Contents

Some weeks later the Einsteins were taken to the Mt. Wilson Observatory in California. Mrs. Einstein was particularly impressed by the giant telescope. 'What on Earth do they use it for?, she asked. Her host explained that one of its chief purposes was to find out the shape of the Universe. "Oh", said Mrs. Einstein, "my husband does that on the back of an envelope. - Bennett Cerf in "Try and Stop Me".

Foreword

Modern astrophysics requires the use of observations over the broadest range of wavelengths to fully understand the physical nature of the objects and processes we wish to study in the universe.

Data are obtained from ground-based and space-based observations operating in radio, infrared, visible, ultraviolet, x-rays and gamma rays. The design and operation of the instrumentation used to gather this information, the telescopes and detectors themselves, depend on the interaction between matter and radiation at the different wavelengths and requires in-depth knowledge of the findings of molecular, atomic, nuclear, and particle physics.

The observer needs to have the data at hand to understand the properties and the limitations of the instrumentation and their relevance to data reduction, analysis, and interpretation.

The theorist who is seeking new models to interpret the findings from the most sensitive and sophisticated observatories that ever existed needs, from time to time, a reality check with what is known.

The *Handbook of Space Astronomy and Astrophysics* gathers in one place the most frequently-used information in modern astrophysics and presents it in the most useful fashion to the non-specialist in a particular field.

I always loved the chapter on relativistic astrophysics and I am glad it has been retained and improved. I am also glad for the new chapters on experimental subjects that bring the Handbook up-to-date.

I am certain that some young person will find here, as I did, useful food for thought and inspiration that he or she will need to design the next generation of telescopes.

Washington, DC
May, 2005

Riccardo Giacconi
Nobel laureate, 2002
Physics

Preface

I have compiled the tables, graphs, diagrams, and formulae in this book in order to provide a ready reference and working tool for the practicing space astronomer and astrophysicist. Ground-based astronomers, students, and advanced amateur astronomers will find much here of interest, too. The material represents a diversified selection based upon the circumstance that the space astronomer and astrophysicist must draw upon knowledge of atomic physics, nuclear physics, relativity, plasma physics, electromagnetism, mathematics, probability and statistics, geophysics, experimental physics, *et cetera,* in addition to the classical branches of astronomy. My hope is that this book will replace hunting through many separate works or a trip to the reference library or to the World Wide Web. In that spirit, I welcome suggestions of material for inclusion in a later edition and, of course, corrections or criticism.

There are 21 chapters in the book. The first chapter contains physical, astronomical, and numerical constants, and unit conversions. Chapters 2-8 cover general astronomy and astrophysics, radio, infrared, ultraviolet, X-ray, and gamma-ray astronomy, and cosmic rays. Chapter 9 contains information on the Earth's atmosphere and environment relevant to space science. Chapter 10 covers special and general relativity and chapter 11 provides relevant information in atomic physics. Electromagnetic radiation and plasma physics are the subjects of chapters 12 and 13. The remaining chapters deal with the tools of the trade, *viz.,* information on radiation and particle interactions, detectors, astronautics, useful mathematical relations, probability and statistics formulae, laboratory radiation safety, a comprehensive list of astronomical catalogs, and computer science. Each chapter ends with a bibliography for further reading on the subject of the chapter and for more extensive reference material. The last chapter contains a glossary of abbreviations and symbols. 11 Appendices contain material that is of a tutorial nature, not suitable for inclusion in the main text, and material suggested recently by reviewers. The book has a complete index.

The question of units is always a problem in a book of this type; sticking to one consistent set (SI, for example) is not very useful to the practitioner; distance to a galaxy in meters, the energy of an X-ray

photon in joules, or the pressure of a gas in newton m^{-2} would leave most scientists frustrated. I have tried to use the unit systems common to the particular field. Thus I have used SI (International System of Units), c.g.s., and Gaussian (e.s.u. c.g.s. units); whatever is customary. What is being used is usually noted and whenever the units are not noted, any consistent system will do. If in doubt, perform a numerical check. Besides a complete set of fundamental constants in SI units, I have also provided a subset in c.g.s. units, which are commonly used in the formulae in this book, and unit conversion tables.

I have established and will maintain a Web site at http://www.astrohandbook.com, where I will provide links to supplementary information for each chapter and a list of *errata,* if any. The links will provide extensive data bases, complete online texts and scientific journal articles, tutorials, online interactive programs for converting units, calculating astronomical coordinates, plotting X-ray absorption and reflectivity, symbolic mathematics, and much more. I have avoided, with a few exceptions, listing the URLs (uniform resource locator) of online source material since locations and file names often change.

I wish to acknowledge colleagues for their useful suggestions and encouragement, especially Gerald Austin, Daniel Fabricant, George Field, who suggested that I first publish the handbook as a Smithsonian Astrophysical Observatory Special Report, Jonathan Grindlay, Paul Gorenstein, F. Rick Harnden, Almus Kenter, Ralph Kraft, Jeffrey McClintock, Gary Meehan, Stephen Murray, who first suggested that I publish my set of notes in handbook form, and Daniel Schwartz of the Harvard-Smithsonian Center for Astrophysics, Joachim Truemper of the Max-Planck-Institut für Extraterrestrische Physik (MPE), and Rashid Sunyaev of the Max-Plank-Institut für Astrophysik.

The typesetting in Latex was initially done by Instill Technologies, BE 277 Salt Lake, Kolkata 700064, India. The partners for this company, Sutanu Ghosh and Pijush K. Maiti did a superior job in typesetting the extensive tables and complex formulae of the handbook. The majority of the typesetting and the completion of the project was accomplished by Gautami Maiti and Pijush K. Maiti of Anin, BC 97 Salt Lake, Kolkata 700064, India. I thank Himel Ghosh, formerly of the Harvard-Smithsonian Center for Astrophysics, for suggesting that I work with Drs. Ghosh and Maiti. The fact that they are physicists helped matters considerably.

My son, Richard, provided substantial technical assistance in the last minute preparations of the book for submission to the publisher.

Many of the quotations are from "Physically Speaking, a Dictionary of Quotations on Physics and Astronomy", Carl C. Gaither and Alma E. Cavazos-Gaither, Institute of Physics Publishing, 1997.

Please cite the original source, if you are referencing any of the material in the *Handbook* in research publications.

I have made every effort to cite the sources for the material presented in this book and to obtain permissions, wherever necessary. If I have omitted a citation, please bring it to my attention.

I have corrected all known errors in this printing. If you find an error(s) please e-mail me.

York, Maine
Summer, 2014

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