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SETI: the argument for artefact searches

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Abstract

For six decades, SETI has attempted to prove the existence of technologically advanced intelligence by detecting artificially generated electromagnetic signals. While such signals could certainly exist and – given the right circumstances – might be measurable here on Earth, contemporary searches are all compromised by limited sensitivity and a reliance on persistent transmissions. The energy required for any putative transmitters, the possible wish of the senders to be cryptic, and a likely ignorance about *Homo sapiens*' existence all lead to the reasonable conclusion that greater attention to artefact searches could hasten the discovery of alien intelligence. We consider both the motivation, the advantages and the disadvantages of this approach. We also enumerate some of the specific artefact strategies that have been proposed and pursued.

Introduction

In the spring of 1960, astronomer Frank Drake established the reigning paradigm for experiments intended to discover evidence for intelligence beyond Earth. His Project Ozma used an 85-foot antenna at the National Radio Astronomy Observatory to examine two nearby (11–12 light-years) Solar-type star systems for narrow-band radio signals (Drake, 1960).

At the time of Drake's experiment, microwave technology – essential for radar – had been well developed, and it was recognized that (a) frequencies above 50 MHz were preferred for SETI because of their ability to pass unhindered through Earth's ionosphere; and (b) there was an obvious spectral marker for any societies attempting to get in touch, the 1420 MHz emission line of neutral hydrogen (Cocconi and Morrison, 1959).

Since 1960 approximately 100 additional radio SETI experiments have been reported in the literature (https://technosearch.seti.org). Nearly all have followed Drake's lead in looking for microwave signals with distinctive narrow-band components. But no confirmed transmissions have been found.

Several explanations have been offered for this result. One possibility, albeit extreme, is that Earth is the only world hosting intelligence. Other suggestions include the possibility that the emitting signals might be at wavelengths not yet explored by SETI experiments, or that few societies engage in transmitting because it might endanger them.

However, the most common explanation for SETI's lack of success is to note that the number of star systems examined over a wide range of frequencies is still small; on the order of 10^3–10^4 – a tiny fraction of the galactic complement of stars (see Wright *et al.*, 2018). If we accept this explanation, then success might simply depend on increased effort. Indeed, the Breakthrough Listen project at the University of California, Berkeley seeks to grow the existing sample of observed, nearby star systems to approximately one million in the next decade (Isaacson *et al.*, 2017)

In this paper, we point out how the usual SETI strategy is compromised by several limitations, and why a hunt for artefacts should be given greater emphasis.

The problem with signals

One undeniable constraint on contemporary radio SETI experiments is their modest sensitivity. We note that the collecting area of antennas used for SETI since 1960 has ranged over two orders-of-magnitude. Front-end amplifiers have differed by approximately a factor of three in their noise temperatures.

But despite this variability, SETI experiments of the past three decades have all had roughly the same sensitivity when considered logarithmically. This is a consequence of the fact that they usually have the same channel bandwidth and target dwell times, respectively ~1 Hz and a few minutes.

As examples, the minimum detectable flux densities for SETI observations made with the Green Bank Telescope, used by the Breakthrough Listen project, and programs with the Allen Telescope Array (Welch *et al.*, 2009) are approximately 2 and 50 Janskys respectively, based on a detection threshold of six sigma.

While these examples appear to be inconsonant in their sensitivity, they are not qualitatively different when looked at from the standpoint of required transmitter power. For the two cited examples, and assuming that a transmitter is a nominal 300 light-years distant – a range that encompasses approximately one million stellar systems – the implied minimum, isotropic transmitter powers are respectively 2.0×10^{12} and 5.1×10^{13} watts, even making a conservative, but probably unreasonable assumption that the signal is devoid of information and entirely contained within a 1 Hz band. This latter constraint implies that an extraterrestrial transmission is only a marker, conveying no information whatsoever. Attaching data to the signal will, of course, both broaden the bandwidth and increase the required transmitter power.

These Effective Isotropic Radiated Power (EIRP) values are comparable to humanity's total power consumption, 2.2×10^{13} watts. While we cannot be sure what energy resources are available to the extraterrestrials, this number would be a substantial investment for any planet-based society.

In addition, it is plausible to suspect that alien societies will avoid behaviours that would make them conspicuous, something that an omnidirectional transmitter would obviously do. Extraterrestrial societies might either ban powerful transmitters or perhaps deploy them in less worrisome locations. It has also been suggested that using two separated transmitting sites while taking advantage of quantum effects could hide the source of emissions (Simmons, 2004). Of course, these considerations would affect SETI searches insofar as such experiments limit their scrutiny to biologically promising stellar systems.

A counter to the above is to note that the alien transmitter power required to produce a detectible signal can be arbitrarily reduced by beaming, using large antenna apertures or arrays. In particular, Nordley (2018) has noted that Dyson (2003) spheres or swarms, whether complete or partial, supply both the required energy and the necessary size for a long baseline array that could be used to focus a strong signal on other worlds. Note that such a construction in our own Solar System, just outside the orbit of Mars, would provide the real estate for an array large enough to focus an L-band signal on a spot about the size of Texas at 300 light-years distance.

A second consideration in SETI is the assumption that signals are persistent and 'on' for centuries, millennia or more, and therefore amenable to detection by our intermittent searches. But that implies that the extraterrestrials have some motivation to continuously target Earth. One might believe that an obvious incentive would be establishing contact with us, a fellow intelligent species. But evidence for *Homo sapiens* is hard to detect from astronomical distances other than by observing our radio or optical emissions. While it is true that earlier 'signals', such as the change to our atmosphere occasioned by the development of agriculture, would surely be present, these are very weak, and possibly swamped by other, natural occurrences, such as volcanic eruptions or ice ages.

Microwave transmitters (radar, television and FM radio) date from the Second World War, so any society more than 40 light-years away would not have had the opportunity to detect us and transmit a signal that could be reaching us today. There are approximately 3000 star systems within this distance, and that number is so small that it seems unreasonably optimistic to presume that these include a transmitting civilization.

The above considerations suggest that we cannot reasonably expect transmissions that are targeted towards us because of our existence. It is possible that Earth would be in the line-of-sight of signals being sent to interesting objects on the other side of our position, or that we are accidentally in the beam (or sidelobe) of any transmission to this part of the Galaxy. Such circumstances would mitigate the energy requirement and possible dangers of launching omnidirectional emissions into the cosmos. But they are a form of special pleading, requiring fortuitous circumstances to generate a detectable SETI signal at relatively low cost to the sender.

To restate, advanced aliens probably do not know we are here, although we can presume that they would have found the long-lived biosignatures in our atmosphere betraying life on Earth.

But even that might be small motivation for signalling as it does not guarantee the presence of intelligence. Indeed, if biology is commonplace, our planet is simply on a list – one of many displaying spectral signatures of life. If biology is uncommon, then it is likely that those who have detected it are far away.

One could argue on this basis that SETI was 'invented' too soon, and we must either (a) wait much longer before attempting to find a signal sent in response to the detection of our presence; (b) assume, despite the above, that there are very powerful omnidirectional transmitters; or (c) bank on the possibility that we are being relentlessly targeted for not-yet-understood reasons.

Considering option (a) further, we note that our microwave radio horizon is at a distance of 75 light-years, and consequently our earliest high-powered, high-frequency emissions are currently washing over extrasolar systems at the rate of about two a day. We do not know the tally of extant, technical civilizations in our Galaxy, but assuming that number is of order 10^4 it will be about ten millennia before we can expect that some extraterrestrials know of our existence.

As a corollary to the *a priori* improbable circumstance that signals will be beamed our way, there is also a constraining observational requirement for synchronicity in today's SETI experiments. We presume that the aliens' transmitted signal will arrive at our receivers within the several minutes window during which our antennas are aimed in the correct direction. Even if Earth is on someone's list as an interesting target, it seems unlikely that their 'ping' to see if anyone is at home would arrive during the interval we are looking, which is roughly 10^{-14} of the time since atmospheric oxygen first became abundant here.

The above encumbering aspects of a signal search clearly encourage a greater consideration of alternative strategies.

The appeal of artefacts

A hunt for artefacts – which is to say deliberate constructions or alterations of natural objects – has several advantages over a signal search. It removes the need to assume that the extraterrestrials wield extremely powerful transmitters or that they know of *Homo sapiens*' existence. It might also benefit from instruments that can detect temporally variable objects, such as the Vera Rubin Telescope. But we can only guess at what artefacts to expect, a circumstance that hinders any estimate of their visibility.

And visibility is an issue. The best resolution for modern optical telescopes is ~0.1 arcsec. So the minimum size of any object that can be imaged is 1.5×10^{11} km at 300 light-years, or comparable to Jupiter's orbit. This suggests that the direct imaging of structures is unpromising. However, just as for exoplanets, not all detection methods depend on directly seeing the targets.

The idea of artefacts as technosignatures is hardly new, and is contemporaneous with the earliest signal searches. Both quasars

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and pulsars were once suspected of being artificial in origin (Kardashev, 1964; Bell Burnell, 1977). A more modern example is the erratically dimming star KIC 8462852, also known as Tabby's star (Boyajian *et al*., 2018). An intriguing suggestion by Wright (2015) was that the dimming was caused by an intervening structure – an incomplete Dyson sphere or swarm – built by ambitious inhabitants.

While this hypothesis became less persuasive with the detection of reddening behaviour consistent with dust associated with the dimming (Meng *et al*., 2017), it reinforced the recurrent idea that novel phenomena might have non-natural origins. Recently, Fast Radio Bursts have been fingered as possibly deliberate phenomena (Lingam and Loeb, 2017).

Because of their notoriety, and their obvious utility for any society transitioning from a Type I to Type II Kardashev civilization, Dyson constructions have been the poster child for artefact searches. Several investigations using catalogue data have been published (Jugaku and Nishimura, 2000; Minniti *et al*., 2004; Carrigan, 2009). However, no sources have been found that can be unambiguously attributed to deliberate structures.

It has been noted that if the waste heat generated by a planetary society exceeds 0.1% of the Solar insolation, it would lead to a catastrophic effect on climate, and force that society to develop schemes to off-load either the heat sources or large amounts of infrared radiation (Rebane, 1993). The Earth intercepts 4.5×10^{-10} of the Sun's output, so a Dyson construction with a completeness factor of $\sim 10^{-7}$ would supply the maximum allowable energy for an Earth-like planet (assuming 50% efficiency in the conversion of sunlight to usable energy). Such a sparse structure would be difficult to detect in transit, and would emit only a relatively small amount of infrared.

Gerald Nordley has pointed out that Dyson constructions have uses other than as a power supply. The combination of an enormous potential energy source and a large physical baseline able to support a focusing array might turn such assemblies into 'death stars', weapons able to threaten societies throughout the Galaxy. Even an incomplete Dyson construction around a Sun-like star could collect 10^{32} joules per month. That is sufficient energy to vaporize an Earth-size planet. In this case, a Dyson sphere might be inferred from its use, rather than its presence.

Whether weaponized or not, Dyson constructions remain difficult to detect, as noted. It is also interesting that engineers have recently experimented with samarium nickel oxides that have the property of disguising the black-body infrared emission one would expect from an object at a non-zero temperature (Shahsafi *et al*., 2019). Conceivably, such technologies might assist the concealment of any large structure.

Our own Solar System remains largely unexplored for artefacts, although several have been suggested. Papagiannis (1978) urged a search for extraterrestrial mining operations in the asteroid belt. More recently, Benford (2019) noted that objects that are co-orbital with Earth would be useful reconnaissance bases for those who have an interest in developments on our planet.

Another scheme by Dyson (2003) for finding biology nearby – including intelligent biology – is to use the technique of pit-lamping. Organisms living on bodies in the outer realms of its Solar System could reasonably be expected to deploy reflectors (perhaps shiny petals) to collect weak star shine for both metabolism and warmth. By making a search in our own ecliptic in the anti-Sun direction – which ensures that we, the Sun and any such reflectors are collinear – we might see these sparkling lights at many AU distance.

Another variant on this approach was offered by Loeb and Turner (2012), who pointed out that any artificially illuminated objects in the outer Solar System might be detectable with large aperture telescopes, assuming that their total brightness was comparable to that of a terrestrial city. Simple intensity measurements could be used to distinguish artificially and naturally illuminated objects as the objects orbit closer and farther from the Sun.

While Dyson was proposing his pit-lamping scheme as a method for finding insensate life in our Solar System, tell-tale reflections could also be expected from O'Neill-style space habitats (O'Neill, 1977), as they too would want the energy that large mirrored surfaces provide, an idea elaborated by Scheffer (2010). Lingam and Loeb (2017) suggest that reflections from Solar panels deployed on the star-facing side of a planet would betray spectral characteristics of the silicon used in their manufacture.

Ergo, transient and spectrally anomalous reflections and light sources offer yet another avenue for the detection of extraterrestrial activity.

Other markers of technical competence

A relatively simple marker of societies that are at least a few centuries more advanced than our own would be large occulting structures deliberately shaped to be noticed by any culture that conducts a transit search for exoplanets (Arnold, 2005). Orbiting triangles or any occulter with holes would, in principle, be observationally distinguishable from the expected dimming curves caused by spherical planets or moons. The advantage of such signalling is that it could be seen at a great distance, and would work over a large range of viewing angles. The disadvantage is the requirement that the search system generates high signal-to-noise data to minimize the degeneracy in inverting a one-dimensional light curve to produce a two-dimensional shape (Sandford and Kipping, 2019). In addition, there is the discouraging fact that this signalling apparatus is expensive for the transmitting society and has only a minuscule data bit rate.

Another, somewhat similar scheme has been proposed by Learned *et al*. (2013) who suggest that an advanced society might change the pulsation period of Cepheid variable stars. As with the orbiting occulters, the information conveyed with such a scheme is akin to that of a cairn: 'There is something interesting here.'

While constructing artefacts such as those described above is demanding from an engineering point of view, they all produce markers that work for long periods of time and require little ongoing effort. They could outlast the intelligence that constructed them. They are also the type of signalling that can be uncovered in the course of conventional astronomical research.

Another artefact suggestion is to search for the exhausts of interstellar rockets that are driven through space with energy-intensive propulsion systems. Mounting engines on O'Neill space colonies would allow a species to not just export themselves to other star systems, but their habitats as well. The latter would be difficult to image. But if any culture wields matter–antimatter annihilation technology, then the 'exhaust' of such engines might be conspicuous by its production of gamma rays. A preliminary literature search for such sources (Harris, 2005) failed to find any candidates that, by their proper motion, might be the sought-for spacecraft.

The above suggestions for objects that might be deliberate constructions are all based on our conceptions of what advanced societies might do. Obviously, these ideas are inevitably shaped by our current technological understanding – consider how, only a century ago, it was thought reasonable that advanced Martians would lace their landscapes with canals (Lowell, 1906). No doubt our current expectations for the types of constructions that sophisticated extraterrestrials will build may prove to be similarly provincial. There is no unassailable reason why other societies might not be millions (or billions) of years more advanced than us. As frequently stated, their activities could be something that 'would look like magic' to us (Clarke, 1973).

Despite the fact that the suggested artefacts described here are firmly rooted in our own expectations and accomplishments, there have been at least a few efforts to look for large-scale engineering that is less tied to current assumptions. The waste heat from Dyson swarms has been mentioned, but a larger-scale – and less-specific – version is to search for galaxies with mid-infrared excess, indicating the presence of a Kardashev Type III civilization (Wright *et al*., 2014). This so-called G-Hat project (Griffith *et al*., 2015) used data from the WISE telescope in such a search, but found no Galaxy where more than 85% of its starlight had been converted to mid-IR emission. However, when the limit for starlight conversion was reduced to 50%, 50 candidate objects were found. The latter are clearly worthy of additional study.

Perhaps the most general artefact search to date has been a comparison of imagery compiled in early sky surveys (the US Naval Observatory Catalog B1.0) with more recent Pan-STARRS observations, looking for objects that either appear or disappear (Villarroel *et al*., 2019). While many candidates for such objects were found, it is not yet clear whether any of these can be ascribed to the workings of advanced intelligence.

Our inability to reliably envision the constructions of advanced societies becomes less of a concern if we look for a reordering of the natural universe. These can be easily verified by straightforward comparison observations.

Hooper (2018) has noted that truly advanced societies would want to harvest other star systems to increase their energy supply. Cosmic expansion (and the more recent acceleration of that expansion) causes the stars of other galaxies to relentlessly retreat. Hooper suggests that very advanced societies will try to collect these stars while they can, perhaps by surrounding them with Dyson swarms to provide the energy necessary to transport them to their energy-hungry home Solar System. This could supply an additional $>10^{10}$ years of stellar energy for any society able to do this. It also would result in an unmistakable visual signature – unnatural assemblages of stars – that might be recognized in the course of routine astronomical surveys.

Zubrin (2019) has proposed another approach to garnering large amounts of energy by constructing artificial singularities (small black holes) that could be used to terraform planets or for other uses. He proposes that these objects could be recognized as having the spectrum of a cool star, but one whose parallax indicates a far smaller distance than expected.

Why an artefact search makes sense now

Traditional SETI signal searches are compromised by the necessity of assuming (1) the presence of unreasonably powerful omnidirectional transmitters; or (2) the existence of directed signals that – barring an accident of transmitting direction or an improbably close society (<40 light-years) – cannot be rationalized as a response to our existence; and (3) a willingness to make their own location known.

An artefact search is not subject to these constraints. However, unlike a radio search, it is hard to quantify its sensitivity. Some crude measure of detectability can be gleaned from the current limits for transit exoplanet experiments. For a star system observed ~100 times, the TESS space-borne instrument can register a repeating dip of $\sim10^{-5}$ the star's brightness (Jenkins, 2002). In the case of a red dwarf star with a diameter ~0.1 times that of the Sun, such sensitivity would be adequate to detect an object with a nominal size of ~440 km or more, roughly the same as the state of South Dakota.

We note that in the past two centuries, humanity has constructed paved roads with a similar total area. It is difficult to argue that structures of these dimensions could not exist in a universe three times the age of the Solar System.

As we have tried to demonstrate, there has been considerable speculation as to what artefacts might exist. However, we cannot presume that our imaginations are in any way either comprehensive or accurate. Would we, a century ago, have hypothesized something like a Dyson sphere? To this uncertainty, we can add the plausible argument that truly advanced intelligence in the cosmos is likely to be synthetic. Biological cognition may be no more than a stepping stone to machine intelligence. Consequently, the extraterrestrials that we seek are not necessarily bound to a stellar system, and our searching should not be so constrained (Shostak, 1998; Dick 2008).

Nonetheless, there are reasons to think that artefact searches are now more than simply an alternative and unusual SETI strategy. The broad range of suggested artefacts demonstrates the substantial interest in the artefact approach, and the deployment of larger telescopes, several with an increased ability to recognize short temporal events, allows a larger class of phenomena to be sought. At the same time, cheap computation and machine learning make it feasible and practical to mine present and future data sets for anomalies (see, for example, Lesnikowski *et al*., 2020.) Just as the development of radio astronomy antennas and autocorrelation receivers fostered the era of conventional radio SETI, these improvements in optical imaging and data analysis make artefact searches more attractive.

Conclusion

We have argued for a greater emphasis on artefact searches given the limitations imposed by (1) the low sensitivity of all modern SETI searches for omnidirectional transmitters ($2–50 \times 10^{-26}$ watts m^{-2} in a 1 Hz channel); (2) the questionable motivation for any intelligence to target Earth with more easily detected transmissions if they have not yet detected signals from us, which imposes a 40 light-years limit on reasonable search targets (encompassing ~3000 stellar systems); (3) the need for either serendipitous synchronicity or for signals that persist for geologically long time periods; and (4) the possibility that strong transmissions might be considered a dangerous activity for any society.

Artefact searches circumvent each of these limitations. However, systematic searches for artefacts have been few. While the best strategy for any such search remains uncertain, one can emphasize the necessity to consider that any unusual phenomenon uncovered in astronomical observation might have non-natural causes, despite a historical record to the contrary. It also remains true that such phenomena should cause intense follow-up with a signal search which, because it is less prone to ambiguity, will remain the gold standard for claiming a SETI discovery.

No one would suggest that we delay searching until technology and new construction can increase conventional SETI sensitivity by several orders of magnitude, or that we fold our hands and wait for our leakage to reach farther into the cosmos to encourage a targeted transmission in our direction. But a greater emphasis on looking for artefacts is clearly merited.

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