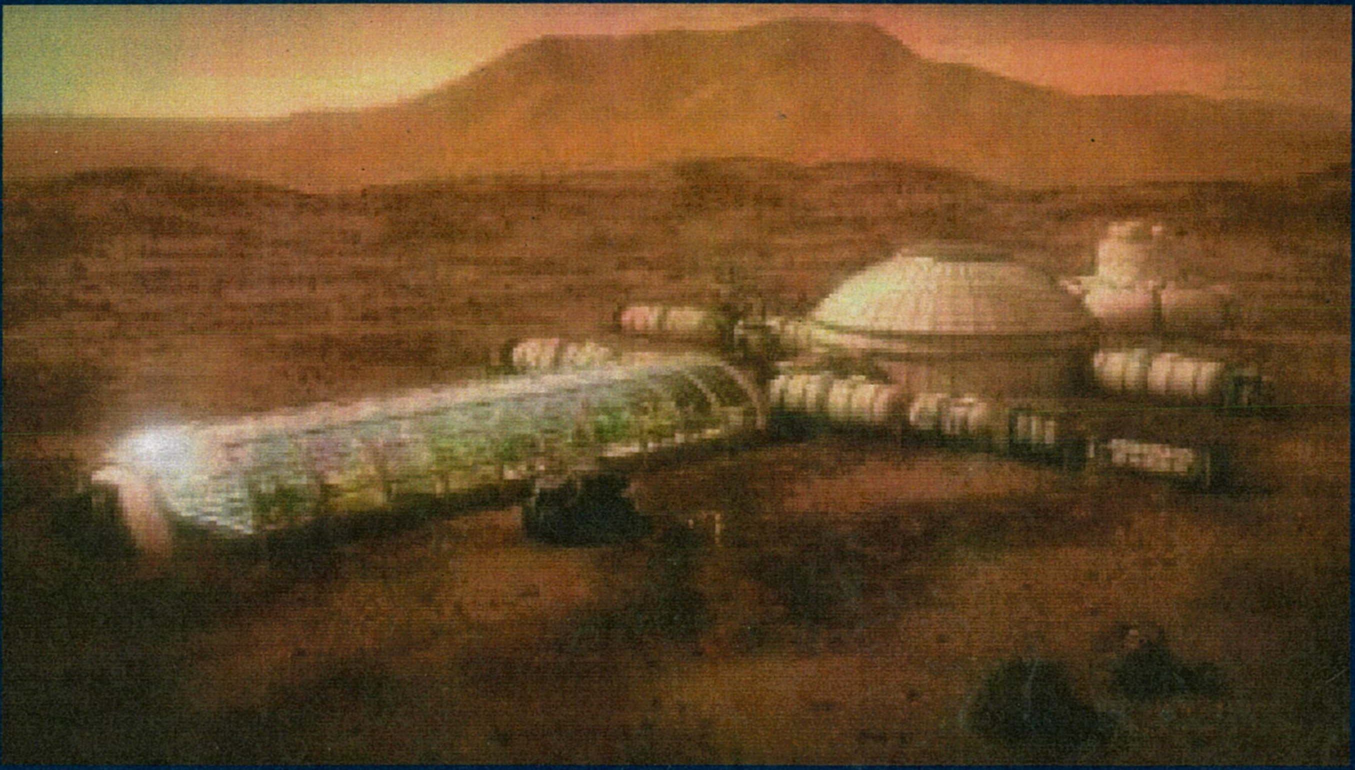
Planet Colonisation



What Are the Chances of Humans Colonising Other Planets?

Independent Study 2018

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Introduction

Have you ever dreamed of living among the stars? Maybe on Mars where you might be seven feet tall and eat food twice its normal size? Well, in my Independent Study I will explore this dream and look at the chances of it becoming a reality. It is a topic that provokes many different opinions. Some, such as Stephen Hawking, think it will be essential to human survival: he said we must colonise another planet within one hundred years to survive. Others think that trying to colonise other planets would be a colossal waste of time and money.

It may be that we need to colonise other planets sooner rather than later. In Part One, I explore the threats to Earth that may force us off-planet. Climate change and overpopulation are threatening to end life on Earth as we know it, but even if we don't have to leave Earth there are other benefits, such as access to minerals and new scientific discoveries. There are also some complexities, such as ethical, political, and legal problems which I explore in Part One.

In getting to other planets, some of the challenges may seem insurmountable: just transporting large groups of humans safely between planets will cost a lot of money and might require revolutionary propulsion technology. I examine these challenges in Part Two, exploring the technology of rocket propulsion and current plans to get us to other planets. And once we get to another planet, we will have to find ways to live there: we will need systems for mineral resources, oxygen, food, and a host of other things. I look at this in detail in Part Three. It will take a great amount of financial input from many sources to build a colony on another planet.

Recently there has been a great amount of activity around colonising planets, especially Mars. Many people, including Elon Musk and Bas Lansdorp, are racing to get there first. Interestingly, NASA are interestingly less prominent in this rush to set foot on the red planet but have other plans with big implications. The Deep Space Gate could change space travel forever. One thing is for certain: the next few decades are likely to see huge advances in human presence in space. Planet colonisation is the next space race.

But what are the chances of humans successfully colonising other planets? This is the big 'So What' question that I tackle in this study. Many a sci-fi film or novel has envisioned humans on other planets, from *Star Wars*, to *The Martian*, and *Star Trek*. There is no question that planet colonisation captures our imaginations. But could this ever be a reality? Where are we now? And how long might it be until we get there?

Part One

Why Might We Colonise Other Planets?

Threats to Human Life on Earth

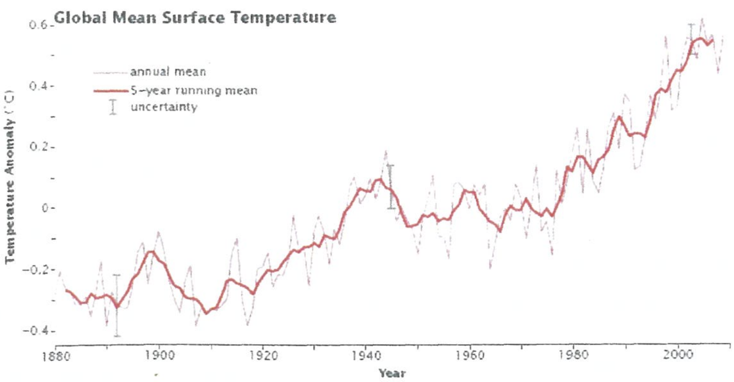
One of the major reasons planet colonisation has recently been under the spotlight is because many people believe that it is essential for the survival of the human race. Both Elon Musk (the founder and CEO of SpaceX) and Stephen Hawking are absolutely adamant that human life on Earth will, one way or another, end.

Many people believe that this idea is completely irrational and is just people fear-mongering. One of many points they make is that it's easier to survive on Earth than to go to a whole new planet. In this section, I will be identifying potential threats to humans on Earth and the damage they might cause. I will then give my analysis on the state that humanity might be in after a major disaster and its chance of pulling through.

Climate Change

Over the last few decades climate change has become a widely recognised problem. Climate change is a rare case of a world issue where many people will at least create the illusion of taking action. Whether you stop using plastic bags, or give up certain dairy products you are doing only a tiny bit of good towards slowing climate change and it is nowhere near enough.

In the early 20th century it was widely believed that an area's climate could change but only because of local activities. For example, cutting down a forest. However in 1958 some precise measurements of carbon dioxide (CO_2) in the atmosphere found that the global temperature was steadily rising. This information was supported by many studies in the years to come. These studies did begin to show that an increase of greenhouse gases was, in fact, warming the climate. At this point there still wasn't much attention drawn to the warming climate; the increases in temperature were minuscule and didn't seem to be a problem. The topic finally gained attention from the media and many scientists during the 1980s when there was a large spike in global temperature. This attention from the media began to raise public awareness and for the first time people began to see the true risk of climate change.

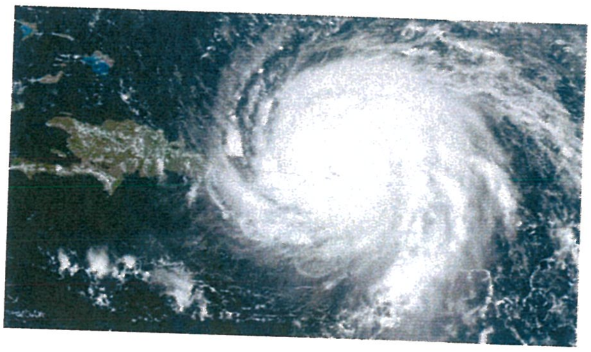


A mapping of climate from 1880-2010.

The cause of climate change is an increase in greenhouse gases in the atmosphere. Human activities are constantly producing greenhouse gases. Cars and factories produce CO_2 which is responsible for the majority of global warming because of the sheer amount we produce. And other industries such as the dairy industry produce methane which is an extremely potent greenhouse gas. Greenhouse gasses trap the Sun's heat and, consequently, warm the climate.

One current effect of climate change, which will become even more pronounced in the future, is reduced food security. In future farmers will have to tackle many issues from decreased nutrients to problems with water availability. All of this comes with a side of an increase in droughts and floods which can kill a farmer's entire crop. Climate change is also expected to have a negative impact on animal farming and fishing for much the same reasons. At the rate we are going, US corn production could have its yield cut in half by the end of the century. If we do not slow climate change we could run into huge problems with food supply, a problem which, as I will cover soon, is intensified by our rising population.

Another current effect of climate change is an increase in severe storms. Humidity is one of the main fuels for storms. Climate change is evaporating more water and increasing global humidity. This is increasing, and will continue to increase, the frequency and intensity of dramatic weather events, especially cyclones. The effects of this are already being seen around the world, especially in the US and Pacific Islands which have been battered by many large storms over the last couple of years. A single cyclone can cause billions of dollars in damage and kill many people. In future these cyclones are obviously going to be a big problem.



Hurricane Ima, a Category Five storm heading for Puerto Rico.

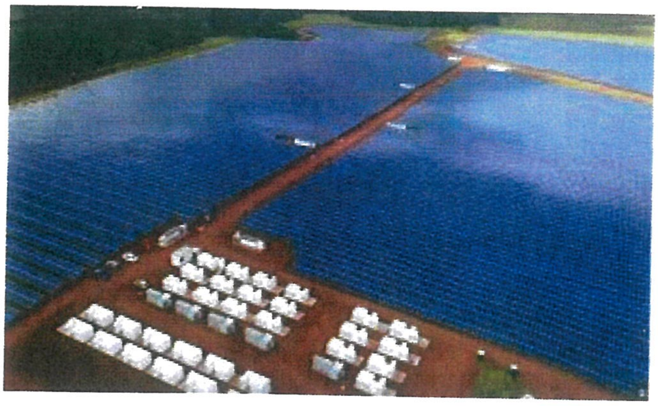
Another effect of climate change is sea level rise. While in New Zealand this may have little effect on most of us due to our mountainous terrain, it is having pronounced effects on some areas of the world. Sea level rise is being caused by two things. When water heats it expands in a process called thermal expansion. This is currently happening with climate change and is a major contributor to sea level rise. The other cause of sea level rise is the melting of the polar ice caps. This is releasing more water into the sea and causing sea levels to rise further. Another effect of melting ice caps is the release of CO_2 which has been trapped in Arctic permafrost. A lot of the ice in the Arctic has been there for many years and holds trillions of tons of CO_2, more than the amount currently in our atmosphere. It would be disastrous if we release this into our atmosphere.

Some of the large countries which will feel the effects of sea level rise include China, India and the US. In total 1-2 billion people could be displaced by sea level rise by the end of the century. The rest of the world isn't ready to deal with this many refugees and if we fail to slow climate change this will be a global refugee crisis, which could strain areas which may already be having problems with food due to climate change.

The final effect of climate change that we need to talk about is the runaway greenhouse effect. Water vapour is actually a greenhouse gas and as the temperature rises, more water vapour enters the atmosphere. This causes the climate to warm and, in turn, causes more water vapour to be evaporated. It is a vicious cycle and if we start the runaway greenhouse effect the results could be catastrophic. The planet Venus is thought to have once been Earth-like and to have had oceans. It is thought then to have suffered from the runaway greenhouse effect. Nowadays Venus has a surface temperature of about 462 degrees Celsius and a surface pressure 90 times that of Earth. If we trigger the runaway greenhouse effect it would not be an overstatement to say that all life on Earth would probably die out.

On the bright side, many people are beginning to realise the true dangers of climate change. All over the world countries are beginning to introduce policies to slow the onset of climate change. The historic Paris Climate Accord brought nearly the entire world into agreement that something has to be done and it has to be done now.

Aside from small acts like giving up plastic bags there are many ways in which the world has begun to stop climate change. Two great examples of this are the development and sale of electric and hydrogen cars and large efforts to increase our production of renewable energy (solar, wind, nuclear, etc). As all of these things become more pronounced it will help greatly to slow the onset of climate change. The problem is, however, that all of these changes come at a massive cost. A full global switch to renewable energy alone would cost over 100 trillion dollars. If we were to really care about climate change these costs could be met, but at the moment it isn't an immediate problem so people don't see it as something we should spend hundreds of trillions of dollars on. This is a mindset we need to change because although it will only have catastrophic effects in a few decades at the earliest, if we wait much longer to enact change we will no longer be able to solve the problem.



Tesla solar farm and batteries.

Once we stop pumping greenhouse gases into the atmosphere they won't just disappear. No, nearly all of the gases we've released will linger there for centuries. There are, however, some plans for how to backtrack and reverse what we have already done. One promising idea is the use of plant life to reclaim the CO_2 we have released. Plants absorb CO_2 and produce oxygen. If we could stop cutting down forests and begin replanting them, it would suck tons of CO_2 out of the atmosphere. This is really something we need to do because currently it is the only feasible way for us to reverse the effects of what we have already done, and what we will do in the future.

Climate change is a potentially devastating problem because it affects nearly everything and I mean everything, plus if we hit the runaway greenhouse effect it could be the end of life on Earth. If we address it properly now we will have a very good chance to balance our climate but even if we do so we have to keep our attention fixed on it. Due to the great cost this issue needs to be put past politics so that the world can tackle this as a whole. If, however, we don't act now it could be too late to reverse what we've already done. If we do not act now climate change could make Earth uninhabitable.

Overpopulation and Food/Resource Shortages

With the rapid growth of the human population on Earth we need to address the fact that the Earth holds limited resources. Over recent years we have become aware of the fact that the world's oil and other fossil fuels are running out. This is the earliest sign of what is to come. As the population expands we need to build more of everything which in turn forces us to use more land and to extract more of the Earth's natural resources. According to a 2017 study the human population on Earth could be too big to feed itself by 2050. It is also expected that other resources like minerals will run out at a similar point.

Let's look at the food situation. Currently, as the population expands, there are more mouths to feed and housing is beginning to swallow valuable farmland. On top of this, climate change is making it so that food can no longer be grown in some areas of the world. When seen together these problems make it seem obvious that we are going to have a food crisis some time in the future, and maybe before too long.

Some ideas are being circulated about how we might solve this problem. One of the more out there ideas is to build skyscraper farms. A design was made in 1999 by Columbia University Professor Dickson Despommier for a thirty story building the size of a city block. On each level there would be a hydroponic farm, a system where there is no soil and the plants are grown in nutrient rich water. It will use intense artificial lighting in the place of sunlight and a one acre street level area of skyscraper farm will have the yield of over six acres of ordinary farmland. However, the design is not without fault. It would take a vast amount of energy to produce food this way. It would require about one hundred times the electrical needs of an ordinary office building. This is needed to power the lights and give enough fake sunlight to the plants. Lighting is the biggest energy requirement and with a host of smaller power-using items, a sturdy power grid would be needed to support one of these buildings. Also, while some plants such as tomatoes thrive, others such as grain can not be grown to such a high standard in a hydroponic farm.

Another part of the solution to food problems may be a major reduction in animal farming. Animal farming is much less efficient than farming crops. This is because it takes a larger land area, and less of the food and water that you give an animal is returned in edible form.

The materials problem is harder to solve. Even Earth's current population could not be sustained indefinitely without huge changes. Running out of oil and gas could cause some major issues. Nowadays we mainly use oil and gas primarily for electricity and vehicles, as well as synthetic materials such as plastic. Were we to run out of these fossil fuels now most of the world's electricity and transport would be down. This would cause major issues no matter which way you look at it.

Fossil fuels cannot be recycled or produced so we need to make some major changes to the way we generate electricity and traverse the world. The problem is, while we have a lot of the technology to change, the cost is immense. Experts predict that a worldwide change to renewable energy sources, such as wind and solar, would cost about 100 trillion dollars over a 20 year span (accounting for rise in demand and essential upgrades to the power grid). This cost is about equal to the world's combined GDP. Despite this huge cost we need to begin doing something to solve the problem or the consequences could be something that money can't solve.

If we are trying to save life on our planet, one of the first things we should be trying to do is to switch over to electric cars. All over the world governments are already trying to encourage this, by building free charging stations and offering tax incentives for the creation and purchasing of electric cars. In terms of the electricity problem there is a new type of power generation in development called fusion energy. I cover this in detail in Part Three and it could also be of great use on Earth due to its high energy production for only a small amount of hydrogen fuel.

While oil and gas is used to make plastic, plastic production accounts for a very small percentage of our oil consumption (about 4% globally). If we were to stop using these fossil fuels for other means there will be enough for plastic for a long time. Still, even if there isn't enough we have part of a solution. Bioplastics are a type of plastic which substitute fossil fuels with plant products such as vegetable fats, oils and corn starch. Bioplastics have pros and cons. They are made from renewable sources with a bonus of being biodegradable; however, they are often not as durable as plastic made the traditional way.

Mineral shortages could become a major problem in the long term because we are stuck with what we've got. Unless we detonate the sun (great solution eh?). Certain minerals are essential for our technology and way of life. We simply can't do without them. Although the Earth holds enough minerals to sustain humans for centuries or even millennia it is expected that economic reserves could run out in about 30-50 years. This means that what remained would be buried deep underground and very hard to extract. If left unchecked this could potentially lead to armed conflict over access to the remaining economic reserves, and many other problems.

One of the very few solutions that have been suggested actually involves planet colonisation. It is possible that we could import resources from other planets to sustain some of the Earth's needs. It is thought that importing some valuable minerals, such as titanium, could be profitable within a few decades. I cover this idea in more detail soon in Benefits of Planet Colonisation.

Overall the Earth's resources running out could become a much larger issue than I previously thought. Of the threats I cover in this section we have the most control over whether or not it will be a problem, but if we fail to find a solution to these problems it could lead to a breakdown of modern society.

Nuclear War

Other threats to human life on earth could have more immediate, and equally catastrophic effects. Ever since the invention of the atomic bomb in World War Two the threat of nuclear annihilation has been ever present. The atomic bomb is the most powerful weapon known to humankind and can render land uninhabitable for a very long time due to radiation. Ever since the first atomic bombs dropped all major nations have rushed to have the largest arsenal of these weapons. Nowadays there is believed to be over 1500 nuclear weapons in the world. The most powerful of these has a yield of over 50 megatons or the explosive equivalent of 50,000 tons, that is 50,000,000 kilograms, of TNT.

So what would happen if a nuclear war was to happen? Well the direct blast of the nuclear bombs could wipe out major cities all over the world killing millions of people. The nuclear bombs would also release radiation which would kill many more people for weeks or even months after the bombs detonated.

The most terrifying thing, however, is that the worst would be still to come. When a nuclear bomb detonates, the force of the blast throws dust particles into the atmosphere. This can block out the sun and cause Earth's temperature to drop significantly. A recent study predicts that if 50-100 small-ish nuclear warheads were to be used, the resulting changes in the Earth's climate could cause over one billion people to die of starvation alone. If the world's entire nuclear arsenal were to be used we could start something called nuclear winter. Nuclear winter is a theoretical situation where nuclear detonations send so much dust into the atmosphere it completely blocks out the sun and causes an ice age. Were this to happen it is likely that the vast majority of the Earth's population would die, killed either directly from the nuclear bombs that would be used, or the ice age that followed it. The point is any nuclear war would have major catastrophic effects and certainly be the end of Earth and maybe civilisation as we know it.

On the bright side there are many things that make this unlikely. Firstly, people are very aware of the destructive power of nuclear weapons and the world's leaders are extremely cautious when it comes to handling them. Over the past few decades there have been some major movements to stop the construction and development of nuclear weapons as well as beginning to dismantle nuclear arsenals. Some of the groups have managed to gain some major publicity especially in the 1980s coming out of the Cold War.

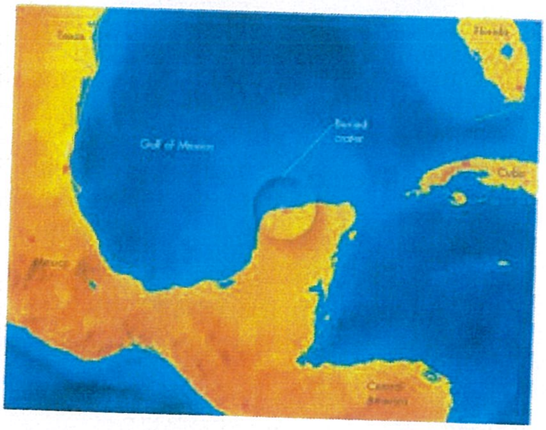
A nuclear bomb.

Overall, I think that it is unlikely that there will be nuclear war, but who knows? Someone might be a bit hasty to press the big red button. Although it is unlikely to happen human life as we know it would have very little chance of surviving a nuclear war.

Impact With Extraterrestrial Object

An impact with an extraterrestrial object was the end of the line for the dinosaurs and it may be so for us too. Most asteroids, comets or other objects, bent on descending from the skies and destroying us, are burnt up in that handy shield, the atmosphere. While most never get a glimpse of the Earth's surface the odd one comes prepared with enough mass and bulk to get past our shield and smash into the ground. Lesson #1 is never totally rely on the atmosphere. The dinosaurs learnt this the hard way when a space rock smashed its face so hard into the ground, that the dinosaurs were blasted into history.

When an object enters the atmosphere at high speed the friction with the air begins to heat the object to an extreme level. This friction also causes the object to break into smaller pieces which are soon vaporised by the heat. So, while our atmosphere is more than adequate at stopping small meteorites and old satellites falling back to Earth, a larger asteroid could get through and have extinction-level results. It is now widely accepted that the dinosaurs were killed by a comet which struck the Earth, but what did it do to kill the dinosaurs? Most research suggests that when the asteroid struck it had an effect similar to nuclear bombs that I talked about earlier. When the asteroid hit the Earth it threw up so much dust into the



atmosphere that it caused an ice age. To sense of the size the crater, located of the co Mexico, is about 150 kilometres wide ar kilometres deep, a significant distance int Earth's crust. The deepest hole that we have dug is just 9.1 kilometres deep.

Location of the Chicxulub crater off the coast of Mexico

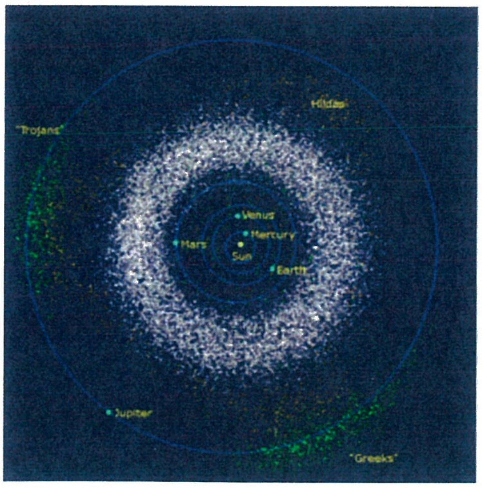
One important aspect of an asteroid impact is that it is an externally generated event anc can have little to no influence on it happening. Were the Earth to be struck by an asteroid similar size to the one that wiped out the dinosaurs, the majority of the human popula would likely die of starvation. We are simply not prepared for the effects of an aste impact.

Benefits of Planet Colonisation

Apart from survival, there are a number of great arguments for planet colonisation. On an undefined timeline the colonisation of other planets seems a natural and essential step for our species. Were we to stay on Earth, we would always be limited to what is available here. Were we to colonise other planets, there would be more resources and new scientific discoveries: it would be a more exciting and progressive future for our species. Think about it this way: if we colonise other planets the sky truly is the limit.

For an example of the potential profit of planet colonisation all you have to do is take a look at the Moon. The Moon has large deposits of titanium, iron and aluminium and it has been suggested that processing those resources and selling them on Earth could be profitable within a matter of decades. The Moon also has another resource called helium-3, a rare isotope of helium valued at around 40,000 dollars an ounce. For comparison gold is currently valued at around 1,200 dollars an ounce. Helium-3 has the potential to be used in fusion reactors, for extremely efficient generation of electricity. (For more details, see Part Three.)

It has also been suggested that the main asteroid belt (between Mars and Jupiter) could be mined to great profit. There is an estimated seven quintillion dollars worth of resources inside the asteroid belt. That number looks like this: 700,000,000,000,000,000,000. It is not yet profitable to mine these resources, but it seems inevitable that eventually mining these resources on other planets will be profitable. This economic opportunity will come as technology improves, demand increases, and supply on Earth decreases. Mining minerals may actually be profitable sooner rather than later. As I covered in Threats, the Earth's economic reserves of some minerals, such as zinc, gold, and lead, are set to run out by 2050.



The location of the main asteroid belt.

Mining raw minerals isn't the only way a profit could be made in space. In low gravity atoms structure themselves differently. This would allow us to make different materials, potentially the most interesting of which are materials formed into large crystalline structures. This allows for the creation of more efficient fiber optic cables and solar panels, as well as more conductive and stronger materials. This production is most effective in microgravity (basically open space) but the low gravity of most planets in the solar system could still be used to produce higher quality materials than we can make here on Earth. This type of industry alone is unlikely to fuel planet colonisation (at least in the near future), but coupled with the production and import of valuable minerals, it could make planet colonisation a much more worthwhile endeavor.

There are, however, other things to consider about the economic potential of planet colonisation. Realistically, no one will colonise a planet until there is profit to be made. Until that point no person, company, or government will have the incentive to do so. Also, until it is profitable, the cost of planet colonisation is a major drawback. This is because it will likely cost tens to hundreds of billions of dollars just to establish the smallest possible self sustaining colony on another planet. This money could be put to great use on Earth solving many of the problems we have here, as I covered in the previous section. Essentially, history tells us that large-scale human endeavors almost always follow economic opportunity and the promise of greater riches.

Another benefit of planet colonisation is that it will allow for much more thorough exploration of any target we go to. It has been suggested that the earliest human presence on another planet is comparable to human exploration and settlement in Antarctica. Since the first exploration of Antarctica in the early 20th century, research in Antarctica has been teaching us a lot about our world. Atmospheric research is looking at the Earth's weather systems, and geological research has also revealed new information, especially clues into the early continental movements of the Earth. Research of a similar kind on other planets could have much the same purpose, teaching us about the geology and atmosphere of these planets. Not only could we learn a lot more about individual planets, but we could also learn about the formation of the solar system and the Earth.

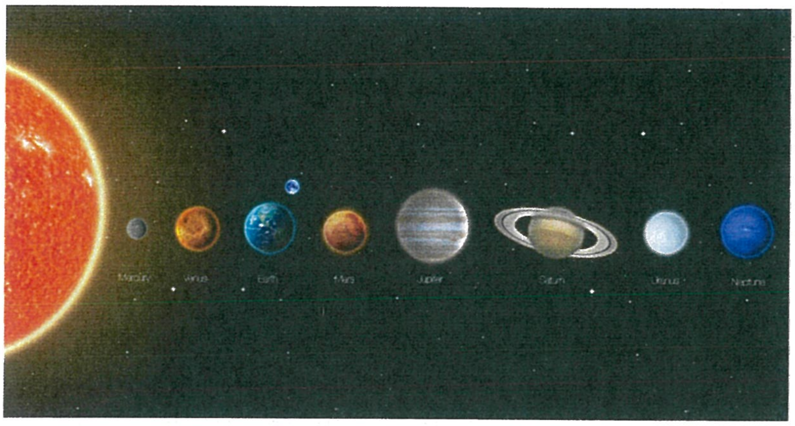
Planet colonisation also has great technological potential. It will force the development of new technologies and lead to the discovery of new materials, such as the crystalline structures I mentioned earlier. Many technologies that are commonplace today were actually developed for use in space. For example: freeze drying was greatly improved upon by NASA to provide meals for astronauts, memory foam was invented to keep astronauts safe from the G forces of a rocket launch, and even systems for removing bacteria and toxins from food were greatly improved upon for the safety of astronauts in space. I think these examples highlight how something developed to solve a difficult problem in space or on another planet may also be of great use to regular civilians down on Earth.

Targets for Planet Colonisation

So what places might we colonise?

I am going to focus here (and in my Independent Study as a whole) on planet colonisation within our solar system, for reasons that will become clear in the next section.

There are a few features of targets for planet colonisation that I will take into consideration through this section. The first of these is their atmosphere. On Earth our atmosphere allows us to breathe, keeps us warm, and puts some pressure on our bodies. No other place in the solar system has a survivable atmosphere so colonists will need to live in habitats (buildings which maintain pressure and atmosphere) to survive. Still, a location's atmosphere can provide small amounts of oxygen for a colony if it is present in the atmosphere. The presence of water on a planet is also important as we need it to survive, and we can take oxygen from that water. And finally the presence of a magnetic field can help to reduce the amount of radiation that reaches the surface of a planet. One thing to note about these magnetic fields is that they deflect radiation but some of it gets captured in belts around a planet.



Planets of the solar system in relation to the sun.

The Terrestrial Planets

Of the eight planets within our solar system only four have a solid surface. These four planets are Mercury, Venus, Earth, and Mars, and have been named the terrestrial planets. I will talk about Mercury and Venus here but I am giving Mars its own section.

Let's start with Mercury. Mercury is the closest planet to the sun and orbits it every 87.9 Earth days. Mercury is very small but quite dense and has a surface gravity 38% that of the Earth's. Mercury has no atmosphere and due to its proximity to the sun, is not a good target for planet colonisation. Its surface temperature gets up to 427 degrees Celsius under the direct glare of the sun. It is also bombarded by much more radiation than any other planet. Both the radiation and temperature would destroy a lot of a colony's equipment and don't get me started on what would happen to the colonists. Overall, Mercury is not a good location for a colony.

What about Venus? Named after the Roman goddess Venus (better if I don't specify her traits), Venus is the second closest planet to the sun. It orbits the sun every 224.7 Earth days and rotates every 223 Earth days, the longest in the solar system. This means it has approximately 1.008 of its days in each of its years. It also rotates the opposite direction from the Earth meaning on Venus the sun rises in the west and sets in the east. On average Venus is 40 million kilometres from Earth and at its closest it is 38 million kilometres from Earth, making it the closest planet to the Earth.

The planet Venus.

Venus is similar to the Earth in some respects. It is a similar size and mass to the Earth giving it similar gravity. However in many other aspects it is a very different cookie. Venus has the densest atmosphere of all four terrestrial planets in the solar system. It has a surface pressure 92 times that of Earth's, or the equivalent of being one kilometre underwater.

Probably the biggest issue with colonising Venus is surface temperature and pressure. The atmosphere of Venus is comprised of 96 percent carbon dioxide. Carbon dioxide or CO_2 is the main gas causing global warming on Earth. This overwhelming percentage of CO_2, combined with the density and size of Venus's atmosphere, results in an average surface temperature of a toasty 462 degrees Celsius. Pretty nice huh? This temperature and surface pressure means that anything that lands there doesn't last very long. In fact we have only ever managed to make a lander last two hours on the surface. This was done in 1981 by the Soviet probe Venera 13. It was able to transmit data for 127 minutes after reaching the surface of Venus. Interestingly it is thought that Venus used to be an Earth-like planet before suffering the runaway greenhouse effect which I explained earlier. So we better work on climate change or we could be in for a high of 460 degrees Celsius, here on Earth, too.

Due to this heat and pressure it would be near impossible to land humans on the surface of Venus, let alone build a colony there.

The Moon

Earth's Moon is a very promising option for a colony. The Moon does not have a magnetic field or atmosphere to protect it from radiation. It does, however, have lots of water ice in craters near its poles. The Moon also has oxygen and other gases infused in its soil. On top of this there are ancient lava tunnels on the Moon from when it was first formed. These can be used to put a colony underground. I explain the importance of this in Part Three.

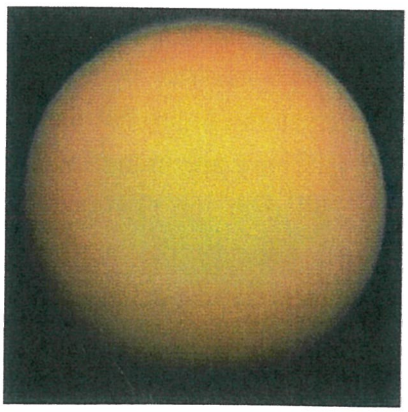
Due to the Moon's proximity to Earth, transport will be cheaper than anywhere else, lowering the overall cost of building a colony there. Also, as I said earlier, the Moon has many resources which could be mined economically. This economic opportunity makes it a much more promising location for a colony. The Moon is quite small with a diameter of just 3,474 km (the Earth has a diameter of 12,742 km). This means it will not be able to sustain as many people as Earth but it could still support many thousands, if not millions of people. Overall the Moon is a very good option for planet colonisation.

Ice and Rock Moons

Aside from Earth's moon there are a few moons orbiting some of the further planets of our solar system which we could colonise.

The most prominent of these moons are the Galilean moons orbiting Jupiter. These moons were first spotted by Galileo in 1610, hence the name. These moons are Io, Europa, Ganymede, and Callisto. None of these moons have an atmosphere or their own magnetic field but all of them are within Jupiter's magnetic field. Both Europa and Ganymede have a crust mostly made of water ice. Callisto is about an even split between water ice and rock. And finally Io has a rocky crust and a lot of volcanic activity. One great factor of three of these moons is the large presence of water ice which could easily sustain a colony. They also fall within Jupiter's magnetic field reducing the amount of radiation they receive, although Io sits within one of Jupiter's radiation belts. There are a few other moons orbiting the other planets of the outer solar system, but the Galilean moons are, overall, the best of all of them.

You may have heard of Saturn's moon Titan and about how it has rivers and oceans and could support human life. Well actually it probably couldn't. Titan has a thick atmosphere and is the only body in our solar system besides the Earth where liquid has been found on the surface. People who believe Titan is the best place to start a colony will point out its atmosphere and oceans but as always is important to look at the details. While Titan may have an atmosphere it is comprised of 97% nitrogen and trace amounts of other gases. Even a thick atmosphere does not stop it from sitting at a nice -179 degrees Celsius, so the atmosphere is of little benefit. The oceans observed on the surface are comprised of liquid ethane and methane (basically lakes of liquid fart) so are also of no benefit to a colony. Even so it is now known that there is water ice beneath the surface and potentially even a water ocean. There is some research pointing towards the possibility of existing or future life on Titan. It is unlikely that there is currently life on Titan but NASA has identified



Titan.

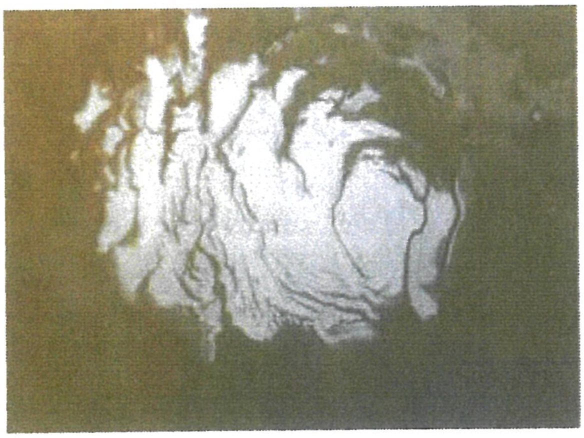
many organic compounds[1] which in the conditions on Titan could develop into new life. NASA has identified Titan as the place we are most likely to find life besides Earth. Overall Titan is a very unique moon but of little potential for a colony.

Mars

At present Mars is at the focal point of most plans for planet colonisation. And this is for good reason. Named after the Roman god of war, Mars is also the second smallest planet in the solar system, the smallest being Mercury. Like Venus, Mars is a terrestrial planet with a rocky surface and thin atmosphere. Mars is the fourth planet from the sun. At its closest it is 54.6 million kilometres from the Earth and it averages at 225 million kilometres away.

So why do people want to colonise Mars? Well as I mentioned earlier it has many similarities to Earth. Mars orbits the sun every 687 Earth days and a Martian day is just 34 minutes longer than our own. Mars is smaller than Earth and has less mass. This results in it having a gravitational pull of 0.4G or 40% of Earth gravity (Earth gravity is 1G). The Martian atmosphere is less than one percent of Earth's and on the surface it has a pressure of just 0.6 percent of Earth's or the equivalent of being 35 kilometres above sea level. This atmosphere is comprised of 95% CO_2 which is good for a potential colony because oxygen can be drawn from that CO_2. Because the atmosphere is so thin it is unable to capture enough heat to keep the temperature up. During the day the temperature can get as high as a comfortable 20 degrees Celsius but during the night it can get as low as minus 140 degrees Celsius. Mars lacks a magnetic field to protect it from radiation.

Mars has plenty of water if you know where to look. The main source of water on Mars is located at the two polar ice caps. The polar ice caps have a top layer of frozen carbon dioxide and then a whole lot of water below that. There are more than five million cubic kilometres of ice at the polar ice caps, enough to cover the entire planet in an ocean, but the predicted depth varies from 10-100 metres deep. So there is plenty of water at the poles but that's not quite the end of it. There are many small deposits of water ice all over the planet, and these are located just beneath the surface. Also, some craters have large sheets of ice at the bottom.



The Southern polar ice cap of Mars.

[1] An organic compound is simply a carbon-based compound where one or more carbon atoms is bonded with another non-metallic element, usually hydrogen, oxygen or nitrogen.

As an added bonus tests on Martian soil found it to be surprisingly hospitable to plantlife, and some crops could be grown in it inside pressurised spaces. This year a new Mars lander was launched by NASA called *Insight*. It is carrying an array of special equipment to study the internal structure of the red planet. Unfortunately it will not touch down until just after the school year finishes.

Currently, Mars is the most promising option for planet colonisation due to its large deposits of water, and also due to some other features which I will cover further in Part Three.

Outside the Solar System

In the previous section I said that I wouldn't be covering much about planet colonisation outside of the solar system in this Independent Study. This is because going outside the solar system raises a number of huge technical problems that are currently insurmountable.

The first, the largest, and pretty much the only one of these is distance. The closest solar system to our own is in Alpha Centauri which is a cluster of three stars and is 4.35 light years from our solar system. This means it would take 4.35 years travelling at the speed of light to reach Alpha Centauri. NASA will soon be launching a space probe to research the sun. During its flight it will reach a record speed of 692,000 kph. Travelling at that speed it would take over 6,800 years to reach Alpha Centauri. Obviously no ship could spend anything like that long in space and sustain human life. So realistically any colony ship attempting to travel to another solar system would need to travel at a very significant percentage of the speed of light. There are some ideas for how we might travel past the solar system but these are very speculative. Of course it's possible we may find a way to reach other solar systems sooner than we expect. Remember that 100-150 years ago no one had any clear idea of the technology that eventually let us land on the Moon. But at the moment it seems impossible.

If we did get to another solar system we would have problems with communication. We can send messages at the speed of light which is completely adequate for uses today. But once great distances are introduced it could become a problem. Within our solar system it wouldn't be a crippling issue - annoying, but not a huge problem. For example, Mars is an average of 14 light minutes from Earth. Astronauts would need to be able to find their own solutions if a time sensitive problem occurred but messages could still flow between a colony and Earth on a regular basis. Between solar systems this is a much bigger issue. You have probably already figured out that at the distance of Alpha Centauri to Earth it would take over four years for a single message to arrive at its destination. There are some solutions to this in early development, but although they look promising they are still decades off at the least.

Despite the problems I have talked about, going beyond the solar system is probably the long term goal of planet colonisation. If we are colonising to expand, push boundaries, and learn new things, going past our solar system is a natural step, if a huge one. Travelling to another solar system would truly be one enormous leap for (wo)mankind (come on it's 2018, we are a progressive society). Also if we are able to travel between solar systems much of the technology we need to live on planets within our solar system would not be needed. This is due to Earth-like planets in orbit of other stars called exoplanets, where we could live on the surface without technology being needed. Of course in these conditions other life could have developed on that planet which could make it unethical and deadly due to foreign life. Still there is an unquantifiable number of planets in orbit of other stars and some may not have developed life. Others would not be hospitable but would be viable targets for terraforming (for more detail, see Part Three). For this a planet would need a magnetic field, water in some shape or form, and either a atmosphere that needed to be thinned or frozen CO_2 to be added to its atmosphere. These may be some very specific conditions but due to the vast number of planets we would have access to there might be hundreds or even thousands that fill this description.

Although traveling to another solar system may be the eventual goal we are only just beginning to take our first steps towards it. In 2016 an operation called *Breakthrough Starshot* was started. Breakthrough Starshot intends to build a one gram space probe consisting of a camera, communications device, power source, and not much else. This payload will be connected to a light sail which can catch rays of light and solar wind for propulsion. A large laser array on Earth will then fire at the light sail and accelerate the craft to 15-20% the speed of light. This system is exponentially less effective as weight increases so it isn't viable for larger craft. This craft will be launched to Alpha Centauri and in the general direction of an Earth-like planet orbiting one of the stars. If this project succeeds it will give us our first up-close look at what is outside our solar system and it will be the very first step towards colonisation throughout the stars.

All in all, while travelling to other solar systems might be the ultimate goal, we currently don't have a way to reach other solar systems and it is currently too far off to see how we will achieve it.

The Ethics of Planet Colonisation

One argument against planet colonisation is that it may be unethical to colonise other planets. There is a lot to be said for this side of the matter. This is mainly the question of whether or not we have the right to go and disturb other planets and the life that might live there. Earth is our one and only property and we must do what we can here. There are, however, many points to be made on the other side of this issue. In this section I will investigate the ethics that may surround life on other planets, both within our solar system and beyond.

Within our solar system there are a surprising number of places that may have life, though none have been confirmed. It is possible that there is life deep within underwater oceans located on some of the moons of Jupiter and Saturn, and also on the surface of Titan, one of Saturn's moons. There is also liquid water deep inside one of the poles of Mars which could hold life.

Any organisms we find within our solar system will likely consist of no more than a few cells. Due to our lack of knowledge about the details of planets in other solar systems, it is impossible to predict the details of the life we might find but I will cover ethical problems for different stages in its evolution and traits it may have.

Now I will cover some of the different ethical theories and how ethics applies to non-human entities. There are three main theories for how to define whether an action is ethical. The first of these is *utilitarianism*, which is the idea that an action is ethical if it results in a bettering of your own wellbeing. The second is *deontology*, which is the idea that you act according to a moral duty, do unto others as you would have others do unto you (it's pretty much treat others how you want to be treated). The third is *virtue ethics*, or the idea that the motives behind an action determine whether or not it is ethical, and these motives must come from, and should be consistent with, one's character.

When it comes to the application of these to non-human entities there are four main theories. The first of these is *anthropocentrism*. This is the idea that no non-human entity has any ethical rights aside from utilitarianism. The next is *sentiocentrism* which is the understanding that all and only sentient beings have moral rights. 'Sentient' is defined as being able to have feelings and sensations. The third theory of application is *ecocentric holism*, which is the theory that all organisms have a moral standing and ethical rights. The final theory is that of *deep ecology* which is about being one with nature and any destruction of any life is the destruction of ourselves.

When it comes down to it, I think that ethical actions only matter to beings capable of some degree of sentience. If you do something kind for a cat it can appreciate your kindness. If you think about it, organisms without mind are simply matter which converts other matter to be as itself, and although that may be the goal of many sentient beings, the outcome of their actions has some meaning to them. For a sentient being there is a task to complete and the outcome has some meaning to them. For non-sentient organisms nothing in the universe holds any meaning to them. Actually non-sentient organisms have no purpose to themselves no ambition, and nothing to compel them into action. You really have to ask yourself why we are compelled to act ethically towards other humans and animals. I think this is because we empathise with them. We know what it is to feel pain and fear so we strive to banish those feelings from all dimensions possible and in all things. For these reasons I think that sentiocentrism is a very ethically understandable theory, and that only as a second priority to the prosperity of sentient beings we should strive to preserve non-sentient organisms.

Overall, I personally believe that deontology is a good theory for it provides good standards for ethical action and it is reflected in my earlier sentiment about how ethical action matters only to organisms with sentience. Deontology makes us set the standards of our ethical action towards others, based on how we would want to be treated. And since everyone wants others to treat them well this is a great way to set high ethical standards. Deontology is a great way to know how to act ethically towards other sentient beings.

Under this ethical conclusion the colonisation of planets with non-sentient organisms is fine and when it comes to sentient beings, a judgment will have to be made as to whether or not we should make contact based on many factors such as their level of technology, and other traits such as aggression. I would like to say that these ethical issues are an extremely complex matter and my opinion could be debated practically forever. I don't think we will ever have a perfect grasp of what's ethical and what's not but I have outlined some of the theories and given my own conclusion on them.

Some steps have been made to stop us from contaminating places with the potential for life. These steps have been taken under the COSPAR planetary protection treaty. COSPAR, which stands for Committee on Space Research, is a committee of the UN which advises it on space research matters and other scientific issues in space. COSPAR put forward a treaty which was passed in the UN basically saying that all countries must strive to avoid contaminating any scientific assets with bacteria and other organisms from Earth. The basis of this treaty was utilitarian and not about broader ethical concerns to do with the life we might find. As long as scientific samples were kept away from contamination in controlled conditions, the treaty's concerns around the spreading of Earth organisms would be diminished.

I hope I have enlightened you on the ethical issues of planet colonisation and have given you the information you need to form your own opinion. It is likely that with more and more interest in planet colonisation, the UN will have to be involved with many new treaties and laws, as I cover in the next section.

Current Law in Space

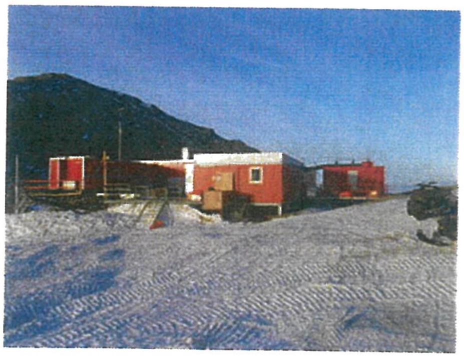
As soon as both America and the Soviet Union began launching objects into space in the late 1950s, the world soon realised that some law and regulation was needed in space. Throughout the 1960s and 70s there was a rush to put proper regulations around activities in space. The most important of these is probably the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, which outlines most of the laws that are present today.

Most of the current law making surrounding space comes from within the UN, overseen by the UN Committee on the Peaceful Uses of Outer Space. Many of the points in these agreements deal with the question of the ownership of space. These run that outer space shall be free for any state to explore. No celestial body can be claimed by any country or person; no one can have legal sovereignty in space. When it comes to use, the Moon and other celestial bodies must be used for peaceful purposes. These laws are an easy solution to the childish squabbles between nations about who owns which bit of land on other planets. But there is nothing specifically banning the exploitation of resources in space.

Some of the UN's agreements deal with the way we should act in space: astronauts shall be regarded as the envoys of humans. States shall be responsible for national space activities whether or not they were carried out by the government. States shall also be responsible for any damage caused by their space objects (collision with another object, crashing into another country's territory etc). States shall avoid the contamination of space and celestial bodies.

Some other agreements have been made around space but most of these are between communications companies to make sure they don't interfere with each other's broadcasting. The UN agreements are a good start but do not cover everything. The UN has recognised that as the mining and occupation of space become more realistic the laws must be reviewed and potentially changed.

I met with one of New Zealand's leading international lawyers Sir Kenneth Keith, who has been involved in international space law since space was first explored, and was on the International Court of Justice. He pointed out that many lawyers regard Antarctica as a legal equivalent with space. An example of this is a book on the legal comparison of Antarctica and space, written by Philip Jessup, who is a legal scholar. Both Antarctica and space are no one country's property and they can only be used for peaceful purposes.



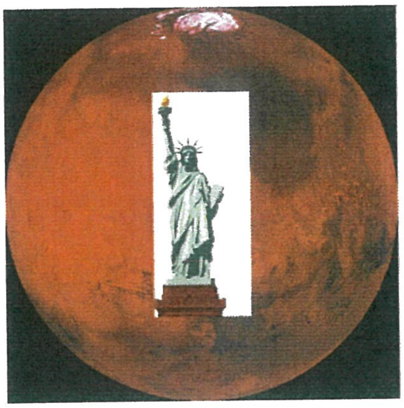
An Antarctic research station.

There was a point where many countries tried to stake their claim on different parts of Antarctica but none would recognise each other's claims. Eventually the UN passed a law making Antarctica the equal property of all, as it remains today. There is now a constant human presence in Antarctica but it is for scientific purposes. Likewise that is currently the main focus of humans in space. There has been some commercial activity in Antarctica but this is slightly contentious. It will likely be similarly contentious when commercial activity begins in space.

Future Space Law

The UN's agreements about space, particularly sovereignty, were made to stop conflict and war that would arise in arguments around colonisation. Given these laws were made partially to prevent 'colonisation' as such, some change would need to be made for a self governing colony to arise, owning its own territory. The UN treaties support the peaceful use of space for scientific or even commercial reasons, but they don't allow for a country or other group to claim territory as their own.

I began this study thinking of a colony as not necessarily owning land or being self-governing, in legal terms. I have instead been defining planet colonisation as being a permanent and self-sustaining human settlement or presence on another planet or moon. I am keeping this as my main definition, but my research into space law shows that there are other important ideas and factors to consider. For example, any colony will likely want legal independence and recognised territory of its own after a while. Take the colonies in America and the revolutionary War of Independence as an example.



Do I need to explain?

For a colony to own territory, the current sovereignty law would have to change, and the problem with changing it is, as I said, that unless handled very well it could lead to conflict and possibly even war. For these reasons it is likely that any proposed changes would be met with some resistance. This has been observed with the Antarctic laws which have had no pressure to change since they were established. If a change was to be suggested the potential implications of any change would have to be seriously thought through.

I found online the main criteria for a country. A country must have a permanent population, a government, the ability to form relations with other nations, and a defined territory. Of course a group of people is currently unable to claim ownership of territory in space, but if a human settlement on another planet met the other requirements there could be a case by case review process by the UN which would allow some settlements to become their own state. In this process they may also be required to do certain scientific activities for the UN as part of the deal. This system would work best if the group claiming land in space would become an independent nation and couldn't be an expansion of a country on Earth.

Speculation aside there is going to need to be a significant amount of work done to keep law in space running smoothly in the future, especially as the prospect of human settlements on other planets becomes all the more realistic. Work is already being done to explore possible updates to the law. While the UN is responsible for the lawmaking, the issue is also being discussed elsewhere, for example at the International Astronautical Conference which was held at Bremen in Germany this year. Any changes to the sovereignty law are likely to be met with resistance, as the example of Antarctica suggests, so they must be well crafted to be appealing and reduce future conflict.