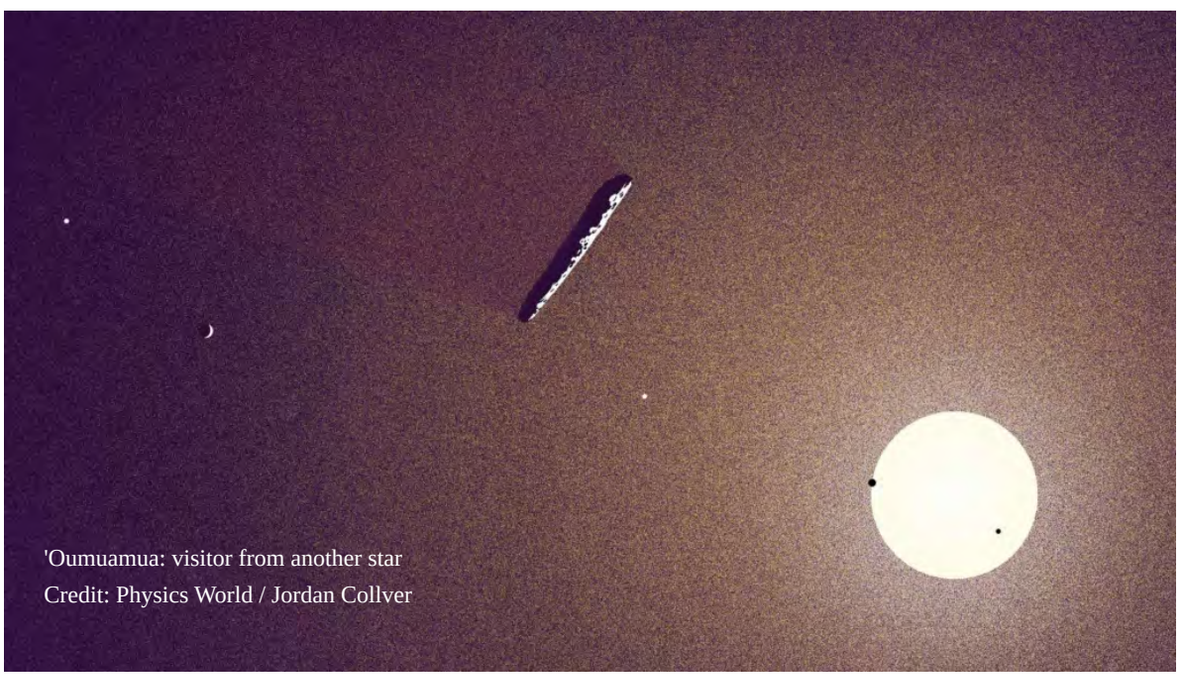
# An Interstellar Visitor:

## sorting the fact from the speculation

Alan Aylward

**Professor Avi Loeb of Harvard University has received both brickbats and bouquets for his widely circulated thinking on the nature of the interstellar object, 1I/'Oumuamua. As Loeb's new book is published, UCL Professor Emeritus Alan Aylward delivers a closely argued contribution to the former. Principium and i4is have no set view on this fascinating object, except perhaps for an enthusiasm for a mission to find out more about it (as in numerous peer-reviewed papers by the i4is Project Lyra team and articles in Principium).**

**Please read on and tell us what you think. We will be reviewing Professor Loeb's book in our next issue.**



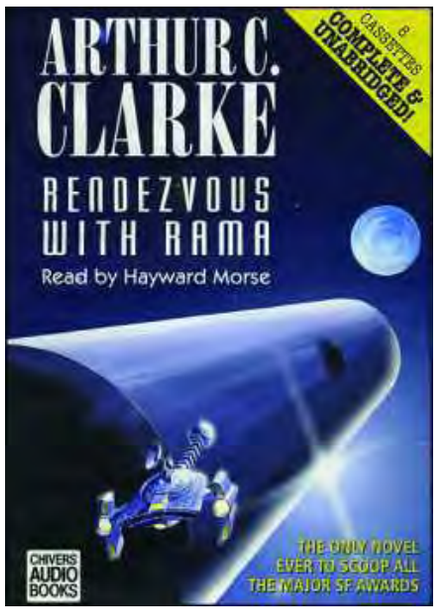
'Oumuamua: visitor from another star
Credit: Physics World / Jordan Collver

There is an unfortunate tendency in some quarters when a new, interesting phenomenon is discovered to jump to far-fetched conclusions before a proper analysis gives us the realistic explanation. I am sure that Bell and Hewish have had much time to wonder whether it was a good idea to have written LGM (Little Green Men) on the paper roll when their radio astronomy experiment detected the first pulsar, giving as it did carte blanche to an array of over-imaginative observers to take that at face value. Percival Lowell spent many fruitless years trying to convince his fellow astronomers that the straight lines he claimed to see on Mars must be the sign of a significant civilization. There were believers in Martian “Canals” right up until the time of the Mariner missions which finally showed the true face of the planet close up. Strange rock formations caught in the right light orientation on the Moon or Mars attract the imaginative into seeing alien faces or other artefacts. Even the great and good tend to sometimes drift into theories they should not have. Fred Hoyle’s illustrious career was somewhat bruised by later work he did with Wickramasinghe where he claimed sudden outbreaks of disease across the world could be explained by alien microbes brought to earth with cometary


Lowell's Mars - with canals - Credit: National Martime Musuem www.rmg.co.uk/

infall. And how many remember the alien spacecraft from Epsilon Boötis transmitting to Earth as an explanation for LDEs (Long Delayed Echoes)? Astronomical phenomena seem to especially set themselves up as targets for wishful thinking. The great difference in albedo between two sides of Iapetus was long a science fantasist's play script until we actually had pictures of the moon.

The latest, previously highly-regarded scientist to dip his toe into speculative fiction is Avi (Abraham) Loeb, an astronomer from Harvard. He has become the delight of the fringe (and not-so-fringe) science scene in the last couple of years for his work on 'Oumuamua, the interstellar object seen passing through the solar system in October 2017. 'Oumuamua was certainly a revelation when it was first discovered. The first object known that was definitely on an interstellar hyperbolic trajectory, it had entered the solar system gravitational well with 26 km/s excess velocity from the direction of Lyra and it had a complex light curve that showed a 15:1 variation in brightness. The best explanation for that was that it was a highly elongated object, maybe cigar-shaped with a length 6 times its narrowest dimension, and it was spinning and coning in a semi-chaotic rotation. The interest grew even further as more detailed analysis of its trajectory showed it seemed to be accelerating slightly as it left the solar system. Despite the fact that such acceleration was not entirely unknown for small asteroids and comets this lead to some heated speculation as to its origins, no doubt fed to some extent by memory of Arthur C Clarke's sci-fi novel "Rendezvous with Rama". Without a close-up inspection of the object – by now well out of detector range – the detailed nature of it was going to take a lot of theoretical and interpretive science, if indeed it could be done at all.



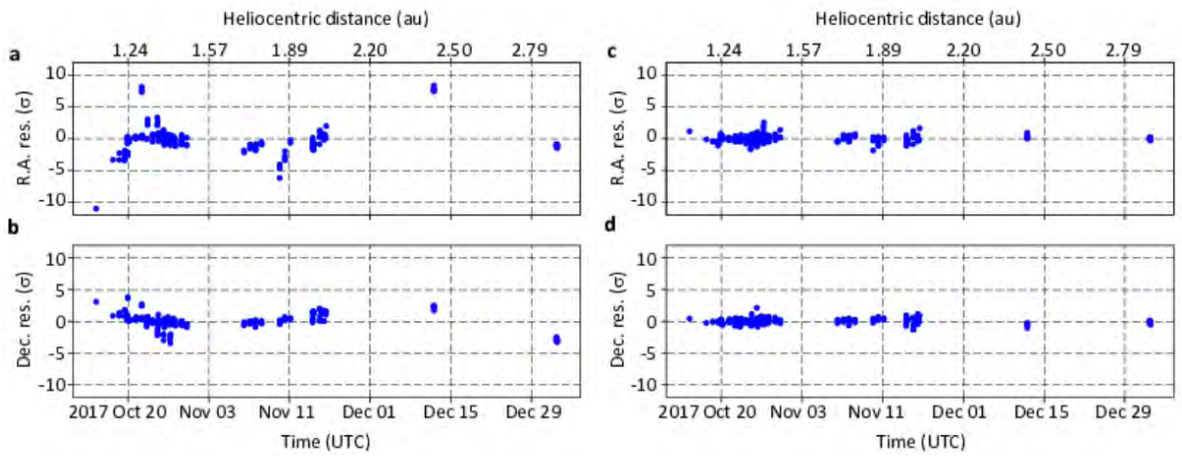

Audiobook cover of *Rendezvous with Rama*, see also *Sir Arthur C Clarke Centenary Celebrations, Thoughts on a mighty imagination and his envisaged interstellar object* by Patrick Mahon, Principium 20 February 2018.

There have been a number of papers on 'Oumuamua - a surprisingly large number considering how restricted were the observations of it, but an indication of how novel it was to have an interstellar visitor of this type. It was found by the Pan-STARRS1 survey telescope after the body had already passed perihelion and its nearest point to Earth. Because it was moving so fast and turned out to be quite small the observations that could be made were limited, but it was seen to be such an important discovery that it was observed by the ESA OGS (Optical Ground Station), CFHT (Canada France Hawaii Telescope), ESO's VLT (Very Large Telescope) and Gemini South, the latter two being 8-metre telescopes. It was also in its latter stages seen by HST (Hubble), including the final images taken in January 2018 when it became too faint to follow further.

Authors from a number of institutions lead by Marco Micheli at ESA produced a fairly comprehensive summary of the results in June 2018 concentrating on the non-gravitational acceleration ("Non-gravitational acceleration in the trajectory of 1I/2017 U1 ('Oumuamua)", Micheli et al, Nature [1]).

Their abstract summed up their findings: "After ruling out solar-radiation pressure, drag- and friction-like forces, interaction with solar wind for a highly magnetized object, and geometric effects originating from 'Oumuamua potentially being composed of several spatially separated bodies or having a pronounced offset between its photocentre and centre of mass, we find comet-like outgassing to be a physically viable explanation, provided that 'Oumuamua has thermal properties similar to comets." Although early observations had ruled out the object being a comet because they had failed to see a (visible) coma the paper said a lack of observation of what was probably water outgassing moving the body was not surprising as the acceleration seen was so low the amount of water vapour would have been below the spectroscopic detection discrimination level of even the most powerful telescopes used. There was one unusual aspect to this, which was that no CN was detected, which would have meant the CN/OH ratio in the outgassing would have been very low (a factor of 15 below solar system abundances). Also, no dust had been detected as might have been expected around the body. These do not comprise "killer" reasons for ruling out outgassing

[1] Micheli, M, Farnocchia, D, Meech, K J et al. *Non-gravitational acceleration in the trajectory of 1I/2017 U1 ('Oumuamua).* Nature 559, 223–226 (2018). Open publication: www.researchgate.net/profile/Harald_Ebeling/publication/326018112_Non-gravitational_acceleration_in_the_trajectory_of_1I2017_U1_'Oumuamua/links/5b4860a645851519b4b4a312/Non-gravitational-acceleration-in-the-trajectory-of-1I-2017-U1-Oumuamua.pdf




Micheli et al achieved a good inverse square law fit for the anomalous acceleration of 1I/'Oumuamua see -
*Astrometric residuals of 'Oumuamua observations.*
*a, b: normalized right ascension and declination residuals against a gravity-only solution.*
*c, d: normalized right ascension and declination residuals against a solution that includes a non-gravitational radial acceleration* $A_1 f^{-2}$
Credit (image and *caption*): Micheli et al fig 2

as the motive force for the body as the low CN/OH ratio is not entirely unknown even in solar system bodies, and if the dust released by the outgassing had been grains larger than a few hundred micrometres they would not have been detected at optical wavelengths anyway.

Some calculations by Micheli et al using a thermal outgassing model treating 'Oumuamua as a "typical" cometary nucleus showed that a relatively small outgassing from the subsolar point of the body was enough to explain the acceleration, and the best fit to the orbit perturbation was a force directed from the Sun radially outward and falling off as $r^{-2}$ or $r^{-1}$ as would be expected for a solar-heated release of gas from at or near the surface. Thus they conclude 'Oumuamua behaves like a miniature comet, which is consistent with the surface colour and albedo. It would have a thin insulating mantle, and slightly unusual chemical composition and dust properties, although how significant this might be was difficult to say without knowing its origin. One should stress that although there were at least 177 ground-based measurements and 30 HST observations, this was a faint and difficult to characterize body and a lot of advanced processing techniques went into the analysis, so there is some uncertainty in nearly all the parameters recovered. On the acceleration side they could rule out an impulsive acceleration - the best fit was for continuous acceleration, falling with distance, directed more or less along the sun-object line (some transverse and normal forces could make a modest improvement to the fit, but the significance was less than 1-sigma).

Following the Micheli et al paper there were a number of follow-up publications concentrating on what were considered to be inconsistencies and the unusual characteristics of the body, largely based on the differences inferred between this and "normal" solar system bodies and on the peculiar shape and dynamic behaviour of the body. It is certainly true that no bodies of this shape were known to date in the solar system. The best fit to the light curve was of a long thin body rotating to show a main 4.3 hour power maximum (assumed to be half the spin period) but with irregular flux variations, with a max/min variation of a factor of 15, which could be explained by positing an elongated shape experiencing complex non-principal axis rotation. One should note that these are noisy irregular observations and that the solution for the motion is not unique. You can get different geometries and different dynamics by, for example, having a variation of reflectivity across the surface and non-uniform structure. The accepted shape that one sees in all the popular depictions of the body is only the current best estimate of what fits the light curve - but that's not totally unique as a solution.

Soon several groups tried to find alternative explanations for what we were seeing. Seligman, Laughlin and Batygin in May 2019 produced a paper [1], which described some modelling they did to see if the Micheli et al conclusions stacked up. They created a dynamic model of the body, based on the preferred shape, assuming a nozzle-like venting of volatiles tracking the subsolar point on the body. They produced a light curve of what their model would look like to observers and concluded they could produce something that looked very close to the data obtained. They concluded the body would lose about 10% of its mass in the 100 days it was nearest the sun. Their model ellipse was 260 metres long and had an albedo of 0.1, both of which were consistent with observations. A perfect fit was not possible, as would be expected because of the uncertainties in the observations and the lack of detailed knowledge about the body shape.

Despite this sort of work some more esoteric theories started to surface about the origins of ‘Oumuamua. It was such a peculiar shape - long and thin - that maybe it was an alien spacecraft. Could it be a probe sent to gather information about our solar system? Or a failed interstellar probe that hadn’t stopped or changed course correctly when it got to its target? Why, if it was “live” did it produce the weak and ineffective acceleration that it did? The strange semi-chaotic motion would suggest that if it was a probe, its attitude control systems were rather compromised. There was some speculation about where it might have come from. It was difficult to pin-point an origin because of the uncertainty in accumulated acceleration (we know nothing of any changes that took place prior to perihelion and passing Earth). There was nothing unusual about its arrival velocity if it was “natural” as 26 km/s was about the average for the dispersion in the local galactic area. Nor was the direction of origin particularly surprising. It was mainly the unusual shape which drove the more bizarre speculation. If this was a body that was self-compacted by gravitational forces alone why did it not tear itself apart as it spun? Some groups carried out radio observations to see if it was transmitting but nothing was detected.

To address some of the speculation a group of scientists under the auspices of ISSI the International Space Science Institute (www.issibern.ch), produced a paper in Nature Astronomy in July 2019, “The Natural History of ‘Oumuamua” [2]. Recognising the limitations on the observations they conclude "the observations are consistent with a purely natural origin for 'Oumuamua". They point out that even the shape is uncertain since how the shape is interpreted depends on the specific state of rotation, including its rotation pole. It could either have a narrow elongated ellipsoid shape, or a shape more reminiscent of a flattened oval. It is almost certainly unusual, but there is nothing certain about the popular representations in the press.

The paper spent a lot of time examining criticisms of the detection based on claims the chances of a detection of a natural object were small (ie so it couldn’t be “natural”). This came down to a scientific evaluation of how many such small objects should exist in interstellar space. The ISSI team pointed out that speculation on the statistics of probabilities of things based on only one sample was poor science (we have since found a second interstellar incursor, 2I/Borisov in October 2019, so things are looking up!). The estimates of how many you expect to see are dependent on the population’s SFD (Size-Frequency Distribution) but this is almost entirely guesswork based on models of the creation mechanisms for non-solar-system bodies. Estimates can be made based on theories of production by, for example, ejection of material from stellar formation regions by Gas Giants in those systems, but all one can really say is that there is nothing in the order of magnitude estimate one gets of creation probability that rules out getting bodies entering the solar system in observable timescales.

[1] *On the Anomalous Acceleration of 1I/2017 U1 'Oumuamua*, Darryl Seligman, Gregory Laughlin and Konstantin Batygin, The Astrophysical Journal Letters, Volume 876, Number 2, May 2019 iopscience.iop.org/article/10.3847/2041-8213/ab0bb5/meta

[2] *The natural history of ‘Oumuamua*. Nature Astronomy, 3 (7). pp. 594-602. Michele T. Bannister (Astrophysics Research Centre, Queen’s University Belfast) et al. Open publication: authors.library.caltech.edu/97422/2/1907.01910.pdf

The ISSI team look at the outgassing needed to produce the acceleration seen and agree with previous work that says the Seligman et al estimates are feasible. The outgassing estimate is consistent with solar system comets of this size. And to quote: “Furthermore, when the Rosetta observations of comet 67P/Churyumov–Gerasimenko (made at comparable heliocentric distances to when ‘Oumuamua was observed) are scaled down to an ‘Oumuamua-sized object, they yield a similar outgassing rate.” They also agree with the previous comments about the lack of observation of dust not being surprising, and that the 15 times depletion in CN from the “expected” was not so far out either -in fact factors of 25 and 72 had been found in previous comets. And “The range of these ratios of volatiles in comets has recently been found to be far greater than was previously known: C/2016 R2 PanSTARRS has CO/H2O at least several orders of magnitude higher than any other measured comet, with no H2O yet conclusively detected.” So ‘Oumuamua gets to look less “special” at every turn.

The paper takes on the alien spacecraft proposition directly. By this point Avi Loeb and others had been suggesting the small acceleration could be consistent with a “solar sail” using solar radiation pressure. The ISSI team comprehensively discount this. While it fits some of the observations like the fact the body may have had a highly flattened shape, other key aspects do not fit the observations and some arguments in favour of this hypothesis are simply wrong. The key argument against is that a solar sail would have to be properly oriented with respect to the sun, but this does not fit with the observed brightness variations. It is not possible to find a geometry that can satisfy all the dynamics and observational facts. (And, they claim, in fact the best solution for the shape is an elongated ellipsoid anyway.) Other arguments about disparities in the body’s albedo and trajectory they also comprehensively dismiss. Some of the sceptics of the received version of the dynamics had produced modelling to question why the outgassing had not produced a change in the spin characteristics over the times of the observations but this has been countered by other modelling that shows the proposed accelerating jet would naturally result in NPA (non-principal axis) rotation with a light-curve amplitude and period comparable to the observations, without causing extreme spin up [1].

Despite these works all showing that the body’s characteristics could be explained by “standard” physics, a number of authors continued to question aspects of this. What about the structural integrity of such an elongated body? There were questions about the origins of the body, and some doubt cast on the acceleration mechanism seen. One more fact-based cause of concern was suggested first by Sekanina in 2019 who calculated that if the acceleration was being driven by the sublimation of $H^2O$ ice then there was insufficient solar energy input to release it and accelerate it to the velocity that would provide the force needed. This was taken up by Seligman and Laughlin [2] who suggested that the accelerating medium was hydrogen rather than water. (There had been a suggestion in 2018 by other authors that ‘Oumuamua was partially composed of hydrogen ice.) Seligman and Laughlin built up a case that the body was composed wholly or partly of hydrogen ice and they did some detailed modelling of sublimation from geometries similar to the putative shape of ‘Oumuamua to show that the acceleration is possible.  They pointed out that Hydrogen outgassing also explained why no coma had been seen around the body – hydrogen would not show one visibly.

They realised however that the biggest criticism of this model would likely be how to create a hydrogen ice body in the first instance. They suggested interstellar environments where this could have happened, though it is difficult to form hydrogen ice in most circumstances. Of course, the assumptions here can anyway be questioned. There are other possible accelerants that have lower sublimation energies than water - like Nitrogen and Neon. Also the Seligman and Laughlin paper seems to assume the same acceleration has been occurring over the full incoming trajectory, whereas it seems possible that the incoming leg could have produced heating with little release of material until the temperature in the surface layer built up enough for the outgassing needed to produce the acceleration seen on the outbound trajectory. The doubts about water supplying the acceleration also seems somewhat at odds with the statements in other papers that the outgassing from ‘Oumuamua is consistent with what is seen in solar system comets.

[1] See references in Bannister et al - 83 Rafikov (sceptic) and 64 Seligman et al (response) - open publication version - *The natural history of ‘Oumuamua*, Open publication: authors.library.caltech.edu/97422/2/1907.01910.pdf.

[2] *Evidence that 1I/2017 U1 (‘Oumuamua) was Composed of Molecular Hydrogen Ice*, Darryl Seligman and Gregory Laughlin. Astrophys J., June 2020). Open publication: arxiv.org/abs/2005.12932

The Seligman and Laughlin paper was fairly quickly criticised by Hoang and Loeb who attack not the acceleration mechanism but the possible existence of a body composed mainly of hydrogen ice. They do this on two bases. First they question whether icy grains rich in $H^2$ can form in dense environments because collisional heating destroys the $H^2$ mantle before grain growth. Secondly in travelling from the creation site - assumed to be GMCs (Giant Molecular Clouds) - the energy encountered in interstellar radiation, gas, dust and cosmic rays would destroy any small body within the time span required to reach the solar system. Their paper details the calculations to support their criticisms and basically boils down to an estimate of how long a hydrogen ice body would survive in interstellar space. Of course the survival time depends on the size of the body but they claim that a typical body entirely made of hydrogen ice would not last.

Seligman agrees that a hydrogen ice body would not survive the journey time from the nearest GMCs, but points out that there are nearby star-forming regions (like the hydrogen left from the Carin and Columba moving groups of stars formed 30-40 million years ago) that are believable creation sites near enough for ‘Oumuamua to have survived the journey to the solar system. Loeb is adamant that the actual formation of hydrogen ice bodies itself is out of the question wherever one may choose - though he hedges his bets by saying if they were made it could only be in GMCs. It is Avi Loeb from the Hoang and Loeb paper who has been particularly promoting these arguments especially because he wants to promote his own ideas about ‘Oumuamua.

This gets us back to where we started and the promulgation of fanciful ideas about the origin of ‘Oumuamua - an article in Scientific American in January 2021 that describes the arguments between Seligman and Loeb points out that Loeb has a vested interest in getting the classical explanation of ‘Oumuamua’s origins questioned - he has a book coming out called *Extraterrestrial: the First Sign of Intelligent Life Beyond Earth*. Loeb is in full promotional mode. The Observer of Sunday 31 January has an article about Loeb and his theories. Because he is a Harvard astrophysicist it takes his ideas seriously and gives him rein amongst other things to criticise Seligman’s ideas again, claiming that he, Loeb, is a misunderstood unconventional thinker that the scientific community cannot understand because they are too blinkered. He is careful not to leave himself too open to possible future ridicule if his ideas are debunked by saying: “I’m not arguing for sure that it was an artificial object. I’m saying it’s a reasonable plausibility based on the evidence”.

**Principium 23- November 2018**

***What is Oumuamua?***

***The Loeb/Bialy Conjecture and i4is Project Lyra***


Front cover of Principium 23 - visualisation of a possible explanation of 'Oumuamua "Wrecked Solar Sail" by Alex Storer - introducing *NEWS FEATURE* -

*What is Oumuamua? The Loeb/Bialy Conjecture and i4is Project Lyra,*

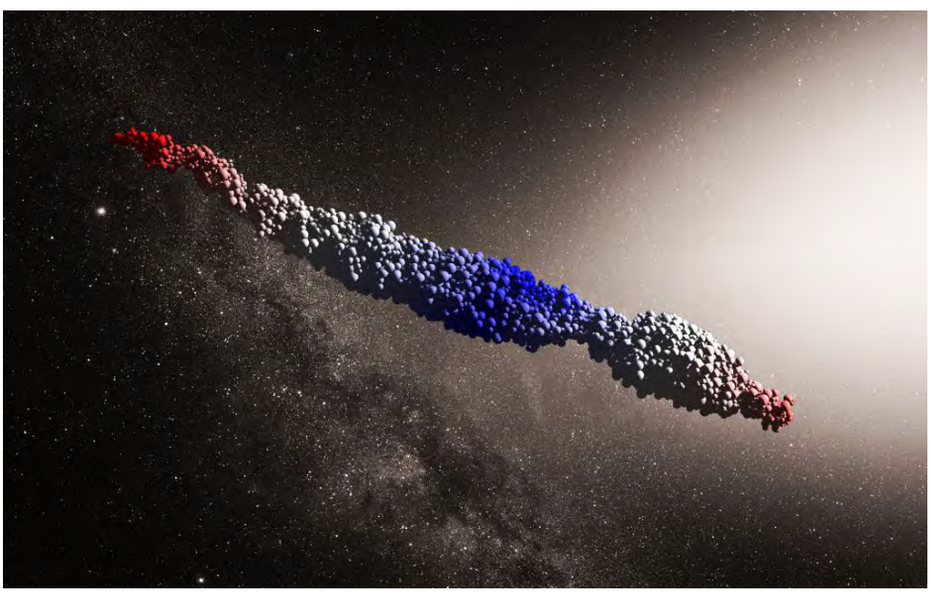
John I Davies

A more destructive criticism of Loeb and his intercession here is by Etan Siegel in Science, Jan 28 2021 [1]. He sees Loeb on a personal publicity campaign. “For the better part of the past four years, Harvard astronomer Avi Loeb has appeared all over the media to gather public support for an idea that absolutely defies the scientific evidence.” Siegel points out that Loeb is connected to the Breakthrough Starshot project, and complains that Loeb has been bombarding journalists for the last 4 years with attempts to get his ideas circulated, while claiming he has no personal wish for fame or recognition. Siegel sums his view up with:

> “Loeb…has written papers with his postdocs and students insisting that ‘Oumuamua is just as likely to be an alien spacecraft (that looks suspiciously like a light-sail) as it is to be one of the expected ~$10^{25}$ naturally occurring objects in our own galaxy. Despite the fact that the spectral signatures of the object — its color, reflectivity, size, etc. — are consistent with a natural origin, Loeb offers only loud, immodest speculation about aliens and diatribes about community groupthink.”

[1] The Uncensored Guide To ‘Oumuamua, Aliens, And That Harvard Astronomer, Ethan Siegel. open version www.forbes.com/sites/startswithabang/2021/01/28/the-uncensored-guide-to-oumuamua-aliens-and-that-harvard-astronomer/?sh=3cac5adf6abe

One recent addition to the canon of work on ‘Oumuamua has perhaps finally laid to rest the more fanciful queries about its characteristics. Zhang and Linn in Nature Astronomy Sept 2020 [1] have modelled a mechanism which can easily explain all the “peculiarities” of the body. They infer that the progenitors of ‘Oumuamua-like ISOs may be kilometre-sized long-period comets from Oort clouds, kilometre-sized residual planetesimals from debris disks or planet-sized bodies at a few astronomical units, orbiting around low-mass main-sequence stars or white dwarfs. The precursor bodies can be “standard” rock-pile bodies. The disturbing body drags these apart gravitationally – similar to what happened to Shoemaker-Levy 9 as it passed too close to Jupiter. Unlike Shoemaker-Levy 9 the elongated body can escape the disruptor, though heated to the extent that most of the volatiles except some deep-buried water and carbon dioxide are evaporated. As it leaves the disruptor, kicked into an interstellar trajectory, the body cools and forms a hard shell strong enough to hold it together despite any wild dynamical motion the ejection from the disruptor has brought about. So we have a long thin body, rigid though possibly rotating chaotically, depleted in most volatiles like CN. As it enters the solar system it heats up and residual water buried deep in the body reaches the surface by the time it passes perihelion and starts to outgas – accelerating it slightly. The arguments about how unlikely it is to have such bodies are answered by the fact the authors provide three mechanisms by which they can come about. They predict we will eventually find many more of them.



Model of rotating 'Oumuamua, colour coded to represent bulk rotation

Credit: Zhang and Linn

Is that it then, proven/disproven? Maybe, maybe not, but the mere fact one can find a realistic mechanism to explain what we have seen should show that one needs to look at viable physical explanations before we get overly fantastical.

Of course there may be no bad thing about a bit of speculation in science and society but the question is how much are we promulgating bad science by producing unfounded speculation where there is a fairly prosaic explanation for something. If we see a corn circle in a field do we still consider it might be made by aliens even after the people who made it tell us they did it? If we can explain the ticks on a roll of chart paper by the signals from a pulsar should we still be saying "of course you never know - it may be Little Green Men"?

[1] Zhang, Y., Lin, D.N.C. *Tidal fragmentation as the origin of 1I/2017 U1 (‘Oumuamua)*. Nat Astron 4, 852–860 (2020).
Open publication: arxiv.org/abs/2004.07218

## About The Author

Alan Aylward is Emeritus Professor of Atmospheric Physics in the Department of Physics & Astronomy at University College London. His main work was in ionospheric research, thermospheric research and modelling of the earth's thermosphere and ionosphere moving on to modelling of planetary thermosphere/ionospheres (Mars,Titan, Jupiter and Saturn) and later modelling of exoplanet atmospheres. He also has substantial experience in spacecraft technology and software development.