THE SEARCH FOR EXTRATERRESTRIAL ARTIFACTS (SETA)

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The Artifact Hypothesis states that an advanced extraterrestrial intelligence has undertaken a long-term programme of galactic exploration via the transmission of material artifacts. An attempt to verify this hypothesis experimentally, the search for extraterrestrial artifacts (SETA), is proposed to detect such evidence in the Solar System by telescopic, radar, infrared, direct probe, or other available means.

1. THE ARTIFACT HYPOTHESIS

Current scientific interest in the search for extraterrestrial intelligence (SETI) is motivated by the recognition that the technology for interstellar communication is now available [1]. In recent decades many searches for interstellar radio beacons and signals have been proposed and actually conducted [2-4]. The two principle assumptions in all such efforts are that (1) advanced extraterrestrial intelligence exists in the Universe, and that (2) these intelligences are presently attempting to locate, examine, or possibly communicate with us.

A previous paper [5] argues that interstellar spacecraft are generally preferable to electromagnetic wave propagation for extrasolar exploration and communication. Further, recent objections to the existence of extraterrestrial intelligence based on the Fermi Paradox [6-8] are invalid [9] because they are based on the unsupported assumption that ETI or their artifacts are not now present in the Solar System. Our ignorance of potential evidence of ETI in the Solar System is not generally appreciated. (As in Ref. 9, it is conceded that the UFO controversy and terrestrial sightings have no direct relevance to the present observational question).

In view of these results, and in order to subject the Fermi Paradox to needed experimental testing, I offer the Artifact Hypothesis:

> *A technologically advanced extraterrestrial civilisation has undertaken a long-term programme of' interstellar exploration via transmission of material artifacts.*

If the hypothesis is correct, then unless the programme has only just begun, some evidence of this extraterrestrial exploratory activity should be apparent within the confines of the Solar System and thus could be detected by a suitable observational effort [10-11]. On the other hand, if testing by observation disproves the Hypothesis, and if the arguments for physical probe superiority are regarded as conclusive, then the case for the nonexistence of ETI based on the Fermi Paradox becomes far more compelling.

2. THEORETICAL BACKGROUND

The nature of observable artifacts depends in part upon unknown alien motives for sending them. Artifacts not intended to be found will not be found. For instance, in one scenario the probe imperfectly camouflages itself with the motive of providing a thresholding test of the technology or intelligence of the recipient species, which test must be passed before communication with the device is permitted. The technological superiority of the sending civilisation guarantees the efficacy of the mission design and the impossibility of discovering the artifact until the predetermined conditions for discovery are satisfied. Since these conditions cannot be specified *a priori*, the result is an observationally null set. In another plausible scenario, the probe hides to ensure the military security of the sending civilisation during clandestine surveillance of the target star system. Again the search space is observationally null because of the necessary technological impenetrability of the disguise.

Thus only those classes of artifacts not subject to a policy of perfect concealment can be observed by us. Observable evidence will be provided by ETI who do not particularly care whether we find them or not [12], or who may actually be interested in communicating with us yet be unwilling or only conditionally willing to initiate contact. This may imply careful and unobtrusive surveillance by ETI, with no special effort to disguise the alien presence. Artifact base sites would then be chosen strictly for reasons of efficiency, maintainability, or low environmental risk, and so should be observable by us. This is the most conservative assumption from the standpoint of the Fermi Paradox, exemplified by many pretechnological peoples on Earth who even today have little knowledge of the modern world. The more restrictive assumption that ETI activities are perfectly concealed leads to a trivial resolution of the Fermi Paradox.

There are four classes of unconcealed, potentially observable artifacts, as follows.

2. 1 Astroengineering

If a highly exploitative civilisation exists or had ever existed in our vicinity, then the Solar System would have been wholly converted to replicating machine mass ("industri-forming".[13]) and the Sun stripped of its fuel. In this case the existence of mankind is negative evidence ruling out such activity. Stephenson [14] suggests that Pluto's unusual orbit may be evidence of past extraterrestrial tampering, and Papagiannis [15] speculates that the Asteroid Belt may be a giant slag heap left over from ETI heavy industry. But the existence of Saturn's rings, eccentric comets, Uranus' axial tilt, Triton's retrograde orbit, Venus' backwards rotation, the Titus-Bode rule for planetary spacing, even the evolution, of life on Earth all could provide similar "evidence." Without corroboration, none is persuasive because in each case more prosaic explanations exist. Kuiper and Morris [12] and Stephenson [16] argue that the only plausible interstellar mission is one of pure exploration - the pursuit of knowledge as a source of wealth - and Tipler [17] points out that this information theory of wealth is widely held by modern economists, all of which supports the iraplausibility of large-scale rapacious activities by ETI.

2. 2 Self-Replicating Artifacts

Self-reproducing machine systems may be present in the Solar System which are building and launching interstellar probes bound for other star systems (exploration motive); organising local resources for outshipment to materials-hungry or "energy crisis" extraterrestrial civilisations (exploitation motive); or helping interstellar arks [18, 19], space colonies [15], crewed interstellar probes [14] or habitats [20-21] to refuel, rebuild, repair, grow or replicate (depot motive) or to settle here permanently (colonisation motive). Also, we might hope to observe the environmental aftermath of such activities, including [22] piles of rubble or debris, palcomagnetic anomalies, radioactive hot spots, derelict machinery or tools, abandoned strip mining pits, rocket plumes from departing replicated daughter probes, and so forth.

While possible in principle, none of the above is likely to be observable in any reasonable time frame. Self-replicating or self-growing probe factories need only produce a dozen or fewer offspring in each target star system to explore the entire Galaxy in less than a dozen generations, requiring 10^2-10^3 years for completion of one generation at each site [23-24]. This is 10^{-6} – 10^{-7} the age of the Earth, an improbably small observational window. Individual replicating systems may be 100 metres in diameter [24], so a fully-grown/replicated factory system for building probes [23] need not exceed 0.1-1 km in size. This is roughly 10^{-12} of the total surface area of all known bodies in the Solar System, so even if the search can be limited by siting logic and many such devices have arrived here and are still active they will be extremely difficult to detect. Interplanetary nonreplicating subprobes built and launched (perhaps into Earth orbit) by the factory are more likely to be observed than the factory itself.

However, a good case can be made that no exploratory replicating systems will be sent to the Solar System at all. Unless life is extremely widespread most star systems will be uninhabited. Hence the argument that humanity's value as an undisturbed intelligence increases with the rarity of the sentience in the Galaxy [16] implies ETI will erect their self-replicating probe factories in obviously uninhabited star systems and just send nonreproducing exploratory probes to the fewer more promising systems. This avoids disturbing valuable indigenous intelligent species which may later come under observation.

Exploitative machinery has no reason to stop short of astrophagy, which is not observed. Interstellar arks using the Solar System as a supply depot would have an unobservably short residence time before returning to their native inter-stellar habitat. Colonisation arks using replication technology could organise the entire Asteroid Belt (and many other bodies as well) into ark mass in less than 10^4 years [24], hence the Belt and especially its larger members such as Ceres or Pallas should be missing, yet this is not observed. Most small-scale environmental effects would be either short-lived or else virtually indistinguishable from natural processes, and in any case low-volume and low-mass, hence extremely difficult to detect.

The sole exception is derelict machinery indisputably of alien manufacture. However, interstellar arks are necessarily highly closed efficient systems and would recycle rather than discard old machinery. A replicative interstellar probe factory will minimise creation of mechanical refuse to mini-raise production time, and will also recycle for reasons of efficiency. Exploitative and colonising replicative systems are ruled out observationally and hence cannot leave derelict machinery. Mishaps producing derelicts, artificial debris or other tangible evidence are improbable when a mature technology is employed.

An intriguing alternative is biological markers. Extraterrestrial data concealed in DNA, representing a low-mass self-replicating artifact, has been suggested as a carrier of extraterrestrial information [25, 28], but attempts to decode possible “virus messages” have been unsuccessful [29]. Further, such messages are unstable even over short periods of time due to thermal degradation or spontaneous cross-linkage; only the genetic code itself, which could contain at most a very simple message (perhaps 100 bits), has remained stable over geological times.

2. 3 Passive Artifacts

The simplest class of passive artifact is monuments, including simple inert blocks or sculptures like the “extraterrestrial message block” displayed at the National Air and Space Museum in Washington, D.C. [30], corner reflectors which reflect optical beams back towards the transmitter no matter from what direction they originate [31], or isotope missives in which the isotopic composition of material samples are encoded to yield information upon being read by a mass spectrometer, up to 2000 bits per alloy sample [28]. Other passive artifacts might include buried alien databanks [32] or marker buoys and beacons - to tag mineral deposits, waste dumps, equipment caches, or to transmit navigational or warning signals [22]. Another possible class is the highly redundant passive artifact. This might consist of a large number of relatively simple (presumably physically small) objects whose purpose is to announce the existence of their creators but may also include a brief communication encoded as isotopic missives or genetic messages. If a band of artificial tektites were found on the Moon or the Earth it might be possible to deduce the existsnce of ETI, the age of the artifacts, and their direction of travel [33]. Large numbers compensate for hostile environments, and might be an inexpensive way to leave a marker behind.

Passive artifacts are unlikely to be observed in the Solar System. If their purpose is merely to leave a calling card, a solar-powered radio or visible light beacon in Earth orbit (or some other equally glaringly obvious marker) would be least ambiguous and most likely to be detected. This alternative can be ruled out on observational grounds. If the purpose is to transmit some body of information to the finders [76], then a purely inactive device with no secure means of avoiding dangerous environmental exigencies and no self-repair capabilities would be unlikely to survive long enough to complete its designated mission. Finally, sophisticated extraterrestrial engineers, having reached out across interstellar distances to investigate the Solar System, are unlikely to leave behind only a passive artifact incapable of providing constant surveillance of an interesting, “valuable” inhabited star system.

2. 4 Active Probes

A probe is a physical device which observes and reports back to its senders. Another possible function is interaction with the subjects under observation, either further to test and observe them or to influence their development in some way. Such influences may be benign [34] or otherwise [35]. The requirements for monitoring an entire star system, and of reporting back to the sending civilisation, rule out purely biological probes, though these could possibly be deployed as subprobes [36] under the control of a mechanical system.

To survive, probes must be active and self-repairing but need not be self-reproducing, although the capacity of a machine to reproduce is inherent in the logic of self-repair [24]. Active artifacts incapable of self-repair are insufficiently durable and will not be sent. A civilisation able to conduct a programme of vigorous interstellar exploration using vehicles which are expensive to build and launch takes decades or centuries to reach their destinations, and which must perform exceedingly complex tasks upon arrival must be highly skilled in automata engineering. NASA has investigated self-testing and repairing (STAR) computers for deep-space missions [37], as did the Daedalus design group in connection with a 100-year interstellar mission [38]. A recent NASA Systems Feasibility Study concluded that spacecraft self-repair, self-reconfiguration, and even self-reproduction are feasible technological goals by the year 2000 AD [24]. Lofgren [39] has shown that a self-repairing, self-reproducing automaton system can possess a theoretically unbounded operational lifespan. Technically proficient ETI should be able to design very-long-lifespan self-repairing machine systems [5].

The discovery of accidental environmental effects caused by the passage or presence of the probe is improbable because such efforts are likely to have been foreseen and avoided. “Spent” devices like Lunar Ranger [40] are ruled out by the self-repair requirement. Similarly, impact devices are unlikely because it seems pointless to send a probe light-years just to end in destruction, although impacting deployed subprobes cannot be ruled out. Crewed probes [14, 19] are less efficient than automata, thus are unlikely for large-scale exploration. Repeater stations (perhaps part of a galactic communications network), telemetry stations, and purely educational databanks, intended primarily not to observe but to teach (upon some given trigger signal or event) are not inconsistent with the notion of an active self-repairing probe and most likely represent some of its many functions. In any case, all have similar observational consequences.

Active, self-repairing interstellar probes are the most likely class of observable ETI artifact in the Solar System. This result permits us to devise a specific observational programme to experimentally validate the Artifact Hypothesis.

3. WHERE SHOULD WE LOOK?

A spherical Solar System boundary enclosing the orbit of Pluto consists of 260,000 AU^3 of mostly empty interplanetary space and 10^{11} km^2 of planetary and asteroidal surface area. To test the Artifact Hypothesis observationally, in theory this entire space should be combed for extraterrestrial probes. Fortunately most regions may be logically excluded from the search because of an extremely low probability of occupation, thus reducing the search for extraterrestrial artifacts (SETA) to manageable proportions.

Clarke [41] and Bracewell [42] suggest an equipartition of effort between senders and recipients in which the sender is required only to send probes through target star systems on hyperbolic orbits and potential recipients are held responsible for detection, the initiation of dialogue, and possibly capture. However, even if the probe decelerates in one year from 10%c to solar escape velocity upon approaching the Solar System, the required reaction energy from a l-ton rocket emitted as a point source of solar-spectrum radiation would appear as a +24 magnitude object at 100 AU and a +19 magnitude object at 10 AU. Detection is improbable in the extreme. The minimum reasonable velocity for heliocentric hyperbolic orbits is that of intramercurial solar escape velocity, about 0.1 AU/day. For a perfectly reflecting 10 square metre body at full phase angle, the threshold detection radius for the GEODSS-prototype automated asteroid search system (mB = +16.5) [43] is 0.01 AU. The object will cross this volume, if at all, in five hours or less with a mean probability of detection of 7×10^{-5}. Even at the limiting magnitude of the Space Telescope the threshold range is 2 AU, a detection sphere which the probe crosses in no more than one month. If the probe does not decelerate from greater than 10%c, visual detection must take place in minutes at most, nearly hopeless even if the artifact employs a radio beacon as an aid to acquisition. The amount and quality of data obtained for the builders of a flyby interstellar probe are quite limited [44], and the idea that probes pass by only briefly on their way to other stars makes little sense in view of the tremendous distances which must be covered to reach the Solar System [45]. Flyby probes thus must be regarded as unsuitable for missions of long-term exploration and surveillance.

Following deceleration and initial system survey, an active probe capable of self-repair will elect to reside in the best possible location to monitor phenomena relevant to its mission to seek out life and intelligent species. This location may include heliocentric orbits, phanetocentric orbits, or surface sites. In keeping with the Principle of Economy [5] the artifact must represent the simplest possible mechanism necessary to perform the mission and will act to maximise the probability of success through longevity and hazard avoidance. Hence the search space of a SETA effort to detect extraterrestrial artifacts must conform to two criteria [11] which have well-defined observational consequences:

(1) Ability to consistently monitor environments most likely to harbour or to evolve intelligent life.

(2) Maximum artifact lifespan with minimum complexity.

Present indications are that the only Solar System site where life has existed for aeons is the Earth, although simple life may exist elsewhere, perhaps on Mars, Titan, or Jupiter, possibly employing some exotic biochemistry [46-48]. These other planets are very interesting, but Earth is clearly the most exotic and complex so the terrestrial environment must be regarded as the principal target for continuous surveillance by the probe. In view of the technical and scientific competence of its designers the probe must be presumed to have correctly recognised the significance of our planet and to have taken up residence nearby. Criterion (1) thus requires the artifact to be sited either in orbit near Earth or the Moon, or in an orbit which frequently carries it close enough to Earth to permit adequate periodic surveillance. Terrestrial surface sites are unlikely because these would restrict the ability of the probe to continuously monitor the entire environment. (Even if the main probe were not situated near Earth, it would likely deploy permanent surveilhnce subprobes in our vicinity which would then be detectable by the less demanding search programme proposed here).

Criterion (2) requiring maximum lifespan implies that the artifact will attempt to spend as much time as possible in regions of low environmental hazard - e.g., minimum high-energy particle..intensities and electric and magnetic field densities, and minimum danger from micrometeorite and debris impacts. Titis rules out the siting of artifacts in planetary magnetospheres or ring systems. Also, to maxgreige lifespan the artifact must have access to sufficient energy. Self-contained systems are unlikely to provide enough power for data processing, self-repair operations, orbit/attitude control and interstellar radio transmission. An onboard fusion power plant is possible, but most likely the artifact will collect solar energy, hence must reside near the Sun. This requirement, as well as criterion (1), eliminates all outer planet sites. Similarly, orbits with intramercurial aphelia may be dynamically stable and yet must be rejected - Poynting-Robertson drag alone could remove such bodies as large as 100 metres over geological timescales [49]. The artifact should operate with maximum efficiency, so long-term (> 10^5 yr), stable parking orbits are preferred to orbits which demand the continuous expenditure of propulsive energy for stationkeeping. This eliminates most heliocentric orbits.

Further, a self-repairing probe need only be thermodynamically open to energy - in principle, rising structural or material entropy can be countered by a sufficient application of low-entropy solar energy. New mass is required only to replace negligible losses due to impact spallation, degassing or volatisation, and accidental or purposeful ejection, so access to large stores of matter as on planetary surfaces or near small asteroids or comets is unnecessary.

Minimum organisational and operational complexity demands that the artifact not site itself in locations which may require it to undertake major external construction projects as a general product factory [24]. In principle, a replication-class artifact could install itself on a planetary surface with the intention of building its own shielding, communications gear, subprobes [44], transport and propulsion mechanisms, using a general product factory industrial complex constructed locally by itself. However, from a hardware standpoint this method of operation is less preferable since it introduces additional failure modes into the mission plan, requires the construction of a fact. ory, and imposes more severe resource requirements. Criterion (2) also argues strongly against siting the artifact on the surface of any celestial body having (a) an appreciable escape velocity requiring a major propulsion system for deorbit or ascent, (b) an appreciable atmosphere requiring complex additional maintenance systems for continuous protection from degradative chemical, biological, thermal, erosional, hydrological, climatic and geological events, or (c) rotation, clouds, and electromagnetic phenomena which may inhibit continuous access to solar energy and which may interfere with the artifact's ability to observe or to transmit progress reports.

Several factors are less significant in fixing the SETA search volume. For instance, cosmic ray intensity is roughly constant throughout the Solar System, except within planetary magnetospheres. The solar wind velocity changes imperceptibly between 1-5 AU, with ion temperature falling by a factor of two and mean ion density decreasing according to the inverse square law [50]. The meteorite flux varies only 1-3 orders over the same heliocentric range [5], less within orbital regions of major interest. Finally, probable orbital insertion trajectories for incoming probes are unimportant because propulsion systems capable of interstellar flight are presumed capable of minor orbital plane corrections such as ecliptic alignment after or during final deceleration.

The potential search volume for extraterrestrial artifacts thus reduces to five distinct orbital classes [11]:

(1) Geocentric orbits located between two Earth-centred concentric spheres of radii 70,000 km and 326,400 km;

(2) selenocentric orbits between 3000-58,100 km lunar altitude;

(3) stable synodic libration orbits around Earth-Moon Lagrangian points L4 and L5;

(4) Earth-Moon halo orbits near collinear Lagrangian points LI and L2; and

(5) Sun-Earth L4/L5 Lagrangian orbits.

This is where we should begin our search for alien artifacts.

In addition, there are several low-probability categories of planet-crossing and other orbits which could possibly prove suitable as long-term parking orbits for extraterrestrial automata. Wetherill [52] has shown that the Earth-approaching Aten, Apollo and Amor asteroids have orbital lifetimes on the order of 10^7-10^8 years, and number > 10^5 in sizes > 100 metres. One special orbit of interest is the unusual resonance of asteroid 1685 Toro with Earth (8:5) and Venus (13:5) which appears to be stabilised by close approaches to within 9 x $l0^5$ km of Earth twice every eight years [53, 54]. The orbit has been found stable for integration times up to 5000 years, and it is believed that Mars perturbations set an upper limit of 3 x 10^5 years for the librations [55]. Other Earth-approaching librating asteroids such as 887 Alinda have also been studied [56]. Searches for objects in stable orbits between Earth and Venus have been proposed [57], and a circular orbit at 0.85 AU has been suggested for the long-term storage of nuclear wastes [58-59], although the claimed I OS-year stability is suspect on the basis of previous numerical experiments [60]. Recent investigation of the problem of satellites of asteroids' (possible 104-107 year stability) [61-62] also could have potential relevance to SETI searches of intramartian orbits. However, objects in Earth-approaching heliocentric orbits spend too much time too far from both Sun and Earth, should have shorter lifetimes than bodies in geocentric, selenocentric, or Lagrangian orbits, and hence are unlikely to have survived long enough to be observable by us.

4. STATUS OF THE SEARCH

The formal observational status of the first four of the five primary orbital sites for extraterrestrial probes is given in Ref. 11 and will not be reviewed here, except to note that the record is woefully incomplete. Preliminary recent SETA searches of three of the potential sites [10, 63] have given negative results to date, but this work is far from complete.

Future direct optical searches may begin by filling the enormous gaps in the observational record using ground-based instruments (cf. [64]). However, detection of the smallest likely probe in geocentric, selenocentric, and Earth/ Moon Lagrangian orbits implies a search to magnitude +27 to +28, which requires the Space Telescope [65] or equivalent technology. Selenocentric probes could more easily be detected using a lunar-based (surface or orbiting) telescope facility because proximity to the target reduces the required magnitude limits to +17 to +23 for an exhaustive search [11]. The proposed 300-inch Very Large Space Telescope (VLST) [66] would only permit the certain detection of 10-20 metre, low-reflectivity artifacts parked in Sun-Earth Lagrangian orbits, so exhaustive ground-based or Earth-orbit-based searches are not feasible. However, a large space telescope with limiting magnitude +29 stationed at Sun/ Earth L4/L5 could guarantee an exhaustive search for small artifacts over a time period of about a century. Radar and infrared observations [11] offer few significant improvements over visual searches.

A few past proposals have emphasised observing probe emissions rather than the probe itself. Bracewell [67] suggested that the well-known long-delay echo (LDE) phenomenon was of the type which might be expected as a call sign from an extraterrestrial artifact parked in Earth orbit and desiring to communicate, and Lunan [68] claimed to have decoded several “LDE messages” based on data from Stormer [69] and van de Pol [70]. Lawton and Newton [71] performed a series of LDE experiments and concluded the reflection signals were of a purely physical nature, though they later proposed [72] that radio call signals should be transmitted to likely probe positions in an attempt to stimulate a response.

Kardashev reported receiving “coded signals” from within the Solar System and of possibly alien origin [73], but Western experts believed the signals came from secret U.S. military communications satellites or from magnetospheric energy. discharge [74]. Kuiper and Morris [12] proposed intercepting radio communications between alien probes in the Solar System and their extrasolar senders, but admitted the alien signals may be spread so widely in frequency that they would be very difficult to detect with a modest antenna.

Targeted radio listening searches could also be conducted of likely probe residence orbits in an eavesdropping mode to detect accidental electromagnetic leakage radiation. Searches for radio beacons could establish indirect limits on the existence of probes in the Solar System - the all-sky survey outlined in [75] would provide observational limits on the minimum size of a solar-powered Earth-Moon orbiting artifact maintaining its own local acquisition beacon.

5. SUMMARY AND CONCLUSIONS

The Artifact Hypothesis states that a technologically advanced extraterrestrial civilisation has undertaken a long-term programme of galactic exploration via transmission of material artifacts. Four general classes of unconcealed observable artifacts are potentially available to test this Hypothesis: Astroengineering activities, self-replicating artifacts, passive artifacts, and active probes. Of these, only active self-repairing probes are likely both to exist and to be observable from within the Solar System.

Fortunately the search for alien exploratory probes does not require combing the entire Solar System. Rationally-designed artifacts will elect to deploy themselves where they can consistently monitor those environments most likely to harbour or to evolve intelligent life, and where they can anticipate maximum lifespan with minimum complexity. Flyby probes are improbable, so the potential search volume for extraterrestrial artifacts reduces to five orbital classes including geocentric, selenocentric, Earth-Moon L4/L5 libration, Earth-Moon LI/L2 halo, and Sun-Earth L4/L5 orbits.

The present observational status of each of these orbital classes is inadequate. Preliminary searches have begun but this work is far from complete. Future direct optical searches should fill the enormous gaps in the observational record using ground-based instruments, space telescopes, lunar-based telescopes, and direct probes to hunt for artifacts, and other indirect means to eavesdrop or intercept alien radio communications originating from within the Solar System.

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