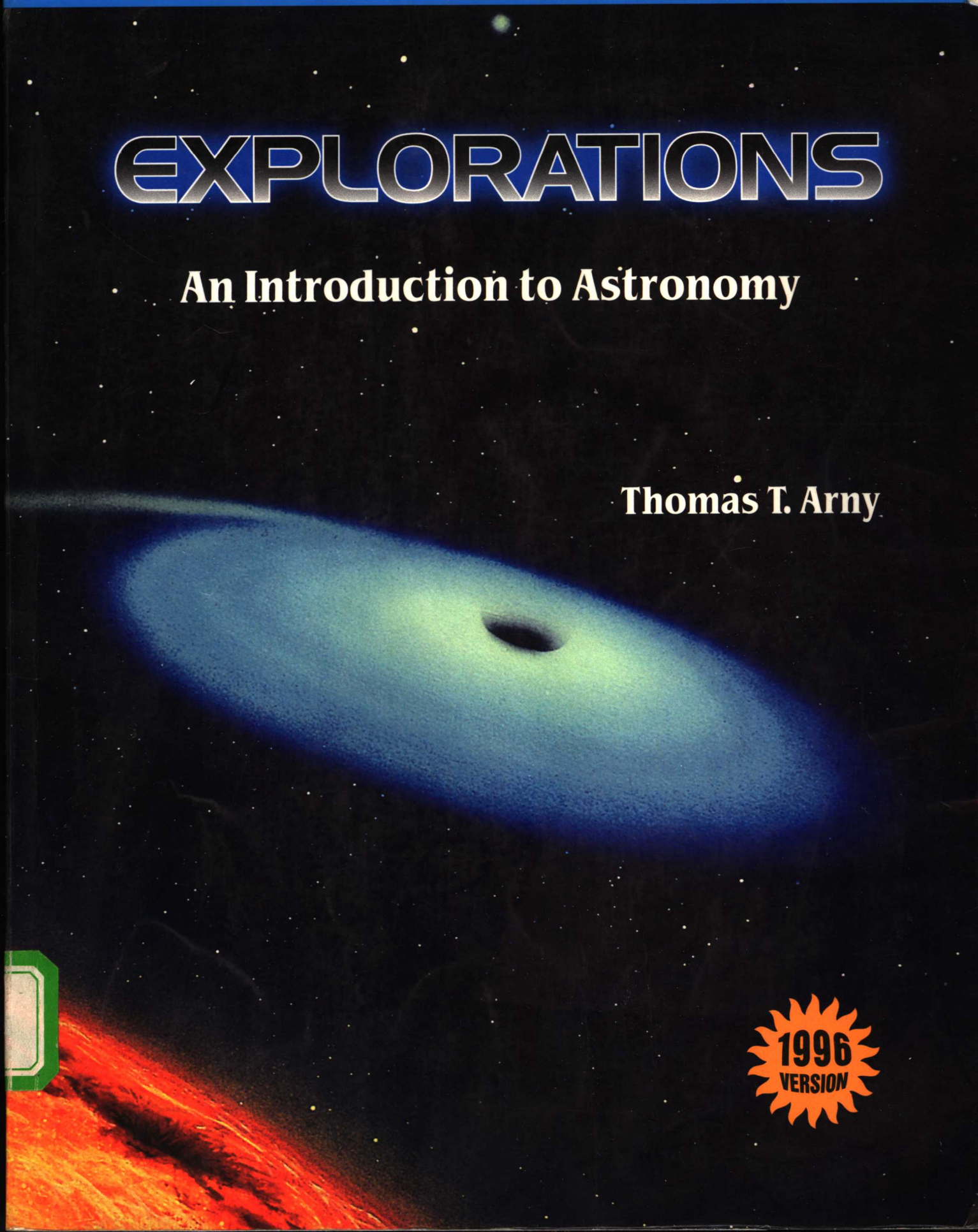
EXPLORATIONS

An Introduction to Astronomy

Thomas T. Arny



1996 VERSION

Explorations

an Introduction to Astronomy

1996 Version

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with 500 *illustrations*

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Courtesy David Malin, Anglo-Australian Observatory.

Preface

Over the past few years, many people have asked me why I was writing an astronomy book. Much of my motivation comes from wanting to share my own sense of wonderment about the Universe. I hope that in an astronomy course students can get some sense of where they fit in the astronomical Universe—a sense of location in the cosmic landscape. I also hope that students will come away from such a course with a sense of the richness of the Universe. When we look around us on our own planet we see incredible bio-diversity. So too when we look at the heavens we see incredible astro-diversity. Stars, moons, and planets are as strange and colorful as tropical butterflies. Finally, I hope that students will gain some appreciation of the methods by which such tiny beings as we have learned so much about the Universe. Those methods are not just laboratory techniques. Far more important is the process of learning: the steps by which we go from observation to hypothesis and then on to what we hope is understanding.

But why write your own astronomy book when so many already exist? Part of the reason is that I have been dissatisfied with the ones I have used. For example, most of the current books have so much material that they are impossible to get through in a single semester. I therefore decided that my first goal was to make a book that was short. However, as I worked at it, I kept finding things that I didn't want to leave out, material such as calendars and history of astronomy. But how could I write a short book and still include such topics? The solution was to organize the book so that instructors and students could omit the unwanted sections without interrupting the flow of ideas. Thus I placed a number of topics, such as telescopes and time keeping, into Essays that may be easily skipped. I also tried to make the book short by limiting its scope. Rather than covering everything, I have tried to focus on only what seemed to me the most important ideas at that time.

Another goal I set myself was to give simple explanations of why things happen. Such explanations generally involve physical principles that are unfamiliar to non-science students. However, many even very complicated physical ideas can be appreciated, if not fully understood, by appeal to analogy or to similarities with everyday phenomena. For example, diffraction effects can be seen by looking at a bright light through a lock of your hair pulled over your eyes or through glasses that you have fogged with your breath. By tying physical principles to everyday observations, many of the more abstract and remote ideas become more familiar. Thus I have used analogies heavily throughout the book, and I have tried to design the art in this book to make those analogies more concrete.

Another goal I set myself was to explain *how* astronomers know the many curious things they have learned about our Universe. Such explanations often

require mathematics, and so I have included it wherever it is crucial to understanding a method of measurement, such as in the use of the modified form of Kepler's third law to determine a star's mass or in Wien's law to measure a star's temperature. However, because math is so intimidating to so many students, I have tried to begin these discussions by introducing the essence of the calculation in everyday language. Thus, if the student or instructor chooses to omit the math, it will not prevent an understanding of the basic idea involved. For example, Wien's law relates the temperature of a hot object to its color by a mathematical law. However, the consequences of the law can be seen in everyday life when we estimate how hot an electric stove burner is by the color it glows. Similarly, I have tried to work through the math problems step by step, explaining that terms must be cross-multiplied, and so forth. Finally, I have used a color code to indicate quantities so that students whose math skills are rusty may have more success in following the manipulations that must be done to obtain the answer.

As a final goal, I have set many of the modern discoveries in their historical context. I want to demonstrate that science is a dynamic process and that it is subject to controversy. Ideas are often not immediately accepted and to appreciate those that scientists finally settle on, it helps to understand the arguments for and against as well as the train of reasoning that leads to the "accepted" answer. On this point I must digress and reveal my own amazement (and naivety) at how many widely accepted ideas have such flimsy underpinnings and how many widely quoted values for astronomical quantities are very imperfectly known.

NEW TO THE 1996 VERSION

This new 1996 version of *Explorations: An Introduction to Astronomy* incorporates significant new discoveries as well as numerous minor revisions. Because this 1996 version retains the same layout and pagination as its predecessor, I couldn't make extensive changes. However, I have added new pictures (including a number from the repaired Hubble Space Telescope) and described important new results, although it has not been easy to pick among the many exciting discoveries of the last 2 years. Two astronomical events, however, seem to me to stand out. The first is the measurements of the Hubble constant of 75 km/s/Mpc (deduced from observations of Virgo cluster galaxies both from the ground and from the Hubble Space Telescope). This value leads (with standard, critical density, cosmological models) to an age for the Universe that conflicts with the age of globular clusters. Thus I have added a brief discussion of how this discrepancy might be resolved. The other big event I have chosen to add is the collsion of Comet Shoemaker-Levy with Jupiter, even though the analysis to date reveals nothing very striking.

In addition to these changes, I've added, where appropriate, more problems and more recent references at the end of the chapters. Color coding of variables in mathematical equations proved to be confusing for some students, so I have removed it from in-text equations. However, I have retained the color coding in figure labels and captions where it is less intrusive and where, I believe, it can be pedagogically useful. Finally, I have tried to clarify a number of points throughout

the text. These modifications leave the pagination unchanged, even though 75 percent of the pages have been altered to some extent. By keeping pagination the same, students who only have access to the 1994 version can still participate in a class using the updated *Explorations* 1996 version.

HOW TO STUDY WITH THIS BOOK

Learning anything requires a certain amount of work. You certainly don't expect to be able to pick up a guitar and play it without practice, nor do you expect to be able to jog 5 miles without working-out regularly. Learning astronomy also requires some work. The steps below may help you learn material better and more easily.

When reading any assignment, begin with the introduction. Then skip to the summary. Finally, start again and read the assigned material through. As you read, make notes of things you don't understand. For example, if you are puzzled about why eclipses don't happen every month, make a note. I would urge you *not* to highlight as you read. Making a few short notes is much more effective than highlighting whole paragraphs.

Look carefully at the pictures and diagrams. If the figure caption has a question in it, try to answer it. Make your own sketch of diagrams to be sure you understand what they represent.

In a first reading of a chapter, I'd suggest that if you are troubled by math you should simply skip it for the time being. Be sure, however, to read the material leading into the math so you at least understand what is being dealt with. When you encounter a mathematical expression of a physical law, put in words what the law relates. For example, the law of gravity relates the force of gravity to the mass of the objects and their distance apart.

If as you read you encounter words or terms that you don't know, look them up in the glossary or index. You are just wasting your time if you read a description of some object and you don't know what it is.

When you finish the assignment, try to answer the review questions. They are short and are designed to show you whether you have assimilated the basic factual material of the assignment. Try to do this without looking back into the chapter, but if you can't remember, look it up rather than skip over the question. You might find it helpful to get a pile of scratch paper and actually write out short answers to the questions.

Having read the material once, go back and try to work through the math parts. Use the color codes to follow the steps. Then try a practice problem to see if you can work through the material on your own.

If you get stuck at any point, go see your teaching assistant or professor for help. Don't be shy about asking questions. I wish someone had beaten this into my head earlier. Learning is a thousand times easier if you ask questions when you get stuck.

Throughout the book, I have also tried to convey some of my own enthusiasm for astronomy. Many astronomical objects are strikingly beautiful. Others conjure up a sense of amazement. To me it is the ultimate wonder that within the Universe life has formed that can contemplate the Universe and ask what it is about. Seeing a clear night sky spangled with stars is for me a nearly religious experience. And yet the beauty that I see and my sense of wonder is enriched even more by an appreciation of the complex processes that make the Universe work. I hope this book will similarly increase your appreciation of our Universe's wonders.

If while using this book you find mistakes or if you have suggestions about how to make it better, *please* let me know. Write me at the Astronomy Program, University of Massachusetts, Amherst, MA 01003-4525, USA. If you have access to e-mail, please let me know that way. My address is arny@donald.phast.umass.edu. I really want your feed-back.

ASTRONOMY ON THE INTERNET

Over the last few years, many teachers and students have gained access to an exciting new astronomy resource: the Internet. Hundreds of scientists around the world have created picture galleries and accompanying explanations that can be read by any user with access to the Internet. All are available "free" at the click of a mouse. Moreover, *no special computer expertise is needed.*

To use this resource, get a computer account at your school on a machine that runs MOSAIC, NETSCAPE, or a similar program. Check with your local computer resource person for how to connect. Typically you'll need about 10 minutes to learn how to use the system. It's time well spent, because the Internet has become one of the best ways to obtain astronomical information and to find out the lastest news about astronomical discoveries (similar systems exist for many other disciplines and hobbies). It would be almost impossible to list all the resources: they number in the thousands and change daily. However, I've listed below a few of the addresses that I've found especially useful. To access them, type in at the command on your computer the full address listed below. Then, depending on your computer, hit the return key, or click on a "go get" button. For those not yet familiar with the Internet, a quick note on abbreviations and terms follows:

http = hypertext transfer protocol
www= world wide web
html = hypertext markup language
page = the computer screen display that appears when you call a given address
link = just that: a link from one page to another, perhaps to a computer on the other side of the world.

Below are some addresses for astronomical pictures and information. You need to type all the characters as shown (although some computers don't distinguish between capital and lower case letters).

http://www.c3.lanl.gov/~cjhamil/SolarSystem/homepage.html
Views of the Solar System: a superb overview of Solar System objects with pictures and text by Charles Hamilton at Los Alamos National Laboratory.

http://www.jpl.nasa.gov
The Jet Propulsion Lab: current information about space probes and a fine archive of pictures.

http://www.stsci.edu/top.html
The Space Telescope Science center: up-to-date pictures from the Hubble telescope and explanatory text.

http://www.yahoo.com/Science/Astronomy/
An amazing collection of astronomical pages, including the beginnings of an on-line introductory astronomy text. (The yahoo site has lots of

special interest pages on other academic subjects as well as on travel and entertainment.)

http://fourmilab.ch/solar/solar.html

The Solar System Live: another good site for pictures and information about the Solar System.

http://www.mtwilson.edu/Services/starmap.html

Generates a star map for any time, date, and location you type in. Also gives Moon phase and planetary positions.

Note: Most of these addresses will suggest links to many additional sources, thus creating a web of information (hence the name, "world wide web").

ACKNOWLEDGMENTS

I owe thanks to many, many people for their help in this book. Help came in the form of advice, pictures, information, encouragement, and improvements to my own understanding of things. I have pestered all of my colleagues in the Five College Astronomy Department and many of them in the Department of Physics and Astronomy. Mike Skrutskie and Martin Weinberg, as neighbors down the hall, bore a disproportionate share of questions, and I owe them special thanks. Gene Golowich read over an early draft on inflationary cosmology and made valuable suggestions. I profited from many conversations with Ted Harrison, Ed Phinney (of the Classics Department), Peter Schloerb, and David Van Blerkom. Other people who contributed are Bill Bates and Rick Newton, who helped with setting up and taking pictures, and Linda Ray Arny, who helped me locate many references. I also want to thank Amy Lovell for reading the page proofs and helping with the last round of checks.

Several readers have been kind enough to make suggestions or point out errors in the 1994 version. They include Daniel Jaffe, Susan Kleinmann, Mesgun Sebahu, Mark Stuckey, and Eugene Tademaru. I particularly want to thank Ben Zellner, Richard White, Mike Skrutskie, and James O'Connell for very detailed critiques of several sections.

Needless to say, any errors that remain are solely my fault.

I am also very grateful to many people at Mosby. James Smith, who began the project that eventually became *Explorations,* made many additional valuable suggestions. Likewise, Lloyd Black offered many helpful comments and ideas for the update. Donata Dettbarn searched diligently and creatively and found many beautiful new pictures. Judy Hauck, the editor for the 1994 version of *Explorations,* made many helpful new suggestions. I am especially grateful to John Murdzek who was the developmental editor for the 1996 version. John read the manuscript meticulously, annotating and querying points that needed clarification and suggesting many improvements. I also want to thank Mark Spann and Jerry Schwartz and the many other people in the production department who turned my scrawling annotations into changes and have again produced such an attractive book. Finally, I am extremely grateful to the many Mosby sales representatives who sent on to me comments from adopters and potential users about points they felt needed fixing. Thank you all.

I also want to thank Carolyn Duffy and Greg Holt of ArtScribe who did the many lovely color figures for the book and Jay Hoagland who did the marginal sketches.

REVIEWERS

The following people have reviewed this book at various stages of its development. I very much appreciate their help, suggestions, and corrections. Any errors that remain are not their fault, but mine.

Bruce Balick, University of Washington, Seattle
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REVISED ANCILLARY PACKAGE

The 1996 version of *Explorations* has a new and expanded set of ancillary materials that should benefit students and professors alike.

First, we have produced a ViewStudy™ CD-ROM that is easy to use and is available in both Windows and Macintosh formats. The ViewStudy™ CD-ROM allows students and professors rapid access to all of the artwork and many of the photographs in the text. These images include the complete figure captions and may be called up by chapter, by topic, or by figure number. Users can browse through the images and captions, enlarge them for projection, or make transparencies from them. Images and captions can also be printed to create "study cards." Images can be organized to create custom-designed slide shows or exported to word processing programs for use in exams and quizzes. The ViewStudy™ CD-ROM is available free to adopters and at a very low cost to students.

Second, 24 new Transparency Acetates have been added to the original set. The new transparencies include several new Hubble Space Telescope images and images from the Comet Shoemaker-Levy impact with Jupiter.

Other revisions in the ancillaries include an updated Instructor's Manual, Test Bank, and Computerized Test Bank. The Computerized Test Bank now uses ESATEST III for Windows and Macintosh, which offers a two-track design (EasyTest for the novice and FullTest for the expert), full editing features, and the ability to import text and graphics. In addition to generating tests, the software includes an electronic grade book and an on-line testing function.

Finally, the following ancillaries are still available from the 1994 version of *Explorations*: full color Transparency Acetates (also available as slides), a two-sided Videodisc, and (to qualified adopters) the *Dance of the Planets* and *Voyager II* software.

Explorations

an Introduction to Astronomy

1996 Version

The Cosmic Landscape

God taking the measure of the Universe in the etching *Ancient of Days*, by William Blake (c. 1794). It was not until we humans could take measure of the Universe that we could begin to make sense of its structure.

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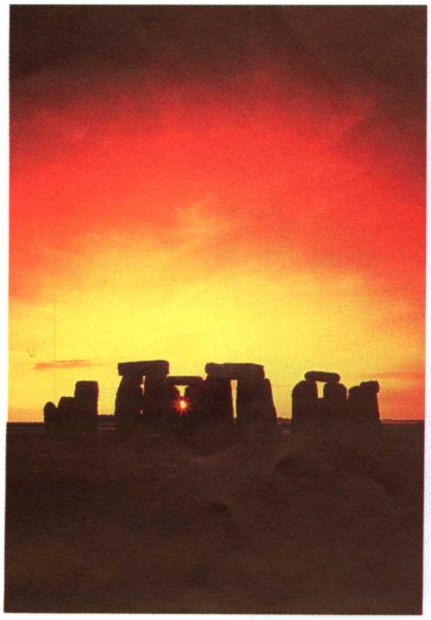

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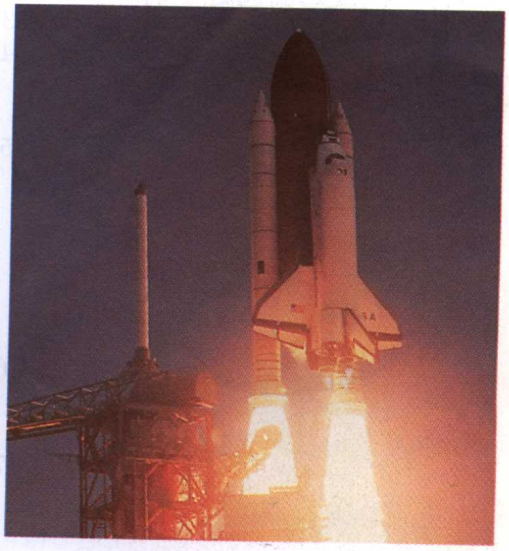
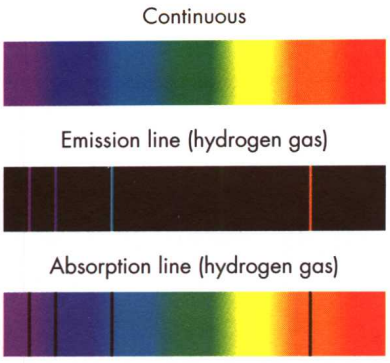
CHAPTER 2 Gravity and Motion

CHAPTER 3 Light and Atoms





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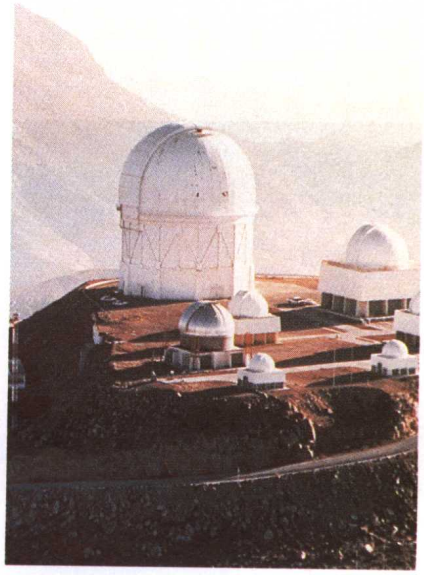

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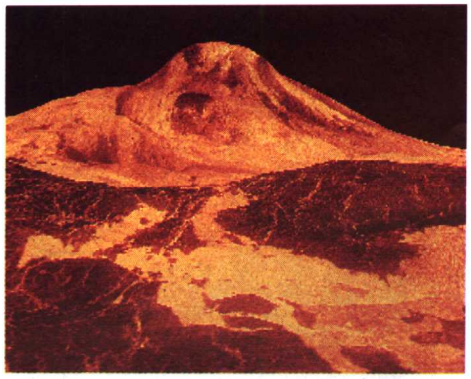
CHAPTER 6 Overview of the Solar System



CHAPTER 7 The Terrestrial Planets