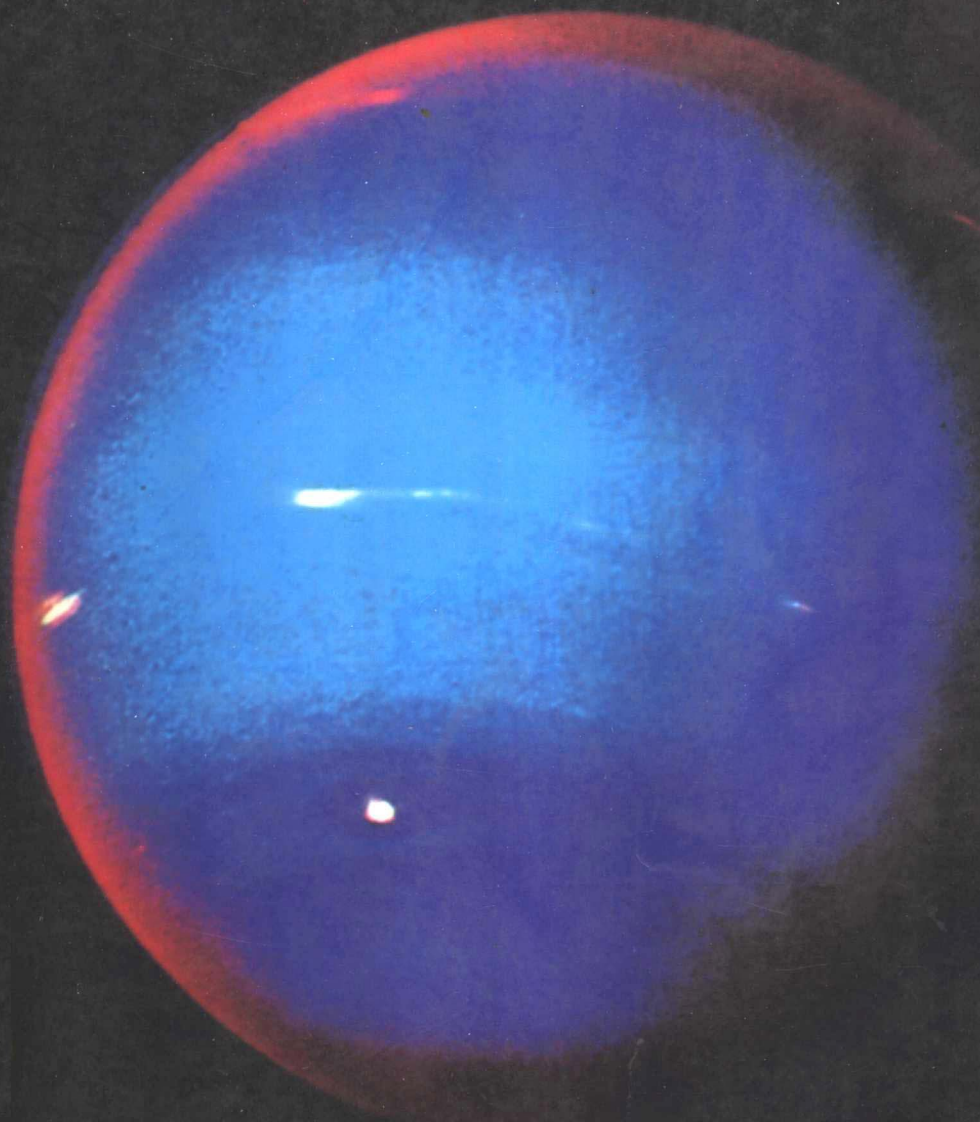
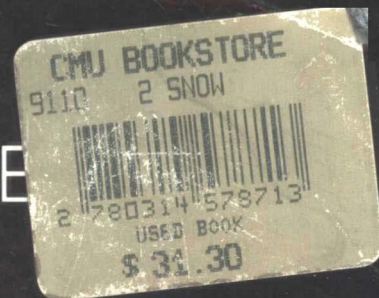


ESSENTIALS OF THE DYNAMIC UNIVERSE

AN INTRODUCTION TO ASTRONOMY

THEODORE P. SNOW



THIRD EDITION



Essentials of the Dynamic Universe

AN INTRODUCTION TO ASTRONOMY

THIRD EDITION

Theodore P. Snow

University of Colorado at Boulder

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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 reason other than to learn whatever there is to be known. Astronomy has produced many useful by-products, of course, and could be (and often is) justified solely on that basis. However, that is not the real reason for astronomy to exist.

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 edition of *Essentials of the Dynamic Universe* is, like its predecessors, an abridged version of the larger *Dynamic Universe*. As in the earlier edition, the emphasis at all times is 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 edition retains the features introduced in the previous two editions, such as “Astronomical Insights,” “Guest Editorials,” and the “Progress of Ideas” prologues to each chapter. These features are designed to enhance student comprehension and enjoyment, by adding historical perspective or clarifying difficult concepts, by presenting the personal viewpoints of leading scientists in the field, and by illustrating the rich variety of ways in which scientific discoveries are made. In addition, the questions at the end of each chapter are entirely new, and the reading lists have been updated to include articles published as recently as the late summer of 1989.

In addition to the increased emphasis on the nature of science, the new edition has been updated to include the most recent discoveries. This means, for example, that major changes have been made in the chapter on the outer planets, in view of the recent successful *Voyager 2* flyby of Neptune, and that substantial rewriting has been done in every chapter. The most extensive changes are to be found in the sections on stellar evolution and in the chapter on cosmology, a field in which new theories with vast implications have been developed since the previous edition was prepared. The launch of the *Hubble Space Telescope* is expected early in the lifetime of this edition, and considerable emphasis has been placed on explaining the many ways in which this space observatory may change our view of the universe.

The esthetic appeal of astronomy continues to be immeasurably enhanced by the four-color format of the book; this allows proper illustrations to be interspersed

throughout the text rather than being relegated to a few color-plate sections. This allows the student to appreciate not only the beauty, but also the relevance, 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.

The arrangement of the text remains traditional, with an introductory section on the background of astronomy, both in history and in basic physics; a section on the solar system, dealing with the planets as individuals before discussing interplanetary bodies and then the formation of the entire system; one 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; 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, and at the end of each is a guest essay in which a leading scientist in the field shares his or her thoughts on current problems or controversies and future directions for research.

The book is designed so that the sequence of sections may be easily changed. For example, if it is desired to teach the sections on stars, the galaxy, and the universe before discussing the solar system, one need only skip directly from Chapter 4 to Chapter 13 and then go on to the end before returning to Chapter 5, where the solar system studies begin. The chapter on the Sun is located at the beginning of the section on stars, so that skipping or delaying the solar system discussion will not prevent the student from learning about the nearest and best-understood star. The summary chapter on the solar system (Chapter 12) includes enough information on the Sun that the discussion of the system as a whole and its formation is complete as it stands.

As already mentioned, the well-received *Astronomical Insights* have been carried over into this edition, with a substantial number of new ones added. These inserts, placed within the chapters, describe people, discoveries, or current controversies or new hypotheses related to the subject matter of the text. They are meant to enhance the students' enjoyment of the material, or add understanding of complex topics, but above all they are designed to increase understanding of the scientific process.

The *Progress of Ideas* articles at the beginnings of the chapters are intended to provide the student some insight into the process of discovery. Most consist of

historical anecdotes used to illustrate how science makes progress by finding new explanations and then testing them in the arena of observation and experiment. Most have been rewritten for this edition.

Supplemental materials for this text include an updated version of the *Study Guide*, now authored by Jeffrey Bennett along with Catharine D. Garmany and the undersigned (all of us from the University of Colorado); and a revised edition of the *Instructor's Manual* by Stephen J. Shawl (University of Kansas). The *Study Guide*, intended to help the student get maximum benefit from the text, contains brief chapter summaries, lists of key words and phrases, and self-tests. In addition to the *Study Guide* and the *Instructor's Manual*, a slide set and overhead transparencies are available to qualified adopters, showing a number of useful diagrams, illustrations, and photographs 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 inadvertently omitted). The most important guidance and support was provided by my wife, Connie; and by the West Publishing Company editors, Denise Simon, who has provided overall guidance for the project, and Stacy Lenzen, who has been responsible for production.

Among my colleagues at the University of Colorado and elsewhere, several have helped by scrutinizing sections of the text, providing new figures, or updating data for tables and appendices. Particularly helpful in the preparation of this edition were Alan Stern, J. M. Shull, John Stocke, Larry Esposito, Charles Hord, and Karen Simmons (all of the University of Colorado), Phil Marcus (University of California, Berkeley), Joseph Jones (Canada France Hawaii Telescope), and J. A. Tyson (Bell Laboratories). I am especially indebted to Kathy Hoyt of the U.S. Geological Survey, for help in providing the most recent planetary images and maps; and to Kelly Aggen of JPL, who made it possible for me to obtain the new *Voyager* images of Neptune in time for inclusion in the book.

A special debt is owed to those who wrote the guest editorials, for adding their thoughts and visions to my own less elegant discussions. Much of the excitement of astronomy lies in the pursuit of new revelations beyond the scope of current knowledge, and the essays contributed by leaders in this pursuit help immeasurably to impart this excitement to the reader. Those contributing new essays to this edition are Roger Culver (Colorado

State University), Henny Lamers (University of Utrecht, the Netherlands), Richard Larson (Yale University), and Robert Bakker (University of Colorado).

I am also very grateful to the many reviewers of the text, who provided comments and suggestions based on their own knowledge of astronomy and their experience in teaching it. The reviewers for this edition were:

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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.

Theodore P. Snow

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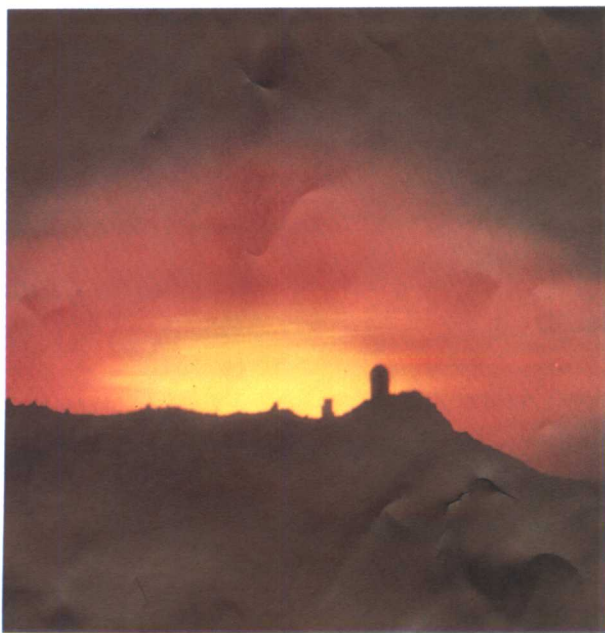
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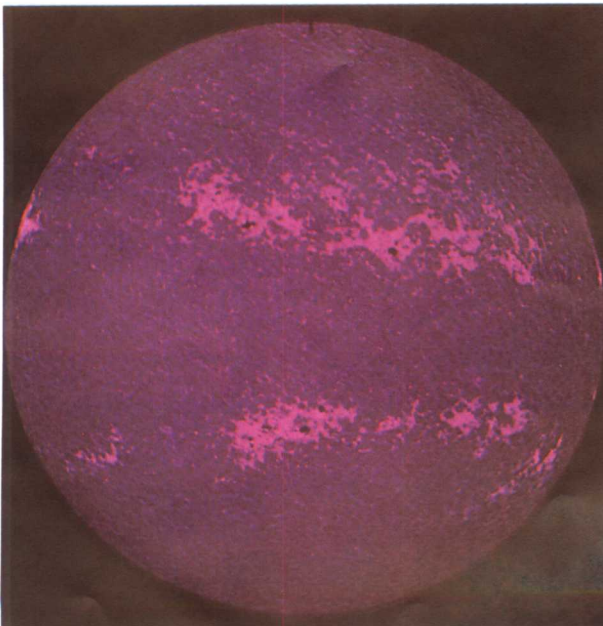


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SECTION ONE

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. This 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 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 hu-

man 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.



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The Essence of Astronomy



Nighttime at Kitt Peak Observatory (National Optical Astronomy Observatories).