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A Universe of Life?

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- 1.2.1 How does astronomy help us understand the possibilities for extraterrestrial life?

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▲ **About the photo:** Earth is home to an abundance of life, making us wonder if other worlds might also be home to life.

Sometimes I think we're alone in the universe, and sometimes I think we're not. In either case the idea is quite staggering.

Arthur C. Clarke (1917–2008)



LEARNING OBJECTIVE

Chapter 1 Overview

The night sky glitters with stars, each a sun, much like our own Sun. Many stars have planets, some of which may be much like Earth and other planets of our own solar system. Among these countless worlds, it may seem hard to imagine that ours could be the only home for life. But while the possibility of life beyond Earth might seem quite reasonable, we do not yet know if such life actually exists.

Learning whether the universe is full of life holds great significance for the way we view ourselves and our planet. If life is rare or nonexistent elsewhere, we will view our planet with added wonder. If life is common, we'll know that Earth is not quite as special as it may seem. If civilizations are common, we'll be forced to accept that humanity is just one of many intelligent species inhabiting the universe. The profound implications of finding—or not finding—extraterrestrial life make the question of life beyond Earth an exciting topic of study.

The primary purpose of this book is to give you the background needed to understand new and exciting developments in the human quest to find life beyond Earth. We'll begin in this chapter with a brief introduction to the subject and to why it has become such a hot topic of scientific research.



LEARNING OBJECTIVE

Goals of Astrobiology

1.1 The Possibility of Life Beyond Earth

Aliens are everywhere, at least if you follow the popular media (**Figure 1.1**). Starships on television and in movies are on constant prowl throughout the galaxy, seeking out new life and hoping it speaks English (or something close enough to English to be understood by a “universal translator”). In *Star Wars*, aliens from many planets gather at bars to share drinks and stories, and presumably to marvel at the fact that they have greater similarity in their level of technology than do different nations on Earth. Closer to home, movies like *Independence Day*, *Men in Black*, and *War of the Worlds* feature brave Earthlings battling evil aliens—or, as in the case of *Avatar*, brave aliens battling evil humans—while numerous websites carry headlines about the latest alien landings. Even serious newspapers and magazines run occasional articles about UFO (or UAP*) sightings or about claims

*UAP stands for “unidentified aerial phenomena,” which is sometimes used (particularly within the U.S. military) as an alternative to UFO, which stands for “unidentified flying object.”



FIGURE 1.1

Aliens have become a part of modern culture, as illustrated by this movie poster.

that the U.S. government is hiding hardware or alien corpses at “Area 51.”

Scientists are interested in aliens too, although most scientists remain deeply skeptical about reports of aliens on Earth (for reasons we’ll discuss later in the book). Scientists are therefore searching for life elsewhere, looking for evidence of life on other worlds in our solar system, trying to learn whether we should expect to find life on planets orbiting other stars, and scanning for signals broadcast by other civilizations. Indeed, the study of life in the universe is one of the most exciting fields of active scientific research, largely because of its clear significance: The discovery of life of any kind beyond Earth would forever change our perspective on how we fit into the universe as a whole, and would undoubtedly teach us much more about life here on Earth as well.

1.1.1 What are we searching for?

When we say we are searching for *life* in the universe, just what is it that we are looking for? Is it the kind of intelligent life we see portrayed in science fiction TV shows and films? Is it something more akin to the plants and animals we see in parks and zoos? Is it tiny, bacteria-like microbes? Or could it be something else entirely?

The simple answer is “all of the above.” When we search for **extraterrestrial life**, or life beyond Earth, we are looking for any sign of life, be it simple, complex, or intelligent. We don’t care if it looks exactly like life we are familiar with on Earth or if it is dramatically different. However, we can’t really answer the question of what we are looking for unless we know what life *is*.

Unfortunately, defining life is no simple matter, not even here on Earth where we have bountiful examples of it. Ask yourself: What common attributes make us think that a bacterium, a beetle, a mushroom, a tumbleweed, a maple tree, and a human are all alive, while we think that a crystal, a cloud, an ocean, or a fire is not? If you spend just a little time considering this question, you’ll begin to appreciate its difficulty. For example, you might say that life can move, but the same is true of clouds and oceans. You might say that life can grow, but so can crystals. Or you might say that life can reproduce and spread, but so can fire. We will explore in [Chapter 5](#) how scientists try to answer this question and come up with a general definition of life, but for now it should be clear that this is a complicated question that affects how we search for life in the universe.

Because of this definitional difficulty, the scientific search for extraterrestrial life in the universe generally presumes a search for life that is at least somewhat Earth-like and that we could therefore recognize based on what we know from studying life on

our own planet. Science fiction fans will object that this search is far too limited, and they may be right—but we have to start somewhere, so we begin with what we understand.

Think About It Name a few recent TV shows and movies that involve aliens of some sort. Do you think any of these shows portray aliens in a scientifically realistic fashion? Explain.

1.1.2 Is it reasonable to imagine life beyond Earth?

The scientific search for life in the universe is a relatively recent development in human history, but the idea of extraterrestrial life is not. Many ancient cultures told stories about beings living among the stars and, as we’ll discuss in [Chapter 2](#), the ancient Greeks engaged in serious philosophical debate about the possibility of life beyond Earth.

Until quite recently, however, all these ideas remained purely speculative, because there was no way to study the question of extraterrestrial life scientifically. It was always possible to *imagine* extraterrestrial life, but there was no scientific reason to think that it could (or could not) really exist. Indeed, the relatively small amounts of data that might have shed some light on the question of life beyond Earth were often misinterpreted. Prior to the twentieth century, for example, some scientists guessed that Venus might harbor a tropical paradise—a guess that was based on little more than the fact that Venus is covered by clouds and closer than Earth to the Sun. Mars was the subject of even more intense speculation, largely because a handful of scientists thought they saw long, straight canals on the surface [[Section 8.1](#)]. The canals, which don’t really exist, were cited as evidence of a sophisticated martian society.

Today, we have enough telescopic and spacecraft photos of the planets and large moons in our solar system to be quite confident that no civilization has ever existed on any of them. The prospect of large animals or plants seems almost equally improbable. Nevertheless, scientific interest in life beyond Earth has exploded in the past few decades. Why?

We’ll spend most of the rest of the book answering this question, but we can summarize the key points briefly. First, although large, multicellular life in our solar system seems unlikely anywhere but on Earth, recent discoveries in both planetary science and biology make it seem plausible that simpler life—perhaps tiny microbes—might exist on other planets or moons of our solar system. Second, while we’ve long known that the universe is full of *stars*, we’ve only recently gained concrete evidence that it is also full of

planets, which means there are far more places where we could potentially search for life. Third, advances in both scientific understanding and technology now make it possible to study the question of life in the universe through established techniques of science, something that was not possible just a few decades ago. For example, we now understand enough about biology to explore the conditions that might make it possible for life to exist on other worlds, and we know enough about planets, and many of their moons, to consider which ones might be capable of harboring life. We are also rapidly developing the spacecraft technology needed to search for microbes on other worlds of our solar system and the telescope technology needed to look for signs of life among the stars.

The bottom line is that while it remains possible that life exists only on Earth, we now have plenty of scientific reasons to think that life might be widespread and that we might detect it if it is.



LEARNING OBJECTIVE Three Contexts

1.2 The Scientific Context of the Search

Almost every field of scientific research has at least some bearing on the search for life in the universe. Even seemingly unrelated fields such as mathematics and computer science play important roles. For example, we use mathematics to do the many computations that help us understand all other areas of science, and we use computers to simulate everything from the formation of stars and planets to the ways in which the molecules of life interact. However, three disciplines play an especially important role in framing the context of the scientific search for life: astronomy, planetary science (which includes geology and atmospheric science), and biology.

1.2.1 How does astronomy help us understand the possibilities for extraterrestrial life?

For most of human history, our conception of the cosmos was quite different from what it is today. Earth was widely assumed to be the center of the universe. Other planets of our solar system were mere lights in the sky, often named for mythical gods, and no one had reason to think they could be *worlds* on which we might search for life. Stars were simply other lights in the sky, distinguished from the planets only by the fact that they remained fixed in the patterns of the constellations, and few people even considered the possibility that stars might be other suns. Moreover,

with the Sun and planets presumed to be orbiting around Earth, there was no reason to think that stars could have planets of their own, let alone planets on which there might be life.

When you consider that this Earth-centered, or **geocentric**, view of the universe dominated human thinking for thousands of years, it becomes obvious that astronomy plays a key role in framing the context of the modern search for life. We will discuss in [Chapter 2](#) how and why the human view of the cosmos changed dramatically about 400 years ago, and we'll consider the modern astronomical context in some detail in [Chapter 3](#). But the point should already be clear: We now know that Earth is but one tiny world orbiting one rather ordinary star in a vast cosmos, and this fact opens up countless possibilities for life on other worlds.

Astronomy provides context to the search for life in many other ways as well, but one more is important enough to mention right now: By studying distant objects, we have learned that the physical laws that operate in the rest of the universe are the same as those that operate right here on Earth ([Figure 1.2](#)). This tells us that if something happened here, it is possible that the same thing could have happened somewhere else, at least in principle. We are not the center of the universe in location, and we have no reason



FIGURE 1.2

The astronomical context tells us that our Sun is an ordinary star in a vast universe, implying that there could be an enormous number of stars with planets that might potentially host life. This Hubble Space Telescope photo shows a cluster of young, massive stars (NGC 3603) surrounded by a gas cloud in which Sun-like stars may still be forming. Careful study of distant stars and gas clouds shows that they are made of the same basic chemical elements and obey the same physical laws that we are familiar with on Earth.

to think we are “central” in any other way, either. To summarize, the astronomical context makes it clear that the universe holds an enormous number of stars that could potentially be orbited by planets with life.

1.2.2 How does planetary science help us understand the possibilities for extraterrestrial life?

Planetary science is the name we give to the study of almost everything having to do with planets. It includes the study of planets themselves, as well as the study of moons orbiting planets, the study of how planets form, and the study of other objects that may form in association with planets (such as asteroids and comets). Planetary science helps set the context for the search for life in the universe in several different ways, but two are especially important.

First, by learning how planets form, we develop an understanding of how common we might expect planets to be. Until just about the middle of the last century, we really had no basis for assuming that many other stars would have their own planets. Some scientists thought this likely, while others did not, and we lacked the data needed to distinguish between the two possibilities [Section 3.5]. But during the latter half of the twentieth century, a growing understanding of the processes by which our own solar system formed—much of it based on evidence obtained through human visits to the Moon and spacecraft visits to other planets—gradually made it seem more likely that other stars might similarly be born with planetary systems.

Nonetheless, as recently as 1995, no one was sure whether planets encircled other stars.* That was the year in which scientists obtained the first strong evidence for the existence of **exoplanets**, or planets outside our solar system (*exo* means “outside” or “external to”). Since that time, additional exoplanets have been discovered at an astonishing rate, so that the number of known exoplanets now far exceeds the number of planets of our solar system (Figure 1.3). Based on the statistics of these discoveries, it seems highly likely that most stars have planets and, as we’ll discuss in Chapter 11, it seems reasonable to imagine that life—and possibly even civilizations—could exist on at least some of these planets or their moons.

A second way in which planetary science shapes the context for the search for extraterrestrial life is by

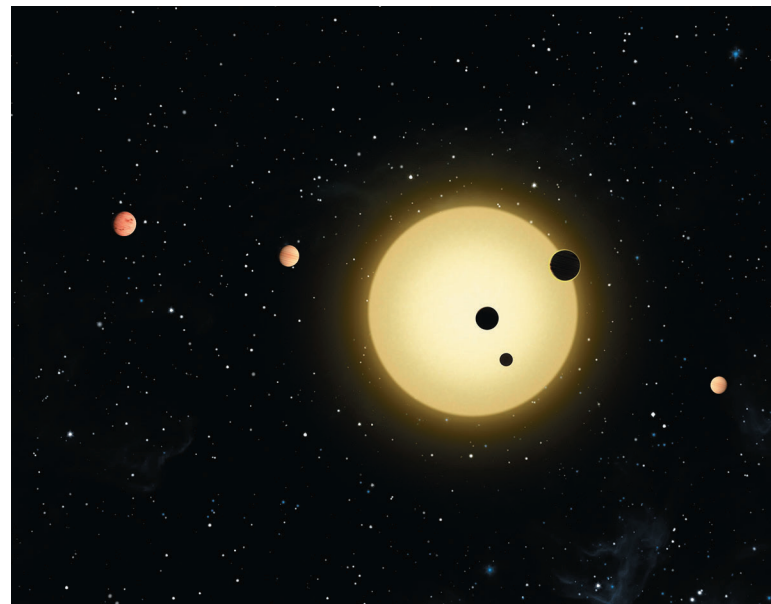


FIGURE 1.3

Artist's conception of the “Kepler 11” system, which contains at least six planets orbiting a Sun-like star. These planets are among thousands discovered by the *Kepler* spacecraft.

helping us understand why planets differ. For example, by studying planets and comparing them to one another, we have learned why some planets are rocky like Earth while others, like Jupiter, lack a well-defined surface and contain vast amounts of hydrogen and helium gas. We’ve also learned why Venus is so much hotter than Earth despite the fact that, in the scheme of our solar system, it is only slightly closer to the Sun. Similarly, we can now explain why the Moon is desolate and barren even though it orbits the Sun at essentially the same distance as Earth, and we have a fairly good idea of why Mars is cold and dry today, when evidence shows that it was warmer and wetter in the distant past.

This understanding of how planets work gives us deeper insight into the nature of planetary systems in general. More important to our purposes, it also helps us understand what to look for as we search for **habitable worlds**—worlds that have the ingredients and conditions necessary for life. After all, given that there are far more worlds in the universe than we can ever hope to study in detail, we can improve our odds of success in finding life by constraining the search to those worlds that are the most promising. Be sure to note that when we ask whether a world is *habitable*, we are asking whether it offers environmental conditions under which life *could* arise or survive, not whether it actually harbors life.

Also keep in mind that when we say a world is habitable, we do not necessarily mean that familiar plants, animals, or people could survive there. For

*There was an earlier discovery (1992) of exoplanets orbiting an object called a *pulsar*, which is an object (a spinning neutron star) that forms only after a star dies in a supernova explosion. We ignore such “pulsar planets” in this book, since we generally presume that planets with life would have to be orbiting a “living” star that shines as a result of nuclear fusion.

The Planetary Science Context

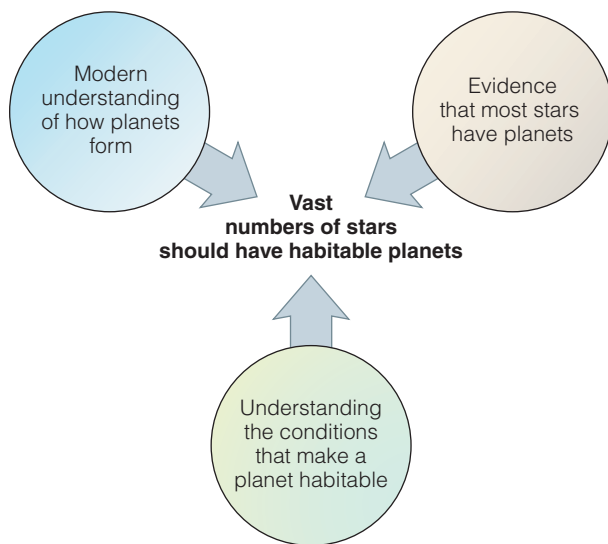


FIGURE 1.4

The astronomical context showed us that vast numbers of stars could be hosts to planets. This diagram summarizes the planetary science context, which suggests that these stars are indeed orbited by planets, many of which should be habitable.

much of Earth's history, nearly all life was microscopic, and even today, the total mass of microbes on Earth is greater than that of all plants and animals combined. The search for habitable worlds is primarily a search for places where microbes of some kind might survive, though we might find larger organisms as well. To summarize, the planetary science context suggests that most of the stars in the universe should indeed have planets and that we should expect many of them to be at least potential homes for life (Figure 1.4).

1.2.3 How does biology help us understand the possibilities for extraterrestrial life?

Astronomy, planetary science, and other science disciplines play important roles in shaping the context for the search for life in the universe, but since we are searching for *life*, the context of biology is especially important. Just as you wouldn't look for a house to buy without knowing something about real estate, it would make no sense to search for life if we didn't know something about how life functions. The key question about the biological context of the search revolves around whether we should expect biology to be rare or common in the cosmos.

Wherever we have looked in the universe, we have found clear evidence that the same laws of nature are operating. We see galaxies sprinkled throughout

space, and we see that the same stellar processes that occur in one place also occur in others. In situations in which we can observe orbital motions, we find that they agree with what we expect from the law of gravity. These and other measurements make us confident that the basic laws of physics that we've discovered here on Earth also hold throughout the universe.

We can be similarly confident that the laws of chemistry are universal. Observations of distant stars show that they are made of the same chemical elements that we find here in our own solar system, and that interstellar gas clouds contain many of the same molecules we find on Earth. This provides conclusive evidence that atoms come in the same types and combine in the same ways throughout the universe.

Could biology also be universal? That is, could the biological processes we find on Earth be common throughout the cosmos? If the answer is yes, then the search for life elsewhere should be exciting and fruitful. If the answer is no, then life may be a rarity.

Because we haven't yet observed biology anywhere beyond Earth, we can't yet know whether biology is universal. However, evidence from our own planet gives us at least some reason to think that it might be. Laboratory experiments suggest that chemical constituents found on the early Earth would have combined readily into complex organic (carbon-based) molecules, including many of the building blocks of life [Section 6.2]. Indeed, scientists have found organic molecules in meteorites (chunks of rock that fall to Earth from space) and, through spectroscopy [Section 3.4], in clouds of gas between the stars. The fact that such molecules form even under the extreme conditions of space suggests that they form quite readily and may be common 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 the step from chemistry to biology is not especially difficult. As we'll discuss in Chapter 6, geological evidence tells us that life on Earth arose quite early in Earth's history, at least on a geological time scale. If the transition from chemistry to biology were exceedingly improbable, we might expect that it would have required much more time. The early origin of life on Earth therefore suggests—but certainly does not prove—that life might also emerge quickly on other worlds with similar conditions.

Think About It Microbial life on Earth predates intelligent life like us by at least 3 to 4 billion years. Do you think this fact tells us anything about the likelihood of finding *intelligent* life, as opposed to finding any life, on exoplanets? Explain.

The Biological Context

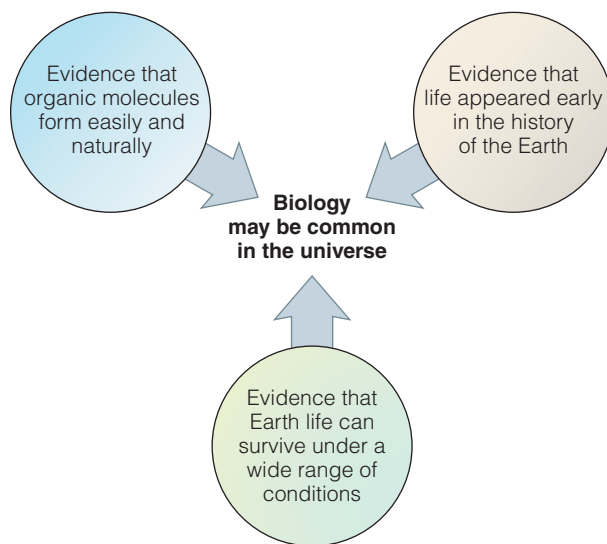


FIGURE 1.5

This diagram summarizes the biological context based on the study of life on Earth, which adds to the astronomical and planetary contexts and gives us at least some reason to think that biology may be common among the many potentially habitable worlds in the universe.

If life really can be expected to emerge 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 microscopic life can survive and prosper under a much wider range of circumstances than was believed only a few decades ago [Section 5.5]. For example, we now know that life exists in extremely hot water near deep-sea volcanic vents, in the frigid environments of Antarctica, and inside rocks buried a kilometer or more beneath the Earth’s surface. Indeed, if we were to export these strange organisms from Earth to other worlds in our solar system—perhaps to Mars or Jupiter’s moon 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 or moons that are significantly different in character from Earth.

In summary, we have no reason to think that life ought to be rare and several reasons to expect that it may be quite common (Figure 1.5). If life is indeed common, studying it will give us new insights into life on Earth, even if we don’t find other intelligent civilizations. These enticing prospects have captured the interest of scientists from many disciplines and from around the world, giving birth to a relatively new science devoted to the study of, and search for, life in the universe.

LEARNING OBJECTIVE

Places to Search

1.3 Places to Search

The study of life in the universe involves fundamental research in all the scientific areas we have already mentioned, and others as well. Indeed, as you’ll see throughout this book, the study of extraterrestrial life goes far beyond simply searching for living organisms. Still, all of this study is driven by the possibility that life exists elsewhere, so before we dive into any details, it’s worth a quick overview of the places and methods we use in the search.

1.3.1 Where should we search for life in the universe?

The search for life in the universe takes place on several different levels. First, and foremost in many ways, it is a study of life right here on Earth. As we discussed earlier, we are still learning about the places and conditions in which terrestrial life exists, and many scientists are busy searching for undiscovered species of life on our own world. After all, the more we know about life here, the better we’ll be able to search for it elsewhere.

SEARCHING OUR OWN SOLAR SYSTEM Turning our attention to places besides Earth, the first place to search for life is on other worlds in our own solar system. Our solar system has many objects worthy of our attention: It has the planets and dwarf planets orbiting the Sun, moons orbiting planets, and huge numbers of smaller objects such as asteroids and comets.

Figure 1.6 shows some of our best current views of the planets (and two of the five currently identified dwarf planets) in our solar system. Note that it is *not* to scale, since its purpose is to show each planet as we know it today from spacecraft or through telescopes; you can turn to Figure 3.3 to see the sizes correctly scaled.

The photos alone make clear how different Earth is from every other planet in our solar system. Ours is the only planet with oceans of liquid water on its surface, a fact that provides an instant clue about why Earth is home to so much life: Water is crucial to all terrestrial life. Indeed, as we’ll discuss in Chapters 5 and 7, we have some reason to think that liquid water may *always* be a requirement for life, though it’s possible that a few other liquids might work in place of water.

Given that we are primarily looking for life that is at least somewhat Earth-like, the need for water or some other liquid places constraints on where we might find life. Among the planets, Mars is the

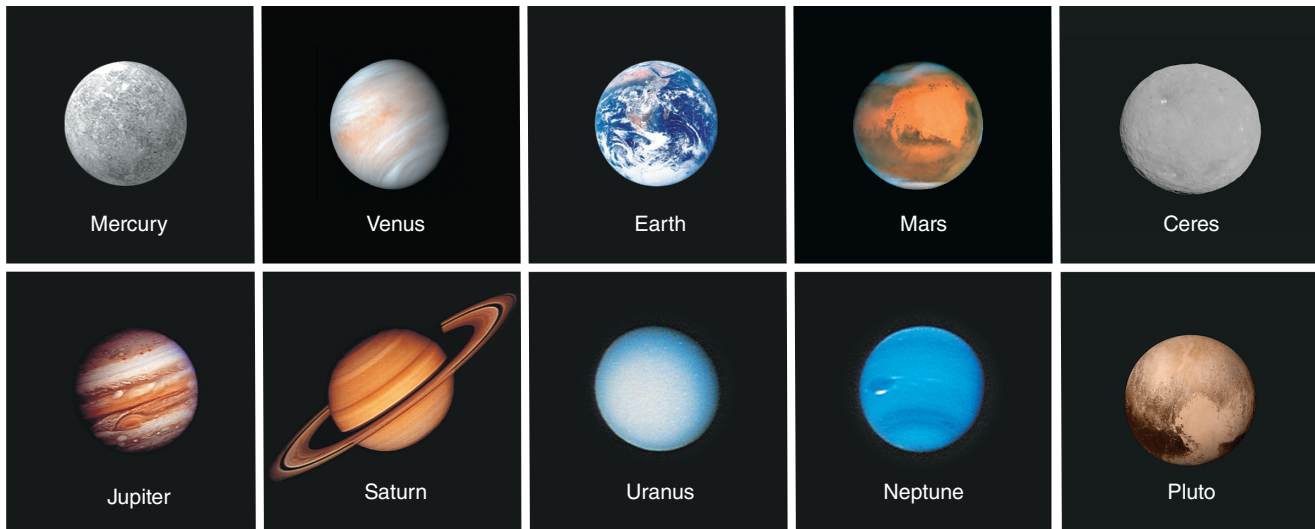


FIGURE 1.6

A “family portrait” of the eight official planets that orbit our Sun, along with two dwarf planets: Ceres (located in the asteroid belt between Mars and Jupiter) and Pluto (located in the Kuiper belt beyond Neptune). Going across the top row and then the bottom row, the planets and dwarf planets are shown in order of increasing average distance from the Sun; the photos are not shown to scale.

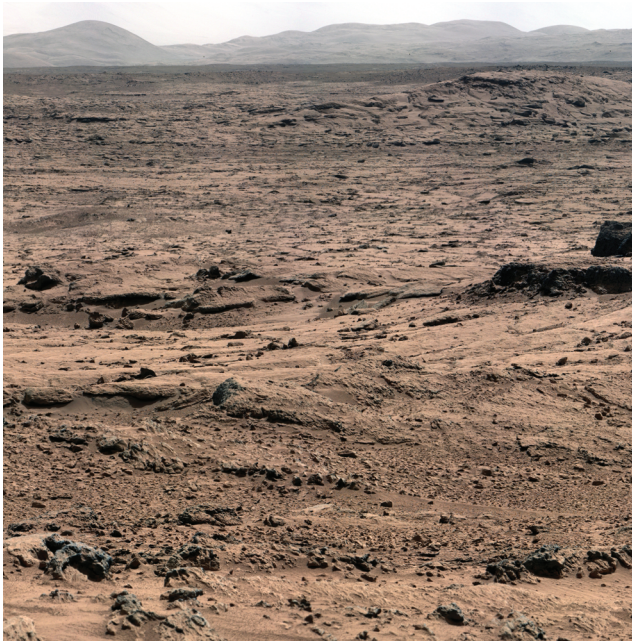


FIGURE 1.7

The surface of Mars, photographed by NASA's *Curiosity* rover. The martian surface is dry and barren today, but strong evidence points to liquid water on it in the distant past.

most promising candidate. As we'll discuss in detail in [Chapter 8](#), strong evidence tells us that the now-barren surface of Mars ([Figure 1.7](#)) once had flowing water, making it seem reasonable to imagine life having arisen on Mars at that time. Mars still has significant amounts of water ice, so it is even possible that life exists on Mars today, perhaps hidden away in places where volcanic heat keeps underground water liquid. Past or present life seems much less likely on any of the other planets, though we can't rule it

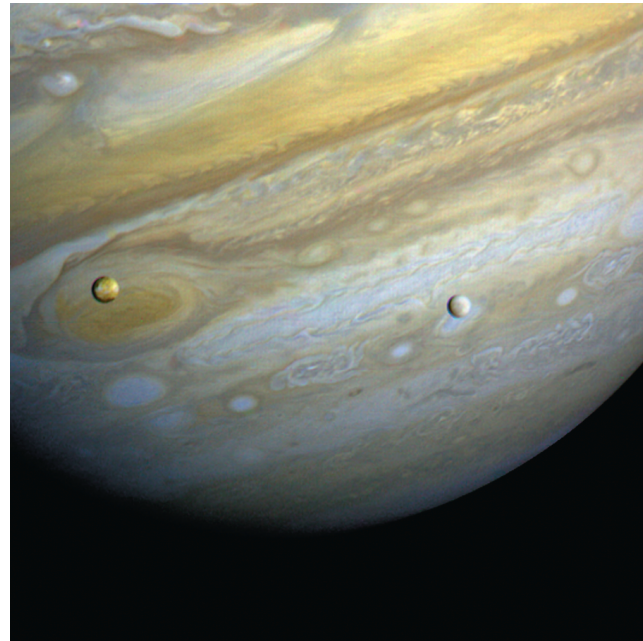


FIGURE 1.8

This photograph shows Jupiter and two of its moons: Io is the moon in front of Jupiter's Great Red Spot, and Europa is to the right. Scientists suspect that Europa has a deep ocean beneath its surface of ice, making it a prime target in the search for life in our solar system.

out completely. We'll discuss general prospects for life within our solar system in [Chapter 7](#).

Aside from the planets, the most promising abodes for life in the solar system are a few of the large moons. At least five moons are potential candidates for life, including Jupiter's moon Europa ([Figure 1.8](#)). Current evidence strongly suggests that Europa hides a deep ocean of liquid water under its icy crust. Indeed, if we are interpreting the evidence

correctly, the European ocean may have twice as much water as all of Earth's oceans combined [Section 9.2]. Because we suspect that life on Earth got started in the deep oceans [Section 6.1], Europa may well have all the conditions needed both for life to have arisen and for its ongoing survival. Two other moons of Jupiter—Ganymede and Callisto—also show some evidence for subsurface oceans, though the evidence is less strong and other considerations (primarily availability of energy) make them poorer prospects for harboring life. Other candidates for life include Saturn's moons Titan, which has a thick atmosphere and lakes of liquid methane, and Enceladus, which appears to have a subsurface ocean from which we observe fountains of ice spraying out into space [Section 9.3].

SEARCHING AMONG THE STARS In terms of numbers, there are many more places to look for life on planets and moons around other stars than in our own solar system. However, the incredible distances to the stars [Section 3.2] make searches of these worlds much more difficult. All stars are so far away that we will need great leaps in technology to have any hope at all of sending spacecraft to study their planets up close. For example, with current spacecraft technology, journeys to even the nearest stars would take close to 100,000 years.

With visits out of reach, telescopic searches represent our only near-term hope of finding life beyond our solar system. As we'll discuss in Chapter 11,

current telescopes can in most cases detect exoplanets only indirectly, which means we don't yet have images or spectra through which we might identify signs of life. But the technology is advancing rapidly. The recently launched James Webb Space Telescope (JWST)* may be able to obtain spectra of at least some exoplanet atmospheres, and within a couple of decades, even more advanced telescopes may be able to obtain moderate-resolution images of planets and moons around other stars. As a result, one important area of research is trying to figure out the photographic or spectral "signatures" that would tell us we are looking at a world with life.

1.3.2 Could aliens be searching for us?

So far we have talked about searching for life that we could identify only by seeing it with our spacecraft or telescopes. But if life really is common in the universe, there could be other places like Earth where life has evolved to become intelligent enough to be interested in searching for life beyond its home world. In that case, it is possible that other civilizations might actually be broadcasting signals that we could detect. The **search for extraterrestrial intelligence**, or **SETI**, which we'll discuss in Chapter 12, focuses on the search for such signals from alien civilizations

*There has been considerable controversy about naming this telescope after former NASA Administrator James Webb. As this book goes to press, NASA considers the matter closed, but some scientists are pushing for it to be reopened.

Movie Madness CINEMA ALIENS

Aliens should probably join the Screen Actors Guild. Every year, Hollywood reliably cranks out a handful of films in which visitors from distant star systems mess with our minds, our bodies, or our entire planet.

Cinema aliens are typecast, usually available in only two flavors: good and bad. A few, like loveable, wrinkly-faced little E.T., are willing to make a field trip of a few million light-years simply to pick some plants and hang with the kids. But most of these uninvited guests are cranky: They spend their time either dithering with our personal lives or blowing up famous landmarks just because they can.

Extraterrestrials didn't snag many movie roles until after the Second World War, when the rapid development of rocketry seemed to suggest that we'd soon be taking rides to the Moon, to Mars, and beyond. For the popcorn-eating public, it seemed inevitable that our descendants would visit other worlds as casually as you might head for the coffee shop. And if we could do this, then it seemed only reasonable that advanced aliens were already roaming space, like motorcycle gangs on a Sunday afternoon.

The movie moguls studiously ignored the fact (which you'll encounter later in this book) that traveling between the stars is enormously more difficult than checking out the planets of your own solar system. The aliens won't do it just to share play time with the neighborhood children, or to abduct you for unauthorized breeding experiments.

But the really big problem with Hollywood aliens, other than the fact that they seldom wear clothes, is that these frequently nasty visitors are inevitably portrayed as being close to our own level of technical development. We can engage the bad ones in aerial dogfights, or challenge them to a light-saber duel. But the reality is somewhat different. As we'll discuss in Chapter 13, if we ever make contact with actual aliens, their culture will almost certainly be thousands, millions, or billions of years beyond ours.

Of course, an invasion by hostile aliens with a million-year head start on *Homo sapiens* wouldn't make for an interesting movie. It would be Godzilla versus the chipmunks. But you don't mistake the movies for reality, do you?



FIGURE 1.9

This 140-foot radio telescope in West Virginia was used in 1996 to search for signals from extraterrestrial civilizations.

(Figure 1.9). Although we don't know whether the search will meet with success, we can be sure that the unambiguous receipt of an alien message would be one of the most significant events in human history—not to mention the fact that it would also probably answer many of our other questions about life in the universe.



LEARNING OBJECTIVE

Goals of Astrobiology

1.4 The Science of Astrobiology

We have seen that the study of life in the universe is a multidisciplinary field of scientific research, involving scientists with training in many different specialties. Nevertheless, because it has become a prominent and important area of study, it's useful to give the science of life in the universe its own name. A number of different names are in use, including “exobiology” and “bioastronomy,” but in this book we follow the lead of NASA and call it **astrobiology**. This term is meant to invoke the combination of astronomy (the study of the universe) and biology (the study of life), so *astrobiology* literally means “the study of life in the universe.”

1.4.1 How do we study the possibility of life beyond Earth?

Because astrobiology is a young science, scientists are still working to decide where to focus their research efforts. One major player in this effort has been the NASA Astrobiology Program, which encourages collaborations between scientists both within the United States and around the world. Similar efforts exist in many other countries, including the United Kingdom, Sweden, France, Spain, Russia, and Australia. These collaborations are among the most interdisciplinary in any area of science, bringing together astronomers, biologists, geologists, chemists, and many others seeking to understand the prospects of finding life beyond Earth.

Although different groups concentrate on different problems, most astrobiology research is concentrated in the following three areas:

1. Studying the conditions conducive to the origin and ongoing existence of life
2. Looking for such conditions on other planets in our solar system and around other stars
3. Looking for the actual occurrence of life elsewhere

Astrobiology therefore includes much more than simply searching for extraterrestrial life or civilizations. At a fundamental level, astrobiology research seeks to reveal the connections between living organisms and the places where they reside. In this sense, finding *no life* (on Mars, for example) is just as significant a result as finding life, because either way we learn about the conditions that can lead to the presence of life, about how life evolves in conjunction with planets, and about whether life is likely to be rare or common throughout the universe.

In the rest of this book, we will focus on the three areas listed above. After discussing the scientific context of the search in greater detail in **Chapters 2** and **3**, we'll turn our attention in **Chapters 4** through **6** to the nature, origin, and evolution of life on Earth. This study of the history of life on our planet will help us understand the conditions under which we might expect to find life elsewhere. We'll then discuss prospects for life elsewhere in our solar system in **Chapters 7** through **10**, and the prospects for finding life—including intelligent life—beyond our solar system in **Chapters 11** through **13**. Along the way, we'll also learn what science can currently say about the future of life on Earth, we'll consider possible futures for our own species, and we'll discuss the philosophical implications of the search for—and potential discovery of—life beyond Earth.

The Big Picture

This chapter has offered a brief overview of the ideas we will cover in more depth in the rest of the book, primarily so that you will have a sense of what to expect in the rest of your study of life in the universe. As we will do in every chapter, we conclude with a brief “big picture” recap of how these ideas fit into the overall goals of the scientific study of life in the universe:

- Despite the abundance of aliens in popular media, we don’t yet have any convincing evidence for life, even microscopic life, beyond Earth. Nevertheless, current understanding of astronomy, planetary science, and biology gives us good reason to think that it is at least reasonable to imagine that life may be widespread, and the discovery of extraterrestrial life of any kind would have profound significance to our understanding of life in the universe.
- It’s conceivable that life may exist on any of several worlds in our own solar system, but it’s extremely unlikely that any of this life is intelligent. However, we find many more possibilities when we consider life on planets or moons around other stars. And, through the search for extraterrestrial intelligence (SETI), it is even possible that we could receive a signal from an advanced civilization.
- The prospect that life may be common in the universe has given rise to the science of *astrobiology*, an exciting and interdisciplinary topic of research that focuses both on understanding the possibility of finding life elsewhere and on the actual search for life beyond Earth.

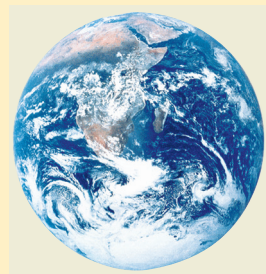
Summary of Key Concepts

1.1 The Possibility of Life Beyond Earth

1.1.1 What are we searching for?

The search for **extraterrestrial life** is in principle a search for *any* kind of life. However, the difficulty of clearly defining life means that it’s easier to focus the search on life that is at least somewhat similar to life here on Earth. This still opens a wide range of possibilities, from bacteria-like microbes to complex plants and animals.

1.1.2 Is it reasonable to imagine life beyond Earth?



People have long considered the possibility of life beyond Earth, but only recently have we been able to examine this possibility through the lens of science. While we have no evidence at this time of actual life beyond Earth, our scientific understanding of the possibilities makes it reasonable to think that life could exist elsewhere.

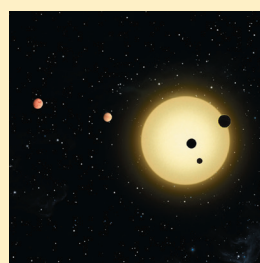
People have long considered the possibility of life beyond Earth, but only recently have we been able to examine this possibility through the lens of science. While we have no evidence at this time of actual life beyond Earth, our scientific understanding

1.2 The Scientific Context of the Search

1.2.1 How does astronomy help us understand the possibilities for extraterrestrial life?

Astronomy tells us that we live on a tiny planet orbiting one rather ordinary star in a vast cosmos, and that the same physical laws that operate here also operate throughout the universe. Together these ideas suggest that there could be many other worlds with life.

1.2.2 How does planetary science help us understand the possibilities for extraterrestrial life?



Based on current understanding of how planets form, we expect planets to be common around other stars—an idea that has been confirmed by discoveries of **exoplanets**. By learning how planets work, we learn the conditions that might make a **habitable world**, meaning a world that has the basic necessities for life, even if it does not actually have life.

1.2.3 How does biology help us understand the possibilities for extraterrestrial life?

Modern biology provides three lines of evidence suggesting that life *might* be common on other habitable worlds: (1) The fact that life arose quickly on Earth suggests that it might occur on any world that has the “right” conditions. (2) We know from observations of meteorites and interstellar clouds that organic molecules are common throughout the galaxy, suggesting that we’ll find them on many other worlds. (3) The fact that some life on Earth survives even under extremely harsh conditions suggests that life is hardy enough to survive in many other places as well.

1.3 Places to Search

1.3.1 Where should we search for life in the universe?



The search begins right here on Earth, as we seek to learn more about the life on our own planet. Elsewhere in our solar system we can search many planets and moons, but current understanding

suggests that the most promising candidates for life are Mars and a few moons, including Jupiter’s moon Europa or Saturn’s moon Enceladus. In the future, we should be able to conduct telescopic searches for life around other stars.

1.3.2 Could aliens be searching for us?

If life is common in the universe, civilizations might also be common, in which case other civilizations might be conducting their own searches and broadcasting signals that would indicate their existence. We look for such signals from alien civilizations through the **search for extraterrestrial intelligence**, or **SETI**.

1.4 The Science of Astrobiology

1.4.1 How do we study the possibility of life beyond Earth?



The science of life in the universe, or **astrobiology**, focuses on three major areas: (1) studying the conditions conducive to the origin and ongoing existence of life; (2) looking for such conditions on other planets in our solar system and around other stars; and (3) looking for the actual occurrence of life elsewhere. Together, these studies should help us understand the connections between living organisms and the places where they reside.

Exercises and Problems

You will find many of these questions and more, including guidance and study aids, in the Life in the Universe courseware.

QUICK QUIZ

Start with these questions as a quick test of your general understanding. Choose the best answer in each case, and explain your reasoning. Answers are provided in the back of the book.

1. An *exoplanet* is (a) a planet that orbits the Sun far beyond Pluto; (b) a planet that orbits a star other than our Sun; (c) a planet that orbits the center of another galaxy.
2. A *habitable planet* is (a) a planet that has oceans like Earth; (b) a planet that has life of some kind; (c) a planet that may or may not have life, but that has environmental conditions under which it seems that life could arise or survive.
3. By a *geocentric* view of the universe, we mean (a) the ancient idea that Earth resided at the center of the universe; (b) the idea that Earth is the only planet with life in the universe; (c) a view of the universe shaped by current understanding of geological science.
4. According to current scientific understanding, life on Earth (a) was exceedingly improbable; (b) arose quite soon after conditions allowed it; (c) may have been inevitable, but took billions of years to develop.
5. The correct order for the eight official planets in our solar system, from closest to farthest from the Sun, is (a) Mercury, Venus, Earth, Mars, Saturn, Jupiter, Neptune, Uranus; (b) Mercury, Venus, Earth, Mars, Jupiter, Uranus, Neptune, Saturn; (c) Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune.
6. Today, the research known as the *search for extraterrestrial intelligence*, or *SETI*, is conducted primarily by (a) scanning the skies for signals from alien civilizations; (b) sending spacecraft to the planets; (c) using telescopes to observe exoplanets.
7. If we sent a spacecraft to a nearby star (besides the Sun) using currently available rockets, the trip would take about (a) a decade; (b) a century; (c) 100,000 years.
8. Scientists today are interested in searching for life on Mars because (a) we see clear evidence of a past civilization on Mars; (b) Mars contains frozen water ice at its polar caps; (c) evidence suggests that Mars had liquid water on its surface in the distant past.

9. Based on current evidence, which of these objects in our solar system is most likely to have a deep, subsurface ocean of liquid water? (a) Mars; (b) Europa; (c) Neptune
10. Based on the way scientists view the study of astrobiology, failure to find life on any other world would mean (a) the whole subject has been a waste of time; (b) we must have done something wrong, since life has to exist beyond Earth; (c) we have learned important lessons about the conditions that made life on Earth possible.

READING REVIEW QUESTIONS

You should be able to answer these questions by re-reading portions of the chapter as needed.

11. Why are scientists interested in the possibility of life beyond Earth?
12. People have long speculated about life beyond Earth. What changed in recent times that now allows us to scientifically investigate the possibility of extraterrestrial life?
13. What do we mean by a *geocentric universe*? In general terms, contrast a geocentric view of the universe with our modern view of the universe.
14. What are *exoplanets*? In what way does their discovery make it seem more reasonable to imagine finding life elsewhere?
15. What do we mean by a *habitable world*? Does a habitable world necessarily have life?
16. What do we mean by the “universality” of physics and chemistry? Although we don’t know yet whether biology is similarly universal, what evidence makes it seem that it might be?
17. Besides Earth, what worlds in our solar system seem most likely to have life? Why?
18. Could we actually detect life on exoplanets or their moons with current technology? Explain.
19. What is the *search for extraterrestrial intelligence (SETI)*?
20. What do we mean by *astrobiology*? What are the major areas of research in astrobiology?

CONCEPTUAL QUESTIONS

Answer each question in short answer or essay form.

21. *Astrobiology Course Goals.* Assuming you are reading this book for a course in astrobiology, write a short statement about what you hope to learn in your course, and why.
22. *Aliens Among Us.* Conduct an informal survey of friends or family, asking each person to tell you whether they believe we have been visited by aliens and why they think so (or why not). Write a brief summary of your survey results, and add a paragraph or two discussing whether the people you spoke with are likely or unlikely to reflect general public opinion on the topic of alien visits.

23. *Three Contexts.* This chapter introduced the idea that astrobiology is informed by three major scientific “contexts”: astronomy, planetary science, and biology. Briefly explain how each of these contexts enables us to study astrobiology as a scientific endeavor.
24. *Universal Laws.* Briefly discuss how the idea that the laws of nature are universal is important to the study of astrobiology. Based on what you know about the universality of the laws of physics and chemistry, do you think it is likely that there are also universal laws of biology? Defend your opinion.
25. *Conducting the Search.* Given the large number of possible places to look for life, how would you prioritize the search? In other words, where would you look first for life on other worlds in our own solar system, and how would you come up with a search strategy for other star systems? Make a list of priorities and write a few sentences to explain your search strategy.
26. *Funding for Astrobiology.* Imagine that you are a member of Congress, so it is your job to decide how much government funding goes to research in astrobiology. What factors would influence your decision? Make a brief list of at least five important factors, then write a paragraph summarizing whether you would increase or decrease such funding from the current level and why.

ACTIVITY AND DISCUSSION

These questions are intended to prompt additional research and/or discussion.

27. *Astrobiology News.* Go to NASA’s Astrobiology home page and read some of the recent news from astrobiology research. Choose one recent news article, and write a one- to two-page summary of the research and how it fits into astrobiology research in general.
28. *International Astrobiology.* Search the Web for information on astrobiology research outside the United States. Learn about the effort in one particular country or group of countries. What areas of research are emphasized? How do the researchers involved in the effort collaborate with other international astrobiology efforts? Write a one- to two-page report on your findings.
29. *The Search for Extraterrestrial Intelligence.* Go to the home page for the SETI Institute. Learn more about how SETI is funded and how the institute does its work. Summarize your findings in about one page.
30. *Group Activity: Aliens in the Movies.* Work in small groups to make a list of movies that involve aliens, listing as many as you can. Then come to a group consensus on ranking the top five such movies of all time, giving a brief reason for why you like each movie in your top five. Compare your top five list with the lists made by other groups.

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