Space Archaeology

By Abraham Loeb on November 8, 2019

The famous Drake equation quantifies our chances of detecting a light signal from an advanced civilization in space. However, it misses a crucial possibility: most technological civilizations that ever existed might be dead by now.

There are two obvious reasons to suspect that this might indeed be the case. First, as soon as we mastered advanced technologies, we also developed the means for our own destruction through catastrophic nuclear, biological or chemical wars, or through a global change in our habitat. Second, recent data from the Kepler satellite implies that about a quarter of all stars host a habitable, Earth-like planet. This naturally reinforces a paradox, formulated in 1950 by the physicist Enrico Fermi. At a lunch discussion about the likelihood that our civilization might not be alone, he asked: “where is everybody?” The simplest answer might be: “dead”.

But this does not mean that we cannot prove other civilizations existed. On Earth, we find evidence for ancient cultures that are not around anymore, like the Mayans, through the artifacts they left behind. Similar to the work of archaeologists who dig into the ground, astronomers can search for technological civilizations by digging into space. I label this research activity as “space archaeology”. What should we expect to find?

It is prudent to start the search in our back yard and look for technological equipment floating through the Solar System. We might discover artificial objects that originated from other stars, since in the first century of our own technological revolution we already sent Voyager 1 and 2 out of the Solar System.

The simplest way to detect alien equipment is through its reflection of sunlight, namely by searching under the nearest lamppost, the Sun. The first interstellar object that originated outside the Solar System and was detected this way near Earth is `Oumuamua. This 100 meter size object showed weird properties, such as an extreme geometry – most likely pancake-like, an excess push without a cometary tail or spin change, an unusually shiny surface and an unlikely low speed relative to the local population of stars.

Another approach is to use the Earth’s atmosphere as a detector and search for artificial meteors. This would be technological equipment that collides with the Earth at a high speed - indicating that it was not gravitationally bound to the Sun, and is detected as it burns up in the Earth’s atmosphere. If the object is bigger than a few meters, it could leave behind a remnant meteorite, providing the best opportunity for us to put our hands around alien equipment.

Similarly, we can search the surface of the Moon for extraterrestrial technological debris that crashed on it. Since the Moon has no atmosphere or geological activity, it keeps a record of all objects that crashed on its surface, like a museum that is billions of years old. We could find traces of technological equipment that crashed on the lunar surface a billion years ago with a letter from an alien civilization saying “we exist”. Without checking our mailbox, we would never know that such a message arrived.

In the above examples, both the Moon or the Earth serve as fishing nets to retrieve interstellar debris. In addition, Jupiter could serve as a gravitational fishing net which traps interstellar objects which pass near it. Most of the time we will likely recover natural rocks or icy bodies like asteroids or comets. But perhaps not always. This reminds me of my favorite activity on vacation - to walk along a beach and examine sea shells that were swept ashore, while occasionally finding a plastic bottle of a technological origin.

Extending the search to the outskirts of the Solar System, one can look for artificial lights that originate from giant spacecrafts. A city like Tokyo could potentially be detected with the Hubble Space Telescope out to the Kuiper belt. One can distinguish an artificial source of light from an object reflecting sunlight by the way it dims as it recedes away from us. A source that produces its own light, like a light bulb, dims inversely with distance squared whereas a distant object that reflects sunlight dims inversely with distance to the fourth power.

The future promises great advances in discovering new interstellar objects in the Solar System with the advent of the Large Synoptic Survey Telescope (LSST), which is far more sensitive than any previous survey telescope like Pan STARRS - which discovered `Oumuamua.

Venturing beyond the Solar System, one could search for artificial light or heat redistribution on the surface of a planet. The nearest star to the Sun is the dwarf star, Proxima Centauri, whose mass is only 12 percent that of the Sun. The habitable zone around this faint star is twenty times closer than the Earth-Sun separation. As it turns out, our neighboring star hosts an Earth-size rocky planet, Proxima b, at that distance. But since this planet is so close in, it is likely tidally locked like the Moon is to the Earth and so it faces the star with the same side at all times. Naturally, the permanent dayside would be hot and bright whereas the permanent nightside is cold and dark. But an advanced civilization might attempt to cover the dayside surface with photo-voltaic cells that would generate electricity to artificially illuminate and warm the night side. As the planet moves around the star, the varying level of light from its surface could inform us whether a global engineering project of this type took place. We could also search for the unusual reflectance and color expected from solar cells on the dayside. These studies can be done just by monitoring the planet’s light and color as it moves around the star without any need to image its surface.

But artificial activities may have other consequences such as industrial pollution of atmospheres. The contamination by a blanket of pollutants or aerosols may be intentional in order to warm up a planet that is otherwise too cold or vice versa. Our archaeological dig could include a search for artificial molecules, such as chlorofluorocarbons (CFCs). Some molecules and surface effects may survive long after the industrial civilization that produced them died.

At even greater distances stretching out to the edge of the Universe, we could search for flashes of light from beams sweeping across the sky. Such beams may be used for communication or propulsion purposes. In particular, spacecraft launch systems which are based on the technology of light sails, would inevitably appear as flashes in the sky due to the inevitable leakage of light over the edge of their sail when the beam happens to be pointed in our direction for a brief moment in time. Whereas radio frequencies are ideal for transporting massive cargos at modest speeds between nearby planets such as Earth and Mars, infrared or optical lasers are optimal for launching lightweight probes to the speed of light, as envisioned by the Starshot project, whose scientific advisory committee I chair.

In addition, one could search for a swarm of satellites or megastructures that block a significant fraction of the light from distant stars, as envisioned by Freeman Dyson. However, such gigantic megastructures may be rare or non-existent as they face major engineering challenges.

If we recover anything artificial through our archaeological dig into space, the natural question to ask is: "are we the smartest kids on the block?". If the answer is negative, we can learn a lot from our findings and perhaps short cut our own evolution by thousands, millions or maybe even billions of years.

While reading a newspaper, it is difficult to avoid the thought that our intelligence bar is not particularly high and difficult to surpass. We fight among ourselves in "lose-lose" situations, we do not promote long-term benefits in favor of short-term manipulations and we have been carelessly broadcasting our existence to the entire Milky Way galaxy in radio waves for over a century without worrying whether there are any predators in outer space. One even wonders whether we had been ignored by predators because we appear so incompetent. But as far as space archaeology is concerned, the key challenge to improving our awareness of other civilizations is whether we are intelligent enough to adequately interpret their products.

Discovering a piece of advanced technological equipment that was developed by an extraterrestrial intelligence may resemble an imaginary encounter of ancient cave people with a modern cell phone. At first, they would interpret the phone as a shiny rock without realizing that it is a communication device.

One fact is clear. If we assign a zero probability for finding evidence for artificial objects, as some scientists did in the case of `Oumuamua by stating "it's never aliens", then we will indeed never find any evidence for aliens.

How can our civilization mature? The same way kids do, by leaving home into the neighborhood, meeting others and comparing notes with them. In other words, we can develop a balanced perspective on our current technological accomplishments by searching for relics of extraterrestrial intelligence. Since our own technological development accelerates exponentially with an *e*-folding time of a few years, it is difficult to imagine the face of a much more advanced technology crafted by a civilization that had lived for a cosmic timescale, lasting billions of such *e*-folding times.

Currently, we keep all our eggs in one basket, the Earth, making it vulnerable to a catastrophe. There is no doubt that we will eventually migrate into space to produce multiple copies of what we hold dear and increase the longevity of our civilization. Just as ancient civilizations migrated towards banks of rivers on Earth, advanced technological civilizations might be migrating throughout the universe towards environments which are rich in resources, such as clusters of galaxies.

Alien spacecrafts might include robots equipped with 3D printers and artificial intelligence, allowing them to use the raw materials they scoop elsewhere in making artificial objects based on blueprints from their home planet. The advantage of 3D printing of life from raw materials on a target planet is that natural biological systems with DNA as-we-know-it, live a finite lifetime and may eventually disintegrate in a few million years, whereas artificial machinery can be constructed to be durable and last much longer.

If biological or technological signatures on other objects would look the same or would appear to be unusually clustered in space, we might realize that it has a common ancestry. The situation would be just like recognizing that too many kids in the neighborhood resemble the milkman.

To move forward we must think outside of the box and avoid prejudice about what we expect to find based on past experience. Let me illustrate the need for a new mindset with a personal anecdote. After six visits to the same university town in Europe I decided that I had had enough. My hosts kept putting me in a small hotel room where I would bump my head against the tilted ceiling while taking a shower and had to crawl into my narrow bed without space to stretch my legs. “Next time I will reserve a double room,” I promised myself. And so I did. But when I arrived to the hotel on my next trip, the receptionist said: “I see that your wife could not make it … I will be glad to downgrade your room reservation to a single room”. I said “no way, please put me in the double room that I reserved.” When I mentioned the story to my hosts and asked why space is so limited in this town, they answered “because the town has a rule that no building can be taller than the church”. This raised the inevitable question: “why don’t you make the church taller?” To which they replied “because it has been like that for centuries”.

Young people often imagine new worlds but their revolutionary ideas are met with skepticism and dismissal by the “adults in the room” who lost their enthusiasm for challenging reality in many bruising fights long ago. The “adults” simply got used to accepting what is known and ignoring the unknown. Youth is not a matter of biological age but of attitude. It means willing to open up new frontiers of scientific discovery, like space archaeology, rather than staying with the traditional ones.

Becoming a scientist offers the great privilege of maintaining our childhood curiosity and questioning unjustified notions. It is commonly believed in the conservative scientific community that intelligent life may be unique to Earth and that it would be a waste of funds to search for artificial signals in the sky or space debris of dead civilizations in outer space. Avoiding the search serves a self-fulfilling prophecy, like that of an ostrich burying its head in the sand. But this notion should be challenged. Today's new generation of researchers has access to telescopes that could turn this notion on its head. Just as Copernicus revolutionized the prevailing dogma about our place in the Universe, our generation can foster a new Copernican revolution by "making the church taller" still.

Finding traces of civilizations that died from self-inflicted wounds, such as wars or climate change, will hopefully convince us to get our act together and avoid a similar fate. But it would be even more remarkable if flyby photography of an interstellar relic within the Solar System would reveal an advanced technology never witnessed before. No lesson is more valuable than the sense of awe and modesty that would accompany such a discovery.

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