Is ET Lurking in Our Cosmic Backyard?

James Benford[1]

[1]Microwave Sciences

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Abstract

The ultimate technosignature is an alien artifact. We should look for them near Earth. The great virtue of searching for artifacts is their lingering endurance in space, long after they go dead. I compare a Search for Extraterrestrial Artifacts (SETA) strategy of exploring near Earth for alien artifacts to the existing listening-to-stars SETI strategy. Stars come very close to Earth frequently. About two stars per million years come within a light year. An extraterrestrial civilization that passes nearby can see there's an ecosystem here, due to the out-of-equilibrium atmosphere. They could send interstellar probes to investigate. The Moon and the Earth Trojans have the greatest probability of a successful search by us, ET archeology. I suggest resources devoted to imaging of our Moon's surface, the Earth Trojans and Earth co-orbitals, and for probe missions to the latter two. The SETA concept can be falsified: if we investigate these near-Earth objects and don't find artifacts, the concept is disproven for this region. Close inspection of bodies in these regions, which may hold primordial remnants of our early solar system, yields concrete astronomical research.

IS ET LURKING IN OUR COSMIC BACKYARD?

PROBES FROM PASSING STARS & A DRAKE EQUATION FOR ALIEN ARTIFACTS

James Benford
Microwave Sciences

jimbenford@gmail.com

3 related papers

How Many Alien Probes Could Have Come From Stars Passing By Earth?

James Benford
Microwave Sciences, 1041 Los Arabis Lane, Lafayette, CA 94549 USA
jimbenford@gmail.com

Abstract

Stars come very close to our solar system frequently. About two stars per million years come within a light year. An extraterrestrial civilization that passes nearby can see there is an ecosystem here, due to the out-of-equilibrium atmosphere. They could send interstellar probes to investigate. We estimate how many probes could have come here from passing stars. And where would they be now? The Moon and the Earth Trojans have the greatest probability of success. Close inspection of bodies in these regions, which may hold primordial remnants of our early solar system, yields concrete astronomical research. This argues for a Search for Extraterrestrial Artifacts (SETA) strategy of exploring for alien artifacts near Earth.

A Drake Equation for Alien Artifacts

James Benford
Microwave Sciences, 1041 Los Arabis Lane, Lafayette, CA 94549 USA
jimbenford@gmail.com

I propose a version of the Drake Equation to include searching for alien artifacts, which may be located on the Moon, Earth Trojans and Earth co-orbital objects. The virtue of searching for artifacts is their lingering endurance in space, long after they go dead. I compare a Search for Extraterrestrial Artifacts (SETA) strategy to the existing listening-to-stars Search for Extraterrestrial Intelligence (SETI) strategy. I construct a ratio of a SETA Drake equation for artifacts to the conventional Drake Equation, so that most terms cancel out. This ratio is a good way to debate efficacy of SETI vs. SETA. The ratio is the product of two terms: One is the ratio of the length of time probes from extraterrestrial (ET) civilizations could be present in the near-Earth region to the length of time ET civilizations transmit signals to the solar system. The second term is the ratio the respective 'origin volumes': the volume from which probes can come, which is affected by the long-term passage of stars nearby the Sun, to the volume of transmitting civilizations. Estimates presented here suggest that looking for alien artifacts near Earth is a credible alternative approach relative to listening-to-stars. This argues for emphasis on artifact searches, ET archeology. I suggest study of existing high-resolution images of the Moon, imaging of the Earth Trojans and Earth co-orbitals and for probe missions to the latter two. Close inspection in these near-Earth regions, which also may hold primordial remnants of the early solar system, yields concrete astronomical research.

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Looking for Lurkers: Co-orbiters as SETI Observables

James Benford
Microwave Sciences, 1041 Los Arabis Lane, Lafayette, CA 94549, USA; jimbenford@gmail.com
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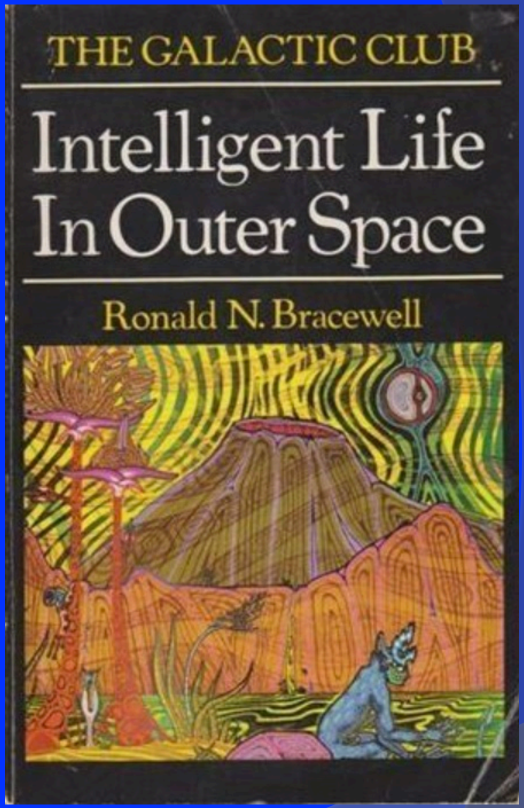
Abstract

A recently discovered group of nearby co-orbital objects is an attractive location for extraterrestrial intelligence (ETI) to locate a probe to observe Earth while not being easily seen. These near-Earth objects provide an ideal way to watch our world from a secure natural object. That provides resources an ETI might need: materials, a firm anchor, and concealment. These have been little studied by astronomy and not at all by the Search for Extraterrestrial Intelligence (SETI) or planetary radar observations. I describe the objects found thus far and propose both passive and active observations of them as possible sites for extraterrestrial (ET) probes.

Unified Astronomy Thesaurus concepts: Near-Earth objects (1092); Earth trojans (438); Trojan asteroids (1715)

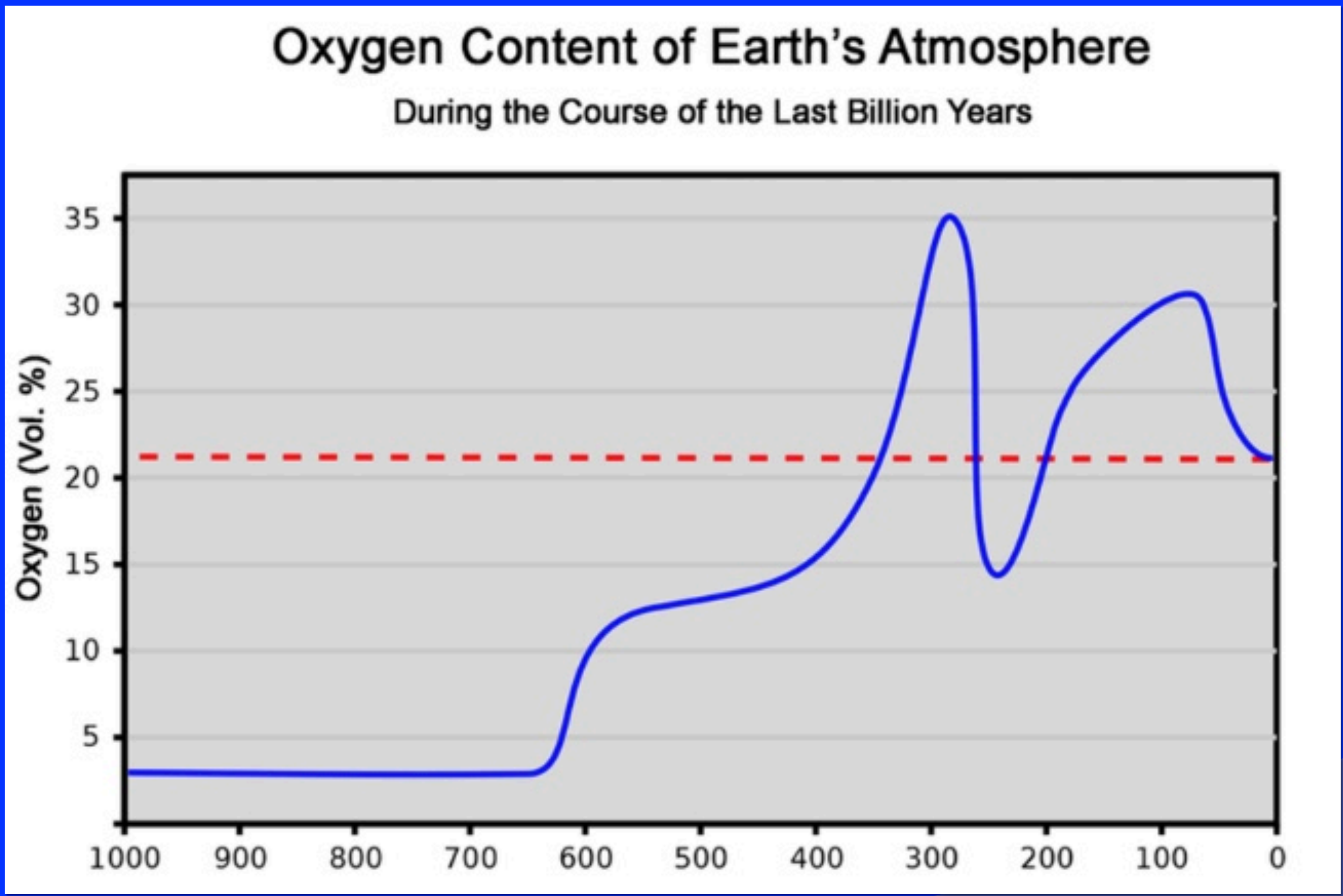
Bracewell's Lurker Hypothesis

- If advanced alien civilizations exist, they might place AI monitoring devices on or near the worlds of other evolving species to track their progress.
- Such a robotic sentinel <u>might</u> establish contact with a developing race once that race had reached a certain technological threshold, such as radio communication, interplanetary flight or *our finding them*.
- Co-orbitals are faint, hard to find, could provide materials, concealment.



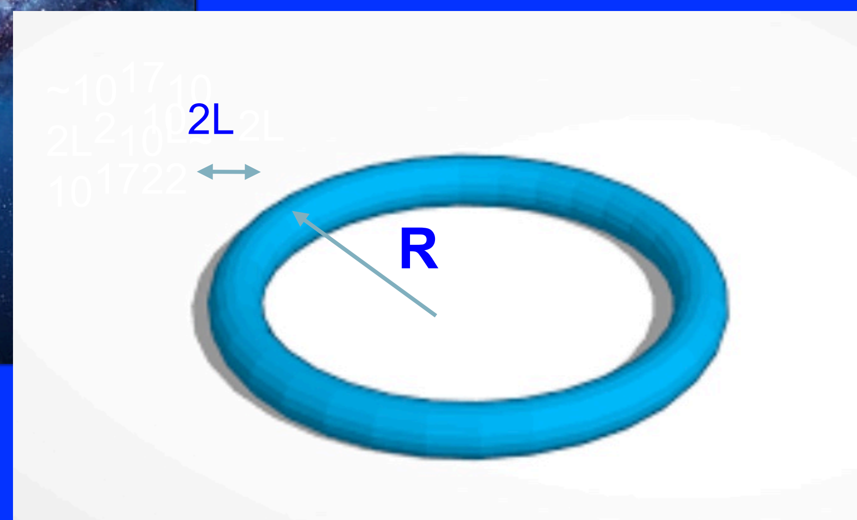
Alien Probes Could Have Come From Stars Passing By Earth

- Stars come very close to our solar system frequently. About two stars per million years come within a light year. In the 10,000-year timescale of our agricultural civilization, about two new stars have come within 10 ly.
- An extraterrestrial civilization that passes nearby can see there is an ecosystem here, due to the out-of-equilibrium atmosphere. *They could send interstellar probes to investigate.*
- This argues for a Search for Extraterrestrial Artifacts (SETA) strategy of exploring for alien artifacts near Earth.
- The Moon and the Earth Trojan(s) have the greatest probability of success. Close inspection of bodies in these regions, yields concrete astronomical research.

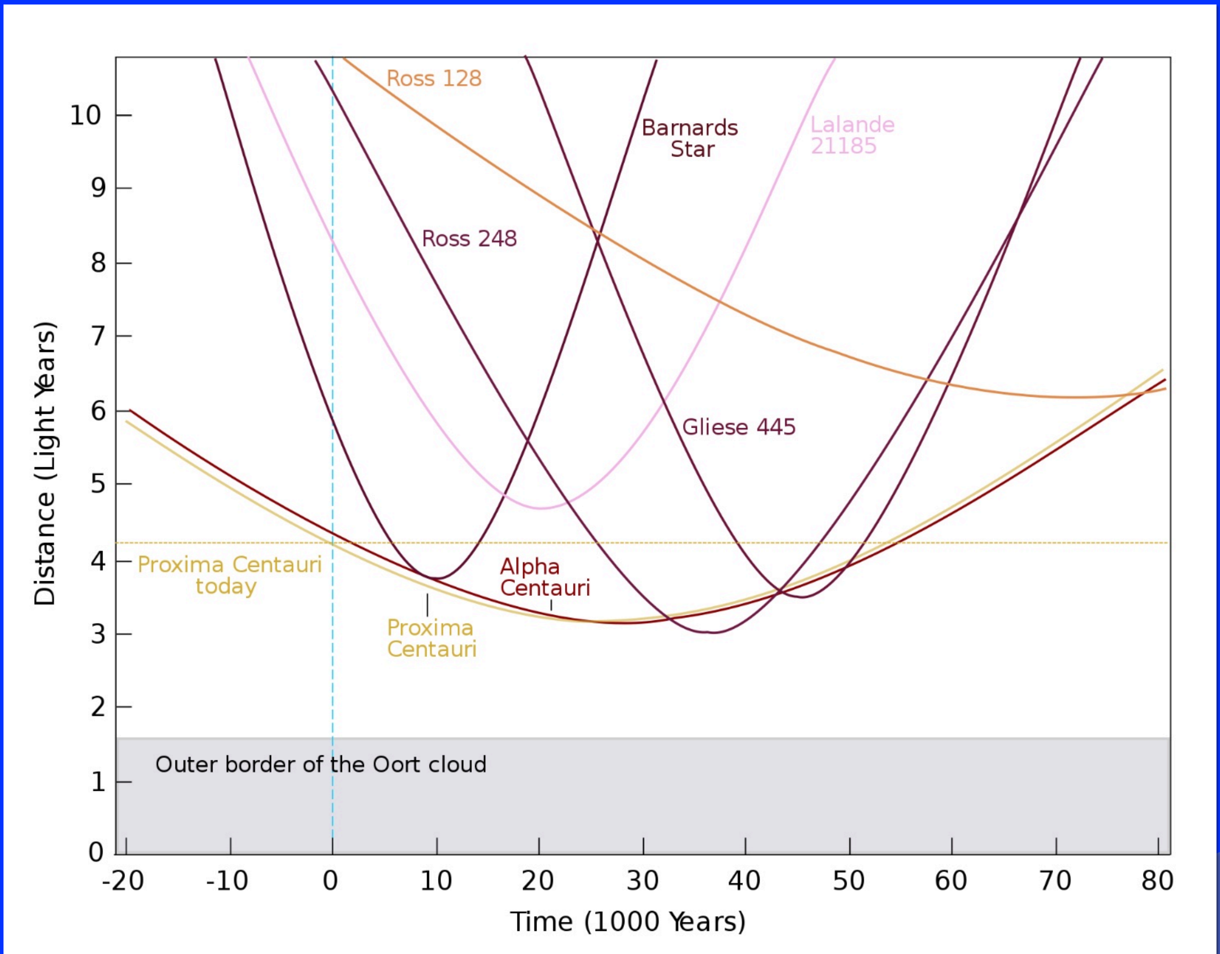


Oxygen Content of Earth's Atmosphere
During the Course of the Last Billion Years
Oxygen (Vol. %)
35
30
25
20
15
10
5
1000
900
800
700
600
500
400
300
200
100
0

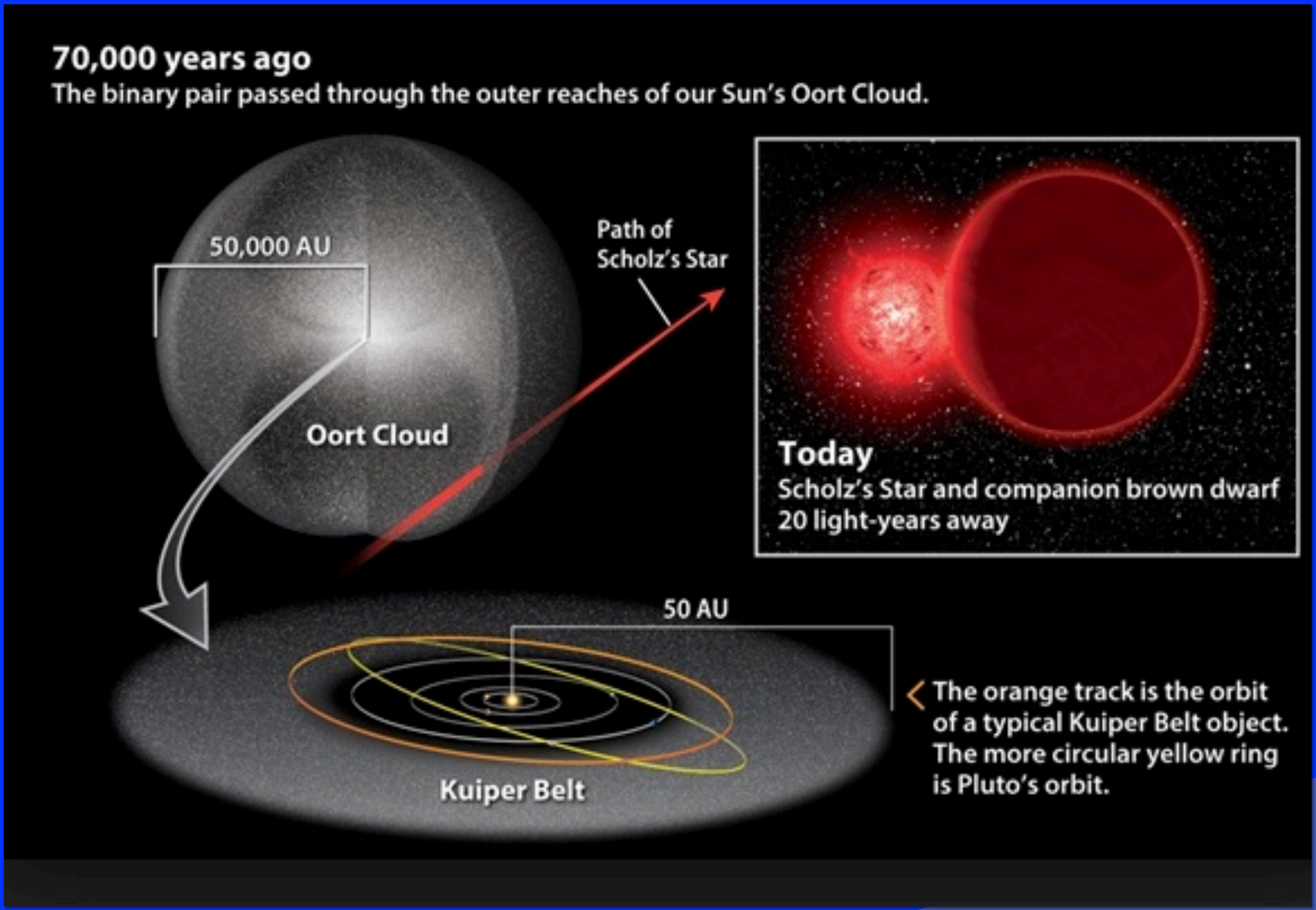
Earth moves around the galaxy in a torus in ~220 million years



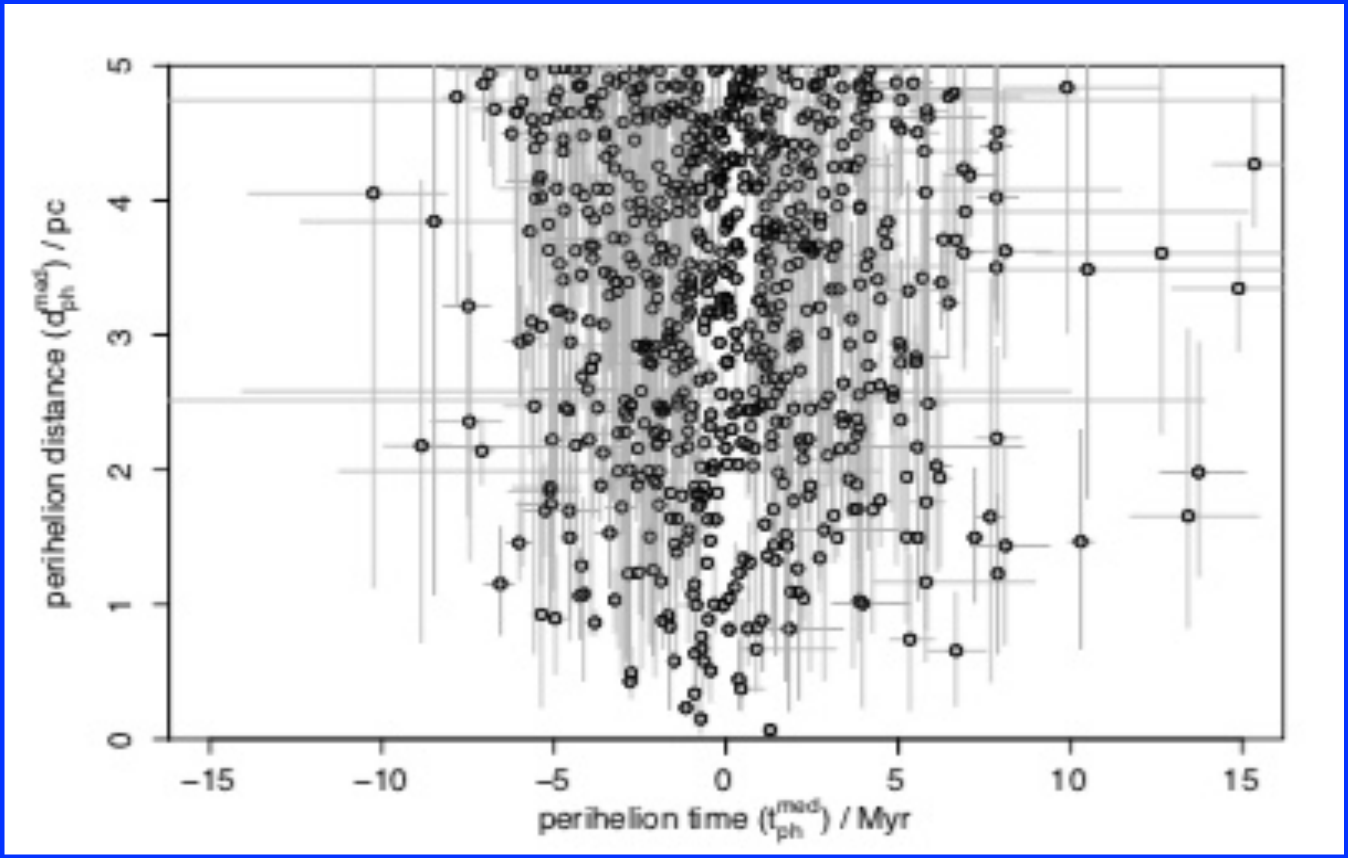
Stars move relative to the Sun. Stars come close to Earth frequently, ~2/Myr within 1 light year



Scholz's Star came within 0.82 light-years from the Sun about 70,000 years ago.



Stars passing by Earth: Perihelion times and closest distances for 694 observed stars.

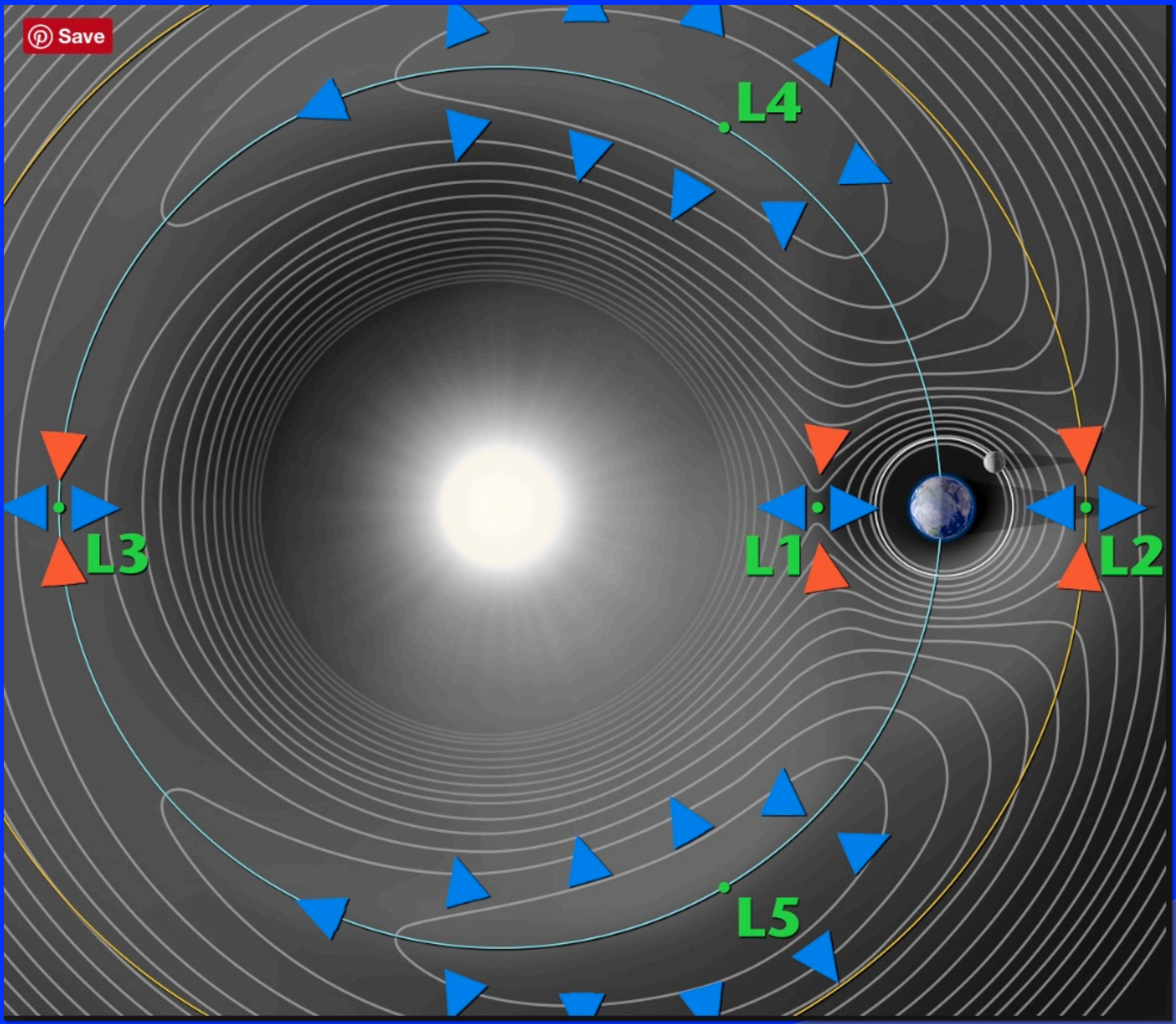


Rate Stars Pass Within R of Sun

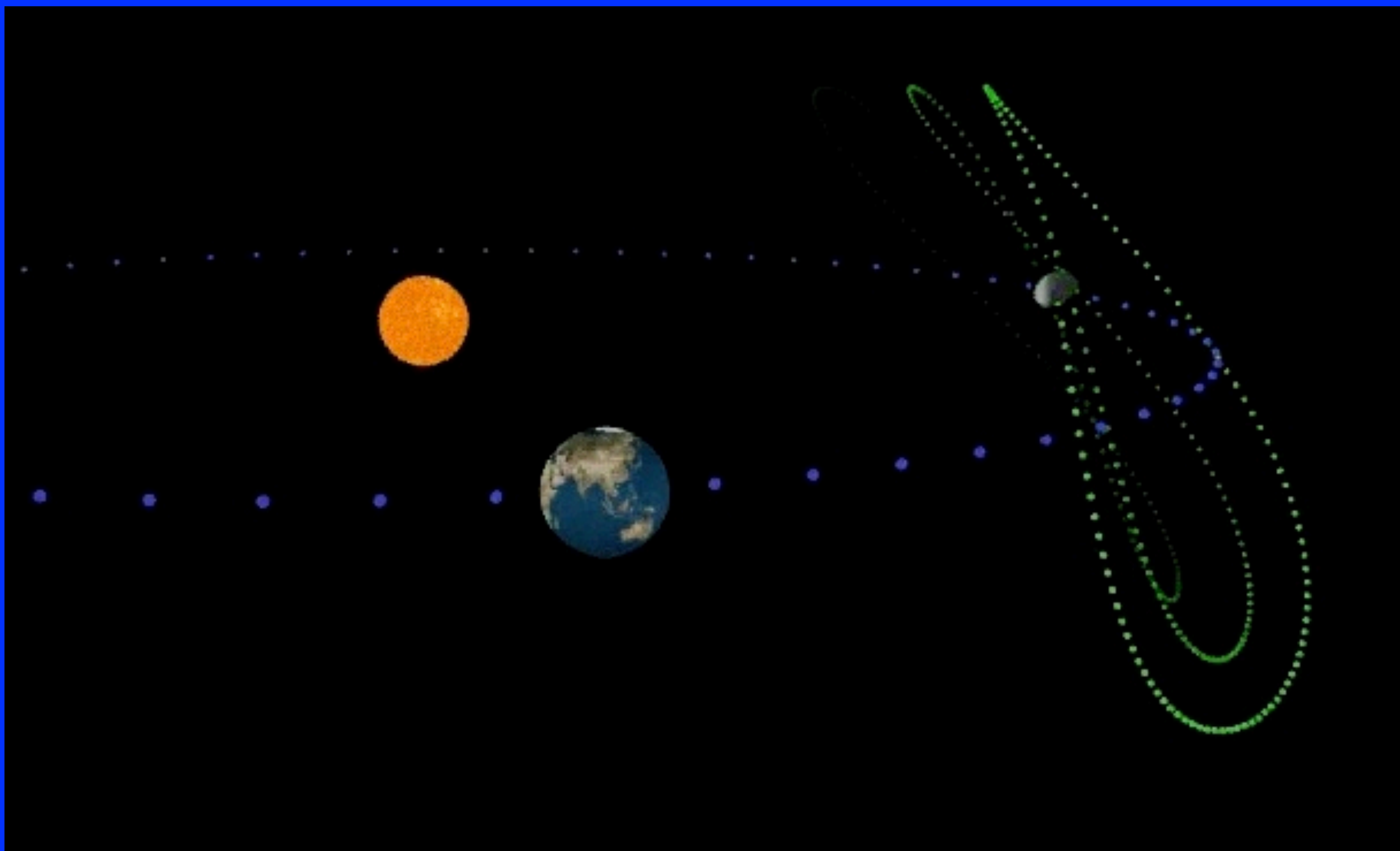
- $dN_S(R)/dt = 2\ 10^{-6}\ R^2$ stars/year = $2\ R^2$ (ly^2) stars/Myear
- Number of Lurkers that could arrive and now be found:
- $N_L = f_{ip}\ T_L\ [dN_S\ (R)/dt]$
- $f_{ip:}$ fraction of civilizations that develop interstellar probe
- T_L: the orbital lifetime of the object upon which the Lurker is resident

Apollo 17 Site

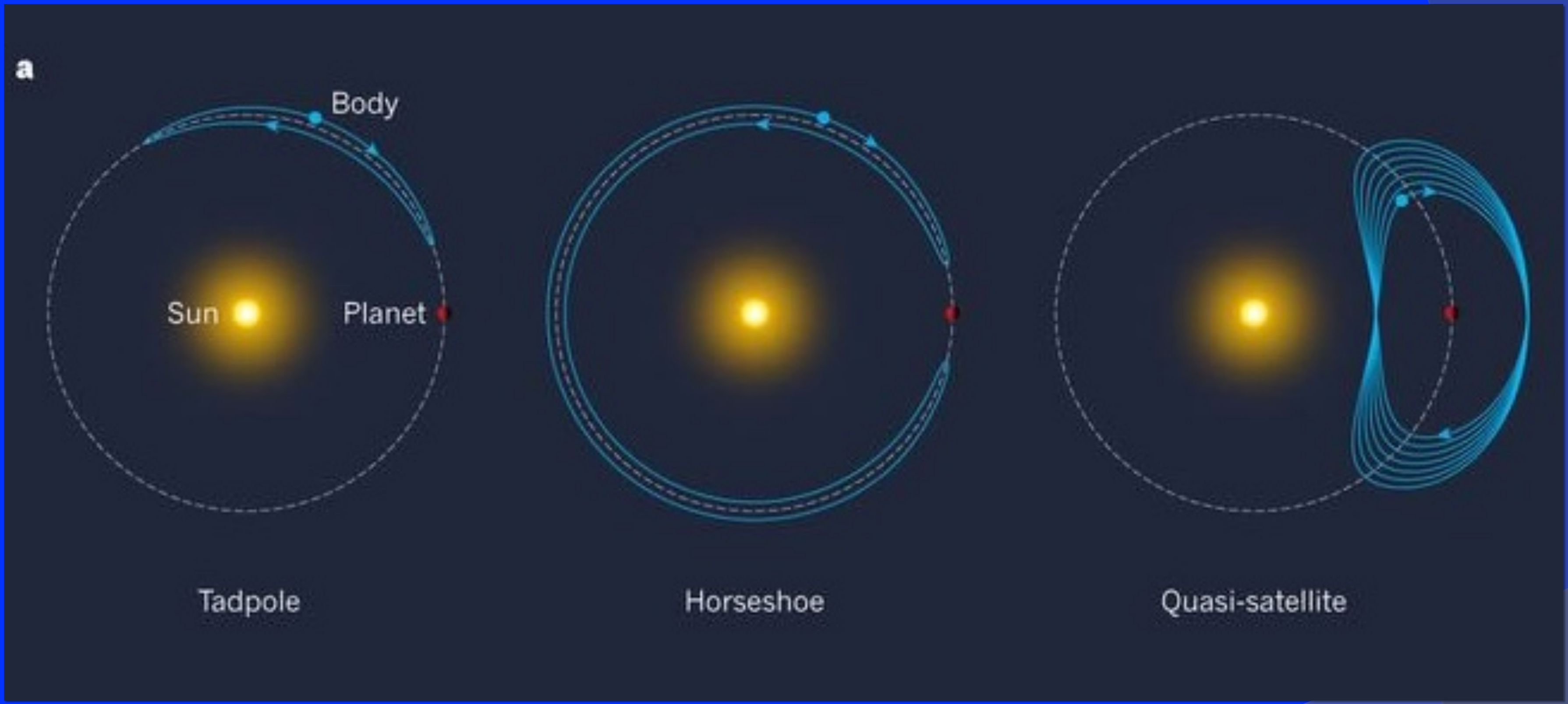
Lagrange Points



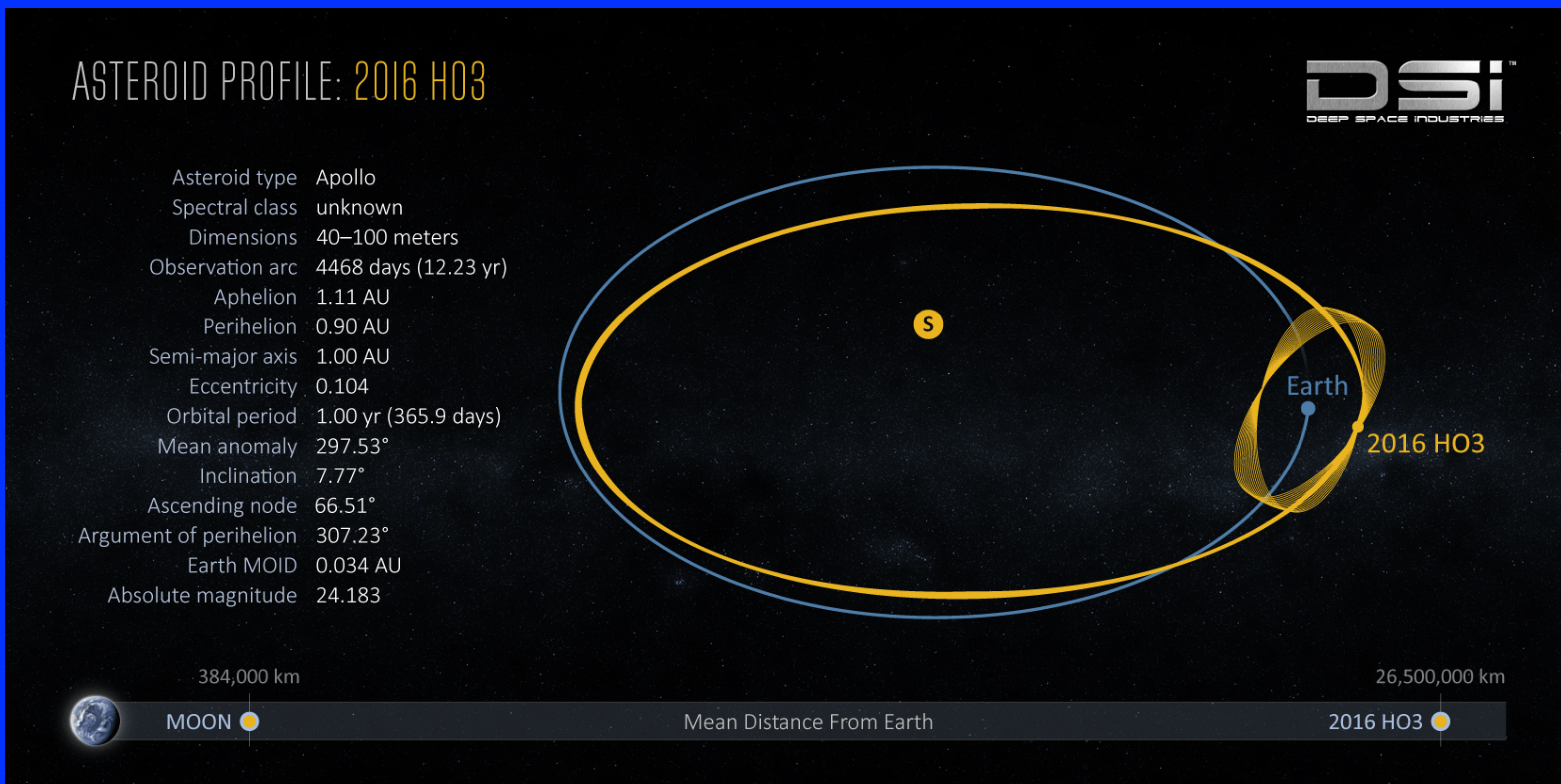
Earth Trojan orbit [2010 TK_7]



3 Types of Co-orbital Orbits



Orbit of 2016 HO_3 around Earth



Research for Finding Alien Artifacts

I advocate a sequence of tasks:

- Develop an AI for searching for alien artifacts in the millions of sites that Lunar Reconnaissance Orbiter has photographed, about 1.6 million at high resolution. The vast majority of the photos have not been inspected by the human eye.
- Conduct passive SETI observations of these nearer-Earth objects in the microwave, infrared and optical.
- Use active planetary radar to investigate the properties of these objects.
- Conduct *active* simultaneous planetary radar 'painting' and SETI listening of these objects.
- Launch robotic probes to conduct inspections, take samples of Earth Trojans and the co-orbitals.

Drake Equations for SETI & SETA (Search for ET Artifacts)

$$\frac{N_L}{N_C} = \left(\frac{N}{N}\frac{R}{R}\frac{f_p}{f_p}\frac{n_e}{n_e}\frac{f_l}{f_l}\frac{f_i}{f_l}\frac{f_c}{f_c}\right)\left[\frac{f_{ip}}{f_R}\frac{T_L}{T_R}\right]$$

$$\frac{N_L}{N_C} = \frac{f_{ip}}{f_R}\frac{T_L}{T_R}$$

The ratio of Eqs means:

- *This is a ‘Success Ratio’ of searching for artifacts compared to listening to stars. It allows us to <u>quantitatively</u> evaluate their relative merits.*
- *The two strategies, SETA and SETI, are competitive.*
- *The Moon and the Earth Trojans have a greater probability of success than the co-orbitals.*

SETA Searches of near-Earth objects-1

- Plan a multiyear program of observations by radio and optical telescopes and planetary radars around the world.
  - discern their size, shape, rotation periods, and optical properties, such as spectra. We would need to discern their optical spectra out to at least J-band (to 1.2 μ).
- Conduct passive SETI observations of these nearer-Earth objects.

SETA Searches of near-Earth objects-2

- Use *active* planetary radar to investigate the properties of these objects.
- Conduct *active* simultaneous planetary radar ‘painting’ and SETI listening of these objects.
- Launch robotic probes to conduct inspections, take samples. For example, 2016 HO_3 at close approach has a relative velocity of 3-5 km/sec, so is within present capability. (China already doing this.)

Costs & Benefits

What Does it Cost?

- Resources such as time on telescopes, radio and optical. And volunteers. Costs start small, then grow.

What do we gain?

1. We would be studying the Moon and newly found objects, which could well be interesting astronomy. Little is known, other than orbital calculations and faint images. We know almost nothing about co-orbitals and the Earth Trojan.
2. *We do something new, an active fresh front in SETI research.*

A Drake Equation for Alien Artifacts

James Benford
Microwave Sciences, Lafayette, California

I propose a version of the Drake Equation to include searching for alien artifacts, which I call Lurkers, which may be located on the Moon, Earth Trojans and co-orbital objects. The great virtue of searching for Lurkers is their lingering endurance in space, long after they go dead. I compare a Search for Extraterrestrial Artifacts (SETA) strategy of exploring near Earth for alien artifacts to the existing listening-to-stars SETI strategy. I construct a ratio of a Lurker Drake Equation for artifacts to the conventional Drake Equation, so that most terms cancel out. This ratio is a good way to debate the efficacy of SETI vs. SETA. The ratio of Lurkers to detectable radiating civilizations is the product of two terms: One is the ratio of the time Lurkers could be present in the solar system to the length of time extraterrestrial (ET) civilizations transmit electromagnetic signals. The second term is the ratio of the respective 'origin volumes': the volume from which Lurkers can come (which is affected by the long-term passage of stars nearby) to the volume of transmitting civilizations. Estimates presented here suggest show that looking for alien artifacts near Earth is a credible alternate approach relative to listening-to-stars**.** This Drake Equation logic argues for emphasis on artifact searches, a strategy of *ETI archeology*. Close inspection of bodies in these near-Earth regions, which also may hold primordial remnants of our early solar system, yields concrete astronomical research. I suggest additional resources devoted to imaging of our Moon's surface, the Earth Trojans and Earth co-orbitals, and for probe missions to the latter two. The SETA concept can be *falsified*: if we investigate these near-Earth objects and don't find artifacts, the SETA concept is disproven for this region.

1. Introduction

In a recent paper, I introduced the term 'Lurker': a unknown and unnoticed observing probe from an extraterrestrial civilization, which may well be dead, but if not, could respond to an intentional signal. And/or it may not, depending on unknown alien motivations [1]. Lurkers include self-replicating probes, based on von Neumann's theory of self-replicating machines, which is why they are often called von Neumann probes [2]. Recently concepts have appeared for self-replicating probes that could be built in the near future [3].

A 'solarcentric' Search for Extraterrestrial Artifacts (SETA) was advocated by Robert A. Freitas, who coined the term SETA in the 1980s [4]. Further analysis has appeared recently [5-7]. SETA is a proposition about our local region in the solar system. SETA is *falsifiable* in its specific domain: ETI wanting to investigate Earth would come to the nearest objects. SETI, on the other hand, is about messages sent from distant stars. For example, one can falsify a proposition such as "Are signals being sent to Earth at this moment within 100 ly?"

But there is the region beyond 100 ly and beyond 1000 ly, etc. So SETI is falsifiable only within larger and larger domains. SETI is testable, but not really falsifiable.

Near-Earth objects could provide an ideal way to watch our world from a secure natural object [1]. They are attractive locations for extraterrestrial intelligence (ETI) to locate a platform to observe Earth while not being easily seen. Co-orbitals are attractive targets for SETA searches because of their proximity and that they are hard to observe (small size, low albedo).

Rose and Wright pointed out the energy efficiency of an inscribed physical artifact vs. an EM signal, because the artifact has persistence and the EM signal has to be transmitted indefinitely [8]. Here I point out that artifacts are not only energy efficient, but *increase the chance of contact*. Rose and Wright did not explore where to locate the artifact so it would be identified; here I suggest that there are attractive locations near Earth where they might be readily observable.

I propose a version of the Drake Equation for Lurkers on near-Earth objects. By using it, one can compare a SETA strategy of exploring for artifacts to the conventional listening-to-stars SETI strategy, which has thus far found no artificial signals of technological origin. In contrast, SETA offers a new perspective, a new opportunity: discovering past and present visits to the near-Earth vicinity by ET space probes.

2. Drake Equations

2.1 The Standard Drake Equation estimates the number of radiating civilizations that are detectable, N_C, as the product of the rate of creation of such radiating civilizations,

This *modified Drake Equation* is:

$$N_C = N \times R_f \times f_p \times n_e \times f_l \times f_i \times f_C \times f_R \times T_R \qquad - \qquad (1)$$

I replace the usual Drake Equation symbol for time over which they radiate L, with T_R. And I also multiply by:

f_R= fraction that actually *do* radiate signals that might be observable at Earth. That is, they radiate with the *intention* of trying to communicate. Not leakage radiation.

These parameters are listed in Table 1:

Table 1 Drake Equation Parameters. Subscripts are italicized letters in definitions

Parameter	Definition
N_C	number of *c*ivilizations in the Milky Way Galaxy who are radiating electromagnetic emissions
N	number of stars in our galaxy
R_f	rate of *f*ormation of stars suitable for the development of intelligent life
f_p	fraction of those stars with *p*lanetary systems
n_e	number of planets, per solar system, with an *e*nvironment suitable for life
f_l	fraction of suitable planets on which *l*ife actually appears
f_i	fraction of life bearing planets on which *i*ntelligent life emerges
f_C	fraction of civilizations that develop a technology that *c*an transmit electromagnetic signs of their existence into space.
f_R	fraction that actually do *r*adiate
T_R	length of time such civilizations build beacons, *r*adiate electromagnetic signals into space

2.2 A Drake Equation for Alien Artifacts An equivalent to the Drake equation for the number of Lurkers in our solar system, N_L, can similarly be expressed as the rate of creation of radiating civilizations, times the fraction that also develop interstellar probe technology f_{ip}, times the sojourn that Lurkers would be in the solar system, T_L:

f_{ip} = fraction that also develop interstellar probe technology and launch them
T_L= time that Lurkers could reside in the solar system

(Note that for such civilizations, f_C =1; a civilization with the capability to build such probes surely can build interstellar transmitters.)

Then a Drake equation for alien artifacts is

$$N_L = N \times R_f \times f_p \times n_e \times f_l \times f_i \times f_{ip} \times T_L \quad - \qquad (2)$$

The new parameters are listed in Table 2:

Table 2 Drake Alien Artifact Equation Parameters

Parameter	Definition
N_L	number of Lurkers in our solar system
f_{ip}	fraction of civilizations that develop interstellar probe technology and launch them
T_L	time that Lurkers could reside in the solar system

In the ratio of equations 1 and 2, of the number of Lurkers in our solar system to the number of radiating civilizations, most terms, in the first bracket, cancel so:

$$\frac{N_L}{N_C} = \left(\frac{N}{N}\frac{R}{R}\frac{f_p}{f_p}\frac{n_e}{n_e}\frac{f_l}{f_l}\frac{f_i}{f_l}\frac{f_c}{f_c}\right)\left[\frac{f_{ip}}{f_R}\frac{T_L}{T_R}\right] \tag{3}$$

$$\frac{N_L}{N_C} = \frac{f_{ip}}{f_R}\frac{T_L}{T_R}$$

This initial result is that the ratio of civilizations sending probes that are now resident in our solar system to the number sending messages is the product of two ratios:
A ratio of motives:

$$\frac{f_{ip}}{f_R}$$

the fraction that also develop interstellar probe technology and launch them, divided by fraction that only radiate, so $f_{ip}/f_R<1$,

and a ratio of times:

$$\frac{T_L}{T_R}$$

the time Lurkers are present in the solar system/ the time ET civilizations release electromagnetic signals. Surely a civilization with the capability to build such probes can build interstellar transmitters, so I will argue that $T_L/T_R>1$.

Our own civilization has been capable of radiating for about 50 years, but has not yet done so, except for message-free Cold War radar transmissions (and perhaps other inadvertent leakage radiation). We cannot yet build interstellar probes capable of traveling to and decelerating into a star system and conducting operations there. That may be possible in the next century. (The Breakthrough Starshot project hopes to conduct interstellar flybys, a fleeting presence at ~0.2 c in this century [9].) If so, relatively soon we will be capable of both radiating to the stars and sending probes to explore nearby star systems.

However, equation 4 does not take account of the space volumes that the two groups operate in.

2.3 Space Volume Factor

Another factor must be included: Equation 4 must be modified for V_L, the volume over which Lurkers can travel, and its corresponding range R_L vs. V_B , the volume over which Beacons can transmit and be plausibly detected, and its corresponding range R_B. Lurker probes traveling at a small fraction of the speed of light should be compared to the transmissions from an interstellar Beacon propagating at the speed of light. That means that *the volumes from which signals can be detected from Beacons is much larger than the volume over which Lurker could travel.*

For example, assume that interstellar probes could operate at ~10% c, the speed of light, as contemporary concepts of fusion rockets are designed for. An example: for the Icarus Firefly magnetically confined Z-pinch concept at 4.7% c, traveling 10 ly would take about two centuries [10]. Starshot, which is a flyby probe concept, at 0.2 c takes a half century to arrive at the Centauri system. Assuming that the attention span of the civilization is measured in centuries, a rough estimate of the distance over which probes will be launched is tens of lightyears. (The signal from the probe reporting back to its origin would travel at the speed of light, of course.) If it is possible for probes to move close to c, then the beacon volume to probe volume would be close to unity.

In contrast, the electromagnetic waves of an interstellar Beacon, be it light, millimeter-wave or microwave, propagate ~20 times faster, at the speed of light. For example, we can estimate the range over which a Beacon would be used to be hundreds of light years. By that I again mean that the attention span of a civilization might be measured in centuries.

I define the volumes and ranges in Table 3:

Table 3 Space Volume Factor Parameters

Parameter	Definition
$\mathbf{V_B}$	*v*olume over which a Beacon is detectable
$\mathbf{V_L}$	*v*olume over which Lurker could travel
$\mathbf{R_B}$	*r*ange over which a Beacon is detectable
$\mathbf{R_L}$	*r*ange over which Lurker could travel

Therefore equation 3 must be multiplied by the ratio of these 2 volumes, V_L/V_B:

$$\frac{N_L}{N_C} = \frac{f_{ip}}{f_R}\frac{T_L}{T_R}\left[\frac{V_L}{V_B}\right] \tag{4}$$

As volume scales as the cube of the distance to them, R_L/R_B:

$$\boxed{\frac{N_L}{N_C} = \frac{f_{ip}}{f_R}\frac{T_L}{T_R}\left[\frac{R_L}{R_B}\right]^3} \tag{5}$$

This is a 'Success Ratio' of searching for artifacts compared to listening to stars. It allows us to *__quantitatively__* *evaluate their relative merits.* Although the volume ratio would argue that long-range Beacons will be much more likely to be detected than probes that come to observe Earth, the time ratio tends to mitigate that advantage.

2.4 Decision Tree Parameters

The ratio of the number of lurkers to the number of radiating civilizations can be estimated using the three factors in equation 5, which have the following's sizes:

$$f_{ip}/f_R<1$$
$$R_L/R_B<1 \qquad (6)$$
$$T_L/T_R>>1$$

So the 'Success Ratio', Eq. 5, will depend on choices for these parameters.

The key parameters making up these factors can be divided into objective and subjective components, where *'objective' means it can be quantified or at least estimated and 'subjective' means it's a matter of opinion*. Here is a table of the parameters:

Table 4: Objective and subjective SETA Parameters and determining factors

Objective Parameters	Determined by:	Subjective Factors	Determined by:
	attention span of civilization & cost of Beacon	R_B	matter of opinion
R_L	speed & cost of starprobes		
		f_{ip}/f_R	<1, matter of opinion
T_L	lifetime of the orbit of the Lurker		
		T_R	matter of opinion

The issues determining he objective parameters are listed; subjective parameters are a matter of taste and underlying assumptions.

By making choices among the objective and subjective parameters, one constructs a *decision tree*: A set of parameter choices leads to a conclusion about the success ratio for SETA and SETI strategies, as embodied in equation 6. Because ET civilizations will vary enormously in motivations, we can expect a variety of outcomes for the Success Ratio.

2.41 Estimates of T_R, time that ETI Beacons radiate

In the literature, estimates of T_R fall between a hundred and 100 million years, a very wide range. Michael Shermer estimated T_R by averaging the lifespans of 60 Earth civilizations, getting 420 years, [11]. Using 28 civilizations since the Roman Empire, he gives ~300 years for "modern" civilizations. Note that the longest operating institution still existing on Earth is the Catholic Church, ~2,000 years. *We'll take the times to be 300-10,000 years, an order of magnitude range.*

2.42 Estimates of T_L, time Lurkers could reside in the solar system

A key point is that Lurkers will still be discoverable even though dead for a long time. That's not true of an EM transmission, which is simply passing through at the speed of light. That fact weighs to the advantage of the Lurker search strategy.

The time over which our biosphere has been observable from great distances of thousands of light years, due to oxygen in the atmosphere, is a very long time, measured in the billions of years [12, 13]. The first oxidation event occurred about 2 .5 billion years ago and the second, largest oxidation event about 0.65 billion years ago, so $0.65\ 10^9 < T_L < 2.5\ 10^9$ years.

Therefore, an ET civilization that passes nearby can see there's an ecosystem here, due to the out-of-equilibrium atmosphere. They could send interstellar probes to investigate.

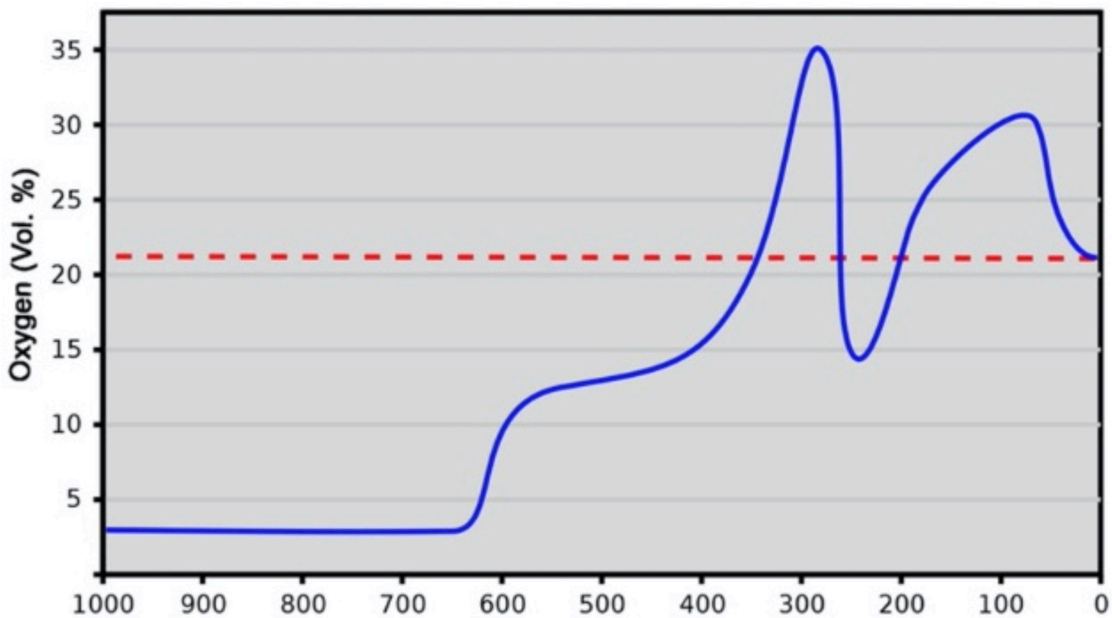


Figure 1 History of oxygen content of Earth's atmosphere.

The time that Lurkers would be in the solar system, T_L, will be limited by the lifetime of the orbits they are in, which provides an upper bound. The Moon, Earth Trojans and co-orbitals of Earth lifetimes are:

<u>The Moon:</u>
Our Moon is thought to have formed about 4.5 billion years ago. For T_L we use the time that life became evident in our atmosphere, $0.65\ 10^9 < t_1 < 2.5\ 10^9$ years.

Earth Trojans
There may be many objects in the Earth Trojan region [14]. Their lifetime in Trojan orbits is likely to be on the order of billions of years, and some objects there may be primordial, meaning that they are as old as the Solar System, because of their very stable orbits about the Lagrange Points [15-18].

The only Earth Trojan yet discovered is TK_7. Its closest approach to Earth is about 70 times the Earth Moon distance. It oscillates about the Sun–Earth L_4 Lagrange Point, ~60 degrees ahead of Earth [19]. It is not a primordial Earth Trojan and is estimated to have an orbital lifetime of 250,000 years, when it will go into a horseshoe orbit about the sun. It is clear why there are no other Trojans of the Earth have been found up to now: they are hard to observe from Earth.

There are large stable regions, so Trojans may exist for long time scales. It is possible that primordial Earth Trojans exist in the very stable regions around the Lagrange Points. Orbital calculations show that he most stable orbits reside at inclinations <10° to the ecliptic; there they may survive the age of the solar system, ~2.5 Gyr.

Earth Co-orbitals
See [1] for a discussion of the co-orbitals of Earth. A large number of tadpole, horseshoe and quasi-satellites of Earth, appear to be long-term stable. Morais and Morbidelli using models of main asteroid belt sources providing the co-orbitals and their subsequent motions, estimate lifetimes to run between 1 thousand and 1 million years [20]. They conclude that the mean lifetime for them to maintain resonance with Earth is 0.33 million years. Morbidelli says that no further studies have been done on their approach [21]. Note that almost all of the co-orbitals have been discovered and their orbits quantified since the Morais and Morbidelli work. And software for orbital calculations has become vastly more capable since then.

3. Success Ratio Estimates

Example 1: Choosing via relative costs at equal ranges:
Assume that:
1) The ratio of fractions of ET civilizations would be proportional to the cost of interstellar probes vs. Beacons. The cost of interstellar probes will be substantially more than the cost of interstellar Beacons. Stated differently, Beacons will have substantially longer range for a fixed cost.
2) R_L and R_C are equal.

If we take as an example a Beacon at 100 ly and a Lurker probe launched from 100 ly, then R_L and R_C in Eq. 5 cancel out. For Beacons that have a range of 100 ly the cost is of order $1 billion [22]. The Firefly interstellar fusion rocket has an estimated cost of $60 billion [10]. (Two thirds of that cost is fuel to accelerate and decelerate.) Therefore the cost ratio is ~100 in favor of Beacons. If cost is the deciding factor, then $f_P/f_R = 1/100$ and Eq. 5 reduces to

$$\frac{N_L}{N_C} \approx \frac{1}{100}\frac{T_L}{T_R} \quad (7)$$

Next, one chooses an orbital location for the Lurker: Our Moon is thought to have formed about 4.3 billion years ago, long before life appeared. So we use the time life became evident in our atmosphere, $0.65\ 10^9 < T_L < 2.5\ 10^9$ years.

Next, one guesses the transmit time of the Beacon: estimates of civilization radiating times T_C vary from ~300 -10^5 years. Here the 'dash' means the range of credible values:

$$\frac{N_L}{N_C} \approx \frac{1}{100}\frac{\left[10^9 - 2.5 10^9\right]}{\left[300 - 10^5\right]} \cong 10^2 to 10^5 \quad (8)$$

So for these parameter choices, a Lurker search is much more likely to be successful. Note, however, that if we assume the Beacon civilization is at 100 ly, and the probe-building civilization is at 10 ly, a factor of 1/1,000 reduces the ratio to 0.1 to 100.

Example 2: What if cost doesn't matter? That would be at variance with all we know of economics on Earth, but is a hypothetical we could consider. If cost doesn't matter, then a civilization wanting to investigate the life of Earth or whether civilization was here would build both probes to investigate the ecosystem, visible in spectra of our atmosphere, and build Beacons to broadcast to us. In such a case, $f_P/f_R = 1$, and, as we're talking about a single civilization, $R_L/R_C = 1$. Consequently the Success Ratio $N_L/N_C = T_L/T_C$, which would surely be >>1. Again, lurker strategy is likely to be more successful. In this example, the time ratio is the important factor.

Example 3: Early spacefaring civilizations: A civilization such as ours, which is presently capable of only interplanetary speeds, cannot build interstellar probes as envisioned by some of our starship concepts. Starships are centuries into our future and will always be more expensive than Beacons. They could be only a radiating society and might build Beacons. In this case the success ratio $N_L/N_C = 0$, and a listen-only strategy is appropriate.

Example 4: Supercivilizations capable of fast interstellar flight. The opposite extreme from example 3 is a civilization where starships can travel at a large fraction of the speed of light. In such case, taking into account time dilation, it would be more expeditious to explore through sending fast starships to become Lurkers to observe Earth's ecosystem and civilization. In this case, Beacons, although still cheaper, would serve only to reveal that civilization to us when their starships could be arriving at about the same time. Existence of a civilization here could be reported by the Lurkers. This could've occurred over geological time frames, so in this case N_L/N_C >>1, and we would expect to find dead Lurkers on the nearby objects described in 2.42.

Estimate 5: Lurker in Co-orbitals and short radiating time: Instead of a Trojan or the Moon, we choose one of the co-orbitals, which have a mean lifetime T_L ~0.33 million years. 1) For T_R, choose the 300-year lifetime estimate of Shermer for the Beacon to radiate. Then T_L/T_R = 1,000. 2) Let's assume that starship probes are launched from a civilization 10 ly away. (A probe such as Firefly, traveling at 0.2c and decelerating into our solar system, would take 50 years to come 10 ly.) 2) Assume the Beacon civilization is at 100 ly, and the probe-building civilization is at 10 ly. So R_L/R_B = 0.1. 3) Further, again assume that the willingness of civilization to undertake the expense would be determined by economics. A continuous Beacon at hundred light-years would cost about $1 billion and a Firefly probe is estimated to cost $60 billion [23], so f_P/f_R = 0.01. Therefore the Success Ratio, eq. 5, is:

$$\frac{N_L}{N_C} = \frac{f_{ip}}{f_R}\frac{T_L}{T_R}\left[\frac{R_L}{R_B}\right]^3 = \frac{(0.01)(1{,}000)}{1{,}000} \cong 0.01 \qquad (9)$$

So in this case listening-to-stars has a higher success ratio. But if one assumes that the radiating civilization *also* develops interstellar probes, $f_R \sim f_p$, the two strategies have a roughly equal success ratio:

$$\frac{N_L}{N_C} = \frac{(1)(1{,}000)}{1{,}000} = 1 \qquad (10)$$

So ones assumptions of the parameters in the Table determine the answer.

Estimate 6: Co-orbitals and long radiating time: If we use the band of estimates in the literature for co-orbital lifetime, ~10^5 years, and estimates of civilization radiating times T_C vary from 10^2 -10^5, then T_L/T_R varies from 1 to 1,000. For the previous 100 ly/10 ly distance ratio, Eq. 5 then gives a Drake Equation ratio of

$$N_L/N_C = f_{IP}/f_R\,[10^{-3} \text{ to } 1] \qquad (11)$$

And the listening strategy will be preferred.

It is clear from these examples that 1) the two strategies, SETA and SETI, are competitive, 2) the Moon and the Earth Trojans have a greater probability of success than the co-orbitals.

4. Research for Finding Alien Artifacts

I advocate a sequence of tasks:

- We have had the Lunar Reconnaissance Orbiter in low orbit around the Moon since 2009. It has photographed about 1.6 million sites at high sub-meter. We can see where Neil Armstrong walked! The vast majority of the photos have not been inspected by the human eye. Searching these millions of photographs for alien artifacts would require an automatic processing system. Development of such an AI is a low-cost initial activity for finding alien artifacts on the Moon, as well as Earth Trojans or the co-orbitals [24, 25].

- Conduct passive SETI observations of these nearer-Earth objects in the microwave, infrared and optical.
- Use active planetary radar to investigate the properties of these objects
- Conduct *active* simultaneous planetary radar 'painting' and SETI listening of these objects.
- Launch robotic probes to conduct inspections, take samples of Earth Trojans and the co-orbitals. The low delta-V, 3-5 km/sec, make this an attractive early option, is well within present capability [26, 27]. China plans a mission to co-orbital 2016 HR 3 in the middle of this decade [28].

5. Conclusion

Clearly looking for alien artifacts in the region of the solar system near Earth is a credible alternative approach, a strategy of *ETI archeology.* The formulation given here is a way of discussing the SETA strategy and comparing it to SETI.
The listening-to-stars strategy that SETI researchers have been following for over 50 years, is now being pursued very vigorously by Breakthrough Listen. What has SETI learned so far about life in the universe? Only that there is no intelligent life broadcasting signals toward Earth at the time we've listened. If the ongoing SETI listening program continues to not hear a signal, the case for looking for Lurkers will grow ever stronger.

The SETA strategy was not pursued after it was suggested in the 1980's, because listening to stars is easier and observing technologies and spacecraft were not sufficiently developed to pursue it. But now SETA is more attractive:

- Close inspection of bodies in these regions can now be done with 21st Century observatories and spacecraft.
- The great virtue of searching for Lurkers is their lingering endurance in space, long after they go dead.
- The Moon and the Earth Trojans have a greater probability of success than the co-orbitals. In a companion paper, I estimate how many probes could have come here from passing stars, and where would they be found [29].
- They may hold primordial remnants of our early solar system, yields *concrete astronomical research*. It will yield new astronomy and astrophysics, quite apart from finding Lurkers.
- There are differences in detection in the two strategies: in the artifact case we should listen to those objects and image them in the optical or radar from Earth or send probes to visit them. In SETI, we can only listen.
- SETA is a concept that can be *falsified*, a fundamental requirement for a science. If we conduct the efforts described in Section 4, and don't find artifacts, the SETA concept is disproven for the near-Earth region, where it is most credible. If we find

them, it's verified. SETI, on the other hand, is testable and falsifiable only to a certain degree.

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How Many Alien Probes Could Have Come From Stars Passing By Earth?

James Benford
Microwave Sciences, Lafayette, California

Abstract

Stars come very close to Earth frequently. About two stars per million years come within a light year. An extraterrestrial civilization that passes nearby can see there is an ecosystem here, due to the out-of-equilibrium atmosphere. They could send interstellar probes to investigate. We estimate how many probes could have come here from passing stars. And where would they be now? The Moon and the Earth Trojans have the greatest probability of success. Close inspection of bodies in these regions, which may hold primordial remnants of our early solar system, yields concrete astronomical research.

1. Searching for Extraterrestrial Artifacts

Alien astronomy at our present technical level may have detected our biosphere many millions of years ago. The Great Oxidation Event occurred around 2.4 billion years ago; it was a rise in oxygen as a waste product due to organisms in the ocean carrying out photosynthesis. Long-lived robotic probes could have been sent to observe Earth long ago. I will call such a probe a "Lurker," a hidden, unknown and unnoticed observing probe, likely robotic. They could be sent here by civilizations on planets as their stars pass nearby.

Long-lived alien societies may do this to gather science for the larger communicating societies in our Galaxy. The great virtue of searching for Lurkers is their lingering endurance in space, long after they go dead.

In a companion paper, I propose a version of the Drake Equation to include searching for alien artifacts that may be located on Moon, Earth Trojans and co-orbital objects [1]. I compare a Search for Extraterrestrial Artifacts (SETA) strategy of exploring near Earth for artifacts to the conventional listening-to-stars SETI strategy. Here I estimate how many such probes could have come here.

2. **How Often Do Stars Pass By Our Sun?**

It is not widely known that stars pass close to our solar system. The most recent encounter was Scholz's Star, which came 0.82 light-years from the Sun about 70,000 years ago [2]. A star is expected to pass through the Oort Cloud every 100,000 years or so, as Scholz's Star did, shown in Figure 1.

Bailer-Jones et al. showed that the number of stars passing within a given distance, N_S (R), scales as the square of that distance, R [3]. This comes about because Earth is in a flow of stars circling the galactic center, so the cross-sectional area is what matters, which gives an R^2 scaling, rather than the volume, ~ R^3. Figure 2 shows that several stars have approached or will approach our solar system over 10^5 years.

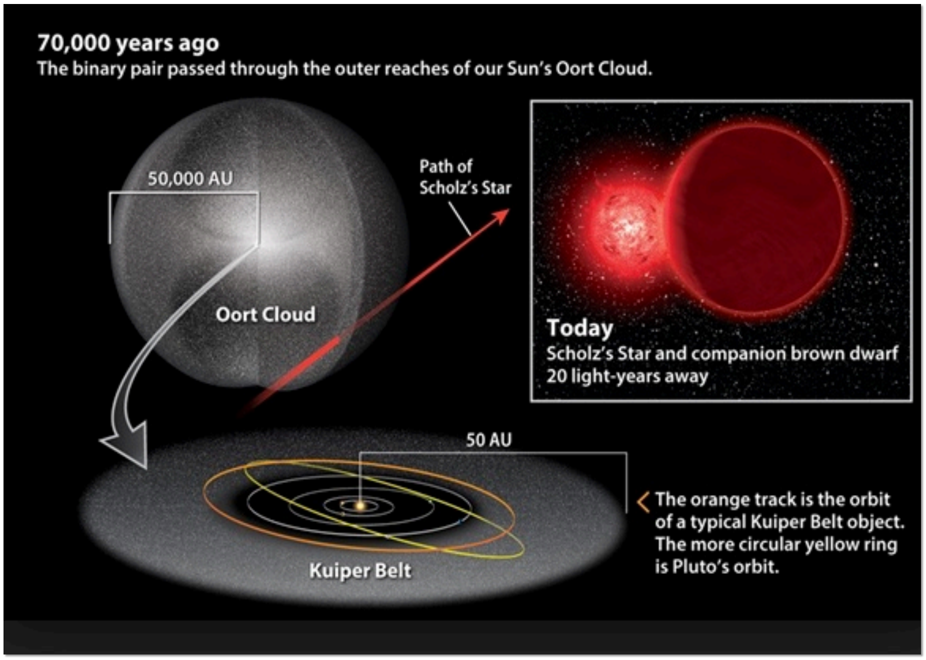

Figure 1. Our most recent visitor: Scholz's Star came within 0.82 light-years from the Sun about 70,000 years ago.

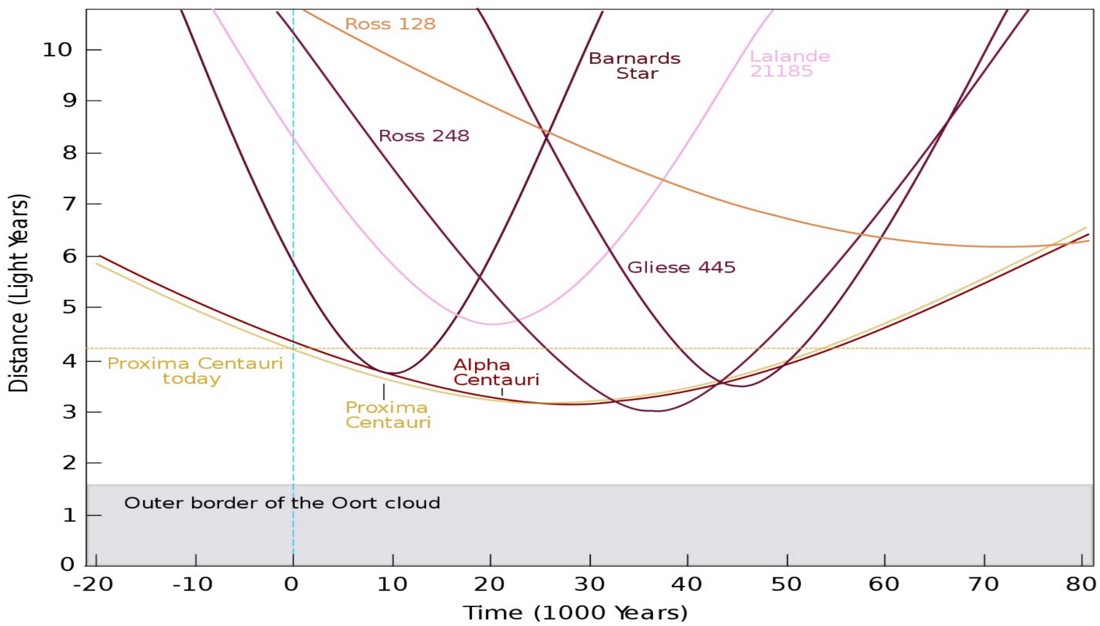

Figure 2. Stars come very close to Earth frequently. About 2 stars come within a light

year every million years. An ET civilization that passes nearby can see there's an ecosystem here, due to the out-of-equilibrium atmosphere. They could send interstellar probes to investigate.

Bailer-Jones et al., using accurate 3D spatial and 3D velocity data for millions of stars from the Second *Gaia* Data Release has shown that a new passing star comes within one light year of our Sun every half million years [3]. Figure 3 shows results for 694 stars.

With the number of stars passing within a given distance, N_S (R), and R the distance of the star from the Sun in light years, the rate is:

$$dN_S(R)/dt = 2\ 10^{-6}\ R^2 \text{ stars/year} = 2\ R^2\ (ly^2) \text{ stars/Myear} \tag{1}$$

So a new star comes within 10 ly every 5,000 years [3]: on the 10,000-year timescale of our agricultural civilization, about two new stars have come within 10 ly.

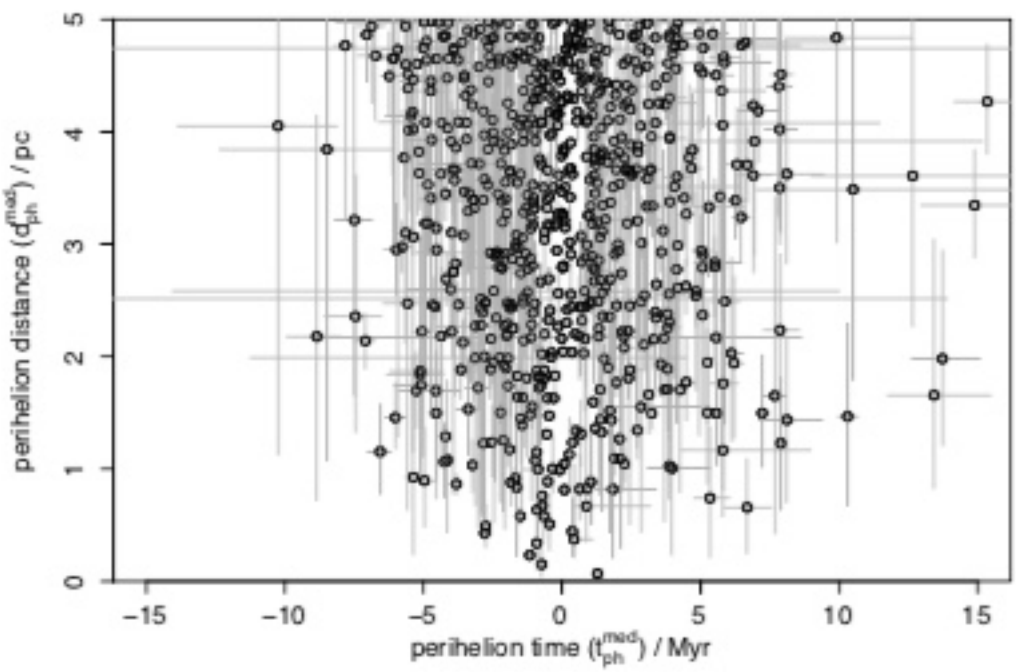

Figure 3. Stars passing by Earth: Perihelion times and closest distances computed for 694 observed stars. Vertical scale is in parsecs; a parsec is 3.26 light years. Horizontal scale is the timescale of passage in Myr. The present is the '0' time. The lack of stars at more distant times is primarily a consequence of the magnitude limit in the sample. Encounters that would occur further in the past/future generally correspond to stars that are currently more distant, and so more likely to be below the limiting magnitude. The effective time limit of this study is 5–10 Myr [3].

3. How Many Lurkers May Have Come Here?

To calculate the number of Lurkers that *could* be located at various sites nearby to Earth, such as the Moon, Earth Trojan zone or the co-orbitals, make the following estimate:

There are two factors to evaluate: 1) How often do stars get within a given range of Earth? 2) How long would a Lurker reside in a given location near Earth?
Of course we do not know what fraction of the stars have spacefaring civilizations. Here I'll define:

f_{ip} = fraction of stars that have civilizations that develop interstellar probe technology and launch them.

Table 1 Passing Stars Parameters

Parameter	Definition
N_S (R)	number of stars passing solar system within a given distance R in lightyears
T_L	orbital lifetime of the object upon which the Lurker is resident
f_{ip}	fraction of civilizations that develop interstellar probe technology and launch them

The number of Lurkers that could arrive and now be found, N_L, would be f_{ip} times T_L, the orbital lifetime of the object upon which the Lurker is resident, times the passing star rate, $[dN_S(R)/dt]$ from Eq. 1:

$$N_L = f_{ip}\, T_L\, [dN_S(R)/dt] \qquad (2)$$

We don't know f_{ip}, but we can calculate the ratio

$$N_L/f_{ip} = T_L\, dN_S(R)/dt \qquad (3)$$

Now we quantify T_L.

4.0 Locations for Lurkers Near Earth

The time that Lurkers would be in the solar system, T_L, will be limited by the lifetime of the orbits they are in, determined by the stability of the orbit of the near-Earth object it lands on. This provides an upper bound. The Moon, Earth Trojans and co-orbitals of Earth lifetimes are:

4.1 The Moon

Searching on the Moon has recently been advocated [4, 5]. Our Moon is thought to have formed about 4.5 billion years ago, long before life appeared. Then the Earth ecosystem would not attract attention, so provides no limitation. Instead, we use the time life became evident in our atmosphere.

From Figure 4, the time over which our biosphere has been observable from great distances of thousands of light years, due to oxygen in the atmosphere, is a very long time, measured in the billions of years [6, 7]. The first oxidation event occurred about 2 .5 billion years ago and the second, largest oxidation event about 0.65 billion years ago, so $0.65\ 10^9 < T_L < 2.5\ 10^9$ years.

An ET civilization that passes nearby can see there's an ecosystem here, due to the out-of-equilibrium atmosphere. They could send interstellar probes to investigate.

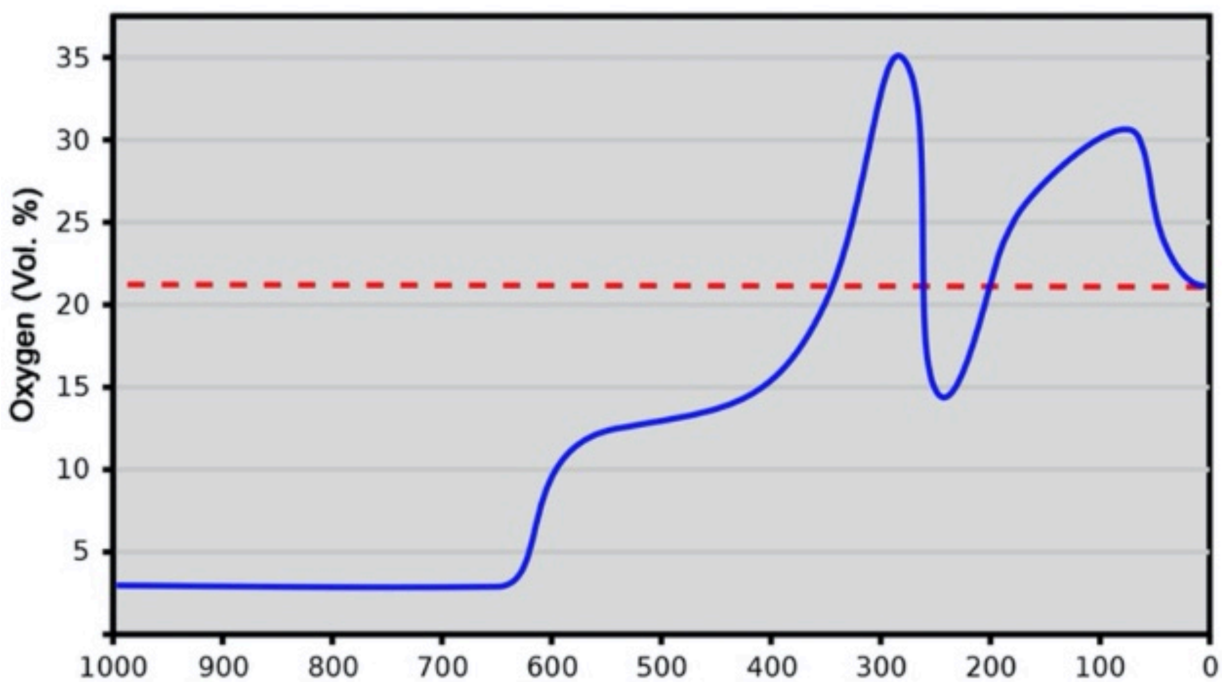

Figure 4 History of Oxygen content of Earth's atmosphere.

Then Eq. 3 gives, for probes launched from <10 ly,

$$(0.65\ 10^9)(2\ 10^{-4}) < N_L / f_{ip} < (2\ 10^{-4})(2.5\ 10^9) \quad (4)$$

$$130{,}000 < N_L / f_{ip} < 500{,}000 \quad (5)$$

Because, from Eq. 1, $r_S\,(R) \sim R^2$, for probes launched from <100 ly,

$$13{,}000{,}000 < N_L / f_{ip} < 50{,}000{,}000 \quad (6)$$

We have had the Lunar Reconnaissance Orbiter in low orbit around the Moon since 2009. It has photographed about 1.6 million sites at sub-meter resolutions. We can see where Neil Armstrong walked! The vast majority of these photos have not been inspected by the human eye. Davies and Wagner have proposed searching these millions of photographs for alien artifacts, which would require an automatic processing system for initial surveys [4]. Development of such an AI is a low-cost initial activity for finding alien artifacts on the Moon, as well as Earth Trojans and the Earth co-orbitals.

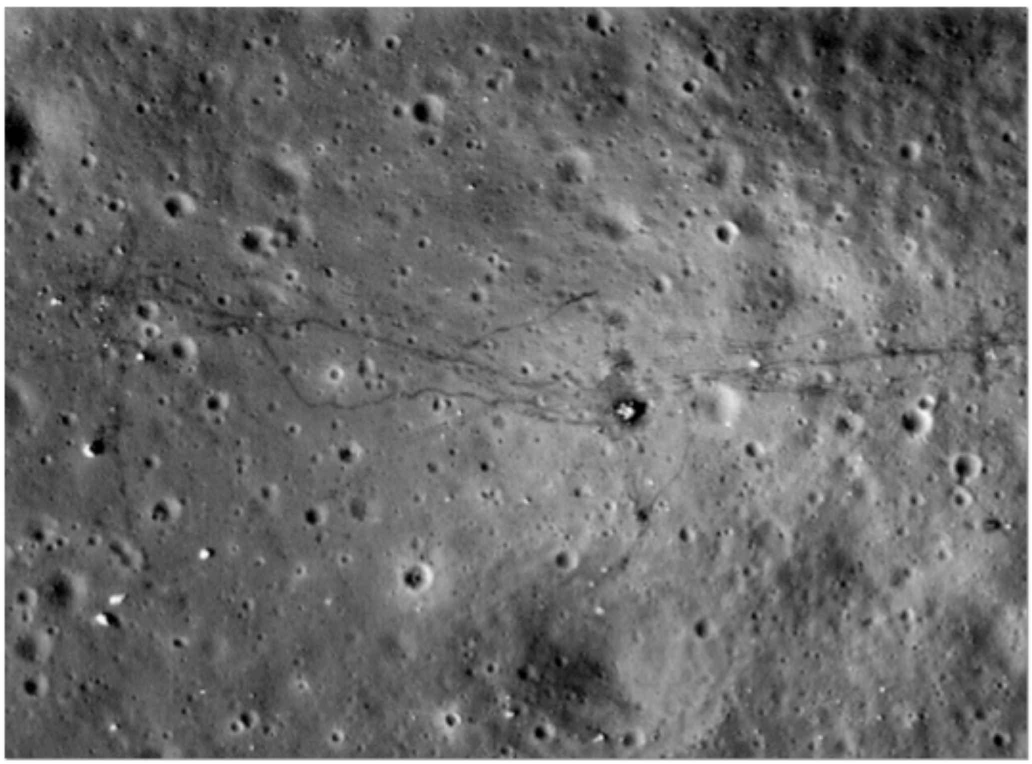

Figure 5 The Apollo 17 site as seen by the Lunar Reconnaissance Orbiter. Note that Moonbuggy tracks can be clearly seen. A study of the >1.6 million such photos could detect possible artifacts on the Moon.

4.2 Earth Trojans

Figure 6 shows the many Jupiter Trojans, located at stable Lagrange Points near that planet. There may be many such objects in the Earth Trojan region [8], ~60 degrees ahead of and following Earth. Their lifetime is likely to be on the order of billions of years, and some objects there may be primordial, meaning that they are as old as the Solar System, because of their very stable Lagrange Point orbits [9-12].

Figure 7 shows a portion of the orbit of the only Earth Trojan found so far, 2010 TK_7. It oscillates about the Sun–Earth L_4 Lagrange Point, ~60 degrees ahead of Earth [13]. Its closest approach to Earth is about 70 times the Earth-Moon distance. It is not a primordial Earth Trojan and is estimated to have an orbital lifetime of 250,000 years, when it will go into a horseshoe orbit about the sun. It is clear why there are no other Trojans of the Earth yet found: they are hard to observe from Earth.

There are large stable regions at Lagrange Points, so Trojans may exist for long time scales. It is possible that primordial Earth Trojans exist in the very stable regions around the Lagrange Points. Orbital calculations show that the most stable orbits reside at inclinations <10° to the ecliptic; there they may survive the age of the solar system, so again we use the oxygen time, ~2.5 Gyr.

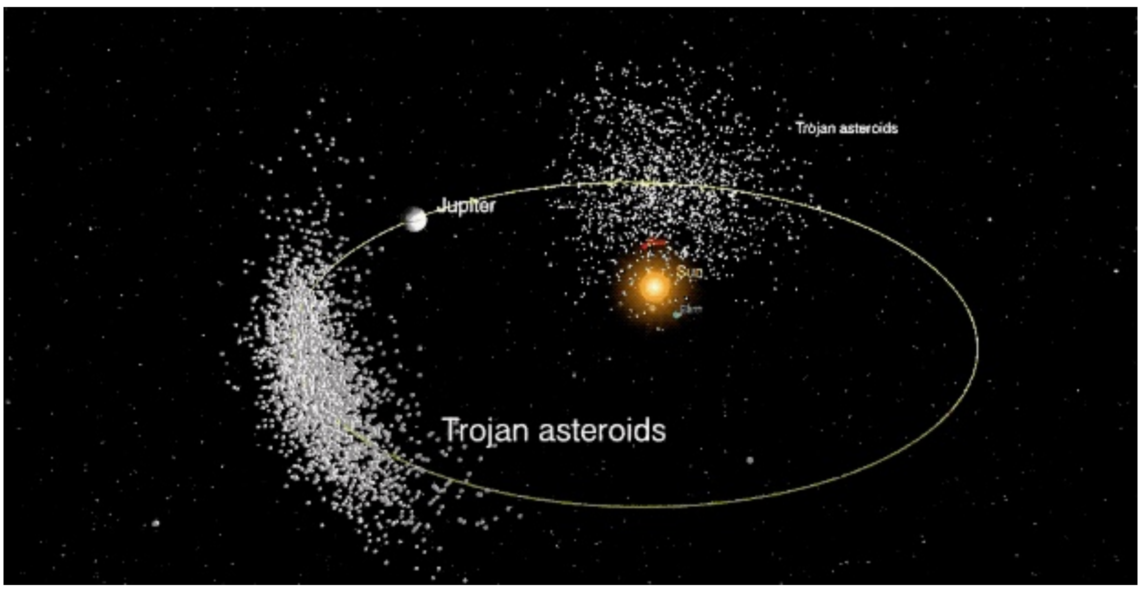

Figure 6. The many Jupiter Trojans, which lead and follow the planet at ~ 60°.

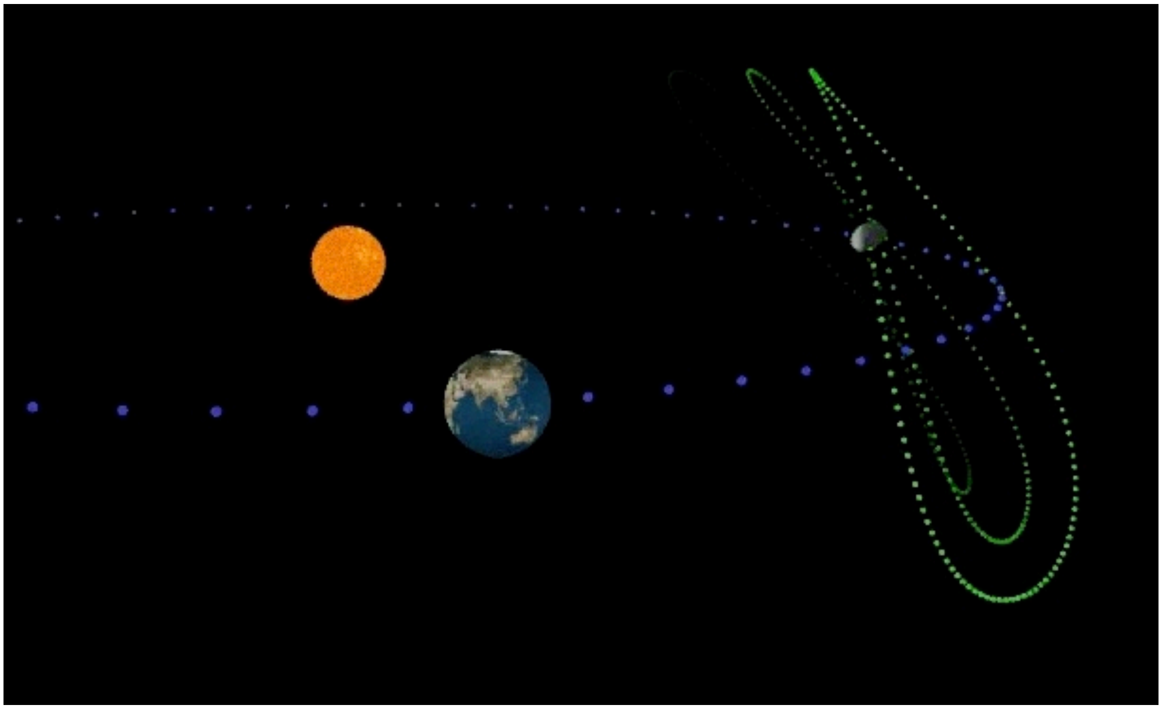

Figure 7. Portion of the orbit of the one Earth Trojan found so far, 2010 TK7.

So Trojans' orbital lifetimes can vary from 2 10^5 years to 2.5 10^9 years. Then Eq. 3 gives, for probes launched from <10 ly,

$$(2\ 10^{-4})\ (2\ 10^{5}) < N_L/\ f_{ip} < (2\ 10^{-4})(2.5\ 10^{9}) \quad (7)$$

$$40 < N_L/\ f_{ip} < 500{,}000 \quad (8)$$

For probes launched from <100 ly,

$$4{,}000 < N_L/\ f_{ip} < 50{,}000{,}000 \quad (9)$$

4.3 Earth Co-orbitals

See [14] for a discussion of the co-orbitals of Earth. A large number of tadpole, horseshoe and quasi-satellites that approach near to Earth appear to be long-term stable. Figure 8 shows to orbit of the nearest one, 2016 HO3. Morais and Morbidelli, using models of main asteroid belt sources providing the co-orbitals and their subsequent motions, estimate lifetimes to run between 1 thousand and 1 million years. They conclude that the mean lifetime for them to maintain resonance with Earth is 0.33 million years (14). Note that almost all of the co-orbitals have been discovered and their orbits quantified since the Morais and Morbidelli work. And software for orbital calculations has become vastly more capable since then, so these estimates can be greatly improved.

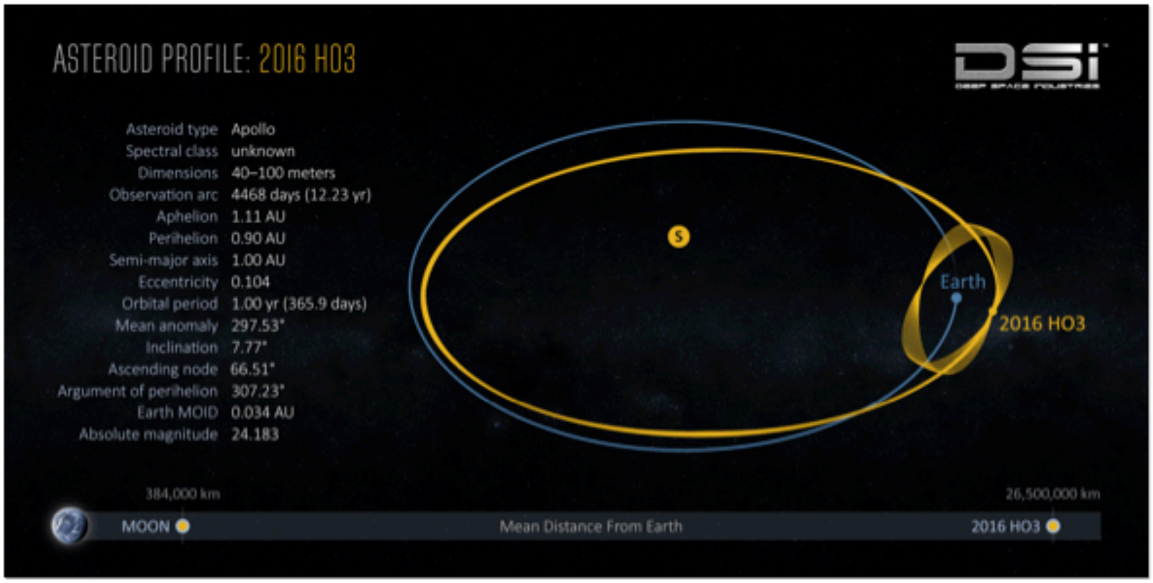

Figure 8. Parameters of the nearby quasi-satellite 2016 HO3. Note the scale at the bottom, showing how nearby the quasi-satellite is to the Moon and Earth.

For co-orbitals, lifetimes in their orbits can vary from 1,00 years to 1 million years. Then Eq. 3 gives, for probes launched from <10 ly,

$$(10^3)(2\ 10^{-4}) < N_L/\ f_{ip} < (2\ 10^{-4})(\ 10^6) \quad (10)$$

$$0.2 < N_L/\ f_{ip} < 200 \quad (11)$$

For probes launched from <100 ly,

$$20< N_L/f\ f_{ip} <20{,}000 \quad (12)$$

Note that, since co-orbitals have a finite lifetime on their orbits near Earth, refers to this is the number of probes that may have landed on what was *at the time* a co-orbital but will now have wandered off somewhere.

5. Conclusions

The estimates above are summarized in the Table, for probes traveling from 10 ly and 100 ly.

Table 2: N_L/f_{ip}, Number of stars that pass by our Solar System in the orbital lifetime of nearby astronomical bodies divided by f_{ip}, the fraction of stars that have civilizations that develop interstellar probe technology and launch them.

Range from which probes could have come	Moon	Earth Trojans	Earth Co-Orbitals
<10 light years	130,000 to 500,000	130,000 to 500,000	0.2 to 200
R<100 light years	13,000,000 to 50,000,000	13,000,000 to 50,000,000	20 to 20,000

- Clearly, the Moon and the Earth Trojans have a greater probability of success than the co-orbitals.

- Of course, f_{ip} is the factor we don't know: how many civilizations develop interstellar probe technology and launch them.

- The great virtue of searching for Lurkers is their lingering endurance in space, long after they go dead.

- Close inspection of bodies in these regions, which may hold primordial remnants of our early solar system, yields *concrete astronomical research*. It will yield new astronomy and astrophysics, quite apart from finding Lurkers.

- A suggestion for SETI observers: Look at the specific stars that have passed our way in the last 10 million years and ask how many of them are 'sunlike' and/or are known to have habitable planets. Observe those stars closely for possible emissions to Earth [14].

For discussion of approaches to study these objects, starting with passive observations, and going on to missions to them, see Reference 12, section 4, "SETI Searches of Co-orbitals". The actions and observations are:

1. Launch robotic probes and manned missions to conduct inspections, take samples.
2. Conduct passive SETI observations.
3. Use active planetary radar to investigate the properties of these objects
4. Conduct *active* simultaneous planetary radar 'painting' and SETI listening of these objects.
5. Launch robotic probes and manned missions to conduct inspections, take samples.

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