The Future of Life on Earth

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Although life is probably widespread in the universe, our pale blue dot, Earth, is the only known place harbouring intelligent life. Even if we manage to stave off extinction by climate change, avoid a nuclear apocalypse and the dangers of runaway AI, biological life on our planet will eventually come to an end in about 5 billion years' time. What are the astrophysical dangers to life on Earth, and the prospects for life's survival into the distant future?

A Message in a Bottle

Carl Sagan, the astronomer and science communicator, needed all of his considerable convincing power to persuade NASA officials to change the Voyager 1's mission from science to reportage, albeit only briefly. It is to him that we owe this unique perspective on ourselves: a photograph of Earth, and of most of our immediate cosmic family members, taken from 3.7 billion miles away (Figure 1).

Voyager 1 had been launched on Sept 5th, 1977 aboard a Titan IIIE-Centaur rocket. Its primary mission was to set course for Jupiter and Saturn, and observe the two giant gas planets from nearby. The data it sent back during its flyby revolutionized our understanding of both. After that part of the job was done, the space probe, the size of a car, was to keep measuring for as long as possible the properties of the stellar wind, conserve power and keep in touch with its creators on Earth for as long as the Sun's light could recharge its batteries. It is still doing so today, when it has reached the end of the Solar System, 4 billion miles from us, past the orbit of Pluto.

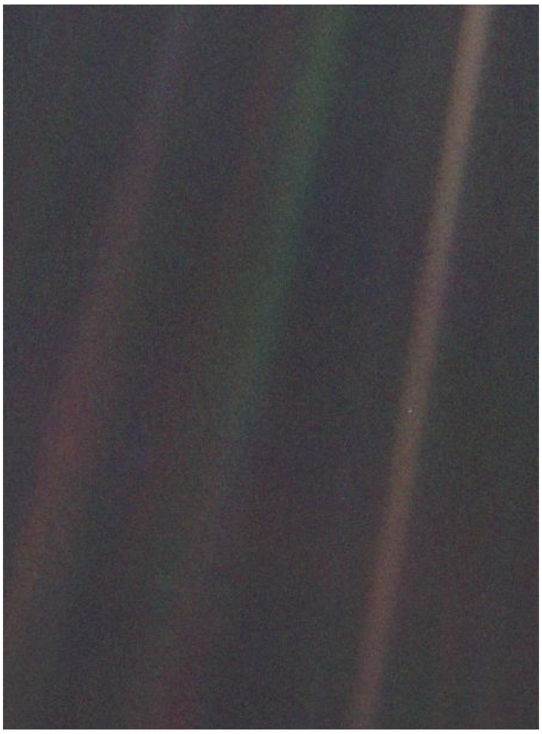

Figure 1: The "pale blue dot" image of the Earth, taken by Voyager 1. The Earth is the little dot in the middle of the brown streak. Credit: NASA/public domain.

Onboard the Voyager 1 (and its twin, Voyager 2), a golden disc was a late addition to the mission (Figure 2). Sagan knew that the probe was destined to leave our solar system, and that in 40,000 years' time it will brush past another star, 17 light years away. He assembled a cross-disciplinary team to create an interstellar postcard that could be understood by any sentient being that might one day pick up the Voyagers. The postcard takes the shape of a gold-plated disc. On its cover, a set of instructions demonstrate how the record is to be played, together with the the number of rotations per minute (16 and ½) in units of the fundamental frequency of the hydrogen atom (also depicted). The location of our solar system is given with respect to 14 nearby pulsars. A layer of ultra-pure Uranium-238 provides a long-term clock to enable hypothetical aliens to work out the time of launch. Its half-life is 4.5 billion years.

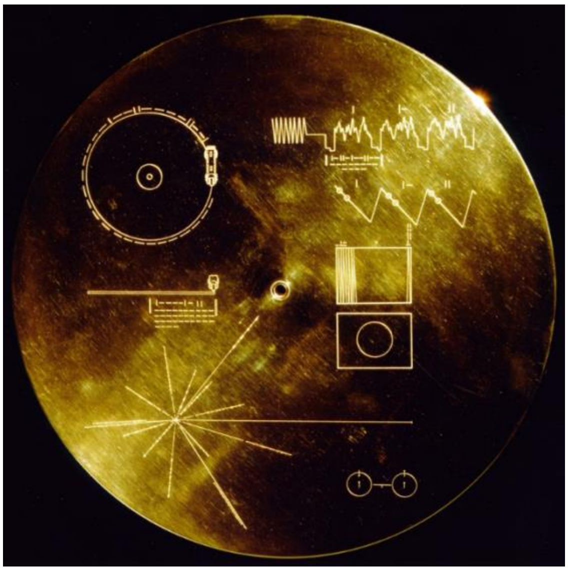

Figure 2: The Golden Record cover, onboard the Voyager spacecrafts, showing instructions to play the content for hypothetical future civilizations. The diagram on the lower left shows the location of the Solar System with respect to 14 nearby pulsars. Credit: NASA.

The alien hand (if it is a hand) that might one day remove the disc from its encasement on the side of Voyager will find behind it the stylus needed to reproduce its contents, and the etching of a test picture on the cover will allow them to check that they got the device working correctly. If the Voyager's golden disc fulfils its mission, sounds and pictures of 1970s Earth will raise again in an unconceivable distant future, in some distant corner of the galaxy: the song of whales, the sound of a mother kissing her baby, Mozart's Queen of the Night aria; the structure of DNA, an EEG recording, bushmen hunting, and a Titan rocket take-off; a traffic jam in Thailand, the Sydney Opera house, a young woman eating grapes in a supermarket aisle. It's impossible to imagine what kind of impression these sound and sights (and the many others that accompany them, including greetings in over 50 languages) might make on the sensory organs of a form of life that we cannot begin to conceive.

Sagan's second momentous idea, after the golden record, was to use the Voyager's unique vantage point to create the iconic picture that is now known as "the pale blue dot" – also the title of the book the picture inspired Sagan to pen. In his book, he wrote:

> *"Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there--on a mote of dust suspended in a sunbeam."*

Sagan must have known fully well that the probability of the Voyagers' message being picked up is vanishingly small. The message was therefore directed to hypothetical future aliens as much as to an audience much closer to home: the inhabitants of planet Earth. Sagan's memorable, heart-felt message was that humanity needs to take good care of our pale blue dot, the only place in the universe we can call home. Seen from 4 billion miles away, the absurdity of humankind's hatred for each other, the blood spilled to conquer a fraction of a pixel floating in the blackness of space, the wrecking of the natural world that supports us appear in all of their madness.

Sagan was also concerned by the existential threats to life on Earth coming from space – particularly the danger of an asteroid strike, a plot line dramatized in many Hollywood disaster movies. Perhaps the first instance can be traced back to a 1942 short story by an American writer named Jack Williamson, "Collision Orbit".

Space Threats

In fact, we do know that asteroid collisions occurred in the past, and that they yanked the course of evolution on our planet. The Moon might have formed when a hypothetical body, a planetary embryo called Theia, impacted the half-formed proto-Earth some 4.4 billion years ago. The existence of a large Moon might have played a crucial role in stabilizing the Earth's rotation axis, which would otherwise have wobbled far more than it does, thus leading to major swings to the Earth's climate over relatively rapid timescales – which would have endangered or even prevented altogether the evolution of life. Once ocean-based life-forms appeared, the strong tides created by the Moon helped life getting a foothold onto land, a fateful step that eventually led to mammals, and humans.

If Theia's impact was life-giving, the asteroid that hit near the Gulf of Mexico 66 million years ago caused enormous disruption to life – and with it, huge new opportunities for evolution. The impact of the 12 km-wide space rock generated apocalyptic tsunamis, and the enormous quantity of vaporized rock spewed in the atmosphere led to a reduction of sunlight reaching the surface. The climate cooled, plants died out and the food chain collapsed. Three quarters of all animal species disappeared, including all land animal weighing more than 25kg – among them all non-flying dinosaurs. This was bad news for the dinosaurs, of course, but it blew open the window of opportunity for mammals to prosper in the void left by the giant reptiles. Millions of years later, descendants of those mammals, naked apes equipped with an oversized brain and an opposing thumb, would excavate the fossilized remains of dinosaurs, marvel at their other-worldly appearance, and create cuddly toys in their shape, much-loved by kids all over the world.

In more recent times, the so-called Tunguska event was caused by the explosion of a meteor of about 50 meter diameter, which disintegrated in mid-air over Siberia in 1908. Thankfully, the meteor struck in a sparsely populated region, with only three people reportedly losing their life in what could have been a much bigger disaster: the blast flattened over 2,000 square km of forest.

Meteors are nothing else than space rocks, called asteroids, that are captured by the Earth's gravitational pull. Most asteroids orbit the Sun in a region called "the main asteroid belt", between the orbits of Mars and Jupiter, the leftover debris from the Solar system formation, 5 billion years ago, from where they can be ejected due to gravitational perturbations. Fortunately for us, large asteroids, of the kind that could threaten major disruption to life on Earth, are much rarer than smaller ones. NASA defines "potentially hazardous objects" as those with a diameter larger than 150m, and which approach Earth to within 7.5 million km. It currently tracks about 2,200 of them. Dangerous asteroids, those with a diameter larger than 100 meters, may strike with a frequency of once every 200,000 years.

Other bodies visit our neighbourhood with more or less regular frequency – comets, balls of ice and rock that typically travel on very elongated orbits. Halley's comet, faithfully returning in proximity to the Sun every 76 years, is perhaps the best known example. In 1994 we have been able to observe, from a safe distance, the immense violence of a cometary impact, when the comet Shoemaker-Levy 9 broke up and fell onto Jupiter with the unimaginable energy of 300 million atomic bombs.

The Lives of Stars

Another long-term danger comes from the very source of energy that sustains life on Earth – our Sun. Nuclear fusion reactions convert hydrogen into helium in the core of our star, generating the energy that keeps the Earth in the narrow range of temperatures necessary for biological life – the so-called "habitable zone". The Sun is today a middle-aged star, having been burning hydrogen for the past 4.5 billion years, and can be expected to keep going for another 4 or so billion years. As the hydrogen supply dwindles, stars more massive than the Sun achieve sufficiently high temperatures in their cores to switch to burning the next heavier element, helium. Not so for our star: its core will fill up with helium, while hydrogen burning will move to an outer shell. As this happens, the Sun will expand and cool, becoming what astronomers call "a red giant". In 5 billion years, the surface of the Sun will have swollen up past the orbit of the Earth, incinerating our planet. But well before this happens, an increase of about 10% in the Sun's brightness in about 1 billion year will warm up the Earth to such a point that water will boil away. Our planet will be sterilized.

A timescale of 1 billion years is nothing to worry about. To put this in context, a billion year ago, life on Earth was still in the form of single-cell organisms. On a much shorter timespan, solar storms might seriously threaten our technological civilization, if not our biological life. Solar storms are a consequence of reconfigurations of the Sun's magnetic field, twisting and snapping in correspondence to sunspots, the cooler, darker patches on the Sun's surface. The magnetic energy is thus released in the form of heat, light, and charged particles – a solar flare. Plasma can be heated up to 60M K, and erupts into space, traveling outwards and impacting whatever is on its way, including us. Fortunately, the Earth's magnetic field acts as a shield for us on the surface, deflecting away the charged particles and gifting us in the process with the mesmerizing beautiful dance of the aurora borealis. In 1859, what has been thus far the largest recorded solar storm had no bigger consequences than an amazing display of Northern lights that reached the Caribbean, and the disruption of telegraph lines. But if such an event, which can be expected to occur every 500 years or so, were to hit us today, it would have an enormously destructive impact on our society, dependent as we are on electronic technology: telecommunication satellites would be fried, GPS signals lost, radio comms disrupted, electric blackouts cascade. By switching off the backbone of our financial, communication, navigation, security and economic systems – including the internet, dependent as it is from electrical power lines and world-wide connections --, a powerful solar storm could create immense chaos, even threatening civilization itself with the anarchy that could ensue.

Other stars have more adventurous lives than the Sun. Rather than swelling up and cooling off, and eventually retiring from active stellar service as a harmless, dozy white dwarf as our star will do, more massive stars burn recklessly through their hydrogen in a few million years; then they rapidly gorge on helium, followed by carbon, neon and oxygen. Reaching to always heavier elements to sustain their nuclear fusion reaction against gravitational collapse, they finally run out of road when they reach silicon, which fuses into iron. Iron cannot be fused further into heavier elements unless energy is provided: the star collapses onto itself, and the rebound destroys it in a mighty explosion[1].

It has been suggested that in the past 10 million years two supernova explosions might have been close enough to alter the Earth's climate. More recently, supernova 1987A, in the Large Magellanic Cloud, was such an occurrence: luckily for us, it was 168,000 light years from Earth, so the X-rays and highly energetic particles it hurled across the universe were rendered harmless by distance by the time they reached us. A supernova explosion within 25 light years from Earth would likely wipe out life with its flux of X- and gamma-rays. But there are no stars likely to go supernova withing that radius – the nearest candidate is Betelgeuse, the red giant that defines the left shoulder of the giant depicted in the constellation of Orion. Some of you might have heard from the news that Betelgeuse got significantly dimmer in 2019, a consequence of its end-of-life convulsions. But Betelgeuse has probably another 100,000 years to go before it goes bang, and when it does the 550 light years between us will ensure that future astronomers – should there be any – can enjoy the spectacle without worrying about any dangers it may pose to life on Earth.

Furthermore, we should remember that supernova explosions have played a crucial role in producing and then spreading through the galaxy the heavy elements on which life is based. Although their violent death can be the source of destruction, it has also been a fountain of life, literally providing the raw material out of which planets, trees, cats and humans are made.

What You Can't See Can Still Harm You

But there is something else out there that might overrun us with deadly consequences – and do so in such a way that we would remain blithely unaware until it was upon us. It has been called "the ultimate ecological catastrophe"[2]: the possibility that the nature of empty space, or more precisely of what physicists call "the vacuum", might spontaneously change.

Consider a ball sitting still at the top of a crest between two valleys, with each of the valley floors at a different

[1] This is one of two main categories of supernova explosion (so-called "core collapse supernova"). Another way of producing a supernova is via the runaway thermonuclear reaction of a carbon-oxygen white dwarf (a type of very compact, very dense star), which accretes mass in a binary system from a companion, leading to a so-called "type Ia supernova". The two bright supernovae, visible to the naked eye and brighter than Venus, one studied by Tycho Brahe in 1572, and another by Johannes Kepler in 1604, were of the type Ia category.

[2] Coleman, S., & Luccia, F. D. (1993). Gravitational effects on and of vacuum decay. In *Euclidean Quantum Gravity* (pp. 295-305): World Scientific.

height. Such a setup is unstable: the slightest push will cause the ball to roll down and, under the influence of friction, eventually come to a halt at the bottom of the valley it will have plunged towards. Say the ball has rolled to the bottom of the higher valley floor: its stability could be further improved if it could be transported to the next valley, where the lower floor enjoys lower gravitational potential energy. In order to do so, we would have to kick the ball back onto the top of the crest, and from there down the next valley. This can only be achieved, for macroscopic objects, by providing kinetic energy.

But if we translate this situation to the quantum mechanical domain, our ball (now replaced by an elementary particle) is only metastable: it has a finite probability of traversing the mountain (now a potential barrier) between the two valleys, thereby spontaneously reaching the lower energy (and thus higher stability) configuration. Classically impossible phenomena can and do happen in the quantum world. This "quantum tunnelling" is for example responsible for alpha decay, the mechanism explaining the radioactivity of uranium-238.

And now, for another conceptual jump: the crest and valleys become a representation of the "Higgs potential", describing the potential energy associated with the value of the Higgs boson field that permeates the whole universe. Measurements of the mass of the Higgs boson, discovered at CERN in 2012, and of another elementary particle called the top quark, have allowed particle physicists to determine that the Higgs field sits currently in the "metastable"[3] region of a double-dip potential. At the beginning of the Universe, the configuration of the Higgs field rolled down the reach the higher of the valley floors, where it has been sitting pretty for the past 13.8 billion years. It will likely continue to do so, but a small probability exists that the field will quantum tunnel into the true vacuum – the deeper valley. Should that happen anywhere in the universe, the field reconfiguration would propagate in a spherical shell at close to the speed of light, overrunning everything in its path.

What would the consequences be of such an event? Nobody really knows, but it is likely that the very laws of physics inside the bubble, with its new Higgs field configuration, would be very different from the ones we know "on the outside". The universe as we know it would cease to exist, and be replaced by something entirely different – at near the speed of light. Depending on the exact details of how the new Higgs vacuum bubble propagates, we might not have any warning before the new configuration overruns us. From one moment to the next, we would just be gone. The Universe would be obliterated with a backhand flick of the Higgs vacuum.

Estimates about how long it might take before such a new configuration witches into existence vary wildly – the calculations are complex. A group from Harvard estimates the lifetime of the Universe to 10^{161} years; another calculation gives values in excess of 10^{600} years! Either way, the "metastable" state of the Higgs vacuum is clearly very long lived.

One can also take a statistically minded approach to all of the above dangers, and a few more. Cosmologist Max Tegmark and philosopher Nick Bostrom have noted[4] that life having survived for 4 billion years on Earth cannot *per se* be used as an indication of how unlikely "cosmic sterilization" events are on average – for the fact that we are here asking the question would necessarily mean that we must have been the lucky ones to escape doomsday, no matter its average rate across the galaxy. By considering instead the formation rate of habitable planets as a function of time, and noting that life on Earth developed at least 9 billion years after the Big Bang, they concluded that cosmic sterilization (by which they mean an event that utterly destroys life on a habitable planet) strikes at most once every billion years, with a 99.9% confidence. They argue that their limit encapsulates all of the above dangers, and any other that is naturally occurring in the universe, as opposed to those deriving from runaway technological development, to which we now turn our attention.

Dangers of the Anthropocene

If Tegmark and Bostrom are right, the average time between life-sterilizing events is 1 billion years. You may worry that we have been overly lucky already, having dodged cosmic catastrophe for over 4 billon years on Earth. But a surprising statistical property of the exponential distribution (which describes waiting times between events happening at a constant rate) comes to the rescue: having waited (thankfully in vain) for 4 billion years for a cosmic sterilization event has no bearing on the amount of time we can expect to have to

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[3] Markkanen, Tommi, et al. "Cosmological Aspects of Higgs Vacuum Metastability." Frontiers in Astronomy and Space Sciences, vol. 5, Dec. 2018. https://doi.org/10.3389/fspas.2018.00040.
[4] Tegmark, M., Bostrom, N. Is a doomsday catastrophe likely?. *Nature* **438,** 754 (2005). https://doi.org/10.1038/438754a

wait for the first sterilization event to happen – it is still 1 billion years.

In searching for the most imminent and present danger to life on Earth, we don't need to invoke Newtonian orbits, stellar evolution physics nor the exotic quantum field theory calculations of Higgs vacuum instability. It is sufficient for each of us to look around this room, and into a mirror: the gravest danger to the future of life on our planet it's not out there; it's in here. It's us.

When we consider the future of life on Earth, we must first and foremost ask ourselves the question that Jonas Salk, the inventor of the polio vaccine, posed: "Will future generations speak of the wisdom of their ancestors as we are inclined to speak of ours? […] Are we being good ancestors?"[5]

At the beginning, the naked ape we call Homo Sapiens seemed harmless enough. The use of fire, stone and wooden tools helped our prehistoric ancestors survive in a world full of better equipped predators, where food was a scarce resource, dangers aplenty and life a constant struggle. Then, some 50,000 years ago, our most powerful weapon somehow appeared: language. And with it or shortly thereafter, abstraction. Now the wheel of technological innovation began to spin in earnest: in a short 10,000 years, the naked ape built cities that light up the night; space stations that circle the Earth; works of art that move the soul. We sent 12 of us to play golf on the Moon and created weapons of unimaginable destructive power. Yet, this technology that is often indistinguishable from magic (as A.C. Clarke once described futuristic tech), has somehow failed to be put to work for the benefit of all: millions of people in the world still suffer from hunger or are under-nourished, while millions others die of premature deaths due to obesity, heart attacks and other illnesses related to overconsumption of highly processed food. Income inequalities are higher than they have ever been: the richest 10% own three quarters of all wealth, with the world's 10 richest men having their collective wealth doubled since March 2020. Mastering our own tech and ensuring that the almost god-like powers it confers serve all humankind, and all life on our planet, is never been our strong suite, it appears:

> *"What the inventive genius of mankind as bestowed upon us in the last hundred years could have made human life care free and happy if the development of the organizing power of man had been able to keep step with his technical advances… As it is, the hardly bought achievements of the machine age in the hands of our generation are as dangerous as a razor in the hands of a three-year old child[6]."*

These words, by Albert Einstein ahead of the 1932 disarmament conference, are even more poignant today than they were 90 years ago – words Einstein surely pondered later in life, after the devastation brought about in Hiroshima and Nagasaki by the nuclear weapons he played a crucial role in creating – something he regretted his whole life.

In the meantime, humans swarmed the Earth – there are close to 8 billion of us, and thanks to science and technology we lengthened our lifespan, wiped out diseases, reduced infant mortality and, for a minority of us, created a world where our almost every material whim can be satisfied at will – in a 2 hours, same-day delivery window. In the words of a character in Richard Powers' powerful novel, "The Overstory": "We are cashing in a billion years of planetary savings bonds and blowing it on assorted bling".

But the price we will eventually pay is enormous: 40% of our world's land is now degraded, according to a recent UN report[7]: deforestation continues unabated, destroying irreplaceable ancient forests, while intensive farming creates salinisation, soil exhaustion, erosion. The havoc that the naked ape is wrecking on the planet is striking from space: our beautiful, blue planet is scarred in ways that would have been unimaginable a generation ago. By clear-cutting thousand-year-old forests to make space for palm oil plantations that will fail in less than a decade, we are undercutting the basis of all life on Earth. On land, we have tilted the balance of large animals to suit our needs: farmed animals outweigh wild mammals and birds by a staggering 10 to 1. The oceans, which once seemed an inexhaustible resource, are over-exploited: 90% of the fish stocks are fully exploited, or depleted already.

After the forest and the oceans, we are now encroaching into the last remaining natural resource: space. The uncontrolled proliferation of low-Earth orbit satellites, linked in megaconstellations aiming to provide

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[5] Salk, J. (1992). Are We Being Good Ancestors? World Affairs: The Journal of International Issues, 1(2), 16-18. Retrieved from http://www.jstor.org/stable/45064193

[6] Einstein, A., The Nation, Sept. 4th, 1931; available from: https://www.thenation.com/article/archive/1932-disarmament-conference-0/

[7] Harvey, F., "UN says up to 40% of world's land now degraded", *The Guardian,* 27.04.2022; from: https://www.theguardian.com/environment/2022/apr/27/united-nations-40-per-cent-planet-land-degraded

high-speed internet connection all over the globe, is creating an overcrowding that multiply the risk of a chain reaction of collisions, which would fill low-Earth orbit with debris and potentially prevent future access to space. The 6,000 satellites already in orbit may grow to up to 100,000 in the next decade, and because they reflect the light from the Sun, they appear on the ground as so many, fast-moving artificial stars. Already now, they are causing major disruption to optical and radio observations of the universe, ruining as much as 50% of astronomers' data. Within a few years, the number of artificial satellites visible with the naked eye is expected to surpass that of stars.

In 1849, Emerson sang the beauty of the night sky thus: “One might think the atmosphere was made transparent with this design, to give man, in the heavenly bodies, the perpetual presence of the sublime.” But the new, commercial space race will rob us forever of the ancient “experience of the sublime”, an experience that has accompanied and guided humankind since the dawn of civilization – and may have contributed decisively to it. No wonder then that astronomers and environmentalists are joining forces to make the case for “space environmentalism” before it's too late.

Figure 3: A passenger pigeons flock in the 1800s. Source: The Illustrated Sporting and Dramatic News, July 3, 1875.

We have been here before: passenger pigeons once numbered in the billions in the Eastern United States. These sleek, slender, gregarious migratory birds gathered in immense flocks that darkened the sky for days when on the move – a colony in Wisconsin in 1871 was 125 miles long and 8 miles wide. They have been described as “a biological storm”, or a “feathered hurricane”. In the late 1800s, in the space of a few decades they were exterminated, as humans hunted them in their millions for their flesh, and often (perhaps a more revelatory motive) just as a pastime. Nobody could imagine that such numbers could ever dwindle to nothing – not until it was too late to save them.

The fate of the passenger pigeon is now faced by *one million* animal and plant species, driven to the brink by habitat destruction, poaching, pollution, and climate change. Our carbon-based economy is rapidly increasing the CO2 in the atmosphere, and therefore heating the planet up: the last 7 years have been the hottest on record, with global temperatures over 1ºC above pre-industrial levels. Glaciers are disappearing, the permafrost is melting, the icecap retreating, sea levels rising. Our planet has entered an out-of-equilibrium phase, whose spiralling feedback loops will endanger the lives and livelihoods of billions of people – sooner than we think. The passenger pigeon tragedy shows that, once kicked out of equilibrium, the abundance of life can decline shockingly quickly. In the words of anthropologist and poet Loren Eiseley, we are “a vast black whirlpool spinning faster and faster, consuming flesh, stones, soil, minerals, sucking down the lightning, wrenching power from the atom, until the ancient sounds of nature are drowned in the cacophony of something which is no longer nature”[8].

How long can we tether on the brink, before the fall?

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[8] Eiseley, Loren C. *The Firmament of Time*. Lincoln, Neb. : U of Nebraska (reprint edition 1999 (1960)).

Time to Flee to the Stars?

In the face of the human-induced existential threat to life on Earth, some are arguing that it is time for us to flee to the stars – to build a modern-era Noah's Ark, not out of wood on a mountaintop, but out of steel and riding on top of a rocket, to ensure survival of the human race against the metaphorical and actual flood that is coming. The idea is not new, and had been championed by Carl Sagan already, who saw it as an "insurance policy" against the not-unreasonable risk that we end up wiping ourselves out – a danger that has perhaps never been more sharply defined than today, with a tragic war raging in Europe once again. He wrote: "If our long-term survival is at stake, we have a basic responsibility to our species to venture to other worlds."

Today's space barons, the multi-billionaires that are transforming space into the final frontier of tourism, have picked up Sagan's flag. NASA's plans to return humans (and take the first woman) to the Moon rely on privately built rockets. The next step is a mission to Mars – whose date keeps slipping back, now slated for 2029 in the mind of one of the space barons. This is a much more ambitious and technically difficult goal than the Moon landing: a trip to Mars might take 6 to 9 months each way, compared to just three days for reaching our satellite. The challenges to get astronauts there and back safely are mighty: prolonged exposure to cosmic rays, the need to take along sufficient supplies for a mission that might last 2 years, or else extract power and consumables from Mars, the difficulty of landing a large spacecraft, the psychological distress of a long journey in cramped conditions are only the tip of the iceberg.

Establishing a colony, especially one that can survive independently from Earth, appears today an even more tenuous prospect. Consider that in 2021, the International Space Station required resupply roughly every 6 to 8 weeks – and that is for a crew of seven, 250 km up – not a colony of perhaps hundreds 100 million miles away. Others claim that it may not be necessary to send our biological bodies there, and that the next step of evolution will shed our organic selves in favour of silicon-based simulacra. Given the current state of AI, this is an even more remote prospect, and even if it were to be realized the artificial lifeforms that are supposed to replace us would be fundamentally other. I doubt that the Neanderthals would have taken comfort on being told that they were to be exterminated only to be replaced by a supposedly superior hominid!

Even if it were possible to build Sagan's Ark – and our technology is today not up to the task – it would be a refuge for one species only: us. There would be no space for whales, falcons, or butterflies; no meadows full of bluebells, no thousand-year-old redwoods, and no coral reefs. No bees, nor earthworms or the sound of crickets on a warm Summer evening (for that matter, there would be no warm Summer evenings – Mars being a desert planet with a thin atmosphere, its surface temperature drops rapidly after sunset, from a chilly -14ºC afternoon high to a freezing -90ºC at the tropics).

Escaping to another planet, leaving an ecologically compromised Earth behind as an empty husk, would be the ultimate outcome of what the philosopher of technology Lewis Mumford has termed "the megamachine" – the relentless focus of Western civilization on organizing and corralling the entirety of human existence into an ever more efficient, ever more powerful (and destructive) mechanized order of the world. Eiseley's insight comes to mind: man has become "a space leaper more deadly than the giant cats"[9].

To Sagan's "basic responsibility" to guarantee our species' survival, I would oppose the moral imperative of our stewardship of the whole planet, and its countless billions of lifeforms that our reckless choices have put in mortal danger. How ironic that we should launch ourselves into space, venturing at great effort to eek a living out of inhospitable, barren planets while doubling down on our efforts to wipe out thousands of species from our own, blue, beautiful home.

Writing in the 1960s, at the onset of the space age, Mumford presciently described the Great Pyramids as "the precise static equivalents of our own space rockets. Both [are] devices for securing, at an extravagant cost, a passage to Heaven for the favored few". And that's a second ethical argument for rejecting Sagan's dash to the stars, for it's only the "favored few" (read, the richest few) who could ever hope to gain passage on those hypothetical interplanetary lifeboats – indeed, the very same men who are today building the rockets, and going to space on joyrides. According to one of them[10], perhaps fifty percent of Silicon Valley billionaires are "doomsday preppers" – people who buy "apocalypse insurance" in the form of well-stocked bunkers guarded by a private militia, or even vast, self-sufficient private estates in remote parts of New

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[9] Eiseley, Loren C., *Life*, 16 feb 1968, Vol. 64, Num. 7, p85.

[10] Osnos, E., "Doomsday prep for the super-rich", *The New Yorker,* Jan 22nd 2017.

Zealand. When the apocalypse comes (in the form of climate change, a deadly virus, civil disorder, or nuclear war, perhaps precipitated by the megamachines they helped build), they want to secure a way out for themselves and their loved ones. And if the whole planet is burning, then space is their ultimate escape route.

Efforts to colonize the solar system to escape dangers on Earth are both practically and ethically misguided. Insofar as Sagan's argument goes, I would counter that when your car starts skidding during an overtake manoeuvre on the highway, it is not the right time to call a life insurance broker – it's the time to focus all of your efforts on regaining control of the vehicle and stave off the worst for all its passengers. Ethically, it deflects attention from the real issues by offering a false hope of salvation.

So Spoke the Silent Stars

If only we could get advice by older, wiser civilizations out there! Or else be spurred into acting by the stark warnings of planetary catastrophes glanced elsewhere! We don't know of any other life in the universe yet, although the last two decades of observational advances have demonstrated that planetary systems are widespread – perhaps 50% of the stars in our galaxy feature planetary systems around them. If just one in a thousand systems hosts a planet in the habitable zone, this gives something like 150 million opportunities for life to arise elsewhere in the Milky Way. The majority of those potentially life-friendly planets might be found in close orbits around red dwarf stars, where conditions would be very different than on Earth: the planet would revolve on its axis in synch with its orbit around its star, so that one side of the planet enjoys permanent daylight, while the other is plunged in perpetual darkness. The transition zone between the too-hot lit side, and too-cold dark side might offer life its best shot – a place where the alien sun would appear as a giant, red sphere, hovering over the horizon in a permanent twilight.

There is no doubt that evolving in such a different environment, life would take unsuspected turns – the human experiment is unlikely to be replicated elsewhere in even vaguely recognizable form. But perhaps the better question to ask is not *where* alien civilizations in the galaxy might be, but *when* and *for how long* do they thrive. Consider the following: if we compressed the 4 billion years of life's existence on Earth to just 24 hours, from midnight to midnight, multicellular lifeforms wouldn't appear until about half past eight in the evening; mammals, at about ten to 11; Neanderthals, 9 minutes to midnight; humans, some 25 seconds to midnight; man-made radio signals into the cosmos, 5 hundredths of a second to midnight. While life in the universe may be widespread, there are two explanations why we haven't heard from aliens yet. Civilizations with interplanetary communication capabilities might be rare – after all, the Neanderthals, who definitely qualified as intelligent life, stuck around for a million years in what has been described as "technical monotony". The alternative is more worrisome for us: it may be that civilizations that do develop megamachines quickly flicker out of existence, snuffed out precisely when their technological power brings about their own demise. In this scenario, the deafening absence of signals from outer space might foreshadow the curtain of silence that might soon fall upon us.

The Future in Our Hands

Our survey of the condition of life on Earth, and of the dangers that threaten it in the 21st century, leads to a simple conclusion. The future of life on our planet will be determined not by astrophysical phenomena in the next hundreds of thousands or millions of years, but by human decisions we will take in the coming months and years: can we avoid nuclear incineration and a catastrophic ecological collapse? The horrendous COVID pandemic demonstrated, if nothing else, that we are capable of huge changes when our minds are focused by present, palpable dangers. Individual and collective actions can and do change the course of history. It is up to us to achieve the shift of perspective that enables us to see humanity as part of the whole ecosystem, and to recognize the essential commonality of our destiny.

Perhaps space tourism might end up having a good side: seeing the Earth from above, delicately suspended in the blackness of space, brings home its fragile beauty, and has had a profound existential impact on astronauts, and now space tourists – among them, some of the most powerful men on Earth. Whether this will have a long-lasting effect on their individual and commercial choices, remains to be seen.

While you have been following this lecture, the Voyager 1 has silently traversed another 60,000 km of almost empty darkness in the outskirts of our solar system, edging towards the star Gliese 445, 17 light years away. The probe, like its twin Voyager 2, will roam the galaxy for something close to eternity – the timescale for the collision with a star is 10 million times the age of the universe. Among the sounds, pictures and greetings on the Golden Record, is a message by the then US president, Jimmy Carter. Written in 1977, Carter's words ring with even greater urgency today:

Of the 200 billion stars in the Milky Way galaxy, some – perhaps many – may have inhabited planets and space faring civilizations. If one such civilization intercepts Voyager and can understand these recorded contents, here is our message: This is a present from a small distant world, a token of our sounds, our science, our images, our music, our thoughts, and our feelings. We are attempting to survive our time so we may live into yours. We hope some day, having solved the problems we face, to join a community of galactic civilizations. This record represents our hope and our determination and our goodwill in a vast and awesome universe.

Whether or not we believe that we will one day join a "community of galactic civilizations", it is our urgent task today to halt the mindless march of the megamachine; to repurpose its planetary power so it may serve the needs of all life on Earth; to fortify our hope and our determination not merely to survive our time, but to create a new time, free of the dangers we are inflicting upon our planet, and upon ourselves.

Should anybody come looking for Earth in a distant future, guided by the 14 pulsars on the golden record's cover, will they be disappointed to find a dead planet, a cosmic tombstone marking the failed promise and misguided hubris of the naked ape? Or will they marvel from the orbit of Jupiter at our beautiful blue dot, sparkling delicate and majestic against the darkness of space? Our actions today will determine not whether we can be "good ancestors", but whether we may become ancestors at all.

We cannot afford to fail.

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