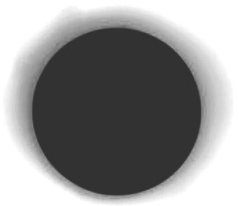
8

SHOULD WE COLONISE SPACE?



Why should we go into space? What is the justification for spending all that effort and money on getting a few lumps of moon rock? Aren't there better causes here on Earth? The obvious answer is because it's there, all around us. Not to leave planet Earth would be like castaways on a desert island not trying to escape. We need to explore the solar system to find out where humans could live.

In a way, the situation is like that in Europe before 1492. People might well have argued that it was a waste of money to send Columbus on a wild goose chase. Yet the discovery of the New World made a profound difference to the Old. Just think, we wouldn't have had the Big Mac or KFC. Spreading out into space will have an even greater effect. It will completely change the future of the human race, and maybe determine whether we have any future at all. It won't solve any of our immediate problems on planet Earth, but it will give us a new perspective on them and cause us to look outwards rather than inwards. Hopefully, it will unite us to face the common challenge.

This would be a long-term strategy, and by long term I mean hundreds or even thousands of years. We could have a base on the Moon within thirty years, reach Mars in fifty years and explore the moons of the outer planets in 200 years. By reach, I mean in spacecraft with humans aboard. We have already driven rovers on Mars and landed a probe on Titan, a moon of Saturn, but if we are considering the future of the human race we have to go there ourselves.

Going into space won't be cheap, but it would take only a small proportion of world resources. NASA's budget has remained roughly constant in real terms since the time of the Apollo landings, but it has decreased from 0.3 per cent of US GDP in 1970 to about 0.1 per cent in 2017. Even if we were to increase the

international budget twenty times, to make a serious effort to go into space, it would only be a small fraction of world GDP.

There will be those who argue that it would be better to spend our money solving the problems of this planet, like climate change and pollution, rather than wasting it on a possibly fruitless search for a new planet. I'm not denying the importance of fighting climate change and global warming, but we can do that and still spare a quarter of a per cent of world GDP for space. Isn't our future worth a quarter of a per cent?

We thought space was worth a big effort in the 1960s. In 1962, President Kennedy committed the US to landing a man on the Moon by the end of the decade. On July 20, 1969, Buzz Aldrin and Neil Armstrong landed on the surface of the Moon. It changed the future of the human race. I was twenty-seven at the time, a researcher at Cambridge, and I missed it. I was at a meeting on singularities in Liverpool and listening to a lecture by René Thom on catastrophe theory when the landing took place. There was no catch-up TV in those days, and we didn't have a television, but my son aged two described it to me.

The space race helped to create a fascination with science and accelerated our technological progress. Many of today's scientists were inspired to go into science as a result of the Moon landings, with the aim of understanding more about ourselves and our place in the universe. It gave us new perspectives on our world, prompting us to consider the planet as a whole. However, after the last Moon landing in 1972, with no future plans for further manned space flight, public interest in space declined. This went along with a general disenchantment with science in the West, because although it had brought great benefits it had not solved the social problems that increasingly occupied public attention.

A new crewed space flight programme would do a lot to restore public enthusiasm for space and for science generally. Robotic missions are much cheaper and may provide more scientific information, but they don't catch the public imagination in the same way. And they don't spread the human race into space, which I'm arguing should be our long-term strategy. A goal of a base on the Moon by 2050, and of a manned landing on Mars by 2070, would reignite the space programme, and give it a sense of purpose, in the same way that President Kennedy's Moon target did in the 1960s. In late 2017, Elon Musk announced SpaceX plans for a lunar base and a Mars mission by 2022, and President Trump signed a space policy directive refocusing NASA on

exploration and discovery, so perhaps we'll get there even sooner.

A new interest in space would also increase the public standing of science generally. The low esteem in which science and scientists are held is having serious consequences. We live in a society that is increasingly governed by science and technology, yet fewer and fewer young people want to go into science. A new and ambitious space programme would excite the young and stimulate them into entering a wide range of sciences, not just astrophysics and space science.

The same is true for me. I have always dreamed of space flight. But for so many years I thought it was just that, a dream. Confined to Earth and in a wheelchair, how could I experience the majesty of space except through imagination and my work in theoretical physics. I never thought I would have the opportunity to see our beautiful planet from space or gaze out into the infinity beyond. This was the domain of astronauts, the lucky few who get to experience the wonder and thrill of space flight. But I had not factored in the energy and enthusiasm of individuals whose mission it is to take that first step in venturing outside Earth. And in 2007 I was fortunate enough to go on a zero-gravity flight and experience weightlessness for the first time. It only lasted for four minutes, but it was amazing. I could have gone on and on.

I was quoted at the time as saying that I feared the human race is not going to have a future if we don't go into space. I believed it then, and I believe it still. And I hope I demonstrated then that anyone can take part in space travel. I believe it is up to scientists like me, together with innovative commercial entrepreneurs, to do all we can to promote the excitement and wonder of space travel.

But can humans exist for long periods away from the Earth? Our experience with the ISS, the International Space Station, shows that it is possible for human beings to survive for many months away from planet Earth. However, the zero gravity of orbit causes a number of undesirable physiological changes, including a weakening of the bones, as well as creating practical problems with liquids and so on. One would therefore want any long-term base for human beings to be on a planet or moon. By digging into the surface, one would get thermal insulation, and protection from meteors and cosmic rays. The planet or moon could also serve as a source of the raw materials that would be needed if the extra-terrestrial community was to be self-sustaining, independent of Earth.

What are the possible sites of a human colony in the solar system? The most

obvious is the Moon. It is close by and relatively easy to reach. We have already landed on it, and driven across it in a buggy. On the other hand, the Moon is small, and without atmosphere, or a magnetic field to deflect the solar-radiation particles, like on Earth. There is no liquid water, although there may be ice in the craters at the North and South Poles. A colony on the Moon could use this as a source of oxygen, with power provided by nuclear energy or solar panels. The Moon could be a base for travel to the rest of the solar system.

Mars is the obvious next target. It is half as far again as the Earth from the Sun, and so receives half the warmth. It once had a magnetic field, but it decayed four billion years ago, leaving Mars without protection from solar radiation. This stripped Mars of most of its atmosphere, leaving it with only 1 per cent of the pressure of the Earth's atmosphere. However, the pressure must have been higher in the past, because we see what appear to be run-off channels and dried-up lakes. Liquid water cannot exist on the surface of Mars now. It would vaporise in the near-vacuum. This suggests that Mars had a warm wet period, during which life might have appeared, either spontaneously or through panspermia (that is, brought from somewhere else in the universe). There is no sign of life on Mars now, but if we found evidence that life had once existed it would indicate that the probability of life developing on a suitable planet was fairly high. We must be careful, though, that we don't confuse the issue by contaminating the planet with life from Earth. Similarly, we must be very careful not to bring back any Martian life. We would have no resistance to it, and it might wipe out life on Earth.

NASA has sent a large number of spacecraft to Mars, starting with Mariner 4 in 1964. It has surveyed the planet with a number of orbiters, the latest being the Mars reconnaissance orbiter. These orbiters have revealed deep gulleys and the highest mountains in the solar system. NASA has also landed a number of probes on the surface of Mars, most recently the two Mars rovers. These have sent back pictures of a dry desert landscape. Like on the Moon, water and oxygen might be obtainable from polar ice. There has been volcanic activity on Mars. This would have brought minerals and metals to the surface, which a colony could use.

The Moon and Mars are the most suitable sites for space colonies in the solar system. Mercury and Venus are too hot, while Jupiter and Saturn are gas giants with no solid surface. The moons of Mars are very small and have no advantages over Mars itself. Some of the moons of Jupiter and Saturn might be possible. Europa, a moon of Jupiter, has a frozen ice surface. But there may be liquid

water under the surface in which life could have developed. How can we find out? Do we have to land on Europa and drill a hole?

Titan, a moon of Saturn, is larger and more massive than our Moon and has a dense atmosphere. The Cassini–Huygens mission of NASA and the European Space Agency has landed a probe on Titan which has sent back pictures of the surface. However, it is very cold, being so far from the Sun, and I wouldn't fancy living next to a lake of liquid methane.

But what about boldly going beyond the solar system? Our observations indicate that a significant fraction of stars have planets around them. So far, we can detect only giant planets, like Jupiter and Saturn, but it is reasonable to assume that they will be accompanied by smaller, Earth-like planets. Some of these will lie in the Goldilocks zone, where the distance from the star is in the right range for liquid water to exist on their surface. There are around a thousand stars within thirty light years of Earth. If 1 per cent of these have Earth-sized planets in the Goldilocks zone, we have ten candidate New Worlds.

Take Proxima b, for example. This exoplanet, which is the closest to Earth but still four and a half light years away, orbits the star Proxima Centauri within the solar system Alpha Centauri, and recent research indicates that it has some similarities to Earth.

Travelling to these candidate worlds isn't possible perhaps with today's technology, but by using our imagination we can make interstellar travel a long-term aim—in the next 200 to 500 years. The speed at which we can send a rocket is governed by two things, the speed of the exhaust and the fraction of its mass that the rocket loses as it accelerates. The exhaust speed of chemical rockets, like the ones we have used so far, is about three kilometres per second. By jettisoning 30 per cent of their mass, they can achieve a speed of about half a kilometre per second and then slow down again. According to NASA, it would take as little as 260 days to reach Mars, give or take ten days, with some NASA scientists predicting as little as 130 days. But it would take three million years to get to the nearest star system. To go faster would require a much higher exhaust speed than chemical rockets can provide, that of light itself. A powerful beam of light from the rear could drive the spaceship forward. Nuclear fusion could provide 1 per cent of the spaceship's mass energy, which would accelerate it to a tenth of the speed of light. Beyond that, we would need either matter–antimatter annihilation or some completely new form of energy. In fact, the distance to Alpha Centauri is so great that to reach it in a human lifetime a spacecraft would

have to carry fuel with roughly the mass of all the stars in the galaxy. In other words, with current technology interstellar travel is utterly impractical. Alpha Centauri can never become a holiday destination.

We have a chance to change that, thanks to imagination and ingenuity. In 2016 I joined with the entrepreneur Yuri Milner to launch Breakthrough Starshot, a long-term research and development programme aimed at making interstellar travel a reality. If we succeed, we will send a probe to Alpha Centauri within the lifetime of people alive today. But I will return to this shortly.

How do we start this journey? So far, our explorations have been limited to our local cosmic neighbourhood. Forty years on, our most intrepid explorer, Voyager, has just made it to interstellar space. Its speed, eleven miles a second, means it would take about 70,000 years to reach Alpha Centauri. This constellation is 4.37 light years away, twenty-five trillion miles. If there are beings alive on Alpha Centauri today, they remain blissfully ignorant of the rise of Donald Trump.

It is clear we are entering a new space age. The first private astronauts will be pioneers, and the first flights will be hugely expensive, but over time it is my hope that space flight will become within the reach of far more of the Earth's population. Taking more and more passengers into space will bring new meaning to our place on Earth and to our responsibilities as its stewards, and it will help us to recognise our place and future in the cosmos—which is where I believe our ultimate destiny lies.

Breakthrough Starshot is a real opportunity for man to make early forays into outer space, with a view to probing and weighing the possibilities of colonisation. It is a proof-of-concept mission and works on three concepts: miniaturised spacecraft, light propulsion and phase-locked lasers. The Star Chip, a fully functional space probe reduced to a few centimetres in size, will be attached to a light sail. Made from metamaterials, the light sail weighs no more than a few grams. It is envisaged that a thousand Star Chips and light sails, the nanocraft, will be sent into orbit. On the ground, an array of lasers at the kilometre scale will combine into a single, very powerful light beam. The beam is fired through the atmosphere, striking the sails in space with tens of gigawatts of power.

The idea behind this innovation is that the nanocraft ride on the light beam much as Einstein dreamed about riding a light beam at the age of sixteen. Not quite to the speed of light, but to a fifth of it, or 100 million miles an hour. Such

a system could reach Mars in less than an hour, reach Pluto in days, pass Voyager in under a week and reach Alpha Centauri in just over twenty years. Once there, the nanocraft could image any planets discovered in the system, test for magnetic fields and organic molecules and send the data back to Earth in another laser beam. This tiny signal would be received by the same array of dishes that were used to transit the launch beam, and return is estimated to take about four light years. Importantly, the Star Chip's trajectories may include a fly-by of Proxima b, the Earth-sized planet that is in the habitable zone of its host star, in Alpha Centauri. In 2017, Breakthrough and the European Southern Observatory joined forces to further a search for habitable planets in Alpha Centauri.

There are secondary targets for Breakthrough Starshot. It would explore the solar system and detect asteroids that cross the path of Earth's orbit around the Sun. In addition, the German physicist Claudius Gros has proposed that this technology may also be used to establish a biosphere of unicellular microbes on otherwise only transiently habitable exoplanets.

So far, so possible. However, there are major challenges. A laser with a gigawatt of power would provide only a few newtons of thrust. But the nanocraft compensate for this by having a mass of only a few grams. The engineering challenges are immense. The nanocraft must survive extreme acceleration, cold, vacuum and protons, as well as collisions with junk such as space dust. In addition, focusing a set of lasers totalling 100 gigawatts on the solar sails will be difficult due to atmospheric turbulence. How do we combine hundreds of lasers through the motion of the atmosphere, how do we propel the nanocraft without incinerating them and how do we aim them in the right direction? Then we would need to keep the nanocraft functioning for twenty years in the frozen void, so they can send back signals across four light years. But these are engineering problems, and engineers' challenges tend, eventually, to be solved. As it progresses into a mature technology, other exciting missions can be envisaged. Even with less powerful laser arrays, journey times to other planets, to the outer solar system or to interstellar space could be vastly reduced.

Of course, this would not be human interstellar travel, even if it could be scaled up to a crewed vessel. It would be unable to stop. But it would be the moment when human culture goes interstellar, when we finally reach out into the galaxy. And if Breakthrough Starshot should send back images of a habitable planet orbiting our closest neighbour, it could be of immense importance to the future of humanity.

In conclusion, I return to Einstein. If we find a planet in the Alpha Centauri system, its image, captured by a camera travelling at a fifth of light speed, will be slightly distorted due to the effects of special relativity. It would be the first time a spacecraft has flown fast enough to see such effects. In fact, Einstein's theory is central to the whole mission. Without it we would have neither lasers nor the ability to perform the calculations necessary for guidance, imaging and data transmission over twenty-five trillion miles at a fifth of light speed.

We can see a pathway between that sixteen-year-old boy dreaming of riding on a light beam and our own dream, which we are planning to turn into a reality, of riding our own light beam to the stars. We are standing at the threshold of a new era. Human colonisation on other planets is no longer science fiction. It can be science fact. The human race has existed as a separate species for about two million years. Civilisation began about 10,000 years ago, and the rate of development has been steadily increasing. If humanity is to continue for another million years, our future lies in boldly going where no one else has gone before.

I hope for the best. I have to. We have no other option.

The era of civilian space travel is coming. What do you think it means to us?

I look forward to space travel. I would be one of the first to buy a ticket. I expect that within the next hundred years we will be able to travel anywhere in the solar system, except maybe the outer planets. But travel to the stars will take a bit longer. I reckon in 500 years, we will have visited some of the nearby stars. It won't be like *Star Trek*. We won't be able to travel at warp speed. So a round trip will take at least ten years and probably much longer.
