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Essential Astrophysics

Springer

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ISSN 2192-4791 ISSN 2192-4805 (electronic)
ISBN 978-3-642-35962-0 ISBN 978-3-642-35963-7 (eBook)
DOI 10.1007/978-3-642-35963-7
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2012955653

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Preface

Essential Astrophysics is a book to learn or teach from, as well as a fundamental reference for anyone interested in astronomy and astrophysics. This unique volume can be used as a textbook, teaching guide, or reference source for just about anyone interested in astronomy and astrophysics.

It serves as a comprehensive, introductory text, which takes the student through the field of astrophysics in lecture-sized chapters of basic physical principles applied to the cosmos. Undergraduate students with an interest in the physical sciences, such as astronomy, chemistry, engineering, or physics, will enjoy this one-semester overview.

The text is of sufficient breadth and depth to prepare the interested student for more advanced, specialized courses in the future. The clarity and comprehensive nature of *Essential Astrophysics* make it a significant resource for the curious reader that is unfamiliar with astrophysics or for professional astronomers who may have forgotten the basics.

Astronomical examples are provided throughout the text, to reinforce the basic concepts and physics, and to demonstrate the use of the relevant formulae. In this way, the student learns to apply the fundamental equations and principles to cosmic objects and situations. All of the example problems are solved with the rough accuracy needed to portray the basic result. Such order-of-magnitude estimates are commonly used in astronomy and astrophysics, where large numbers are involved, and an understanding of the underlying physics does not require engineering accuracy.

Essential Astrophysics is a serious introduction to astrophysics complete with the necessary formulae. These equations sometimes include the calculus of integration, or adding up, and differentiation, that are found in the author's classic *Astrophysical Formulae* and more advanced textbooks. Nevertheless, the end result in *Essential Astrophysics* is always a simple algebraic relationship that can be applied to cosmic objects. These fundamental equations are given in the text and collected at the end of the book in Appendix III, for future reference and use. Therefore, only elementary algebra is required to solve any of the example problems or other numerical conclusions in this book.

There are two types of intended readers. One type will be interested in broad, general conclusions, without use of calculus. This reader will be content with the existing text with no further elaboration. The more mathematically competent reader will want to use *Essential Astrophysics* as a foundation for more advanced considerations, with the guidance of the references, an instructor, or an advanced textbook, using the formulae found in the text or within set aside Focus Elements of *Essential Astrophysics* as a starting point.

The modern SI (International System) units are used in the equations and example problems, which is another unique aspect of this book when compared to most previous texts of astrophysics. A conversion table between the SI and c.g.s. units is provided in the first chapter, to help the reader follow the details of many papers and textbooks that use the older c.g.s. system. Astronomical and physical constants, units, and fundamental equations are provided in appendices, for quick reference.

Essential Astrophysics goes beyond the typical textbook by providing comprehensive access to astrophysical discoveries, concepts, and facts that are not available in any other way. It gives us access to that long-forgotten formula, idea, or reference, while also providing the material needed to introduce anyone to a new area of astrophysics. Here, the reader can obtain the background required for a general understanding and find guidance to the relevant literature including seminal discoveries, original research, and comprehensive up-to-date reviews that will enable the curious reader to delve deeper into a particular topic. A more extensive reference compilation of developments in astrophysics, from then to now, can be found in *Astrophysical Formulae*.

We are the benefactors of 300 years of cumulative discovery in astronomy and astrophysics, and *Essential Astrophysics* helps pass on these fundamental insights to the next generation. It also reveals both the exciting moments of the past and relatively recent discoveries. Historical aspects are illuminated through a progressive flow of chapter topics and by guidance to the earliest ideas, with reference to the original sources as well as contemporary reviews. Perhaps because of the rapid pace of modern research, contemporary texts often focus on specialized topics and overlook these broader perspectives that *Essential Astrophysics* provides.

There are 50 set-aside focus elements that enhance and amplify the discussion with fascinating details. They include the intriguing development of particular themes, which is missing in most astrophysics textbooks, or provide further astrophysics or equations for use in examples, problems or further investigations.

In *Essential Astrophysics* we can rediscover basic physical concepts such as space, time, radiation, mass, gravity, motion, heat, atoms, radioactivity, and cosmic rays, which are required to understand the observable universe. These fundamental topics are discussed in the first seven chapters, beginning with the introductory chapter that describes how astronomers observe the contents of the universe and how astrophysicists interpret them. The SI units of distance, mass, time, energy, and luminosity are introduced, together with their astronomical units

such as the Ångström, light-year, parsec, and the Sun's mass, luminosity, and radius. The magnitude unit is also defined, but used sparingly in examples.

Chapter 2 describes radiation, of both the visible and invisible sort, which carries messages from the cosmos and tells us much of what we know about it. Chapter 3 discusses gravity, together with mass that helps determine its strength, and related tidal phenomena and space curvature. Chapter 4 discusses cosmic motion, and its balanced equilibrium with gravitation. Chapter 5 discusses the motion of particles in a gas, together with the related concepts of speed distribution, heat, temperature, and pressure. The inside of the atom is explored in Chap. 6, where the reader learns about atomic spectral lines and their use in determining the composition of stars and the measurement of motions and magnetic fields. The transformation of elements in both radioactivity and by subatomic bombardment is presented in Chap. 7.

The fundamental concepts described in these first seven chapters provide a necessary prelude to the rest of the book. It includes the discoveries that the universe is predominantly hydrogen; that the stars shine by nuclear fusion; that the stars live and die while new ones continue to be formed; that the interstellar spaces are not empty but filled with dust, atoms, and molecules; and that the observable universe is expanding and has a history. The last half of *Essential Astrophysics* also includes relatively recent discoveries, such as pulsars, black holes, the three-degree cosmic microwave background, the formation of stars and galaxies, invisible dark matter, and the dark energy that is now accelerating the expansion of the universe.

Chapter 8 provides an account of the nuclear fusion reactions that make the Sun shine. This is followed in Chap. 9 by modern discoveries of the Sun's expanding atmosphere, the solar winds, explosions on the Sun, the solar flares and coronal mass ejections, and their space–weather threats to spacecraft and humans in space.

Chapter 10 presents an overview of the stars, telling us how far away, bright, luminous, hot, big, and massive they are. It also includes discussions of stellar spectra, as well as the evolution of stars and their role in the origin of the chemical elements.

The space between the stars is discussed in Chap. 11, beginning with bright stars that illuminate nearby space and continuing with the dust, gas, radio emission, and molecules within interstellar space. This is naturally followed in Chap. 12 by the ongoing formation of stars and their planets; recent discoveries of protoplanetary disks and planets around nearby stars can also be found in this chapter.

The final destiny of stars, when they have depleted their nuclear resources, is presented in Chap. 13. It includes planetary nebulae, white dwarf stars, degenerate pressure, novae, supernovae, neutron stars, pulsars, and stellar black holes.

Our last two chapters discuss the observable universe in its entirety, including the Milky Way, the receding galaxies, the big bang with its background radiation, the first atoms, stars, and galaxies, the evolution of galaxies, dark matter and dark energy, and the ultimate destiny of the universe.

A total of 69 tables provide vital facts and physical information for the main types of cosmic objects; students, teachers, and researchers may also consult this information throughout their careers. In alphabetical order, they include the physical properties of atmospheres, clusters of galaxies, the cosmic microwave background radiation, the Earth, emission nebulae, galaxies, our Galaxy, giant molecular clouds, H I regions, H II regions, interstellar molecules, the Milky Way, our Moon, neutron stars, novae, planetary nebulae, planets, pulsars, radioactive isotopes, the Sun, stars, star clusters, supernova explosions, and supernova remnants.

Our tables also include information about cosmic magnetic fields, cosmic rays, cosmological parameters, and nuclear fusion processes, as well as the range of cosmic pressures, cosmic temperatures and stellar luminosity, and the spectral lines of active galaxies, emission nebulae, stars, the Sun's corona, and the Sun's photosphere.

There are also excellent line drawings, prepared by Kacha Bradonjich, and several images of astronomical objects from the ground and space that help cement our newfound knowledge together. They help crystallize a new concept with a visual excitement that adds another dimension to our understanding.

The author also writes another sort of popular book, filled with personal anecdotes, the lives of contributors to the field, and human metaphors, without an equation or reference in sight. For this complementary approach, the reader is referred to the author's two books *The Life and Death of Stars* and *Parting the Cosmic Veil*, which deal with many of the same general topics as *Essential Astrophysics* in a different, lighter perspective.

I am indebted to Gayle Grant for help in assembling this book, and to the Tufts Faculty Research Committee for modest support for typing some equations in it. And last, but not least, the author thanks Ramon Khanna for his skillful editorial suggestions that have made *Essential Astrophysics* a better book.

Medford, November 2012 Kenneth R. Lang

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