Chapter 7
Life in Our Universe

B. Moore, *Elephants in Space*, Astronomers' Universe,
DOI 10.1007/978-3-319-05672-2_7,

After Berkeley I went to Seattle to start my second postdoctoral research position. The goal of my work for the next two years being to simulate the universe using a supercomputer. Seattle is the coffee and grunge capital of the world and my new colleagues laughed at my jar of instant coffee, but at least their music was good. Our enclosed suite of offices in the astronomy building had a wide range of uses at night, from multiplayer "Doom" tournaments to a climbing gym. The challenges ranged from who could hang the longest from their fingertips from the top of the narrow door frame, to circumnavigating the offices without touching the floor. Many late nights were spent in the underground College Inn pub next to the university, together with my good friend and colleague, Joachim Stadel. We played pool and darts and discussed topics from aliens and evolution to the origin of the Earth and the meaning of life. Today we are still working on some of those inspiring early ideas...

Surrounded by snowy mountains and steep volcanoes that Joachim and I loved to climb, we thought it appropriate to learn to snowboard, a much faster way down them than the usual hiking. We rented snowboards and set off after work to Stevens Pass, driving in my old beat-up American car that was like driving a tank crossed with a boat albeit with the addition of wheels. We took the chairlift to the very top of the mountain where the only means of descent was via a single steep black run—aptly named double-black diamond—the most difficult on the mountain. We had never snowboarded before but our strategy, formulated the night before at the pub, was clear and logical at the time of concept. We had concluded that if we made it down the hardest run, everything else would seem easy and we could progress quickly. Since there was no other way off the top of the mountain, we would not be able to back out and take an easier route down. We usually followed through on those ideas that somehow seem illogical when faced with the stark reality. It was snowing heavily as we walked over to the start of the descent and peered over the edge of a cliff. "Looks kind of steep, don't you think?" said Joachim. It appeared almost vertical. "No, I'm sure it's not so bad. But you go first," I replied—the snow was deep and soft so at the worst it would be a spectacular tumble and slide down to the bottom. Joachim was an expert skier, but snowboarding was new to him too. I wanted to watch his mistakes and hopefully avoid what I saw as an inevitable consequence of learning to snowboard the hard way. He set off and indeed immediately crashed and began the long but rapid descent to the bottom of the slope, upside down, on his back and head over heels. It was a spectacular show, like an out-of-control gymnastics display by an irregularly shaped snowball. I looked on scared at the top, knowing I had the same fate in store. The journey home was as memorable as the night's accomplishments. Our plan had worked. We had progressed well and were the last to leave the mountain. It snows a lot in the North Cascade mountains: Over the course of a year more than a hundred metres of snow can fall there, and that night was no exception. One problem with the beat-up old car was that the heater never seemed to work, and this night the windscreen wipers had given up too. It was below –15 degrees centigrade outside, and Joachim hung out of the window with a snow scraper in one hand and a can of antifreeze in the other to keep the windscreen defrosted and clear. The car made several 360 degree spins on the icy road while we careered on our way back to Seattle.

Life is fun, but dangerous!

Our galaxy appears devoid of life elsewhere, even though it may contain a billion stars with their own planetary systems possibly similar to our own solar system. As Carl Sagan wrote, "Absence of evidence is not evidence of absence." In fact, I would be shocked to learn that our solar system was the only place in the galaxy where intelligent life had developed. The Earth is already rather crowded, and it is in our nature to want to explore—indeed, there is no reason why our descendants should not spread throughout the galaxy to form a hyper-civilisation. In the next chapter I will explain how the Sun evolves in time, and although it has maintained conditions on Earth for over four billion years that are ideal for life to flourish, in a shorter timescale this will no longer be the case.

We have the necessary scientific and engineering knowledge to begin this exploration of our galaxy now. We could create a global population that would dwarf our tiny home called Earth, becoming something akin to how an ant or bee colony works: colonising the surrounding land by sending out teams of explorers until all the available space has been filled. Today we are concerned with our global ecosystem on Earth as we watch our energy requirements escalate and see the negative impact of our industrial activities. If we can survive this era and continue to progress as a species, within ten million years we could have filled the galaxy with life. In a further ten billion years we may be concerned about our global cosmic ecosystem as we watch our galactic energy reserves start to decline.

Life in the Solar System

Humans, like all life forms on the surface of the Earth, depend on the Sun for energy, air and food. Plants convert sunlight, carbon dioxide and water into organic carbon-based compounds such as sugars, producing oxygen as a by-product. The planet Earth is indeed a global ecosystem with a vast diversity of living things with their complex interdependencies. Sometimes, just the loss of one species can have a major impact across the planet over many levels of the food chain. Since life on Earth is so dependent on the Sun, we look for life elsewhere in similar environments, but perhaps life can also exist independent of a star. Life on Earth has adapted to very extreme conditions, some even existing on energy not derived from sunlight. Quite recently, "extremophilic" life forms have been discovered living in some of the most hostile environments on our planet.

The surface of the Earth is a thin crust of rock that is cracked in many places. The enormous broken pieces—the tectonic plates which roughly define our continents—jostle each other as they are pushed this way and that by the hot molten rock on which they float. As they slowly slip and slide past each other over timescales of millions of years, they cause earthquakes and create mountain ranges. The San Andreas Fault, which stretches through part of California, moves at a rate of about 3 centimetres a year, so that in about 20 million years San Francisco will be next to Los Angeles. Sometimes the plate boundaries lie deep under the ocean, such as the 10,000-kilometre-long Mid-Atlantic Ridge, where the North and South American plates move apart from the Eurasian and African plates. As they slowly separate, lava flows out of the crack, creating new subterranean land. Sometimes seawater flows into the cracks and re-emerges from hydrothermal vents superheated to temperatures much higher than the usual boiling point of water.

A fascinating discovery was made during the 1980s: Entire communities of life were found to exist around these vents at the bottom of the ocean, well away from sunlight, which does not penetrate to these depths. It is not just unicellular microbial life that can thrive within extreme environments. Two-metre-long bright-red wormlike creatures were found at the bottom of the ocean living alongside the hydrothermal vents. It was a mystery how these "tube worms" sustained themselves since they do not have mouths or digestive systems. The puzzle of how they survived was solved by Colleen Cavanaugh, who found that these creatures owe their existence to chemosynthesis. Their bodies are filled with billions of sulphur-oxidising bacteria which convert carbon dioxide, hydrogen sulphide and oxygen into organic matter, providing the giant worms' bodies directly with all the food that they need. It is a true symbiotic relationship—half of the worm's body weight is living bacteria!

The environment is extreme; thousands of metres below the surface of the sea the water temperature is usually just above freezing point, but around the deep ocean cracks it can be heated to above four hundred degrees centigrade. The pressure from the weight of the water is intense, three hundred times as high as we feel on the Earth's surface, which prevents the water from turning into steam. Many of the life forms in this environment are anaerobic, existing without oxygen, just like early life on Earth. The source of energy and elements for this process comes from the hydrothermal vents. Some types of bacteria even use the dim glow of the lava as the light energy that they need for photosynthesis. Another unique evolutionary strand recently found in this environment is the "scaly-foot gastropod", the only living creature known to have processed iron and pyrite into its skeletal structure. Its armour-plated foot has been investigated by the US military as part of their research into exoskeletal armour.

Perhaps most remarkable for their ability to survive the harshest of conditions are tardigrades, commonly known as water bears. They are microscopic water-dwelling eight-legged creatures about a millimetre long. When they walk, they swagger like bears, hence the name. Over one thousand species of tardigrades have been identified. They are found all over the world, from the Himalayan mountain tops over six thousand metres above sea level to a depth of four thousand metres under the surface of our oceans. Despite their name, these creatures can survive for at least 10 years without any water. They can live through temperatures as cold as −270 degrees centigrade or, at the other extreme, in water that is superheated to 150 degrees centigrade. In 2007 a colony of tardigrades was taken on a space satellite and exposed to the vacuum of space and the intense solar radiation from which we are protected by our atmosphere. After 10 days, on return to Earth, most had survived and laid eggs that hatched apparently normally.

Basic life forms can even survive deep within the Earth itself. In 2010 scientists exploring a South African gold mine two miles underground discovered an isolated self-sustaining bacterial community. Its energy derives from radioactivity. The bacteria depend on geologically produced sulphur and hydrogen for food—one of the few ecosystems found on Earth that does not depend on energy from the Sun. The hydrogen necessary for their survival originates from ancient water deposits and is liberated from the water by the radioactive decay of the elements of uranium, thorium and potassium in the surrounding rocks. These bacteria have been cut off from the surface of the Earth for millions of years. When they are exposed to our oxygen-rich atmosphere, they die.

Knowledge of such life forms that can withstand extreme conditions is very new. There are bound to be more discoveries over the coming years. It is incredible that life could evolve under the harsh early conditions on Earth with its constant bombardment by space rocks and fluctuating climate. It is also fascinating that life, even as we know it, can withstand a great range of conditions and can survive on very unique sources of energy. It is thus not so farfetched to think that bacteria and perhaps even tardigrades could travel through the solar system, immigrants on a space rock that was once ejected via a giant impact which sent debris into space. It is possible that life on Earth originated on Mars—we know that Mars had abundant water on its surface in the past and we know that some rocky pieces of Mars have landed on Earth. However, life is not going to make it to another star this way since the journey would take millions of years at the speeds at which asteroids travel and the chance of a fragment landing on another planet orbiting a distant star is negligible.

One of the biggest dangers to astronauts and life in space are cosmic rays—ultra-high-energy particles that fill our galaxy. They are charged particles, such as protons and helium nuclei, which are thought to gain their energies from inside the expanding shock fronts of supernovae remnants. When a star explodes, its debris expands into the interstellar medium close to the speed of light and carries a magnetic field which acts like a giant cosmic particle accelerator. The highest-energy cosmic rays are travelling very close to the speed of light and have energies that are up to ten million times higher than the protons inside the LHC beam tunnel! That is quite something: A single subatomic particle with an energy equivalent to the record-breaking 161-kilometre-per-hour cricket ball bowled by Shoaib Akhtar of Pakistan against England during the 2003 World Cup. If that single proton had collided with you, it might have knocked you over!

Cosmic rays fill our galaxy and are continuously striking the Earth at a rate of about one per square centimetre each second. Luckily, our atmosphere does a remarkably good job at shielding us from these particles—the cosmic rays collide with the molecules of air which prevent most from reaching the ground. Our atmosphere is a small coating on the surface of the planet—its density and pressure drop the further out one travels such that 99 percent of the air is below an altitude of 30 kilometres. When you fly in a commercial airplane at an altitude of 10,000 metres, the density of the air is one third that at sea level and the shielding effects from cosmic rays are much weaker. For each flight you take, you receive damage equivalent to what you would get from a chest x-ray, the same as a person on the ground receives over an entire year from the cosmic rays that penetrate our atmosphere. Cosmic rays are a serious threat to space travel since they not only damage biological life by destroying cells but also affect electronics by damaging their transistors and changing the charges stored in computer memory units.

There is another interesting location in our solar system that should be explored for new life forms—Enceladus, the beautiful blue/white satellite moon of Saturn. It measures only five hundred kilometres across. It should be frozen solid at this distance from the Sun, yet its interior is kept warm by a combination of heating from radioactive decays and from the gravitational field of Saturn, which continuously squeezes its moon. When the Cassini spacecraft passed by Saturn, it was manoeuvred to fly just 50 kilometres above Enceladus and captured images of enormous geysers of water erupting from the cracks on its icy surface. Moreover, organic compounds, such as methane and carbon dioxide, were detected in the water. Perhaps the interior oceans of Enceladus are filled with life, which would raise the fascinating question of whether its DNA structure is the same as life on Earth, or whether it evolved completely separately. If life has developed within its oceans, the only light will be a very dim glow of heat from the water which would radiate photons at radio frequencies. Creatures there may have evolved large radio antennae as eyes! We may even find life that is not carbon based. These would indeed be major discoveries.

Life Beyond Our Solar System

Life on Earth has evolved into numerous co-existing species: over 5,000 species of mammals; 10,000 of birds; 30,000 of fish; 1 million of insects and plants; and 10 million of bacteria. All of this happened within four billion years. The evolutionary steps from fish to apes took place in just the last half a billion years, whereas the steps from apes to humans took just three million years. It is the only example that we have of an evolutionary timescale, but it is an example. Half of the stars in our galaxy are older than 5 billion years, and some are 12 billion years old. Surely our galaxy must be filled with life at different stages of evolution. Just imagine for a moment how advanced life could be if it developed for a billion years beyond us. The capabilities of a future advanced and highly evolved civilisation, be it our own, or alien life on a distant planet, are probably beyond our imagination.

In 1995 the Swiss astronomer Michel Mayor discovered a planet orbiting the solar-like star 51 Pegasi which lies many light years from the Sun. Astronomers are now routinely finding and characterising these so called extra-solar planetary systems, many stars even having multiple planets orbiting them. It is hard to see the planets directly since they are so much fainter than the stars around which they orbit, but we can detect them and measure their properties in several ways. Just as a planet orbits the Sun because of gravity, the Sun also moves in a regular periodic way owing to the gravitational attraction of its planets. These small wobbles of stars can be observed, and the period and strength can be used to determine the mass of the planet and to measure how far it is from the star it orbits. Another planetary detection technique uses the fact that the brightness of the star decreases if a planet passes directly in front of it in our line of sight. By monitoring the change in brightness over many days, we can characterise the orbit of the planet and measure its size. The Kepler space telescope has been doing just this. It has discovered numerous new extra-solar planets at a rate consistent with most stars hosting planets in our galaxy. Detecting Earth-like planets, characterising their atmospheres and compositions to detect the bio-signatures of existing life is one of the most fascinating research topics today.

An “Earth-like” habitable planet broadly describes a mostly rocky planet, large enough to hold an atmosphere, close enough to its star so as not to be continually frozen but not too close such that water would boil from its surface. The other class of planets is the larger “gas giants” like Saturn and Jupiter, which are mainly hydrogen. These are in a sense failed stars since they never became massive enough for their internal temperatures to ignite the process of nuclear fusion. Our computer simulations showed that habitable Earth-like planets should be very common.

Understanding how life emerged is a fascinating problem to study, and in principle easier than trying to understand what happened during the first millionth of a second of our universe. It is easier to answer because life has evolved according to laws of physics and rules of chemistry that we know and understand very well. The instant after time began, our known physics fails. So we are in a much worse position to achieve an understanding of the origin of our universe. The “primordial mud soup” from which life crawled is very different from the “primordial fireball soup” of the early universe. Because we have good ideas as to how life developed, they can be tested through laboratory experiments and computer simulations.

Water on Earth is filled with molecules. They move around bumping this way and that, colliding with each other and sometimes sticking together because of the electromagnetic force. The tendency for molecules to organise themselves into complex configurations is the starting point for the origin of life. Perhaps the first reproductive molecules formed near the oceans’ volcanic vents, which in turn led to complex structures such as ribonucleic acid. These were followed by prokaryotic single-celled life that underwent generations of mutations and natural selection until we reached the stage of computation—the brain. This is indeed an amazing series of events. And although we do not understand these early steps in great detail, they are certainly possible given the timescales, boundaries and behaviour of the laws of nature.

Life managed to evolve on Earth. There is no reason why it should not have occurred elsewhere in our galaxy. If just one of those distant planets developed life akin to humans, with the desire or need to leave their planet, they could already have filled the galaxy with life.

We have the technology today to begin to design and construct spaceships that could take a breeding population of humans to nearby stars. It represents a major project that would take the cooperation of many countries from across the world. The financial cost is huge but less than the global expenditure on war. Within just a few hundred years we would be ready to begin the ultimate era of human exploration—that of our entire galaxy. Let us send several pioneering craft in different directions and to the closest stars that we will have already determined to have habitable planets with atmospheres not too unlike our own.

On arrival they could begin building a new civilisation. They would not have to reinvent everything; they could take their knowledge and tools with them to quickly establish their societies and cities. If each spaceship were to take one hundred pairs of humans, it would only take about 15 generations to reach a million people on their new planets. And they would begin their colonisation with all the knowledge about science and medicine that we now have. As these colonies develop, they can still communicate with Earth, learning about new developments as they grow. It would not be like a video conference though, since it would take 10 years for a message to be exchanged with the closest stars. The Earth would broadcast a continuous stream of information to the new colony. Within a thousand years these first explorers would have built up the resources and infrastructure to each construct and send several new spacecraft in new directions, to continue the process of populating the galaxy.

A wave of colonies would spread outwards from Earth and begin to fill the galaxy with life at a rate which would depend on the speed of the spaceships that we could construct. The typical distance between the stars is about five light years, and the galaxy is two hundred thousand light years across. If we could build spacecraft that could travel at 10 percent of the speed of light, the average journey between stars would take 50 years, which is within the lifetime of the astronauts. Adding in the time to colonise each planet, we could literally populate the galaxy within ten million years. That seems like a very long time, and it is for our short lives. But to a species, it is just better than average survival rates. A million years is a small period of time in terms of geological and evolutionary events, let alone the enormous cosmological timescale—billions of years—in which stars live. On our 24-hour universal day the project would be accomplished within one minute after midnight.

What is the reward for such an effort? Imagine our descendants witnessing the landing of these spacecraft, the first footsteps on new worlds. When Apollo astronauts landed on the Moon, the world watched transfixed, proud of the achievement. The entire planet felt part of a united purpose and could do so again. As we optimise and design these giant craft, with their self-sustaining ecosystems, we will advance the state of knowledge on Earth. The spin-offs of such an investment cannot be predicted in advance; perhaps we would learn to control nuclear fusion as a means of flight energy, thus giving our planet a limitless resource of clean energy. Eventually, if our species wishes to continue to exist, we will have to leave the planet—the climate on Earth has been suitable for life to develop for billions of years, yet even the Earth will not last forever. Already, 80 percent of its life span as a habitable planet has passed. As we shall see later, the conditions on Earth are slowly becoming less hospitable for the hosting of life.

The Fermi Paradox

If we could begin to colonise the galaxy now, and it would take less than ten million years to complete, could it have already happened? If so, why is the galaxy not obviously full of superintelligent life? Humans did not arrive here in spaceships; we clearly evolved on this planet. Life today is genetically linked to the life that existed on Earth a million years ago. We know this through the study of plants and insects preserved in ancient ice at the bottom of glaciers. Of course, it is possible that the bacteria-like seeds of life were transported here by an advanced civilisation several billion years ago—their means of transport no longer visible, buried like a fossil deep inside rocky strata.

Why are there no signs of life in our galaxy? This is a paradox that has puzzled many people, most notably the physicist Enrico Fermi in 1950. There is no compelling evidence that alien life forms have ever visited us, nor do we see any sign of other life as we peer out into the cosmos.

In 1959 American astronomer Frank Drake wrote his famous equation describing the probability of life existing elsewhere in our galaxy. A year later he searched for alien signals by observing two nearby stars in the radio wave part of the electromagnetic spectrum. Various SETI (Search for Extra Terrestrial Intelligence) projects are taking place using some of the world's large telescopes to monitor many of neighbouring stars. The projects look for signals deemed "intelligent" by searching through the electromagnetic spectrum, looking for non-random complex behaviour, in the same way you search for a desired radio station. Turning the tuning dial scans the small part of the electromagnetic spectrum in the radio wavelengths (spanning about 10 centimetres–10 metres), amplifying the signals from stations.

The lowest-energy photons we can measure are very long radio waves that penetrate through the ocean and are used to communicate with submarines—wavelengths of three thousand kilometres which are broadcast from two large ground stations, one Russian and the other American. The submarines can receive the signals but cannot transmit anything back since the transmission antennae are many tens of kilometres across. The highest-energy photons are gamma-ray photons, which can arise from nuclear fusion or radioactive decay. They have wavelengths less than a few picometres, which is smaller than the size of an atom. So far, the SETI searches have revealed nothing.

Intelligent beings living on distant planets could also be looking for signs of life among their neighbours. If they were just a little more advanced than us, they could have known for over a billion years that our own planet most likely hosted some forms of life. The signatures of life on Earth are present in the abundance of numerous organic molecules in our atmosphere, which could be imaged by a remote alien species and analysed for detailed composition. For two billion years of our history on Earth, this was all the evidence that could be learned from far away. In the last 80 years we began broadcasting radio and TV signals in the radio and microwave bands. These signals leave Earth in all directions and have already filled a sphere with a radius of 80 light years. Within this distance are over one thousand stars that have received our broadcasts and aliens may have already dispatched a high-speed spacecraft to pay us a visit. If they are advanced enough to use nuclear or antimatter propulsion, they could reach the Earth anytime soon. Let us hope they are friendly and, after watching us develop our primitive nuclear weapons, have not come to wipe us out before we become more advanced. Our electromagnetic signals spread outwards into the galaxy at the speed of light. In 1,000 years, potential knowledge of our presence will have reached over 100 million stars.

In 1974 we not only listened for messages, but we broadcast an extremely powerful 3-minute radio message towards a star cluster that contains one million stars 25,000 light years away. It was transmitted using the giant three-hundred-metre Arecibo radio telescope that is usually used to map the structure of our galaxy. The encoded message contained some of our basic knowledge about atoms, DNA, a map of the solar system and more. We expect no reply for another 50,000 years though, which is how long it would take before a message could come back from any remote listeners.

If humans can survive their selfish tendencies to destroy each other and thus themselves, they could evolve inhibited only by the laws of physics for millions of years. We would have the technology to create giant beacons in space, beaming out our messages, easily visible across our Milky Way and reaching even to the most distant galaxies. Perhaps intelligent life elsewhere does not want to be found. Or perhaps our alien-filled galaxy does not broadcast in the electromagnetic spectrum. Perhaps they have discovered a different and more efficient way of communicating, such as with gravitational waves, neutrinos or some physical process that we have yet to discover.

There are many other logical solutions to the Fermi paradox:

Perhaps there is no other life out there. It just did not happen elsewhere because the conditions were not exactly right. The chances of reproductive organisms forming from the random motions of interacting colliding molecules may be incredibly small. That would make me feel very lonely in this vast universe.

There may be abundant life, but nothing comparable to humans. After all, there were millions of species on our planet prior to *Homo sapiens* and none of them have evolved beyond using a few primitive tools, let alone having mastered the use of fire. Perhaps it is the same on other planets that orbit distant stars; some may be teeming with life which we would call primitive.

Even if intelligent life were to develop elsewhere, it would seem to be an intrinsic part of evolution that certain individuals of a species seek to survive and profit at the detriment of the welfare of the global society. Thus any intelligent society will self-destruct before it reaches the global coordination necessary to begin exploring the stars.

There is the possibility that, when life becomes intelligent enough, it creates a machine that can "think"—a computational mind comparable to our own. This may inevitably lead to the rapid demise of a species that has evolved through the long process of natural selection in the presence of machines that can undergo exponentially fast evolution through intelligent design.

I will discuss some of these interesting possibilities in more detail in the final chapter. But I prefer the notion that there is life, plenty of it and some of which is indeed far more intelligent than us. We just have not seen it because we are not looking in the right way or in the right places. If we were to find life on a distant planet, it should not make us feel less insignificant in our universe, but it should fill us with a desire to understand far more. Perhaps another life form has already figured out the answer to my question regarding the first instant in time: Why and how did the universe appear?

A Journey to the Stars and Beyond

The two Voyager spacecraft were launched in 1977 by NASA with the main purpose of exploring the planets in the outer solar system. They still transmit data back to Earth using instruments powered by small nuclear reactors that have a lifetime of about 50 years. In 2020 they will leave the confines of our solar system, the region that is still influenced by the Sun’s wind of particles that are constantly escaping from its surface, and will travel through the vast empty interstellar medium of our galaxy. They are our most distant man-made objects, already over 10 billion kilometres from Earth. Voyager 1 is travelling at 17 kilometres per second. In about 40,000 years it will be close to a star named AC+79 3888, close to Polaris in the constellation of Camelopardalis.

As a statement regarding the intelligence of the human race, NASA placed records on the spacecraft which contain a short summary of our knowledge and culture. These are actual phonographic records made of gold-plated copper encased in aluminium. They contain a selection of Earth music from genres as diverse as Chuck Berry and Beethoven. This was the medium of choice for music for most of the last century until magnetic tapes took over, then CDs and so on. The records also contain images encoded in analogue form composed of 512 vertical lines, which contain key findings from mathematics, physics and other scientific disciplines.

It is unlikely that these craft will ever be discovered. Yet, although the onboard power is expected to cease to function around the year 2025, the Voyagers and their contents will most likely travel for billions of years through our galaxy unharmed. They are symbols of the state of development of our species that an advanced alien civilisation could easily decode. They could then recognise that the inhabitants of our small blue planet are relatively harmless and primitive, and perhaps like Darwin, they will listen to our music and look at our behaviour and call us “savages”.

Within 20 light years of Earth there are about 80 visible stars. Space-based observational missions that are being proposed and designed now would allow us to determine not only whether they have planets but where the planets orbit and what their atmospheres are composed of. We will know where to go, and we already have the resources to design and construct a spaceship capable of sustaining the one or two generations of people that are necessary to make this journey. I suspect there will be no shortage of volunteers to depart on the first one-way trip.

A commercial airplane has a top speed of about 1,000 kilometres per hour and would take 15 days to reach the Moon, 6 years to get to Mars and a further 137 years to reach Saturn. At this rate it is going to take a long time to reach the nearest star, about five million years in fact, so we need something a little faster. Our fastest existing spacecraft is Voyager 1, travelling at 60,000 kilometres per hour. Like fireworks, it obtained part of its speed from burning combustible fuel; the reaction of the exhaust blowing out of the back of the engines causes the spacecraft to accelerate faster forwards (this is a consequence of Newton’s third law, which states that every action has an equal and opposite reaction). Once the fuel is gone, the spacecraft will just continue to travel at the same speed forever (a consequence of Newton’s first law of motion).

Travelling with a rocket-propelled spacecraft at Voyager 1 speeds will be our low-budget mission to the stars, but later we will see what we are really capable of. We would reach the Moon in just a few hours. This is the farthest that humans have so far explored in person. Outside the spacecraft is the near vacuum of space. On Earth our atmosphere is filled with oxygen, nitrogen and other elements: Over a billion billion particles are packed together in a single cubic centimetre of air. The Moon has no atmosphere; its gravitational field is not strong enough to prevent the atoms from escaping its surface all together. With no atmosphere there is no natural erosion from wind and rain. The footsteps of the Apollo astronauts from 50 years ago are still imprinted on the Moon's dusty surface as if they were made yesterday. They will remain preserved for thousands or even millions of years, until eventually another meteoroid or asteroid strikes the surface and completely erases the evidence of our presence.

A cubic centimetre of space beyond the Earth contains just a few particles. We hear no sound—there is no medium through which a sound wave can propagate, at least on the scale of our human ear. On Earth we are kept warm by the random collisions of numerous molecules of air with our skin. Those molecules are kept moving by the radiation of the Sun. It is extremely cold in space. If you happen to find yourself outside the spacecraft, your skin would radiate heat until it cooled down to the temperature of the photons hitting your body. The side of your body away from the Sun would cool down to a temperature close to absolute zero. Away from our light-polluted atmosphere, the sky glows bright with stars of the Milky Way. They do not twinkle as we see them from Earth, where the light is constantly navigating different paths through our turbulent atmosphere. Away from the womb of Earth, where we evolved and where all of human history has taken place, most of our senses are useless. We cannot hear, feel or smell anything.

Our last excitement for a long period of time will be passing by the cold and barren icy surface of Pluto, 10 years after departure. The Sun's light is feeble at this distance and warms its surface to a temperature of only -230 degrees centigrade. Communication with Earth is already difficult and verbal conversations are not possible because it takes the signals about 6 hours to travel in one direction. It is a soul-destroying sight on our journey to see the Earth fading from a pale blue dot to nothing as we leave the farthest reaches of our solar system. Our Sun eventually becomes just another distant star in the night sky.

Time ticks on, year after year, century after century, millennium after millennium as we journey across the empty expanses of our galaxy. After 80,000 years we finally approach the next-closest stars to Earth, Alpha Centauri, 4.4 light years away—a binary system of two stars, each of which is similar in mass, size and age to the Sun. The two stars in Alpha Centauri move on elliptical orbits around each other that take them between 1.7 and 5.3 billion kilometres apart every 40 years. Computer simulations have shown that it is possible that an Earth-like planet could exist in the habitable zone around either star orbiting at a distance of about 100 million kilometres from one of the stars. In 2012, an Earth sized planet was discovered orbiting Alpha Centauri B. The view of its two suns must be quite spectacular!

At this speed the time taken to reach the nearest star roughly equals the amount of time required for most of the recorded intellectual history of the human race to unfurl. During this time, thousands of generations of people will have been born, lived and died on the craft. This is too long a journey, unless suspended animation or cryostasis becomes a reality. The principle is simple. If a body is cooled down to about −200 degrees centigrade, all the essential biological activity stops. Everything is frozen in time and can be thawed out at some arbitrary point in the future. It doesn't quite work yet though. If you simply freeze a human, the cell structures are destroyed by the ice crystals that form around them. Researchers working on cryopreservation are looking at ways of soaking bodies in a type of antifreeze, like ethylene glycol, which soaks into the cells and prevents them from crystallising.

Despite the failure to resuscitate any human who has been frozen for a long time, it is possible to pay to be placed in suspended animation before death. The selling point of the companies that provide this service is that in the distant future, the technology will have advanced such that our descendants will be able to bring you back to life—despite the fact that they may not want to! We know that the technique works for simple parts of the human body, such as blood or embryos. We just have not mastered it for the body in its entirety. Many insects, fish and amphibians naturally produce cryoprotectant chemicals in their bodies to minimise damage from freezing. Those tough little water bears can survive extreme temperatures because they have very little water content and are filled with the glucose sugar trehalose, which maintains cell structures in a gel-like state even when frozen to −270 degrees centigrade.

I imagine that one day it will be possible to place humans into a low-power hibernation mode for long periods of time. Today it is only an emerging future technology. We want to see more immediate results, so let us look at ways of speeding up our journey using existing technology. Is there a way of making the journey to the nearest stars within one human lifetime? This would require a spacecraft that could travel at least 30,000 kilometres per second—that is 10 percent of the speed of light and over a thousand times faster than our rocket-propelled ships are capable of. The surprising answer is yes, we could start to design and construct such a spacecraft today. There are two known ways: laser powered sail crafts and nuclear pulse propulsion.

The principle of the first method is that photons of light have a tiny momentum which is imparted to any object with which they collide. In the early universe, the photon pressure drove the expansion of space. In dying stars, the photon pressure pushes away the outer layers of material. In the solar system, the radiation from the Sun strikes the icy surface of comets and creates long dust tails as it literally blows away the material. This is why the tails of comets always point away from the Sun. Our spacecraft would have a 10- to 100-kilometre-diameter very thin metallic "sail" which would need to be constructed or unfolded in space. Then, extremely powerful gigawatt lasers on Earth, or orbiting the Sun, would focus their light beams on the sail, pushing and constantly accelerating the craft all the way to its final destination. They would have to operate continuously for many years. And although this technology uses “clean energy”, it would take a large fraction of the energy output of our planet to provide the propulsion.

The photon pressure is so small that the craft barely moves at first. But it begins to accelerate faster and faster until, after several years, it will have reached its top speed, which is over 10 percent that of light. Slowing down the craft when it reaches its destination would be difficult, but the sail could be detached and sent ahead of the spacecraft. The laser beams from the solar system would be used to reflect back onto the craft, slowing it down over the final part of its journey. The first space mission to use a “solar sail”, which captures the photon pressure from the Sun, is the ongoing Japanese IKAROS (Interplanetary Kite-craft Accelerated by Radiation Of the Sun) mission, launched in 2010. We could develop the technology for an interstellar mission, but the cost of this method is very high.

Perhaps the method of choice for propelling ourselves to the nearest stars is to use the raw energy contained in matter and to detonate a series of small nuclear fission or fusion bombs immediately behind a specially designed spacecraft. A huge steel or lead shock-absorbing plate would take the impact of the bomb debris, which occurs in a few nanoseconds, spreading the impulse over a few seconds. The spacecraft would literally be pushed forward by the blast wave of particles coming from the nuclear explosion. After about a thousand blasts, the spacecraft would be accelerated up to 10 percent of the speed of light. Allowing for speedup and slowdown, the journey to the next star could take as little as 50 years; it could thus be made in a single human lifetime.

A design for this mission was already created in 1950 at Los Alamos National Laboratory in New Mexico, named Project Orion. British physicist Freeman Dyson worked on the project and designed missions of several sizes, up to the Super Orion craft, a 400-metre vessel that could hold a small city. However, interest in nuclear pulse propulsion declined in 1963 following the Nuclear Test Ban Treaty signed by the United States, the Soviet Union and the United Kingdom. This agreement banned nuclear weapons tests in the atmosphere, underwater and in outer space.

Given the limitations of the speed of light, and the fact that warp drives from *Star Trek* are in the realm of science fiction, the ultimate mode of rocket propulsion known to be possible uses antimatter as fuel for propulsion. Protons and electrons have antipartner particles that have opposite charge and opposite magnetic properties. The existence of the antiproton was predicted by the British physicist Paul Dirac in 1933 and was discovered experimentally in 1955. When a proton comes into contact with an antiproton, the pair annihilate each other and their entire rest masses are converted into pure energy. It is the ultimate form of energy generation. Unfortunately, it is very difficult to manufacture and store antimatter using today’s technology. It is the world’s most expensive substance to produce, costing 50 trillion euros per gram. But the technology can certainly be improved to bring the manufacturing costs down considerably.

Antimatter drives could potentially yield enough energy to send spacecraft travelling at close to the speed of light. The journey between stars could be made within a decade and with the bonus that, at these speeds, the traveller receives the benefits of time dilation. That is a consequence of Einstein’s relativity that I mentioned earlier. The faster you travel, the slower your clocks run and the slower your body ages. At 99 percent of the speed of light, time is stretched by a factor of seven. To someone watching from Earth the journey might take 10 years, but to the astronauts it would take only a year and a half!

It would take our nuclear-powered spacecraft about one million years to cross the entire galaxy. It would be a spectacular journey, during most of which time you would have to be cryogenically preserved, but could be woken at key moments to see some of the spectacular sites on the way. In principle, with future technology using antimatter drives, we could continuously accelerate our spacecraft to speeds closer and closer to the speed of light, allowing us to cross the entire galaxy within a human lifetime. But at these speeds we have the additional complexity of preventing the spacecraft being destroyed from the collisions with large molecules and dust within the interstellar medium.

After we have travelled through our galaxy, what next? What about the galaxies beyond our own? Perhaps many are already filled with life. The nearest large galaxy to us is Andromeda, which is 2.5 million light years away. That would indeed be a long and lonely journey to make. The distance to the edge of our visible universe is called the horizon. This is the largest distance we can ever measure or travel to, since it is the distance that light has travelled since the beginning of our universe. We cannot see past this distance: Light from farther away has yet to reach us. There is no way of communicating information on scales larger than our horizon, which is why we can never measure the true size of our universe. Our horizon distance grows with time because, as the universe gets older, the light from more distant regions has had more time to reach us. Today, our visible universe is a vast 90 billion light years across. But like atomic matter, our universe is mostly empty space.

If we spread out all the stars from all the galaxies within our horizon, there would only be one star in every 10 billion cubic light years of space. The universe is mostly empty space between the galaxies that we see. If we travelled in a straight line, we could cross the entire universe without colliding with a single star. In fact, you would have to travel across the universe a trillion times before you had a good chance of directly colliding with one star. This is why the night sky is dark and not glowing brightly with light from an infinite number of distant stars. In most directions there is simply nothing.

Even if our galaxy were empty of life, I hope that I have convinced you that we have the capabilities to fill it with our own species in the near future. But what about the far future and the question of how long life could exist? The gas supply for forming new stars is slowly being depleted, and more and more stars are beginning to fade and die. The energy sources on which life depends today will begin to dwindle. This would be a good place to begin to discuss the future of our universe and the prospects for our species to continue given all the theoretical and observational knowledge that we have. This is particularly timely given the cosmic matter and energy inventory that we have established. Can life exist for eternity, becoming ever more advanced and sophisticated? Or is life itself just a fleeting event in cosmic history viewed from the eyes of our ancient universe?

http://www.springer.com/978-3-319-05671-5

Elephants in Space
The Past, Present and Future of Life and the Universe
Moore, B.
2014, XI, 189 p. 13 illus., Softcover
ISBN: 978-3-319-05671-5