Identifying the Unidentified: Seeking Extraterrestrial Equipment Near Earth

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Summary

Science offers the privilege of following evidence, not prejudice. The first interstellar object discovered near Earth in October 2017, `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. In June 2021, the Office of the Director of National Intelligence reported to Congress about the existence of Unidentified Aerial Phenomena (UAP) of an unclear origin. The *Galileo Project* aims to collect and analyze open scientific data that will identify the nature of new `Oumuamua-like objects and UAP near Earth.

I. The Astronomers' Perspective

I.1 `Oumuamua's 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[1].

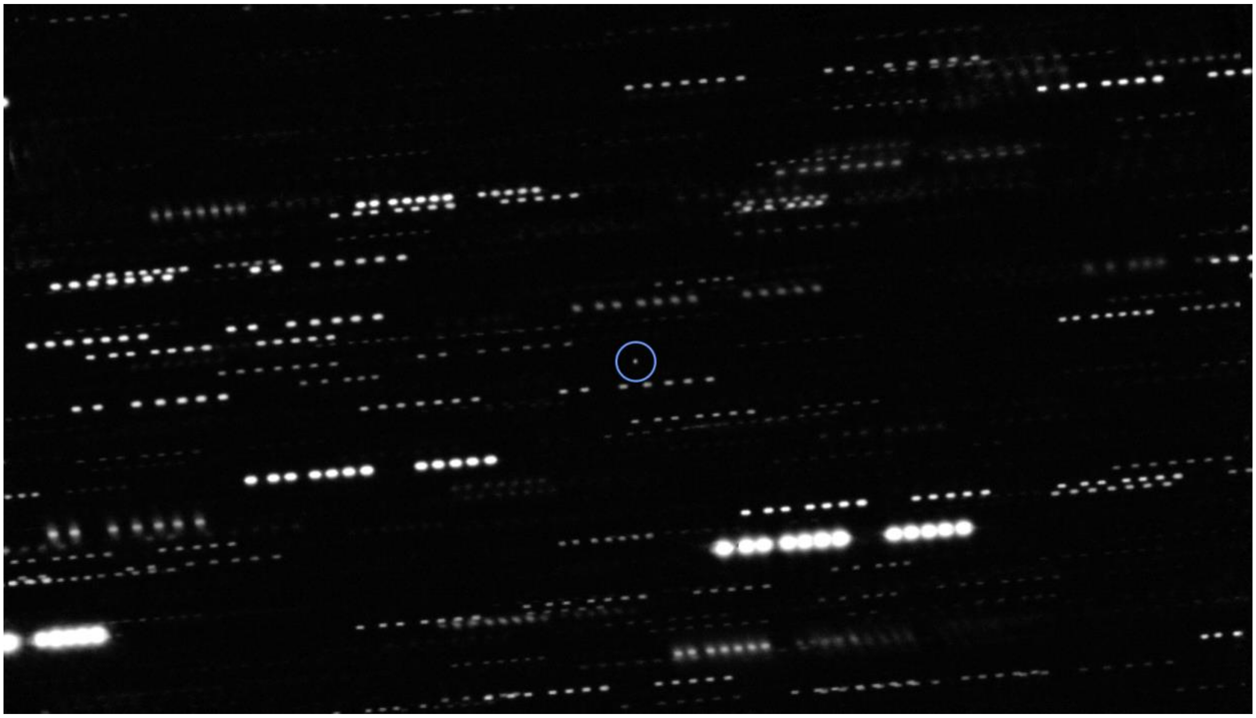

Figure 1: Combined telescope image of the first interstellar object `Oumuamua, circled in blue as an unresolved point source at the center. It is surrounded by the trails of faint stars, each smeared into a series of dots as the telescope snapshots tracked the moving `Oumuamua. (Credit: ESO/K. Meech 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[2] (see Figure 3).

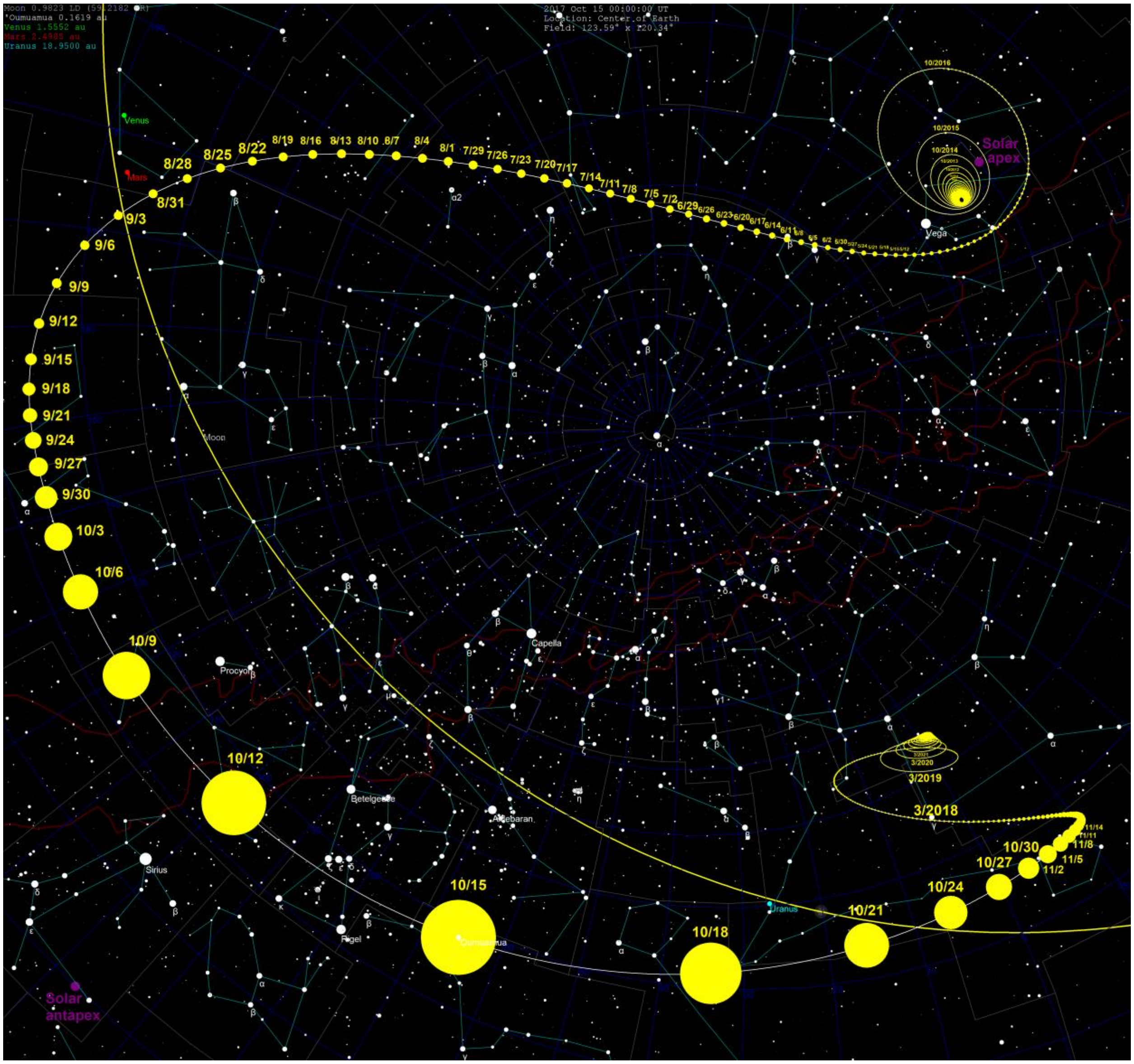

Figure 2: Sky path of `Oumuamua, labeled by date, as seen from Earth. The relative size of each circle gives a sense of the changing distance of `Oumuamua along its apparent trajectory. Also shown are the direction of motion of the Sun in the Local Standard of Rest (purple, labeled "Solar apex"), Venus (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[3]. The Spitzer Space Telescope did not detect any carbon-based molecules or dust around `Oumuamua, setting a tight limit on ordinary cometary activity[4]. 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 ~10% of its mass if it was caused by the rocket effect from normal cometary evaporation[5]. 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[6]. Finally, there was no apparent cut-off in the push at the distance beyond which evaporation of water ice by sunlight is expected to stop (see Figure 5).

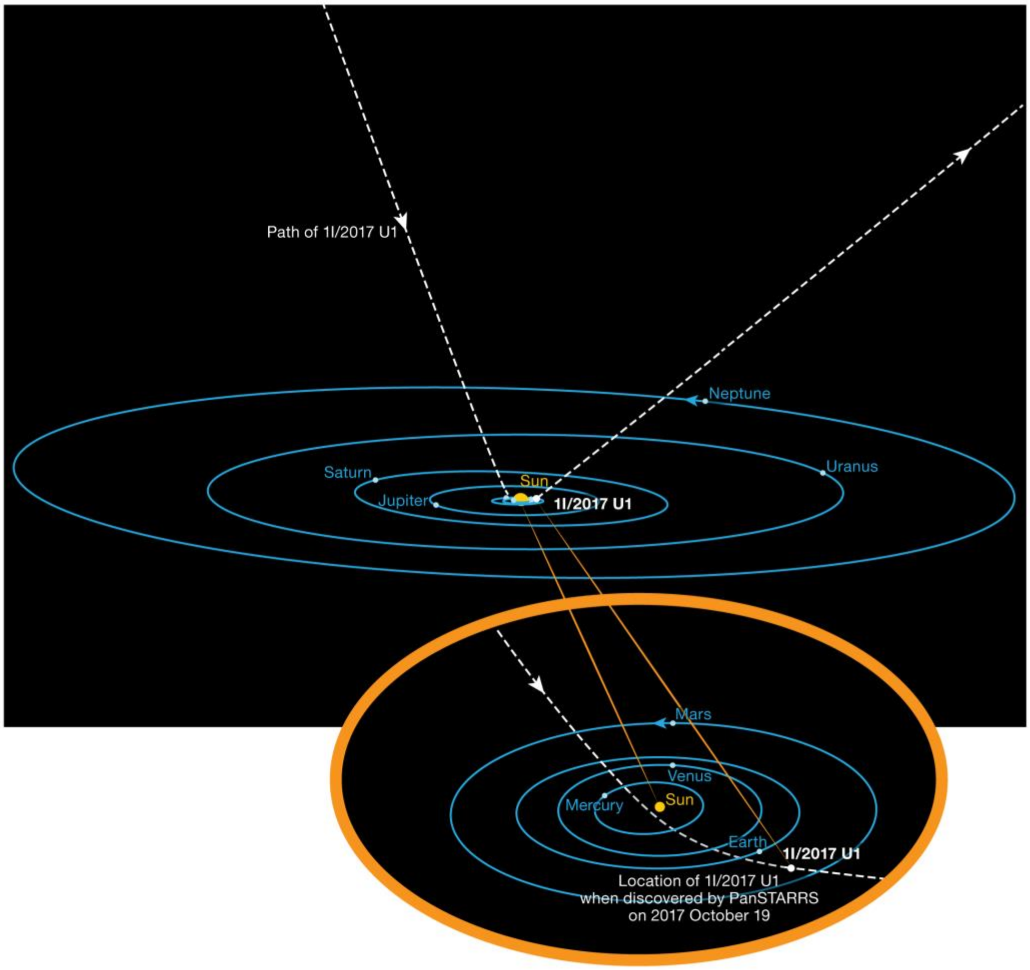

Figure 3: Trajectory of `Oumuamua through the Solar System. Unlike all asteroids or comets observed before, this orbit is not bound by the Sun's gravity. `Oumuamua originated from interstellar space and will return there with a velocity boost as a result of its passage near the Sun. Its hyperbolic orbit 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[7]. 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[8-10].

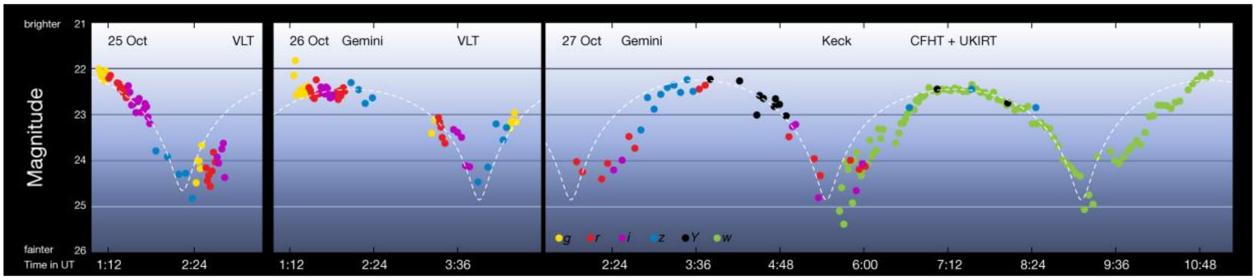

Figure 4: Variation in brightness of `Oumuamua as observed by various telescopes during three days in October 2017. Different colored dots represent measurements through different filters in the visible and near-infrared bands of the color spectrum. The amount of reflected sunlight changed periodically 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.

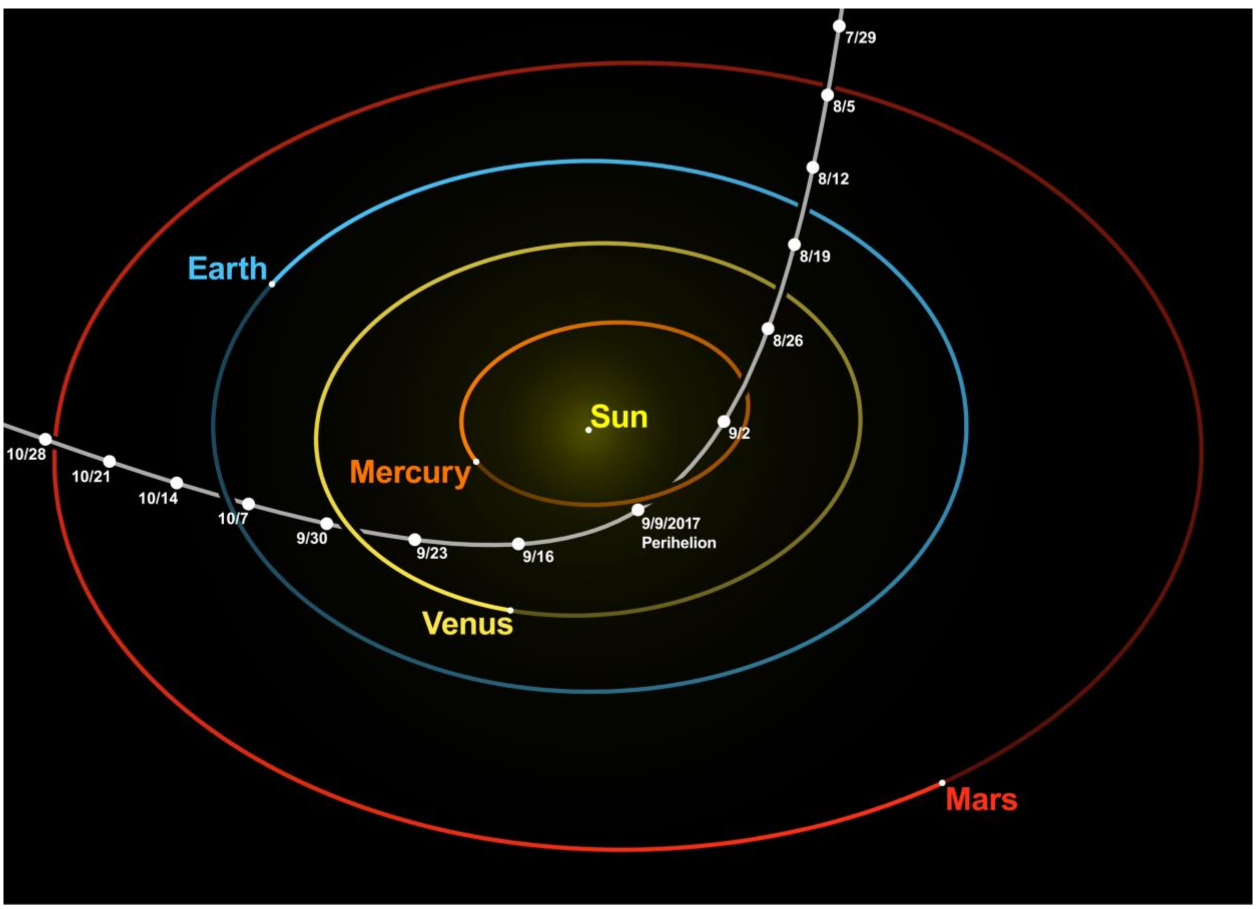

Figure 5: Trajectory of `Oumuamua through the inner region of the Solar System, dated weekly. The planet positions are fixed at the time of `Oumuamua's closest approach to the Sun (perihelion) on September 9, 2017.

In September 2020, another object[11] 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[12]. 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.

I.2 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[13-14] - which is unlikely to maintain its integrity after being heated to hundreds of degrees by the Sun;

(ii) fragments from tidal disruption[15] – whose shape is more likely to be that of a cigar than a disk as inferred for `Oumuamua;

(iii) an iceberg of molecular hydrogen[16] – which evaporates too quickly along its interstellar journey[17] (see Figure 6);

(iv) a nitrogen iceberg chipped off the surface of a planet like Pluto around another star[18] – a mechanism that cannot supply enough material to explain the implied abundance of objects like `Oumuamua[12,19-20] (see Figure 7).

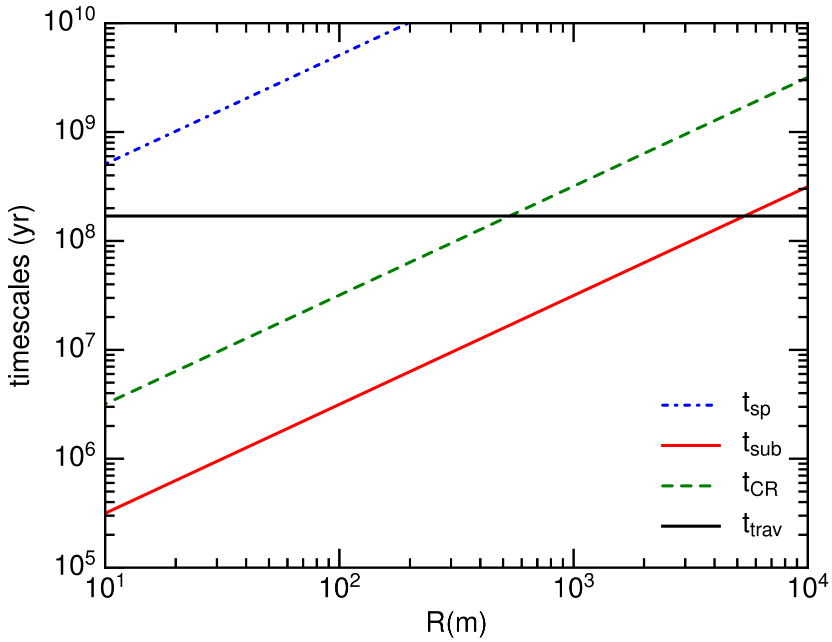

Figure 6: Comparison of various destruction timescales for a hydrogen H_2 iceberg (slanted colored lines) as a function of the object radius (in meters) to the travel time from the likely source of a giant molecular cloud at a distance of 5.2 kpc, assuming a characteristic speed of 30 km s−1 (horizontal black line). (Credit: Ref. 17)

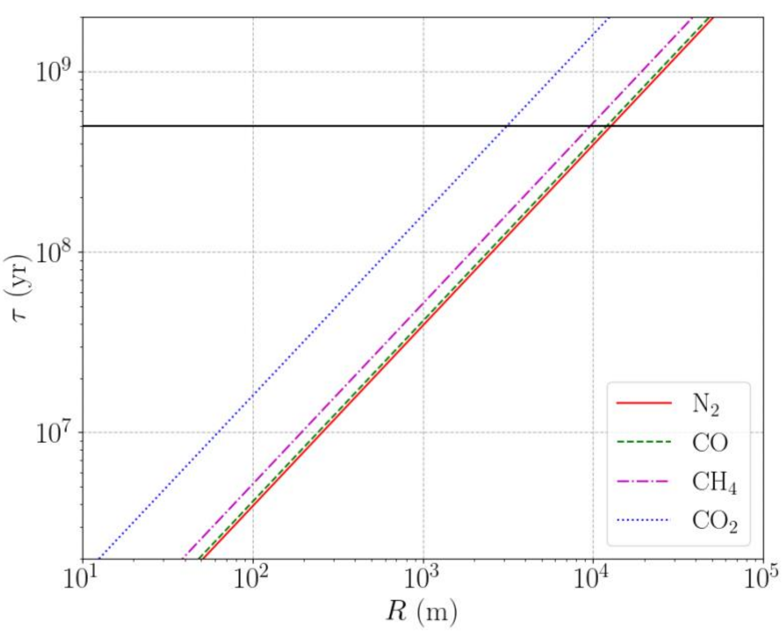

Figure 7: Erosion time by cosmic rays for various types of ices including nitrogen N2 (solid red line), CO (dashed green line), CO2 (dotted blue line), and CH4 (dash-dot magenta line) in comparison with the suggested travel time of ~0.5 Gyr for 'Oumuamua (solid black line). A short travel time, would 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)

I.3 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[3]. 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***[21]. 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[22]. 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[23]. As Galileo Galilei instructed us four centuries ago, the nature of celestial objects must be found through our telescopes rather than philosophical prejudice.

II. The Government's Perspective: Unidentified Aerial Phenomena (UAP)

II.1 The ODNI Report and the new UAP Office

On June 25, 2021, the Office of the Director of National Intelligence (ODNI) delivered a report to Congress about Unidentified Aerial Phenomena (UAP) whose nature is unclear. Six months after the ODNI report, President Biden signed into law — with bipartisan support in Congress — the establishment of a new UAP office. This office, to operate by June 2022, will have the authority to start a coordinated effort of reporting and responding to UAP and significantly improve data-sharing between government agencies on UAP sightings. This new office will be administered jointly between the Secretary of Defense and the Director of National Intelligence, and will empower military and civilian personnel as well as the Intelligence Community to report incidents and information involving UAP.

I was recently asked why the search for extraterrestrial techno-signatures would be of interest to a common person, like a taxi driver worried about paying the rent. Interestingly, the congressional task for the new UAP office involves a science plan that aims to: *"(1) account for characteristics and performance of unidentified aerial phenomena that exceed the known state of the art in science or technology, including in the areas of propulsion, aerodynamic control, signatures, structures, materials, sensors, countermeasures, weapons, electronics, and power generation; and (2) provide the foundation for potential future investments to replicate any such advanced characteristics and performance."* The taxi driver would care about the second item if it would offer an opportunity for a higher paying job in driving a faster transportation device.

II.2 The Galileo Project

A month after the ODNI report, a new scientific research project which I am heading, was announced on July 26, 2021. This so-called *Galileo Project*, pioneers a search for extraterrestrial equipment near Earth. It has two branches: the first aiming to identify the nature of interstellar objects that do not resemble comets or asteroids, like `Oumuamua, and the second to understand UAP similar to those mentioned in the recent ODNI report. The project is supported by generous donations to my research funds at Harvard University.

By now, the Galileo research team includes more than a hundred scientists who plan to assemble the first telescope system on the roof of the Harvard College Observatory in spring 2022. The system will record continuous video and audio of the entire sky in the visible, infrared and radio bands, and track objects of interest. Artificial intelligence algorithms will distinguish birds from drones, airplanes or something else. Once the first system will operate successfully, the *Galileo Project* will make copies of it and distribute them in many geographical locations.

The *Galileo Project* has drawn a remarkable base of expert volunteers, from astrophysicists and other scientific researchers, to hardware and software engineers, to non-science investigators and generalists who volunteer their time and effort to the project in various ways. The project brings together a broad community of members, including believers and skeptics, united by the pursuit of evidence through new telescopes without prejudice. The project values the input of many different voices since its main conclusions will be guided by evidence and not prejudice. The rapid progress it already made is a testament to its open approach. As different as the perspectives of the researchers and affiliates may be, however, *every* contributor to the *Galileo Project* is bound by the following ground rules:

1. The *Galileo Project* is only interested in openly available scientific data and a transparent analysis of it. Thus, classified information, which cannot be shared with all

scientists, cannot be used. Such information would compromise the scope of our scientific research program, which is designed to acquire valid scientific data and provide transparent analysis of this data.

2. The analysis of the data will be based on known physics and will not entertain fringe ideas about extensions to the standard model of physics. The data will be published and available for peer review as well as to the public, when such information is ready to be made available. The scope of the research efforts will always remain in the realm of scientific hypotheses, tested through rigorous data collection and sound analysis.

The Galileo team developed a design of telescope systems optimized for imaging UAP, as well as a blueprint for a space mission to image unusual interstellar objects like `Oumuamua.

The outcome of scientific research cannot be forecasted. Here's hoping that the findings of the *Galileo Project* will be the highlight of the next decade in Astronomy. As Robert Frost noted in his poem "The Road Not Taken":*"Two roads diverged in a yellow wood… I took the one less traveled by, And that has made all the difference."* There is a great advantage to taking the road not taken. If there is any low hanging fruit along that path, the *Galileo Project* will harvest it.

II.3 Looking Down at UAP

UAP are often found by looking up.

But it is also possible to find UAP by looking down, from satellites that image the Earth. For example, *Planet Labs* uses its fleet of 210 CubeSat miniature satellites, called *Doves*, to image the entire Earth once a day with a spatial resolution of a dozen feet per pixel. Planet Labs was founded in a garage, similarly to Google. When speaking with the company leaders, I joked that we need to build more garages in Silicon Valley – not for the purpose of storing cars but to provide cheap space for teams of young innovators.

The *Galileo Project* aims to unravel the nature of UAP. Aside from building ground-based telescope systems, the Project plans to use satellite data in searching for UAP from above.

Artificial Intelligence (AI) algorithms can distinguish extraterrestrial equipment from familiar objects like a meteor, or an atmospheric phenomenon. Since there are no birds, airplanes or lightnings above the Earth's atmosphere, any object with an elevation larger than 50 kilometers would appear highly unusual, as long as it is not a rare meteorite.

The simplest method to address this task was defined by Arthur Conan Doyle in "*The Case-Book of Sherlock Holmes*", where he stated: "*When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth.*" Deduction by elimination is the best way for a cave dweller to conclude that a cell phone is not a shiny rock, based on the device's ability to record voices and images. Similarly, when analyzing new data from telescopes, the AI algorithms of the *Galileo Project* could separate unfamiliar objects from those that are natural - like birds and meteors, or human made – like drones and airplanes. This could be part of a learning experience because: "*Whatever remains, however improbable, must be the truth*."

An artificial object from an extraterrestrial origin can be distinguished from a terrestrial object, not just by resolving unusual bolts or labels imprinted on its hardware but also by noticing unusual behavior while physical markers remain unresolved. Behavioral anomalies include motion at unprecedented speeds or accelerations, not accessible to human-made or natural phenomena, as well as intelligent activity - seeking information or responding to circumstances in ways that cannot be mimicked by familiar objects. We use behavioral traits routinely in our daily life to recognize intelligent people even before engaging with them. The combination of unusual physical and behavioral characteristics could establish the case for extraterrestrial technological equipment beyond a reasonable doubt.

Once extraterrestrial equipment is identified, the main challenge shifts to figuring out its purpose. Knowing the intent of visitors to our home is of upmost importance in guiding us how to engage with them. An encounter with an extraterrestrial visitor could be easily misinterpreted, as in the *Trojan horse* story of Greek mythology, especially if the guest's AI system is far more advanced than our natural intelligence.

The extraterrestrial hardware may take advantage of the physical reality that goes beyond our current scientific understanding. This would be natural if the object was manufactured by a scientific culture whose scientific knowledge base was far more advanced than our century-old understanding of quantum mechanics and gravity.

We are confident that our understanding of the universe is incomplete, because we label two of its most abundant constituents as "dark matter" and "dark energy", for lack of a better knowledge of their nature. We only know that dark matter induces attractive gravity like the ordinary matter we find on Earth, whereas dark energy induces repulsive gravity - triggering the accelerated expansion of the Universe.

If an extraterrestrial technological civilization was able to harness these unknown but most abundant cosmic constituents to fuel the propulsion of its engineered vehicles, the *Galileo Project* telescopes would not detect the standard exhaust plumes that usually surround human-made crafts.

The known laws of physics and mathematics must apply to all technological civilizations that ever existed in the 13.8 billion years since the Big Bang. Nevertheless, there might still be propulsion and communication capabilities beyond our imagination, consistent with our current knowledge. In that case, an encounter with extraterrestrial equipment will educate us about nature itself and not just about the existence of other civilizations beyond ours. The new lesson about nature might be far more important because it will broaden our understanding of the universe at large. The eureka experience would be similar to a cave dweller finding a cell phone and learning about distant landscapes, far beyond those experienced, based on the images stored in the cell phone.

By watching human history, an interstellar committee might decide that there is no evidence for intelligence in the Solar system as of yet. But our AI systems might receive a higher score by having a kinship with their technological relatives, those AI systems produced by extraterrestrials. Here's hoping that our technological kids, namely the AI systems we develop, will do better than humans. In the bigger scheme of the universe, the sky's the limit.

III. Extraordinary Evidence Requires Extraordinary Funding

The *National Defense Authorization Act* specifies the amount of money that the nation allocates to defending itself against the threat from other nations. For *Fiscal Year 2022*, it is 768 billion dollars, a hundred times more than the budget of the largest scientific projects, such as the *Large Hadron Collider* or the *James Webb Space Telescope*. Since these projects took decades and involved multiple nations, one concludes that the monetary priority of defense-related concerns is currently thousands of times higher than the largest science projects that humanity contemplates.

As already mentioned, the *Galileo Project* engages in a scientific search for objects near Earth that might have been artificially produced by an extraterrestrial technological civilization. Lets imagine a situation where one of these telescopes will discover undisputable evidencefor extraterrestrial equipment. This finding would obviously be of great scientific and international importance, not adhering to the borders between nations. As a result, we might realize that we are being childlike in focusing on conflicts among nations while something bigger exists out there.

Now, lets go one step further and imagine that the political system will subsequently change its priorities by realizing that learning about more advanced neighbors on our cosmic block is of higher priority than national security. If a trillion dollar per year wasallocated to learning more about our cosmic neighborhood, what could we do with it?

The first action item would have been to passively observe our cosmic environment with new telescope systems. This effort would constitute a scaled-up version of the *Galileo Project*, using bigger telescope apertures and more observatories around the globe and in space. They would provide us with new scientific information of higher fidelity and quantity, as we look around into space.

The second agenda item would have been to design new space missions that will explore the environment far from Earth. A robot like the *Perseverance Rover* explores the surface of Mars by following orders from engineers at the Jet Propulsion Laboratory in Pasadena. More ambitious space missions could launch autonomous systems, equipment with artificial intelligence (AI) and machine-learning capabilities. With current propulsion technologies, voyages exploring interstellar space - light years beyond the solar system, would take tens of thousands of years to reach their destinations and cannot be guided by timely communication from Earth. Hundreds of billions per year could be spent on developing propulsion, communication, AI and 3D-printing technologies that will be used in these expeditions and then sending numerous probes to explore our cosmic neighborhood and report back. The search for new information will likely accelerate over time. The more we will spend on searching for intelligent neighbors, the more questions our findings might raise.

Finally, we will need to consider societal implications by establishing an organization that will represent Earthlings and by exploring the reorganization of human society on Earth as a result of the broader perspective we gain by retrieving new information about our extraterrestrial neighbors.

The scientific exploration of other technological civilizations in interstellar space will lift our spirit away from the pitiful mud-wrestling on social media and international politics. There might be something bigger out there, and we better learn more about it by changing our priorities.

My bottom line is simple: extraordinary evidence requires extraordinary funding. We could end up investing a trillion dollar per year in what may ultimately matter the most after the Sun will boil off all the oceans on Earth. As Oscar Wilde noted: “we are all in the gutter, but some of us are looking at the stars.”

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Avi Loeb is the head of the Galileo Project, founding director of Harvard University's - Black Hole Initiative, director of the Institute for Theory and Computation at the Harvard-Smithsonian Center for Astrophysics, and the former chair of the astronomy department at Harvard University (2011-2020). He chairs the advisory board for the Breakthrough Starshot project, and is a former member of the President’s Council of Advisors on Science and Technology and a former chair of the Board on Physics and Astronomy of the National Academies. He is the bestselling author of “*Extraterrestrial: The First Sign of Intelligent Life Beyond Earth*” and a co-author of the textbook “*Life in the Cosmos*.”

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