PART ONE

THE AGE OF THE COSMOS
Building a Perfect Planet

The world we know came into existence long, long ago at a moment that we have come to call the *Big Bang*. Scientists sought for much of the twentieth century to find out exactly when the Big Bang happened, but not until the year 2003 was there overwhelming evidence that this moment occurred 13.75 billion years ago.* This was the birth of the observable universe and the beginning of the story of how we got here. Nine billion years after this explosive birth, our star and planet emerged from the cosmos. In Part I of our story we will see how the cosmos grew from a single point that was infinitely hot and dense into the elegant and beautiful universe we now see and the blue-green planet that nurtures and protects complex life.

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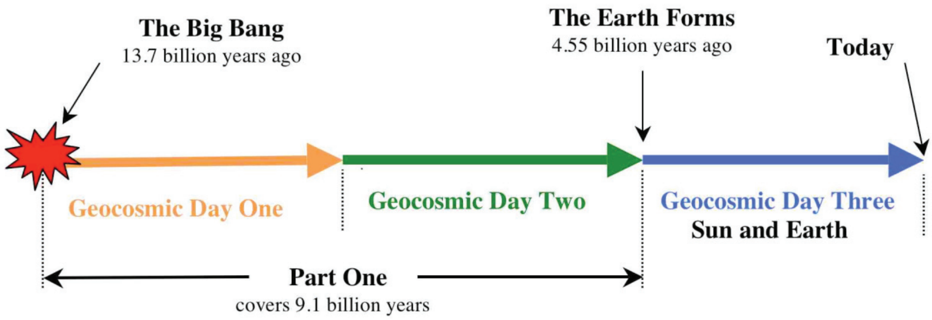
* See Appendix I for an explanation of how we found the age of the universe.

Time Context for Part One



Main Events of Part One: The Age of the Cosmos

Event	Time after Big Bang	Geocosmic Time
First nucleons	1.0 second	Day one, 12:00 am
First neutral atoms	380,000 years	Day one, 12:00:07 am
First stars	400 million years	Day one, 2:00 am
First galaxies (including our own, the Milky Way)	400 - 600 million years	Day one, 2:00-3:00 am
Dark energy begins to dominate over gravity	6 billion years	Day two, 8:00 am
The Sun forms	9.0 billion years	Day two, 11:30 pm
The Earth forms	9.1 billion years (4.55 billion years ago)	Midnight between day two and day three.

Chapter 1
The First 380,000 Years

In the Beginning

In the beginning, when the universe was born, all was one. Matter, energy, space, time, and anything else we can name, did not exist separately but were all merged together in a pure oneness, the tiniest seed that would grow into the complex and elegant universe we now live in. We have no physics or mathematics that can describe this moment, this originary state of cosmic unity when everything was compressed into a single point that was infinitely hot and dense; scientists call this state a *singularity*.

From this singularity, as time itself came into existence, the universe was born in a gigantic detonation that hurled everything outward, triggering a relentless expansion that we can still see today. The starting temperature and density of the universe were nearly infinite, but as expansion set in and the universe grew in size, the temperature and density dropped steadily; the universe has expanded and cooled for its entire life.

As the infant universe expanded and cooled, it slowly took on the structure of the world we know today: a world made of quarks and electrons, of atoms and molecules, that gathered into stars and galaxies and planets; a world with at least one planet where molecules assembled into something called life; a world where life, in one location at least, continued for so long that it evolved into intelligent, reflective, self-aware beings who now ponder all this.

Exploring Deeper

An Inevitable Question

Can we ask what was happening *before* the Big Bang, before the beginning of the universe? Some scientists feel that something may indeed have been happening before our universe was born—a previous universe, perhaps, that ended in a crushing *Big Crunch*. Or, maybe our universe is but one of many universes that exist independently of ours—the *multiverse* scenario that some mathematical theories predict. Still, it seems very unlikely that we will ever know anything about what happened before our universe began because the nearly infinite temperatures and densities of the Big Bang would surely have destroyed any remnants of information from before. It seems certain that no information could survive the Big Bang—it was the ultimate sterilizing event that eliminated all traces of anything that preceded it. Our universe must have begun with an absolutely clean slate, a completely unknown past. So, while we *can* ask what was happening before the Big Bang, it seems that we may never be able to know the answer.

Science and Discovery

The Two Great Pillars

How is it possible to find the moment when the universe began, to date the Big Bang? How does science go about finding the answer to that question? Who are these scientists on such a quest, and what are their tools of discovery? They are astronomers following in the footsteps of Galileo, who first used the telescope in 1609 to gaze upward and probe the hidden secrets of the heavens. In more recent years they have become astrophysicists, combining the observations and data from astronomy with the tools of physics to understand what's out there—from stars and galaxies, to black holes and planets. And among physicists, astronomers, and astrophysicists are specialists called *cosmologists* who study the universe as a whole, seeking to know how and when it was born, how it became the world we know, and what its future may hold. For more details about how scientists built on Galileo's early discoveries to find and date the birth of the universe, see Appendix I.

Today the most widely accepted theory of the universe among cosmologists is called the *Hot Big Bang Theory*. It is built on the mathematical predictions of the two great pillars of physics, *quantum mechanics* and *general relativity*, aligned with the data that astronomers gather from their ever-more powerful telescopes. The field of quantum mechanics deals with the very smallest things in the world—atoms and nuclei and subatomic particles. In contrast, the field of general relativity describes gravity and the very large-scale universe. Each of these theories was developed in the early twentieth century, but quite differently: quantum mechanics was first developed over more than ten years, culminating in 1927, by a stellar collection of physicists and mathematicians that included Werner Heisenberg, Erwin Schrödinger, Niels Bohr, Paul Dirac, and Max Born, while the general theory of relativity was created almost entirely by just one man, Albert Einstein, and first published in 1915.

However, these two great theories of the world, relativity and quantum mechanics, have never been compatible with each other—they make conflicting predictions in some cases. One of the great dreams of modern physicists is to somehow merge the two into one unified theory that has been dubbed *quantum gravity*. A more complete understanding of the early universe awaits this merger, yet even without a theory of quantum gravity, cosmologists have been able to construct a likely chronology of the early universe that is supported by recent observations. We know that by the time the universe was one second old, many very important events had already taken place.

Much Ado About One Second

The first *one second* was the busiest time in the entire existence of the universe. A number of crucial events must have taken place by the time the universe was one second old, and cosmologists have created an elaborate and detailed chronology of events that occurred during this time (see Figure 1-1 for a summary).

Figure 1-1
The First Moments in the Life of the Universe

Name	**Time after the Big Bang**	**What was happening**
The Planck Epoch	10^{-43} seconds	Unknown
Grand Unification Epoch	10^{-35} seconds	*Gravity*, then the *strong nuclear force* separate. Quarks form.
Inflationary Epoch	10^{-34} to 10^{-32} sec	Universe expands in size by at least 10^{25} and quantum fluctuations amplify. Electrons and neutrinos form by the end of this time.
Electroweak Epoch	10^{-12} seconds	The *electromagnetic* and *weak nuclear forces* separate, making four fundamental forces. Neutrinos separate (decouple) from matter and radiation can stream out into space.
Hadron Epoch	10^{-6} to 1.0 seconds	Free quarks join to form protons and neutrons (hadrons). This is the birth of "normal" matter. Matter and anti-matter meet and annihilate, leaving only matter.

For the first fraction of a second after the moment of the Big Bang—for just 0.0 000000000000000000000000000000000000000001 (or 10^{-43}) seconds—nothing is known except that the size of the currently visible universe was virtually zero while the density and temperature were nearly infinite. Cosmologists call this the *Planck Epoch* and say that it cannot be understood until a theory of quantum gravity emerges. However, in the next phase, just after the Planck Epoch, the first recognizable features of our universe began to appear. This has been called the *Grand Unification Epoch* and is marked by the emergence of gravity, the strong nuclear force, and the fundamental particles of matter known as *quarks*. And when this work was done, about 10^{-34} seconds into the lifespan of the universe, something preposterously unimaginable apparently took place; that something is now referred to as *cosmic inflation*.