IN THIS CHAPTER

- Knowing the "big questions" that astrobiology seeks to answer
- Learning the range of topics covered in astrobiology
- Getting a glimpse of what's in store later in this book

Chapter 1
Astrobiology in a Nutshell

COPYRIGHTED MATERIAL

On a clear summer night perhaps you've gone outside, looked up at the thousands of glittering stars in the sky, and wondered what and who is out there in the universe. You may even have asked yourself if there are any intelligent lifeforms on a planet circling one of those stars who, right now, are perhaps looking back up toward *you* and wondering if you exist!

Or maybe you've pondered a photograph of a bizarre deep-sea creature or a weird-looking microorganism under a microscope and wondered why it looks that way, and whether it could have ended up appearing differently. You may even have wondered how long humans have been around on Earth to ask these questions!

If you've thought about any of these conundrums, then congratulations, you're in good company. These mysteries have kept human thinkers and philosophers awake at night for millennia, from Aristotle to Einstein, along with most of the rest of us at some point in our life. But wait, can we really answer these questions? If they've been around for so long, what hope do we have to answer them now?

The good news for curious minded among us is that in recent decades we have made enormous progress toward finally unraveling some of these mysteries. Although we don't know everything yet, we now have reason to believe that these questions are indeed solvable, and that the answers may even be just over the horizon. The new field of scientific study that has emerged to probe these questions is *astrobiology*, the subject of this book.

Asking the Big Questions

Because you've picked up this book, I already know something about you — that you're extremely curious about two big questions:

- How did life start on Earth?
- Is there life elsewhere?



REMEMBER

Finding the answers to those questions is the ultimate goal of *astrobiology*, which could be stated as the field devoted to "*understanding life in the universe.*" Think *astro* = stars, plus *biology* = life. That wasn't so bad, was it?

Well, yes and no. It turns out that asking the questions is the easy part! Answering those questions is considerably harder, and has been vexing philosophers, theologians and scientists for millennia. In Chapter 2, I explain some of the historical thinking and theories that laid the groundwork for present day astrobiology.

Sometimes astrobiology is defined to include these questions:

- What environments are habitable?
- What is the future of life in the cosmos?



TIP

Note that we make a distinction between *habitable* (somewhere that life *could* exist) and *inhabited* (somewhere that life *does* exist). Through the course of the book, I explain which environments we think are habitable as part of the wider search for life.

Regarding the future of life, this is quite an open-ended subject, and one that's not much constrained by our current scientific knowledge. However, you'll learn some ideas on this topic when I discuss advanced extraterrestrial civilizations (see Chapter 17), and the close relation between astrobiology and science fiction (see Chapter 19).

The Scope of Astrobiology

The scope of the present-day field of astrobiology encompasses both the origins of life on Earth, and the search for life elsewhere. Tools and techniques used by modern astrobiologists include:

- Giant telescopes on the Earth and in space.
- Space missions to explore environments in our solar system.
- Cutting-edge laboratory experiments to analyze samples from the Earth and space, and to probe the workings of biology.
- Expeditions to collect samples from extreme locations on Earth — such as polar regions, high deserts, volcanoes and the deep sea — and from space.
- Computer simulations of life's origins and evolution, and of cosmic environments.

Origins of Life on Earth

One of the two key questions of astrobiology tackled in this book is to understand the origins of life on Earth — where do we come from?

Defining life

A precursor even to finding life's origin is to define "life" — after all, we can't search for something if we don't know exactly what we're looking for. This perhaps seems simple at the outset, but turns out to be trickier than it looks.



TIP

NASA has formulated a concise definition: "Life is a self-sustaining chemical system capable of Darwinian evolution." This works well in most circumstances, but isn't perfect. For example, it excludes the possibility that a computer-based intelligence could ever be considered alive.

Although it's proven difficult to arrive at a universally acceptable and robust definition of life, the process of searching for a definition may have been as useful as the (elusive) result itself. By trying to define life, we explore the boundaries in a productive way that enlarges our understanding.

Classifying life

After we've decided for the most part what is "in" and "out," an important process is to sort and categorize the various types of life we observe — a subdiscipline known as *taxonomy*. This was a key undertaking during the scientific revolution that helped to define the modern field of biology.


REMEMBER

Besides helping us to organize our butterfly collections, the process of taxonomy led to the realization that various forms of life are more or less closely related to each other, and resulted in the "tree of life" — an organizational diagram that continues to be refined today.


TIP

The tree of life encompasses not only present-day specimens, but also evidence of earlier animals and plants in the fossil record, leading to a linking of the fields of geology, paleontology, and biology.

This tree of life and the idea that diversification progressed over time, albeit in fits and starts, led to the concept of evolution (the branching of the tree), and even the idea of a "last universal common ancestor" (LUCA) — a hypothetical single-celled organism from which all other life subsequently evolved — the "trunk" of the entire tree of life.

Understanding the earliest life

The idea of a simple, universal common ancestor takes us to the heart of question 1: the origin of life on Earth. Today, paleobiologists and astrobiologists seek to understand how life made the leap from non-biological ingredients to the simplest self-replicating organisms.

They want to know how the first cells formed, and subsequently diversified. I explain ideas about this in Chapter 6, which although not yet definitive, are certainly progressing. I also describe the key distinction in the tree of life between two types of organisms: eukaryotes and prokaryotes — cells with and without a distinct nucleus.


REMEMBER

Eukaryotes are the entry point to the study of multi-cellular life, since all multi-cellular lifeforms (including us) belong to the gang of eukaryotes. In Chapter 7 I explain the advantages of multi-cellularity, such as allowing cells to cooperate and specialize to perform different tasks like workers in a factory. This gives us some neat evolutionary advantages over our unicellular cousins, often allowing us to survive in a wider range of environments.

Since sadly we don't yet have a time machine that would take us back to Earth's past to observe the earliest stages of evolution in action, scientists instead try to replicate some of these processes in the lab. A famous example is the Miller-Urey experiment, which showed that complex ingredients can be formed from simpler ones relatively easily under the right conditions.


TIP

Other fascinating experiments include the creation of minimal organisms and artificial life forms, and even life simulations *in silico* — inside the memory of a computer.

Probing life's limits

I mentioned that astrobiologists are interested in the limits of life on Earth, since that informs us about where we can search for life in space. This leads to the study of *extremophiles*, life forms that can survive the most challenging environments known on Earth.

These range from frigid polar terrains, to boiling hot springs, and from high-pressure, deep-undersea locations to the vacuum of space. Some extremophiles love salty plains, whereas others prefer acidic baths, alkaline springs or arid deserts. Extremophiles include many single-celled creatures, but some larger ones as well, such as the hardy little tardigrades, sometimes called "water bears."

Searching for Life in Our Solar System

The second part of astrobiology focuses on the search for life in space. This takes us out into the solar system, including the study of materials in comets and asteroids, to the characteristics of other planets and moons.

Comets and meteorites

Comets were once-feared omens and harbingers of disaster that are now known to be not messengers of the gods, but giant dirty snowballs. Comets are among the most pristinely preserved precursors of our modern solar system, leftovers from the giant celestial baking experiment that produced our planets and moons.



TIP

Comets are of intense interest to astronomers, as they provide clues not only to the simpler materials that comprise the solar system worlds, but also to our oceans and even the origins of life itself.

Another class of primitive bodies are meteorites and their parent bodies, which are (mostly) asteroids. Some meteorites are remnants from the earliest eras of solar system formation and even before, including grains from earlier stars and solar systems than our own.

Meteorites were somewhat belatedly identified to arrive from space in the 1800s and today are classified as either *falls* (witnessed falls from space) or *finds* (meteorites found without a witnessed fall). I'll explain what has been learned from the collection and study of meteorites, as well as from asteroid samples directly collected at the source and returned to Earth.

Planets and moons

The planet Mars has been a perpetual fixture in astrobiology for hundreds of years, giving us visions of canal-building farmers and fearsome invaders. However, since our first landings on the red planet in the 1970s our understanding of Mars has changed profoundly, to a vision of an uninhabited and dusty barren desert. Yet Mars has not yielded up all its secrets yet, and scientists continue to delve for clues of extinct or even extant life beneath the soil, with today's rovers and future sample return missions.

In the past several decades, significant astrobiological focus has shifted toward the moons of the outer known solar system, now known to include many "water worlds" within vast oceans inside. These include Jupiter's cracked-up moon Europa, and Saturn's active satellite Enceladus. You'll learn what evidence exists for watery oceans inside these worlds, and our current best understanding of their habitability and potential for life. I also describe current deep space missions, as well as future missions we hope to send to learn more about worlds such as Titan and Triton.

Finally, some scientists are pursuing ideas of exotic life in the clouds of Venus, Jupiter, and other gas planets. Despite being perhaps fanciful and remote possibilities, these ideas help to push the boundaries of potentially habitable environments, making sure that no stone (or cloud droplet) is unturned in our search for life, which may well surprise us by differing greatly from life on Earth. One lesson we have learned from extremophiles is not to be too conservative in where we look.

Life beyond Our Solar System

Whereas our solar system includes many fascinating and yet-unexplored possible habitats for life, these pale into insignificance when compared to vast expanse of space, including the other stars and their planetary systems in our galaxy, and beyond to innumerable other galaxies.

Astrochemistry is the field that seeks to identify complex chemicals in space. I describe the tools of the trade, especially the workhorse radio telescope, and show how far and fast astronomers are expanding our inventory of space substances, from carbon *buckyballs* to space sugars.

Today many astrobiologists are focused on exoplanets — planets orbiting other stars in our galaxy, which already vastly outnumber the eight planets in our own solar system by a factor now approaching a thousand to one! You'll learn in this book how exoplanets were first discovered and what are the closest, hottest, largest and most Earthlike examples yet known. Be aware though, the subject matter is literally changing every day, so always be sure to check online for the latest news and results.

The search for extraterrestrial intelligence (SETI), is what many people first think of when life in space is mentioned. SETI is guided by the Drake Equation, a simple formula which seeks to place a value on the number of extraterrestrial civilizations that we could communicate with today. I'll explain some of the false starts and dead ends that have historically given SETI a bad rep over the years, but also how modern SETI is seeking to put the search for aliens on a more robust and scientific footing.

Astrobiology and Culture

Later in the book I discuss some fun cultural topics around astrobiology, including hoaxes and conspiracies (see Chapter 18) and astrobiology in the arts (see Chapter 19). From the "ancient aliens" and pyramid builders of pseudo-factual conspiracy books and TV documentaries to the outright engaging fictions of sci-fi novels, games, TV series, and movies, you'll see how far the human imagination stretches when it comes to imagining aliens.



REMEMBER

These fictions do however often serve a useful purpose to advance science and technology, by challenging our ideas of what is possible in astrobiology, and inspiring and motivating budding sci-fi fans to go into serious science in later life.