Elementary Cosmology (Second Edition)

From Aristotle's universe to the Big Bang and beyond

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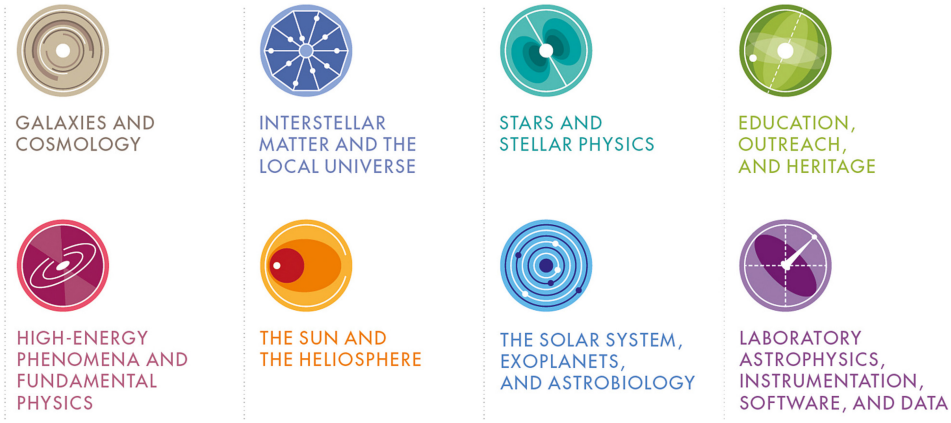

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Cover image: Eta Carinae Nebula (NGC 3372), optical image. This nebula (a vast cloud of dust and gas) surrounds the variable star Eta Carinae. This massive star, over 100 times the mass of the Sun, is the most luminous star known in our Galaxy. It radiates its energy at a rate that is 5 million times that of the Sun. Because of its huge mass, it is extremely unstable. It is in the constellation Carina, about 9000 light years away from Earth. This image includes filters for the light from hydrogen (H-alpha), oxygen (OIII) and sulphur (SII) ions. Image credit: Dr Luke Dodd/Science Photo Library.

"Isn't that what it means to be a scientist? To push the boundaries of the unknown? To bravely, actively explore the enormity of our universe?"

—Robyn Mundell, Brainwalker

"The more clearly we can focus our attention on the wonders and realities of the universe about us, the less taste we shall have for destruction."

—Rachel Carson

"One of the basic rules of the universe is that nothing is perfect. Perfection simply doesn't exist. Without imperfection, neither you nor I would exist."

—Stephen Hawking

"Tune your television to any channel it doesn't receive and about 1 percent of the dancing static you see is accounted for by this ancient remnant of the Big Bang. The next time you complain that there is nothing on, remember that you can always watch the birth of the universe."

—Bill Bryson, A Short History of Nearly Everything

Contents

Preface

Cosmology is the study of the origin, size, and evolution of the entire universe. Every culture has developed a cosmology, whether it be based on religious, philosophical, or scientific principles. In this book, the evolution of the scientific understanding of the universe in the Western tradition is traced from the early Greek philosophers to the most modern 21st century view.

This book began as a series of lecture notes for a one-semester course at the University of Notre Dame called "Elementary Cosmology." An elective for non-science majors, it was designed to acquaint the non-mathematically-inclined student with the most important discoveries in cosmology up to the present day and how they have constantly altered our perceptions of the origin and structure of the universe. It examined such questions as: "Where did the universe come from?" or "Why do scientists now feel sure that its birth was in a great cosmic fireball called the Big Bang?" and "Where did the Big Bang itself come from?" The emphasis was on class discussion of readings from "science popularizations" for the curious and intelligent layperson, focusing eventually on the many interesting and exciting new discoveries in cosmology in the late 20th and early 21st century.

After a brief introduction to the concept of the "scientific method," which underpins all scientific approaches to the study of the universe, the first part of the book describes the way in which detailed observations of the universe, first with the naked eye and later with increasingly complex modern instruments, ultimately led to the development of the "Big Bang" theory which supplies the framework for our current understanding of cosmology. The key to this theory is the realization that our universe, far from being static and eternal, has instead been expanding in size since its origin some 13.5 billion years ago. While the fact of this expansion was accepted rather soon after it was first proposed in the 1920s and 1930s, the more radical idea that the universe had a birthday was more difficult for scientists to accept. It was only with the development of modern, satellite-based communication devices in the 1960s that instruments sensitive enough to detect the "cosmic microwave background" (CMB) were produced. It is now understood that the CMB consists of ancient light, emitted at a time near to the formation of the universe. As such it's the "smoking gun" of the Big Bang, and detailed studies of its properties have led to many interesting and fascinating new discoveries in cosmology.

The second part of the book traces the evolution of the Big Bang theory itself, including the very recent observation that the expansion of the universe is itself accelerating with time. In addition, the contribution of modern physics to our understanding of the mechanism of the Big Bang is discussed, and the state of the universe at various eras throughout its history is described. Finally, some speculations beyond current knowledge that bear on cosmology are introduced and the implications for future developments in our understanding of the universe are described.

The text contains many links to websites that clarify and extend the discussion. By following these links (some to images and videos), the reader can attain a much more in-depth understanding of many of the concepts introduced in this book. This is especially true for those seeking a more mathematical discussion of these topics, which is beyond the level of the current text.

Acknowledgements

To my wife Ann who encouraged me throughout this book project, and to the many Notre Dame students whose questions and comments over the years contributed immensely to the development of the Elementary Cosmology course. I also acknowledge with gratitude the assistance of Robert Trevelyan of IOP Publishing in the production of this manuscript in its final form.

Author Biography

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James J. Kolata is an emeritus professor of physics at the University of Notre Dame in the USA and a Fellow of the American Physical Society. He is the author of over 300 research publications in nuclear physics.