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2nd Edition
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To Measure the Sky

An Introduction to Observational Astronomy

Second Edition

The second edition of this popular text provides undergraduates with a quantitative yet accessible introduction to the physical principles underlying the collection and analysis of observational data in contemporary optical and infrared astronomy. The text clearly links recent developments in ground- and space-based telescopes, observatory and instrument design, adaptive optics, and detector technologies to the more modest telescopes and detectors students may use themselves. Beginning with reviews of the most relevant physical concepts and an introduction to elementary statistics, students are given the firm theoretical foundation they need. New topics, including an expanded treatment of spectroscopy, Gaia, the Large Synoptic Survey Telescope, and photometry at large redshifts bring the text up to date. Historical development of topics and quotations emphasize that astronomy is both a scientific and a human endeavor, while extensive end-of-chapter exercises facilitate the students' practical learning experience.

Frederick R. Chromey is Professor of Astronomy on the Matthew Vassar, Jr. Chair at Vassar College, and Director of the Vassar College Observatory. He has almost 45 years' experience in observational astronomy research in the optical, radio, and near infrared on stars, gaseous nebulae, and galaxies, and has taught astronomy to undergraduates at Brooklyn College and Vassar.

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Vassar College, New York

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To Molly

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Preface

There is an old joke: a lawyer, a priest, and an observational astronomer walk into a bar. The bartender turns out to be a visiting extraterrestrial who presents the trio with a complicated-looking black box. The alien first demonstrates that when a bucketful of garbage is fed into the entrance chute of the box, a small bag of high-quality diamonds and a gallon of pure water appear at its output. Then, assuring the three that the machine is his gift to them, the bartender vanishes.

The lawyer says, “Boys, we’re rich! It’s the goose that lays the golden egg! We need to form a limited partnership so we can keep this thing secret and share the profits.”

The priest says, “No, no, my brothers, we need to take this to the United Nations, so it can benefit all humanity.”

“We can decide all that later,” the observational astronomer says. “Get me a screwdriver. I need to take this thing apart and see how it works.”

The first edition of this text grew out of 16 years of teaching observational astronomy to undergraduates, and this second edition benefited from six years of using that edition in my classes and from hearing from colleagues who had done the same. In both editions, my intent has been partly to satisfy – but mainly to cultivate – my students’ need to look inside black boxes. The text introduces the primary tools for making astronomical observations at visible and infrared wavelengths: telescopes, detectors, cameras, and spectrometers, as well as the methods for securing and understanding the quantitative measurements they make. I hope that after this introduction, none of these tools will remain a completely black box, and that the reader will be ready to use them to pry into other boxes. The second edition has brought the discussion a bit more up to date with current technology and practices, and has added a few recent examples of discoveries that relied on careful application of fundamental practices.

The book, then, aims at an audience similar to my students: nominally second- or third-year science majors, but with a sizable minority containing advanced first-year students, non-science students, and adult amateur astronomers. About three-quarters of those in my classes are *not* bound for graduate school in astronomy or physics, and the text has that set of backgrounds in mind.

I assume my students have little or no preparation in astronomy, but do presume that each has had one year of college-level physics and an introduction to integral and differential calculus. A course in modern physics, although very helpful, is not essential. I make the same assumptions about readers of this book. Since readers' mastery of physics varies, I include reviews of the most relevant physical concepts: optics, atomic structure, and solid-state physics. I also include a brief introduction to elementary statistics. I have written qualitative chapter summaries, but the problems posed at the end of each chapter are all quantitative exercises meant to strengthen and further develop student understanding.

My approach is to be rather thorough on fundamental topics in astronomy, in the belief that individual instructors will supply enrichment in specialized areas as they see fit. The table of contents indicates that my choice of topics is blatantly selective and slanted toward the kind of observations students might make themselves at a campus observatory.

The text lends itself to either a one- or two-semester course. I personally use the book for a two-semester sequence, where, in addition to most of the text and a selection of its end-of-chapter problems, I incorporate a number of at-the-telescope projects both for individuals and for "research teams" of students. I try to vary the large team projects: these have included a photometric time series of a variable object (in different years an eclipsing exoplanetary system, a Cepheid, and a blazar), an H–R diagram, and spectroscopy of the atmosphere of a Jovian planet. I am mindful that astronomers who teach with this text will have their own special interests in particular objects or techniques, and will have their own limitations and capabilities for student access to telescopes and equipment. My very firm belief, though, is that this book will be most effective if the instructor can devise appropriate exercises that require students to put their hands on actual hardware to measure actual photons from the sky.

To use the text for a one-semester course, the instructor will have to judiciously skip many topics. Certainly, if students are well prepared in physics and mathematics, one can dispense with much of Chapters 5 and 6 (geometrical optics and telescopes), Chapter 7 (atomic and solid-state physics), and possibly all detectors (Chapter 8) except the CCD. One would still need to choose between a more thorough treatment of photometry (skipping Chapter 11, on spectrometers) and the inclusion of spectrometry with exclusion of some photometric topics (compressing the early sections of both Chapters 9 and 10).

Compared with other texts, this book has strengths and counterbalancing weaknesses. I have taken some care with the physical and mathematical treatment of basic topics, like detection, uncertainty, telescope design, astronomical seeing, and array processing, but at the cost of a more descriptive or encyclopedic survey of specialized areas of concern to observers (e.g. little treatment of the details of astrometry or of variable star observing). I believe the book is an excellent fit for courses in which students will do their own optical/infrared observing. Because I confine myself to that wavelength region, I can develop ideas more systematically, beginning with those that arise from fundamental astronomical questions like position, brightness, and spectrum. But that narrowness makes the book less suitable for a more general survey that includes radio or X-ray techniques.

The sheer number of people and institutions contributing to the production of both editions of this book makes an adequate acknowledgment of all those to whom I am indebted impossible. Inadequate thanks are better than none, and I am deeply grateful to all who helped along the way.

A book requires an audience. The audience I had uppermost in mind was filled with those students brave enough to enroll in my Astronomy 240–340 courses at Vassar College. Over the years, more than a hundred of these students have challenged and rewarded me. All made contributions that found their way into this text, but I especially thank those who asked the hardest questions (so sorry this list is incomplete): Liz Blanton, Megan Vogelaar, Claire Webb, Deep Anand, Sherri Stephan, David Hasselbacher, Trent Adams, Leslie Sherman, Kate Eberwein, Olivia Johnson, Iulia Deneva, Laura Ruocco, Ben Knowles, Aaron Warren, Jessica Warren, Gabe Lubell, Scott Fleming, Alex Burke, Colin Wilson, Charles Wisotzkey, Peter Robinson, Tom Ferguson, David Vollbach, Krista Romita, Ximena Fernandez, Max Fagin, Jenna Lemonias, Max Marcus, Rachel Wagner-Kaiser, Tim Taber, Max Fagin, Roni Teich, Zeeve Rogozinski, Alex Shvonski, Nico Mongillo, Lauren Bearden, Angelica Rivera, Megan Lewis, Sean Sellers, Alex Trunnell, Caitlin Rose, and Liz McGrath.

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Debra Elmegreen, my colleague at Vassar, collaborated with me on multiple research projects and on the notable enterprise of building a campus observatory. Much of our joint experience found its way into this volume. Vassar College, financially and communally, has been a superb environment for both my teaching and my practice of astronomy, and deserves my gratitude. My editors at Cambridge University Press have been uniformly helpful and skilled.

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My family and friends have had to bear some of the burden of this writing. Clara Bargellini and Gabriel Camera opened their home to me and my laptop during extended visits, as did my sisters, Nancy and Tina Chromey. Ann Congelton supplied useful quotations and spirited discussions. I thank my children, Kate and Anthony, who gently remind me that what is best in life is not in a book.

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