

Interstellar Travel

If aliens haven't visited us, could we go to them? In this lecture we will have some fun speculating about future interstellar travel by humans. Please keep in mind that, as we discussed earlier, this cannot be considered a solution for the problems that we have on Earth, for the simple reason that the expense per person is utterly prohibitive and will remain so in any conceivable future scenario. Nonetheless, given enough time it could be that we have the capacity to move out into the galaxy. Incidentally, we will leave discussions of really far-out concepts such as wormholes to a future class.

Interstellar distances

The major barrier to interstellar travel is the staggering distance between stars. The closest one to the Sun is Proxima Centauri, which is 4.3 light years away but not a likely host to planets. There are, however, a few possibilities within roughly 10 light years, so that is a good target.

How far is 10 light years? By definition it is how far light travels in 10 years, but let's put this into a more familiar context. A moderately brisk walking pace is 5 km/hr, and since one light year is about 10 trillion kilometers, you would need about 20 trillion hours, or about 2.3 billion years, to walk that distance. The fastest cars sold commercially go about 400 km/hr, so you would need about 250 billion hours or about 30 million years. The speed of the Earth in its orbit, which is comparable to the speed of the fastest spacecraft we have constructed (all unmanned, of course), is about 30 km/s and even at that rate it would take about a hundred thousand years to travel ten light years.

The point is that for humans to engage in interstellar travel will require either dramatically improved propulsion technology or the willingness to commit to extremely long voyages. We will consider both, but will first discuss some of the hazards of interstellar travel.

Hazards of travel

Even if we improve our propulsion to an astonishing degree, so that we can travel at a tenth the speed of light and thus reduce the duration to just a hundred years, it is clear that the trip will take a very long time. Some of the issues faced on the journey could include:

The necessity for being self-contained.—There will be no stops along the way, so absolutely everything that is needed for a hundred years or a hundred thousand will have to be brought along. This isn't easy. When we've thought about locations for life on planets, one of our criteria was that there had to be a source of energy. Where would this come from on an interstellar trip? If we picture a standard science-fiction scenario, in which we have hundreds of people and a thriving ecosystem, the energetic demands grow pretty large. Since the ship would be far from any star, starlight is not an option. Since there are no big

planets along the way, tidal forces and geothermal energy won't contribute. Perhaps a crew could tap into whatever energy source was propelling the ship. Another option, which we will discuss later, is that we put the crew in stasis or send eggs rather than sending living people.

Radiation damage.—We are pretty well-protected on Earth from high-energy charged particles from the Sun and other sources, simply because the Earth has a significant magnetic field. Unless the ship did as well, the inhabitants would not be protected from such particles. Even if a magnetic field were generated, it would have to be very strong indeed to prevent particles from hitting the ship. The problem is that Earth's field extends over a large region, meaning that particles can be deflected gently, but over the size of a ship the field would have to be huge to have the same effect. The radiation itself doesn't even have to be the main problem. Impacts of the particles with atomic nuclei in the ship can produce unstable nuclei that radiate later; this actually happens with some spacecraft away from the Earth. Over hundreds to hundreds of thousands of years, this could have a devastating cumulative effect.

Micrometeoroids.—Even for a stationary spacecraft in space, impacts with interstellar dust occur at speeds of several tens of kilometers per second, i.e., a hundred or more times the speed of a bullet. If our ship moves at a tenth of the speed of light, we get to tens of thousands of kilometers per second. The dust is somewhat charged but not enough to be deflected by any reasonable magnetic field. Therefore, as the ship travels it is continuously damaged by minute impacts. Unless there is careful and continuous repair, the ship would ultimately lose air and other supplies.

Weightlessness.—This is primarily a problem if we want to send active people along on the mission. Russian cosmonauts and (to a lesser extent) our astronauts have occasionally spent several consecutive months in near weightlessness. The results are terrible for their bodies. They lose weight and more importantly bone mass, often being so affected that they cannot stand up when they return to Earth. Over centuries or much more, the inhabitants of the ship would lose muscle tone from birth. One perspective on this is that reputedly sleeping on Earth gives you more net exercise than activity in zero gravity, because of the load borne by your heart.

One could imagine producing artificial gravity to counteract this. Constant linear acceleration towards the target, then deceleration, would do this, but maintaining one Earth gravity's worth of acceleration seems absurdly beyond what we could do in the foreseeable future. A more realistic possibility, as shown in the movie "2001: A Space Odyssey", is to spin the ship so that the outer portions experience acceleration. The potential drawback is that this would exert stress on the ship, but you can't have something for nothing!

Isolation.—Also a problem only if we require live humans on our ship, but a potentially

dicey issue. Unless we have gigantic starships with at least dozens of people (which would require monumental amounts of energy to accelerate and support), the small number of people and large amounts of time would be a recipe for psychological conflict and isolation. For comparison, consider the ill-fated Biosphere 2 experiment. This was an attempt to put eight people in a completely self-contained and self-sustaining environment with plants. This suffered many difficulties, one of which was cliques and sabotage after a number of months.

All in all, the problems are many and a great deal of development will be needed to deal with them. We now explore some ways that at least propulsion might be improved so that we can wait merely centuries instead of hundreds of thousands of years! See the eighth supplement for a discussion of some of the physics behind rocket science.

Propulsion methods

Since current methods obviously won't work, what are some other suggestions? One that appears technically feasible is nuclear pulse propulsion, such as was proposed in Project Orion. Invented by the mathematician Stanislaw Ulam, the idea is that explosives powered by nuclear fission or nuclear fusion would be dropped out of the back of the rocket. Some tens of meters away, these would be detonated and caught by a large metal plate on springs. The springs would catch the blast and spread the impulse out over several seconds, leading to a less jerky ride. Various other clever methods were designed to reduce risks, but the spacecraft would have had to be pretty massive (at least 300 tons) to survive the blasts. One model would have had thousands of such impulses, each adding about 50 km/hour to the speed. It has therefore been likened to an atomic pogo stick!

With this design it was estimated that a spacecraft could get up to 8–10% of the speed of light. Some of the ideas included a “super-Orion” which would have been 400 meters in diameter and weigh 8,000,000 tons. At this size there could have been a significant colony aboard, possibly mitigating concerns about isolation. This is therefore an intriguing design. However, serious work on this project stopped in 1963 with the Partial Test Ban Treaty, which said that any nuclear detonations had to be underground (to prevent fallout in the atmosphere). Such a ship could not realistically be launched from the Earth as a result, and construction in space would magnify the undoubtedly gargantuan costs by many times.

There are other more far-fetched suggestions along these lines as well. For example, the highest efficiency engine possible would involve matter-antimatter reactions, since these would convert all the reactants into energy and provide the highest achievable thrust. The issue here is creation of the antimatter and confinement away from matter. Right now antimatter can be created in particle accelerators, but only in incredibly tiny quantities. Moreover, although in principle one might imagine magnetic “bottles” that would confine the antimatter, in practice any reasonable density of the stuff would leak out in matters of seconds, leading to explosions we didn't intend! Maybe in the far future we will find ways

around this.

Since the fuel mass is a major limiting factor, can we find clever ways to bypass this problem? One suggestion is called the Bussard ramjet after its originator Roger Bussard. The idea is that rather than carrying along, say, hydrogen to use in fusion reactions, we should take advantage of the huge amount of hydrogen already in space. Yes, it has very low density, but with a big enough scoop in front perhaps the hydrogen could be channeled to reaction chambers where it would be fused into helium and used for propulsion. That way, the rocket is almost all payload and passengers rather than almost all fuel. It's a great idea, but unfortunately more detailed calculations suggest that the drag on the scoop caused by motion through the hydrogen would be greater than the thrust produced, for pretty much any conceivable scoop design. Pity.

Another possibility has the thrust generated by laser light produced in the home system rather than on the spaceship. That is, we can imagine attaching a large reflective sail on the front of a ship that intercepts a beam of light that is sent out from Earth. Again we benefit from not carrying fuel along. This design could even be used to decelerate the ship when it neared its destination, by having the sail partially detach and bounce some of its light off the forward-facing part of the sail. Robert L. Forward, who wrote several science fiction books and also did many serious calculations, proposed some specific possibilities that would allow the spacecraft to achieve speeds up to half the speed of light. The difficulty is that for human missions, this would require lasers with powers on the order of 75,000,000 gigawatts! Given that the current world power output is 15,000 gigawatts, this may also be a bit in the future.

Long-duration voyages: interstellar arks

Given that any reasonable trip will take between several and several thousand human generations, how can this be managed? Several strategies have been proposed. Note, incidentally, that even if as a species we decided that this was to be our highest priority, improvements in propulsion technology mean that any ship launched now would be passed by future ships with better acceleration, so we should wait.

The most straightforward one conceptually is a “generation ship” or “interstellar ark”. There would be a colony of people on the ship living normal lives, so the excessive duration of the trip means that those who arrived at the destination planet would be descendants of the original crew. Because of this, there would be an additional consideration beyond essentials such as how well the environment could be maintained or the psychological health of the people. As we discussed in the lectures on evolution, genetic diversity is critical to maintenance of good health. With too few people the diversity would not be enough, and many generations down the line the inbreeding would have led to catastrophic problems. In saying this, of course, I am limiting myself to current biological knowledge and technology;

if it becomes possible in the future to correct genetic deficiencies in the womb this may not be so bad after all. Even if that is the case, trips lasting hundreds to thousands of years could lead to major cultural changes on the ship; how many societies do you know that have maintained their culture and purpose unchanged for millennia?

Another possibility is extension of human lifetimes, either normal lifetimes or via suspended animation or cryogenics. Many technical obstacles must be overcome for this to be practical. In addition, one would have to have either a rotating series of wakeups for the crew or outstanding computers to maintain and guide the ship while the crew is in stasis. If this is possible, it seems to me that an even better option would be to launch a completely automated ship that contains frozen human eggs (or even just DNA information; the whole human genome has ~ 1 GB of information, so you could store 1000 such genomes on a \$50 external drive right now) and a means to gestate them. One could do similar things with other terrestrial animals and plants. This would have the advantage that no energy would be required for food. It would also mean that ship accelerations could be much higher than would be tolerable for adult humans. On the other hand, it would require confident identification of habitable planets and the development of robots that could take the role of human parents until the children had become adults.

Any way you slice it, the enterprise would be difficult and costly. It would, however, be an extension of humans beyond Earth and would render us much less vulnerable to total extinction. Do you think this is something we should pursue actively?

The Fermi Paradox

Thus far in this lecture we have discussed some of the many reasons why interstellar travel will be very challenging. Now we will indicate that it should be easy... given enough time. More specifically, we will address the Fermi Paradox. In 1950, the Italian physicist Enrico Fermi was at a lunch where a number of his fellows were expressing optimism that our galaxy is teeming with intelligent civilizations. He asked the simple question “then where is everybody?” That is, if technologically sophisticated aliens are common, why don’t we have obvious evidence of them?

In the ninth supplement we show that although our galaxy is large, the time available is so enormous that there has in principle been plenty of opportunity to colonize the entire Milky Way. Given this, if aliens are so common, why don’t we have definitive evidence that they exist? Shouldn’t they have visited us by now? We now explore a sequence of suggested answers.

Solution #1: we are unique in our galaxy

Maybe it took one or several spectacularly lucky accidents for life on Earth to reach the

point of intelligence. Various things we've discussed in the course could be key. For example, life itself emerged so rapidly that it seems tough to argue that it wouldn't happen elsewhere. But the three billion years it took to produce multicellular life is a sign that this step is a tough one. Suppose it took a tremendously unlikely event for this to stick. Then maybe there are a billion planets in our Milky Way with single-celled life but only ours developed further. Maybe intelligence is not nearly as important an adaptation as we'd like to think.

Alternatively, it could be that although intelligence develops on a fair fraction of planets, technology is extremely rare. Our opposable thumbs allow us to create things and manipulate our environments to an amazing level, from the construction of cars and computers to writing, which has done more than anything else to allow one generation to build on the successes of its predecessors rather than reinventing everything. A world in which dolphin-like creatures acquire human-level intelligence and communication skills would not be able to progress far because they would be limited to their innate capabilities.

Note also that with intergalactic distances being so large, it is also possible that there are millions of galaxies (out of tens of billions in the visible universe) that have life much more advanced than ours, but they haven't had time to get here yet. Or, perhaps we are truly unique in our universe.

Solution #2: advanced civilizations are short-lived

There are various reasons why this might be so. Self-destruction is one obvious possibility: perhaps on any sufficiently advanced world the toys get too big, and competition automatically leads to global wars that set the society back. Another prospect is something we see today, that use of nonrenewable resources exacts a toll. If viable alternatives are not found, it could be that we will have to take a step backwards in our technological level. One could imagine other catastrophes, including famine or disease cutting out a high enough fraction of the population that interstellar travel is put on hold eventually. I hope this isn't the reason, because I'd like to think that we have what it takes to choose wise future courses.

It has also been pointed out that if the last few hundred years of human history had unfolded differently, the situation could be dramatically different with respect to nonrenewable resources. For example, suppose that oil deposits had been deeper down than they actually are, which would have meant that it took longer to discover them. We could imagine that wind, water, and solar power would have taken the lead. If they got sufficiently entrenched, perhaps our dependence on oil would have been minimal and our society would have been that much more sustainable. Could this have happened on other planets?

Solution #3: interstellar travel is too hard

We have no idea whether this is true, given our small number of space travel attempts. Note, though, that we argued that apart from situations similar to Jupiter's moons it appears

highly valuable to have a host planet with enough mass to hold onto an atmosphere and probably to have plate tectonics. That is, we want a planet with a mass similar to that of the Earth.

An inevitable consequence is that getting off our planet is tough due to its strong gravity. Recall that putting a few people on the Moon cost about \$150 billion in today's money. Other than national pride it is not clear what purpose going back to the Moon would serve. Interstellar trips with creatures you wanted to keep alive would be vastly more expensive. The costs could be cut dramatically by sending unmanned vehicles (such as self-replicating robots), but even those would be multibillion dollar missions. If no shortcuts are found, it could be prohibitively difficult to adopt the colonization procedure we discussed.

A completely automated expansion would also have to face some technical issues that might be solvable in the future but that are certainly not trivial now. Millions of years may be a blink of an eye to the galaxy as a whole, but individual stars can move a lot in that time. For example, our Sun orbits our galaxy in about 200 million years, at an average rate of about 700 light years per million years. Complete automation therefore requires careful tracking of a couple hundred billion stars to avoid repeat visits or misses. It might also be that self-replication itself is not easy after many generations, with cumulative errors coming in with a vengeance.

With all that said, however, my feeling is that with the astonishing technological progress we have made in the last century, I would expect that another thousand years of similar progress would allow us to solve these problems if we decided that galactic colonization was a worthy goal. Presumably aliens would have the same capabilities.

Solution #4: advanced civilizations wouldn't have the motivation

Really, who can tell about alien sociology. There are, however, several reasons why such expansive missions might not be attractive:

- Interstellar colonization can't solve the problems of a planet. As we have mentioned a few times, only a negligible fraction of individuals could be launched from a planet that is sufficiently massive to host life.
- There would be no net economic return. This is also true of many unmanned missions to planets in our Solar System, but the scale of interstellar colonization would be tens of thousands of times greater. Why do it?
- Even the benefit to society is questionable. The distances are so great that communication would be difficult. Perhaps, though, this is something that would acquire different significance if conditions on Earth were so dire that extinction was a possibility.

By the way, even if aliens did have the motivation the question is how long it would

take to colonize *every* habitable planet in our galaxy. For example, it could be that some civilization has occupied 90% of habitable planets, but because we are away from the center of the galaxy we have a pretty good chance of being one of the 10% that are left out.

So far we have examined solutions in which galaxy-spanning civilizations do not exist. Now let's explore some possibilities in which they do exist, but for various reasons we have not detected them yet.

Solution #5: aliens are holding off on contact

Perhaps aliens abide by a form of Star Trek's Prime Directive, which basically says it is forbidden to interfere in the internal workings of another society, particularly if that society is sufficiently primitive. Naturally the real prime directive is that Captain Kirk does anything he wants, but suppose aliens abide by the letter of the law. In this view, our planet has been off-limits since its origin, and will remain so until we reach some designated threshold of technology or social structure. The aliens might be observing, but will not visit or communicate with us.

This is an interesting solution that has been explored many times in science fiction. I have to admit that it would be rather cool for us to accomplish something major and then be told that we now qualify for membership in the galactic federation. Perhaps it will happen the next time the Cubs win the World Series. More seriously, how likely is this solution? If there is only one civilization that spans the galaxy, it might be by accident that they really do have principles like this and stick by them. But having only one versus none is really not that big a difference, so if we think that technology and an urge to expand are common we have to consider interactions between many such civilizations. The more there are, the greater the likelihood that at least some of them would have no qualms about interference, so the odds of this being the right answer go down. Of course, if it is inevitable that galaxy-spanners will compete with each other and only one will emerge the victor, perhaps there really is only one around. In that case, though, it might seem less likely that the winner would leave us alone!

Solution #6: we are too primitive to communicate

Maybe aliens haven't been everywhere but there are thriving groups of thousands to millions of planets and they communicate all the time. However, we have not yet developed the proper technology to understand the communication. For example, perhaps they use X-rays instead of radio waves (because of the much greater bandwidth of X-rays), beaming them rather than broadcasting over a wide range of angles. Or, maybe they use normal speech rather than recognizably artificial signals such as a series of prime numbers. It could also be that their signals are everywhere around us but they think and communicate in such utterly alien ways that we have no chance to detect them yet. In this scenario, once we

develop further we will be able to detect their signals.

Solution #7: they are here but we cannot recognize them

I'm not talking about aliens kidnapping people on deserted country roads at 3 AM. I'm supposing instead that they are observing us with such superior technology that we cannot tell at all. For example, suppose the aliens have nano-technology with robots the size of sand grains or dust, measuring many things and reporting back. We might not ever be able to tell. We could even imagine that such aliens are favorably disposed towards us, and that they even give us pushes in the right direction on occasion. That would also be nice to believe, but as there is no evidence in favor of this (even if we can't rule it out) it seems wise to proceed as if we are on our own!

Summary

From my standpoint it appears that some combination of Solutions 1, 2, or 3 are most likely. The late origin of complex life on Earth might be typical and might speak to some extremely rare accident being needed. If so, by the way, it doesn't mean that we were particularly favored; only places that develop intelligent life would be able to speculate about this, so there is a rather strong bias towards such places having developed complex life! The unfortunate possibility of a short technological lifetime exists, and interstellar travel will always be resource-intensive, so these seem possible to me as well. The other solutions seem to me to rely too much on uncertainties of alien sociology, but that very uncertainty means that they are at least possible.

What do you think?