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

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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, $\sim R^3$. Figure 2 shows that several stars have approached or will approach our solar system over 10^5 years.

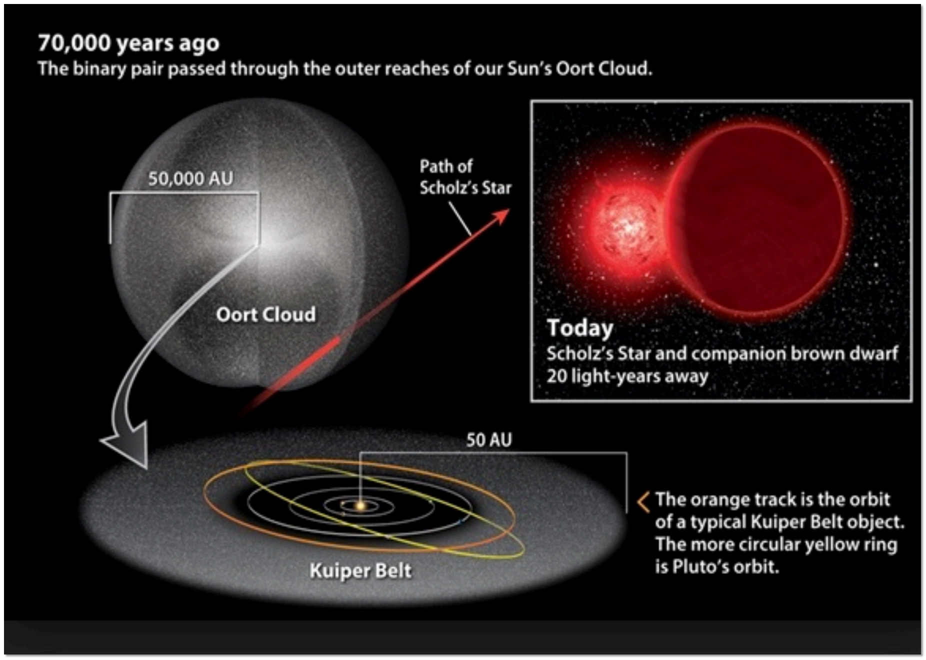

Figure 1. Our most recent visitor: Scholz's Star came within 0.82 light-years from the Sun about 70,000 years ago.

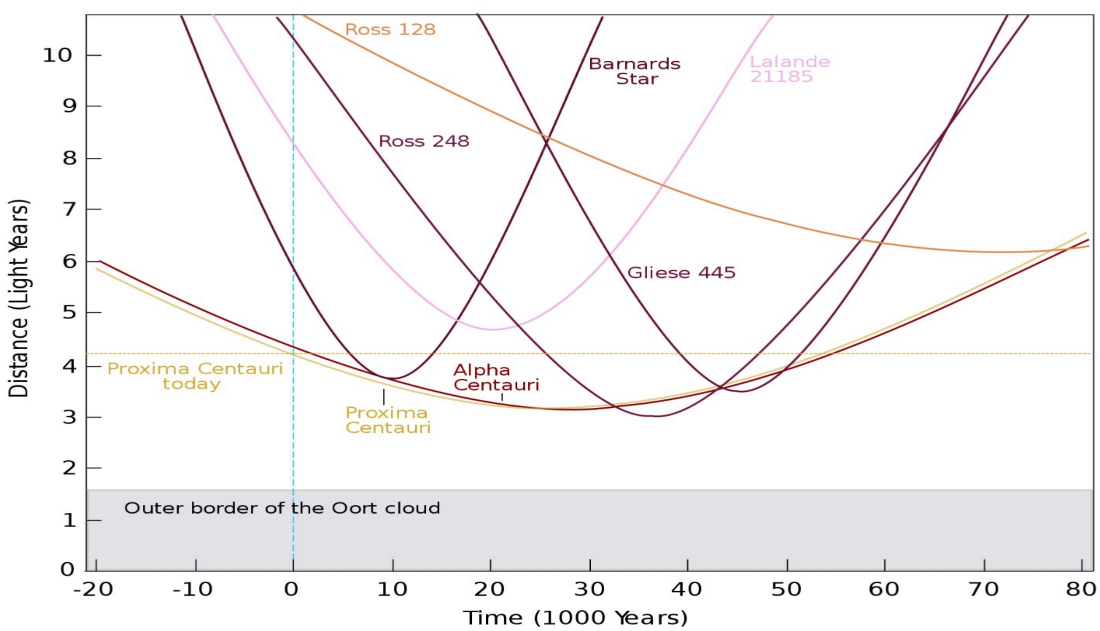

Figure 2. Stars come very close to Earth frequently. About 2 stars come within a light

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:

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

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.

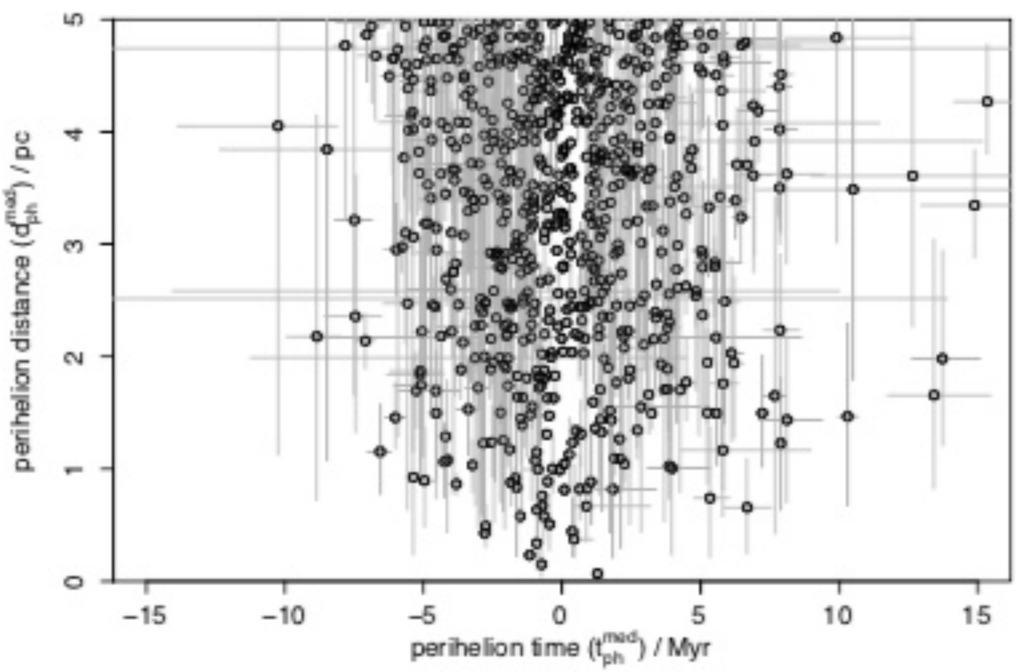

Figure 3. Stars passing by Earth: Perihelion times and closest distances computed for 694 observed stars. Vertical scale is in parsecs; a parsec is 3.26 light years. Horizontal scale is the timescale of passage in Myr. The present is the '0' time. The lack of stars at more distant times is primarily 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.

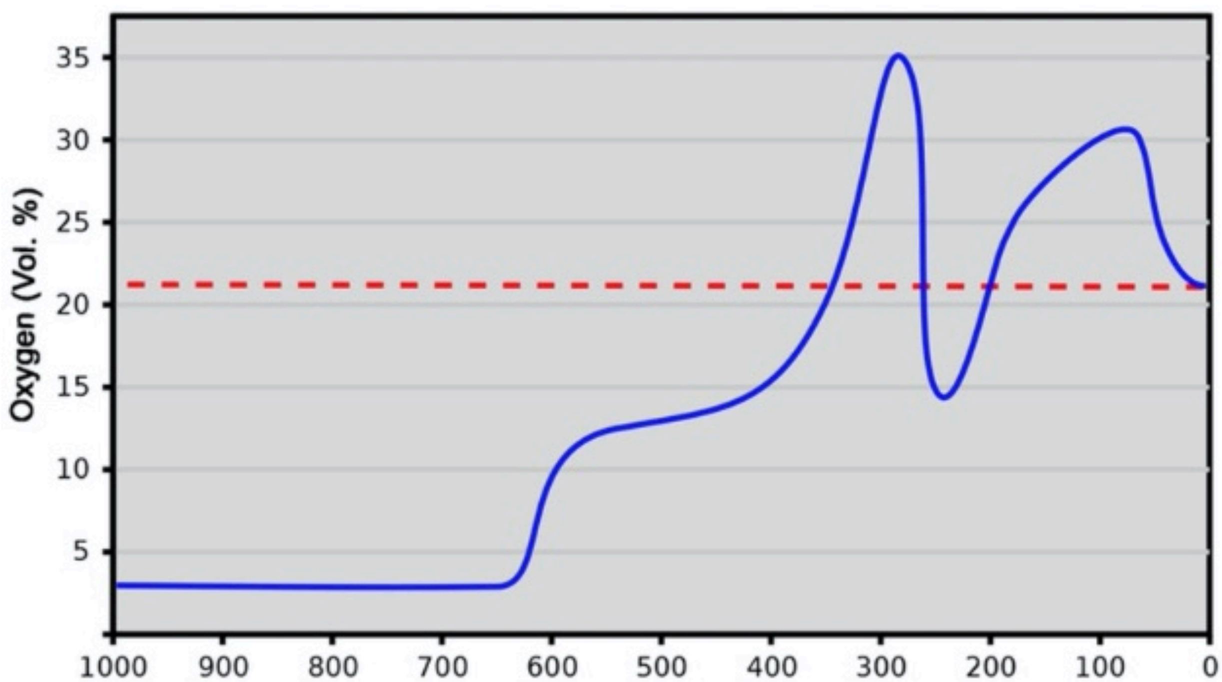

Figure 4 History of Oxygen content of Earth's atmosphere.

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

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

$$130{,}000 < N_L / f_{ip} < 500{,}000 \tag{5}$$

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.

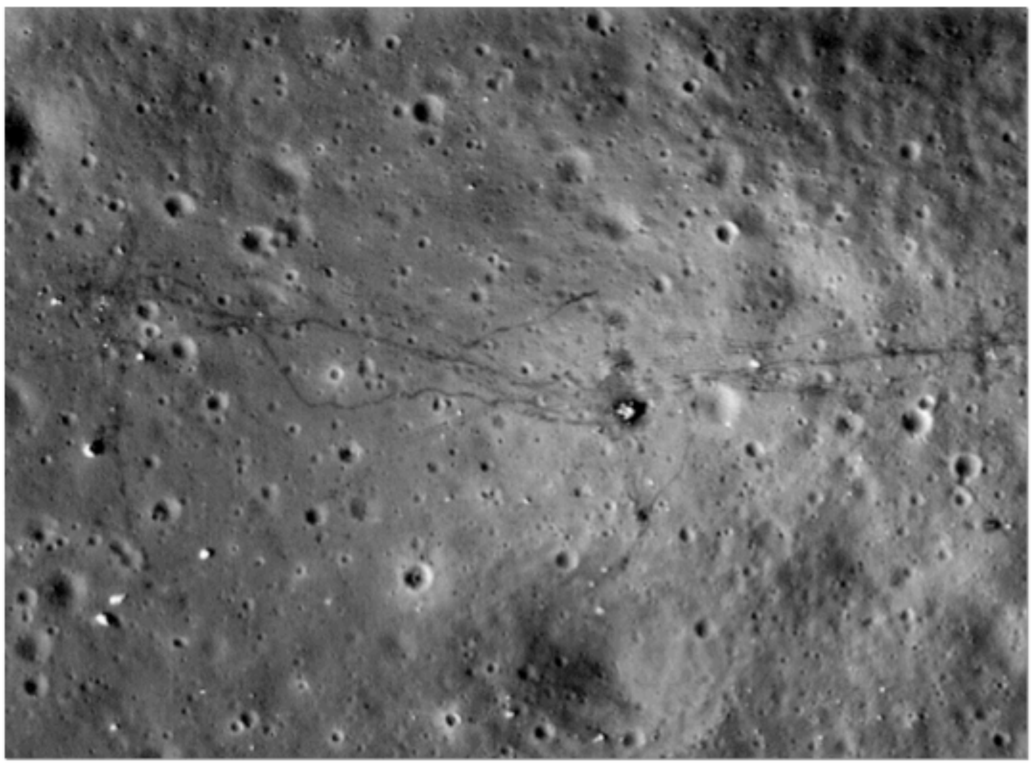

Figure 5 The Apollo 17 site as seen by the Lunar Reconnaissance Orbiter. Note that Moonbuggy tracks can be clearly seen. A study of the >1.6 million such photos could detect possible artifacts on the Moon.

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.

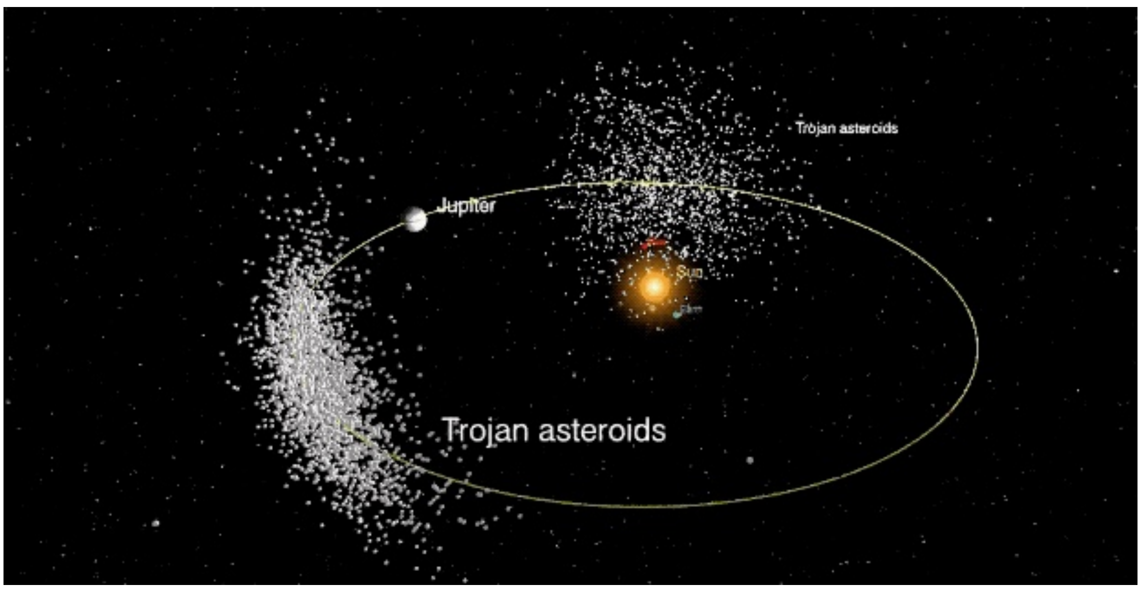

Figure 6. The many Jupiter Trojans, which lead and follow the planet at ~ 60°.

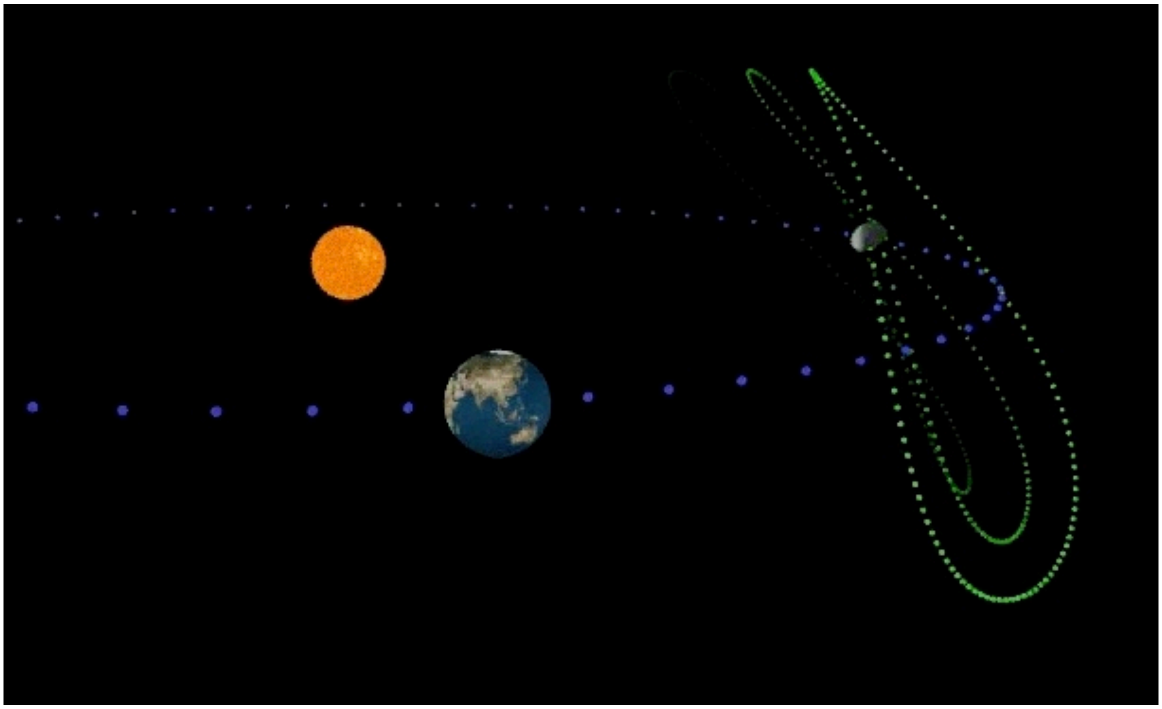

Figure 7. Portion of the orbit of the one Earth Trojan found so far, 2010 TK7.

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.

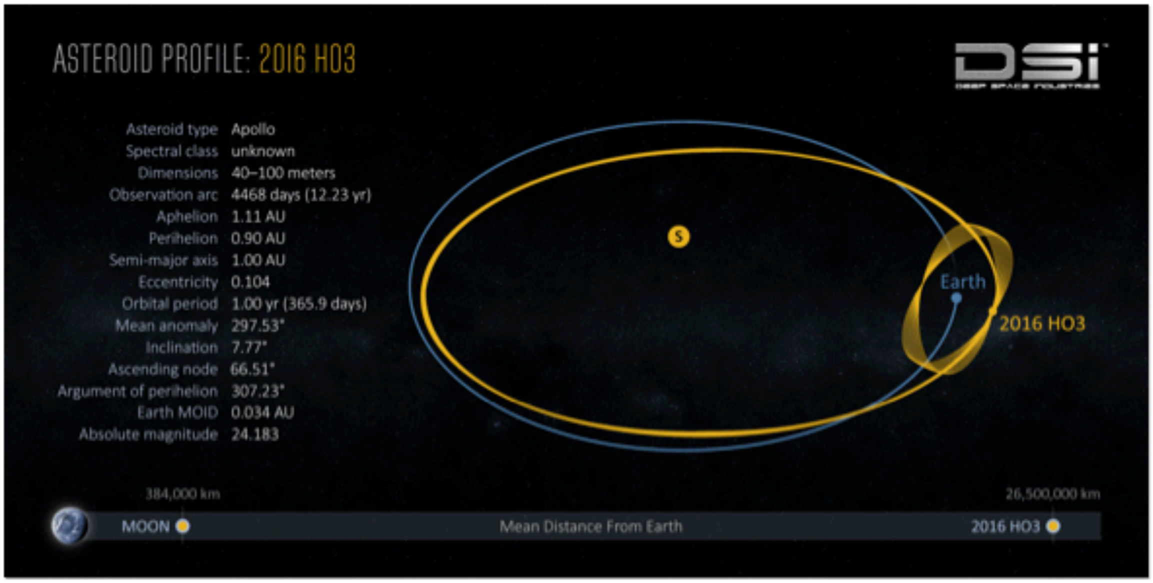

Figure 8. Parameters of the nearby quasi-satellite 2016 HO3. Note the scale at the bottom, showing how nearby the quasi-satellite is to the Moon and Earth.

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,

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

$$0.2 < N_L/\ f_{ip} < 200 \tag{11}$$

For probes launched from <100 ly,

$$20< N_L/f\ f_{ip} <20{,}000 \tag{12}$$

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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References

1. J. Benford, "A Drake Equation for Alien Artifacts", in press, 2020.

2. E. Mamajek et al, "The Closest Known Flyby Of A Star To The Solar System" *ApJ Lett.,* 8003 L17, 2015.

3. C. A. L. Bailer-Jones et al, "New Stellar Encounters Discovered in the Second *Gaia* Data Release", *Astronomy & Astrophysics* 616 A37, 2018.

4. P.C.W. Davies, R.V. Wagner, "Searching for Alien Artifacts on the Moon", *Acta Astronaut*ica, doi:10.1016/j.actaastro.2011.10.022, 2011.

5. L. Bickel and D. Angerhausen, "Unsupervised Distribution Learning for Lunar Surface Anomaly Detection", arXiv:2001.04634. 2020.

6. X. L. Kaltenegger, Z. Lin and J. Madden, ""High-resolution Transmission Spectra of Earth Through Geological Time", *Astroph. Lett.,* 2041, 2020.

7. Y. V. S. Meadows et al., "Exoplanet Biosignatures: Understanding Oxygen as a Biosignature in the Context of Its Environment", *Astrobiology* 18, 620, 2018.

8. R. Malhotra, "Case for a Deep Search for Earth's Trojan Asteroids", *Nature Astronomy* 3, 193, 2019.

9. M, Ćuk, D. Hamilton and M. Holman, "Long-term stability of horseshoe orbits", *Monthly Notices Royal Astronomical Society,* 426, pp. 3051, 2012.

10. F. Marzari, H. Scholl, "Long term stability of Earth Trojans", *Celestial Mechanics and Dynamical Astronomy*, 117, 91, 2013.

11. Zhou, Lei; Xu, Yang-Bo; Zhou, Li-Yong; Dvorak, Rudolf; Li, Jian, “Orbital Stability of Earth Trojans”, *Astronomy & Astrophysics*, 622, 14, 2019.

12. R. Dvorak, C. Lhotka, L. Zhou, “The orbit of 2010 TK7. Possible regions of stability for other Earth Trojan asteroids”, *Astronomy & Astrophysics*, 541, 2012.

13. P. Wiegert, K. A. Innanen and S. Mikkola, “An Asteroidal Companion to the Earth”, *Nature*, 387, 685, 1997.

14. J. Benford, “Looking for Lurkers: Objects Co-orbital with Earth as SETI Observables”, *AsJ*, 158:150, 2019.

13. M. Morais and A. Morbidelli, ‘The Population- of Near-Earth Asteroids in Co-orbital Motion with the Earth”, *Icarus* 160, 1, 2002.

14. Paul Davies, private communication.