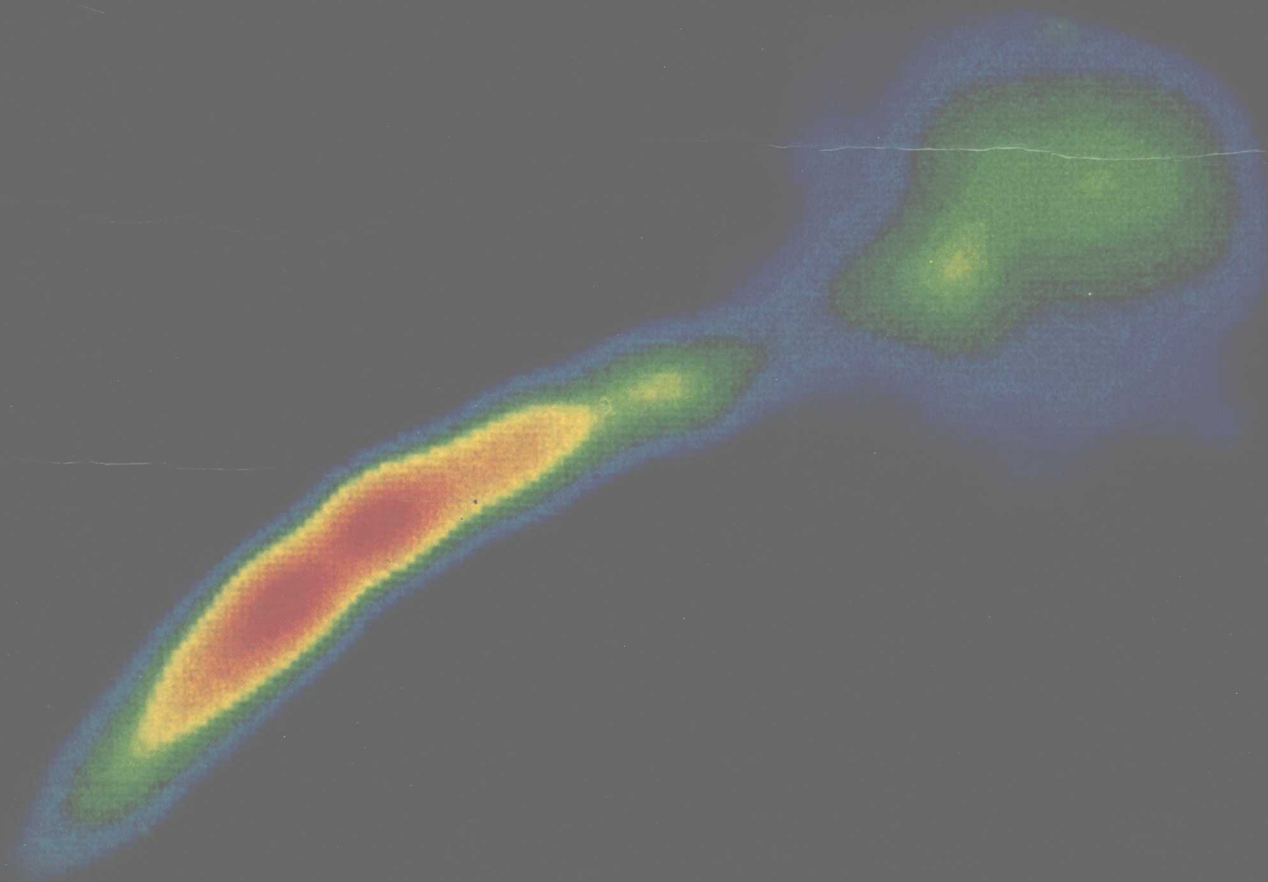


IASTROW & THOMPSON



ASTRONOMY

FUNDAMENTALS & FRONTIERS

FOURTH EDITION

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FOURTH EDITION



ROBERT JASTROW
MALCOLM H. THOMPSON

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FOREWORD

In the introduction to the present textbook the authors briefly discuss the Copernican revolution. We are reminded that the ideas of Copernicus, Kepler, Galileo and Newton profoundly influence human culture, and we recall how long it took for these ideas to be generally understood and accepted. The addition of knowledge that is taking place in our day in astronomy occurs at a spectacularly rapid pace. There can be no doubt that the task of making the results of astronomical research generally available is a most important one. The challenge is strongly felt by the astronomical community.

Professors Jastrow and Thompson have written an astronomy textbook with the liberal arts student in mind at every point of the development. There is a very good balance between the discussion of basic methods and description of the results of astrophysical research, including the most recent advances.

I believe that the authors have chosen wisely in emphasizing the central problems of modern astrophysics, dealing only briefly with some of the chapters of classical astronomy. In placing the discussions of stellar structure and evolution of galaxies, and large scale cosmology before the discussion of the solar system and problems of structure and history of planets, the authors are guided by considerations of evolution in time rather than location in space. This way of arranging the subject material has obvious advantages.

If this textbook is as widely used and read as it deserves the authors will have made a very significant contribution in the area of communication between scientist and the community. For the book tells compellingly about basic research, important to us all, and of its results, its spirit and its excitement.

Bengt Stromgren

PREFACE TO THE FOURTH EDITION

The pace of new discoveries in astronomy has quickened in the interval between the publication of the third and fourth editions of *ASTRONOMY: FUNDAMENTALS AND FRONTIERS*. Much of the new progress can be explained by the acquisition of new observational tools, such as the orbiting telescopes that open up the infrared, ultraviolet, x-ray and gamma ray regions, and the Very Large Array and Very Long Baseline Interferometry facilities in radio astronomy. Charge coupled devices and other new types of detectors have enhanced the sensitivity and usefulness of existing ground-based optical telescopes. Finally, new computerized methods of processing data have enhanced the value of observations at all wavelengths. The picture of stellar evolution presented in the third edition has not changed a great deal as a result of these observational developments. However, dramatic changes have occurred in the study of galaxies and the large-scale structure and evolution of the Universe. Evidence for massive galactic halos, superclusters and voids, the nonluminous "hidden mass," and new observations of active galactic nuclei and cosmic jets have required the addition of large amounts of new material to the corresponding chapters on galaxies and cosmology.

The new developments in instrumentation—including innovative designs for large ground-based optical telescopes, such as the multiple mirror telescope and the segmented mirror telescope, and the impressive VLA facilities and VLBI links, in radio astronomy, with their extraordinary resolutions approaching 10^{-4} arc seconds—are so interesting as to merit fairly complete explanations of their working principles. The chapter on telescopes and detectors has been expanded into two full chapters as a result of the additions in these areas.

The Voyager spacecraft missions have led to great advances in our knowledge of the properties of the giant planets and their moons. These remarkable flights have yielded exciting images of alien worlds. The images and other data collected by Voyager reveal planetary bodies with strange geologies and surface conditions. We have incorporated the new information, all of it unavailable at the time of the third edition, into the sections on the giant planets and their moons and into the color insert.

A new chapter has been added on the evolution of astronomical

thought from the Greeks to Newton. The theme of this opening chapter is the Copernican revolution, and its impact on man's understanding of his place in the cosmic order. The entire development of astronomy in the centuries after Newton has been, in a sense, a continuation of that revolution in human thought whose roots can be traced back to the work of a handful of early astronomers living more than 2000 years ago.

The organization of the fourth edition continues the unusual arrangement in which material on stars and galaxies is presented before the discussion of the solar system. This arrangement has the advantage of providing students with early information on star formation and element synthesis in stars, that permits deeper insights into the evolution and structure of the major and minor bodies of the solar system than the more conventional treatments beginning with a discussion of the earth and planets. However, the section on the solar system has been written in such a way that with only minor omissions of material, this section can be taught before the sections on stars and galaxies.

Several friends and colleagues have been kind enough to prepare critical reviews of the manuscript of the fourth edition. We are particularly indebted to Professor Neville J. Woolf of the University of Arizona and Professor John Thorstensen of Dartmouth College for their careful reading of the entire manuscript. The book has benefitted enormously from their thoughtful suggestions and criticisms. We are also indebted to Dr. Richard Stothers of the Goddard Institute for Space Studies, for valuable suggestions relating to the chapters on the history of astronomy and on stellar evolution.

We are deeply grateful to Doris Cook who worked with us throughout the preparation of the fourth edition and provided invaluable counsel on all matters of clarity and organization. She also brought the manuscript through its many successive stages of draft and revision. The fourth edition could not have come into being without her collaboration. We also wish to thank Margaret Newfield and Dorothy Davis, who typed and copy-edited several chapters.

The high competence and cooperative spirit of the Wiley staff continue to make this publishing relationship professionally pleasant and rewarding for both authors. We wish particularly to express our appreciation to our editor, Donald H. Deneck, whose gentle pressure and unfailing good humor brought our project to fruition far earlier than would otherwise have been the case. Words will not express the debt we owe to Don for his efforts. We also wish to thank Maureen Conway and her colleagues for their extremely competent guidance in carrying the manuscript through the complexities of the production process.

Robert Jastrow
Malcolm Thompson

PREFACE TO THE FIRST EDITION

Astronomy, more than any other physical or behavioral science, offers the nonscience student a mind-expanding educational experience. The steadily increasing enrollments in introductory astronomy courses reflect a growing awareness of this fact on the part of liberal arts students. The historical and philosophical elements in astronomy, always a large factor in the appeal of this subject for the nonscience major, have been strengthened by new discoveries in stellar evolution and cosmology. Progress in these fields during the last twenty years has filled in many details of the sequence of events that led from the explosive beginnings of the Universe through the birth of innumerable stars and planets to the formation of the sun and the earth. When the latest advances in astronomy are combined with developments in the life sciences, the result is a chain of cause and effect that stretches back over 10 billion years and links the earth and its life forms to events that occurred early in the history of the Universe. At that point—on the threshold of the appearance of life on our planet—the direct contribution of astronomy ends, and the story is taken up by other branches of science.

The advances in astronomical knowledge provide many points of contact between this subject and other scientific disciplines. Modern astronomy, fascinating in itself, seems increasingly to be a fragment of a mosaic that, when viewed from a distance, forms an image of the human observer. The appeal of astronomy to the nonscientist is further strengthened by the fact that its subject matter forces the imagination to contemplate larger expanses of space and time than fall within the province of any other scientific discipline. These qualities make the study of astronomy a uniquely attractive means of introducing the liberal arts student to the physical sciences.

We have focused on the needs and interests of the liberal arts student in our choice of topics, as well as in the style of writing and in the level of required mathematical skills. No mathematics is used beyond the level of elementary algebra, and technical terms are avoided. Each chapter opens with the statement of a central theme to which the previous chapters of the book are clearly re-

lated. The remainder of the chapter is an explicit development of this central theme.

The central problems of twentieth century astronomy are emphasized. Full chapters are included on the Hertzsprung-Russell diagram, nuclear reactions in stars, stellar evolution, galactic structure and evolution, radio galaxies, Seyfert galaxies and quasars, cosmology, the history of the moon, and the evolution of planetary atmospheres. Much discussion is devoted to recently opened areas of research such as infrared astronomy, x-ray and gamma-ray astronomy, gravitational waves, pulsars, and black holes in space. The choice of topics and the allotment of space to each topic reflect much of contemporary research publication. An unusual feature is the inclusion of a final chapter on the evolution of life in the Cosmos.

A complete discussion of these topics in a one-semester textbook necessitated the omission of some areas, such as astrometrics, which are centers of active research on contemporary astronomy but are not as directly related to the book's central line of development. Celestial mechanics is treated very briefly in the chapter on the solar system. The motions of the earth in space, tides, eclipses, and celestial coordinates are described in an introductory, separately paginated section.

A basic innovation in the book is its presentation of material on stars and galaxies before the discussion of the solar system. This is the reverse of the traditional presentation, in which astronomical knowledge is given in the order in which it was acquired in human history, starting with the earth and then radiating outward to the moon, planets, stars, and galaxies. Our book embeds the study of the solar system in the context of a general study of stars and planets, and more accurately reflects the impact of the Copernican Revolution on the history of astronomy.

The new organization of material has the advantage that it permits the instructor to use astrophysical knowledge when discussing the structure, chemical composition, and origin of the earth, moon, and planets. Astrophysics reveals how elements are made in the stars; why some are more abundant than others; and how these elements condensed to form the clouds out of which the sun, moon, and planets were born. An astrophysical background is required to discuss conditions at the beginning of the solar system, when the earth and other planets were newly formed. Instructors who prefer the traditional organization, but like other features of the book, can start their course as usual with "The Solar System," whose opening chapters summarize the astrophysical background needed for studying the solar system.

The rapid pace of change in modern astronomy makes the task of the textbook author very difficult if he wishes to present a balanced view of recent developments. We are deeply indebted to a

number of friends and colleagues, closely associated with these developments, who have been willing to spare time from their research for careful reviews and detailed criticisms of portions of the manuscripts dealing with subjects of which they have a profound knowledge. We are particularly grateful to Dr. Richard Stothers for many informative discussions on stellar evolution and numerous detailed criticisms of Chapters 1 to 8; to Professor Lodewijk Woltjer for a careful commentary on the Chapters dealing with galaxies and cosmology; to Professors Paul Gast and Robert Phinney and to Dr. Vivien Gornitz for their comments on the Chapters relating to the solar system, the earth, the moon and the planets; and to Dr. S. I. Rasool for illuminating discussions of the planets in general and critical review of Chapter 17 in particular. We also profited greatly from conversations with Dr. Patrick Thaddeus on topics in radio astronomy and interstellar chemistry. Professor Neville Woolf gave us the benefit of his reading and criticism of the entire manuscript, and offered valuable comments on the balance of the contents between traditional and contemporary areas of astronomy. Drs. J. W. Hogan, R. Stewart, and Dennis Hegyi reviewed the manuscript for pedagogical effectiveness and offered many helpful suggestions based on classroom testing of the materials.

The completion of the manuscript would not have been possible without the devoted editorial and secretarial assistance of Misses Judith Silverman and Ruth McCarthy. Finally, with particular pleasure we express our thanks to Donald Deneck and Dennis Hudson in particular, and to the extremely capable Wiley editorial, production, picture research, illustration and design departments for their enthusiastic support and cooperation in bringing the raw material of our text into finished form.

Robert Jastrow
Malcolm Thompson

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EARTH AND SKY

PART
ONE

