# On the Possibility of an Artificial Origin for `Oumuamua

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#### Abstract

Science offers the privilege of following evidence, not prejudice. The first interstellar object discovered near Earth, 'Oumuamua, showed half a dozen anomalies relative to comets or asteroids in the Solar system. All natural-origin interpretations of 'Oumuamua's anomalies contemplated objects of a type never-seen-before, such as: a porous cloud of dust particles, a tidal disruption fragment or exotic icebergs made of pure hydrogen or pure nitrogen. Each of these natural-origin models has major quantitative shortcomings, and so the possibility of an artificial origin for 'Oumuamua must be considered. The Galileo Project aims to collect new data that will identify the nature of 'Oumuamua-like objects in the coming years.

#### I. Anomalies

On October 19, 2017, the first object from outside the Solar system was discovered near Earth by the Pan STARRS telescope in Hawaii. It was given the name, `Oumuamua, which means `a messenger from afar, arriving first' in the Hawaiian language (see Figure 1). I was intrigued by this first interstellar object because a decade earlier I co-authored a paper forecasting that Pan STARRS should not detect any rock from other stars based on what we know about the Solar system<sup>1</sup>.



**Figure 1:** Combined telescope image of the first interstellar object `Oumuamua, circled in blue as an unresolved point source at the center. It is surrounded by the trails of faint stars, each smeared into a series of dots as the telescope snapshots tracked the moving `Oumuamua. (Credit: ESO/K. Meech et al.)

Astronomers initially assumed that 'Oumuamua is a comet, because comets are most loosely bound to the Sun, residing in the Oort cloud at the periphery of the Solar system where they can be easily sent to interstellar space by the perturbation of a passing star. But there was no visible cometary tail around 'Oumuamua. Moreover, a cometary origin implies that 'Oumuamua would have inherited the motion of its parent star. But instead it was found to originate from the so-called "Local Standard of Rest" (see Figure 2). This frame averages over the motions of all stars near the Sun, and only 1 in 500 stars is so much at rest as 'Oumuamua was in that frame, before the Sun kicked it gravitationally<sup>2</sup> (see Figure 3).



**Figure 2:** Sky path of `Oumuamua, labeled by date, as seen from Earth. The relative size of each circle gives a sense of the changing distance of `Oumuamua along its apparent trajectory. Also shown are the direction of motion of the Sun in the Local Standard of Rest (purple, labeled "Solar apex"), Venus (green), Mars (red) Uranus (turquoise) and the opposite direction to the motion of the Sun (purple, labeled "Solar antapex"). `Oumuamua's trajectory moved from the Local Standard of Rest to south of the ecliptic plane (marked by the thin yellow line) of the Solar System between September 2 and October 22, 2017. (Credit: JPL Horizons)

These were just the initial anomalies that made `Oumuamua different from all the comets and asteroids that we had seen before in the Solar system. As it tumbled every eight hours (see Figure 4), the brightness of sunlight reflected from it changed by a factor of ten. This meant that it has an extreme shape, which at the ~90% confidence level was disk-like<sup>3</sup>. The Spitzer Space Telescope did not detect any carbon-based molecules or dust around `Oumuamua, setting a tight limit on ordinary cometary activity<sup>4</sup>. The lack of heat - detectable in the infrared, placed an upper limit of about 200 meters on its size, the scale of a football field. But most remarkably, `Oumuamua exhibited an excess push away from the Sun which would have required it to lose  $\sim 10\%$  of its mass if it was caused by the rocket effect from normal cometary evaporation<sup>5</sup>. An extensive evaporation of this magnitude was absolutely ruled out by the Spitzer telescope data; moreover, the repulsive force declined smoothly with distance from the Sun, showing no change in spin or sudden kicks as routinely observed from jets on the surface of comets<sup>6</sup>. Finally, there was no apparent cutoff in the push at the distance beyond which evaporation of water ice by sunlight is expected to stop (see Figure 5).



**Figure 3:** Trajectory of `Oumuamua through the Solar System. Unlike all asteroids or comets observed before, this orbit is not bound by the Sun's gravity. `Oumuamua originated from interstellar space and will return there with a velocity boost as a result of its passage near the Sun. Its hyperbolic orbit was inclined relative to the ecliptic plane of the Solar System and did not pass close to any of the planets on the way in. (Credit: ESO/K. Meech et al.).

The excess force without a cometary tail convinced me that this object is not a familiar rock. Since the push away from the Sun was consistent with a smooth inverse-square law, I reasoned that it may result from the reflection of sunlight from a thin object<sup>7</sup>. For the reflection of sunlight to exert a strong enough force, the object had to be thinner than a millimeter, like a light sail. Since nature does not make thin objects, I suggested that it might be artificial in origin<sup>8-10</sup>.



**Figure 4:** Variation in brightness of `Oumuamua as observed by various telescopes during three days in October 2017. Different colored dots represent measurements through different filters in the visible and near-infrared bands of the color spectrum. The amount of reflected sunlight changed periodically by about a factor of ten (2.5 magnitudes) as `Oumuamua rotated every 8 hours. This implied that it has an extreme shape which is at least ten times longer than it is wide when projected on the sky. The dashed white line shows the curve expected if `Oumuamua were an ellipsoid with a 1:10 aspect ratio. However, the best fit to the light curve from its tumbling motion implies a flattened, pancake-shaped configuration rather than an oblong, cigar-shaped object as commonly depicted in the media. (Credit: ESO/K. Meech et al.)

This possibility was intended to encourage scientists to obtain a high-resolution image of `Oumuamua-like objects in the future. It is often said that `a picture is worth a thousand words.' In my case, a picture is worth 66 thousand words, the number of words in my book titled, *Extraterrestrial*. I would have never written this book if we had a megapixel image of `Oumuamua.



**Figure 5:** Trajectory of `Oumuamua through the inner region of the Solar System, dated weekly. The planet positions are fixed at the time of `Oumuamua's closest approach to the Sun (perihelion) on September 9, 2017.

In September 2020, another object<sup>11</sup> was discovered by Pan STARRS sharing `Oumuamua's anomalies of no cometary outgassing and excess push by reflection of sunlight. It was given the astronomical name 2020 SO and later found to be a rocket booster from a 1966 mission to the Moon. It had thin walls and hence a large area for its mass. It was not designed to be a light sail but was thin for a different purpose. Its discovery illustrates that the difference between a rock and an artificial object can be inferred from the unusual dynamics of an object. We know that humanity manufactured 2020 SO. The question is who manufactured `Oumuamua?

A cave dweller finding a cellphone would argue that it is a rock of a new type, in the same way that earthlings who studied the anomalies of the first interstellar object `Oumuamua suggested that it is a comet of a type "never seen before", such as an iceberg made of pure hydrogen or pure nitrogen, even though these possibilities face "serious difficulties" in the words of some of their proponents<sup>12</sup>. When a colleague of mine, specializing in solar system rocks, heard about `Oumuamua, he said: "this interstellar object is so weird ... I wish it never existed." His statement explains why innovation is often suppressed in the face of

anomalies. Mainstream scientists would prefer these anomalies to go away in order to maintain the prestige that they can forecast all data with their existing knowledge. They find anomalies to pose a threat to their status as "experts" in the field.

#### II. Possible Natural Origins and Their Challenges

Astronomers who attempted to explain the anomalies of `Oumuamua by a natural origin were all forced to contemplate objects that were never seen before, with major quantitative challenges. These possibilities are:

- (i) a porous structure with a mean density a hundred times lower than air<sup>13-14</sup> which is unlikely to maintain its integrity after being heated to hundreds of degrees by the Sun;
- (ii) fragments from tidal disruption<sup>15</sup> whose shape is more likely to be that of a cigar than a disk as inferred for `Oumuamua;
- (iii) an iceberg of molecular hydrogen<sup>16</sup> which evaporates too quickly along its interstellar journey<sup>17</sup> (see Figure 6);
- (iv) a nitrogen iceberg chipped off the surface of a planet like Pluto around another star<sup>18</sup> a mechanism that cannot supply enough material to explain the implied abundance of objects like `Oumuamua<sup>12,19-20</sup> (see Figure 7).



**Figure 6:** Comparison of various destruction timescales for a hydrogen H<sub>2</sub> iceberg (slanted colored lines) as a function of the object radius (in meters) to the travel time from the likely source of a giant molecular cloud at a distance of 5.2 kpc, assuming a characteristic speed of 30 km s-1 (horizontal black line). (Credit: Ref. 17)



**Figure 7:** Erosion time by cosmic rays for various types of ices including nitrogen N2 (solid red line), CO (dashed green line), CO2 (dotted blue line), and CH4 (dash-dot magenta line) in comparison with the suggested travel time of ~0.5 Gyr for 'Oumuamua (solid black line). A short travel time, would imply origin from nearby young stars, which are much less abundant than old stars. This makes the required nitrogen mass budget untenable. (Credit: Ref. 20)

### III. The Possibility of an Artificial Origin

Given these challenges to natural origins of `Oumuamua and the similarity in the anomalous dynamics of 2020 SO and `Oumuamua, the possibility of an artificial origin should be left on the table (see Figure 8).



**Figure 8:** Artist's impressions of two possible shapes for `Oumuamua. The object's length is estimated to be between tens to hundreds of meters, up to the size of a football field. It is either an oblong, cigar-shaped rock - as depicted in the upper image (Credit: ESO/M. Kornmesser), or a flattened, pancake-shaped object - as shown in the lower image (Credit: Mark Garlick). The pancake shape provides the best fit to `Oumuamua's light curve<sup>3</sup>. Even a razor-thin object, like a flat sheet of paper, would appear to possess some width when projected at a random orientation on the sky, so the intrinsic aspect ratio of `Oumuamua can be much smaller than the value of 1:10 inferred from its light curve.

Thanks to the generous donations from people who were inspired by the vision of my book *Extraterrestrial*, I was able to inaugurate in July 2021 the *Galileo Project*<sup>21</sup>. One of the major goals of the project is to search for `Oumuamua-like objects in future surveys, like with the upcoming Vera Rubin Observatory. An early alert to `Oumuamua-like objects would allow to design of a space mission that will intercept their trajectories and take close-up photographs of them. Such data could resolve their nature and unambiguously determine whether they are natural or artificial in origin.

Finding equipment from an extraterrestrial technological civilization would have a major impact on the future of humanity. Here's hoping that we will be open minded enough to search for objects that resemble the equipment that our technological civilization is launching to space. We know that half of the Sun-like stars host a planet the size of the Earth roughly at the same separation<sup>22</sup>. Many of these stars formed billions of years before the Sun, allowing for the possibility that numerous probes were sent to interstellar space. Ridiculing the notion that `Oumuamua may have been artificial in origin will not get rid of our neighbors<sup>23</sup>. As Galileo Galilei instructed us four centuries ago, the nature of celestial objects must be found through our telescopes rather than philosophical prejudice.

# References

- 1. <u>Moro-Martin, A., Turner, E.L., Loeb, A. 2009. Will the Large Synoptic Survey</u> <u>Telescope Detect Extra-Solar Planetesimals Entering the Solar System?. The</u> <u>Astrophysical Journal 704, 733–742. doi:10.1088/0004-637X/704/1/733</u>
- Mamajek, E. 2017. Kinematics of the Interstellar Vagabond 1I/Oumuamua (A/2017 U1). Research Notes of the American Astronomical Society 1. doi:10.3847/2515-5172/aa9bdc
- 3. <u>Mashchenko, S. 2019. Modelling the light curve of `Oumuamua: evidence for torque</u> <u>and disc-like shape. Monthly Notices of the Royal Astronomical Society 489, 3003–</u> <u>3021. doi:10.1093/mnras/stz2380</u>
- 4. <u>Trilling, D.E. and 22 colleagues 2018. Spitzer Observations of Interstellar Object</u> <u>1I/Oumuamua. The Astronomical Journal 156. doi:10.3847/1538-3881/aae88f</u>
- 5. <u>Micheli, M. and 16 colleagues 2018. Non-gravitational acceleration in the trajectory</u> of 1I/2017 U1 ('Oumuamua). Nature 559, 223–226. doi:10.1038/s41586-018-0254-<u>4</u>
- 6. <u>Rafikov, R.R. 2018. Spin Evolution and Cometary Interpretation of the Interstellar</u> <u>Minor Object 1I/2017 Oumuamua. The Astrophysical Journal 867.</u> <u>doi:10.3847/2041-8213/aae977</u>
- 7. <u>Bialy, S., Loeb, A. 2018. Could Solar Radiation Pressure Explain 'Oumuamua's</u> <u>Peculiar Acceleration?. The Astrophysical Journal 868. doi:10.3847/2041-8213/aaeda8</u>
- 8. <u>Loeb, A. 2018. Are Alien Civilizations Technologically Advanced?. Scientific</u> <u>American, January 8.</u>
- 9. Loeb, A. 2018. How to Search for Dead Cosmological Civilizations, Scientific American, September 27.
- 10. Loeb, A. 2018. 6 Strange Facts About the Interstellar Visitor `Oumuamua, Scientific American, November 20.
- 11. <u>Wikipedia, 2020 SO.</u>
- 12. Levine, W.G., Cabot, S.H.C., Seligman, D., Laughlin, G. 2021. Constraints on the Occurrence of 'Oumuamua-Like Objects. arXiv e-prints.
- 13. <u>Moro-Martin, A. 2019. Could 1I/Oumuamua be an Icy Fractal Aggregate?</u>. The <u>Astrophysical Journal 872. doi:10.3847/2041-8213/ab05df</u>
- 14. <u>Luu, J.X., Flekkoy, E.G., Toussaint, R. 2020. 'Oumuamua as a Cometary Fractal</u> <u>Aggregate: The ``Dust Bunny'' Model. The Astrophysical Journal 900.</u> <u>doi:10.3847/2041-8213/abafa7</u>
- 15. <u>Zhang, Y., Lin, D.N.C. 2020. Tidal fragmentation as the origin of 1I/2017 U1</u> (`Oumuamua). Nature Astronomy 4, 852–860. doi:10.1038/s41550-020-1065-8
- 16. <u>Seligman, D., Laughlin, G. 2020. Evidence that 11/2017 U1 ('Oumuamua) was</u> <u>Composed of Molecular Hydrogen Ice. The Astrophysical Journal 896.</u> <u>doi:10.3847/2041-8213/ab963f</u>
- 17. <u>Hoang, T., Loeb, A. 2020. Destruction of Molecular Hydrogen Ice and Implications for</u> <u>1I/2017 U1 ('Oumuamua). The Astrophysical Journal 899. doi:10.3847/2041-8213/abab0c</u>

- 18. <u>Desch, S.J., Jackson, A.P. 2021. 11/`Oumuamua as an N2 Ice Fragment of an Exo Pluto</u> <u>Surface II: Generation of N2 Ice Fragments and the Origin of `Oumuamua. Journal of</u> <u>Geophysical Research (Planets) 126. doi:10.1029/2020JE006807</u>
- **19**. <u>Siraj, A., Loeb, A. 2021. The Mass Budget Necessary to Explain `Oumuamua as a Nitrogen Iceberg. Accepted for publication in New Astronomy. arXiv e-prints.</u>
- 20. <u>Phan, V.H.M., Hoang, T., Loeb, A. 2021. Erosion of Icy Interstellar Objects by Cosmic</u> <u>Rays and Implications for `Oumuamua. arXiv e-prints.</u>
- 21. Galileo Project website 2021. https://projects.iq.harvard.edu/galileo
- 22. <u>Bryson, S. and 81 colleagues 2021. The Occurrence of Rocky Habitable-zone Planets</u> <u>around Solar-like Stars from Kepler Data. The Astronomical Journal 161.</u> <u>doi:10.3847/1538-3881/abc418</u>
- 23. Loeb, A. 2021. Extraterrestrial. Book publisher: Houghton-Mifflin-Harcourt.

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