KAUFMANN

# DISCOVERING THE UNIVERSE

SECOND EDITION

*To Wanda, with love*

**Front cover:** This picture of Neptune was produced from images taken by the *Voyager 2* spacecraft through ultraviolet, violet, and green filters. The resulting "false color" photograph emphasizes details of the cloud structure and paints the clouds different colors associated with altitude. The highest clouds are colored white and pink, lower clouds are blue, and the lowest clouds are shaded green. The most prominent feature seen in this picture is the Great Dark Spot, a high-pressure storm system roughly the same size as Earth. (JPL; NASA)

**Title page:** Neptune's south pole was tilted slightly toward *Voyager 2* when the spacecraft took this picture. The planet's distinctive bluish color is caused by methane in its atmosphere. The Great Dark Spot is located 22° south of Neptune's equator. White, wispy clouds accompany the Great Dark Spot. A smaller dark spot, seen faintly in a dark blue band encircling the south pole, is at a latitude of 54° south. (JPL; NASA)

**page vii:** $\eta$ Carinae Nebula (NOAO); **page viii:** Spacewalk (NASA); **page ix:** A solar prominence (NASA); **page x:** Dust lanes in M16 (Anglo-Australian Telescope Board © 1986); and **page xi:** A Seyfert galaxy, NGC 1566 (Anglo-Australian Telescope Board © 1987).

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# Preface

Each of us has probably had the experience of looking at the sky on a starry night, feeling overcome by its vastness, and wondering what kind of order governs it. It is easy to imagine the earliest people doing this; it is no wonder that astronomy is the oldest of sciences. Prehistoric ruins throughout the world bear witness to human preoccupation with the heavens.

An adventuresome spirit pervades astronomy, a sense that things wonderful and unimagined are yet to be discovered. For millenia people have been fascinated by topics that astronomers explore today: the creation of the universe, the formation of the Earth and other planets, the motions of the stars, the structure of space and time. Armed with the powers of observation, the laws of physics, and the resourcefulness of the human mind, astronomers survey alien worlds, follow the life cycles of stars, and probe the distant reaches of the cosmos.

In *Discovering the Universe* we join astronomers both past and present in their quest for knowledge about the cosmos. We will investigate phenomena and explore realms far removed from our daily experience. Indeed, many of the objects that astronomers study are too vast, distant, or intangible to sample directly; in fact, many of the phenomena observed today occurred very long ago. When viewed in the context of the evolution of the universe, even the dimensions of space and time take on new meaning.

This book was written with the conviction that the subjects astronomers concern themselves with can—and should—be understood by just about everyone. In today's increasingly technological world, we owe it to ourselves to stay informed as best we can. In this spirit, *Discovering the Universe* offers a broad view of astronomy to readers having little or no background in science or mathematics. The narrative is largely descriptive, and a minimum of equations and formulas appear.

As its title implies, this book is as much about the nature of scientific inquiry as it is about the physical universe itself. Of all the lessons to be derived from an introductory science course, perhaps none is more important than an understanding of how scientists reason. In this book I have tried to convey how astronomers have come to know what they know. By studying the methods that astronomers have used to explore and understand the universe, we sharpen our own reasoning skills and are better able to address other scientific issues.

## Organization

This text was written for the one-term, descriptive astronomy course. It is considerably shorter and less rigorous than its parent text, *Universe,* which offers a different selection of detail and much more expansive coverage.

Having just nineteen succinct chapters, *Discovering the Universe* can be covered in a course as short as ten weeks.

The traditional Earth-outward organization of the text emphasizes how our understanding of the universe developed and invites the reader to share in the excitement of astronomical discovery. The first celestial objects we will examine are those that were observed by ancient astronomers. Moving outward from the planets to the stars and galaxies, we encounter a modern realm of observations, including those from outside the visible range and those made from space. These new observations in turn raise new questions, which draw the reader on to the limits of our universe and understanding.

The first five chapters introduce the foundations of astronomy, including descriptions of such naked-eye phenomena as eclipses and planetary motions and such basic tools as Kepler's laws and the optics of telescopes. A discussion of the formation of the solar system in Chapter 6 prepares the reader for the next four chapters, which cover the planets.

Chapter 11 introduces the Sun and sets the stage for stellar astronomy in Chapter 12. In Chapters 13 through 15, stellar evolution is described chronologically from birth to death. Molecular clouds, star clusters, nebulae, neutron stars, black holes, and various other phenomena are presented in the sequence in which they naturally occur in the life of a star, thus unifying the discussion of a wide variety of objects that astronomers find scattered about the universe.

A survey of the Milky Way introduces galactic astronomy in Chapter 16, followed by a chapter each on galaxies and quasars. Chapter 19, on cosmology, emphasizes exciting recent developments in our understanding of the physics of the early universe. An afterword addresses the question of whether intelligent life might exist elsewhere in the universe.

## Major changes in this edition

The first step in planning the second edition of *Discovering the Universe* was to turn to a broad spectrum of instructors who had used the first edition, whose comments were most influential. Numerous suggestions that friends and colleagues have been sending me since the publication of the first edition also served to inspire this edition. Many of the improvements made in the second edition therefore reflect considerable classroom experience.

Two major organizational changes were made in this edition. The first involves the treatment of light. Virtually all topics relating to the physics of electromagnetic radiation, including spectroscopy and the Doppler effect, are now consolidated in one chapter near the beginning of the book. This chapter, entitled "The nature of light and matter," provides a complete and concise treatment of this critical topic, and increases the text's flexibility as well. For instance, an instructor who chooses to defer or sidestep coverage of the planets can go directly from the chapter on light (Chapter 5) to the first chapter on stellar astronomy (Chapter 11) without any loss of continuity.

The second significant organizational change in this edition is the placement of the chapter on the Sun, which now precedes the discussion of stars in general. As a result, the chapter on solar astronomy offers a comfortable transition between our studies of the planets and the stars.

Many of the people who commented on the first edition expressed the desire for expanded coverage of stellar and galactic astronomy. Chapters 12 through 14 of this edition therefore cover such topics as mass transfer in

close binaries, Type I and II supernovae, and SN 1987A. Chapters on galactic and extragalactic astronomy (Chapters 16 through 18) now include extended discussions of the formation of spiral arms, the evolution of galaxies, and collisions between galaxies. The afterword on life in the universe is also new to this edition. Here we consider how life may be the result of ordinary chemical processes and how scientists determine whether a search for extraterrestrial life is worthwhile.

Many smaller, yet equally important revisions enhance the rest of the text. The text was, of course, updated throughout. Indeed, the latest results from the *Voyager 2* flyby of Neptune was added while the book was in press. The writing has become sharper and numerous color illustrations have been enhanced and added. With these changes, I have ventured to create a comprehensive yet entertaining text that gives a fair and accurate picture of the full scope of astronomy.

## Pedagogical emphasis

I very much care that students find this book a pleasure to read and learn from. The field is dynamic, compelling, and relevant, and no book about it should be otherwise. I hope these pages will be turned with relish and that interest in astronomy will grow daily.

For those taking astronomy as a first science course, I would have the experience be as rewarding as possible. Ease in understanding will play a large role in this. To this end, I have tried to emphasize the central ideas around which astronomy (and indeed other sciences) revolves. Each chapter begins with a one-paragraph abstract that gives a clear idea of the chapter's contents. The chapter headings are given in the form of declarative sentences to highlight main concepts, and a formal summary outlines the essential facts addressed in each chapter. Each chapter concludes with a series of questions grouped by difficulty and content into three categories: review, advanced, and discussion. Answers to questions that require computation (marked with an asterisk) appear at the end of the book. Care has been taken to include questions whose answers require reasoning rather than rote memorization. Finally, a glossary is included that provides page references, so the reader may easily refer back to an appropriate discussion in the text if desired.

## Ancillaries

It is a pleasure to announce the availability of the following outstanding ancillaries to the second edition of *Discovering the Universe:*

An *Instructor's Manual* prepared by Thomas H. Robertson at Ball State University contains chapter outlines, key points and teaching strategies, sample test questions, and suggestions for lecture topics. Included is a resource update of *Universe in the Classroom* by Andrew Fraknoi of the Astonomical Society of the Pacific, providing an invaluable bibliography of books, articles, audiovisual materials, and software.

A printed *Test Bank* and an *IBM PC Test Bank,* revised and expanded by T. Alan Clark at the University of Calgary, Alberta, Canada, are designed for a one-term course in basic astonomy. This two-disk set of multiple-choice

questions, indexed by chapter and topic category, uses an upgraded, comprehensive question editing and handling program, QED, written by Uwe Oehler, University of Guelph, Ontario, Canada. Both the computerized test bank and the printed version are available free to adopters.

An attractive and useful set of *Overhead Transparencies* of full-color line diagrams from the text is available to adopters.

For more information and to request copies of these supplements, please contact:

Marketing Department
W. H. Freeman and Company
41 Madison Avenue
New York, NY 10010


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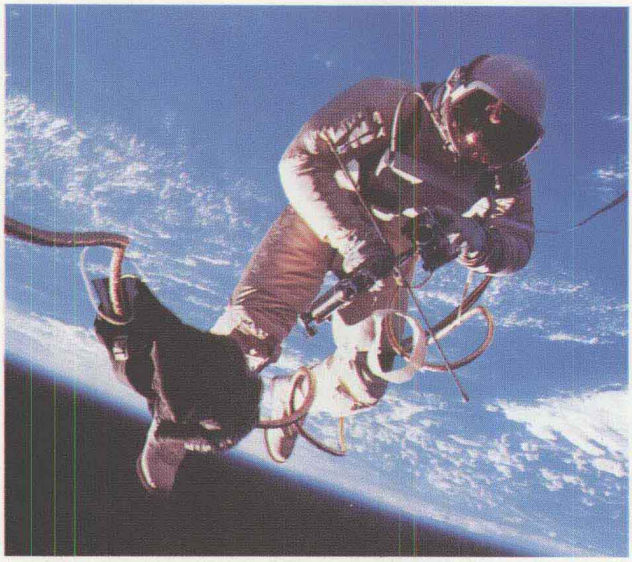
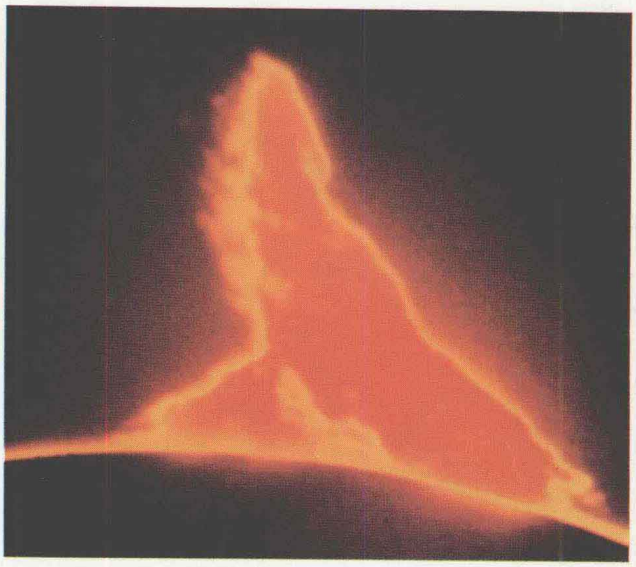
Every effort has been made to make this book error-free. Nevertheless, some errors may have crept in. I would appreciate hearing from anyone who finds an error or who wishes to comment on the text. You may write to me care of the Physics Department at SDSU. I will respond personally to all correspondence.

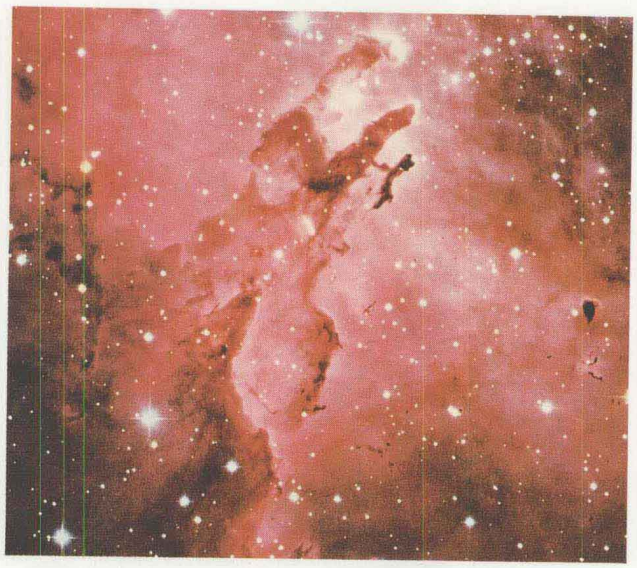
William J. Kaufmann, III
*Department of Physics*
*San Diego State University*

# Contents overview

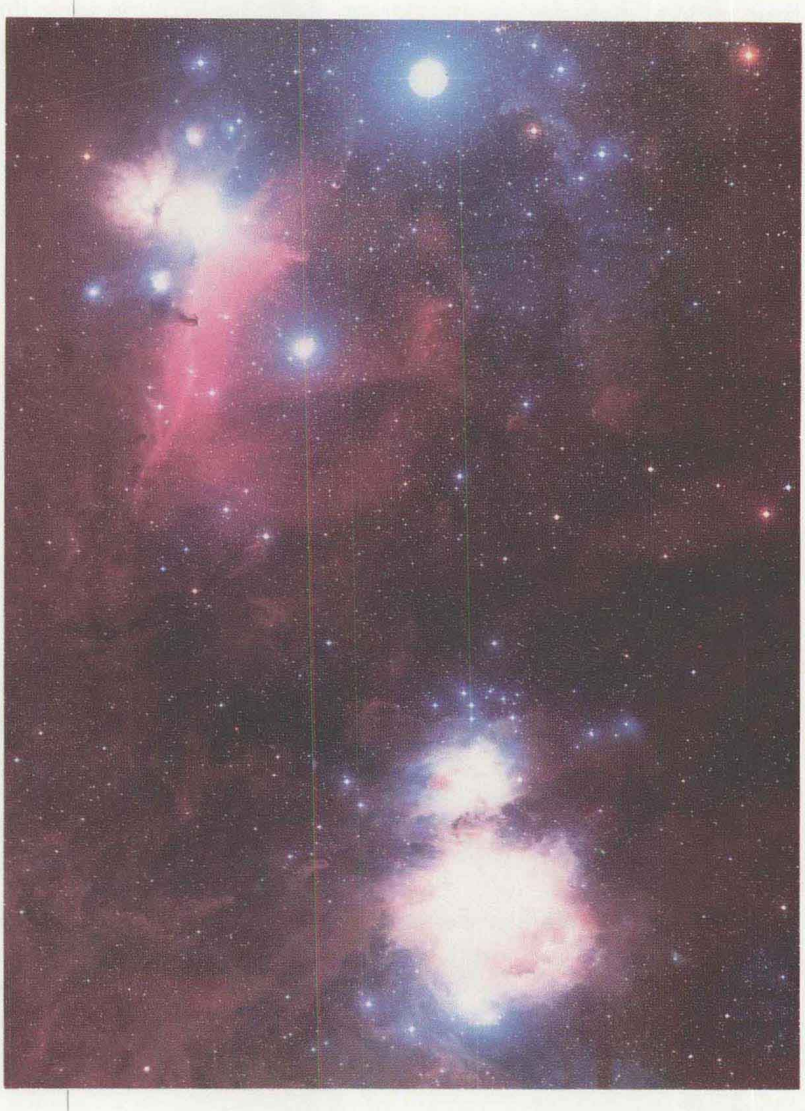
# Contents







# 1 Astronomy and the universe



***The Horsehead and Orion Nebulae*** *New stars are forming in the clouds of interstellar gas and dust shown in this photograph, which covers an area of the sky approximately 4° × 6°. The gases glow because of the radiation emitted by newborn, massive stars. Clouds of interstellar dust block light, and so they appear as dark regions silhouetted against glowing background nebulosity. The two brightest stars near the top of the picture are in Orion's belt. The Horsehead Nebula, so named because of the shape of a silhouetted dust cloud, is in the upper left corner (also see Figure 13-1). The Orion Nebula, overexposed in this view, is at the bottom (also see Figure 13-9). Most of the nebulosity and many of the stars in this photograph are 1600 light years from Earth. (Royal Observatory, Edinburgh)*

**Astronomy is the study of the universe. A brief preview here of the following chapters provides an outline of the scope and content of astronomy. We introduce important tools such as angular measure and powers-of-ten notation. We learn enough about the solar system, stars, nebulae, and galaxies to get a sense of where we will be going in this book. Above all, we learn that the universe is indeed comprehensible. Although some questions remain unanswered, there is no reason to think that any aspect of the physical universe is arbitrary or unexplainable.**

Modern city dwellers usually pay little attention to the night sky. If they do look toward the heavens, they are likely to see little more than the Moon and a few of the brightest stars.

For the many generations who lived without electric lights and smog, however, the breathtaking panorama of the night sky was one of the central experiences of life. Thousands of stars are scattered from horizon to horizon, with the delicate mist of the Milky Way tracing a faerie path through the patterns of brighter stars. The Moon and the planets shift their positions from night to night against this glorious stellar background while the entire spectacle swings slowly overhead from east to west as the night progresses. Our ancestors learned to tell time and directions from these changing patterns in the sky. They mapped the stars into picture outlines of the most important legends and ideas in their cultures.

When we gaze at the stars, as did these earlier people, we find our thoughts turning to profound questions. How was the universe created? Where did the Earth, Moon, and Sun come from? What are the planets and stars made of? And how do we fit in—what is our place in the cosmic scope of space and time?

Speculation about the nature of the universe is one of the most ancient human endeavors. The study of the stars transcends all boundaries of culture, geography, and politics. The modern science of astronomy carries on an ancient tradition of observation and speculation, using the newest tools of technology and mathematics. In the most literal sense, astronomy is a universal subject—its subject is indeed the universe.

## Astronomers use angles to denote the apparent sizes and positions of objects in the sky

Astronomers have inherited many useful concepts from antiquity. For example, ancient mathematicians invented angles and a system of angular measure that is still used to denote the positions and apparent sizes of objects in the sky.

An **angle** is the opening between two lines that meet at a point. **Angular measure** provides an exact description of the shape or "size" of an angle. The basic unit of angular measure is the **degree,** designated by the symbol °. A full circle is divided into 360°. A right angle measures 90°. As shown in Figure 1-1, the angle between the two "pointer stars" at the front of the Big Dipper is 5°.

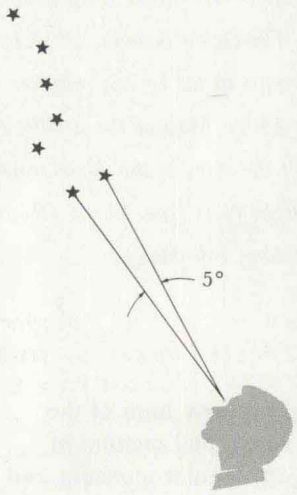



***Figure 1-1 An angle*** *An angle is the opening between two lines that meet at a point. The angular distance between the two stars at the front of the Big Dipper is 5°. For comparison, the angular diameter of the Moon is $\frac{1}{2}$°.*

Astronomy uses angular measure in a wide range of situations. For example, we can use an angle to describe how big an object appears in the sky. Imagine looking up at the full moon. The angle covered by the Moon is nearly $\frac{1}{2}$°. We therefore say that the **angular diameter** or **angular size** of the Moon is $\frac{1}{2}$°. Alternatively, astronomers say that the Moon **subtends** an angle of $\frac{1}{2}$°. Ten full moons could fit side by side between the two pointer stars in the Big Dipper.

From everyday experience, we know that an object looks big when it is nearby, but small when it is far away. The angular size of an object therefore does not necessarily tell you anything about its actual physical size. In order to convert angular size to physical size, you also need to know the distance to the object. For instance, the fact that Moon's angular diameter is $\frac{1}{2}$° does not tell you how big the Moon really is. But if you also happen to know that the distance to the Moon is 376,300 km, then it is possible to calculate that its physical diameter is 3476 km.