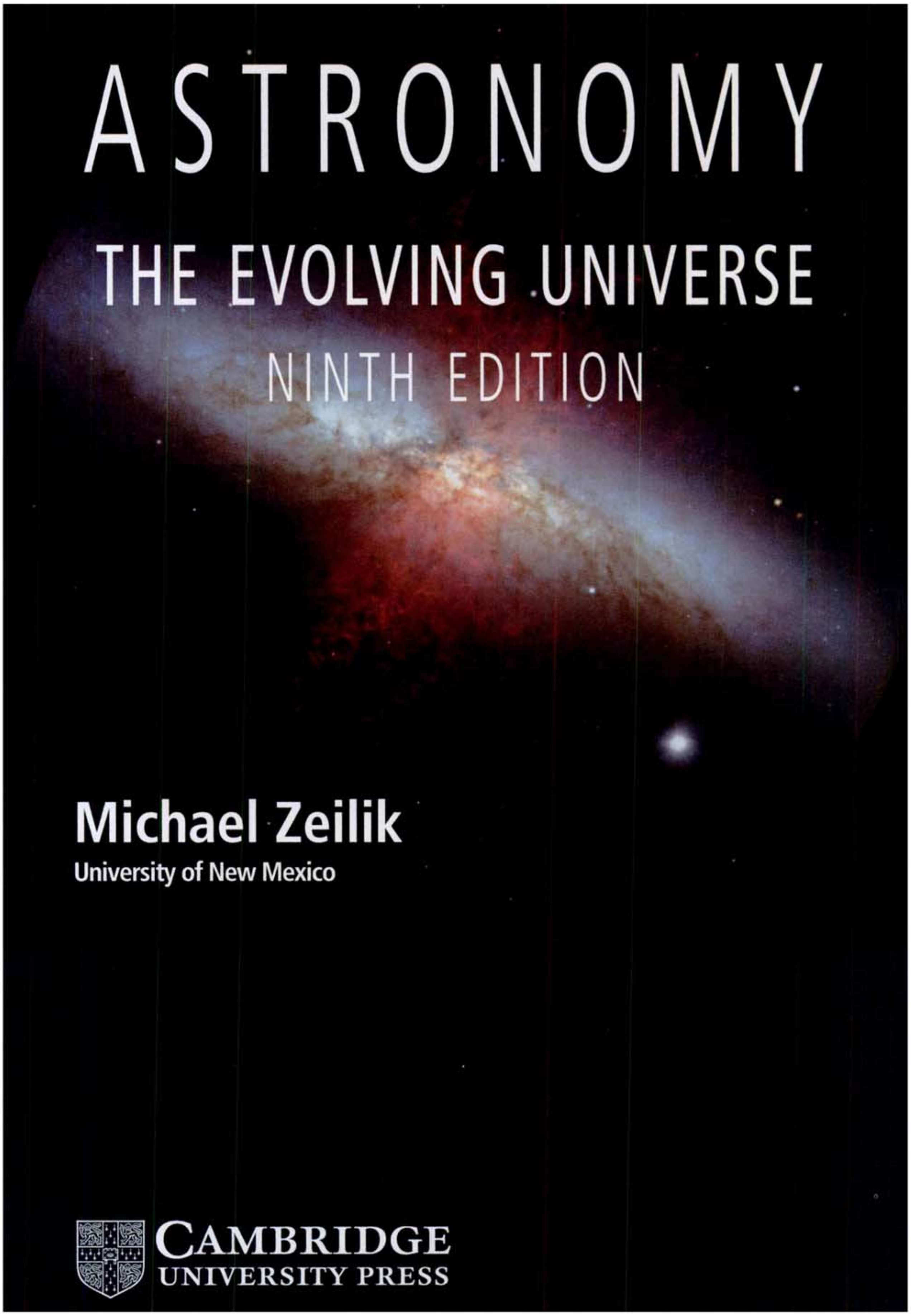
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Magnificent Messier 82 (sometimes called the Cigar galaxy) captured by the Subaru Telescope on Mauna Kea, Hawaii, U.S.A. This irregular galaxy lies about 12 million light years away in the constellation Ursa Major. Messier 82 is the brightest galaxy in the sky in infrared light. Its core appears to have been disrupted by a close encounter with another galaxy, triggering a colossal round of starbirth. Winds from these hot, young stars expel supersonic hydrogen gas (red filaments) from the galaxy. Copyright 2000 National Astronomical Observatory of Japan.

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Dr. Michael Zeilik works as Professor of Astronomy at the University of New Mexico. In his teaching, he specializes in innovative, introductory courses for the novice, non–science major student. His classes include cooperative learning teams to explore key astronomical concepts with hands-on activities. He has been supported by grants from the National Science Foundation, NASA, the Exxon Educational Foundation, and the Slipher Fund of the National Academy of Sciences for innovations in astronomy education, delivery of astronomy to the general public, and astronomy workshops for in-service teachers.

Dr. Zeilik's current research activities focus on two areas: astronomy education and astronomy in the historic and prehistoric Pueblo world in the U.S. Southwest. He has published more than 100 professional articles and four books and has given more than 200 talks to professional and lay audiences.

Dr. Zeilik earned his A.B. in Physics with honors at Princeton University and his M.A. and Ph.D. in Astronomy at Harvard University. He has been a Woodrow Wilson Fellow, a National Science Foundation Fellow, and a Smithsonian Astrophysical Observatory Predoctoral Fellow. At the University of New Mexico, he has been named a Presidential Lecturer, the highest award for all-around performance by a faculty member. In 1998, he was appointed a Research Fellow with the National Institute of Science Education.

In 2000, he became Chair of the Astronomy Education Committee of the American Association of Physics Teachers.

Dr. Zeilik is listed in *American Men and Women of Science*, *The Writers Directory*, *Contemporary Authors*, *Who's Who in the West*, and *Who's Who of Emerging Leaders in America*. He is a member of the Authors Guild and the Text and Academic Authors Association. The 8th edition of *Astronomy: The Evolving Universe* won a 1997 Texty Award from the Text and Academic Authors Association.

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Preface

A *ninth* edition! I really cannot believe that an idea that I had some twenty-five years ago has lived so long and gone so far. Many instructors and students have told me that they've enjoyed using the book, and that feedback has certainly helped me along. I also desire to improve this book so that it innovates and evolves as a better learning tool. Finally, astronomy changes rapidly, especially with the advent of new space and ground-based telescopes. Our outer vision grows, and our inner one intensifies. So what's new for this edition?

One, the obvious **updating of the material.** Constant change drives the excitement of astronomy. That is a main reason why astronomy appeals to me, and, I hope, to you. There's always something new and unexpected for us to discover in the universe. However, I have done the updating with great care to focus on discoveries that I think have long-term value and connect with the major concepts.

Two, a **streamlining of the material** so as to make the descriptions, concepts, and explanations as clear and concrete as possible. I have taken great care to minimize the use of technical terms and the passive voice. I also gave special attention to the Learning Outcomes and Key Concepts to keep them concise and precise.

Three, a **refined art program.** The figures have been reviewed and revised with the goal of better understanding by the novice student (while keeping the science accurate). I have tried to incorporate a human perspective whenever possible. I have also aimed for clarity and simplicity so that careful "viewing" of the figures will illuminate key concepts.

Four, a **research-based pedagogy.** I have targeted concepts in this edition more than ever, based on research in astronomy education carried out by myself and others. But concepts in isolation have little value – they must be *connected*. The right connections of key concepts result in the "big picture" of the cosmos. My goal for my course and this book is to provide a connected understanding of astronomy. To do so, I have introduced a new organizing feature, Celestial Navigators™.

Each chapter contains one **Celestial Navigator™.** These maps provide visual guides of major concepts in the chapter and explicitly show their connections. I have tested them in my classes, and they result in large, robust gains in students' connected understanding of astronomy.

To promote an even higher level of conceptual unification, each part begins with a **Part Concept,** followed by an **Inquiry Focus** – a series of "How do we know . . . ?" questions to link concepts across chapters within a Part. Again, the goal is the "big picture," this time within a thematically-unified Part.

THEMATIC AND TOPICAL STRUCTURE

Previous editions have developed the notion of "how do we know?" in astronomy. I have made that question more explicit and the central theme for the entire book. I believe that answering the "how do we know?" promotes the understanding of any subject, but astronomy more so than many others do. Why? Because once we leave the earth and solar system, astronomy becomes quite abstract, essentially light, physics, and models.

Yet people tend to view science as a disconnected collection of facts, and our culture reinforces this view. Take for instance, the quiz show *Who Wants to Be a Millionaire*. The questions use a multiple-choice format, which is common in schools in the United States. Here is one question for the big prize, $1,000,000:

How long does it take the light from the sun to reach the earth?

- **A.** 42 seconds
- **B.** 3 minutes
- **C.** 8 minutes
- **D.** 1 hour

Do you know the answer? (It is C.) Now, that's OK, but do you know the unasked question? *How do we know that the sun is 8 light-minutes from the earth?* That's a much deeper question and requires a level of understanding far more fundamental than the first (which can just be memorized).

"How do we know?" is the governing theme of this edition. In terms of topics, this book has two main aspects: to describe in narrative form the range of the astronomical universe and its cosmic connections; and to introduce students to how astronomers think about the cosmos so they can gain some understanding about its operation. I hope that students will become so enticed by the contents that they will become intrigued by the concepts linking and illuminating astronomical phenomena.

This edition is designed for a one-semester introduction to astronomy. Note that it is much shorter than previous editions, with fewer and shorter chapters. Yet it retains the previous structure of four coherent parts, each focusing on a key subtheme of cosmic evolution. Like the cosmos, each part connects to the others, so you can really approach the four parts in any order.

Part 1: Changing Conceptions of the Cosmos

This part accents the evolution of cosmological ideas, from the geometric views of the Greeks to the mind-boggling visions of modern astronomy. It leads off with the simplest observations you can make without a telescope from the earth and ends with the farthest reaches of the visible universe. Part 1 acquaints the reader with the idea of *scientific models*, the conceptual core of modern scientific thought. Scientific models are born from our imagination and experience; they mark the essential creative act of the scientific enterprise. As such models evolve, they shape our changing conceptions of the cosmos. The development of scientific models resounds throughout the book; it is *the* fundamental tool to understand the universe.

Essential to the formation of models are new astronomical observations. In the age of microelectronics and space astronomy, we have greatly expanded our vision of the cosmos. Many space telescopes, especially the Hubble Space Telescope, marked great changes in the outer vision of twentieth-century astronomy. In this century, we know that new technology telescopes on the earth will surpass space telescopes in some ways. We can hope that lunar-based telescopes will augment the observational legacy of space telescopes. New generations of computers endow our minds with another way to see the physical processes in the cosmos by the simulation of astronomical systems. Together, computers and telescopes work as the tools to impart innovative ideas to astronomers.

Part 2: The Planets: Past and Present

Flyby spacecraft and gangly landers have provided new insights to our understanding of the planets. This part focuses on the physical properties of the planets to infer their origin and evolution. It first takes a comparative look at our current knowledge of the planets, especially our earth and moon, as well as Mercury, Venus, and Mars. These planets show different degrees of evolution, with the earth being the most evolved. The other planets – Jupiter, Saturn, Uranus, Neptune, and Pluto – have, in contrast, changed little since their birth.

Space missions have disclosed that the moons of the outer planets are really worlds unto themselves, places of rock and ice scarred by violence in the past. These new worlds provide important clues, along with comets and meteorites, of the early history of the solar system. So planetary evolution traces back to origin – the birth of the solar system from an interstellar cloud of gas and dust. By astronomical standards, that birth was quick, violent, and chaotic – shaping the primitive forms of the planets. This picture implies that many other single stars have planetary systems and that these other worlds resemble the local planets in broad ways.

Part 3: The Universe of Stars

Our sun and its planets swing around in a vast island of stars called the Milky Way Galaxy – our home galaxy. As the nearest star, our sun serves as the close-up model for other stars, especially to understand the physical processes within them. The Galaxy contains some hundreds of billions of stars at various stages of their lives. These stars have been born, like the sun, from clouds of interstellar gas and dust. Modern technology supplies us with views deep into the regions of starbirth, showing us the early lives of stars.

Because stars live long by human standards, we cannot directly observe their evolution. We can build models of stars with computers, and these models provide us with the dimension of time to map out the lives of stars. Ordinary stars, powered by fusion reactions, grow old and blow off material before their demise. Many have violent deaths, leaving bizarre corpses such as neutron stars. Massive stars undergo violent deaths, which are signaled by enormous explosions that build heavy elements and propel them into space to seed the next generation of stars. The span of the lives of stars guides us to an understanding of what will happen to our sun in its old age.

Part 4: Galaxies and Cosmic Evolution

The universe contains galaxies, in which the most visible material of the cosmos resides. This part first examines ordinary galaxies, like our Milky Way, and then hyperactive ones. We now realize that galaxies with unusual activity are interacting by gravity with their neighbors, which triggers the celestial fireworks. The show includes long, thin jets of material, confined by magnetic fields, rocketing out of the cores of these galaxies. All these galaxies dwell in clusters with other galaxies, and we have just come to the realization that clusters are laid out in long chains with vast voids in between – the cosmic tapestry. Amid this remarkable layout of visible matter lurks matter that we cannot yet see – the so-called dark matter that shapes the visible universe, both its structure and destiny.

The cosmic design in the large-scale architecture was imprinted in the awesome explosion in which the universe began. That explosion – the Big Bang – linked the smallest pieces of matter to the universe at large. The Big Bang also left relics that we observe today, evidence of the violence of creation. From the Big Bang some 15 billion years ago, cosmic evolution shaped us at where we are and when we are in the universe.

QUICK START

This book is for students, who are probably novices to astronomy. I want them to learn effectively from it. I have designed a four-part structure so that you can investigate each part somewhat independently of the others. Many cross-references, especially to the basic physical and astronomical ideas, should help you to link the parts together. I have made a concerted effort to introduce ideas as concretely as possible. Within parts, I deal with the most familiar first: Chapter 1 (Part 1) with the visible sky; Chapter 8 (Part 2) with the earth; Chapter 12 (Part 3) with the sun; and Chapter 17 (Part 4) with the Milky Way Galaxy. Within chapters, I have tried to present concrete examples before abstract notions.

The **Enrichment Focus** sections furnish another linkage throughout the text. I have set these optional sections off from the main text to enrich ideas by basic mathematics (algebra, trigonometry, and geometry). You will need to decide which of them will be specifically assigned. You will note problems and activities at the end of each chapter. Some of them draw on the material in the Focus sections.

To aid novice science students, I worked to simplify the language as much as I can by using ordinary English rather than technical jargon. My rule when using technical terms is: *Define every term you use, and use every term you define.* I try to avoid a one-time use of a technical term just for the sake of completeness.

If your students are really baffled by a good strategy to learn astronomy, please tell them to read carefully the special section by Mark Hollabaugh (who teaches at Normandale Community College in the United States) on "How to Study Astronomy." It provides a general strategy for studying plus specific guides to each of the learning features of this book.

NOTE. If you have picked up this book because you are curious about astronomy, you may be interested in taking a college-level course by mail for academic credit. Write to: Independent Study, Continuing Education, The University of New Mexico, 1634 University NE, Albuquerque, NM 87131, USA. The course is called Astronomy 101C; I am the instructor.

INSTRUCTORS' RESOURCES

We have centralized all instructor resources on the Web site for this book. The URL is

http://www.The Evolving Universe.com.

ACKNOWLEDGMENTS

Locally, Sabrina Moore initiated the effort to acquire the new visual images in the book. Louise Shaler provided in-depth editorial work on the manuscript. She also assisted me in the final round of exploring for astronomical images and acquiring the permissions for them. Artist Boris Starosta and I collaborated on the art and the creation of the Celestial Navigator™ maps.

Other folks include my correspondence students (who have just the book and their brains) and the students in my regular Astronomy 101 course at UNM. I have also received letters and e-mail from students at other colleges and universities, as well as from instructors. Thank you all!

Any errors in the text are my responsibility. It is a little known fact that minor corrections and changes *can* be made in future printings of *this* edition. Please keep this fact in mind and send me any errors you may find. When ordering, please request the *latest printing* of the book so your students will have the most correct version.

Your feedback can improve this book! Please send any comments to me at the Department of Physics and Astronomy, The University of New Mexico, 800 Yale Blvd NE, Albuquerque, NM, 87131–1156, USA. My Internet mail address:

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Michael Zeilik
Santa Fe, New Mexico, U.S.A., October 2001

Abbreviations

Abbreviations are often used for the names of major observatories and agencies (particularly in the figure captions). These are:

AAO – Anglo-Australian Observatory
AUI – Associated Universities, Inc.
AURA – Association of Universities for Research in Astronomy
CTIO – Cerro Tololo Interamerican Observatory
ESA – European Space Agency
ESO – European Southern Observatory
HST – Hubble Space Telescope
KPNO – Kitt Peak National Observatory
NASA – National Aeronautics and Space Administration
NCAR – National Center of Atmospheric Research
NCSA – National Center for Supercomputer Applications
NOAO – National Optical Astronomy Observatories
NRAO – National Radio Astronomy Observatory
NSO – National Solar Observatory
SAO – Smithsonian Astrophysical Observatory
SOHO – Solar and Heliospheric Observatory
STScI – The Space Telescope Science Institute
TRACE – Transition Region and Coronal Explorer
VLA – Very Large Array radio telescope
VLT – Very Large Telescope, ESO

Concept Clusters

The material in this book falls into four clusters of related concepts; these clusters themselves are interrelated. The Celestial Navigators(tm) include a subset of the most important concepts, also organized by cluster.

1. Cosmic Distances

Angles/angular diameters/positions
Angular speeds/relative motions
Astronomical Unit/Kepler's laws
Heliocentric parallax/triangulation
Inverse-square law for light/flux
Luminosity classes from H-R diagram/ spectroscopic distances
Doppler shifts of interstellar clouds/rotation curve of the Galaxy
Period-luminosity relation for cepheids
Structure of the Milky Way Galaxy/distances
Distance indicators to galaxies (cepheids, supernovas)
Clusters and superclusters of galaxies
Hubble law/Hubble constant/red shifts/ age of universe

2. Heavenly Motions

Angles/angular speeds/relative distances
Motions of sun, moon relative to horizon, stars/eclipses
Motions of the planets relative to sun, stars/ retrogrades/oppositions/elongations
Geocentric/heliocentric
Heliocentric parallax
Kepler's laws/orbits/periodic motion/ dark matter
Newton's laws of motion and gravitation/ orbits/mass/weight/freefall/escape speed
Binary stars/masses of stars/center of mass
Tidal forces
Gravitational accretion/contraction
General relativity/spacetime/curved geometry
Conservation of energy/types of energy
Conservation of angular momentum

3. Celestial Light and Spectra

Electromagnetic radiation/spectrum
Emission/absorption
Kirchhoff's rules (emission, absorption, continuous spectra)
Atomic energy levels/photons/excitation/ radiative energy

Telescopes: detectors; resolving, light-gathering, magnifying power; interferometers
Planck curve/black body/colors/temperature
Synchrotron emission/magnetic fields
Fusion reactions/nucleosynthesis
Energy transport (radiation, convection, conduction)
Chemical composition/spectra
Doppler shift/radial velocity/blue and red shifts
Stellar spectral and luminosity classes
Hertzsprung-Russell (H-R) diagram/ star clusters
Mass-luminosity (M-L) relation/stellar lifetimes
Spectra of the interstellar medium/ inter-
galactic medium
Spectra of galaxies/ red shifts/expansion of cosmos
Cosmic background radiation/Big Bang model

4. Scientific Models

Assumptions, aesthetics/Geometry, physics
Observations (errors)/Predictions, explanations
Quantum theory/photons/energy levels
Age/radioactive dating/half life
Properties of matter (solids, liquids, gases, plasmas)/density
Solar system (geocentric/heliocentric)
Planets/planetary evolution/tectonics/ volcanism/thermal energy
Magnetic fields/dynamo model
Sun/stars/stellar evolution/H-R diagram
Novas/supernovas/nucleosynthesis/mass loss
Stellar corpses /white dwarfs/neutron stars/ black holes
Starbirth/planetary systems/protostars and protoplanets/brown dwarfs
Milky Way Galaxy/normal galaxies
Active galaxies/supermassive black holes
Formation of galaxies/protogalaxies
Big Bang model/critical density/ inflationary models/GUTs

How to Study Astronomy

Mark Hollabaugh
Normandale Community College, Minnesota, U.S.A.

Welcome to astronomy! When I was growing up in Michigan, I would go outside on crisp winter nights to watch the northern lights dance across the sky. In August, I counted meteors during the Perseid meteor shower. I could imagine the terror ancient peoples must have felt as the moon turned blood red during a lunar eclipse. I looked through a real telescope for the first time when I was in seventh grade. A science teacher who spent summers in our town set up his telescope each Friday night in the city park. After a brief peek through the scope, I would run back to the end of the line for another look. I was hooked on astronomy. Later, after studying physics, I did research on comets and asteroids, and on cosmic rays.

Throughout these experiences, I have marveled with fascination at the grandeur and intricacies of the universe. Now, I try to pass that fascination on to my students. That is also what Dr. Zeilik does in *Astronomy: The Evolving Universe*. My association with Mike began with my interest in Native American astronomy. We also share an interest in helping college students like you to enjoy learning astronomy effectively. Your professor has chosen a superb textbook for you to use in your astronomy course. I'd like to give you some suggestions to assist your learning.

UNDERSTANDING YOUR LEARNING STYLE

Each of us learns in different ways. Some of us learn best by reading. Others find listening to a lecture to be most helpful. Talking with others can help us clarify our own understanding. Drawing diagrams or pictures can help us see the relationships among concepts.

When learning something new, it helps to know our own strengths, weaknesses, and learning style. As you begin your study of astronomy, make a list of the kinds of activities that help you learn best. You will find a variety of learning resources presented in your astronomy course: lectures, textbook readings, laboratory exercises, classroom demonstrations, computer simulations, learning team activities, Web sites, videotapes, or slides. These are all a part of your "tool kit" for understanding astronomy. Concentrate extra effort on those kinds of learning activities where you are the weakest. You may, for example, need to learn how to use your textbook as a resource to clarify ideas you don't understand from a lecture.

Memorization may help you correctly answer questions on an examination, but you will not be able to apply the concepts later. Avoid memorizing and seek rather to understand concepts and relate them to one another. The connected understanding of astronomy will reward you with the grand "big picture" of the cosmos!

Learning to Learn

Ask yourself some questions about your study habits. Do you set aside a specific block of time each day to study a given subject? Do you work in a quiet place, free of distractions, such as the library? Do you study at a time of the day when you are at your best for learning new material? When you prepare for an examination, have you kept up with your reading of the text so all you need to do is review? Do you attend all class lectures and other activities? Do you concentrate on understanding concepts as opposed to memorizing facts or data? If you have answered yes to these questions, you have developed some excellent study habits! If not, set goals for yourself to change your learning habits during the current semester. Find out if your institution has an office that helps students to improve their study skills.

Learning from Lectures

Should I read the book first or go to the lecture first? How you personally answer the question depends on your own learning style. It is usually helpful if you have some basic introduction to a topic before you go to your lecture. Look at the syllabus and make a note of the topics for the day. Then scan the *Learning Outcomes* for the chapter. Read the *Key Concepts* at the end of the appropriate chapter. Then skim the chapter in the textbook. If, for example, the lecture will be on Venus and Mars, page through Chapter 9. Examine the images and make note of any questions you might have about them. Pay special attention to the diagrams; be sure that you understand them. After class you should, of course, read the chapter more carefully.

Learning by Taking Notes

Taking effective notes is a two-step process. First, you will make some notes in class as your professor lectures. Try to keep your notes in outline form. Don't worry about making a formal outline. Rather, just indent subtopics under major topics. If your professor has provided a course outline for you, *use it.* Concentrate on getting down the "big ideas" and explanations of concepts. Your instructor wants you to *understand* astronomy! You can fill in the details later as you read the text.

The second step in taking good notes is editing them. Check for concepts or learning objectives that you don't understand and look them up in the textbook. Jot down any definitions you may have missed. In short, edit your notes, making sure you understand the principal ideas. This process will keep you well prepared for taking examinations.

Learning with Other Students

Other students are *the* most important resource to your learning. You will understand more about astronomy if you explain, elaborate, or defend ideas to others. Forming small, informal study groups out of class is an important strategy. You can use the resources of the textbook to quiz one another. Come to such study groups prepared: Edit your notes, review the key concepts, and make a list of questions for your group. Learning together means you learn more. Don't wait to work together until the night before an examination. Make time in your schedule for regular meetings of your study group. If your institution has a computer network available to all students, you can contact other students by electronic mail or an electronic bulletin board.

Learning astronomy with a small group of students is an effective and fun way to increase your understanding of this fascinating subject. Your professor may use formal cooperative learning groups or may simply ask you to work together on a task or assignment. In either case following a few simple guidelines will enable your group to work well together. First, and perhaps most important, come to your group *prepared.* Be ready not only by mastering concepts in astronomy but also with questions about things that you do not yet understand.

Actively talk with one another. Make sure everyone participates. Ask questions. No idea or question is too trivial! Don't rush to conclusions, explore all the possibilities, and dig deeper! You will learn more in a learning group if you and the other group members explain or elaborate upon ideas. This process often happens in response to the simple question, "Why?" So don't be hesitant to challenge or to be skeptical about a group member's idea. Finally, ask yourselves, "What did we do well as a group and what can we do better next time?" Working together will give you a better understanding of the evolving universe.

Learning from the Textbook

Dr. Zeilik has incorporated many useful learning tools into your textbook to help you discover the excitement of astronomy. You should be aware of what your instructor expects of you. He or she probably will omit some topics, even whole sections of the textbook, perhaps even entire chapters! You may or may not be assigned specific Learning Outcomes from each chapter. It may help you to view your textbook as your primary reference. It supplements the lecture and other activities in the class. The textbook is your teacher away from the classroom. Your professor will expect you to read carefully and understand the assigned sections in *Astronomy: The Evolving Universe*.

Take notes as you read. Simply highlighting text is not particularly effective in placing concepts into our long-term memory. You will learn more, and recall it later, if the process of jotting down notes stimulates your brain as you read. Make notations in the margins of your textbook. Later, transcribe these notes into outline form to your notebook. Try to focus on the big ideas and reasons the universe works the way it does.

Take a few moments to become familiar with the design of the book by looking at the various sections of a chapter.

Learning Outcomes. Your instructor may indicate to you the learning outcomes for which you are responsible. These outcomes will help you know what is important. Before beginning to study the chapter, read the objectives. Then, as you read the chapter, think of the outcomes. *After* you have studied the chapter, write out a brief (one or two sentences) response to *each* outcome. If the outcome says "explain" or "describe," do just that. Although this may seem time-consuming, it is an excellent way to summarize and apply what you have learned. You will find review questions at the end of each chapter keyed directly to the outcomes.

Central Concept. Each chapter has a theme. Keeping this theme in mind as you read will help you to understand the unifying idea of each chapter. Try to relate concepts back to the central question.

Celestial Navigators™. To help you see the "big picture," each chapter contains one Celestial Navigator™ map. These serve as visual guides to the main concepts of a chapter and their connections with other concepts. You can copy these maps and use them as an organizing guides to the entire chapter. Write in your annotations on them as you read and study the material.

Key Concepts. When you read a mystery novel, you probably wouldn't read the ending first. However, in reading *Astronomy: The Evolving Universe*, begin a chapter by studying the *Key Concepts* at the end of the chapter. Along with the Concept Clusters and Celestial Navigators™, this will give you an overview of the principal ideas in the chapter. The *Key Concepts* also will be very useful when reviewing for an examination.

Enrichment Focus. For some astronomy students, encountering a mathematical equation in a text can be both distracting and discomforting. You will notice that mathematical topics are discussed in short, compact essays. If your instructor covers these topics, you will want to review carefully these focus boxes. In most cases you should actually work through the calculations with your calculator. By using some of the data tables in the text, you can make up other examples to work.

Study Exercises. At the end of each chapter are a series of review exercises. They require you to explain concepts you have encountered in the chapter. Use these in your study group. These review exercises are keyed back to the Learning Outcomes. Test your understanding of specific outcomes with specific questions.

The most effective way to use these Study Exercises is to work on them with other students. You, and your friends, will learn more in the process. If you do not answer a question to your satisfaction, check the objective and discuss the material again. Then attempt the question a second time. It is not particularly beneficial for you simply to look up the answers to the multiple-choice questions. Try to give explanations of *why* your answer is correct, or *why* other answers to multiple-choice questions are incorrect.

Problems and Activities. These typically require some knowledge of simple geometry or algebra. Or they may involve graphing or some observations. Your instructor will inform you about them.

Key Terms. Astronomy, and all of science, is rich with specific, technical terms. Each chapter includes boldface key terms. Write a brief definition of each term as you encounter it and then check it with the *Expanded Glossary.* Simply being able to define a term may not mean you understand it. Always give explanations. When you read, you may even encounter nontechnical words you don't fully understand. If you can't determine the meaning from the context, look the word up in a dictionary. A small, paperback dictionary in your book bag is as essential as a pen or calculator. If you forget the meaning of an astronomical term, look in the Expanded Glossary first. The Expanded Glossary contains additional terms that may not be used in the text itself but which you may encounter in other astronomical readings.

Appendices. At the end of the textbook, these contain many tables of useful data and information. If it has been some time since you have taken a science class, or you are unfamiliar with the units of measurement in astronomy, you should carefully review Appendix A.

We hope you will enjoy your study of astronomy. Approach your class with a sense of awe and curiosity. Try to understand how the universe works. And, as another famous "science officer" has said, "Live long and prosper!"