10 A species with a future and a past

Everything changes and nothing remains still … you cannot step twice into the same stream.

Greek philosopher Heraclitus, quoted in Plato's *Cratylus*

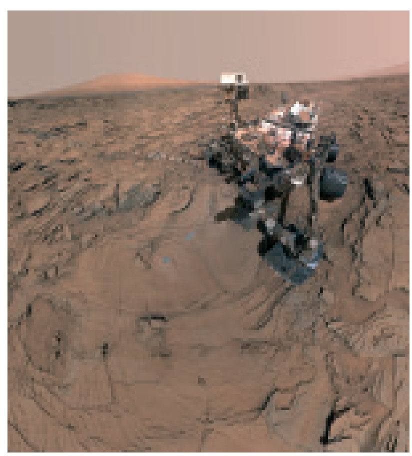
How surprised should we be that a species such as ours evolved and has recently been so successful in its proliferation and cultural evolution? We know it happened once, but do past trends and patterns imply we were an inevitable outcome of evolution or simply an incredibly fortuitous one? If all the alternative possible outcomes to each event considered necessary for our arrival since the big bang are added up, then our being here would appear nothing short of miraculous. Or was a world – not identical but perhaps largely similar to our own – bound to come about eventually once the first self-replicating molecule emerged and evolved into ever more diverse and complex life forms?

However it happened that the specific sequence of events played out over time, we know that Earth and the many life forms it has harboured have had a singular, unique history. But the actual sequence of events was just one of many possible histories. History is full of contingencies, the infinite alternative scenarios that never happened. If any of the major events chronicled here did not take place, would we find ourselves where we are today? What if gravitational waves associated with the inflationary flash in the first fraction of a second into the big bang had not initiated variations in density that would ultimately lead to galaxies full of stars? If matter had expanded uniformly rather than in clumps, then there would have been no stars, and no elements heavier than hydrogen and helium necessary for life. If among the many species of mammal-like reptiles none had managed to survive the end-Permian mass extinction, would mammals live today? If the end-Cretaceous meteorite had never struck Earth, would the dinosaurs still rule the world? Rewind the tape of life back to any point in the past and let it run from that point forward again: the sequence of contingencies would undoubtedly result in a history different from the one that actually played out, but how different?

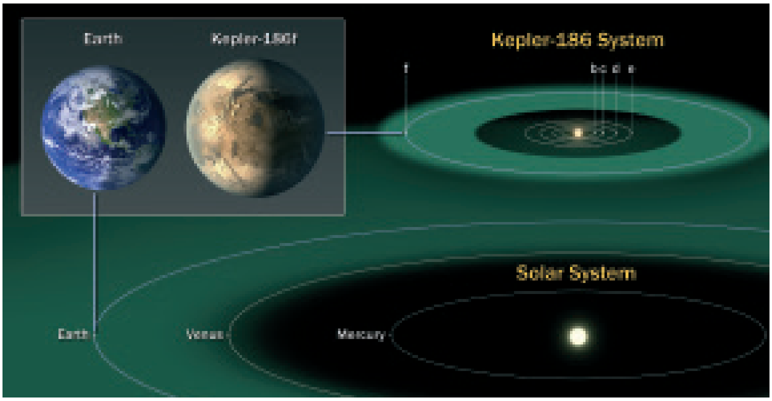
Inevitable or lucky?

We have no other universes to compare, but if others do exist it seems likely that they too would have their mass organised into burning stars swirling about galaxies – gravitational waves being a physical outcome of how big bangs everywhere unfold. If no mammal-like reptiles had survived the end-Permian mass extinction, then it is likely that something resembling a mammal would eventually evolve because mammals have many beneficial traits distinct from those of reptiles. And if not by the end-Cretaceous, then at some point a catastrophe of sufficient magnitude would have wiped out the vulnerably large dinosaurs. Thus, it is possible that our arrival would have occurred only much later than it did. But it is equally possible that we may have appeared much earlier if, for example, mammals had been more successful than reptiles in the aftermath of the end-Permian mass extinction, rather than having to wait for the meteorite that wiped out the dinosaurs at the end of the Cretaceous. The evolution of life was derailed or reset by numerous major mass-extinction calamities in the past, but the trend to increasingly diverse and complex life forms appears to be irreversible. No question luck played a role in who survived and who didn't, but given a planet like Earth, the fossil record appears to indicate that it is highly probable, if not inevitable, that diverse, complex life would evolve eventually.

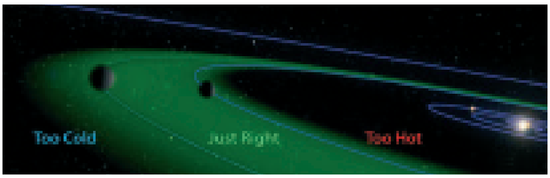
If the evolution of life were inevitable and irreversible, then life should exist elsewhere on planets similar to our own. NASA's Curiosity Mars rover has documented ancient deposits formed by running water, but has yet to reveal definitive evidence that anything ever lived on Mars. There are 200 billion stars in our galaxy, and planets (exoplanets) are



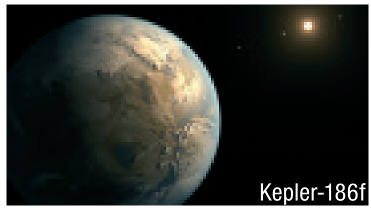
Selfie of NASA's Curiosity Mars rover



Like Earth, the planet Kepler-186f orbits within the 'habitable zone' (green band) of a star half the size of our Sun 500 light years away, but does it have life? (artist's interpretation of Kepler-186f below)



Habitable zone

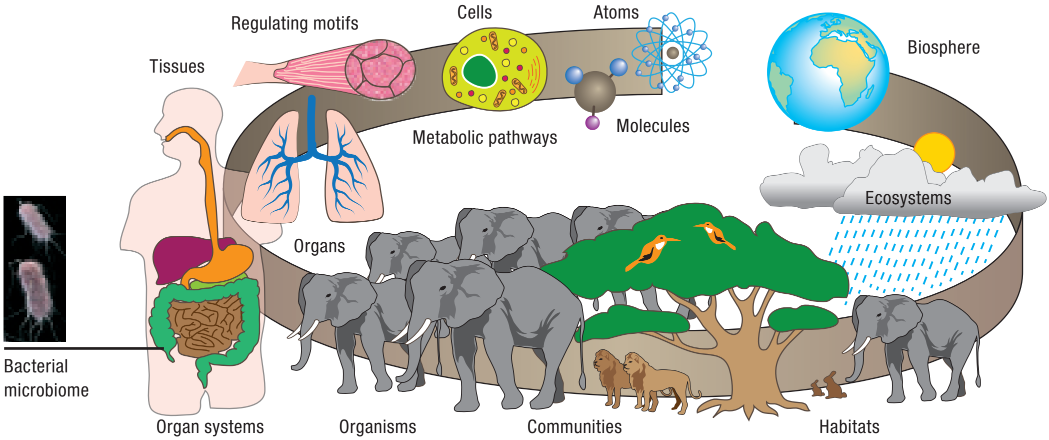


Kepler-186f

increasingly being detected in orbits around some of these stars. Many of these newly discovered solar systems appear to be unlike ours in many respects. However, as in our solar system, most exoplanets probably don't harbour life because they orbit outside of the 'habitable zone', the band about a star where liquid water can exist. However, many planets beyond the thousands so far detected undoubtedly exist that, like Earth, have oceans of water in which life may have evolved under the similar long-term influence of volcanism – including submarine hydrothermal vents – and episodic meteorite impacts. Of course, many such planets may have life forms that have yet to evolve beyond the equivalent of simple bacteria, even after the passage of billions of years.

NASA's Curiosity Mars rover is actively searching for chemical clues that life exists on Mars or did at some earlier time when water flowed freely over its surface, and Earth-bound radio telescopes listen for evidence that we are not alone. However, the fact that it took Earth 4 billion years to evolve a life form capable of trying to make contact suggests that if life does exist elsewhere, it is unlikely to respond. In addition, it is unknown how long life forms capable of searching and responding exist before they become extinct; we've only been actively searching for several decades. Given that it may be a while before we can confirm life's existence elsewhere, we can look to Earth's fossil record to inform us about the inevitability of our species.

A radio telescope listening for evidence of extraterrestrial life



Life's complexity

Stepping back and canvassing the fossil record of life on Earth, we can see that one trend clearly stands out: since the earliest evidence of life 3.7 billion years ago, life on Earth, its biosphere, has evolved into ever more abundant, diverse and interconnected forms. Earth's biosphere today is home to millions of species of every description, from microscopic single-celled bacteria to 100-ton blue whales. Although the rate was far from steady, life over time has not only become more abundant in terms of the total mass of living organisms on Earth and more diverse in terms of the number of different life forms (species), but has also become more complex. The increase in complexity is reflected both in the organisms themselves and in the myriad ways in which these ever more abundant and diverse life forms interface with their habitats (ecosystems) and interact with each other. It is important, however, not to confound life's increasing diversity and complexity with our notions of progress. All organisms are interdependent to some degree, and among the many diverse species, including multicellular organisms such as us with highly complex brains, none is 'better' or 'more evolved' than the others. The multitudes of species of bacteria we harbour are essential to our well-being, and most will carry on long after we as a species have become extinct.

We are perhaps accustomed to thinking of the evolution of life in terms of the constant struggle to survive 'red in tooth and claw'. But evolution is as much about cooperation as it is about competition. In the proposed origin of life, it is RNA and eventually DNA that proved to be the most successful among self-replicating molecules. Relatively simple prokaryote bacteria through cooperation (endosymbiosis) evolved organelles, and their loosely packaged DNA became tightly wound within a nucleus of the more complex eukaryote cells. Eukaryote cells then joined together, forming multicellular organisms whose many cells became highly differentiated

Earth's complex biosphere spans from the inner workings of cells to the many distinct ecosystems, each including diverse organisms having myriad interactions with one another and with their environment