at a professional level, be it as an observer, theoretician, or engineer. This book is intended to fill this gap. How to do so requires choices; there is a long history of instrumentation approaches as well as a diverse range of them in current application. My choice has been to concentrate solely on instrumentation that is currently in wide use. As a result, I can give a reasonably complete description of each; those interested in earlier approaches can find descriptions in other textbooks. I apologize for omitting areas, either inadvertently or from a conclusion that they were too specialized for a general treatment.

I have also avoided detailed descriptions of individual astronomical instruments or facilities. Although of current interest, such material is likely to become dated quickly. A better alternative than a book is to locate the website for the facility and instrument of interest.

Many have improved this text by critiquing earlier versions or by supplying material: Jill Bechtold, Olivier Guyon, Michael Hart, Philip Hinz, Eugene Lauria, David Lesser, Michael Lesser, Daniel Marone, Peter Michelson, Stephanie Moats, Jane Morrison, Richard Perley, Paul Smith, Christopher Walker, Martin Weisskopf, Michelle Wilson, and especially Megan Bagley, Nicholas Ballering, and Melissa Dykhuis. The book would have been a disaster without their help, and if it is still a disaster it is not their fault.

I thank Shiras for drawing the illustrations. Shiras and I thank Murray Stein very, very much for his contributions to the illustrations. Many of the figures have been redrawn to make the style consistent. I thank the original sources in all cases, specifically (in addition to references given in the text): 1.5 (adapted from Wikipedia, Robert H. Rohde); 2.11 (from Norman Koren, with permission); 3.11 (adapted from "The Last of the Great Observatories" by myself, 2006, copyright the Arizona Board of Regents; 4.3 (from PASP, with permission) ; 4.5 (from Tim Hardy and John Hutchings); 4.7 and 6.11 (Gemini Observatory/AURA); 5.6 and 7.18 (from *ApJ*, with permission); 5.9 (Wikipedia, original by Bob Mellish); 6.23 and 6.24 (Russell Scaduto); 7.1 (Wikipedia, prepared by R. N. Tubbs); 7.7, 7.8, 7.11, 7.12, and 7.13 (Sebastian Egner); 7.15 and 10.8 (from *A&A*, with permission); 7.16 and 7.17 (Robert J. Vanderbei); 7.23 (Olivier Guyon); 8.2 (Patrick Agnese, CEA Electronics and Information Technology Laboratory (Leti)); 9.2 (Jim Condon). I also thank Mairi Sutherland for a careful editing of the final draft. Please address any comments about the book to me at grieke@as.arizona.edu. SI units are assumed by default, but alternatives are used where they are conventional. Solutions to selected problems, along with color versions of figures, are available at www.cambridge.org/9780521762298. Additional problems will be posted there, if they are submitted to me with solutions.

Further reading

Harwit, M. (1984). *Cosmic Discovery*. Cambridge, MA: The MIT Press.