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# 1 The Search for Extraterrestrial Life

## Are We a Privileged Generation?

For many millennia, humans have gazed up in wonder at the night-time sky. The full panoply of the Milky Way is an awesome sight. The scale of space is immense. Is there life out there somewhere? If so, where, and what form does it take? In the space of a couple of sentences, we've already gone from generalized wonder to specific questions. The next step is from questions to hypotheses, or, in other words, proposed answers. Here are two such hypotheses that I'll flesh out as the book progresses: first, life exists on trillions of planets in the universe; second, it usually follows evolutionary pathways that are broadly similar to – though different in detail from – those taken on Earth.

Going from cosmic wonder to questions about alien life and on to hypothetical answers has been possible for a long time. But the final steps – from hypothetical answers to testing the hypotheses to arriving at an understanding of reality – have so far proved beyond humanity's grasp. That may be about to change. We may be on the threshold of being able to answer the age-old question 'are we alone in the universe?' with a resounding 'no'. But what is the basis of this claim? The short answer is advancing technology, and in particular advancing design of telescopes. We'll get to that topic soon. But first, let me reassure you that I'm not alone in my optimism about the imminent discovery of evidence for alien life.

A 2021 paper in the leading scientific journal *Nature*, by the American physicist James Green and his colleagues, began with the following sentence: 'Our generation could realistically be the one to discover evidence of life beyond Earth.' Its authors clearly share my optimism in this respect. Of course, there's a question-mark hanging over the meaning of 'our generation', as the six authors are varied in age, and their readers even more so. But that's a small uncertainty in the grand scheme of things. The key point is that many scientists suspect that the first evidence of life beyond Earth will be forthcoming on a timescale of years to decades, not centuries. Even if it takes five decades to acquire the first conclusive evidence, a reasonable proportion of those alive today (regrettably not including me!) will still be here to see it.

In the previous paragraph, I used the phrase 'many scientists'. But scientists of what type? Science is a broad endeavour, and some parts of it are more relevant to the search for life than others. However, that said, many scientific disciplines have a role to play. They include cosmology, astronomy, astrophysics, planetary science, atmospheric science, geology, ecology, evolutionary biology, genetics, molecular biology, and organic chemistry – and that is far from being an exhaustive list. The principal discipline is astrobiology, which is a mix of some or all of the above, with the exact mix depending on the astrobiologist concerned. Astrobiologists of my generation weren't trained as such, as there were no courses in the subject, so we've migrated towards it from various starting points – in my case evolutionary biology. But there's a younger cohort of astrobiologists who have indeed been trained in this discipline.

Importantly, the 'many scientists' who suspect that the first evidence of alien life will be found on the years-to-decades timescale include specialists in all of the disciplines mentioned above, and indeed others too. So this optimism isn't a passing fad in one particular narrow branch of science. Rather, it's a reasoned assessment of the stage we have reached in the process of searching for life, and where we're likely to get to with the new generation of space telescopes that are currently at various stages of planning, construction, or early operation, including the James Webb Space Telescope (alias JWST or simply 'Webb'), more on which later.

The paper in *Nature* that I mentioned above is focused on formulating a policy for reporting possible evidence of alien life. The authors highlight the complementary problems of false positives and false negatives. The former involve concluding that some observation is evidence for life when in fact it's not; the latter involve failing to detect life on a planet when it's actually there. They particularly stress their concern about the likely sensationalization in the popular media of results that turn out to be false positives, and I think they are right to do so. Their approach to avoiding – or at least reducing – such problems is to develop a scale of the quality of possible evidence of alien life, and to make clear where on this scale any particular finding falls. This way, a hint of possible life shouldn't be mistaken for a certainty. In Chapter 5, we'll apply their approach to claims of extraterrestrial life in the solar system.

In a way, I see this book as being complementary to the paper by James Green and colleagues. Those authors were concerned with understanding the nature of possible evidence for alien life in a rational framework, and preventing distortion of that evidence. I'm concerned with understanding the multidisciplinary basis of the search for life, and preventing flights of fancy that are too narrowly based. For example, a biologist might get excited about the possibility of evolution taking place on a particular planet, when astronomical considerations suggest that's unlikely – for example because of a short lifespan of its host star. Equally, an astronomer might get excited about evolution taking place very rapidly on some planets via large-effect mutations, when the biological argument against this happening isn't restricted to evolution on Earth. And some scientists (or, more likely, some non-scientists) might get excited about the possibility of life based on silicon rather than carbon, without being aware of the unlikelihood or impossibility (it's hard to say which) of having a silicon-based molecule that can rival DNA in terms of informational capacity.

## A Brief History of the Search

To look at the history of our search for extraterrestrial life, and its philosophical foundations, ancient Greece is a good place to start. Most of the impressive philosophers there in the period from about 600 to 150 BCE (Before the Common Era, alias BC for Before Christ) included astronomical matters in their thoughts. They wondered very deeply about the things they saw in the night-time sky. Anaximander (*c.* 610 to 546 BCE) argued for a plurality of worlds rather than a single one. However, his approach was constrained by the limited knowledge available at the time on the nature of what we now know to be stars and planets. His ‘many worlds’ were abstract philosophical entities, not solid rocky bodies orbiting stars. Anaxagoras (*c.* 500 to 428 BCE) is thought to have been the first person to propose that stars are distant suns – or conversely that our Sun is a close-up star. And Aristarchus of Samos (*c.* 310 to 230 BCE) may have been the first person to propose a heliocentric solar system, with Earth and the other planets known at the time orbiting the Sun.

Prior to the realizations that (1) stars are suns and (2) planets orbit suns, hypotheses about extraterrestrial life couldn’t be formulated in the way that’s possible today. However, as early as Aristarchus’s time, such hypotheses would have been possible. We don’t know of any hypotheses of this kind from way back then. One of the reasons for the lack of them was the unfortunate failure of Aristarchus to persuade most of his contemporaries of the truth of his heliocentric view. It wasn’t until the sixteenth century that Copernicus (1473–1543) would succeed where Aristarchus had failed, and a heliocentric view became commonplace among astronomers.

Although future historical research may turn up ideas about life being found on planets other than Earth between the times of Aristarchus and Copernicus, the earliest known hypotheses of this kind at the time of writing were those of the post-Copernican Italian priest–astronomer Giordano Bruno (1548–1600). Bruno’s view was that stars were distant suns (following Anaxagoras), that each of these had planets orbiting it in the same way as does our local Sun (a generalization of the views of Aristarchus and Copernicus), and that many of these planets were homes to life. Bruno was a man before his time; the first planets orbiting other stars than the Sun – collectively termed exoplanets – weren’t discovered until the late twentieth century. Unfortunately for humanity, and even more so for him personally, his free-thinking approach to both astronomy and theology fell foul of the Catholic Church’s Roman Inquisition. Bruno was burned at the stake – an unimaginably cruel form of homicide – in 1600, in the Campo de’ Fiori in central Rome, where a statue of him can now be found.

The first recognized telescope was made in the Netherlands in 1608, though there may have been previous prototypes. Galileo famously used a telescope to observe the moons of Jupiter orbiting the giant planet in 1610, setting him off on a course that would also fall foul of the Church, though in his case terminating in house arrest rather than execution. As far as we know, Galileo himself didn't develop hypotheses about alien life, but as telescopes evolved, other users did. The Italian astronomer Giovanni Schiaparelli (1835–1910) observed linear features on Mars that he called *canali* – which translates into English either as 'canals' (which implies human construction) or 'channels' (which doesn't). Schiaparelli wrote about a possible technological civilization on Mars, as did the American astronomer Percival Lowell (1855–1916), who was much struck by the supposed canals. Lowell published a 1906 book entitled *Mars and Its Canals,* with a 1908 follow-up, *Mars as the Abode of Life*. In the end, this whole line of enquiry came to nothing, when it was shown that the 'canals' were optical illusions.

The modern era of the search for life can be dated to around 1960, with the start of the endeavour called SETI (Search for Extraterrestrial Intelligence). A pioneering paper on the possibility of communication with intelligent life on other planets was published in 1959 by the astronomers Giuseppe Cocconi and Philip Morrison. Frank Drake and others began practical SETI work with Project Ozma in 1960. This was a search for radio signals from alien civilizations, conducted using the National Radio Astronomy Observatory, now the Green Bank Observatory, in West Virginia. Of course, the search for alien intelligence is only one part of the search for life. Nevertheless, from the 1960s onwards, both astrobiology in general and SETI in particular have evolved side by side in a much more continuous way than did the search for life before the second half of the twentieth century.

## The Importance of Telescopes

It's a long way from Galileo's tiny telescope of 1610 to today's large ground-based instruments such as Chile's VLT (Very Large Telescope), and their space-based counterparts such as Hubble and Webb. I'll now look at a few selected milestones along this evolutionary journey. If you'd like a bit more detail than I can give in just a few pages on the functioning and/or history of telescopes, I can recommend Geoff Cottrell's 2016 book *Telescopes: A Very Short Introduction*.

Before examining milestones in the evolution of telescopes, it's worth reminding ourselves of why, from an astrobiological perspective, they are collectively important. Telescopes of Galileo's day were great for astronomy – especially when compared with the naked eye – but they weren't much use for astrobiology. In contrast, today's telescopes have the capability of addressing hypotheses about alien life. For example, we can now use telescopes to examine the atmospheres of distant exoplanets. We can search for signs of oxygen, which is regarded as a biosignature. In particular, it may be a signature of photosynthesis by microbes and plants. It's true that oxygen may come to exist in planetary atmospheres by abiotic means. However, as we'll see in Chapter 6 (penultimate section), it may be possible to distinguish the two types of origin of oxygen. This is a hugely exciting prospect.

So, what changes in telescope design have contributed to our current ability to look for biosignatures? Here are the main ones. First, increasing size. Telescopes are first and foremost light-gathering devices. The amount of light they can collect depends on their size – and in particular the diameter of their primary lens or mirror. The earliest telescopes were very small. Galileo's had a diameter of 3.7 centimetres, Newton's (in 1668) 2.5 centimetres. They're not directly comparable because Galileo's was a refractor (a telescope that uses lenses) while Newton's was a reflector (a telescope that uses mirrors), but they were both tiny by current standards. Today's large telescopes have mirrors with diameters measured in metres rather than centimetres. For example, the Gran Telescopio Canarias, situated on the Spanish island of La Palma, has an aperture of 10.4 metres.

The increase in telescope size has been continuous from the 1600s to the 2000s, though it has speeded up significantly since 1900. The largest telescope in the world at the end of the nineteenth century was the Leviathan of Parsonstown in County Offaly, Ireland, which had a diameter of 1.83 metres. This size was exceeded in 1917 with the construction of the Hooker Telescope on Mount Wilson in southern California, with a diameter of 2.5 metres. So the last 100 years have seen the largest increase – more than 8 metres between the early twentieth and early twenty-first centuries.

However, these measurements in metres don't quite suffice to explain just how much more powerful modern telescopes are than their ancient forerunners. The light-collecting capability of a telescope scales not with the diameter of its primary mirror but with its surface area. So, in terms of functionality, a 10-metre mirror is not 10 times as good as a 1-metre mirror; rather it's better by a factor of 100. Given that Galileo's tiny telescope allowed him to see the moons of Jupiter, and discern individual stars in the 'milk' of the Milky Way, the capabilities of today's telescopes are truly amazing.

But, for astrobiology, size is not enough. There are several other developments that we need to understand. First, so obvious that it hardly needs to be said, the advent of photography in the 1800s, and its later coming together with telescopes in the form of astrophotography. Second, Earth's atmosphere is a major cause of distortion in the business of seeing clearly into space. As is well known, stars don't twinkle – they only seem to do so because of atmospheric effects. The main exoplanet-detecting telescopes have been placed above the atmosphere so that this distortion is avoided. These are the Kepler and TESS space telescopes (more on which in Chapter 6). The first is named after the German astronomer Johannes Kepler (1571–1630), who formulated the laws of planetary motion; the second is an acronym of Transiting Exoplanets Survey Satellite, with 'transiting' referring to the movement of a planet across the face of its host star, as seen from our perspective.

As well as making a telescope bigger, enabling it to take images, and in some cases launching it into space, another development we need to consider is the range of wavelengths it can see. 'Light' is a slippery term. It's sometimes used for the part of the electromagnetic spectrum we can see, though this is better described as 'visible light'. Alternatively, it can be used more broadly to refer to the whole of the spectrum – as in the distinction between the speeds of light waves and sound waves. Early telescopes were designed – understandably – to see visible light. Today's telescopes are much more varied in this respect. Some can see in the ultraviolet range, some in the infrared range, some can see radio waves, and some can see across boundaries between our quasi-arbitrary sections of the spectrum.

One example of 'seeing across boundaries' is the James Webb Space Telescope, launched in December 2021. Another will be a future space telescope, which, at the concept stage, was called LUVOIR, an acronym of Large Ultra-Violet, Optical, and Infra-Red (telescope). This design survived NASA's 2020 decadal survey, which produced its report in late 2021 due to the Covid pandemic. However, it was scaled down in size for reasons of cost.

The primary mirror will be of a smaller diameter than was originally envisaged. When constructed, the diameter will be about 6 metres – still a considerable size for a space telescope. Its final name will probably be different. In the immediate aftermath of the decadal survey, some astronomers jokingly suggested simply losing the L (large) and calling it UVOIR, but a better name will almost certainly be found. The ability to see across the boundary between visible and infrared light that characterizes both James Webb and LUVOIR means that they will be ideally placed to see oxygen biosignatures.

This point brings us to the other important development in telescopes that we need to examine: the use of a technique called spectroscopy. Here's the basic idea behind this technique, as applied in space telescopes for astrobiological purposes. You look at light from a distant source – say a star that has an orbiting planet. In fact, you look at it twice, once when the planet is behind the star or a long way off to one side, and once when it is transiting – i.e. in front of its star from our perspective. You compare graphs of amount of light received versus wavelength for the two occasions (Figure 1.1). Dips in the amount of light at particular wavelengths when the planet is in front of the star are interpreted as resulting from absorption of light by gases in the planet's atmosphere. Since different gases have different characteristic patterns of absorption, you can identify them.

There's a final twist to this story. The effects of a planetary atmosphere are tiny compared with the immense blast of light that hits our telescope from the fiery furnace of the planet's host star. A better approach would seem to be this: look not at the star with the planet in front of it but rather at the planet itself. There's a big problem here that at first seems insurmountable but is not. Even when the planet is a long way off to the side of the star, starlight dominates what you see, and in any event planets don't produce light of their own. The solution to this problem is twofold. First, where possible, blot out the light from the star using some form of starshade. Second, observe in the infrared range because, while planets don't emit their own visible light, they *do* emit in the infrared; in contrast, starlight peaks in the visible region and declines in the infrared. Looking directly at planets in this way is called direct imaging.

Seeing (or 'listening') in the radio range is also important – especially from a SETI perspective. As well as searching for biosignatures that could come from very

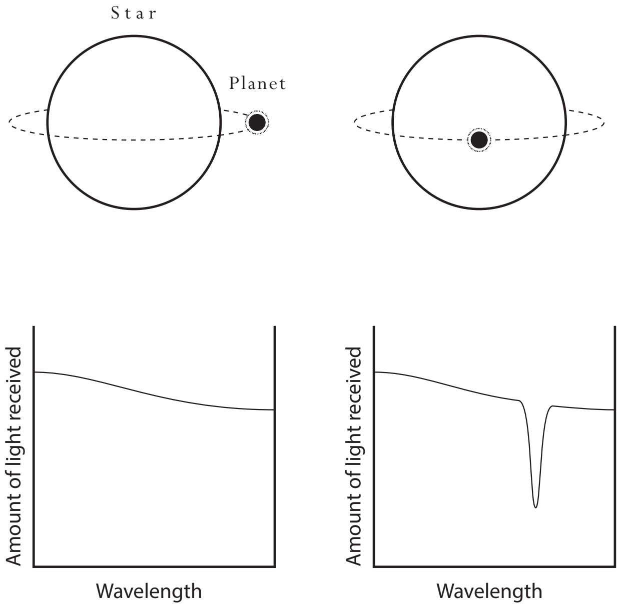


**Figure 1.1** Detecting gases in exoplanet atmospheres. Left: amount of light received by a space telescope when the planet is 'off to one side' from our perspective. Right: amount of light received when the planet is in a direct line between its host star and the Earth. Note the dip in the amount of light received at a particular wavelength in the right-hand panel. If instead of looking at this graph you were looking at the light itself, after it had been split into its various colours by a prism, you would see a dark band at the wavelength (= colour) concerned. Such a dip (or band) is interpreted as the result of absorption by a particular gas in the planet's atmosphere, and is known as an absorption band. Since different gases have different patterns of absorption centred on different wavelengths – in other words different 'signatures' – they can be identified. Some gases, notably oxygen, are regarded as *bio*signatures. As we will see later (in Chapter 6), the idea of a single absorption band is a simplification; each gas typically has several of them.

simple forms of life such as bacteria, we also look for technosignatures – those that could only come from an advanced civilization. If such a civilization decides to broadcast its existence in the way that humans have done since the

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middle of the twentieth century, it will probably use radio signals to do so. Thus, radio telescopes come into their own in the search for intelligence in the universe. Well-known radio telescopes include Jodrell Bank in Cheshire, England, and the Arecibo telescope in Puerto Rico, the latter now lamentably defunct following damage sustained in 2020. It gave its name to the famous Arecibo message broadcast by it into space in 1974. There are also large *arrays* of radio telescopes – for example ASKAP (Australian Square Kilometre Array Pathfinder), located about 700 kilometres north of the city of Perth, which started observing the sky in 2012.

## A Working Definition of Life

We are about to *feel* the multidisciplinary nature of the search for extraterrestrial life that I mentioned at the outset, because we are about to move from the astronomical realm to its biological counterpart. In particular, we are going to move from the telescopes used in the search for habitable planets – and ultimately the life that's on some of them – to the search for a workable definition of life. How can we search for life if we can't define it? And yet the task of defining life is not an easy one – even in the restricted context of planet Earth (are viruses alive?). It's more difficult again to attempt a definition that will work in a cosmic context. But an imperfect definition is better than nothing – so here goes.

One way of looking at a definition is as an abstract generalization about a class of entities that's based on prior knowledge of many *concrete individual entities* of the sort concerned. So, let's start with a list of 'concrete' living entities – organisms – on our home planet. Not a complete list, of course, for that would include more than a million names. But we don't need a complete list, nor even a particularly lengthy one. A short one will suffice, and indeed is preferable, in terms of not drowning in detail. Here it is: humans, snails, whales, trees, toadstools, and bacteria.

A definition of 'X' – in this case 'life' – only works if we also have entities that we know are 'not X', which in this case means 'not life', or alternatively 'inert objects'. Here's a short list of such objects, all of which are generally agreed *not* to be living things: rocks, clouds, cars, smoke, and water. Of course, some of these entities might *contain* life forms – for example a cloud might contain