Concluding Remarks:

The crater chronology technique thus helps us to find absolute ages of the planetary surfaces of the solar system through remote sensing. High-resolution satellite images such as TMC (Chandrayaan-1) and LROC-NAC (LRO) from Moon and HiRISE from Mars etc., have been recently made available. In accordance, many image processing and GIS based techniques are being developed (e.g., Kneissl et al., 2011) to precisely count the craters in a specific area of interest and to find the absolute age of that surface. The availability of high resolution datasets has also given an opportunity to improve upon and revise the existing production functions. Before the crater counting task of a specific area is undertaken, it should be ensured that surface to be dated does contain only primary craters. There should be no relic and ghost crater from an underlying older unit in the measurement. Secondary and volcanic craters are also eliminated, the area of measurement is determined accurately and the size of craters is measured with high precision since the exponential size frequency distribution dependence amplifies small error in diameter as large error in crater density per unit area.

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Is Interstellar Space Travel Possible?

Recently, India had successfully launched Chandrayaan - 1 a mission to Moon. A second mission to Moon is already in the offing and there are plans for sending probes to other planets, e.g., Mars. Perhaps in a decade or so India may achieve a manned landing on the moon. After that, one could imagine manned trips to Mars. Other countries are also planning such expeditions. As for the Jovian planets like Jupiter or Saturn, manned missions if any, will have to have bases on one of their satellites, e.g. Ganymede or Titan, as the planets themselves are all gaseous, lacking a solid surface to make a landing.

This begs a question: Could man possibly ever travel to distant stars to visit some exo-planets, perhaps in a habitable zone, to possibly encounter some extraterrestrial life? Of course the distances involved are immense. The nearest star outside the solar system (Proxima Centauri) is as many times (~a hundred million times) farther than the moon, as the latter is compared to distance between adjacent rooms (~4 m) in a building. From a simple logic one could then expect that going to a star will at least be as much more difficult than going to Moon as the going-to-Moon has been with respect to that walking just next door within an office building. With the maximum speeds achieved so far by the space ships within the solar system it will require about 85,000 years to reach this nearest star. Thus, it may not look possible to reach other stars within a human lifetime, although on a theoretical basis theory of relativity would allow one to do so. For example, a spaceship accelerating constantly by a convenient value ‘*g*’, that is the acceleration that we are used to on the surface of Earth, could travel to the most distant parts of the universe within a human lifetime, without violating the speed-limit of ‘*c*’, the speed of light. In principle, interstellar travel may thus appear possible.

However, energies involved in such an endeavour would make it next to impossible. In a space ship the fuel needed for the later parts of the journey has to be carried aboard and thus also needs to be accelerated till it is utilized. Therefore, the initial mass at the start of the journey is much more than the actual payload. With conventional chemical fuel, such an arduous journey will need a fuel-mass of a whole galaxy, as we will show later. Even within the best possible scenario where almost 100% of mass is converted into energy (in a typical thermonuclear reaction only about 0.7% of mass is converted into energy) one would require initial mass to be millions of times the mass of the final payload and the energy which required may be worth 200 years of total energy consumption of the whole world. If we imagine that the energy is beamed from power plants on Earth to the space ship, it will again require many hundred million megawatts of power throughout the duration of such a trip, which might last for a very long

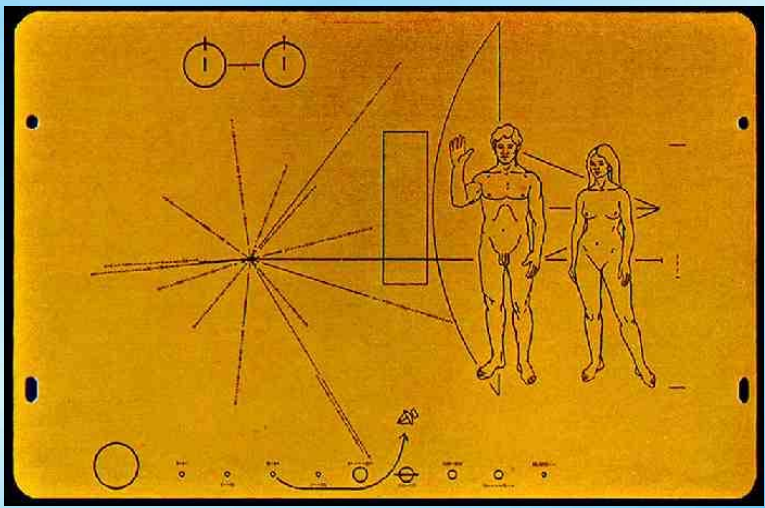

Figure 1: The plaque aboard Pioneers 10, carrying the message to stars

time. It therefore looks that at most, we might travel to other planets within our solar system but the distant stars will ever remain a distant dream only.

In this article, we ignore the technical aspects of the mission as technology is bound to improve rapidly over time. We carry forth the possibility of such an endeavour without delving into many other equally important issues such as the long-term effects of cosmic radiation on the health of space travellers and their requirements for food, medical and other life-sustaining needs. We consider mainly the minimum basics of the travel, which are distance, time and energy.

The story so far

Till date there have been five spacecrafts that have crossed the threshold of escape velocity from the solar system and four of them are already headed towards the interstellar space.

Pioneer 10 was launched in 1972, flew past Jupiter in 1973 and became the first spacecraft to achieve escape velocity from the solar system. The contact was lost in January 2003 and is heading in the direction of Aldebaran in Taurus. *Pioneer 11* was launched in 1973, flew past Jupiter in 1974 and Saturn in 1979. The contact was lost in November 1995. The spacecraft is headed toward the constellation of Aquila.

Pioneer 10, as well as Pioneer 11, carry gold-anodized aluminum plaques in case either spacecraft is ever found by intelligent life forms from another planetary system. The plaques feature the human figures along with several coded-symbols that are designed to provide information about the origin of the spacecraft.

The content of the message should be clear to an advanced extraterrestrial civilization, which will have, of course, the entire Pioneer 10 spacecraft itself at its disposal to examine as well. But being the product of billions of years of independent biological evolution, they may not at all resemble humans, nor may the perspective and line-drawing conventions be the same there as here. The human beings will perhaps be the most mysterious part of the whole message for them.

Voyager 1 was launched in September 1977, flew past Jupiter in 1979 and Saturn in 1980, making a special close approach to Saturn's moon Titan. Voyager 2 was launched in August 1977, flew past Jupiter in 1979, Saturn in 1981, Uranus in 1986, and Neptune in 1989. Both probes have passed the heliosheath, the region where the solar wind is slowed, compressed and made turbulent by its interaction with the interstellar medium at distance 80 to 100 astronomical units (AU), and continue exploring where nothing from Earth has flown before. They will continue to explore the boundary between the Sun's influence and interstellar space and are expected to return valuable data for at least another decade. Since the Pioneers were launched first, they had a head start on the Voyagers, but because they were traveling slower Voyagers eventually overtook them.

New Horizons, launched in 2006, made a flyby of Jupiter in 2007, and will make a flyby of Pluto in 2015. New Horizons was launched with the largest-ever launch speed for a man-made object. It will, however, slow down to an escape velocity of only 2.5 AU per year as it moves away from Sun, and it will never overtake the Voyagers.

The Pale Blue Dot

The pale blue dot is a photograph of planet Earth taken in 1990 by the Voyager 1 spacecraft when the spacecraft

Figure 2: A panoramic (!) view of our Earth from space.

reached about Pluto's distance [i.e., ~ 6 billion km, or 40 AU]. This is the photograph (Fig. 2) of the earth taken from the farthest distance till now and it appears like pale bluish dot [the faint brown band is due to the reflection of sunlight from camera optics]. If it could be photographed from the distance of our nearest star [Proxima Centauri], its diameter would appear about 7000 times smaller and would be about 50 million times fainter!

This picture is very significant as a perspective on our place in the cosmos as our blue planet literally pales into insignificance within the larger scheme of things. And this is the only actual image of Earth ever seen by anybody from such a vantage point. It is both a chastening and humbling realization for us humans that our huge planet is such a tiny speck of dust seen from an outpost (Pluto!) of our planetary system.

The cosmic distances involved

The main challenge facing interstellar travel is the vast distances that have to be covered, requiring very high speeds as well as long travel times. The latter make it particularly difficult to design manned missions.

Cosmic object	Distance from Earth
Moon	384000 km = 1.3 light secs
Sun	150 million km = 500 light secs
Proxima Centauri	4.2 light years
Orion Nebula	1300 light years
Centre of Milky-way	25,000 light years
Andromeda Galaxy	2 million light years
Size of Universe!	14 billion light years

Table 1: An idea of the distances involved.

How far can a manned mission travel from Earth?

Assuming one cannot travel faster than light, one might conclude that a human can never make a round-trip farther than 20 light years, assuming the traveller is active between the ages of 20 and 60. Thus one would never be able to go beyond a few star systems which exist within the limit of 10–20 light years from Earth. Even if we design a spaceship that can travel at 0.99c, interstellar travel beyond the nearest stars seems impossible.

To survive for long years on a spaceship, a gravity of 1*g* would have to be maintained. This could be achieved if a rocket continuously accelerates by this amount. Since we also plan a return journey from the source, we divide our journey into four separate stages. In the onward Journey while the spaceship is moving towards the star it will be accelerated in the first half of the journey, while in the second half it will have to be decelerated. In the same way for the return Journey, it will have to be accelerated in first half and then decelerated in the second half of the journey.

Effects of the relativity: the time dilation

A constant acceleration of 1*g* for a year would bring the speed of spaceship approximately close to '*c*'. Thus relativistic effects of time dilation would have to be taken into consideration. We know that time passes relatively slower by a relativistic factor $\sqrt{[1-(V/c)^2]}$ on a frame of reference moving with a velocity *V*.

Detailed calculations show that by the time the space ship lands back on Earth, the time that would have passed on Earth (T_e) would be related to that passed on the space ship (T_s) by $T_e = 4c/g\ [\sinh (gT_s /4c)]$ and the maximum distance of the reachable destination will be given by $x = 2c^2/g\ [\cosh (gT_s / 4c)-1]$, a factor of 4 in these formulae appears because of the four stages of the journey.

Table 2 gives us an idea of the time dilation involved from the total duration and distance reached in a round trip, involving a constant acceleration of 1g for the crew. A future spacecraft, using technologies that we have not even dreamed of, may use an engine that could sustain a constant acceleration of 1*g*.

Time on spaceship (years)	Time on Earth (years)	Distance reached (light years)
1	1.04	0.065
2	2.2	0.27
5	6.7	1.9
7	12	4.2
10	26	11
15	95	46
20	345	170
25	1,250	625
30	4,500	2,250
40	60,000	30,000
50	780,000	390,000
60	10,000,000	5,000,000
90	24,000,000,000	12,000,000,000

Table 2: Time and distance relation

Traveling even at the speed of light, on earth-time visiting the stellar nursery in Orion nebula would require at least 2600 years, while a cruise to the centre of our Milky-way galaxy will take more than 50,000 years, and a round trip to Andromeda, the nearest spiral galaxy, will need at least 4 million years. But due to the relativistic time dilation, for the traveler the time spent could be much smaller. With a 1*g* engine, a vacation trip to Andromeda may be possible within a human lifetime! For those astronauts, however, returning back home is out of the question. Back on Earth, millions of years would have passed and entire civilizations would have come and gone, while the astronauts who left in their 20s would be still in their 80s.

Table 2 gives travel times for an astronaut himself, traveling in such a 1g constant acceleration rocket, for various distances covered as seen from the earth and the time lapsed on the earth.

The rocket equation

If the fuel needed for the journey has to be carried aboard it also needs to be accelerated until it is utilized. Therefore, the initial mass at the start of the journey is much more than the actual payload. This is given by the rocket equation, which gives the final reachable speed V as a function of the exhaust speed u of gas/ion/light emission and M, the ratio of the initial mass (payload + fuel) to the final mass (only payload). From the momentum conservation we have,

$$dM/dt\ u = M\ dV/dt, \quad \text{or}$$
$$V = u \times \ln M.$$

The logarithmic function makes the required mass ratio increase very fast with V/u.

For example,

$$M = 10 \text{ for } V = 2.3\ u, \text{ but}$$
$$M = 10^{10} \text{ for } V = 23\ u.$$

Thus, to obtain a final speed, V close to 'c', it is necessary for u to be of the order of c as well, otherwise the required mass ratio will be prohibitively large.

In a relativistic case the rocket equation becomes

$$V/c = (1 - M^{-2u/c}) / (1 + M^{-2u/c}), \quad \text{or}$$
$$M = [(1 + V/c)/(1 - V/c)]^{c/2u}.$$

For $u<<c$, it reduces to the familiar non-relativistic equation..

The acceleration of the rocket would be given by,
g = thrust of the rocket / total mass of the rocket.

Now, the thrust of the rocket equals the exhaust mass flow times the exhaust velocity; and the needed power of the engine equals the mass flow times one-half the square of the exhaust velocity. From that we get,

$$P = g\,u/2,$$

where P is the ratio of the power of the engine to the total mass of the rocket. For a relativistic exhaust speed ($u \sim c$) it becomes

$$P = g\,c.$$

If at the maximum speed achieved so far by any spaceship we are able to make a return trip to the moon within half a day, a similar trip at this speed to Proxima Centauri, the star nearest to our solar system, will take about 85,000 years which is over 3,000 human generations, and this is also roughly the time that has passed since the homo-sapiens (humans) first came on the scene. One can thus conclude that in order to reach these interstellar destinations, one would have to travel much faster, in fact with speeds close to that of light, *c*, which is the maximum attainable speed for any object. Otherwise, such a trip would be unimaginable. And to get close to *c*, we need alternative fuels.

Various rocket concepts

Till now the chemical energy being used comes from a mixture of liquid oxygen and hydrogen, which yields 100 MJ (Mega Joules) per kg of fuel. The highest efficiency is achieved if the end products of the chemical reactions themselves can be expelled for propulsion with the energy produced. Then one will get an exhaust speed of u=14 km/s. Reaching a modest maximum final value of one thousandth of the speed of light, which means at least 8500 years of travel time for a return trip to Proxima Centauri, will itself need such a high mass ratio ($\sim 1.6 \times 10^{37}$), that a ten ton payload (a minimum from any standards) will need a fuel mass of a whole galaxy. Not at all a viable possibility, considered from any angle. Perhaps nuclear fuel might be a better option.

Nuclear fuel - fission or fusion?

Uranium yields about 6.5×10^{7} MJ/kg of energy through fission, or about a million times better than the chemical reactions. In this case, we could get an exhaust velocity u=12,000 km/s. We could possibly increase V to 0.1c, using a mass ratio of 12. But considering the 4 stages of the journey, a mass ratio of more than 20,000 will be needed. A round trip to the nearest star would require a minimum of 85 years of travel time. Relativistic effects of time dilation would be insignificant at such speeds. Fusion could provide ten times more energy per unit fuel mass. Despite the fact that controlled reactions of fusion of lighter nuclei have not been possible to establish, we can imagine that the technology required for it could be developed in the years to come. Banking on this assumption, one could propose the energy required by the trip to be given by the fusion of lighter nuclei.

We could show that in fusion an exhaust speed of $c/8$ may be possible, and that we could obtain a top speed of 0.3c, requiring a mass ratio of 15,000 for a return journey. At these speeds a round trip to the nearest star would require a minimum of 28 years of travel time, just within the possible limits. Of course, a ten ton payload will mean 150,000 tons of hydrogen to be carried aboard and to be converted into helium and propelled behind during the journey. This will be $\sim 10^{17}$ MJ of energy, which is 200 years worth of total energy consumption (5×10^{14} MJ for the year 2010) of the whole world!

Hence higher exhaust speeds and thereby lower mass ratios are needed for any realistic travel to a star, and using fission or even fusion for the energy of locomotion is not promising and interstellar space travel would be very much inhibited if we were to depend on only these modes of energy.

Antimatter rockets:

An antimatter rocket would have a far higher energy density and specific impulse than any other proposed class of rocket. When matter and anti-matter is made to fuse, the entire mass gets converted to radiation, but the technology supporting such a mode of energy production, would require matter and anti-matter to be stored at a safe distance from each other and to be able to combine them, a proper amount, at a proper time in order to be able to use the energy which is produced due to annihilation.

The problem, however, is that all of the current methods of manufacturing antimatter require enormous particle accelerators and produce antimatter in very small quantities, and to store antimatter, if we need a ton of magnets for one gram of antimatter, the entire idea of a lightweight way to store and carry immense amounts of energy remains no longer meaningful. Antimatter could nevertheless perhaps find use in interstellar spaceships as a way to help trigger nuclear reactions.

Non-rocket concepts:

A scoop on the way:
In a fusion rocket a huge "scoop" could collect diffuse hydrogen from the interstellar space and "burn" it on flight, using proton-proton fusion reaction and expel the fusion product to get the thrust. The idea is attractive as the fuel would be collected en route, but all attempts to design some kind of a scoop has the unfortunate effect of producing more drag than you get back thrust.

Sailing away:
Solar sails are a form of spacecraft propulsion using the solar pressure, of a combination of photons and solar wind from Sun, to push large ultra-thin mirrors to high speeds. Comets tails are pushed away from the sun by the same mechanism.

The momentum of a photon or an entire flux is given by $p = E/c$, where E is the photon or flux energy, p is the momentum. At 1 AU the flux density of solar radiation is 1.36 kW/m^2, resulting in a pressure of ~ 4.5 μPa. A perfectly reflecting sail with 1-sq. km area could thus yield a force ~ 9 N, while Sun's gravitational force on one ton mass there is about 6 N. As both the radiation pressure and the gravity fall with the square of distance from Sun, a 1-ton load attached to a sail of 1-sq. km area could get pushed outward by the radiation pressure and thus escape the solar system.

Solar wind on the other hand exerts only a nominal dynamic pressure of about 3 to 4 nPa, three orders of magnitude less than solar radiation pressure on a reflective sail, and would not relatively have much effect.

A physically realistic approach would be to use the light from Sun to accelerate. The ship would begin its trip away from the system using the light from Sun to keep accelerating. Beyond some distance, the ship would no longer receive enough light to accelerate it significantly, but would maintain its course due to inertia. When nearing the target star, the ship could turn its sails toward it and begin to decelerate. Additional forward and reverse thrust could be achieved with more conventional means of propulsion such as rockets.

Laser sails or particle beams:
Laser sails might be another way to go. Instead of relying just on the enormous amount of light given off by Sun, laser sails to Proxima Centauri could also ride laser beams that earthlings would fire carefully at those ships to give an extra boost, especially when sails were too far away to catch much light from our Sun. The problem with laser sails is that a lot of light needs to be used for a long time to get fast enough to get to Proxima Centauri within a human lifetime. This means very powerful and extraordinarily large lasers are needed in order to focus on sails that get farther and farther away.

An idea similar to light sails could be firing a particle beam at a spaceship that would ride that energy. The problem with laser beams is that they disperse over distance, so we could use particle beams. The beam would have to have a neutral electrical charge so as not to disperse itself over time.

Bombs!:
Another idea for space travel would involve riding explosions through space. Such "pulsed propulsion" would hurl bombs behind a ship, which is shielded with a giant plate. The explosions would push against the plate, propelling the ship. Nuclear pulsed propulsion works best for really big systems. If we want to send a colony of 1,000 people to space, this might be the way to do it

Some other fanciful ideas

Interstellar travel by transmission:
If physical entities could be decomposed as "information", then transmitted and then reconstructed at a destination, travel at nearly the speed of light would be possible, which for the "travellers" would be instantaneous. However, sending an atom-by-atom description of (say) a human body would be a daunting task. Extracting and sending only a computer brain simulation is a significant part of that problem. "Journey" time would be the light-travel time plus the time needed to encode, send and reconstruct the whole transmission.

Generation ships:
A "generation ship" is a kind of interstellar ark in which crew that arrive at the destination are descendants of those who started the journey. Generation ships are not currently feasible, because of the difficulty of

constructing a ship of the enormous required scale, and the great biological and sociological problems that life aboard such a ship raises.

Suspended animation:

Scientists and writers have postulated various techniques for suspended animation. These include human hibernation and cryonic preservation. While neither is currently practical, they offer the possibility of sleeper ships in which the passengers lie inert for the long years of the voyage, hopefully without many after-effects.

Other difficulties of interstellar travel

Ex-communication! :

The round-trip delay time is the minimum time taken for to-and-fro communication between the probe and Earth. For Proxima Centauri this time would be 8.5 years. Of course, in the case of a manned flight the crew can respond immediately to their emergencies. However, the round-trip delay time makes them not only extremely distant from but, in terms of communication, also extremely isolated from Earth. In fact, the communication issue could become the biggest problem. How will the people born in an interstellar colony identify themselves with no attachment to Earth? Will they not feel literally excommunicated from Earth?

Hard-hitting interstellar medium:

A major issue with traveling at extremely high speeds is that interstellar dust and gas may cause considerable damage to the craft, due to the high relative speeds and large kinetic energies involved. A robust shielding method to mitigate this problem would be needed. Larger objects (such as macroscopic dust grains) are far less common, but would be much more destructive. The risks of impacting such objects, and methods of mitigating these risks, will have to be adequately addressed.

Manned missions:

The mass of any craft capable of carrying humans would inevitably be substantially larger than that necessary for an unmanned interstellar probe. The requirements for food, water, medical and other life-sustaining needs of the crew will literally put huge burden on the mission. In the case of interstellar missions, given the vastly greater travel times involved, there will thus be the necessity of a closed-cycle life support system, which would last over decades. In generation ships, will there be a large enough gene pool for healthy future generations? There will be the ethical questions – should a new-born be "condemned" to a life-time of journey in which he or she may have no choice whatsoever. Then there is the possibility that the new generations aboard might change their mind and abandon the mission or go elsewhere, keeping no contact with Earth

A Hypothetical Journey

Though recently an earth-size planet has been found orbiting around α-Centauri B, but it is estimated that it is too close to the parent star and would be very hot and perhaps not habitable. It is estimated that to visit a habitable planet and hopefully encounter some extraterrestrial life we may have to probe stars up to about 12 light years. Let us make a hypothetical return trip to such a distance, with the crew always under an acceleration of 1*g*. Then with top speed reaching 0.99*c* midway point of the journey, it will take 28 years of the earth time, but the traveler would age by only about 10 years. For nuclear fusion, the best possible exhaust speed is $u=c/8$, then the relativistic rocket equation gives us a mass ratio M ~ 1.6×10^9 to reach 0.99*c*, while for matter-antimatter (with an exhaust speed of *c*) the mass ratio is M = 14. However, if we consider the deceleration and the return journey as well, the mass ratio for nuclear fusion case becomes M ~ $(1.6 \times 10^9)^4 \sim 6.6 \times 10^{36}$. So for a 10 ton payload we will need a fuel mass of ~ 6.6×10^{43} gm, that is, about 33 billion suns or the mass equivalent of one-third of our galaxy. With matter-antimatter the mass ratio is M = $(14)^4$ = 40,000, implying 200,000 tons of matter and a similar amount of antimatter. For the early part of the journey, we will need ~1.2×10^{12} MW, about seven times more than the radiation that Earth receives from Sun. But with all that in gamma-rays, our problem will be not only to shield the *payload* but also to shield *Earth*. Not a very promising scenario!

"Could we?" Or "should we?

So far no one has created technology that is widely agreed upon as capable of caring for or preserving humans across the lifetimes it might take to get to Proxima Centauri.; so it might easily take more than one lifetime to reach the star system?. If that is so, mission designers might have to take procreation and family into account so that offspring of the original crew would get properly educated and trained to manage the ship in due course.

Thus a trip to our nearest star requires not only ingenious methods of propulsion and a minimum of decades en route, but also a sophisticated system of life support for the human crew to survive the journey. Not only the costs and difficulties are almost insurmountable, but they would also require almost unparalleled public and governmental support. The ultimate question then might change from "could we?" to "should we?"

Here we restricted ourselves to consider travelling only a few lights years within the reach of our own Solar System. Even if the constraints imposed by the technology are ignored, the requirement of energy plays a huge constraint by itself. A huge amount of fuel would have to be put to use for such an endeavour and many generations of earthlings would have to work on such a project.

There is a very strong likelihood that the mission would fail due to many other factors. We have ignored the requisites of food and water and other medicinal requirements for the crew. There is also the effect of the harmful radiation such as cosmic rays and impacts with other larger bodies. What if some deadly disease strikes? It is unlikely that living beings will be able to survive such ordeals for time periods of the order of decades.

Further we have not even considered the time and resources needed for possible research and conduction of experiments at the place of the destination, without which such a trip would not be of much advantage to us, anyway.

Conclusion:

Taking these severe limitations into account, we can conclude that space travel, even in the most distant future, will remain confined to our own planetary system, and a similar conclusion will hold forth for any other civilization, no matter how advanced it might be, unless those extraterrestrial species have life spans order of magnitude longer than ours. Even in such a case, it is unlikely that they will travel much farther than their immediate stellar neighborhood, as each such excursion will exhaust the resources of their home planet so much that those will dwindle rather fast and there might not be much left for the further scientific and technological advancements. So, the science-fiction fancy of a "Galactic Empire" may ever remain in our fantasies only. And as for the mythical UFOs, whose quiet appearances do get reported in the press once in a while, recent explorations have shown no evidence that any such thing could have an origination within our own solar system itself. And a 'quiet trip' back and forth from a distant star is almost impossible as the exhaust in any such trip will dazzle the sky like another sun or perhaps more like a gamma ray burst occurring but not in a distant part of the universe instead going off right in our own solar backyard.

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