Scientific researchers on a bat-collecting expedition in Sierra Leone. *Photo by Simon Townley/Panos*

There's no planet B

The scientific evidence is clear: the only celestial body that can support us is the one we evolved with. Here's why

by Arwen E Nicholson & Raphaëlle D Haywood

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At the start of the 22nd century, humanity left Earth for the stars. The enormous ecological and climatic devastation that had characterised the last 100 years had led to a world barren and inhospitable; we had used up Earth entirely. Rapid melting of ice caused the seas to rise, swallowing cities whole. Deforestation ravaged forests around the globe, causing widespread destruction and loss of life. All the while, we continued to burn the fossil fuels we knew to be poisoning us, and thus created a world no longer fit for our survival. And so we set our sights beyond Earth's horizons to a new world, a place to begin again on a planet as yet untouched. But where are we going? What are our chances of finding the elusive planet B, an Earth-like world ready and waiting to welcome and shelter humanity from the chaos we created on the planet that brought us into being? We built powerful astronomical telescopes to search the skies for planets resembling our own, and very quickly found hundreds of Earth twins orbiting distant stars. Our home was not so unique after all. The universe is full of Earths!

This futuristic dream-like scenario is being sold to us as a real scientific possibility, with billionaires planning to move humanity to Mars in the near future. For decades, children have grown up with the daring movie adventures of intergalactic explorers and the untold habitable worlds they find. Many of the highest-grossing films are set on fictional planets, with paid advisors keeping the science 'realistic'. At the same time, narratives of humans trying to survive on a post-apocalyptic Earth have also become mainstream.

Given all our technological advances, it's tempting to believe we are approaching an age of interplanetary colonisation. But can we really leave Earth and all our worries behind? No. All these stories are missing what makes a planet habitable *to us*. What *Earth-like* means in astronomy textbooks and what it means to someone considering their survival prospects on a distant world are two vastly different things. We don't just need a planet roughly the same size and temperature as Earth; we need a planet that spent billions of years evolving with us. We depend completely on the billions of other living organisms that make up Earth's biosphere. Without them, we cannot survive. Astronomical observations and Earth's geological record are clear: the only planet that can support us is the one we evolved with. There is no plan B. There is no planet B. Our future is here, and it doesn't have to mean we're doomed.

Deep down, we know this from instinct: we are happiest when immersed in our natural environment. There are countless examples of the healing power of spending time in nature. Numerous articles speak of the benefits of 'forest bathing'; spending time in the woods has been scientifically shown to reduce stress, anxiety and depression, and to improve sleep quality, thus nurturing both our physical and mental health. Our bodies instinctively know what we need: the thriving and unique biosphere that we have co-evolved with, that exists only here, on our home planet.

There is no planet B. These days, everyone is throwing around this catchy slogan. Most of us have seen it inscribed on an activist's homemade placard, or heard it from a world leader. In 2014, the United Nations' then secretary general Ban Ki-moon said: 'There is no plan B because we do not have [a] planet B.' The French president Emmanuel Macron echoed him in 2018 in his historical address to US Congress. There's even a book named after it. The slogan gives strong impetus to address our planetary crisis. However, no one actually explains *why* there isn't another planet we could live on, even though the evidence from Earth sciences and astronomy is clear. Gathering this observation-based information is essential to counter an increasingly popular but flawed narrative that the only way to ensure our survival is to colonise other planets.

> The best-case scenario for terraforming Mars leaves us with an atmosphere we are incapable of breathing

The most common target of such speculative dreaming is our neighbour Mars. It is about half the size of Earth and receives about 40 per cent of the heat that we get from the Sun. From an astronomer's perspective, Mars is Earth's identical twin. And Mars has been in the news a lot lately, promoted as a possible outpost for humanity in the near future. While human-led missions to Mars seem likely in the coming decades, what are our prospects of long-term habitation on Mars? Present-day Mars is a cold, dry world with a very thin atmosphere and global dust storms that can last for weeks on end. Its average surface pressure is less than 1 per cent of Earth's. Surviving without a pressure suit in such an environment is impossible. The dusty air mostly consists of carbon dioxide (CO_2) and the surface temperature ranges from a balmy 30ºC (86ºF) in the summer, down to -140ºC temperature ranges from a balmy 30°C (86°F) in the summer, down to -140°C (-220ºF) in the winter; these extreme temperature changes are due to the thin atmosphere on Mars.

Despite these clear challenges, proposals for terraforming Mars into a world suitable for long-term human habitation abound. Mars is further from the Sun than Earth, so it would require significantly more greenhouse gases to achieve a temperature similar to Earth's. Thickening the atmosphere by releasing CO_2 in the Martian surface is the most popular 'solution' to the thin atmosphere on Mars. However, every suggested method of releasing the carbon stored in Mars requires technology and resources far beyond what we are currently capable of. What's more, a recent NASA study determined that there isn't even enough CO_2 on Mars to warm it sufficiently.

Even if we could find enough CO_2, we would still be left with an atmosphere we couldn't breathe. Earth's atmosphere contains only 0.04 per cent CO_2, and we cannot tolerate an atmosphere high in CO_2. For an atmosphere with Earth's atmospheric pressure, CO_2 levels as high as 1 per cent can cause drowsiness in humans, and once we reach levels of 10 per cent CO_2, we will suffocate even if there is abundant oxygen. The proposed absolute best-case scenario for terraforming Mars leaves us with an atmosphere we are incapable of breathing; and achieving it is well beyond our current technological and economic capabilities.

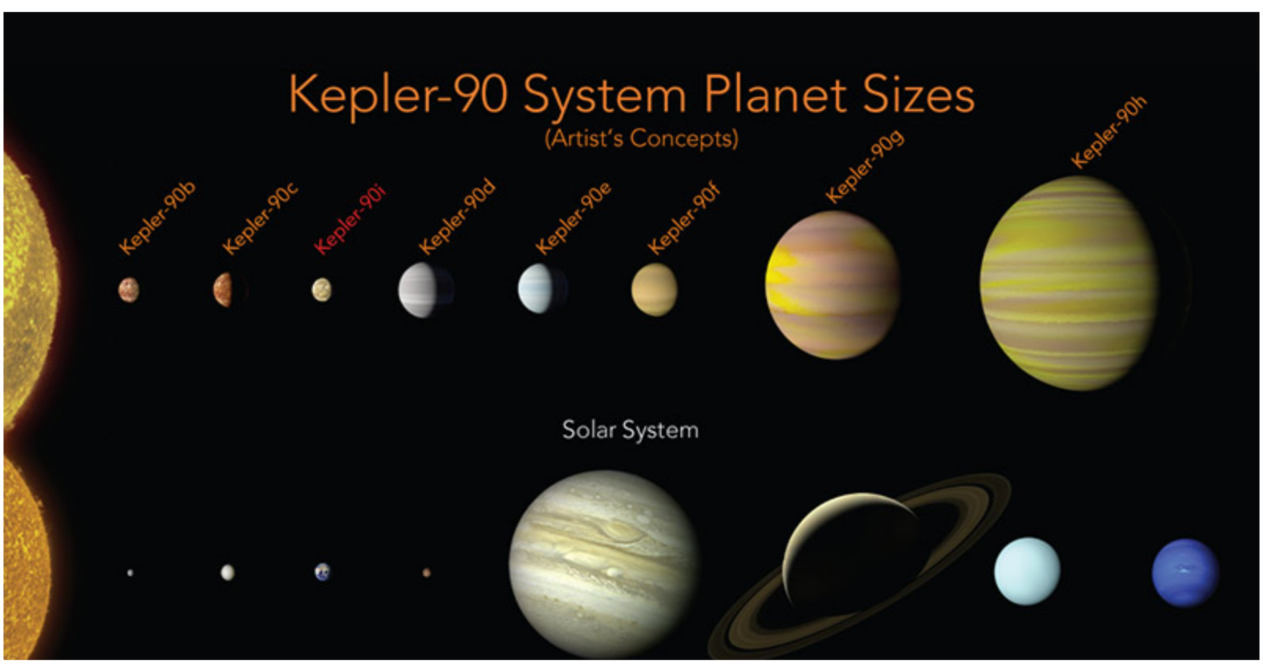
Instead of changing the atmosphere of Mars, a more realistic scenario might be to build habitat domes on its surface with internal conditions suitable for our survival. However, there would be a large pressure difference between the inside of the habitat and the outside atmosphere. Any breach in the habitat would rapidly lead to depressurisation as the breathable air escapes into the thin Martian atmosphere. Any humans living on Mars would have to be on constant high alert for any damage to their building structures, and suffocation would be a daily threat.

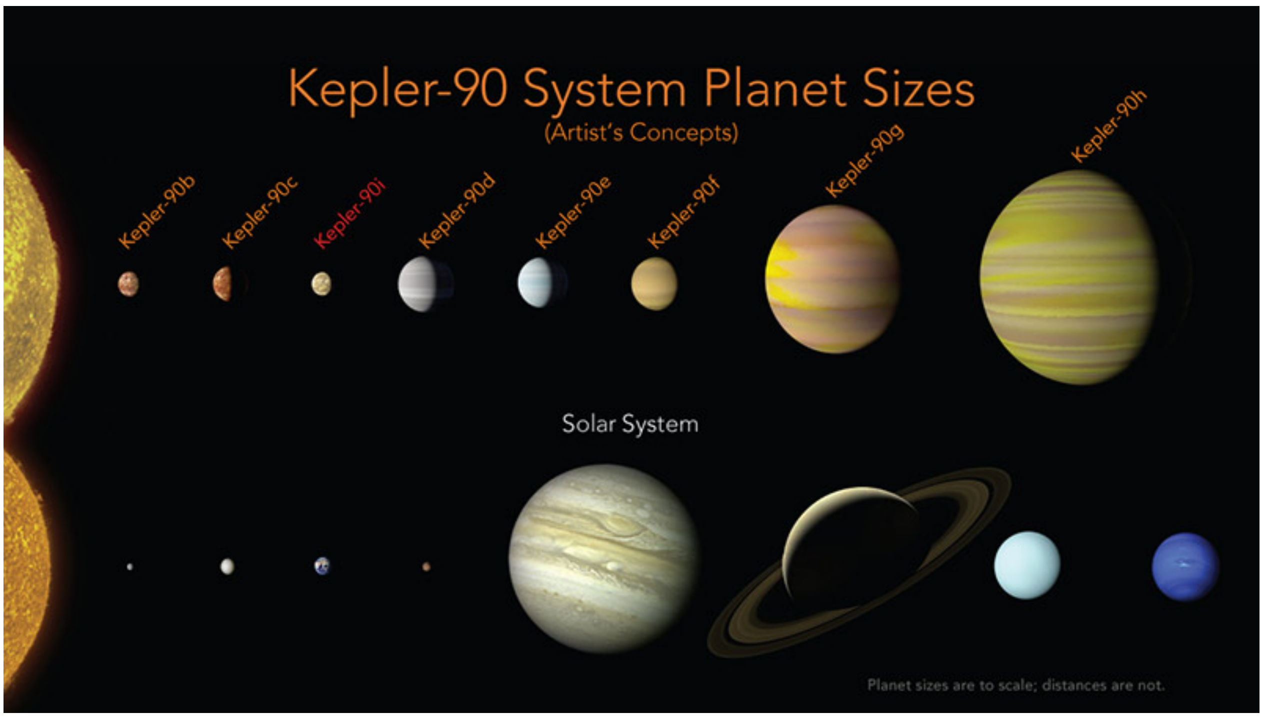
From an astronomical perspective, Mars is Earth's twin; and yet, it would take vast resources, time and effort to transform it into a world that wouldn't be capable of providing even the bare minimum of what we have on Earth.

Suggesting that another planet could become an escape from our problems on Earth suddenly seems absurd. But are we being pessimistic? Do we just need to look further afield?

Next time you are out on a clear night, look up at the stars and choose one – you are more likely than not to pick one that hosts planets. Astronomical observations today confirm our age-old suspicion that all stars have their own planetary systems. As astronomers, we call these exoplanets. What are exoplanets like? Could we make any of them our home?

The majority of exoplanets discovered to date were found by NASA's Kepler mission, which monitored the brightness of 100,000 stars over four years, looking for dips in a star's light as a planet obscures it each time it completes an orbit around it.


Kepler-90 System Planet Sizes
(Artist's Concepts)
Kepler-90b
Kepler-90c
Kepler-90i
Kepler-90d
Kepler-90e
Kepler-90f
Kepler-90g
Kepler-90h
Solar System



The solar system associated with star Kepler-90 has a similar configuration to our solar system with small planets found orbiting close to their star, and the larger planets found farther away. Courtesy NASA/Ames /Wendy Stenzel

Kepler observed more than 900 Earth-sized planets with a radius up to 1.25 times that of our world. These planets could be rocky (for the majority of them, we haven't yet determined their mass, so we can only make this inference based on empirical relations between planetary mass and radius). Of these 900 or so Earth-sized planets, 23 are in the habitable zone. The habitable zone is the range of orbits around a star where a planet can be considered *temperate*: the planet's surface can support liquid water (provided there is sufficient atmospheric pressure), a key ingredient of life as we know it. The concept of the habitable zone is very useful because it depends on just two astrophysical parameters that are relatively easy to measure: the distance of the planet to its parent star, and the star's temperature. It's worth keeping in mind that the astronomical habitable zone is a very simple concept and, in reality, there are many more factors at play in the emergence of life; for example, this concept does not consider plate tectonics, which are thought to be crucial to sustain life on Earth.

> Planets with similar observable properties to Earth are very common: at least one in 10 stars hosts them

How many Earth-sized, temperate planets are there in our galaxy? Since we have discovered only a handful of these planets so far, it is still quite difficult to estimate their number. Current estimates of the frequency of Earth-sized planets rely on extrapolating measured occurrence rates of planets that are slightly bigger and closer to their parent star, as those are easier to detect. The studies are primarily based on observations from the Kepler mission, which surveyed more than 100,000 stars in a systematic fashion. These stars are all located in a tiny portion of the entire sky; so, occurrence rate studies assume that this part of the sky is representative of the full galaxy. These are all reasonable assumptions for the back-of-the-envelope estimate that we are about to make.

Several different teams carried out their own analyses and, on average, they found that roughly one in three stars (30 per cent) hosts an Earth-sized, temperate planet. The most pessimistic studies found a rate of 9 per cent, which is about one in 10 stars, and the studies with the most optimistic results found that virtually all stars host at least one Earth-sized, temperate planet, and potentially even several of them.

At first sight, this looks like a huge range in values; but it's worth taking a step back and realising that we had absolutely no constraints whatsoever on this number just 20 years ago. Whether there are other planets similar to Earth is a question that we've been asking for millennia, and this is the very first time that we are able to answer it based on actual observations. Before the Kepler mission, we had no idea whether we would find Earth-sized, temperate planets around one in 10, or one in a million stars. Now we know that planets with similar observable properties to Earth are very common: at least one in 10 stars hosts these kinds of planets.

An artist's concept shows exoplanet Kepler-1649c orbiting around its host red dwarf star. Courttesy NASA/Ames

Let's now use these numbers to predict the number of Earth-sized, temperate planets in our entire galaxy. For this, let's take the average estimate of 30 per cent, or roughly one in three stars. Our galaxy hosts approximately 300 billion stars, which adds up to 90 billion roughly Earth-sized, roughly temperate planets. This is a huge number, and it can be very tempting to think that at least one of these is bound to look exactly like Earth.

One issue to consider is that other worlds are at unimaginable distances from us. Our neighbour Mars is on average 225 million kilometres (about 140 million miles) away. Imagine a team of astronauts travelling in a vehicle similar to NASA's robotic New Horizons probe, one of humankind's fastest spacecrafts – which flew by Pluto in 2015. With New Horizons' top speed of around 58,000 kph, it would take at least 162 days to reach Mars. Beyond our solar system, the closest star to us is Proxima Centauri, at a distance of 40 trillion kilometres. Going in the same space vehicle, it would take our astronaut crew 79,000 years to reach planets that might exist around our nearest stellar neighbour.

Still, let's for a moment optimistically imagine that we find a perfect Earth twin: a planet that really is exactly like Earth. Let's imagine that some futuristic form of technology exists, ready to whisk us away to this new paradise. Keen to explore our new home, we eagerly board our rocket, but on landing we soon feel uneasy. Where is the land? Why is the ocean green and not blue? Why is the sky orange and thick with haze? Why are our instruments detecting no oxygen in the atmosphere? Was this not supposed to be a perfect twin of Earth?

As it turns out, we have landed on a perfect twin of the Archean Earth, the aeon during which life first emerged on our home world. This new planet is certainly habitable: lifeforms are floating around the green, iron-rich oceans, breathing out methane that is giving the sky that unsettling hazy, orange colour. This planet sure is habitable – just not *to us*. It has a thriving biosphere with plenty of life, but not life like ours. In fact, we would have been unable to survive on Earth for around 90 per cent of its history; the oxygen-rich atmosphere that we depend on is a recent feature of our planet.

The earliest part of our planet's history, known as the Hadean aeon, begins with the formation of the Earth. Named after the Greek underworld due to our planet's fiery beginnings, the early Hadean would have been a terrible place with molten lava oceans and an atmosphere of vaporised rock. Next came the Archean aeon, beginning 4 billion years ago, when the first life on Earth flourished. But, as we just saw, the Archean would be no home for a human. The world where our earliest ancestors thrived would kill us in an instant. After the Archean came the Proterozoic, 2.5 billion years ago. In this aeon, there was land, and a more familiar blue ocean and sky. What's more, oxygen finally began to accumulate in the atmosphere. But let's not get too excited: the level of oxygen was less than 10 per cent of what we have today. The air would still have been impossible for us to breathe. This time also experienced global glaciation events known as snowball Earths, where ice covered the globe from poles to equator for millions of years at a time. Earth has spent more of its time fully frozen than the length of time that we humans have existed.

We would have been incapable of living on our planet for most of its existence

Earth's current aeon, the Phanerozoic, began only around 541 million years ago with the Cambrian explosion – a period of time when life rapidly diversified. A plethora of life including the first land plants, dinosaurs and the first flowering plants all appeared during this aeon. It is only within this aeon that our atmosphere became one that we can actually breathe. This aeon has also been characterised by multiple mass extinction events that wiped out as much as 90 per cent of all species over short periods of time. The factors that brought on such devastation are thought to be a combination of large asteroid impacts, and volcanic, chemical and climate changes occurring on Earth at the time. From the point of view of our planet, the changes leading to these mass extinctions are relatively minor. However, for lifeforms at the time, such changes shattered their world and very often led to their complete extinction.

Looking at Earth's long history, we find that we would have been incapable of living on our planet for most of its existence. Anatomically modern humans emerged less than 400,000 years ago; we have been around for less than 0.01 per cent of the Earth's story. The only reason we find Earth habitable now is because of the vast and diverse biosphere that has for hundreds of millions of years evolved with and shaped our planet into the home we know today. Our continued survival depends on the continuation of Earth's present state without any nasty bumps along the way. We are complex lifeforms with complex needs. We are entirely dependent on other organisms for all our food and the very air we breathe. The collapse of Earth's ecosystems *is* the collapse of our life-support systems. Replicating everything Earth offers us on another planet, on timescales of a few human lifespans, is simply impossible.

Some argue that we need to colonise other planets to ensure the future of the human race. In 5 billion years, our Sun, a middle-aged star, will become a red giant, expanding in size and possibly engulfing Earth. In 1 billion years, the gradual warming of our Sun is predicted to cause Earth's oceans to boil away. While this certainly sounds worrying, 1 billion years is a long, long time. A billion years ago, Earth's landmasses formed the supercontinent Rodinia, and life on

Earth consisted in single-celled and small multicellular organisms. No plants or animals yet existed. The oldest *Homo sapiens* remains date from 315,000 years ago, and until 12,000 years ago all humans lived as hunter-gatherers.

The industrial revolution happened less than 500 years ago. Since then, human activity in burning fossil fuels has been rapidly changing the climate, threatening human lives and damaging ecosystems across the globe. Without rapid action, human-caused climate change is predicted to have devastating global consequences within the next 50 years. This is the looming crisis that humanity must focus on. If we can't learn to work within the planetary system that we evolved with, how do we ever hope to replicate these deep processes on another planet? Considering how different human civilisations are today from even 5,000 years ago, worrying about a problem that humans may have to tackle in a billion years is simply absurd. It would be far simpler to go back in time and ask the ancient Egyptians to invent the internet there and then. It's also worth considering that many of the attitudes towards space colonisation are worryingly close to the same exploitative attitudes that have led us to the climate crisis we now face.

Earth is the home we know and love not because it is Earth-sized and temperate. No, we call this planet our home thanks to its billion-year-old relationship with life. Just as people are shaped not only by their genetics, but by their culture and relationships with others, planets are shaped by the living organisms that emerge and thrive on them. Over time, Earth has been dramatically transformed by life into a world where we, humans, can prosper. The relationship works both ways: while life shapes its planet, the planet shapes its life. Present-day Earth is our life-support system, and we cannot live without it.

While Earth is currently our only example of a living planet, it is now within our technological reach to potentially find signs of life on other worlds. In the coming decades, we will likely answer the age-old question: are we alone in the Universe? Finding evidence for alien life promises to shake the foundations of our understanding of our own place in the cosmos. But finding alien life does not mean finding another planet that we can move to. Just as life on Earth has evolved with our planet over billions of years, forming a deep, unique relationship that makes the world we see today, any alien life on a distant planet will have a similarly deep and unique bond with its own planet. We can't expect to be able to crash the party and find a warm welcome.

Living on a warming Earth presents many challenges. But these pale in comparison with the challenges of converting Mars, or any other planet, into a viable alternative. Scientists study Mars and other planets to better understand how Earth and life formed and evolved, and how they shape each other. We look to worlds beyond our horizons to better understand ourselves. In searching the Universe, we are *not* looking for an escape to our problems: Earth is our unique and only home in the cosmos. *There is no planet B.*

aeon.co 16 January 2023