Exploring the Dynamic Univer

An Introduction to Astronomy

Theodore P. Sn

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Preface

To study astronomy is, in a sense, the most human thing we can do. What distinguishes us from lower creatures, if not our curiosity, our compulsion to explore and discover? And what exemplifies this compulsion better than the study of the universe?

We probe the heavens (and the Earth) by all possible means, and we do it for no other reason than to learn whatever there is to be known. Astronomy has produced many useful byproducts, or course, and could be (and often is) justified solely on that basis. That is not the real reason for astronomy, however.

This textbook represents an attempt by an astronomer to share both the knowledge and the intellectual gratification of our science. There is considerable beauty in the universe for the eye and mind to behold. Just as it is visually stimulating to gaze at a great glowing nebula or a colorful moon, it is pleasing to the intellect to grasp a new understanding of one of the grand themes of the cosmos. It is hoped that the reader of this book will gain by doing both.

This textbook is intended for the student who has not chosen science as his or her major area of study, but who needs an appreciation of science as a vital aspect of preparation for a career. It is as important for such a student to gain some perspective on the general nature of science as it is to learn a great deal of specific information about a particular discipline in the sciences. For that reason, this text stresses the philosophy and outlook of the scientist as well as the knowledge we have gathered about the physical universe we live in.

It is probably as important for the student to understand how we know what we know as it is to understand what we know. In this era of instantaneous communication and universal access to information, we need more than ever to be able to discriminate among competing hypotheses, to be able to judge the reasonableness of ideas that are advanced. This text in astronomy is written with the underlying theme that to know the workings of science is one of the most important tools we have for meeting the challenges of our technological society.

This book, as its predecessors *The Dynamic Universe* and *Essentials of the Dynamic Universe,* places the emphasis at all times on *how* we learn about the cosmos; on the nature of scientific reason and the methods of scientific progress. The text presents a full overview of our current state of knowledge, while at the same time preparing the student for the changes in our understanding that will surely follow.

This book has been tailored to suit introductory astronomy courses in which the emphasis first is on stellar, galactic, and extragalactic astronomy, with the discussion of the solar system (except for the Sun) coming later. The book is brief enough to be easily covered in a one-term course.

We have made *Exploring the Dynamic Universe* current, by ensuring that the most recent discoveries have been included, such as the influx of new information on the outer planets gained from the *Voyager* flybys, the most recent discoveries on cold matter in the universe gleaned from the infrared maps obtained by the *IRAS* satellite; the news on the nature of comets brought back from the recent apparition of Halley; the many fascinating new results of deep extragalactic surveys and of modern cosmological theory; and, perhaps most spectacular of all, extensive coverage of the great supernova of 1987. We have gone to great lengths to ensure that this most significant event is covered extensively, and that the information is as current as possible. There is a special insert section on the supernova, updated as recently as December 1987, which describes not only what has happened so far, but also the expectations and key questions of astronomers as we wait to see what will be revealed as the infant remnant expands and dissipates.

This book includes many of the successful features of its predecessors. There are extensive tables of data throughout the text and in the appendices; there are Astronomical Insights within the chapters, providing

additional anecdotal, historical, or technical information; and there are chapter summaries, review questions, and supplemental reading lists at the end of each chapter. All of these features are designed to enhance student understanding and, perhaps more importantly, student appreciation of the manner and methods of science.

The esthetic appeal of astronomy has been immeasurably enhanced by the full four-color format of the book; this allows the illustrations to be interspersed with the text throughout, rather than being relegated to a few color plate insert sections. This allows the student to appreciate not only the beauty, but also the relevence of astronomical photographs and diagrams, without the need to locate plates in a remote section of the book. Many of the drawings have been updated to use color or to clarify concepts previously less obvious.

The arrangement of the text is largely traditional, with an introductory section on the background of astronomy, both in history and in basic physics; a section, beginning with the Sun, on stars and their lives and deaths; a section on the structure and evolution of our galaxy; a set of chapters on extragalactic astronomy and the universe as a whole; a section on solar system objects and evolution; and a final, brief section on the possibilities that life may exist elsewhere. At the beginning of each of these sections is an introduction that leads the student into the material.

The section on the solar system is much shorter and more concise than is the case in either *The Dynamic Universe* or *Essentials of the Dynamic Universe*, and is written on a comparative planetology basis, instead of an object-by-object sequence. This section opens with a discussion of the overall properties of the solar system and our understanding of its origin, which is followed by a chapter on the Earth and the Moon, which serves not only to describe these two bodies but also to set the stage for comparisons with the other planets and satellite systems. The other three terrestrial planets are then discussed collectively in the next chapter, in the context of what has been learned about the Earth, and this is followed by a similar comparative treatment of the outer planets in the following chapter. The final chapter in this section discusses interplanetary bodies; asteroids, comets, meteoroids, and dust grains.

Supplemental materials for this text include a *Study Guide* authored by Catharine D. Garmany and myself (both University of Colorado), and an *Instructor's Manual* by Stephen J. Shawl (University of Kansas). The *Instructor's Manual* contains helpful discussions of strategies in teaching, provides a large number of exam questions (with answers), and gives complete answers to all the review questions from the main text. The *Study Guide*, intended to help the student get maximum benefit from the text, contains brief chapter summaries, lists of key words and phrases, self-tests, and complete bibliographies of articles on relevent topics, taken from a wide assortment of magazines and journals. In addition to the *Study Guide* and the *Instructor's Manual*, another aid to teaching is offered to large adopters of the text: a set of transparencies for use with overhead projectors, showing a number of useful diagrams and illustrations from the text.

At every step during the preparation of this text, vital assistance was provided by a number of people, whose help is acknowledged with gratitude (with apologies to anyone inadvertantly omitted). The most important guidance and support was provided by my wife, Connie; by the West Publishing Company editor, Denise Simon, and the production editor, Tad Bornhoft. Steve Shawl helped scrutinize the galley proofs, as did M. M. Allen, who also helped gather data for tables and reading lists. K. S. Bjorkman helped to prepare the *Study Guide*.

Among my colleagues at the University of Colorado and elsewhere, many contributed generously to this book, by reviewing portions of the text, by providing new data, and by allowing me the use of illustrations. Particularly generous in this connection were J. M. Shull, L. Esposito (both University of Colorado), and H. Eichhorn (University of Florida). Others in this category include J. Doggett, J. K. Malville, J. C. Brandt (all of the University of Colorado); U. Fink (University of Arizona); L. Frederick (University of Virginia); R. Dreiser (Yerkes Observatory); W. Golisch (NASA Infrared Telescope Facility); M. Phillips (Cerro Tololo Inter-American Observatory); D. Malin (Anglo-Australian Telescope); and C. Covault (*Aviation Week*). Reviewers of the manuscript were:

William Anderson, Phoenix College
Timothy Barker, Wheaton College
Howard Brooks, DePauw University
Neil Comins, University of Maine–Orono
Thomas Johnson, Ferris State College

John Kasher, University of Nebraska
Lawrence Mink, Arkansas State University
John Noble, Western Illinois University
Charles Sawicki, North Dakota State University
Horace Smith, Michigan State University

For all of these people, and to the students whose responses to my teaching philosophies have also helped to shape this book, I am grateful. With their continued input, I trust that this book will continue to evolve, as does our understanding of the dynamic universe.

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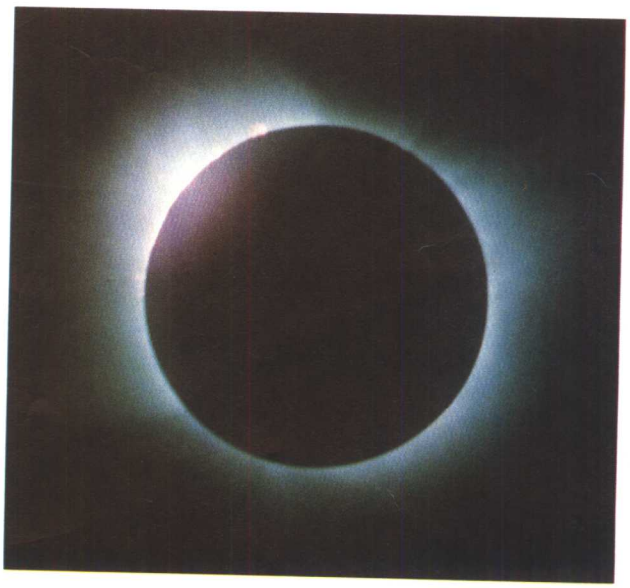
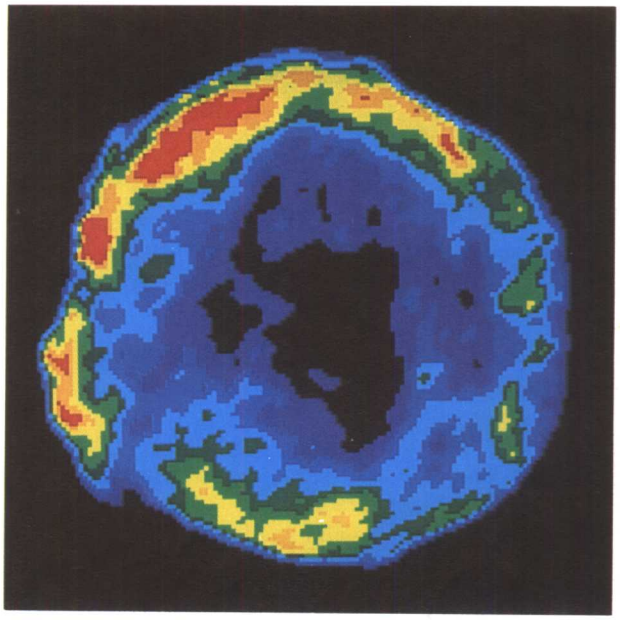
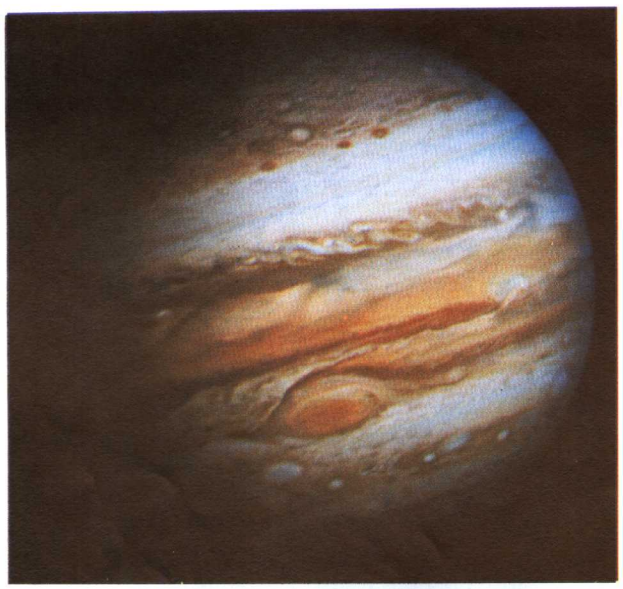
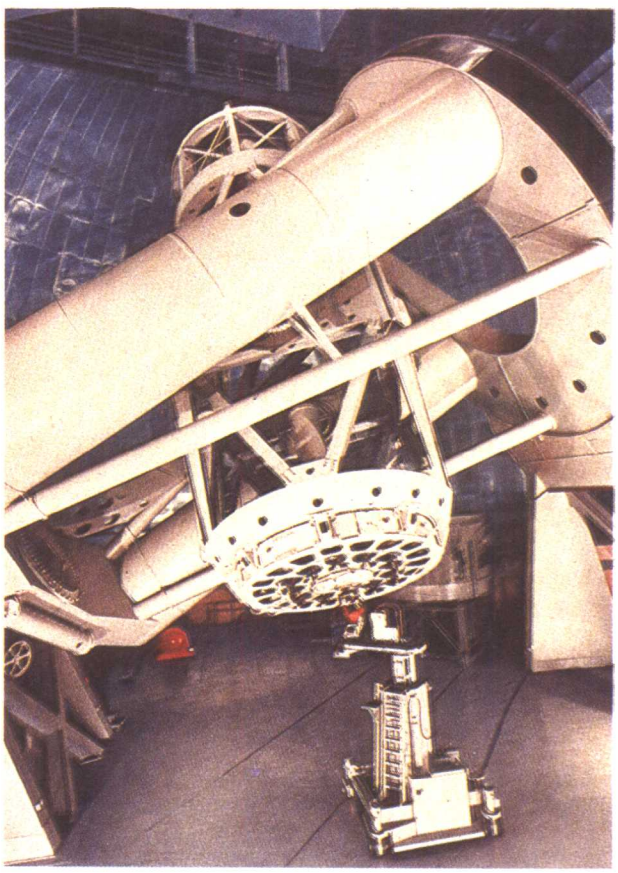






Section VI

Appendices



Section I

The Nighttime Sky and The Tools of Astronomy

We begin our study of astronomy with a discussion of the nature of astronomy and science. Chapter 1 defines astronomy and provides an overview of the nighttime sky and the scale of the universe.

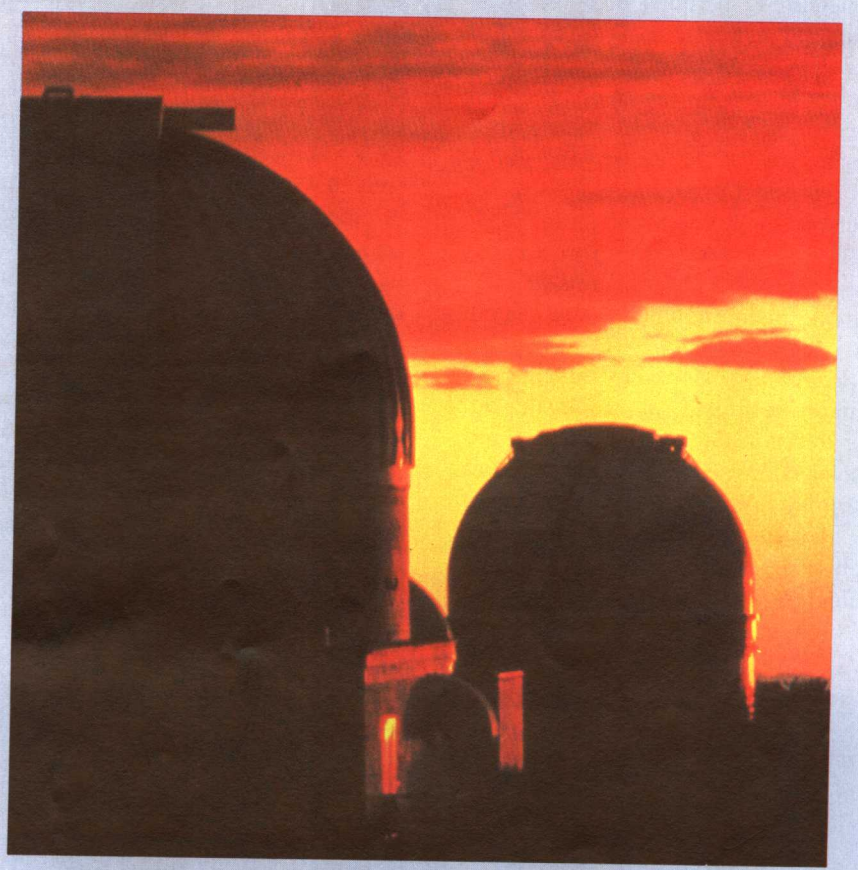
Chapter 2 begins with a description of the motions of celestial objects that can be seen by the unaided eye. It will provide us with an immediate understanding of many of the phenomena that can be seen and appreciated with only our eyes as observing equipment. Thus, armed with all the knowledge our ancestors had, we will see how the ancients fared as they sought to develop a successful picture of the cosmos and their place in it. We will concentrate our historical discussions on the civilizations that arose on the shores of the Mediterranean, for it was here that the foundations of modern astronomy were laid.

Chapter 3 discusses the major developments of the Renaissance, when fresh ideas arose in astronomy, as in all forms of human endeavor. We will learn to appreciate the awesome breakthroughs made by such giants as Copernicus, Brahe, Kepler, Galileo, and Newton, who led the way toward a correct understanding of the universe and the place of our planet in it. We will then move on to the laws of physics that govern such diverse phenomena as planetary orbits, the motions of molecules in a gas, and the tides on the Earth and other celestial bodies.

We would know nothing of the external universe were it not for the light that reaches us from faraway objects, and Chapter 4 describes the nature of light and the way we decipher its messages. We will find that an amazing variety of information can be derived from the spectra of objects like planets and stars. Things once considered forever beyond our grasp are now routinely measured, and in this chapter we will learn how this is done. Chapter 4 includes a description of telescopes and their principles and how they are used to measure light in all portions of the spectrum.

Chapter 1

The Essence of Astronomy



Sunset at Kitt Peak National Observatory. (*National Optical Astronomy Observatories*)

Chapter Preview

The oldest of all sciences is perhaps also the most beautiful. No artificial light show can rival the splendor of the heavens on a clear night, and few intellectual concepts can compare with the beauty of our modern understanding of the cosmos.

Today we study astronomy for a variety of technological and practical reasons, but no one loses sight of the underlying majesty, of the human instinct for intellectual satisfaction. To study astronomy is to ask the grandest questions possible, and to find hints at their answers is to satisfy one of humankind's most deeply ingrained yearnings.

In this text we explore astronomy in the modern context, which is highly technical and sophisticated, but we will endeavor to retain the sense of wonder and beauty that has motivated the science since the beginning. Although some may argue that astronomy is not a practical science, we will see that its origins are rooted in very practical requirements for methods of keeping time and maintaining calendars. In this chapter we begin our study by defining astronomy and introducing some simple terminology that will assist us in later chapters.

What is Astronomy?

Astronomy is the science in which we consider the entire universe as our subject. It is the science in which we derive the properties of celestial objects and from these properties deduce the laws by which the universe operates. It is the science of everything.

Technically we might say that astronomy is the science of everything except the earth, or that it is the study of everything beyond the earth's atmosphere, since the earth and its atmosphere fall into the purview of other disciplines such as geophysics or atmospheric science. We will find, however, that the study of astronomy necessarily includes an examination of the properties and evolution of the earth and its atmosphere.

In the modern sense astronomy is probably more aptly called **astrophysics.** Ever since the time of Sir Isaac Newton (the late seventeenth century), the universe has been explored by applying the laws of physics—most of them derived from earthly experiments and observations—to celestial phenomena. Other scientific disciplines enter into our discussions as well: To study the planets, for example, we must know something of geology and geophysics; to analyze molecules

Figure 1.1 An Ancient Astronomical Site. Stonehenge, a stone monument in England, was built according to astronomical alignments in prehistoric times. *(C. D. McLoughlin)*