Introduction: The Mysteries Ahead

The universe is full of magical things patiently waiting for our wits to grow sharper.

EDEN PHILLPOTTS (1862-1960)

Picture yourself near a mountain lake as twilight falls on a crisp, clear summer evening. You've arrived here on foot, with only the sounds of nature for company. Sitting near the water's edge, you watch patiently as the sky fills slowly with stars. Soon the band of the Milky Way comes into view, stretching high across the sky and shining with a brilliance city dwellers never see. The depths of the heavens are reflected in shimmering lights on the lake, creating an image of infinity both above and below you. If you set your mind free, you cannot help but ask some of the most fundamental questions imaginable. What is the universe and what is Earth's place in it? How did it all come to be? As you let your thoughts wander through time and space, you could be anyone at any time in history. After all, your questions are the same ones that humans of every culture have asked since history began.

But there's a difference. You are living at the start of the third millennium of the common era, at a time when the boundaries between the known and the unknown are shifting faster than they ever have before. Questions that seemed imponderable just a few decades ago are now all but settled, and many of today's biggest questions could not even have been imagined by our ancestors in centuries and millennia past. Of course, we still don't know why the universe exists in the first place or why we are here to ask such questions, and it's possible that we never will. But modern science offers satisfactory answers to many of the "what" and "how" questions that have puzzled humans for thousands of years. So before we move on to discuss the mysteries that lie ahead, it's worth looking back at the mysteries of previous millennia that already have been solved.

If anyone had bothered to make a list of the top ten mysteries of the universe at the dawn of the last millennium, it would undoubtedly have been dominated by questions concerning the layout of the heavens and the phenomena of the sky. What are stars and planets? How big and how far away are the Sun and Moon? Why do the planets and stars move through the sky as they do? And so on. Indeed, these questions probably would have been on the list at the start of the first millennium, and perhaps even on the list a thousand years before that.

The biggest mystery of all dealt with Earth's place in the universe. Until Kepler and Galileo settled the matter some four hundred years ago, Earth was generally assumed to be the center of the universe. But a few dissenting voices were heard through the centuries. In about 260 BC, the Greek astronomer Aristarchus reasoned that the Earth must go around the Sun, rather than vice versa. His contemporaries and later scholars rejected his arguments, but not without at least some impassioned debate. In 1440, Nicholas of Cusa wrote a book titled De docta ignorantia ("On Learned Ignorance"), in which he claimed that the Earth turns on its axis as it orbits the Sun, that stars are other suns and hold other inhabited worlds in their grasp, and that the heavens are infinite in extent. Interestingly, while Galileo was punished by the Church for holding similar beliefs two centuries later, Nicholas was ordained a priest in the same year his book was published, and later was elevated to cardinal. Thus we see that science and religion were not always in conflict, and there is no need for them to be in conflict today.

It was another Nicholas—Nicolaus Copernicus—who set in motion the wheels of science that would finally prove Earth to be a planet orbiting the Sun. We'll discuss this story in greater detail in Mystery 8, but for now we should look at the modern picture of the universe that has since emerged.

Today we know that Earth is the third (in order of distance) of nine planets that orbit the Sun. The Sun, the nine planets and their moons, and a myriad of smaller objects including asteroids and comets make up what we call our *solar system*—one of more than 100 billion star systems that make up the huge, swirling disk of the Milky Way galaxy. Our location in the Milky Way is a little over halfway from the galactic center to the edge of the galactic disk.

The Milky Way galaxy is one of the two largest galaxies in a group of thirty or so galaxies that we call the Local Group. (The other large member is the Great Galaxy in Andromeda.) Many other groups of galaxies are scattered throughout the heavens, and those groups that contain more than about a hundred galaxies are often called *clusters* of galaxies. The groups and clusters, in turn, often appear to make up larger structures called *superclusters*. Not surprisingly, the supercluster to which the Local Group belongs is called the Local Supercluster.

Finally, the universe encompasses all the superclusters and everything within and between them. Said differently, the universe is the sum total of all matter and energy. The postcard shown here summarizes the basic levels of structure in our cosmic address, and the painting on the inside front cover shows the same idea in a more visual way.

Questions about the origins of Earth The Earth and Moon and the universe might also have made the list of mysteries in past millennia, You wallant believe what to the life went Soft seens on the third was though many philosophers probably Deal and I sured that I saw your brother there we considered those questions unanthe to catch up to hall but new rowing our rowing we Were want want out in the new swerable by science. After all, until Fatthful Lots of love recently no one could imagine Interfected and the second and the s methods of studying the past such as the radioactive dating of rocks. Only a few brave souls even ventured guesses about how a planet might have developed. Still, one of the earliest guesses was uncannily modern; before 400 BC, the Greek philosopher Democritus

postcard shows how a distant friend might address a postcard to

someone on Earth.

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The Solar Suistery Milky Way Galaxy

The Local Group The Local Supercluster

The Universe

45A Earth

This

suggested that the universe began as a chaotic mix of atoms that slowly clumped together, ultimately forming the Earth and other worlds. Today's scientific story of creation similarly holds that simple components gradually developed into galaxies, stars, planets, and life. The difference between the modern story of creation and that envisioned by Democritus lies mainly in the details—and, more important, in that scientific evidence now makes this story far more than a guess.

According to modern science, the universe began somewhere between about 10 billion and 16 billion years ago with an event called the *Big Bang.* As we'll discuss in Mystery 4, several strong lines of evidence support the idea of a Big Bang. But the simplest evidence is the most direct. As first discovered in the 1920s by Edwin Hubble (for whom the Hubble Space Telescope is named), the universe is expanding in the sense that the average distance between galaxies is increasing with time. If intergalactic distances are growing with time, we can logically conclude that galaxies must have been closer together in the past. By running the current rate of expansion backward, we find that all galaxies would have been on top of one another something over 10 billion years ago. Since you can't get any closer together than that, this time must mark the beginning of the universal expansion, which is all we really mean by the Big Bang.

The expansion that began with the Big Bang has continued ever since, but the expansion rate has not always been the same in all places at all times. In particular, the force of gravity, which attracts all objects to all other objects, has presumably slowed the overall expansion, and in some relatively small regions of the universe gravity has halted and even reversed the expansion altogether. Those regions where gravity has halted the local expansion are the galaxies themselves—and also some groups and clusters of galaxies. Gravity also drove the collapse of smaller clumps of gas and dust within galaxies, thereby forming stars and planets. Galaxies like our own Milky Way probably looked much as they do today when the universe was less than half its present age.

Stars live and die within galaxies, expelling much of the matter from which they were made at the ends of their lives. This expelled material is then recycled into new generations of stars and planets. In this sense, galaxies function as cosmic recycling plants, providing the astronomical equivalent of ecosystems for stars, planets, and clouds of interstellar gas.

The earliest generation of stars had no Earth-like planets, because the Big Bang produced only the two simplest elements: hydrogen and helium (plus trace amounts of a third element, lithium). The rest of the elements, from which we and our planet are made, were manufactured in stars. Stars shine for most of their lives with the energy released by the nuclear fusion of hydrogen into helium. (Nuclear fusion is the process of making heavier elements from light ones by joining together nuclei of light elements.) But near the ends of their lives, advanced fusion reactions in the more massive stars produce all the remaining elements, including primary ingredients of life such as carbon, oxygen, nitrogen, and iron. That's how these elements came to be present in the universe, and it is from this "star stuff" (to quote the late Carl Sagan) that Earth and its life were made. The painting on the inside back cover summarizes this scientific story of our cosmic origins.

The ease with which we can state our cosmic address and origins hides some amazing ideas of scale. Interstellar distances are so vast that ordinary units of measure like miles or kilometers are almost useless. Instead, we usually measure cosmic distances in units of *light-years*, with one light-year being the distance that light can travel in a year. (If you prefer converting to ordinary units, a light-year is roughly 10 trillion kilometers, or 6 trillion miles.) Keep in mind that light travels extremely fast by Earth standards: it could circle the globe nearly eight times in just one second and takes only about six hours to journey from Earth to Pluto, the outermost planet of our solar system. But even at this incredible speed, light takes more than four years to travel the distance to the nearest star system, Alpha Centauri, which is why we say that Alpha Centauri is a little over four light-years away.

The fact that light takes significant amounts of time to traverse the vast expanses of space causes space and time to be inexorably intertwined. For example, Color Plate 1 shows a photograph of the Great Galaxy in Andromeda, also known as M31, which lies about 2.5 million light-years away. The photograph therefore shows how M31 looked about 2.5 million years ago, when early ancestors of modern humans were walking the Earth. Moreover, the diameter of M31 is about a hundred thousand light-years, so light from the far side of the galaxy required a hundred thousand years more to reach us than light from the near side. Thus, the photograph of M31 spans a hundred thousand years of time.

Ultimately, the finite age of the universe and the speed of light combine to limit the portion of the universe that we can see. For example, if the universe is 12 billion years old, then light from galaxies more than 12 billion light-years away would not yet have had time to reach us. We would therefore say that the *observable universe* extends 12 billion light-years in all directions from Earth. (This explanation is somewhat oversimplified, but the details are not important for our purposes.) The entire universe, meaning the whole of creation, is greater in size than the observable universe; in fact, as we'll discuss later, the entire universe might even be infinite in size.

The scale of time is no less incredible. The late Cornell University astronomer Carl Sagan pioneered the use of a wonderful device for comprehending astronomical time, which he called the cosmic calendar (below). We imagine the entire history of the universe compressed into a single year: the Big Bang occurs at the first instant of January 1, and the present day is the stroke of midnight on December 31. On this scale, the Milky Way galaxy probably formed sometime in February, but it was not until mid-August that our solar system was born. Life on Earth took hold by mid-September, but the great burst in diversity of life known as the Cambrian explosion did not occur until mid-December. The earliest dinosaurs walked the Earth on Christ-

JANUARY Jan. 1 Big Bang	FEBRUARY Milky Way forms	MARCH	APRIL	Jan. 1: The Big Bang February: The Milky Way forms	$\begin{array}{ c c c c c c } \hline \textbf{DECEMBER} \\ \hline S & M & T & W & T & F & S \\ \hline 1 & 1 & 2 & 1 & 3 & 1 & 4 & 1 & 5 & 1 & 6 & 1 & 7 \\ \hline \end{array}$					ξ	S	Dec. 13: Invertebrate life arose Dec. 25: Dinosaurs walked the Earth
MAY	JUNE	JULY	AUGUST Aug.13 Earth forms	Aug. 13: The Earth forms	8	9 16	10 17	11 18	12	13 20	14 21	Dec. 30: Extinction of dinosaurs
SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	December	22 29	23 30	24 31	25	26	27	28	December 31

mas. Early in the morning of December 30, an asteroid or comet crashed to Earth, precipitating a global catastrophe that wiped out the dinosaurs and many other species of the time.

With the dinosaurs gone, small furry mammals inherited the Earth. Some 60 million years later, or around 9 PM on December 31 of the cosmic calendar, the earliest hominids (human ancestors) walked upright. Most of the major events of human history have taken place within the final seconds of the final minute of the final day on the cosmic calendar. With *now* being the stroke of midnight on December 31, agriculture arose only about thirty seconds ago. The Egyptians built the pyramids about thirteen seconds ago. It was only about one second ago on the cosmic calendar that Kepler and Galileo provided concrete proof that Earth is a planet orbiting the Sun. The oldest living humans were born less than three-tenths of one second ago. On the scale of cosmic time, the human species is the youngest of infants, and a human lifetime is a mere blink of an eye.

So here we are today, babes staring into the infinite unknown. Put yourself back on the shore of the mountain lake. Listen to the sounds of the night, and watch the reflections of the stars slowly circling overhead. Let your mind wander freely once again, contemplating the deepest questions of human existence. But this time consider the great foundation of knowledge that we have inherited through the efforts of thousands of our ancestors over thousands of years. This is their gift to you, a gift that enables you to join the human adventure of astronomical discovery. Now it is time to look ahead and see what mysteries have been laid at the door-

step for our generation to solve.

This version of the cosmic calendar assumes that the universe is 12 billion years old, so that each month represents about 1 billion years and each second represents about 380 years.

1.00	DECEMBER 31
1:00 PM _	
2:00 PM _	
3:00 PM _	
4:00 PM _	
5:00 PM -	
6:00 PM -	
7:00 PM -	
8:00 PM -	
9:00 PM	9:00 PM Earliest human ancestors
10:00 PM -	
11:00 PM	11:58 PM Modern humans evolved
12.00 pM	

9:00 рм: Earliest human ancestors 11:58 рм: Modern humans evolved

60 seconds to midnight...

11:59:30 рм: Agriculture arose 11:59:47 рм: Pyramids built 11:59:59 рм: Kepler and Galileo proved Earth a planet