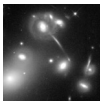
PROLOGUE



Could God Have Made the World Any Differently?

The preeminent mystery is why anything exists at all. What breathes life into the equations of physics, and actualized them in a real cosmos? Such questions lie beyond science, however: they are the province of philosophers and theologians. For science, the overarching problem is to understand how a genesis event so simple that it can be described by a short recipe seems to have led, 13 billion years later, to the complex cosmos of which we are a part. Was the outcome "natural," or should we be surprised at what happened? Could there be other universes? Scientists are now addressing such questions, which had formerly been in the realm of

speculation. Cosmology has a history that stretches back for millennia, but the conceptual excitement has never been more intense than it is at the start of the twenty-first century.

The Sun and the firmament are part of our environment—our cosmic habitat. Artistic and mystical geniuses share this perception with scientists. D. H. Lawrence wrote, "I am part of the Sun as my eye is part of me." Van Gogh's "Starry Night" was painted in the same spirit as his pictures of cornfields and sunflowers. One can find numerous other such examples in the arts.

Science deepens our sense of intimacy with the nonterrestrial. We are ourselves poised between cosmos and microworld. It would take as many human bodies to make up the Sun's mass as there are atoms in each of us. Our existence depends on the propensity of atoms to stick together and to assemble into the complex molecules in all living tissues. But the atoms of oxygen and carbon in our bodies were themselves made in faraway stars that lived and died billions of years ago.

Technical advances during the twentieth century, especially its later decades, have enriched our perspective on our cosmic habitat. Space probes have beamed back pictures from all the planets of our solar system: new technology enables a worldwide public to share this vicarious cosmic exploration. Pictures of a comet crashing into Jupiter, made with the Hubble Space Telescope, were viewed almost in real time by more than a million people on the Internet. During this first decade of the twenty-first century, probes will trundle across the surface of Mars and even fly over it; they will land on Titan, Saturn's giant moon; and samples of Martian soil may be collected and brought back to Earth.

Our universe extends millions of times beyond the remotest stars we can see—out to galaxies so far away that their light has taken 10 billion years to reach us. Bizarre cosmic objects—quasars, black holes, and neutron stars—have entered the general vocabulary, if not the common understanding. We have learned that most of the stuff in the universe is not at all in the form of ordinary atoms: it consists of mysterious dark particles, or energy that is latent in space. We now envision our Earth in an evolutionary context stretching back before the birth of our solar system—right back, indeed, to the primordial event that set our entire cosmos expanding from some entity of microscopic size.

Deeper insight into the nature of space and time may enlarge our conception of the cosmos to embrace other universes beyond our own. These may manifest extra spatial dimensions and other concepts so far from our intuition that we shall grasp them with difficulty, if at all. What is surely astounding is that this enterprise has made any headway at all.

The public image of Albert Einstein is not the single-minded and ambitious researcher of his creative youth, but the benign and unkempt sage of his later Princeton years. One of the most-quoted of his aphorisms is: "The most incomprehensible thing about the universe is that it is comprehensible." He was here expressing his amazement that the laws of physics, which our minds are somehow attuned to understand, apply not just here on Earth, but everywhere we look. Our universe could have turned out to be an anarchic place, where atoms and the forces governing them are bafflingly different elsewhere in the cosmos from those we can study locally. But atoms in the most distant galaxies seem

identical to those in our laboratories. Without this simplifying feature, we would have made far less progress in understanding our cosmic environment.

But what about the many things that remain incomprehensible? The most daunting challenge is posed by our biosphere—the immense complexity and variety of organisms, ecosystems, and brains. My interest lies in issues that I genuinely think are more tractable: probing and constraining the underlying laws that govern the microworld of atoms and the grand scale of the cosmos, and understanding how these set the stage for life by allowing the emergence of planets, stars, and galaxies.

In the last few years of the twentieth century, an exciting new research area opened up: the detection of planets around other stars. The night sky will soon be far more interesting. Stars will not be just points of light: many will have a distinctive retinue of planets whose main properties we will know. Will any of these harbor intelligence—or, indeed, even the most primitive life?

If aliens exist, and if we ever establish contact with them, what common culture might we share? The obvious answer is: our cosmic habitat. However different their evolution, the aliens would be made of atoms and governed by the same forces that govern us. If they had eyes and their world had clear skies, they would gaze out on the same vista of stars and galaxies that surround us. We and they would be confronted with stupendous expanses of space, as well as huge spans of time. Contemplative aliens might already have answered questions such as: What happened before the Big Bang? What causes gravity and mass? Is the universe infinite? How did

atoms assemble—on at least one planet around at least one star—into beings able to ponder these mysteries? These questions still baffle all of us. Rather than the "end of science" being nigh, we are still near the beginning of the cosmic quest.

To link cosmos and microworld requires a breakthrough. Twentieth-century physics rests on two great foundations: the quantum principle (governing the "inner space" of atoms) and Einstein's relativity theory, which describes time, outer space, and gravity but doesn't incorporate quantum effects. The structures erected on these foundations are still disjoint. Until there is a unified theory of the forces governing both cosmos and microworld, we won't be able to understand the fundamental features of our universe: these features were imprinted on it at the very beginning, when everything was so squeezed that quantum fluctuations could shake the entire universe.

In his later life, Einstein focused on deep issues that are likely to attract more interest in the twenty-first century than they ever did in the twentieth. He spent his last thirty years in a vain (and, with hindsight, premature) quest for a unified theory of physics. Will such a theory—reconciling gravity with the quantum principle and transforming our conception of space and time—be achieved in coming decades?

The smart money is on a concept known as "superstring theory," or M-theory, in which each point in our ordinary space is actually a tightly folded origami in six extra dimensions, wrapped up on scales perhaps a billion billion times smaller than an atomic nucleus, and particles are represented as vibrating loops of "string." There is still an unbridged gap

between this elaborate mathematical theory and anything we can actually measure. Nonetheless, its proponents are convinced that string theory has a resounding ring of truth about it and that we should take it seriously.

A universe hospitable to life—what we might call a *biophilic* universe—has to be very special in many ways. The prerequisites for any life—long-lived stable stars, a periodic table of atoms with complex chemistry, and so on—are sensitive to physical laws and could not have emerged from a Big Bang with a recipe that was even slightly different. Many recipes would lead to stillborn universes with no atoms, no chemistry, and no planets; or to universes too short lived or too empty to allow anything to evolve beyond sterile uniformity. This distinctive and special-seeming recipe seems to me a fundamental mystery that should not be brushed aside merely as a brute fact.

How we respond to this mystery will depend on the answer to another of Einstein's questions: "Could God have made the world any differently?" Our universe, along with the physical laws that prevail in it, may turn out to be the unique outcome of a fundamental theory—in other words, nature may allow only one recipe for a universe. Alternatively, the underlying laws could be more permissive: they may allow many recipes, leading to many different universes; and these universes may actually exist.

We do not know which one of these options prevails. The answer will have to await a successful fundamental theory, and it would be presumptuous to prejudge the answer. Nonetheless, this book will focus on the fascinating consequences of the answer to Einstein's question—posed as the

title of this Prologue—being "yes": God did have a choice. The entity traditionally called the universe—the entire domain that astronomers study, or the aftermath of "our" Big Bang—would be just one small element, or atom, in an infinite and immensely varied ensemble. The entire "multiverse" would be governed by a set of fundamental principles, but what we call the laws of nature would be no more than local bylaws—the outcome of historical accidents during the initial instants after our own particular Big Bang.

In this book I argue that the multiverse concept is already part of empirical science: we may already have intimations of other universes, and we could even draw inferences about them and about the recipes that led to them. In an infinite ensemble, the existence of some universes that are seemingly fine-tuned to harbor life would occasion no surprise; our own cosmic habitat would plainly belong to this unusual subset. Our entire universe is a fertile oasis within the multiverse.