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# WORLDS BEYOND IMAGINATION

> Do there exist many worlds, or is there but a single world? This is one of the most noble and exalted questions in the study of Nature.
>
> —*Saint Albertus Magnus (c. 1206–1280)*

This is a book about possibilities. It is about the possibility that, within a decade or two, robotic or human explorers will drill into the Martian surface and discover microscopic life in subterranean pockets of liquid water. It is about the possibility of landing spaceborne submarines on Jupiter's moon Europa, where they might melt their way through miles of ice and observe life swimming in a volcanically heated ocean. It is about the possibility of strange, cold-adapted life forms on Saturn's moon Titan, a world on which we have already landed a robotic emissary, despite its being located nearly a billion miles away. It is about the possibility of SETI researchers detecting an unmistakable signal coming to us from a civilization that has grown up around a faraway star. It is about the possibility that we may already be surrounded by a galactic civilization, populated by beings who surpassed our own current level of development millions or even billions of years ago. Most of all, it is about the possibilities that await *us,* if and when we learn that we are not alone in the universe.

It doesn't take long to begin to appreciate these and other possibilities, but you have to be in the right frame of mind. If you're reading at night and you happen to live in a place with clear, dark skies, take a moment to put the book down and go out and look at the stars. If you live in a city or it is cloudy or daytime, close your eyes and picture yourself at a favorite vacation spot on a perfect night. Personally, I like the mountain lakes not far from my home in Colorado, where the stars sometimes shine so brightly that I can make out the constellations by their reflections in the still water.

As you look out into the seemingly infinite heavens, you should feel a change in your mental state as your thoughts shift from the daily trials of life to questions of who we are, how we got here, why we exist, and whether we have companionship among the planets and stars.

The mere sight of the myriad stars may seem enough to answer the last question. After all, when you consider the fact that each star is a sun, possibly orbited by planets of its own, it may seem inevitable that others are out there, looking at us as a dot of light in their own skies. But possibilities are not certainties, and despite everything we know about the universe today, we still have no proof that even the tiniest microbes live beyond the confines of our small world. We may have good reason to be entranced by the possibilities for life beyond Earth, but it is also possible that such life exists nowhere except in our own minds.

That is where science comes in. Science is a way of distinguishing possibilities from realities. We can imagine all the possibilities that we want, but science asks us to put them to the test. If we find confirming evidence for our possibilities, then we have at least some reason to think they reflect reality. If our possibilities conflict with reality, then we know they were figments of our imagination. Of course, oftentimes we have no clear evidence either way, as is the current case for the possibility of extraterrestrial life. In such cases, the job of science is to help us keep looking and learning, until we someday acquire the evidence we seek.

Today, many hundreds of scientists around the world are engaged in the scientific search for life in the universe, a topic of study that is often called *astrobiology* or *exobiology*. In the United States, NASA has established an Astrobiology Institute, which functions as a collaborative effort between scientists at NASA research centers and at more than a hundred universities and independent research laboratories. The European Union has a similar collaborative effort with its European Exo/Astrobiology Network. Australia, Great Britain, Spain, France, and Russia also have formal astrobiology centers, and almost every other nation on Earth has at least a few scientists whose research bears on the question of life in the universe.

Given that we don't yet know of any life beyond Earth, you might wonder how so many scientists can be gainfully employed in its study. The answer, like this book, is about possibilities. Only a few scientists—those involved in the search for extraterrestrial intelligence, or SETI for short—are currently engaged in a direct effort to detect alien life. For all the others, current efforts focus on learning about the possibility of life existing elsewhere. For example, planetary scientists explore other worlds in our solar system either telescopically or by sending out robotic spacecraft. While their efforts could in principle turn up direct evidence of life, for the time being they are more focused on helping us understand the conditions found on different worlds, thereby allowing us to evaluate whether those conditions might be conducive to life. Many scientists working in astrobiology study the basic chemistry and nature of life, which should help us recognize alien life if we happen to come across it. Others seek to understand the origin of life on Earth; after all, an understanding of how life arose on our own planet ought to make it easier for us to determine the likelihood that life might arise somewhere else. Still others study Earth itself, which teaches us about how the geological nature of Earth helps make it home to abundant life. Even astronomers get in the game, seeking stars that could make good suns, looking for planets around those stars, and developing technologies that may someday help us detect life even on worlds that we can study only through telescopes.

Of course, all this effort is predicated on the idea that the possibility of extraterrestrial life is worthy of scientific study. Here, we must distinguish between an idea that is *philosophically reasonable* and one that is *scientifically testable*. The fact of our own existence makes it philosophically reasonable to wonder if life exists beyond Earth, but until quite recently there was no way in which we could actually test out the idea. In most of the rest of this chapter, I will try to explain why, in just the past couple of decades, the search for life in the universe has suddenly become a topic of intense scientific interest. First, however, it's worth developing a bit of historical perspective on the philosophical question that drives us to wonder if we are alone.

## THE ANCIENT QUESTION OF WORLDS BEYOND EARTH

Even aliens need a place to call home. No matter whether we consider the tiny intelligent beings who I once imagined visiting my bedroom or the most primitive single-celled slime, all life must have gotten its start somewhere. Thus, the question of life beyond Earth makes sense only if we have reason to think that there are other worlds upon which life could live.

Those of us who would like to meet aliens generally take it for granted that the universe is indeed full of hospitable planets on which life and civilizations might have arisen. We cannot yet be certain that this is the case, because our technology is not quite yet up to the task of discovering such planets around other stars. Nevertheless, as I'll discuss in more detail shortly, the idea seems reasonable today because we know that other stars have at least some planets, and our understanding of planetary formation makes it plausible to imagine that planets with life could turn out to be common. But if we go back just a few centuries, the context for considering life beyond Earth was quite different.

Consider the quotation from Saint Albertus Magnus that opens this chapter, which begins: "Do there exist many worlds, or is there but a single world?" If you read Magnus's quotation with a modern eye, you might think he's using the term *world* in the sense of an Earth-like world with life. But he was actually using it in a much more basic way. Before the time of Copernicus, Kepler, and Galileo, all of whom lived less than 500 years ago, scholars generally assumed that Earth held a central place in the universe. Our solid home—which, by the way, had been known to be spherical since the time of the ancient Greeks—was assumed to be surrounded by a great sphere of stars, and between Earth and the stars lay additional spheres that carried the Sun, the Moon, and the five planets known at the time. Thirteenth-century philosophers and theologians had no more reason to think of any of these objects as "worlds" than to think of them as gods—an idea that had long since been rejected as ancient mythology.

In fact, pre-Copernican scholars did not even consider Earth to be a planet. The word *planet* comes from the Greek for "wanderer," and it originally referred only to objects that appear to wander among the stars in our sky. The idea will be clear if you think about the universe as it appears to the naked eye. We live on our seemingly central and unmoving home, while the stars appear to circle around us with each passing day, always staying in the fixed patterns of the constellations. The Sun also makes a daily circle around us, but not quite at the same rate as the stars. That is why the Sun gradually makes its way through all the constellations of the zodiac over the course of a year. The Moon follows this same basic pattern of motion, but moves more quickly through the constellations than the Sun, completing a full circuit and cycle of phases in about a month (think "moonth"). Before the era of airplane lights and aside from an occasional comet, the only other objects that ever seemed to move against the background of the stars were the five bright points of light known as Mercury, Venus, Mars, Jupiter, and Saturn. Thus, from the perspective of people living more than 500 years ago, there were seven objects that appeared to wander among the stars and hence qualified as "planets": the Sun, the Moon, and the five innermost planets besides Earth. The planetary status of these seven objects is enshrined in the names of the seven days of the week.[1] In English, only *Sun*day, *Moon*day, and *Saturn*day are obvious, but

[1] Want an example of how deeply astronomy is intertwined with our everyday lives? Just think about the fact that the planet Uranus *is* faintly visible to the naked eye, and that if ancient people had noticed it wandering relative to the stars we probably would have had 8 days a week instead of 7.

if you know a romance language like Spanish you'll be able to figure out the rest: Tuesday is Mars day (martes), Wednesday is Mercury day (miércoles), Thursday is Jupiter day (jueves), and Friday is Venus day (viernes).

Because the Earth-centered belief system implied that our world should be fundamentally different from any of the lights in the sky, you might wonder how Saint Albertus Magnus could even have conceived of other worlds. The answer is that, following a line of thought dating back to ancient Greece, he was considering the possibility of other worlds that were more like what we might think of as separate universes—each world the center of its own cosmos, circled by its own sun, planets, and stars. The question he asked also dated back to the ancient Greeks, inspired by his reading of Aristotle, which at the time had recently been translated into Latin.

It can be tempting to think that people who lived more than 2,000 years ago were more primitive or simpleminded than we are, but in fact many ancient civilizations were remarkably sophisticated. The ancient Greeks, geographically positioned at a crossroads that gave them access to ideas and inventions from cultures throughout Eurasia and northern Africa, developed philosophies that still resonate today. On the question of other worlds and extraterrestrial life, the Greeks split into two distinct camps.

On one side were the *atomists*, Greek philosophers who held that everything is made of tiny, indivisible atoms of four basic elements: fire, water, earth, and air. The atomist doctrine was developed largely by Democritus (c. 470–380 B.C.), who argued that the world—both Earth and the heavens—had been created by the random motions of infinite atoms. For example, he imagined atoms of earth to be rough and jagged, like tiny pieces of a three-dimensional jigsaw puzzle, so that they could stick together when they collided and thereby explain how our world had formed in the first place. Because the atomists believed the total number of atoms to be infinite, they assumed that the same processes that created our world should also have created others. This inevitably led them to conclude that other worlds and other life must exist, an idea summarized in the following quotation from the atomist philosopher Epicurus in about 300 B.C.: "There are infinite worlds both like and unlike this world of ours. . . . we must believe that in all worlds there are living creatures and plants and other things we see in this world."[2]

[2] From Epicurus's "Letter to Herodotus"; I found both this quotation and the next one from Aristotle in David Darling's wonderful reference book, *The Extraterrestrial Encyclopedia* (New York: Three Rivers Press, 2000).

Although it's difficult to ascribe modern sentiments to ancient beliefs, the atomists seem to have been essentially atheistic. They did not see the need for any hand of God in creation, instead just seeing random events in infinite time and space. However, in the pre-Christian era it was not the question of God that bothered their detractors so much as the question of infinity.

Aristotle (384–322 B.C.) represented the opposing camp. Like the atomists, Aristotle assumed the world to be made of the four elements, fire, water, earth, and air. But he did not necessarily accept that these elements could be broken down into indivisible atoms, and he certainly didn't agree that they floated randomly in an infinite space. Instead, Aristotle held that all elements had their own natural motion and place. For example, he believed that the element earth moved naturally toward the center of the universe, an idea that offered an explanation for the Greek assumption that Earth resides in a central place. Water, being lighter, settled on top of earth, thus explaining oceans, while air settled above that to explain the atmosphere. The element fire, he claimed, naturally rose away from the center, which is why flames jut upward into the sky. These incorrect ideas about physics, which were not disproved until the time of Galileo and Newton almost 2,000 years later, caused Aristotle to reject the atomist idea of many worlds. If there were more than one world, there would be more than one natural place for the elements to go, which would be a logical contradiction. Aristotle concluded: "The world must be unique. . . . There cannot be several worlds."

Aristotle also came to a very different conclusion than the atomists about the nature of the sky. Because he had natural places for all four elements to go, he concluded that the heavens must be made of something else, which he called the *ether* (literally, "upper air"). That's how the word *ethereal* came to mean "heavenly." You may also recognize that the ether was in a sense a fifth element after fire, water, earth, and air, thus explaining how the word *quintessence*—which literally means "fifth element"—came to be associated with heavenly perfection.

Interestingly, Aristotle's philosophies were not particularly influential until many centuries after his death, when his books were finally translated into Latin and came to the attention of people like Saint Albertus Magnus and one of his students, Saint Thomas Aquinas (1225–1274). Aquinas found Aristotle's philosophy particularly appealing and integrated it into Christian theology. The contradiction between the Aristotelian notion of a single world surrounded by heavens and the atomist notion of many worlds in an infinite universe became a subject of great concern to Christian theologians. Many even argued that extraterrestrial life could not be possible because it would contradict the Aristotelian notions of Earth and heaven. While a few biblical fundamentalists still take this position, it's fairly clear that the Bible itself does not weigh in on the question of life beyond Earth. As a result, today you can find fundamentalist Christians who also believe in UFOs.

From my own standpoint, the most fascinating part of this historical debate is that it continued for some two thousand years and led many people to question the very foundations of theology, even though it not only lacked any facts to back it up but was based on something that we now know to be patently untrue: Earth is *not* the center of the universe, after all. You might think this would have been a lesson learned for later generations, but sadly, we humans never learn quite so easily.

## IF ARISTOTLE WAS WRONG . . .

In 1543, Nicholas Copernicus published *De Revolutionibus Orbium Coelestium* ("Concerning the Revolutions of the Heavenly Spheres"), a book in which he made the radical suggestion that Earth was not in fact the center of the universe, but instead was one of the planets going around the Sun. It was not an entirely new idea; some 1,800 years earlier, a Greek philosopher named Aristarchus (c. 310–230 B.C.) had proposed the same thing, and Copernicus was aware of Aristarchus's work when he wrote his book. However, while Aristarchus had little success in convincing any of his contemporaries of the idea's validity, Copernicus started a revolution. It took a few decades and the help of people like Tycho Brahe, Kepler, and Galileo, but by the mid-1600s the idea of an Earth-centered universe was essentially dead.

The death of the Earth-centered idea had many profound, philosophical implications. Among other things, it forced a redefinition of the word "planet": Instead of being something that moved relative to the stars in our sky, it came to mean an object that orbits the Sun. Placing Earth among the planets also provided the first actual evidence with which scientists could evaluate the ancient debate between Aristotle and the atomists, and the verdict couldn't have been more clear: Aristotle was wrong, because his entire argument for Earth's uniqueness had been based on the suddenly discredited idea that it was located at the center of the universe.

Of course, the fact that Aristotle was wrong did *not* automatically mean that the atomists had been right, but many of the Copernican era scientists assumed that they had been. Galileo suggested that lunar features he saw through his telescope might be land and water much like that on Earth. Kepler agreed and went further, suggesting that the Moon had an atmosphere and was inhabited by intelligent beings. Kepler even wrote a science fiction story, “Somnium” (“The Dream”), in which he imagined a trip to the Moon and described the lunar inhabitants.

Later scientists took the atomist belief even further. William Herschel (1738–1822), most famous as co-discoverer (with his sister Caroline) of the planet Uranus, assumed that all the planets were inhabited. In the late nineteenth century, Percival Lowell famously imagined seeing canals on Mars, attributing them to an advanced Martian civilization, an idea that led H. G. Wells to write *The War of the Worlds*.

If all this debate about extraterrestrial life shows anything, it’s probably this: *It’s possible to argue almost endlessly, as long as there are no actual facts to get in the way.* With hindsight, it’s easy for us to see that everything from the musings of the ancient Greek atomists to the Martian canals of Percival Lowell were based more on hopes and beliefs than on any type of real evidence.

Nevertheless, the Copernican revolution really did mark a turning point in the debate about extraterrestrial life. For the first time, it was possible to test one of the ancient ideas—Aristotle’s—and its failure led it to be discarded. And while the Copernican revolution did not tell us whether the atomists had been right about life, it did make clear that the Moon and the planets really are other *worlds*, not mere lights in the sky. This fact alone made it plausible to imagine life elsewhere in our solar system, even if we still knew little about the nature of those worlds.

## THE NATURE OF WORLDS

The post-Copernican optimism regarding life on other worlds of our solar system never fully subsided, as even today we regard a few places—such as Mars, Europa, and Titan—as potential homes for life. Nevertheless, scientific enthusiasm for life in our solar system dampened significantly during much of the twentieth century. Improvements in telescopic technology gave us better images of the Moon and planets, and scientists learned to use techniques of spectroscopy—the dispersal of light into a rainbow-like spectrum—to learn about the composition and other properties of distant worlds.

Images and spectra quickly ruled out the idea of oceans and atmosphere on the Moon, and it likewise became clear that Lowell's Martian canals simply did not exist. Spectroscopy helped scientists discover that Venus is a searing hothouse, making life of any kind seem highly unlikely. By the mid-1960s, the advent of the space age had brought us our first close-up images of Mars, revealing a landscape littered with craters. Not only was there no sign of civilization, but the absence of liquid water made prospects look bleak even for much simpler forms of Martian life. Other worlds offered little more encouragement, as we soon realized that, in our solar system at least, surface liquid water is unique to Earth.

The Copernican revolution also opened the possibility of life among the stars. Once we learned that stars are distant suns, it seemed plausible to imagine that other stars could have their own planets, perhaps with life. However, even this idea suffered during the first half of the twentieth century, a time during which many scientists thought our solar system might have been created by a rare near-collision between stars. Calculations showed that if our planetary system was born in such a stellar collision, the odds were long against there being even a single other planetary system among the stars visible in the night sky. Prospects of life within our solar system looked dim, and prospects of worlds beyond seemed even dimmer. No wonder that scientists in the mid-twentieth century paid fairly little attention to the search for life beyond Earth.

So what changed to make extraterrestrial life such a hot topic of scientific research today? A lot. As we learned more about our own solar system, we began to realize that other planetary systems probably are *not* uncommon, making it seem much more reasonable that other stars could have Earth-like planets. Moreover, while we now have enough spacecraft images to say confidently that no other world in our solar system has ever been home to a civilization, we've also learned that at least a few worlds have conditions that might allow for life of some kind. At the same time, astronomers began to get a real handle on the size and age of the universe, demonstrating not only that there must be an enormous number of worlds on which life might have arisen, but also that there has been plenty of time for life to arise and evolve. Meanwhile, as biologists learned more about the nature of life on Earth, we began to realize that humans and other animals are not really "typical" of most life. Instead, most life is microscopic, and lives under conditions that would seem quite alien to us—so alien that it suddenly became plausible to imagine life surviving under the harsh conditions of places like Mars. Let's discuss these ideas in a little more depth, so that you will understand why, here at the dawn of the third millennium, it seems eminently reasonable to imagine that we'll soon discover life beyond Earth.

## THE PLANETARY CONTEXT

Science often progresses in fits and starts, and the question of the origin of our solar system is a good case in point. Today, scientists think that our solar system formed from the gravitational contraction of a giant cloud of gas and dust floating in interstellar space. This basic idea was first proposed in 1755 by the German philosopher Immanuel Kant (1724–1804). About 40 years later, French mathematician Pierre-Simon Laplace (1749–1827) put forth the same idea independently.

According to the idea of Kant and Laplace, the Sun and the planets formed naturally as a result of processes that should occur in any collapsing cloud of interstellar gas. Their idea therefore leads almost automatically to the conclusion that other stars should have formed similarly to our own Sun and should be similarly surrounded by planets. However, while Kant and Laplace had an idea that we now believe to be correct, they were unable to back their idea with much in the way of evidence. Moreover, Laplace proposed a specific mechanism by which he claimed the planets were made; by the early twentieth century, other scientists had concluded that the mechanism could not really work as Laplace had thought.

With no real evidence to back the Kant-Laplace hypothesis and at least some reason to think that it could not work, early-twentieth-century scientists sought alternate explanations for the birth of our solar system. Many began to favor an even older idea: In 1745, ten years before the publication of Kant's hypothesis, French scientist Georges Buffon (1707–1788) suggested that the planets had been born when a massive object collided with the Sun and splashed out debris that coalesced into the planets. In the twentieth-century version of Buffon's idea, a direct collision was no longer necessary; instead, scientists imagined that the planets formed from blobs of gas that were gravitationally pulled out of the Sun during a near-collision with another star. As I noted earlier, the near-collision idea would have had dire consequences for the possibility of finding other Earth-like planets and life, because it would have meant that planets could form only in exceedingly rare events rather than as a natural part of the star formation process.

The ascendance of the near-collision hypothesis caused scientists to study it in much more depth, and to try to work out the precise physics by which the planets would have formed. As the calculations improved, the near-collision idea began to run into problems similar to those that had earlier plagued the Kant-Laplace hypothesis. In particular, try as they might, scientists could not come up with any way by which a near-collision could explain either the precise orbits of the planets in our solar system or the fact that the four inner planets (Mercury, Venus, Earth, and Mars) are made mostly of rock, while the four large outer planets (Jupiter, Saturn, Uranus, and Neptune) contain huge amounts of hydrogen and helium gas.

It was back to the drawing board, or more accurately, back to reconsider old ideas in a new light. The same efforts at calculation that led scientists to conclude that the near-collision idea would not work also helped them realize that Laplace's specific mechanism might not be the only way to form planets from a collapsing gas cloud. As they worked out the details anew, scientists soon found that the Kant-Laplace idea *could* explain nearly all the observed characteristics of our solar system. The idea returned to favor.

In science, it is difficult if not impossible ever to prove an idea true beyond all doubt. Nevertheless, it now seems a near certainty that our solar system did indeed form from the gravitational collapse of an interstellar gas cloud. Like any idea in science, this one has gained support because of evidence. In this case, the evidence is so overwhelming that the idea has risen in status to become what scientists call a *theory*. Note that, by this scientific definition, a theory is very different from a guess or a hypothesis; it is an idea that has been carefully checked and tested and that has passed every test yet presented to it. As we'll discuss more later, this difference in the way scientists define theory from the way it tends to be defined in everyday language explains why things like stickers reading "it's only a theory" don't make any scientific sense.

Part of the support for our current theory of the solar system's birth lies in the fact that it explains so many characteristics of our own solar system. Perhaps more important, the theory makes predictions that have been borne out with recent observations. In particular, it predicts that other star systems should form similarly from clouds of interstellar gas and that planets should be common around other stars. Both predictions have been verified. Scientists using the Hubble Space Telescope and other observatories have photographed stars that are in the process of being born today. These stars are clearly forming from the gravitational collapse of gas clouds, and they are forming in just the way our theory predicts they should form, with the stars surrounded by spinning disks of material just like the disk in which we think the planets of our own solar system formed. While these observations prove only that other stars have the *potential* to have planets around them, recent discoveries of bona fide planets demonstrate that, in at least some cases, the potential becomes a reality.

As recently as 1995, we still did not know for certain whether planets like those that orbit our Sun existed around any other star. In the little over a decade since, discoveries of extrasolar planets—planets in other solar systems—have come so rapidly that we now know of far more planets outside our solar system than within it. So far, most of these new planets are closer in size to Jupiter than to Earth, but that is probably just an artifact of the remarkable technology required to find them. I'll discuss this technology in some depth in chapter 8, but for now I can put it to you like this: Detecting a planet the size of Jupiter in another star system is rather like detecting a marble in a haystack from a distance of thousands of miles away. It is truly astonishing that we can now do this successfully for many Jupiter-size planets, and perhaps not too surprising that we cannot yet do it for planets the size of Earth, which would be like pinheads in the same haystack. Scientists are rapidly improving their planet-detection capabilities, however, and a NASA mission called *Kepler,* scheduled for launch in 2009, ought to be capable of finding at least a few Earth-size planets. Thus, if all goes well, within the next 5 to 10 years we will have a definitive answer to the question of whether planets similar in size to Earth exist around other stars. I'd bet my shirt that the answer will be "yes."

At the same time that we've been learning that planetary systems ought to be common, we've also been learning much more about what makes planets tick. In the inner solar system, we now understand why Venus is *so* much hotter than Earth, despite the fact that, relatively speaking, it is only slightly closer to the Sun. We understand why the Moon is desolate, even though it is essentially at exactly the same distance as Earth from the Sun. We even think we understand why Mars is cold and dry today, but shows clear evidence of having had rivers and perhaps seas in the distant past. In the outer solar system, we now understand why the large outer planets have moons that in some cases (such as Europa) might have underground oceans. This general understanding of planetary science means that we can evaluate the different worlds of our solar system in terms or their potential suitability for life, even though we are not yet capable of making definitive searches for life. The preliminary indications are promising—while we don't expect to find anything large or complex, at least a few other worlds in our own solar system seem good candidates for simple or microscopic life.

If you put all these ideas together, the planetary context for the search for life beyond Earth boils down to these three facts: First, there is at least some possibility that other worlds in our own solar system are capable of harboring life, although it would probably be very primitive life. Second, it is virtually inevitable that planets similar to those in our solar system exist in other star systems, making primitive life equally likely in those systems. Third, while we do not yet know it for sure, it seems likely that planets very much like Earth exist in many other star systems, opening up the possibility that they could harbor abundant and complex life—and perhaps even beings curious about whether life exists beyond their own world.

## THE ASTRONOMICAL CONTEXT

The planetary context tells us that it is reasonable to imagine planets with life around other stars. But if we really want to understand just *how* reasonable it is, we need to turn to astronomy. Perhaps my background as an astronomer makes me biased, but it is the astronomical context that I find the most amazing of all.

The night sky may seem crowded with stars, but even under the best of conditions, you can see no more than a few thousand stars with your naked eye. If you want to understand the real meaning of the word "astronomical," you need to think about what lies beyond the naked eye limit.

I like to think about our place in the universe by considering what you might call our "cosmic address" (figure 1.1). We live on a planet, Earth, that is the third planet out from the star that we call the Sun. Our Sun, in turn, is one of a vast collection of stars that make up what we call the *Milky Way Galaxy*. Our galaxy travels through the universe along with about 40 other galaxies that, together, make up what astronomers call the *Local Group* of galaxies. Most other galaxies also reside in groups, which are called *clusters* when they have hundreds or thousands rather than just dozens of member galaxies. Groups and clusters are also grouped together, making what astronomers call *superclusters* of galaxies. Together, all the superclusters and all the spaces between them make up what we call our *universe*.

In terms of possibilities for life in the universe, the first thing to understand is that the universe is big, really BIG. I'll talk more about the scale of the universe in chapter 3, but for now let's just think about the number of stars and planets, starting with our own Milky Way Galaxy.

We do not know the precise number of stars in our galaxy, but it is at least 100 billion and perhaps one trillion or more. Are you wondering why

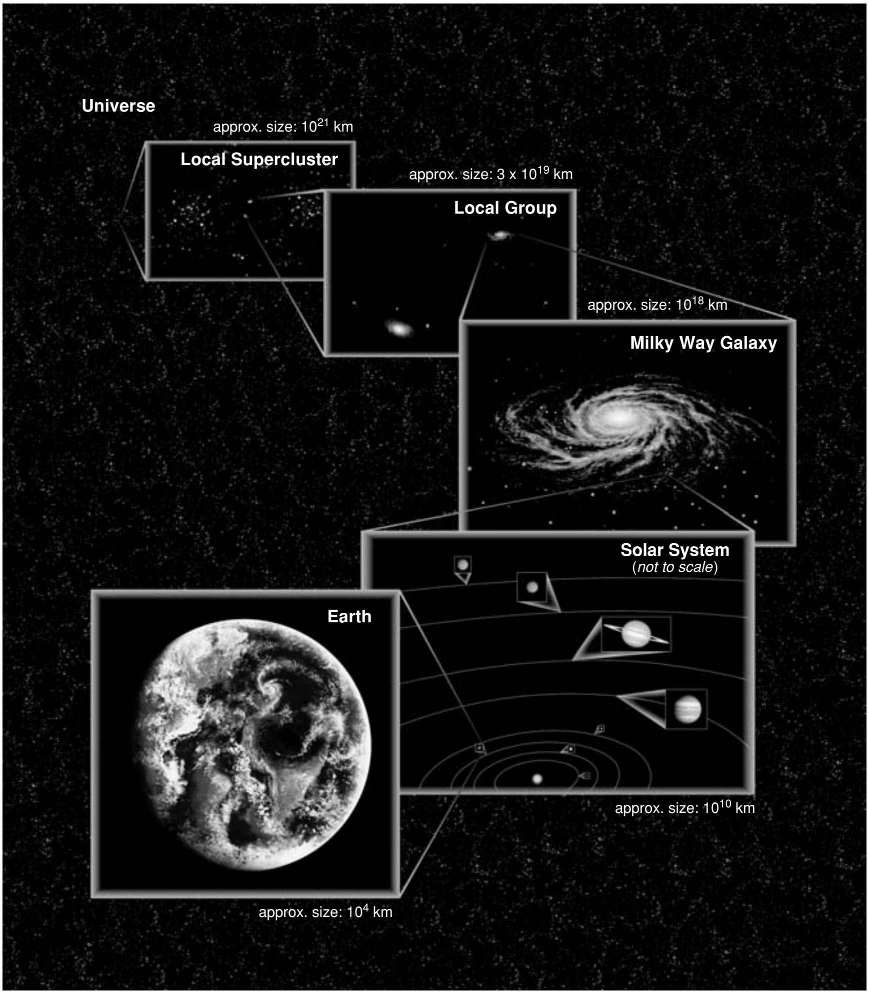


Figure 1.1. Our cosmic address. (Illustration courtesy of Addison Wesley, an imprint of Pearson Education)

we don't know the exact number? Imagine that you are having difficulty falling asleep tonight, perhaps because you are contemplating the possibilities of life beyond Earth. Instead of counting sheep, you decide to count stars. Let's be conservative, and suppose that our galaxy has only our minimum number of 100 billion stars. How long would it take you to count them? If you could count them at a rate of one per second, then it would obviously take you 100 billion seconds.[3] But how long is that? You can get the answer quite easily by dividing 100 billion seconds by 60 seconds per minute, 60 minutes per hour, 24 hours per day, and 365 days per year. If you do this calculation, you'll find that 100 billion seconds is nearly 3,200 years. In other words, you would need thousands of years just to *count* the stars in the Milky Way Galaxy, let alone to study them or search their planets for signs of life. And this assumes you never take a break—no sleeping, no eating, and absolutely no dying!

Now, take a look at the photo in color plate 1, which was made with 11 days of exposure time by the Hubble Space Telescope. To understand what you are seeing in this photo, imagine holding a grain of sand at arm's length against the sky; everything you see in this photograph would fit within the field of view directly behind that grain of sand. Almost every blob and dot that you see in the photo is an entire galaxy—each with so many stars that it would take thousands of years just to count them. Try to imagine the total number of stars located in this sand-grain-size piece of the sky, and then try to imagine the total number of stars in all directions around the entire sky. In truth, it's unimaginable, but I'll give you something that you can at least grasp onto: The total number of stars in the sky is roughly the same as the total number of grains of sand on *all* Earth's beaches, put together.

With as many stars as grains of sand on all Earth's beaches, it might seem almost impossible to believe that ours could be the only star orbited by a planet with life and a civilization. But numbers alone cannot tell the whole story. After all, if our solar system is very different from others—as would have been the case if, for example, the near-collision idea for the birth of the planets had turned out to be correct—then planets and life elsewhere might be quite unlikely. Since we do not yet have the ability to detect Earth-like planets around even nearby stars, we have no direct data from which we can decide whether such planets are common. However, everything we have learned about the universe since the Copernican revolution all points in the same direction: While we do not yet have proof of the existence of other planets like ours, we should expect them to be fairly common.

[3] When I give this question to children, they invariably object that they can count faster than that. However, while most kids can indeed count from 1 to 10 in less than 10 seconds, I like to point out that it's much more difficult to maintain a pace of one per second when you get to, say, "sixty-two billion, four hundred seventy-nine million, three hundred eighty-one thousand, five hundred forty-four" (and can you even remember what comes next?).

I say this because the central lesson of the Copernican revolution and nearly everything we have learned since has been that we are *not* central, after all. We are not the center of our solar system. Our Sun is not the center of the Milky Way Galaxy. Our galaxy is not the center of the Local Group. The Local Group is not the center of the Local Supercluster. The Local Supercluster is not the center of the universe; indeed, as we understand it today, the universe does not even *have* a center. Our place in the universe is completely ordinary, which makes it reasonable to think our planet is quite ordinary as well.

Could it be that, despite our ordinary location, there is something unusual about right here? Observations say no. We can measure the chemical compositions of distant stars, gas clouds, and galaxies by studying their spectra. The results tell us that the composition of our Sun and solar system are, like our location, ordinary. Spectra also tell us about the physical laws operating in distant objects; for example, if the laws of chemistry in distant stars were different from those on Earth, we'd be able to tell because the spectra of chemical elements in those stars would be different from the spectra of the same elements on Earth. But they are not, demonstrating that the same laws of nature act throughout the universe.

Our understanding of the origin of chemical elements gives us further reason to think that other stars should be like our Sun, making it possible for them to have planets like Earth. Observations show that chemical content of the universe consists almost entirely of just two elements: hydrogen and helium. These two lightest and simplest of the chemical elements make up at least 98 percent of the matter found in all stars and all gas clouds in space.[4] All the rest of the elements, from the carbon and oxygen that make up a large proportion of our bodies to the gold and silver that we wear as jewelry, make up no more than 2 percent of the overall chemical content of the universe. Moreover, we find that older stars have even smaller proportions than younger stars of elements besides hydrogen and helium, suggesting that the heavier elements have somehow been manufactured through time. I won't go into the details here, but we now think we know how: They were manufactured by nuclear fusion in

[4] When I speak of the chemical composition of the universe, I mean the "ordinary" matter made of atoms. As some readers may know, we now have reason to think that most of the mass of the universe consists of so-called "dark matter," which is presumably not chemical in nature. But this matter is not found in planets or stars, and thus should have little bearing on the search for life.

stars. In other words, we now think the universe was born containing only hydrogen and helium, and the rest of the elements have been made by stars. This idea implies that the same elements should be found in the same proportions everywhere, because the basic nature of stars is the same everywhere. It also implies that almost every atom in our bodies and in our planet Earth (except for the hydrogen) was made inside a star that lived and died before our Sun was born. As Carl Sagan was fond of saying, we are "star stuff."

Given that we live in an ordinary location in a solar system with ordinary composition and that the same laws act in all the other ordinary locations, is there anything else that could make our situation unusual? Some people point to time, but there's nothing special about the present, either: According to current understanding, our solar system was born about four and a half billion years ago, at a time when the universe as a whole was already nearly 10 billion years old. In other words, most of the stars in the universe are older than our own Sun, so even if life needs billions of years to arise and evolve into intelligence, plenty of stars with plenty of planets should have had plenty of time.

The last refuge of those who want to believe that our circumstances are unique is to imagine that it is some combination of multiple factors that, together, makes planets like Earth extremely rare. Proponents of this "rare Earth" hypothesis make some very interesting arguments, though as we'll see in chapter 8, there are also seemingly good counterarguments to each point they raise. Scientifically speaking, we simply do not yet have enough data to decide whether the rare Earth arguments have merit. But philosophically, and to remove the suspense, I'll tell you where I stand right now: For thousands of years, people have used every argument at their disposal to make the case that we humans somehow hold a central or special place in our universe. And every time that data have allowed us to evaluate one of those arguments in detail, the arguments have turned out to be flawed, removing us from our central place. I don't think the fate of the new "rare Earth" arguments will be any different from the fate of Aristotle's arguments about why other worlds could not exist at all.

So now you know how this chapter got its title: Like the number of grains of sand on all the beaches on Earth, our universe is filled with worlds that are truly beyond imagination. Neither I nor anyone else can yet prove that even a single one of those worlds harbors even the most primitive single-celled organisms, but it sure seems worth looking.

## THE BIOLOGICAL CONTEXT

Together, the planetary and astronomical contexts tell us that we should expect to find lots of planets that are capable of harboring life. But the potential to have life and actually having life are not the same thing. Could it be that, even under perfect conditions, biology is extremely rare?

Until just a few decades ago, we did not even know where to start in addressing this question. The theory of evolution told us how life gradually changed through time, but by itself it gave no clue as to how life got started in the first place. The existence of life, with all of its biochemical complexity, remained beyond scientific understanding.

We still do not know how life on Earth got started, and it's possible that we never will. Nevertheless, recent biological discoveries give us at least some reason to think that life could prove to be almost as common as worlds capable of harboring it. Three lines of evidence point us in this direction.

First, laboratory experiments have demonstrated that chemical constituents found on the early Earth would have combined readily into more complex organic (carbon-based) molecules, including virtually all the building blocks of life (such as amino acids, nucleic acids, sugars, and lipids). Indeed, scientists have found organic molecules in meteorites and, through spectroscopy, in clouds of gas between the stars. The fact that organic molecules form even under the extreme conditions of space suggests that they form quite readily. In that case, the building blocks of life should be present on many worlds.

Of course, the mere presence of organic molecules does not necessarily mean that life will arise, but the history of life on Earth gives us some reason to think that it will. The relevant evidence comes from geological studies of the early Earth which, as we'll discuss further in chapter 5, tell us that life on Earth arose almost as early as it possibly could have after the Earth's formation. What does this early arrival of life on Earth prove? Absolutely nothing, because you cannot draw general conclusions from the single example of Earth. Nevertheless, it is at least suggestive of the idea that it's fairly easy for a planet to go from simply having organic material to actually having life. If the transition from organic chemistry to biology were difficult, we might expect that it would have required much more time. While we cannot say anything definitively, the early origin of life on Earth makes it reasonable to think that life would emerge just as quickly on other worlds with similar conditions.

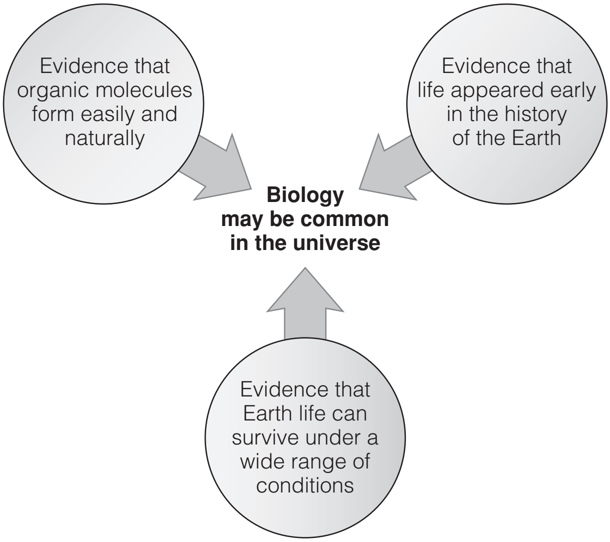


Figure 1.2. Three lines of evidence that give us at least some reason to think that biology may be common in the universe. (Illustration courtesy of Addison Wesley, an imprint of Pearson Education.)

If life really can emerge easily under the right conditions, the only remaining question is the prevalence of those "right" conditions. Here, too, recent discoveries give us reason to think that biology could be common. In particular, biologists have found that life can survive and prosper under a much wider range of conditions than was believed only a few decades ago. For example, we now know that life exists in extremely hot water near deep-sea volcanic vents, in the frigid conditions of Antarctica, and inside rocks buried a mile or more beneath the Earth's surface. If we were to export the strange organisms that live in these extreme environments to other worlds in our solar system—perhaps to Mars or Europa—it seems possible that at least some of them would survive. This suggests that the range of "right" conditions for life may be quite broad, in which case it might be possible to find life even on planets that are quite different in character from Earth. Figure 1.2 summarizes the three lines of evidence that suggest life could be common.

Now, before we go any further, it's important to address a question that is probably on many of your minds: Where does God fit into this picture? The way I've described the possibility of getting life, it may sound like it requires nothing more than random interactions of atoms, much as the

Greek atomists might have claimed some 2,300 years ago. But if you've followed my words closely, you'll see that I've said no such thing. In essence, we are still in the same place as Kepler and Galileo after they confirmed the Copernican idea: We know that Aristotle was wrong, but that doesn't necessarily mean the atomists were right. As far as current scientific evidence goes, we have no means of distinguishing whether we are a random accident in a universe without purpose or the pinnacle of creation in a miraculous process that God has directed from start to finish. So if a scientist tries to tell you that there's no room for God in our present understanding of life and evolution, he's just plain wrong: We may not have any scientific evidence of a role for God, but neither do we have any scientific evidence against it.

Of course, the same idea should also hold on the other side. The Bible is a complex and beautiful book that different people can interpret quite differently, even while believing that it is the word of God. Pope John Paul II, for example, believed in the literal truth of the Bible yet saw no contradiction between that truth and the scientific theory of evolution. If someone tries to tell you that science and evolution contradict the Bible, you can be quite certain that they are expressing their personal interpretation of God's words, not the actual words themselves. You can be a good Christian—or a good Jew, good Muslim, good Buddhist, or anything else—and a good scientist at the same time.

Indeed, the lack of conflict between science and religion seems to me so self-evident that I'm flabbergasted at the fact that not everyone else sees it the same way. Can't everyone just calm down, and realize that science and religion do not pose threats to one another? I say these things not just because I enjoy getting up on my soapbox (I admit it), but because I don't want anyone to miss out on the human joy of science. I am a scientist because I find the process of discovery to be inherently exciting, and I'm a writer because I want to share that excitement with others. I've chosen to write about the scientific search for life in the universe because, in my opinion, it is a topic brimming with more excitement than any other. It may not qualify as the greatest story ever told, but it's a darn good one, and if and when we find other life or other civilizations, I believe that it will cause a revolution in the way we think about ourselves that will be every bit as profound as the revolution that occurred some 400 years ago when we learned that Earth moves. I'd like to think that everyone, regardless of culture or religion, can be a part of this ongoing story of discovery. So perhaps I'm too naive . . . but, at least, I hope that those of you with deeply religious beliefs will not feel threatened by reading the rest of this book.

## BEYOND UFOS

I've briefly addressed religion, so now there's one more group of people I need to address before we go on: the roughly half of the public who, according to polls, believe we are already being visited by UFOs. Rest easy, because I will not tell you that you are wrong.

How could I? I've spent the entire chapter explaining why, according to current scientific understanding, it is eminently reasonable to think that life could be quite common on worlds that number beyond imagination. And while we haven't yet discussed the scientific issues that differentiate getting intelligent life and civilizations from just getting life of some kind (that will come in chapters 5 and 9), sheer numbers suggest that if life is very common, civilizations ought to be at least somewhat common. Moreover, if civilizations are common, the age of the universe ought to ensure that many of them have had time to advance far beyond us technologically, in which case they might well have the ability to travel from their home worlds to here. As I see it, it would not be at all surprising if aliens really are visiting Earth.

Still, I am personally very skeptical of any and all the claims I've ever heard of UFOs and other alien visitation to Earth. This might sound strange: How can I say that alien visitation is likely and then, in nearly the same breath, doubt the reports of visits? My answer is twofold. First, there's the issue of evidence. In science, we can't accept an idea just because it's reasonable; we need verifiable evidence, and the evidence presented for UFOs just doesn't measure up to scientific standards. Second, once you understand the technology that aliens must have if they really are visiting us, you'll see that most of the claims that people make about the supposed visits don't make any sense. But don't just take my word for these things now; read on, and in the next two chapters I'll explain these ideas and their remarkable consequences.