Preface

Out for no reason this universe came to be
Out of a place to be, this universe filled itself
Rumi
1207–1273

Many cultures throughout the history including the Greeks, ancient Egyptians, Indians, Chinese, and Persians fascinated by the night sky studied stars and the heavens for centuries. However, the study of the cosmos in the form of classical scientific astronomy using mathematical descriptions is traced back to early seventh century AD. From seventh to fourteenth century, Persian mathematicians and astronomers Kharazmi (780–850), Biruni (973–1048), Khayyam (1048–1131), Tusi (1201–1274), and Kashani (1380–1429) each contributed a lot to the field of astronomy. Their contributions were further developed and improved by European astronomers Copernicus (1473–1543), Galileo (1564–1642), and Kepler (1571–1630) over the next three centuries. Sir Isaac Newton's theory of gravitation revolutionized astronomical calculations by late sixteenth century (in 1687, Newton published his Principia). Newtonian mechanics made it possible to formulate the motion of all celestial bodies in the solar system and beyond.

New discoveries and theories within the last century have drastically changed our understanding of the cosmos. With the advent of Einstein's General Theory of Relativity and the observational discovery on the expansion of the Universe by Slipher, as well as Hubble's discovery of Hubble's law (indicating that far galaxies are receding from us) as early as 1920s, cosmology became a much more distinct science than astronomy. In 1922, Alexander Friedmann's solutions to Einstein's equations formulated the evolution of a relativistic expanding or contracting dynamic Universe. The more advanced models are now known as Friedmann–Lemaitre–Robertson–Walker (FLRW) models of cosmology due to many enhancements and contributions from other cosmologists.

From 1930s onward, the Big Bang theory formed the basis for explaining the expansion of the Universe. However, the original Big Bang theory endured three problems, namely, the smoothness problem, the horizon problem, and the flatness problem. The first problem asks why the matter is uniformly distributed in the Universe. The second problem concerns the large-scale uniformity of the observable Universe. Finally, the third problem asks why the Universe is close to being spatially flat. With the introduction of the Inflationary Model of cosmology in 1980s by Alan Guth, the three problems of the Big Bang cosmological model were solved. According to inflationary cosmology, the size of the Universe expanded exponentially to an extremely huge number (10^{60}) of its original size. This happened in a very short time from 10^{-35} to 10^{-32} s after the Big Bang. Collectively, the Big Bang model and Inflation Models of cosmology described the origin and expansion of the Universe.

By the mid-1990s, new observations led to new models of cosmology. The modern Standard Model of Cosmology, which is generally accepted among cosmologists, integrates the following theories, models, and concepts: a fixed background space-time, the General Theory of Relativity, Dark Matter, Dark Energy, initial conditions at Big Bang (best described by Inflationary Models), and the Standard Model of particle physics. Although the Standard Model of Cosmology has its own outstanding problems such as Dark Matter and Dark Energy, and issues with inflation, yet it explains all the observations.

Today cosmologists work with some of the most intriguing and yet fundamental questions such as:

- What is the overall shape and size of the Universe?
- Why did the Universe start in an improbable state?
- Did inflation happen?
- Is there a multiverse?
- What is the ultimate fate of the Universe?
- What is the true nature of Dark Energy?
- Can physics describe what was happening before the Big Bang?
- What happens to the notions of space and time before the Big Bang?

Currently there is no single theory that successfully answers all of the above questions. Beyond the Standard Model of cosmology, speculative theories in quantum gravity are used to research solutions for the problem of the selection of initial conditions of the Universe.

The purpose of this book is to present and explain the following unique topics in modern cosmology:

- A novel approach to uncover the dark faces of the Standard Model of cosmology.
- The possibility that Dark Energy and Dark Matter are manifestations of the inhomogeneous geometry of our Universe.
- On the history of cosmological model building and the general architecture of cosmological models.
- Illustrations of the large-scale structure of the Universe.
- A new perspective on the classical static Einstein Cosmos.
- Global properties of World Models including their topology.
- The arrow of time in a Universe with a positive cosmological constant Λ.

- Exploring the consequences of a fundamental cosmological constant Λ for our Universe.
- Exploring why the current observed acceleration of the Universe may not be its final destiny.
- Demonstrating that nature forbids the existence of a pure cosmological constant.
- Our current understanding of the long term (in time scales that greatly exceed the current age of the Universe) future of the Universe.
- The long-term fate and eventual destruction of the astrophysical objects that populate the Universe – including clusters, galaxies, stars, planets, and black holes.
- All evidence of the Big Bang including the Cosmic Microwave Background (CMB), and of the existence of other galaxies outside our own will disappear in about 100 billion years.

The material is presented in a layperson-friendly language followed by additional technical sections that explain the basic equations and principles. This feature is very attractive to readers who want to learn more about the theories involved beyond the basic description.

Each chapter is self-contained. Chapter 3 and Appendix A are related and collectively describe the future of the Universe.

Chapter 1 discusses a new perspective on the concept of Dark Matter and Dark Energy. The conventional view on Dark Matter is that these are particles that respond to the gravitational force, but they do not respond to strong, weak, and electromagnetic forces. We simply just have not discovered them yet. Whether they will be produced in the near future with LHC experiments at CERN, or detected with other experiments such as the Cryogenic Dark Matter Search (CDMS), remains to be seen. The nature of Dark Energy, however, is more mysterious than that of Dark Matter. It is believed to be the vacuum energy with negative pressure in its simplest form that causes the Universe to accelerate. It accounts for about 75% of the matter/energy of the Universe.

Chapter 1 argues that the Standard Model of cosmology may be just too simple, since it assumes that the Universe as a whole can be described by the homogeneous solutions of Einstein's equations. The chapter recalls the historical development of the Standard Model of cosmology and illustrates modern developments of our understanding of the large-scale structure of the Universe. It explains the shortcomings of the Standard Model and develops a more general model of cosmology that takes into account the inhomogeneities in the matter distribution, but also in the geometry of space-time. The tight relations between this geometry and global properties of our Universe, as implied by a full application of the General Theory of Relativity, provide possible solutions to the Dark Energy and Dark Matter problems. In this new framework, the classical Universe model, favored by Einstein, is put into perspective and, using this example, the limits and possible generalizations of the Standard Cosmological Principle are discussed.

Chapter 2 investigates the Arrow of Time in a Universe with a positive cosmological constant Λ. On the observed acceleration of our Universe, the analysis predicts that this acceleration is a temporary bleep and not our final destiny due to a fundamental scale Λ in nature. The chapter concludes that nature forbids the existence of a pure cosmological constant. This prediction can be tested by the combined observations from SN1a, large-scale structure LSS and, CMB, from existing or upcoming experiments such as Planck, Supernova Acceleration Probe (SNAP), and Laser Interferometer Space Antenna (LISA), will soon be able to pin down whether the equation of state of Dark Energy is a constant or if it evolves with time.

Chapter 3 covers the long-term fate of the cosmos. The evolution of planets, stars, galaxies, and the Universe itself over time scales that greatly exceed the current age of the Universe are addressed. The chapter follows the long-term development of stars and the stellar remnants (the neutron stars, white dwarfs, and brown dwarfs) remaining after the end of stellar evolution. Five ages of the Universe are summarized, namely: Primordial Era, Stelliferous Era, Degenerate Era, Black Hole Era, and Dark Era. The appendix at the end of the chapter outlines some of the basic equations that describe the astrophysical processes related to the future history of the Universe. It covers the Universe as a whole, galaxies, stars, planets, and black holes.

Appendix A demonstrates that in about 100 billion years (about ten times older than the current age of the Universe), all evidence of the Big Bang and of the existence of other galaxies outside our own will disappear.

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