The Cosmic Dawn of Technology

By Avi Loeb on December 2, 2020

We are late bloomers, cosmologically speaking. The first stars formed as early as a tenth of a billion years after the Big Bang. The Sun formed 9.1 billion years later, merely 4.6 billion years ago - when the Universe already matured to two thirds of its current age. The late birth of the Sun marked the tail end of the star formation history of the Universe.

At present, the Earth-Sun system is an abundant occurrence. Based on the Planet Candidate Catalog compiled from the Kepler space telescope data, we know that of order half of all Sun-like stars host an Earth-size planet in their habitable zone. These planets could accommodate ponds of liquid water on their surface and exhibit the chemistry of life. If this was also true near stars formed at earlier cosmic times, life may have started in our universe long before the Sun was born. And consequently, the first technological civilizations may have sprung into existence billions of years ago. Given that our technologies advance exponentially on a timescale of a few years, the signals that may result from billions of years of technological development are unimaginable.

Even if there is only one species like ours in a large galaxy like our Milky-Way, and this civilization transmits signals for just one century of technological development - as we already did, there should still be of order a hundred active civilizations on the sky at any given time. This follows from the fact that the observable volume of the Universe contains about ten billion such galaxies for ten billion years. Can we detect artificial sources from cosmological distances and distinguish them from natural signals in the early universe?

An example for a distinct technological signal would be a spectral line with a puzzling radiation frequency that does not correspond to any known atomic or molecular transition. Such a signal would appear peculiar if it originates from a distant galaxy whose redshift is known based on identified emission or absorption lines originating from its stars or interstellar gas. An unidentified spectral line can be produced artificially by tunable lasers, like the free electron lasers that our civilization developed to generate bright emission centered on a single frequency that could range from microwaves through terahertz radiation, to infrared, visible, ultraviolet or even X-rays. The advantage of producing single-frequency radiation, as in a spectral line, is that it can be focused to the maximum possible level, so-called the diffraction limit, yielding the brightest beam for its power. The focused laser beam can be used, for example, to push a light sail to a high speed, as envisioned in the Starshot Initiative. For propulsion purposes, the optimal frequency of the laser depends on the desired terminal speed and weight of the payload. For example, the optical-infrared band is ideal for reaching the speed of light with lightweight spacecrafts aimed at interstellar travel (e.g., from the Sun to Alpha Centauri), whereas the radio band is best for reaching a thousandth of the speed of light, still ten times faster than chemical
rockets, with heavy crafts used for interplanetary transport of cargos (e.g., between the Earth and Mars).

The leakage of light from a powerful launch facility that harnesses all the starlight that is intercepted by a habitable Earth-size planet and focuses it into a diffraction-limited laser beam, can be detected across the entire Universe. Since the source moves relative to us, the beam would sweep across our sky and appear like a flash of light from a lighthouse. The resulting optical flashes can be searched for with the Legacy Survey of Space and Time (LSST) on the Vera C. Rubin Observatory, which is expected to start its scientific operation in late 2023. The confusing background for cosmological signals would be transient flashes from reflected sunlight by our communication satellites, which might add up to constellations of tens of thousands of independent pieces filling our sky in the coming years. This techno-signature of our own making might compromise our ability to search for cosmic flashes from Earth. An already known class of brief transients at cosmological distances are Fast Radio Bursts, but these are thought to originate from highly magnetized neutron stars based on a known Galactic source.

A civilization that harvests only the energy available on its planet was classified as Type I by Nikolai Kardashev in 1964. Types II and III civilizations on the Kardashev scale use the energy available to their planetary system and host galaxy, respectively. These advanced types are already constrained by available data since they are easier to notice. But the realm of possibilities extends beyond the levels first considered by Kardashev. In principle, it is possible to imagine hypothetical civilizations which harvest the energy available in their cluster of galaxies or their entire cosmological horizon. Of course, space and time do not end at the farthest reach of our telescopes. The possibilities might be even grander beyond our cosmic horizon and before the Big Bang.

Finding evidence for the cosmic dawn of technology will place our own existence and aspirations in a broader context. We wouldn’t have needed to invent the wheel if we saw it first spinning on our land under a rover manufactured by a more advanced species.

Currently, we have no clue for the sophistication level of the technologies that preceded us in the cosmos. But one thing is clear. If any of us would decipher an alien technology that represents a quantum leap relative to what we possess today, then that person will become extremely wealthy by marketing the same idea on Earth. The “gold rush” opportunity of mining the sky for new technological ideas offers a financial incentive for becoming an observational astronomer. In the long run, if - as many of us expect - we are not the smartest kids on the cosmic street, astronomy may offer prospects for more affluence than Silicon Valley or Wall Street.
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(Credit: Nick Higgins)