INTRODUCTION

With equal passion I have sought knowledge. I have wished to understand the hearts of men, I have wished to know why the stars shine. And I have tried to apprehend the Pythagorean power by which number holds sway above the flux. A little of this, but not much, I have achieved.
Bertrand Russell (1872–1970), Autobiography, *Prologue*

PROLOGUE

Cosmology, the science of the universe, attracts and fascinates us all. In one sense, it is the science of the large-scale structure of the universe: of the realm of extragalactic nebulae, of distant and receding horizons, and of the dynamic curvature of cosmic space and time. In another sense, it seeks to assemble all knowledge into a unifying cosmic picture. Most sciences tear things apart into smaller and smaller constituents in order to examine the world in ever greater detail, whereas cosmology is the one science that puts the pieces together into a "mighty frame." In yet another sense, it is the history of mankind's search for understanding of the universe, a quest that began long ago at the dawn of the human race. We cannot study cosmology in the broadest sense without heeding the many cosmic pictures of the past that have shaped human history. We trace the rise of the scientific method and how it has increased our understanding of the physical universe. Which brings us to the major aim of this book: gaining an elementary understanding of the physical universe of modern times.

Cosmology compels us, willy-nilly, to examine our deepest and sometimes most cherished beliefs. It awakens an awareness of ancient vestigial paradigms that control our lives and direct the destiny of societies. A person who migrates to a new land, joins a revolution, goes to war, seeks political power, gains or loses a fortune, gets married, or does any momentous thing is influenced by cosmic beliefs.

A brief summary of the contents of this book serves as an introduction to the scope of cosmology as a modern science. In outline only, chapter by chapter, the subjects covered are as follows.

CHAPTER 1
WHAT IS COSMOLOGY?

The history of cosmology shows that in every age in all societies people believe that they have at last discovered the true nature of the Universe. But in each case they have devised a mask fitted on the face of the unknown Universe. In this book we use "universe" to denote "a model of the Universe" and avoid making claims to true and final knowledge of the Universe. Where there is a society of rational individuals, there we find a universe, and where there is a universe, there we find a society of rational individuals. Proud of their knowledge and confident of its final truth, the members of a society pity the ignorance of their ancestors and fail to foresee that their descendants will also pity them for their ignorance.

Cosmology is the study of universes, how they originate, how they evolve. Plausibly, hundreds of thousands of years ago, in an Age of Magic, the world was explained by the activity of ambient spirits. In an Age of Myths, tens of thousand years ago, lasting until recent times, the world was explained by the capricious acts of nature spirits and the will of remote gods and goddesses. In an Age of Science, we have abandoned much of our anthropocentric heritage, and have devised a series of mechanistic universes. The old historic universes (Sumerian, Egyptian, Judaic, Zoroastrian, Confucian, Taoist, Jainic, Buddhist, Aristotelian, Platonic, Stoic, Epicurean, Neoplatonic, Medieval, . . .) dealt with cosmic themes that gave meaning to human life, themes that now fail to fit naturally into the current physical universe. This causes concern and prompts us all to think deeply. The last section in this chapter considers how cosmology relates to society and affects our everyday thoughts, actions, and beliefs.

CHAPTER 2
EARLY SCIENTIFIC COSMOLOGY

This chapter briefly reviews known early scientific cosmology with comments on the Babylonian, Pythagorean, and Platonic systems. Emphasis is placed on the three important and enduring Hellenistic world systems: Aristotelianism, Epicureanism, and Stoicism. The Aristotelian universe, finite in size, consisted of planetary spheres bounded by an outer sphere of stars; the Epicurean universe, infinite in extent, consisted of endless worlds composed of atoms; and the Stoic universe, finite in size, consisted of a cosmos of planets and stars surrounded by empty infinite space. These world systems have shaped the history of subsequent cosmology.

The Medieval universe, with Aristotelian foundations, reached its peak in the High Middle Ages. Because of the Condemnations by the bishop of Paris of Aristotelian cosmology in 1277, the Medieval universe evolved into a Stoic-like system, able to accommodate an omnipotent God of unlimited extent. The Copernican revolution overthrew geocentric astronomy in favor of heliocentric astronomy, which in turn was soon overthrown by the rise of the Cartesian and Newtonian world systems.

CHAPTER 3
CARTESIAN AND NEWTONIAN WORLD SYSTEMS

In the seventeenth century, the revolutionary Cartesian and Newtonian systems mathematized and mechanized the natural world. From medieval mathematics and dynamics, René Descartes fashioned a mechanized atomless Epicurean-like world of matter and motion operating in strict obedience to natural laws. The repercussions – scientific, philosophical, and theological – were, and still are, profound. The body–mind (or body–soul) duality became more sharply etched than ever before and haunts us to this day.

Isaac Newton reacted strongly against Cartesian materialism and at first believed in a finite Stoic cosmos surrounded by an infinite mysterious space. What Descartes had denied – the existence of atoms, the vacuum, and forces acting at a distance – Newton affirmed. Newton's laws of motion and the theory of universal gravity transformed astronomy. The atomic theory lost its atheistic associations and began to make sense of the properties of matter. Where there is no matter, declared Newton, space still exists by virtue of the presence of spirit. Bodies act upon one another across empty space by means of long-range gravity. The implications of universal gravity caused Newton later to change his mind and believe in an infinite Epicurean-like universe, endlessly populated with uniformly distributed stars.

CHAPTER 4
COSMOLOGY AFTER NEWTON AND BEFORE EINSTEIN

But even the naked eye sees that stars do not cover the sky uniformly. Thomas Wright in the eighteenth century proposed that the Milky Way is an enormous assembly of stars, and that possibly other milky ways exist far away. Immanuel Kant expanded on this idea and devised a hierarchical universe. The renowned astronomer William Herschel explored the heavens, surveyed the Galaxy, and formed the opinion that many of the small fuzzy patches of light (nebulae) not only are clusters of unresolved stars but also some are distant milky ways (galaxies) similar to our own Milky Way (Galaxy). The nebula hypothesis, the idea that the Sun and planets formed from a rotating and contracting cloud of interstellar gas, was suggested by Kant and later considered in more detail by Pierre Simon de Laplace. Thus began the riddle of the nebulae: are the nebulae distant milky ways in a many-island universe or are they solar systems in the process of formation in a one-island universe? Herschel later in life changed his mind and favored the one-island universe. In the nineteenth century, the spectroscopic analysis of starlight by William Huggins and other astronomers and the development of photography established the "new astronomy" that later became known as astrophysics. At last human beings knew the stars consist of chemical elements exactly the same as on Earth. And astronomers knew that many nebulae consist only of gas (tipping the balance in favor of the Kant–Laplace nebula hypothesis and against the Wright–Kant milky way hypothesis). Astronomers succeeded in measuring the radial velocities of stars by the Fizeau–Doppler displacement in spectral lines. The Victorian universe of the nineteenth century was a one-island universe. The Solar System occupied the center of the Galaxy, which existed in a void of infinite, mysterious space. The Darwinian theory of natural selection exacerbated the age-of-the-universe problem and brought fundamental cosmological issues into every home. The old conflict between the Stoic and Epicurean systems climaxed in the early years of the twentieth century and the many-island universe emerged triumphant. We now know that some of the fuzzy patches of light are unresolved star clusters, some are swirling gas clouds, and others are distant galaxies.

CHAPTERS 5 AND 6
STARS AND GALAXIES

These two chapters discuss stars and galaxies and their treatment is oriented toward cosmology. Readers familiar with elementary astronomy may wish to skip these two chapters and proceed immediately to the next two chapters that discuss the important subjects of location and containment.

CHAPTER 7
LOCATION AND THE COSMIC CENTER

Generally, the subject of location (Chapter 7) deals with the cosmic center, and the subject of containment (Chapter 8) deals with the cosmic edge. The location and containment principles, which seem deceptively simple, serve to guide us among the pitfalls that trapped earlier cosmologists and still trap students.

This chapter deals with the rise and fall of the geocentric and heliocentric universes, and the rise of the centerless universes. We live in an isotropic universe in which all directions in space are alike. The location principle states that "probably we do not occupy a cosmic center." The observed isotropy of the universe, coupled with the location principle, leads us to the conclusion that the universe is probably homogeneous.

The homogeneity of the universe, meaning that all places in space are alike at a common instant in time, is the essence of the cosmological principle. The perfect cosmological principle, which states that all places in both space and time are alike, applies not only to the Cartesian and Newtonian world systems, but also to the more recent expanding steady-state universe.

CHAPTER 8
CONTAINMENT AND THE COSMIC EDGE

Containment deals with the edge and contents of the physical universe. The containment principle states: "the physical universe contains only physical things." In modern physics, both space and time in the form of spacetime are physically real and therefore part of the physical universe. As cosmophysicists we deal with the physical universe. But the Universe contains also nonphysical things and this aspect of containment has implications in the social and life sciences. Various topics are considered, such as cosmic design and the finely tuned fundamental physical constants, the theistic and anthropic principles, and the laws of nature.

A word of warning comes not amiss while on the subject of containment. Cosmology is incomplete in the fundamental sense that we do not know how to put ourselves, as cosmologists, into our world systems. The Universe is self-aware – it contains us who are conscious beings – but the physical universe is not self-aware and does not contain us as self-aware beings. We can put our physical bodies and biochemical brains into a physical universe, which is a model of the Universe, but we cannot put our minds (whatever that means) into a universe conceived and studied by our minds. When we try, we fall into an infinite regression: the cosmologist studies a universe, which contains the cosmologist studying that universe, which contains the cosmologist, ... and so on, indefinitely. For the same reason, painters in the act of painting landscapes leave themselves out of the landscapes they paint. Otherwise they would have to include themselves painting a picture that includes themselves painting a picture that includes.... This subject is referred to as the containment riddle: "Where in a universe is the cosmologist studying that universe?" The solution to the riddle requires that we distinguish between the inconceivable Universe (of which we are totally a part) and our conceived universes (of which we are not totally a part) that we create to make sense of our experiences.

CHAPTER 9
SPACE AND TIME

In more depth than usual in an elementary work, we consider the fascinating nature of space and time in pre-Newtonian and post-Newtonian universes. Some topics discussed are the arrow of time, the "now," time travel, Zeno's paradoxes, Parmenidean states of being, Heraclitean acts of becoming, and conjugate time in the Islamic Kalam universe.

Our everyday understanding of time is a patchwork of primitive and sophisticated concepts. The time that is used in special relativity is not the same as that used in most other sciences, which is not the same as that in everyday speech, which in turn is not the same as the time we actually experience. Conflict and contrast abound whenever we discuss the nature of time. With not much hope of success, we try to clarify some of the issues involved in this perplexing subject; any fundamental change in our understanding of time will undoubtedly profoundly affect cosmology.

CHAPTER 10
CURVED SPACE

The development of non-Euclidean geometry in the nineteenth century forms an engrossing subject in the history of science and mathematics. Understanding curved space is not easy, even for people who live in curved spaces. Much of our attention in this chapter focuses on the three homogeneous and isotropic spaces that are of basic importance in modern cosmology.

CHAPTER 11
SPECIAL RELATIVITY

Special relativity, contrary to students' expectations, is easy to understand, and a true grasp of the essential ideas does not require mathematics. The secret lies in spacetime pictures and the realization that in spacetime the shortest distance is not a straight line. Space travel close to the speed of light provides interesting applications of relativity theory. The "twin paradox" is puzzling only when the most elementary aspects of the theory are not understood.

CHAPTER 12
GENERAL RELATIVITY

Special relativity and curved space lead us to general relativity and the labors of Albert Einstein. The first stepping-stone is the principle of equivalence. This is established by means of experiments in imaginary laboratories that move freely in space near to and far from stars. The second stepping-stone is the realization that this dynamic state of affairs is analogous in many respects to the geometric properties of curved space. In a flight of inspiration we are catapulted to the theory of general relativity and the Einstein master equation. Many ingenious tests of general relativity have been performed, successfully verifying the validity of the theory on astronomical (not cosmic) scales.

We consider the bootstrap ideas embodied in Mach's principle, a principle so-named by Einstein who found Mach's ideas inspiring. The old bootstrap theory, periodically revived, asserts that all things are immanent within one another, and the nature of any one thing is determined by the universe as a whole. So far, science has failed to make sense of the bootstrap theory. Mach's principle, a bootstrap theory, claims that the inertia of a body is determined by all the matter distributed in the universe. Many persons dislike an "undressed" space that exists in its own right, and with the ancients, Bishop Berkeley, and Ernst Mach, think that space cannot exist in a real sense unless decently dressed in a distribution of matter. Berkeley's ideas, revamped by Mach, played a historic role in the formulation of general relativity. But the idea: the materialization of space, championed at first by Einstein, was dropped when Einstein performed the converse: the geometrization of matter.

CHAPTER 13
BLACK HOLES

Although black holes were anticipated in the eighteenth century on the basis of Newtonian theory, the proper theory for their study is general relativity. Of spherical bodies of similar mass, black holes have the highest density and the strongest gravitational force at their surface. They are wrapped in their own curved spacetime. A black hole exists in a frozen state of permanent free-fall collapse. Owing to the extreme distortion of spacetime, an external observer sees the black hole in a frozen state, from which nothing (according to the classical theory), not even light, can escape. We consider several topics of interest, such as nonrotating and rotating black holes, the energy liberated by accretion of matter, miniholes and superholes, the temperature of black holes, Hawking radiation, and violation of certain cherished laws of conservation.

CHAPTER 14
EXPANSION OF THE UNIVERSE

The expansion of the physical universe ranks as one of the greatest discoveries in the history of the human race. We invoke the expanding space paradigm and perform imaginary experiments with ERSU – Expanding Rubber Sheet Universe. To aid us in our investigations we use the two different observers introduced in Chapter 7: the ordinary stay-at-home "observer" who looks out at distant things in the same way that we do, and the imaginary gadabout "explorer" who rushes around at infinite speed and traverses the universe in zero cosmic time. The explorer in these experiments is really us looking down on ERSU as external observers. Our experiments shed light on many topics, such as homogeneous expansion, cosmic time, recession of the galaxies, the velocity–distance law of expansion, and the Hubble redshift–distance law. The experiments stress that the galaxies are not hurling away through space but are actually at rest in space that is expanding. This is why distant galaxies can recede from us faster than the speed of light. Recession velocity is unlike the ordinary velocity with which we are familiar. Measuring the expansion requires the introduction of comoving coordinates, coordinate distances, the scaling factor, the Hubble term, and the deceleration term, and we show how universes are classified according to the way the scaling factor changes in time.

CHAPTER 15
REDSHIFTS

Light rays from distant galaxies are redshifted because of the expansion of the universe. This cosmological redshift, which is distinct from the Doppler and gravitational redshifts, is produced by the stretching of wavelengths as radiation propagates through expanding space. Space expands, wavelengths are stretched, and the cosmic redshift is as simple as that. There are a few redshift curiosities. The oddest curiosity of all is the unwise practice in popular literature of failing to distinguish between cosmic and Doppler redshifts. The Doppler effect implies that galaxies are rushing away through space and that special relativity explains the universe. This is a dangerous interpretation and leads to endless confusion for those trying to understand modern cosmology. It restores the cosmic edge at which recession reaches the speed of light. Our treatment stresses two concepts: first, recession is the result of the expansion of space (and galaxies are more or less stationary in expanding space); and second, cosmic redshifts are the result of the stretching of wavelengths as light and other forms of radiation travel through expanding space. It is now clear why we have previously insisted that space and time are physically real (this is the essence of general relativity) and are contained in the universe; the universe is not expanding in space, but consists of expanding space.

CHAPTER 16
NEWTONIAN COSMOLOGY

Isaac Newton resolved the gravity paradox (or war of cosmic forces) by assuming that the universe is perfectly homogeneous. Under certain limiting conditions Newtonian theory gives the same results as general relativity. The dynamics of the universe showing how gravity and the lambda force determine expansion are discussed with the aid of Newtonian ideas. We try to explain why Newtonian theory under certain conditions yields the same results in cosmology as general relativity.

CHAPTER 17
THE COSMIC BOX

The principle that all places in the universe are alike at each moment in cosmic time has far-reaching consequences. Distant regions are in the same state as local regions when compared at the same time, and we can discover much about the universe by studying the history of only a sample region. This is the basic idea of the “universe in a nutshell.” We suppose that a part of the universe is enclosed in an imaginary cosmic box that has perfectly reflecting walls and expands with the universe. What happens inside is exactly the same as what happens outside. The cosmic box is small on the cosmic scale, hence we assume Euclidean space and the ordinary laws of physics, as used in the laboratory, to study the various forms of cosmic phenomena. The enclosed cosmic box serves as a useful tool for tackling subjects that otherwise would be difficult, such as the entropy of the universe and the nonconservation of energy on the cosmic scale.

CHAPTER 18
THE MANY UNIVERSES

In the past, many cosmological theories, now mostly of historical interest, have been proposed. We look at various “mighty frames,” or cosmic models, such as the Einstein, de Sitter, Friedmann, and Friedmann–Lemaître universes. These models may be classified as static, bang, whimper, or oscillating. Other methods of classifications are given. In this great gallery of universes, the lambda force, popularized by Einstein, adds much to the variety. From this cosmological supermarket we select and examine Milne’s kinematic universe, steady-state universes, and universes in compression, tension, and convulsion. We consider also inflation, chaos, and antichaos. The “dream machine” of the scalar–tensor theory is discussed; by adjusting its control knobs the cosmologist converts a universe into any one of an infinite number of different universes.

CHAPTER 19
OBSERVATIONAL COSMOLOGY

We consider first local observations, then observations at intermediate distances, and finally observations at cosmically large distances. The local observations are confined to the Solar System, Galaxy, and Local Group of galaxies and extend no farther than a few million light years. They determine the first steps in a distance ladder, the distribution and density of matter, the ages of stars and the age of the Galaxy (setting lower limits on the age of the universe), the abundance of the chemical elements, the cosmic background radiation that originated in the early universe (and reveals the peculiar motion of the Galaxy), and give cosmological information on topics such as the baryon density and properties of the cosmic background radiation.

Observations at intermediate distances are confined mainly to the Local (or Virgo) Supercluster and extend a few hundred million light years. They explore only the sub-Hubble sphere and do not extend into the full Hubble flow. They determine the structure, distribution, and motions of galaxies, extended distance scales, redshift–distance and velocity–distance laws in approximate form, and give information on topics such as the age of the universe, baryon density, the density parameters, and the approximate value of the Hubble term.

Observations at cosmically large distances extend deep into the Hubble flow where the redshift–distance relation ceases to be linear. We piece together evolutionary histories by comparing nearby and distant astronomical systems. What is seen in the world picture (on the observer's backward lightcone) must be projected forward onto the world map (in which the linear velocity–distance law holds). This mapping procedure greatly complicates the determination of the cosmological parameters and we are still far from a secure knowledge of the values of the Hubble term, the density parameters, the deceleration term, the cosmological term, and the curvature constant.

CHAPTER 20
THE EARLY UNIVERSE

The cosmic background radiation, discovered in 1965, provides unambiguous evidence of a big bang in the early history of the universe. We explore the big bang, not by traveling in space, but by remaining where we are and traveling far back in time. The big bang was everywhere. If the universe extends infinitely in space, then so also did the big bang. As we journey back in time, the cosmic density and temperature rise steadily and the universe at age a few hundred thousand years is filled with brilliant light. We stand at the threshold of the radiation era. From this epoch descends directly the cosmic background radiation, cooled by expansion, that we nowadays observe. When the universe is one second old, and the temperature is 10 billion kelvin and the density is one million times that of water, we quit the radiation era and enter the bizarre world of the lepton era. Hordes of electrons and muons, and their antiparticles, struggle to survive and from the lepton battlefields flee hosts of ghostly neutrinos condemned forever to wander unseen through the universe. We continue our journey back in time, traveling through the hadron era and its warring matter and antimatter ruled by the strong, electromagnetic, and weak forces. Eventually we enter the quark era ruled by the strong and electroweak forces. Finally phase transitions pass us through an inflation era into a world ruled by the hyperweak force in which matter and antimatter are indistinguishable. Our journey back in time ultimately comes to a halt at the impenetrable Planck barrier. At the Planck epoch the age of the universe is one billion-trillionth of a jiffy (a jiffy is one billion-trillionth of a second) and the density of the universe is 1 followed by 93 zeros times the density of water. Quantum fluctuations of space and time are now of cosmic magnitude and spacetime forms a foam of tangled discontinuities.

We return from the early universe and with our time machine turned to the future we journey to the end of time. We find that perhaps the universe ceases to expand, then collapses and terminates in a new big bang, or perhaps it expands forever and dies in a long drawn-out whimper. In the first possibility, during the collapse of the universe, galaxies are crushed together, and in the devastation that follows, dissolving stars zip through space at speeds close to that of light. The brilliance of the radiation era returns and the universe reverts to its original primordial state. In the second possibility, the galaxies continue to recede from one another and after hundreds of billions of years are dead and lifeless. In the enormous stretches of time that follow, star systems and galaxies contract to form black holes, and particles slowly decay and convert into radiation. After eons of time all black holes evaporate, mostly into low-temperature radiation, and the universe then contains almost no matter, only feeble radiation forever growing feebler.

CHAPTER 21
HORIZONS IN THE UNIVERSE

How far can we see in the universe? The answer depends on the things that we see, whether they are events or world lines. Event and particle (or world line) horizons are discussed, first in the static Newtonian universe to illustrate their nature, and then more generally in nonstatic universes. The horizon riddle, the horizon problem, the Hubble sphere, and other topics are discussed. Also discussed is the photon horizon, beyond which photons emitted in our direction actually recede.

CHAPTER 22
INFLATION

Possibly, the universe begins in a state of utmost symmetry, and progresses through a series of phase transitions to states of lower symmetry and richer diversity. Among the first-born in the very early universe are the magnetic monopole particles. These massive monopoles cannot decay and should still exist and be as abundant as the photons of the cosmic background radiation. An era of inflation explains why they have not been observed. During the grand-unified phase transition, in which the hyperweak force split into the electroweak and strong forces, the universe is thrown into a state of extreme tension. In this state, the universe expands (or inflates) enormously at constant density. This inflation solves not only the monopole problem but also the flatness and horizon problems. But inflation exacts a price: it creates the problem of missing nonbaryonic matter.

CHAPTER 23
THE COSMIC NUMBERS

Cosmic numbers connect the subatomic and cosmic properties of the universe. These dimensionless numbers have intriguing coincidences. Discussed are the cluster hypothesis and Dirac's large-number hypothesis, and their connection with the anthropic principle. The art of cosmonumerology began long ago in the ancient world when Archimedes calculated in the *Sand Reckoner* the number of grains of sand needed to fill the universe.

CHAPTER 24
DARKNESS AT NIGHT

The dark night-sky riddle, known as Olbers' paradox, originated during the Copernican revolution in the sixteenth century. Why the sky at night is dark, and not ablaze with light from countless stars has puzzled many scientists, and played a conspicuous role in the history of cosmology. Many writers in recent times have said the night sky is dark because of the expansion of the universe. But this cannot be true because calculation shows that if our universe were static the sky at night would still be dark. The universe does not contain enough energy to create a bright-sky universe. The correct solution was anticipated by the poet Edgar Allan Poe and investigated in depth by Lord Kelvin. The sky at night is dark because the stars shine for too short a time to fill the universe with radiation in equilibrium with stars; equivalently, stars shine for too short a time for the universe to contain sufficient visible stars to cover the sky.

CHAPTER 25
CREATION OF THE UNIVERSE

We consider miscellaneous topics in cosmogeny, beginning with the creation myths of earlier societies. The Mosaic chronology that fixes the date of creation of the universe to five or six thousand years before the present has been the cause of considerable conflict between science and religion. Creation and fitness of the universe are distinguished as separate subjects and examined in current theistic, anthropic, spontaneous, and natural selection theories. Eschatological myths and end-of-the-world theories are also briefly reviewed.

CHAPTER 26
LIFE IN THE UNIVERSE

In this last chapter we consider past and present theories of the origin of life and discuss aspects of evolution and natural selection. Understanding the nature of intelligence is vitally important in cosmology, and we consider how human beings might have acquired their large brains. As cosmologists, in our finely tuned universe, we feel impelled to believe that intelligent life must exist elsewhere in the multitudes of galaxies. But what is life? What is intelligence? Does intelligent life, technologically advanced, exist elsewhere in our Galaxy? Avenues of inquiry open up in pursuit of answers to this and other questions.

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Excerpt
More Information

Part I