OUR FIRST INTERSTELLAR VISITOR; THE BIZARRE 1L/2017 U1 = OUMUAMUA

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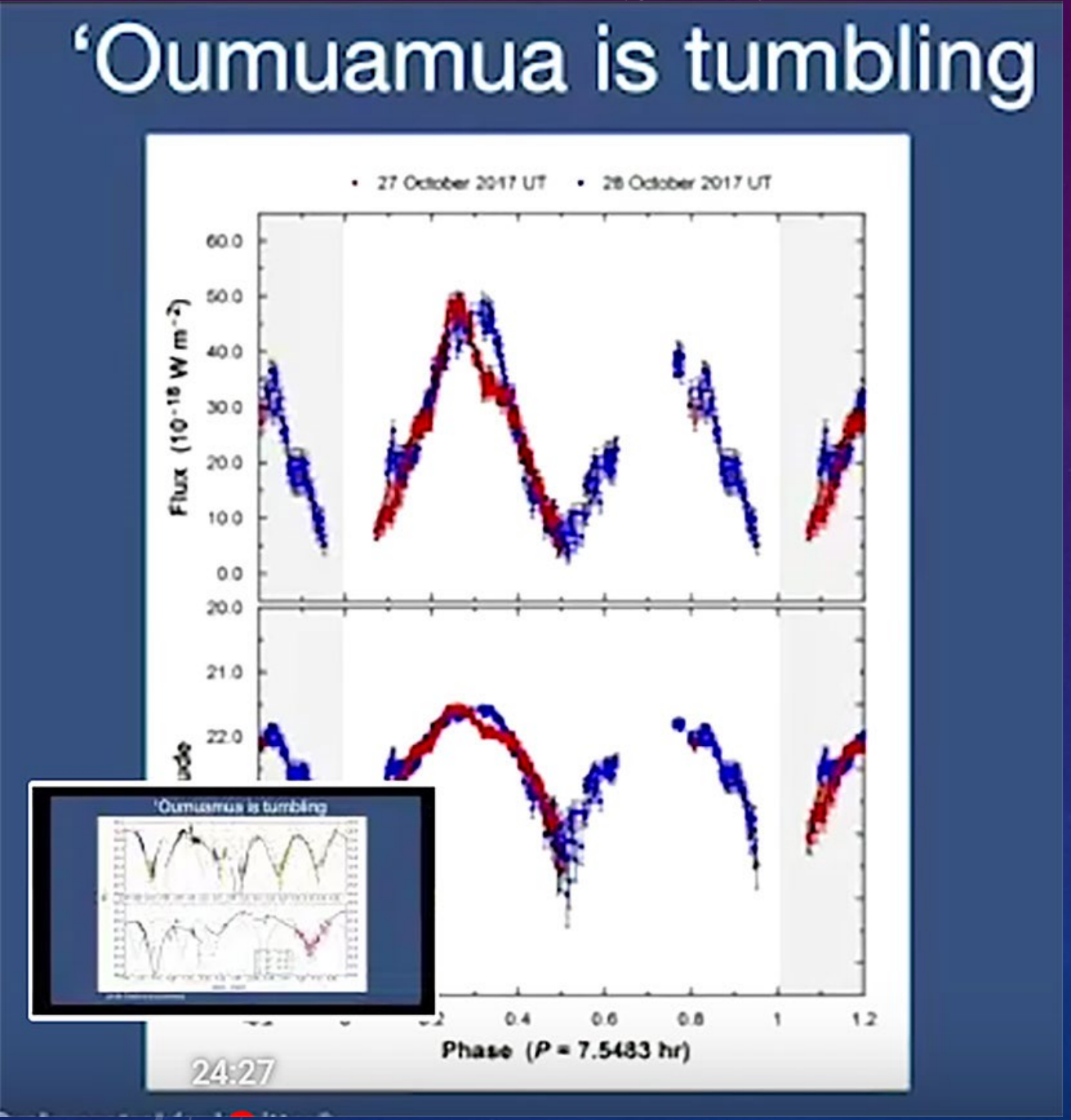
ON OCT 19, 2017, THE PANSTARRS TELESCOPE (SURVEY SCOPE) SPOTTED A FAINT OBJECT MOVING RAPIDLY ACROSS THE STELLAR BACKGROUND

- Its velocity and position allowed an orbit to be calculated, and it was found to be moving significantly faster than if it were gravitationally bound to the solar system. Its orbital eccentricity is 1.20; hyperbolic, far bigger than the 0.999 for a barely bound ellipse. It's unbounded from the solar system and was moving fast…
- Indeed, faster than could be accounted for by any plausible "kick" it could have gotten by gravity from other objects on its journey in from the Kuiper Belt or Oort Cloud, if that were the case.
- It was identified quickly as a true interstellar visitor. Our first ever detected, and immediately ~all big telescopes were commandeered to use all their instruments to learn as much as we could, while we could.
- It was christened "Oumuamua", which means "Scout" or "First distant messenger". (Hmmm. Is the Mother Ship on its way??)



ITS PROPERTIES WERE UNLIKE ANYTHING WE'D EVER SEEN, AND NOT AT ALL CONSISTENT WITH WHAT WE EXPECTED. WHAT WE EXPECTED AS OUR FIRST VISITOR WAS AN OORT-CLOUD LIKE COMET. NOT WHAT WE GOT!

ONE THEORY WHICH CAN'T BE EASILY DISMISSED, IS THAT FROM HARVARD ASTROPHYSICIST ABRAHAM LOEB…

- … that Oumuamua is perhaps a non-functioning stellar "sail" ship from an alien civilization. Itsobserved properties would then be easier to explain. As a natural object, its properties become rather difficult to explain.
- Let's examine this ….

SO WHAT IS IT?

- There's no explanation that's a "slam dunk" high probability answer – as Yale's Professor Greg Laughlin expresses it, and after reviewing what is not behind a pay-wall, I agree.
- It's like nothing we've ever seen in our solar system, and all explanations require stretching "the known" to a rather striking extent.
- Let's weigh and consider the hypotheses which have been advanced up until now.

STARS ARE DOZENS TO THOUSANDS OF LIGHT YEARS AWAY. AND ONE SINGLE LIGHT YEAR IS 6 THOUSAND BILLION MILES

- There's a LOT of empty space out there. Matija Cuk interviewed here, is skeptical of the interstellar alien probe theory.
- Occam's Razor leads first speculations to being a strange comet and then assumes it is highly reflective and therefore can be small; about 100-300m wide, and be consistent with its brightness.
- If rock or metal, and darker, then it must be larger to permit the observed brightness. But, if it's more than 500m, then its thermal radiation should have been detected by the Spitzer Telescope, which saw none.

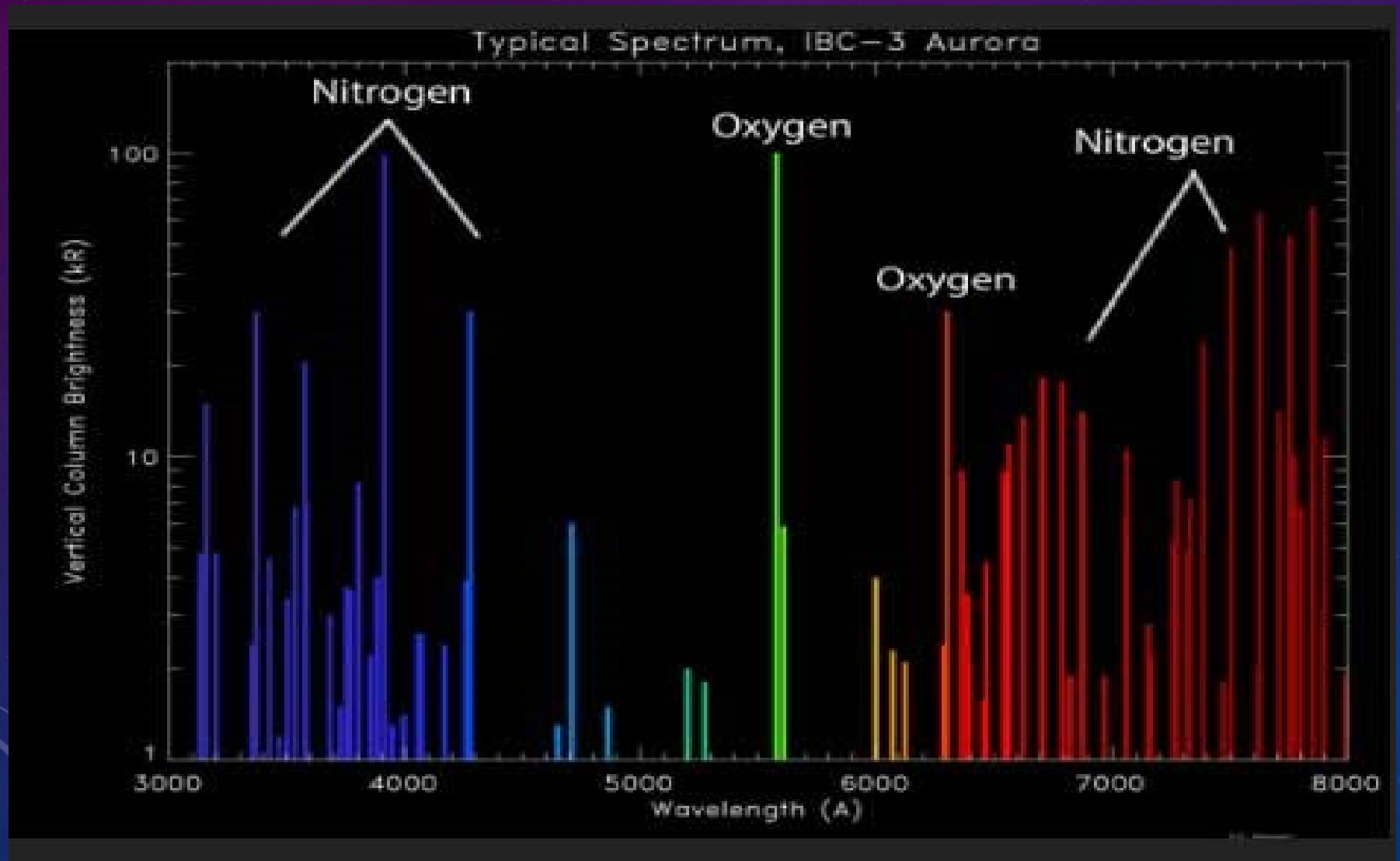
THERE MUST BE ABOUT 10^{16} OF THESE GENERATED PER STELLAR SYSTEM IF THEY'RE NATURAL OBJECTS NOT OF ALIEN DESIGN. THAT'S A LOT…

- Why? You need this many to make plausible how soon after PanSTARRs was operational – just 7 years after the first science operations - that it found a clearly interstellar object, given its size and how close it came to Earth.
- We'll do that calculation soon.

JACKSON AND DESCH, (2021 AND NOW PUBLICLY HERE) HAVE A HOT-OFF-THE-PRESSES PAPER SUGGESTING OUMUAMUA IS A PURE NITROGEN ICE N_2 FRAGMENT FROM IMPACTS ON "PLUTO-LIKE" OBJECTS. THIS IS LIKELY OUR BEST THEORY TO DATE. WE'LL RETURN TO THIS IDEA IN MORE DETAIL LATER.

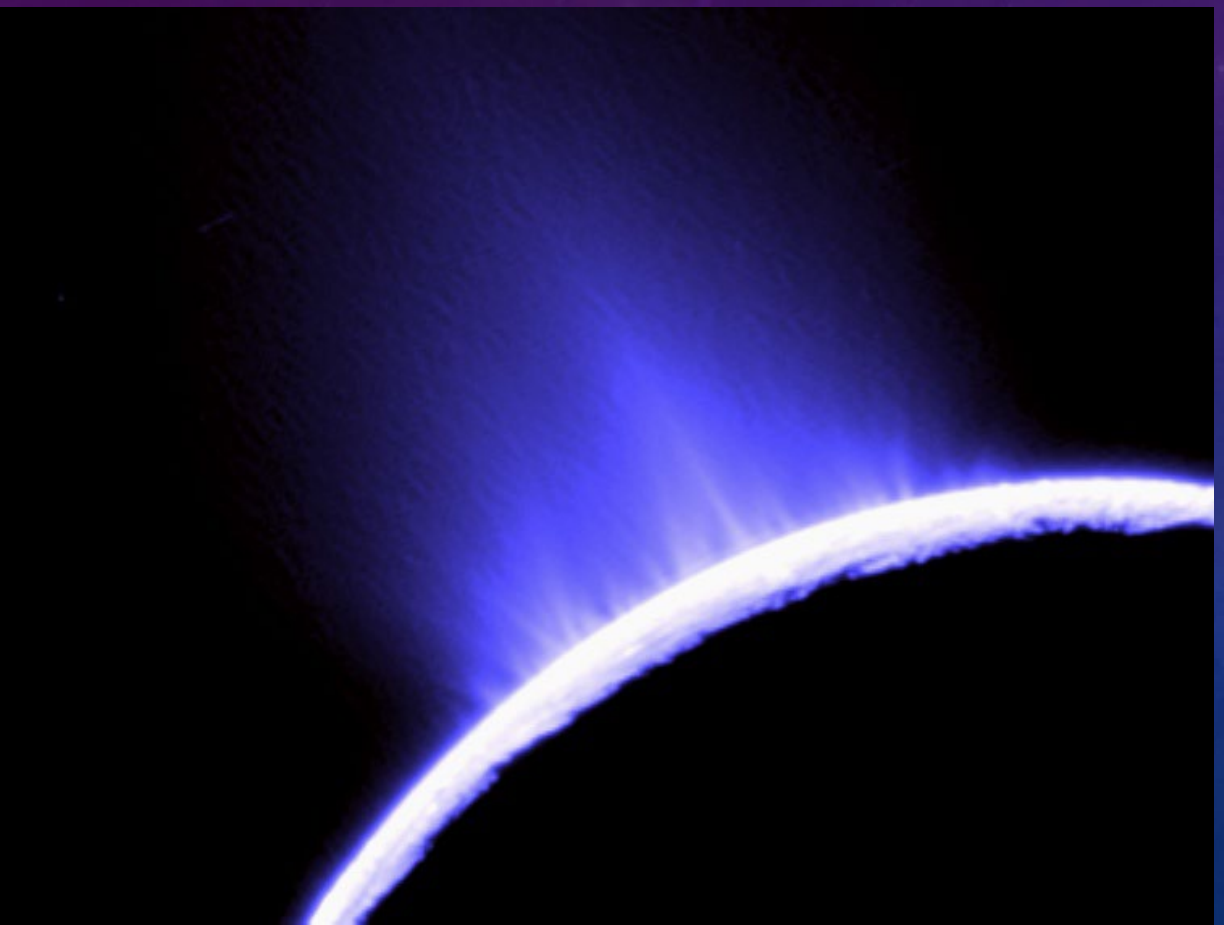
- By hypothesizing impacts, the heating from tidal disruption is avoided nicely.
- But I'd argue - wouldn't N_2 in the vicinity of the sun, where equilibrium temperatures here in the inner solar system where it remained for weeks before we saw it, have caused severe sublimation of most of the mass, and dissociation of the N_2 into atomic N, and then into ionized N II?
- N II is easy to see, as it has emission lines in the blue and red; prime wavelengths where the Spitzer IR telescope observed it (see spectrum here, later). I see no mention anywhere of limits on N II emission lines.

THE SPECTRUM OF AURORA ON EARTH. OUR 80% NITROGEN ATMOSPHERE, IMPACTED BY SOLAR WIND PARTICLES, GENERATES SOME STRONG EMISSION LINES



THE BLUE HERE IS DUE TO NITROGEN, THE GREEN TO OXYGEN. AURORA OVER ALAKSA.

IF OUMUAMUA IS TO BE ONLY 100M ACROSS, THAT REQUIRES IT BE EXTREMELY REFLECTIVE, AS REFLECTIVE AS THE WHITEST OBJECT IN OUR SOLAR SYSTEM. LIKE ENCELADUS



- But Enceladus is reflective because it’s continually repaved with fresh white snow from erupting geysers of water.
- Oumuamua instead had a reddish surface. And just one pulse of heating by the sun, yet retained its red color after solar passage.

A WATER ICE SURFACE IS NOT POSSIBLE. WATER SUBLIMATION IS FAR TOO WEAK TO CAUSE THE OBSERVED ACCELERATION (JACKSON AND DESCH 2021, SEE LATER)

- If it is made of rock or metal, it must be much less reflective, and therefore larger, more like 500+ meters, making acceleration ~impossible to explain if of natural origin.
- The red surface, as red as our deep freeze KBO's, perhaps argues its albedo is more moderate than Enceladus' very high albedo, and therefore also meaning it must be larger. Larger, is problematic.
- The reddish color in our Centaurs and KBO's is attributed to (Brown, *et al.* 2011) methanol and CH_3OH – carbon rich compounds. If true for Oumuamua, says carbon is there…

BUT CARBON-RICH COMPOUNDS ARE ~RULED OUT BY THE LACK OF SPECTRAL CARBON SIGNATURES, AND CARBON GRAINS AS COMETARY DUST TAILS WOULD ALSO BE EASILY VISIBLE BUT AREN'T

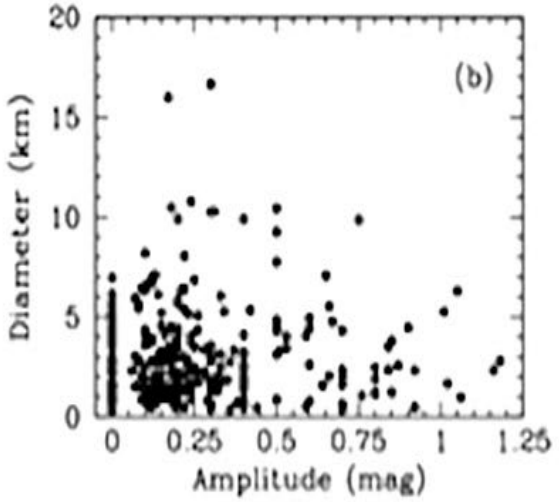
- Very puzzling. So, to begin to try to get a handle on what Oumuamua is, let's back off and first estimate its size and mass, and how it was affected by interstellar space and its passage by the sun.
- If it's less reflective than the very reflective fresh active surfaces of *e.g*. Pluto's shiny spots and Enceladus, then the brightness and distance argue it's roughly 150-250 meters across
- Let's assume a small 200m diameter, to try to minimize the needed masses and not assume extreme reflectivity.
- This is still with the icy idea, with high reflectivity, but yet not the highest albedo of any solar system object.

THE VOLUME AND MASS, IF SPHERICAL WOULD THEN BE…

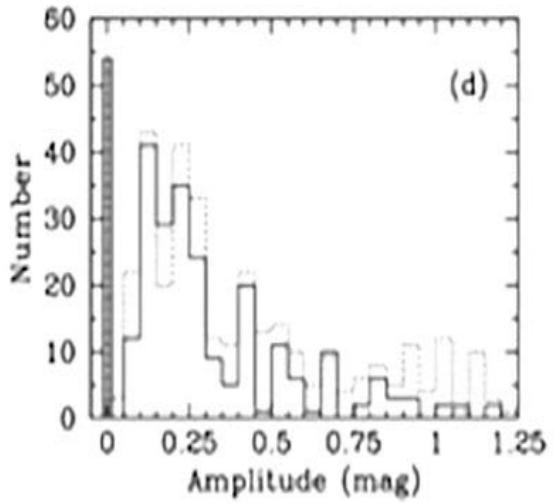
- …if made of pure nitrogen ice (Jackson and Desch 2021) it has a density of 0.85 g/cm^3
- a 200 m diameter = 100 m radius object would then have a volume of (4/3)(3.14)(100m)^3 = 4.2x10^6 m^3 = 4.2x10^{12} cm^3
- And at 0.85 g/cm^3 that gives a
- **Mass = 3.6x10^{12} g, if spherical**

BUT THE PHOTOMETRY IS BEST FIT BY A TUMBLING PANCAKE SHAPED OBJECT. ARTIST'S GUESS BELOW – (DON'T TAKE THE ARTISTIC CRATER DETAILS SERIOUSLY!). MORE ON THAT LATER

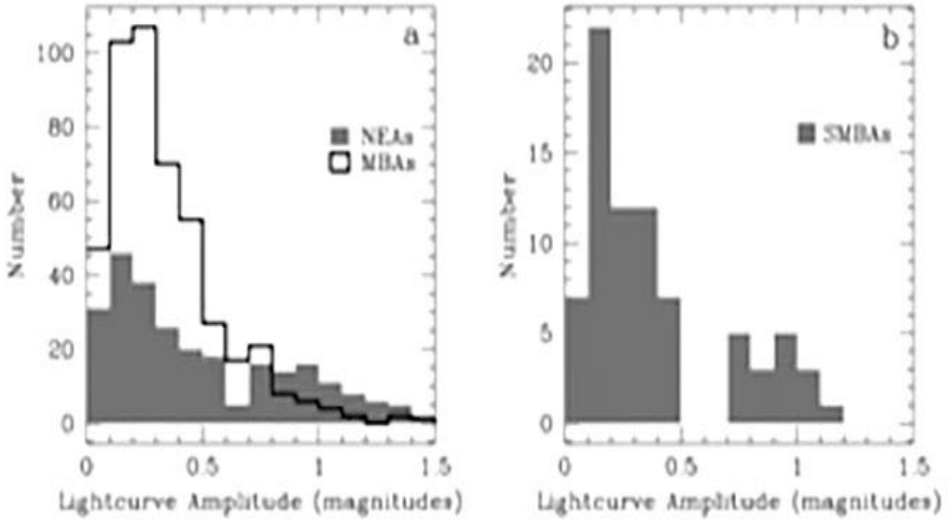
Asteroid Elongations



`Oumuamua's lightcurve amplitude is 2.5 magnitudes (10 times)



Masiero et al. (2009)



Walsh and Richardson (2008)

BUT THE MOST EXTREME ASTEROIDS EVER DISCOVERED HAVE A LIGHT CURVE AMPLITUDE OF ONLY 3:1.

OUMUAMUA'S IS 10:1 (!), IMPLYING IT IS NON-SPHERICAL BY 6:1 - FAR MORE THAN ANY ASTEROID WE'VE SEEN IN OUR OWN SOLAR SYSTEM.

SO, AS A MORE PANCAKED AXISYMMETRIC SHAPED OBJECT…

- Then the volume and mass need to be multiplied by the aspect ratio of about 1/6
- So the mass at the time we observed it, after its closest approach to the sun and heading back out, would be **~6×10^{11} g, <u>if it is nitrogen ice</u>**

BUT WE DIDN'T DISCOVER IT UNTIL IT HAD ROUNDED THE SUN AND WAS WELL ON ITS WAY BY AND PAST EARTH.

- By this time, the severe heating from the sun would, Jackson and Desch find (2021), have lost 90% of its mass to sublimation by solar heating.
- That means the object as it entered our solar system must have been 10x more massive than we estimated….
- So at entry to our solar system it would be 10x more, or about
- **Interstellar Mass= $6x10^{12}$ g**

BUT JACKSON AND DESCH ALSO FIND THE MOST LIKELY AGE IS ~500 MILLION YEARS IN INTERSTELLAR SPACE

- During that time, cosmic ray caused erosion would, they estimate, cause the loss of ~92% of its nitrogen mass (uncertain erosion rate, though)
- So we have to raise the mass of the object at the time of ejection by another factor of 1/(1 - 0.92) or a factor of 12
- That means the mass at time of ejection from its parent stellar system would be **~8×10^{13} g**. (And higher if it suffered a close encounter with its parent star as the tidal disruption event. Perhaps another 10x. We won't include that below)
- **Mass of Oumuamua as it left its parent system: about ~8×10^{13}g**

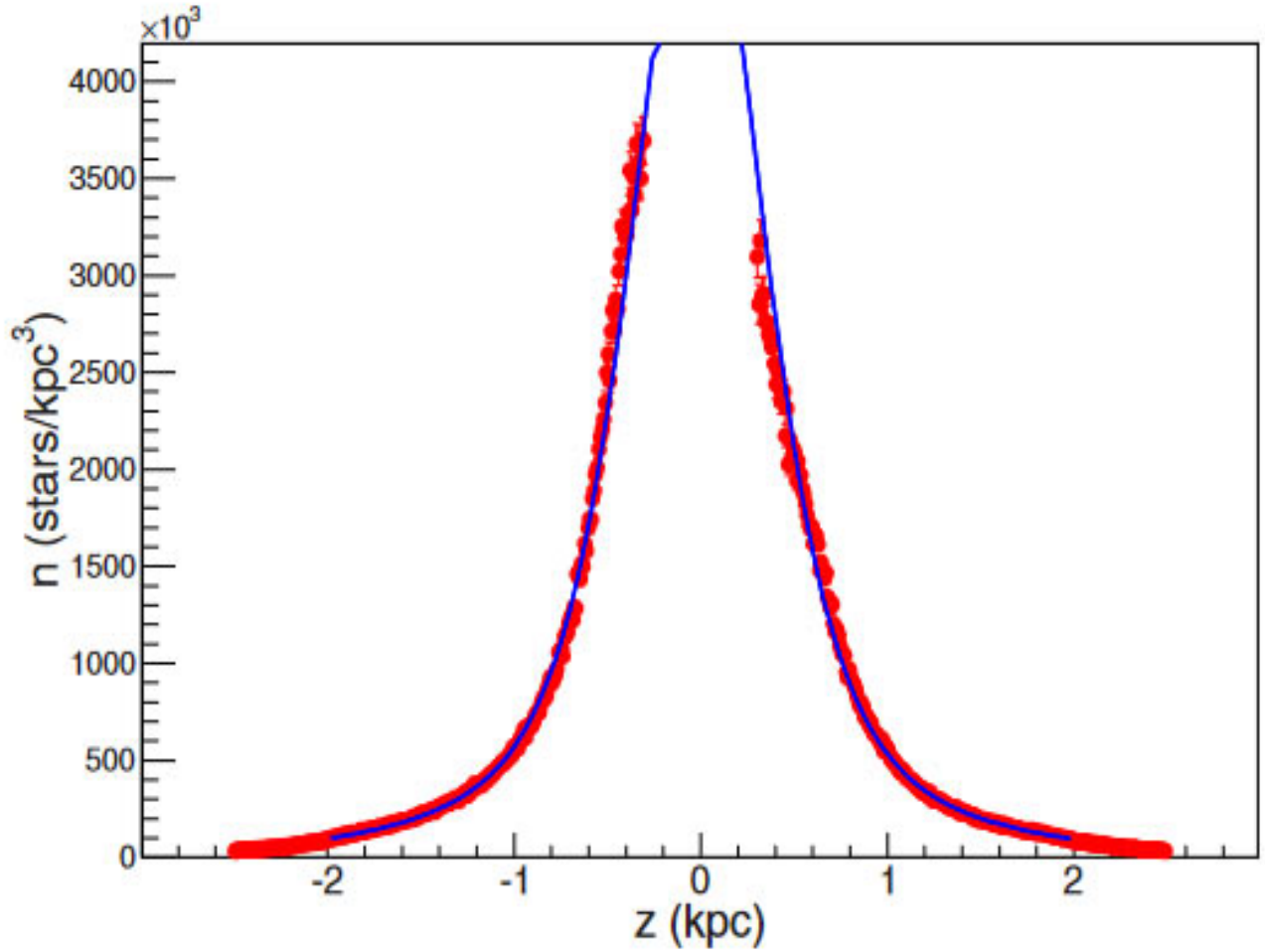


Figure 17. Histogram of the stellar density as a function of the vertical displacement z from the Sun. We employ the selection function and color and saturation cuts described in the text and compute distances using Equation (3). Even at this coarse scale, the wave-like north–south asymmetry can be seen on top of the symmetrical model.

(A color version of this figure is available in the online journal.)

HERE IS THE STELLAR DENSITY IN OUR GALACTIC NEIGHBORHOOD, FROM YANNY AND GARDNER 2013

THE SUN IS VERY NEAR THE GALACTIC PLANE, WHERE STELLAR DENSITY IS HIGHEST

HOW MANY SUCH NATURAL OBJECTS MUST THERE BE?

- Do *et al.* 2018 calculate that Oumuamua-like objects must exist at a density of 0.2 per cubic AU to account for its early discovery by PANSTARRs.
- 206,265 AU per parsec => 8.8×10^{15} AU^3/pc^3
- And 0.2 Oumuamua/AU^3 x 8.8×10^{15} AU^3/pc^3 = 1.8×10^{15} Oumuamua/pc^3
- Now, for the observed 0.14 stars per pc^3 stellar density in our solar neighborhood, we then have…
- $(1.8 \times 10^{15}\ pc^{-3})/0.14$ stars-pc^{-3}
- Or **~1.2×10^{16}** such fragments per star system, in the solar neighborhood of our Galaxy, if it was natural and un-targeted. A thousand trillion!

THIS IMPLIES AN IMPLAUSIBLY LARGE MASS OF SUCH OBJECTS LEAVING THEIR PARENT STELLAR SYSTEM…

- If there are **1.2×10^{16}** of them to account for the statistical argument, that gives a total of…
- (1.2×10^{16} objects) x (8×10^{13} **g/**object, at ejection) = 10^{30} g for the total mass of the unbounded fragments, per stellar system.
- The mass of the Earth is only **6×10^{27}g. So that's 167 Earths!**
- **That says the mass of unbounded frozen objects, per stellar system, is 167 times the mass of the Earth. Or, about 11x the mass of Neptune. This seems implausibly large, if our solar system is at all typical.**

IF ONLY A FEW STELLAR SYSTEMS PRODUCE SUCH TIDAL DEBRIS…

- …such as suggested by the mechanism of losing one's Oort Cloud after passing through the mass loss of the Asymptotic Giant Branch (AGB) phase of evolution (Zhang and Lin 2020, cited later)…
- Then the number of fragments for these systems would have to be quite a bit larger still, to compensate for all the systems (most) that have not gone through such AGB adventures yet.

BUT WAIT – IT GETS STRANGER…

- Because heavy elements (elements heavier than helium) make up only 1-3% of the mass of stars and the stellar disks that formed their planets.
- So you need about 167 times the mass of the Earth (the largest inner planet) in rare heavy element material, and this is just the fraction of material that was unbounded by hypothesized near encounters with large gravitational objects.
- Compare that to the mass of the entire Kuiper Belt in our own solar system – which is only ~2% of the mass of the Earth (Pitjeva and Pitjev 2018).

THE MASS OF OUR ENTIRE KUIPER BELT, AT LOWER LEFT, IS ONLY 0.02 EARTH'S

THE INFERRED MASS OF UNBOUNDED OBJECTS PRODUCING "OUMUAMUA'S", PER STAR SYSTEM, IS AT RIGHT; 167 EARTH'S

inferred typical unbounded mass

IN OTHER WORDS, WE'RE TALKING ABOUT *8,000 TIMES THE MASS OF OUR OWN ENTIRE KUIPER BELT* , IN HEAVY ELEMENTS, AS AN AVERAGE TO BE EXPECTED TO BE EJECTED FROM STELLAR SYSTEMS

- **Again, this cannot be for a very unusual system, but for the average stellar system.**
- **So, per typical solar neighborhood star.**
- That's just in the fraction that was somehow launched into interstellar space, not the material remaining bounded.

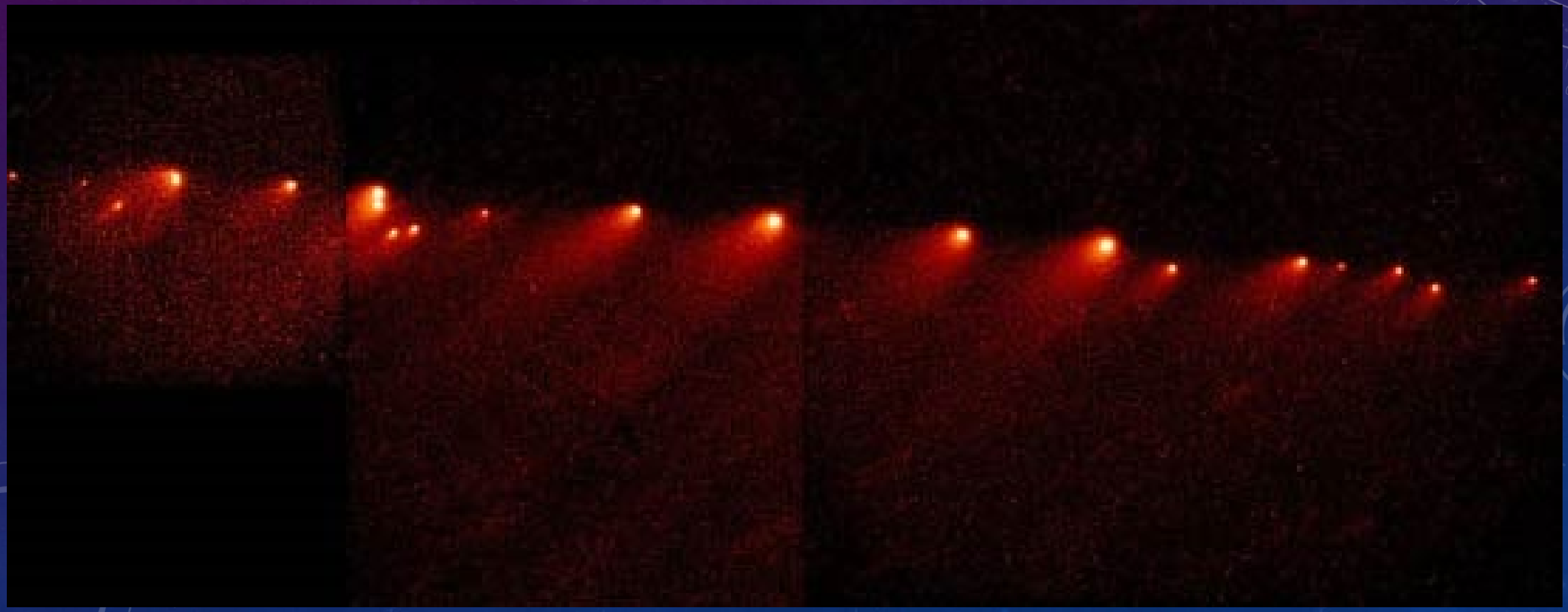
MATERIAL ACQUIRING ESCAPE VELOCITY BY PURELY GRAVITY ENCOUNTERS AND WITHOUT INFERRING AN AGB MASS LOSS EVENT BY PARENT STAR, MUST…

- …by conservation of energy, have resulted in a compensating lessening of orbital energy by a roughly equal amount of mass.
- So unless virtually all of this was destroyed by the sun or planets, then where is it now? It's not, in our solar system, not in the asteroid belt, Oort Cloud, or Kuiper Belt

THESE KIND OF MASSES MAKE THE TIDAL DISRUPTION IDEA RATHER HARD TO SQUARE WITH THE DATA…

- …the original mass must have been part of the original stellar system – bound gravitationally to it.
- If orbital changes led to a close encounter with its parent star to explain the tidal disruption of such a large mass (again, discounting AGB phases, which medium mass stars go through near the end of their lives only), then we need to realize that tidal disruption takes orbital energy and converts much of it to the internal stress energy of disruption; ultimately heat and mechanical breakup.
- This makes the orbit of the center of mass of the disrupted body have LESS energy, by conservation of total energy, and therefore even **more** bound to the parent system.
- This means that the mass of the object disrupted would have to be much larger than the mass we calculated, as if 167 Earth's of mass was not already amazingly high.

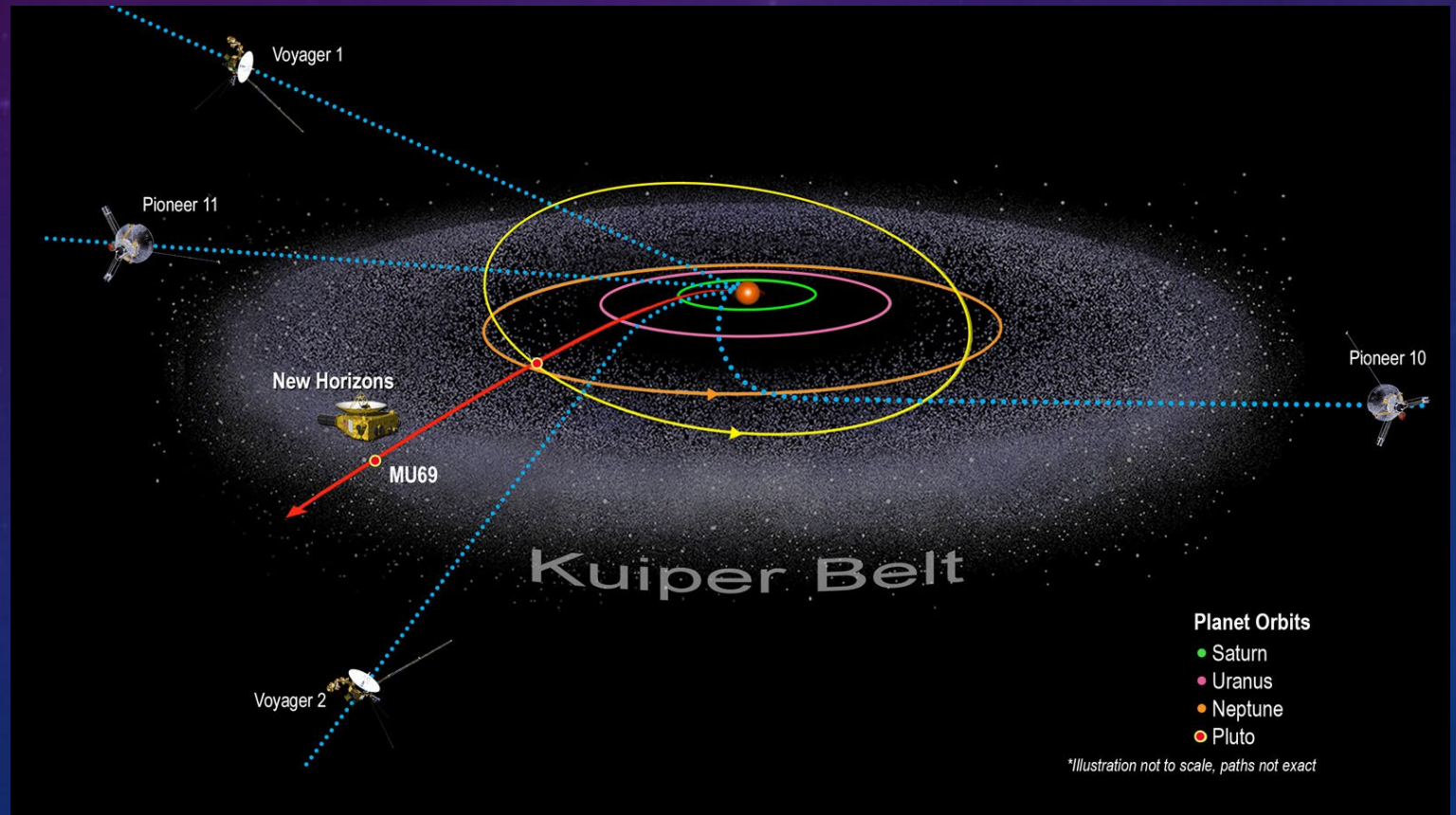
EXAMPLE: COMET SHOEMAKER-LEVY 9. YET SL9 WAS NOT EVEN GRAVITATIONALLY BOUND TO JUPITER WHEN IT FIRST CAME IN, BUT ITS TIDAL DISRUPTION LED TO LOSS OF ENOUGH ORBITAL ENERGY THAT ITS FRAGMENTS ALL CRASHED INTO THE PLANET, IN 1994



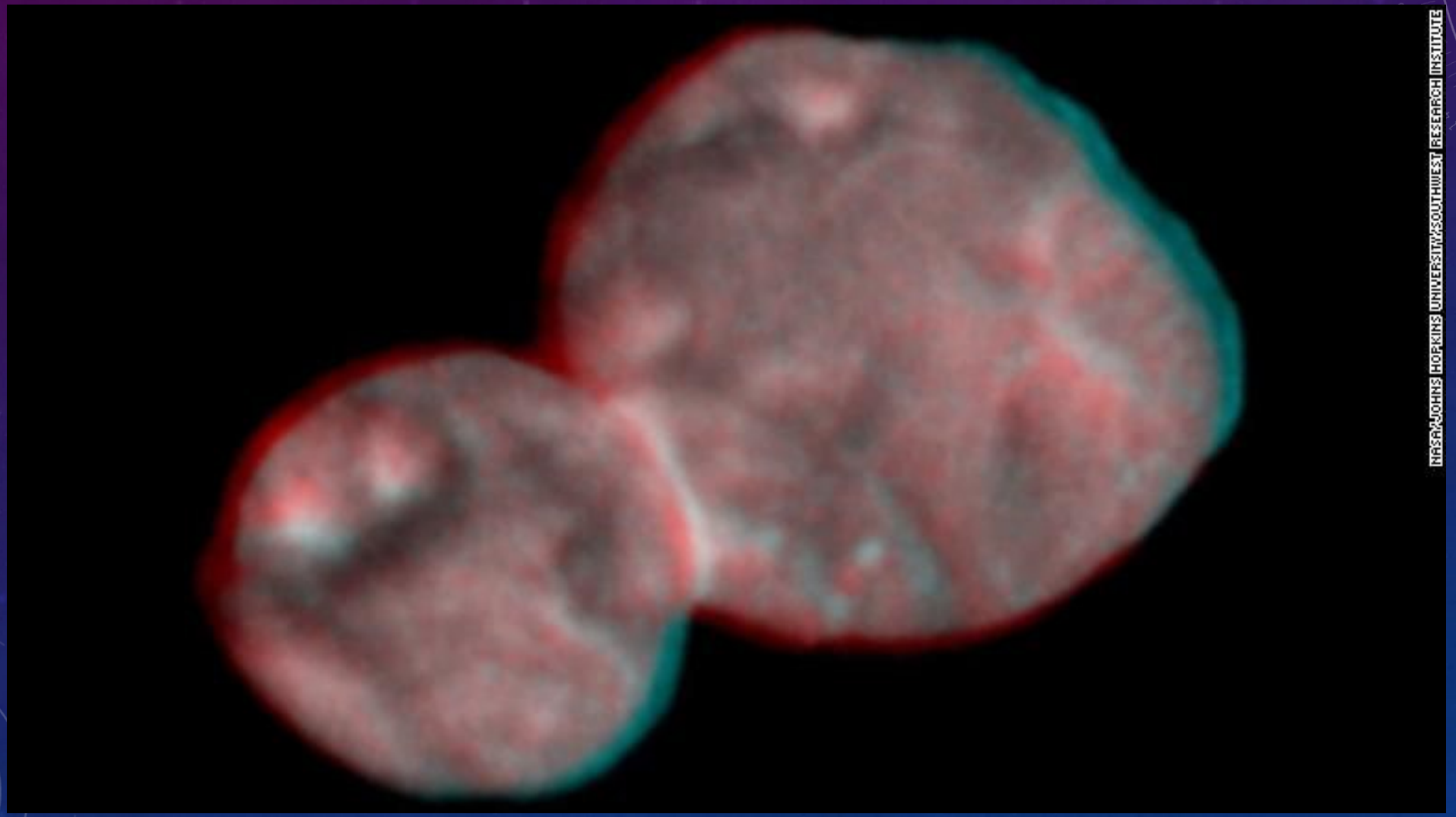
BUT NEXT – CONSIDER THE EVIDENCE THAT OUMUAMUA-SIZED KUIPER BELT OBJECTS ARE INSTEAD SURPRISINGLY RARE

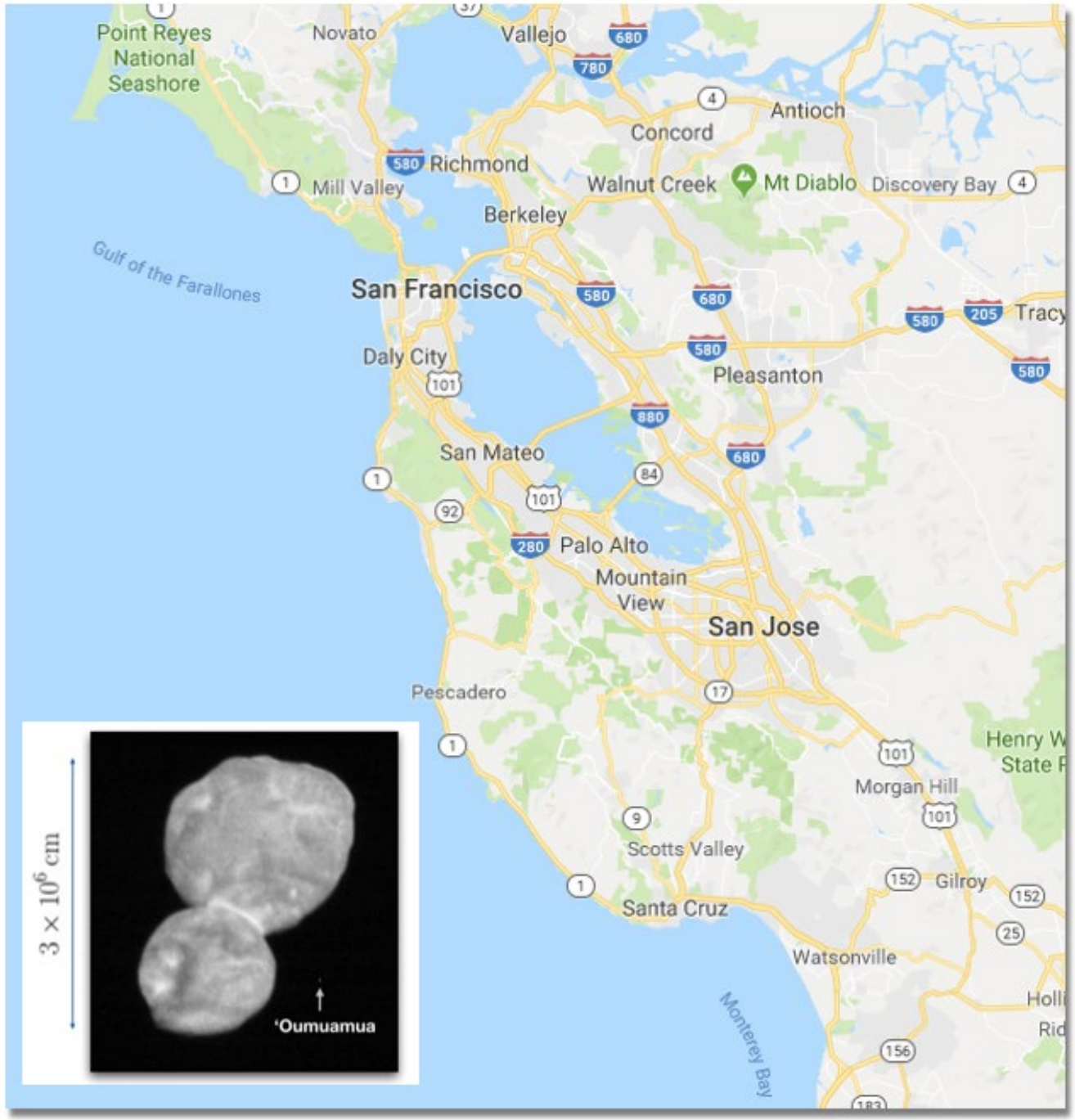
- The Kuiper Belt objects, *vs* closer planets, are nearer to being on unbound orbits, and are calculated to be the easiest to unbind.
- But the large majority of the material in our solar system's Kuiper Belt is in large objects, much larger than Oumuamua.
- We determine this from the statistics of the sizes of craters on the surfaces of Pluto, Charon, and **Ultima-Thule** (*aka* Arroketh).
- Objects the size of Oumuamua then may be very rare. Especially if they are made of rock, unlike KBO's.

THE CRATER SIZE DATA PROVIDES AN ADDITIONAL ARGUMENT THAT THIS OBJECT WAS MUCH LARGER THAN ITS CURRENT SIZE WHILE IN ITS OWN PARENT STAR'S KUIPER BELT OR OORT CLOUD.



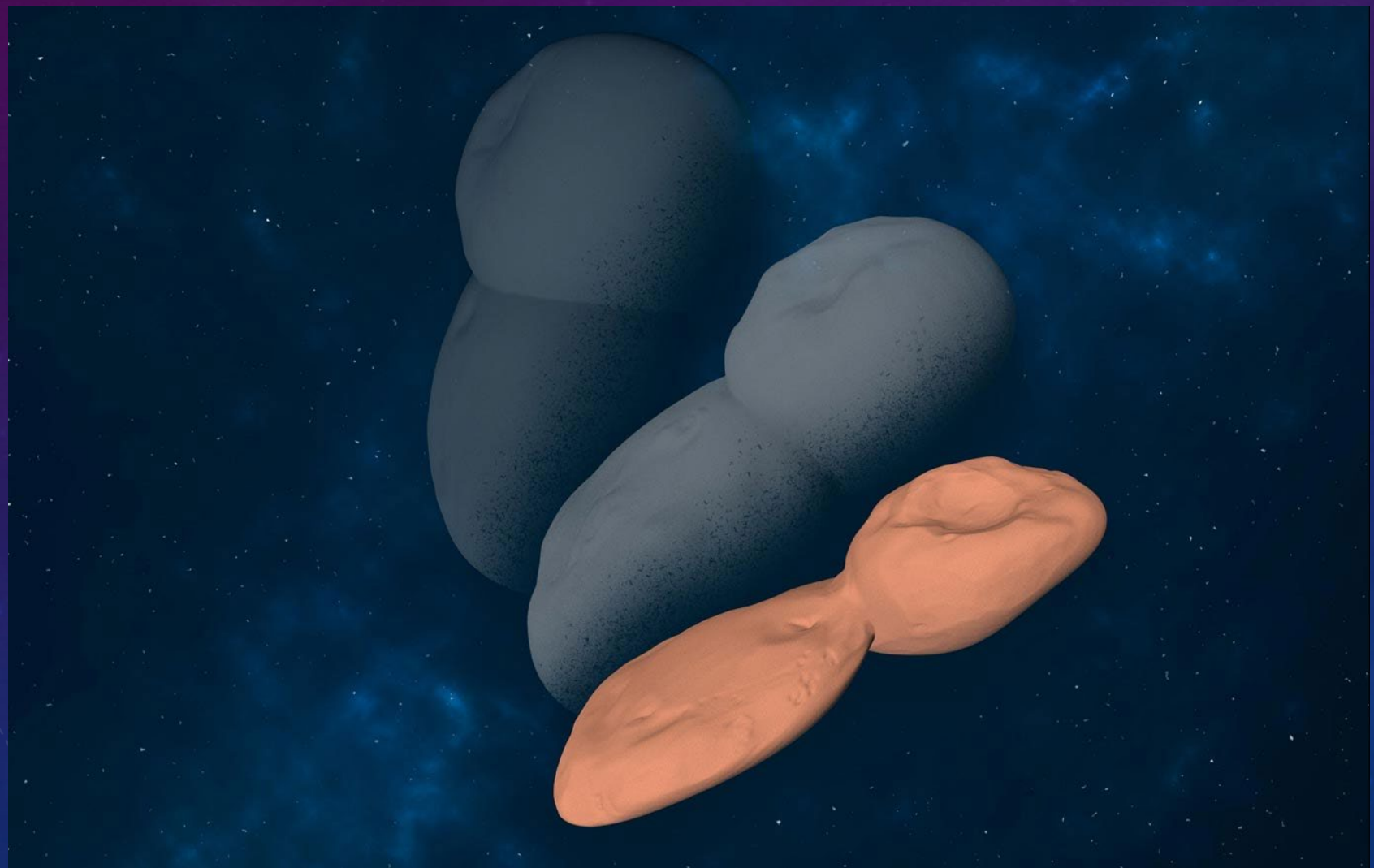
ARROKETH– TWO “PITA BREADS” SHAPES, WELDED TOGETHER. BIZARRE! AND ONLY SOME LARGE CRATERS - ~NO MEDIUM-SIZED CRATERS AS MIGHT BE MADE BY OUMUAMUA SIZED IMPACTS.





HERE'S ARROKETH TO SCALE; BUT OUMUAMUA WAS SO SMALL, AT ~200 M DIAMETER, IT WOULD EASILY FIT WELL INSIDE THE ENCLOSED PART OF THE "A" IN "SANTA CRUZ" AT BOTTOM.

ARROKETH; IRRADIATION EROSION WOULD CAUSE IT TO THIN, FROM FAT TO PAN-CAKED.



PLUTO; ITS SURFACE DISTRIBUTION OF CRATER SIZES SUGGESTS A RARITY OF SMALL KBO OBJECTS OF THE SIZE OF OUMUAMUA

PLUTO’S LARGE MOON CHARON, SHOWS A SURPRISING RARITY IN IMPACTORS OF OUMUAMUA SIZE: 100 METERS TO ~1/2KM ACROSS.

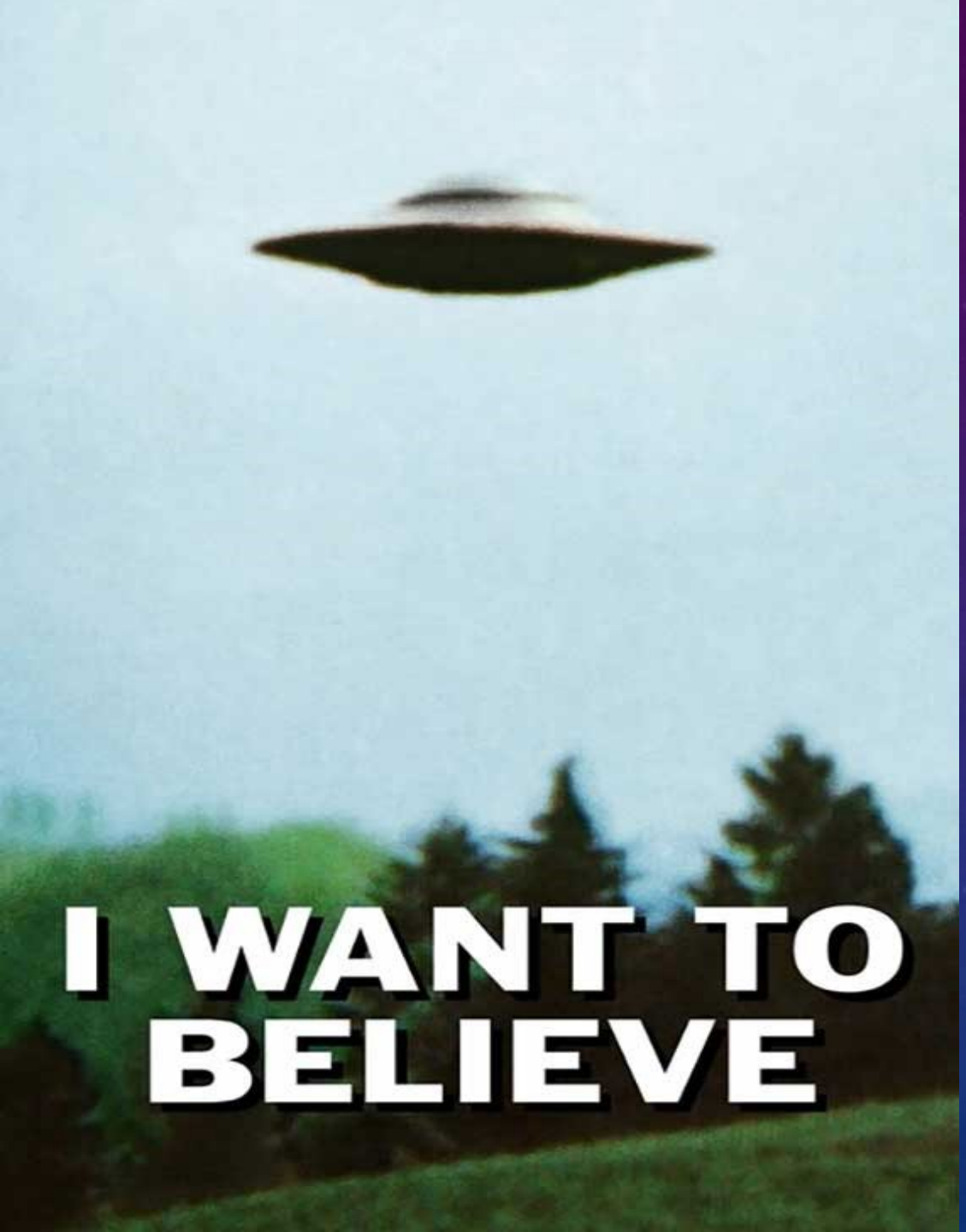
THIS IS ADDITIONAL EVIDENCE POINTING AWAY FROM AN ORIGIN INSIDE OUR SOLAR SYSTEM.

IN FACT, I WOULD LIKE TO SEE SOME CALCULATIONS…

- Calculations… showing how the crater size distributions and believed rate of re-surfacing might constrain how often Oumuamua objects arrive, since our KBO surfaces are a “fly paper” record of potential past Oumuamua’s.
- Does this provide an interesting constraint? Or not.
- Perhaps the lack of Oumuamua-sized impacts says right away that there can’t be very many entering our solar system, and showing we were just extremely lucky to catch Oumuamua so soon after power-up of PANSTARRS.
- If so, that would lower the inferred original masses at ejection from their parent system.

LET'S WIDEN OUR SPECULATION: FIRST, THE LIGHT CURVE WAS ANALYZED BY SERGEI MASHCHENKO, PUBLISHED IN 2019

- He finds the best fitting shape is that of a saucer or disc, very nearly axisymmetric, with an aspect ratio of 6:1
- *"Our best-fitting models are a thin disc (aspect ratio 1:6) and a thin cigar (aspect ratio 1:8) that are very close to being axially symmetric"*
- The statistical mathematics give a confidence of **91%** for the saucer shape, and only 16% for the cigar shape (Mashchenko, 2019)
- So – it's almost certainly "Flying Saucer" shaped…That's…. spooky



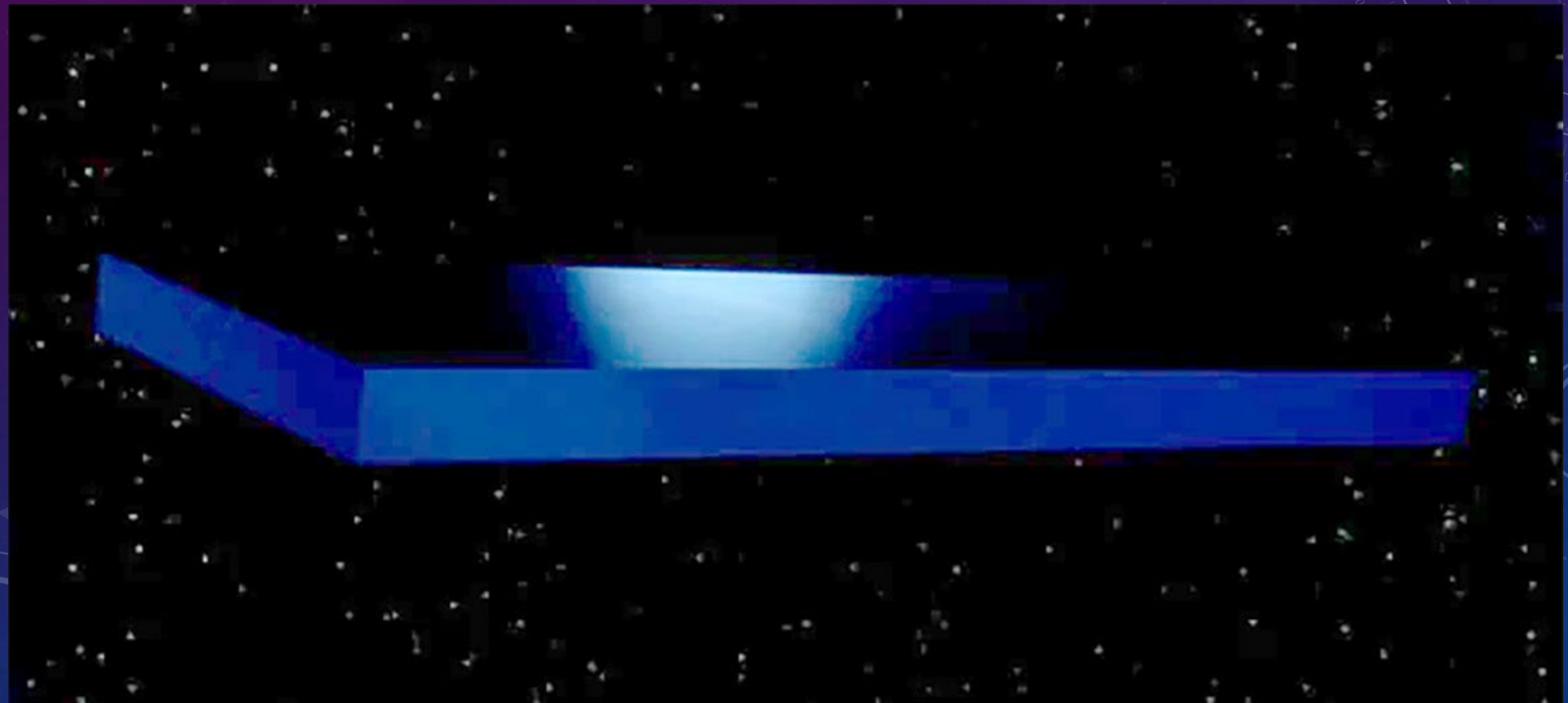
THIS IS ABOUT THE RIGHT SIZE AND ASPECT RATIOS; 6:1 AND AXISYMMETRIC.

INTERESTING!

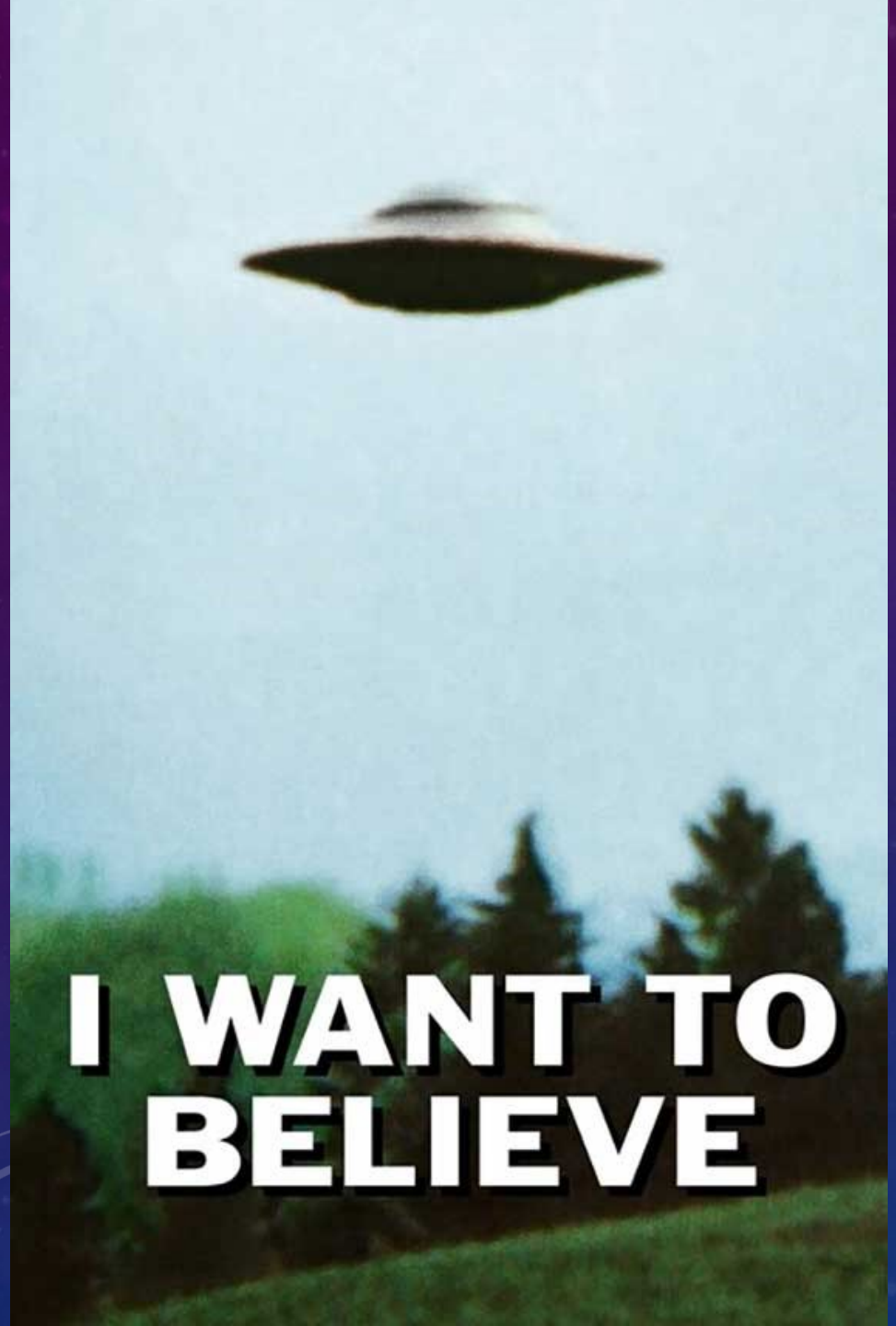
“MULDUUUUURRRR !”

…AND THIS IS ABOUT THE RIGHT SIZE TOO, FROM THE PHOTOMETRY LIGHT CURVE. (“I CAN’T DO THAT, DAVE…”)

SPOOKY…



ALSO NOT A BAD MATCH FOR SIZE AND SHAPE. YIKES.

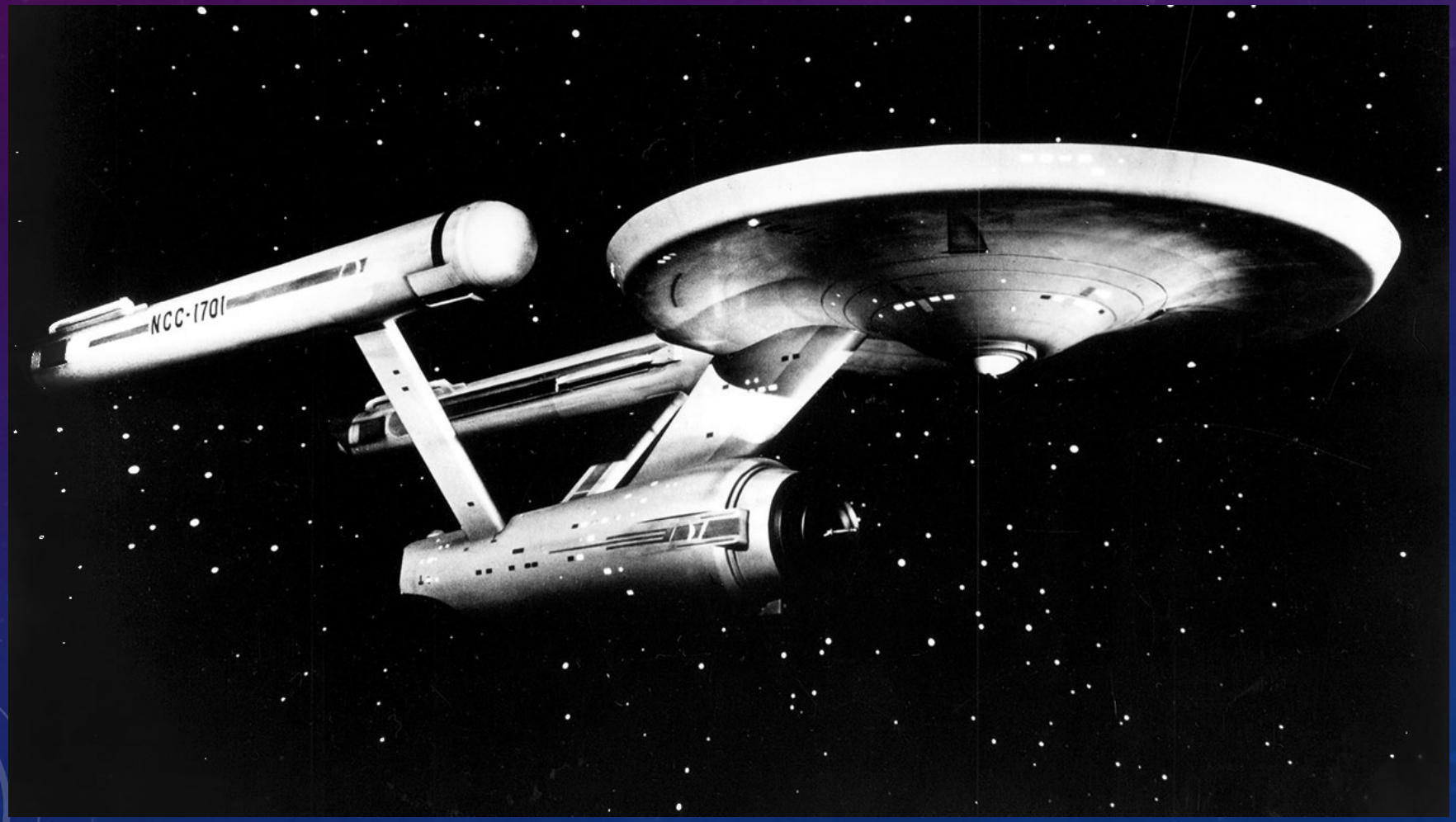


ALIENS???

IF NOT COMPLETELY AXISYMMETRIC, THEN PERHAPS MAINLY AXISYMMETRIC, AS REQUIRED BY THE LIGHT CURVE, BUT WITH SOME MASS IN NON-SYMMETRIC FASHION

LIKE THIS….? (SEE NEXT SLIDE)

A FLYING SAUCER WITH SOME JETS! THIS COULD FIT THE LIGHT CURVE DECENTLY. (HEY… I'M JUST SAYIN'!)



COMETS EXPERIENCE “NON-GRAVITATIONAL” ACCELERATIONS DUE TO THE SUBLIMATION OF THEIR ICES AND “THE ROCKET EFFECT” FROM THIS OUTGASING

- Oumuamua exhibited a substantial and unusually large acceleration as it moved away from the sun.
- It would have required about ~10% of the mass of a typical “comet” (if that had been what it was) in typical ices sublimation and outgasing, to account for it.
- More important, Oumuamua was studied very closely in high sensitivity by the Spitzer IR space telescope and it saw no outgasing at all, and no thermal radiation.

THIS ALSO ARGUES IN FAVOR OF IT'S SOLIDITY

- Unlike so many asteroids, it's not a "rubble pile".
- It's spin period of 8 hours is short enough it would fly apart if it weren't held together with solid state forces.

WE SAW NO "JITTER" IN ITS LINEAR OR ROTATIONAL MOTION, SUCH AS YOU'D EXPECT TO SEE…

- …if there were multiple changing outgasing points as is typical on observed comets with crusty exteriors of dark material, and fresh volatiles coming through cracks and bare areas.
- (This is worth remembering when we get to this year's Zhang and Lin proposed idea, later)
- And more – the acceleration fits the prediction of a solar sail – dropping off as $1/r^2$, and that's different than the behavior of water outgasing from comets, as we'll see.

IT DOESN'T ADD UP…

- If Oumuamua is $6x10^{11}$ g, and it requires 10% of its mass (if water) be vaporized to power the non-gravitational acceleration, then that's $6x10^{10}$ g of material.
- For a molar weight (if water or nitrogen) of ~17g/mole, that's **35 billion moles vaporized**
- And, if over a period of time since leaving perihelion (early October '17) till observations of the acceleration, that's a few weeks. Say, 35 days.
- 35 days = 3 million seconds. **So that implies a vaporization rate of order <u>10,000 moles per second</u>**

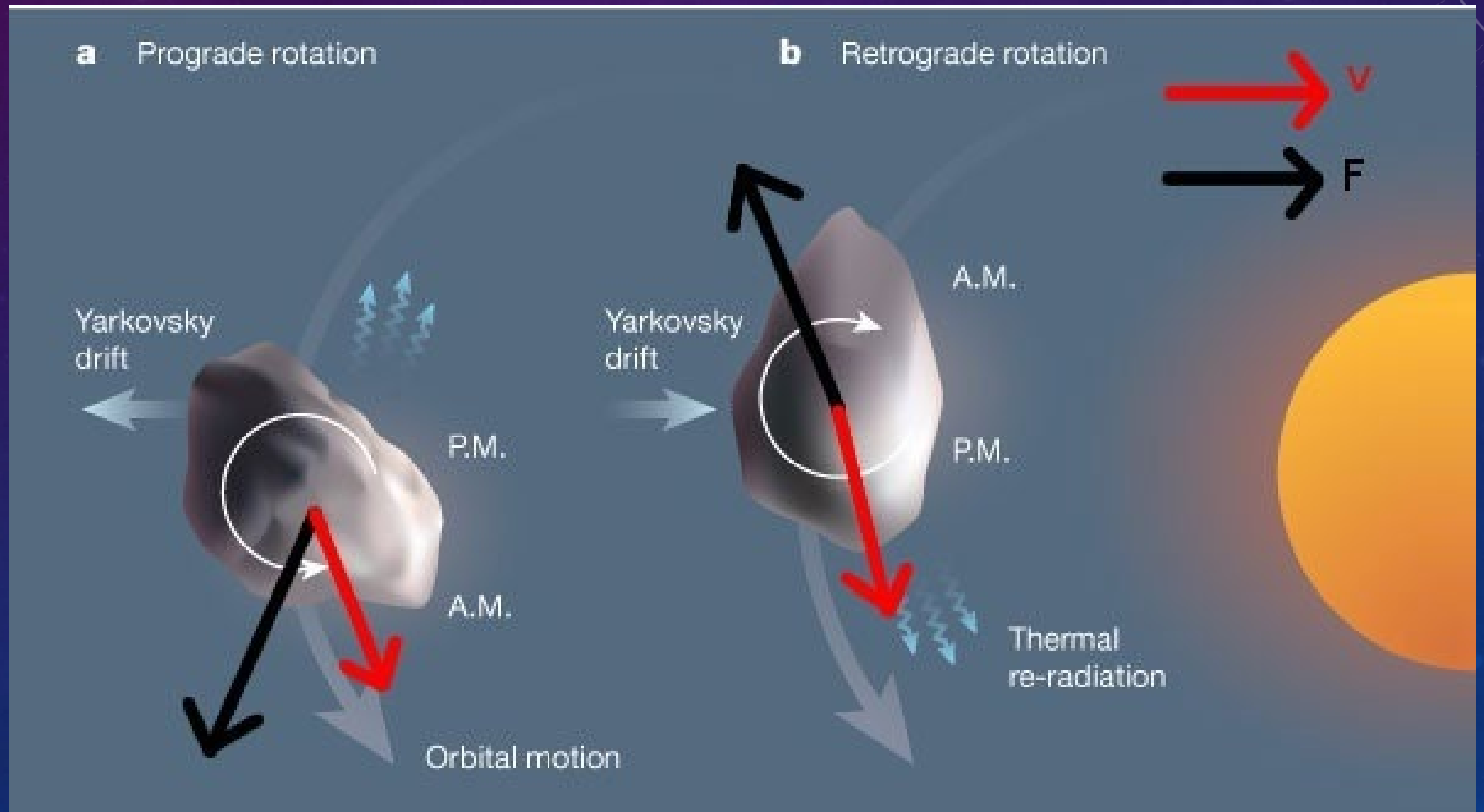
REPEAT: REQUIRES ~10,000 MOLES PER SECOND OF OUTGASING, TO ACCOUNT FOR THE OBSERVED ACCELERATION FOR AN ICE MASSED OBJECT

- Yet Sekanina (cited later here) claims the **upper limits on carbon molecular associated outgasing was only 1 mole per second**
- **That's a 10,000 to 1 inconsistency!**
- More than a mole/sec, and it would have been detected by telescopes.
- And again, its reddish color, if caused on the surface of a natural object, most naturally suggests a chemical composition of CH_3OH, or methanol, or other carbon-rich compounds. But that's in severe conflict with the Sekanina / Spitzer carbon limits.
- It does not appear possible to account for the acceleration as cometary outgasing, unless the carbon content was essentially perfectly 0.0000000% of the material, something unknown in our own solar system.
- Even former our Neptune's former KBO Triton shows significant carbon "geysers" from its frozen polar areas.

COULD THE ACCELERATION INSTEAD BE FROM THE YARKOVSKY EFFECT?

- An object near the sun is warmer on one side than the other, and the warm side will radiate more photons, and photons have momentum and therefore a back-reaction on the object they emit from.
- So, the object will experience a non-spherically symmetric force due to its own thermal radiation.

THE THERMAL RADIATION KICK IS HIGHEST IN THE SIDEWAYS DIRECTION, NEAR THE SUNSET LONGITUDE ON THE OBJECT. SO IT DOESN'T ACCELERATE THE OBJECT DIRECTLY AWAY, NOR DIRECTLY TOWARDS THE SUN, BUT RATHER SIDEWAYS TO IT



SO DID WE SEE ACCELERATION CONSISTENT WITH THE YARKOVSKY EFFECT?

- No.
- The acceleration was observed to be purely radial; directly away from the sun
- NO Yarkovsky effect!

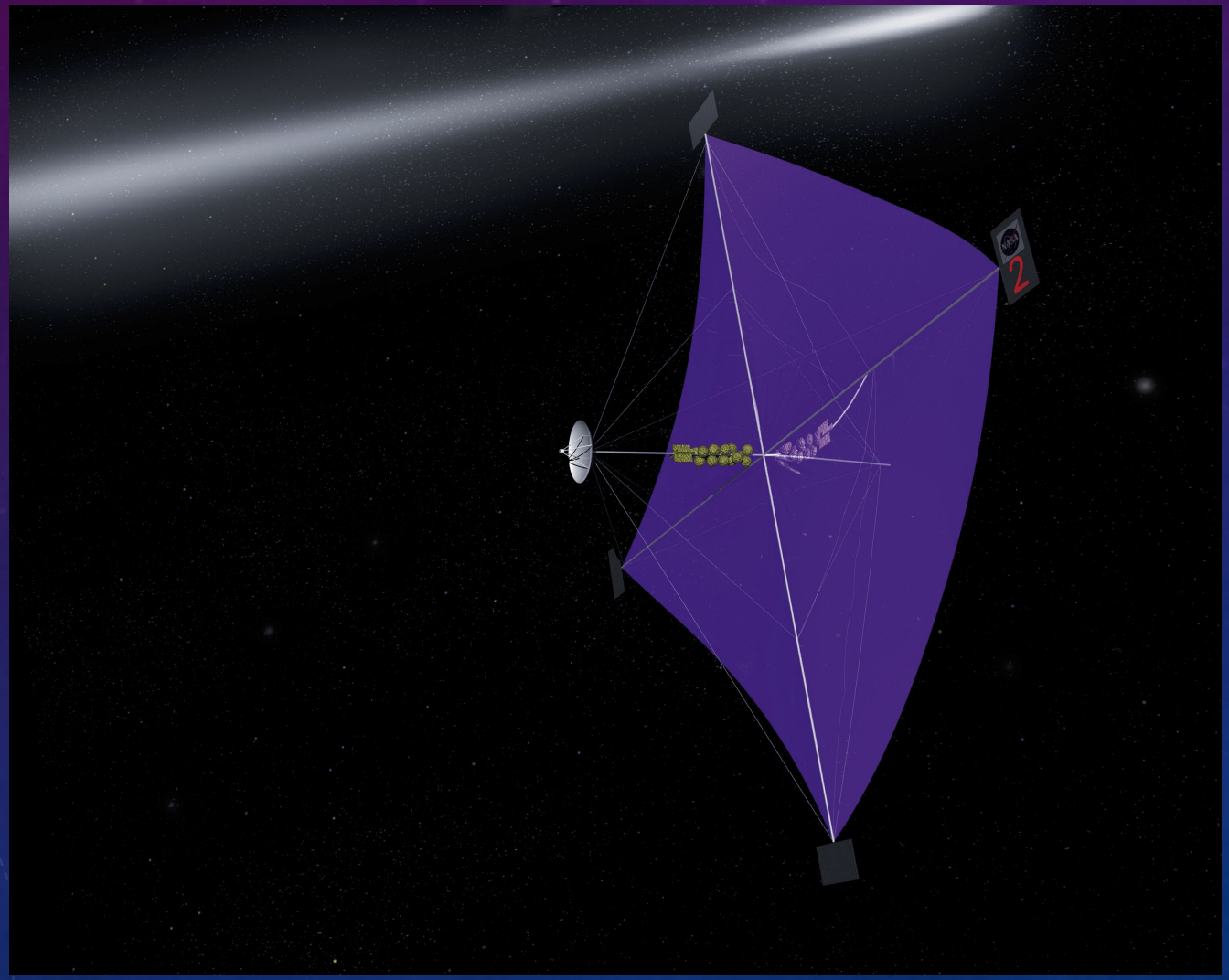
A GOOD PAPER ON THE NON-GRAV ACCELERATION AND PROPOSED MODELS, IS MICHELI *ET AL.* 2018

- They find consistency with a $1/r^2$ thermal forcing, which is the distance dependence you'd get if it were a solar sail.
- The authors rule out solar radiation pressure, however, because the magnitude of the acceleration is thousands of times larger than you would expect if, as they assumed, Oumuamua was a typical ice or ice/rock asteroid or comet like object. But observe the bias here…

BUT THE KEY IS THIS - THEY DID NOT ADDRESS OR CONSIDER THE IDEA OF A SOLAR SAIL. THIS IS AVI LOEB'S CONTENTION

- Michelli *et al.* are essentially assuming what they want to prove – that it can't be solar radiation pressure causing the acceleration because they don't consider a solar sail as worth including in the possibilities.
- But… If it is absolutely pure nitrogen ice, it is able to produce this level of acceleration and r^{-2} behavior, yet not be a solar sail – see later…

A SOLAR SAIL? – MAXIMUM AREA WITH MINIMAL MASS, SO THAT ACCELERATION BY STAR LIGHT IS MAXIMUM



CLEARLY THE FIT IS BETTER FOR A $1/R^2$ DEPENDENCE FOR THE NON-GRAV ACCELERATION, WHICH IS WHAT WOULD BE PRODUCED BY SOLAR RADIATION PRESSURE. THE AMOUNT OF THE ACCELERATION SUGGESTS LOW MASS, EASIER TO ACCELERATE WITH THE SMALL FORCE AVAILABLE FROM SUNLIGHT, OR A LASER.

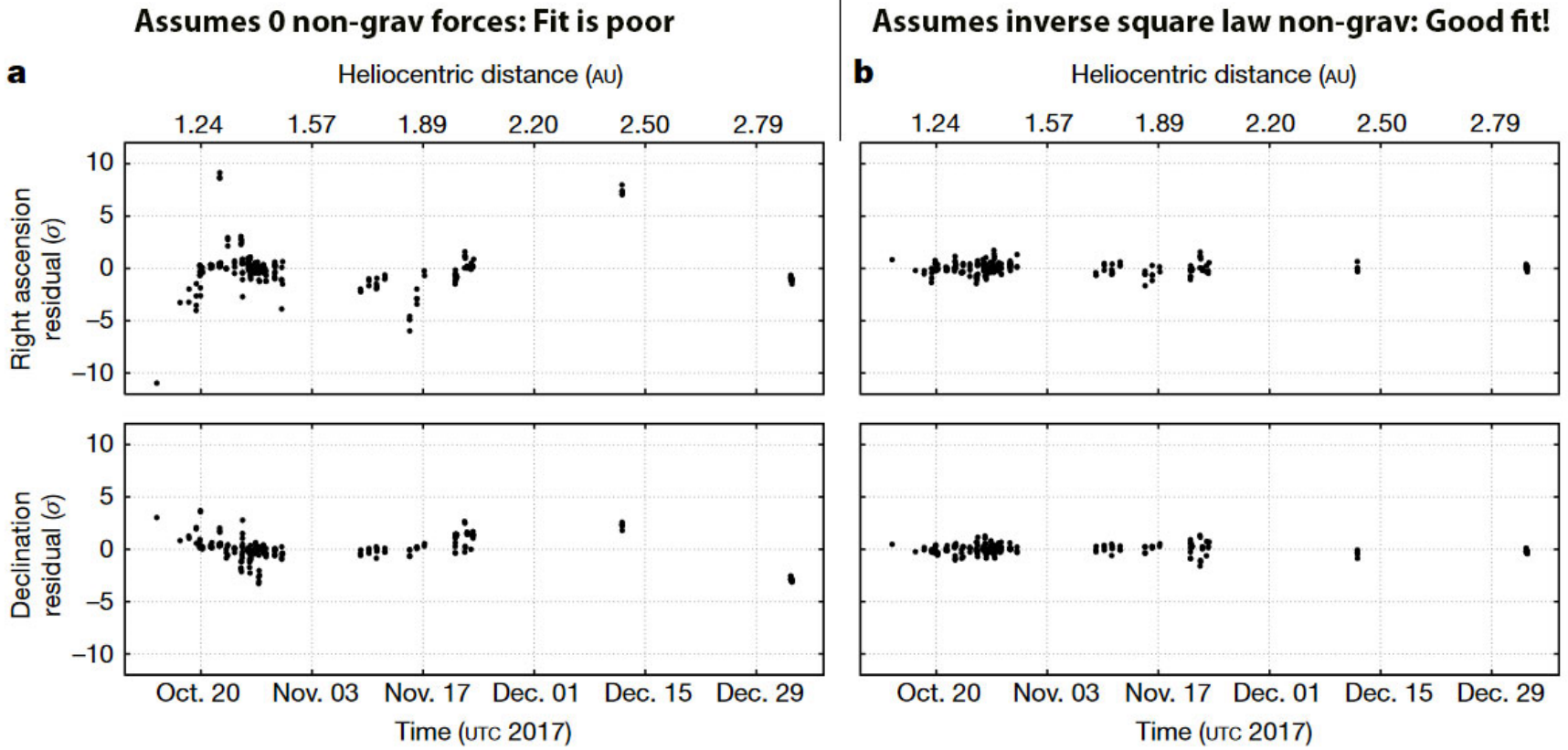
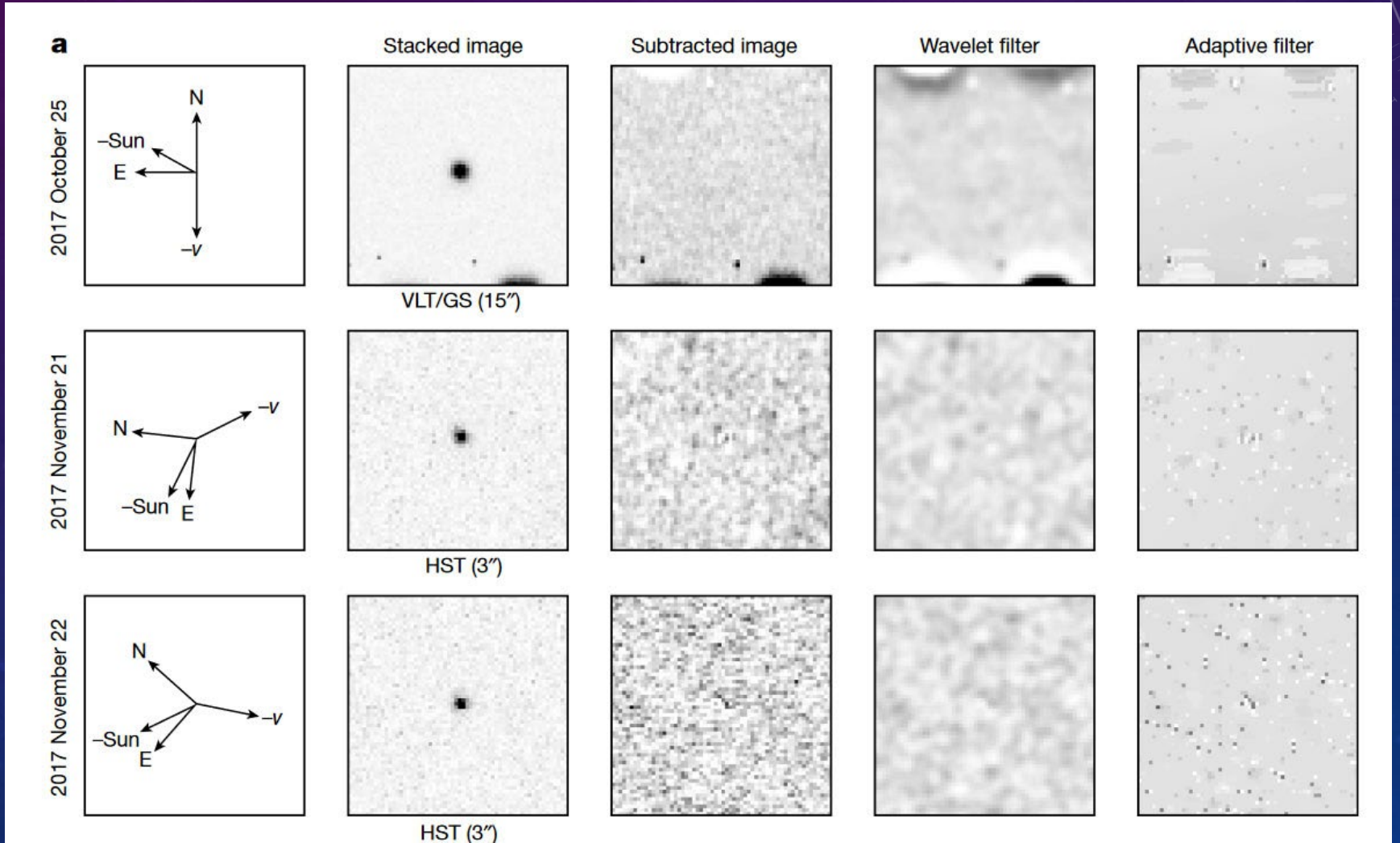


Fig. 2 | Astrometric residuals of 'Oumuamua observations. a, b, Normalized residuals for right ascension and declination compared to a gravity-only solution (**a**) and a solution that includes a non-gravitational radial acceleration of $A_1 r^{-2}$ (**b**). Because each residual is normalized to its formal uncertainty, each data point has a 1σ error bar (not shown) equal to 1 on this scale.

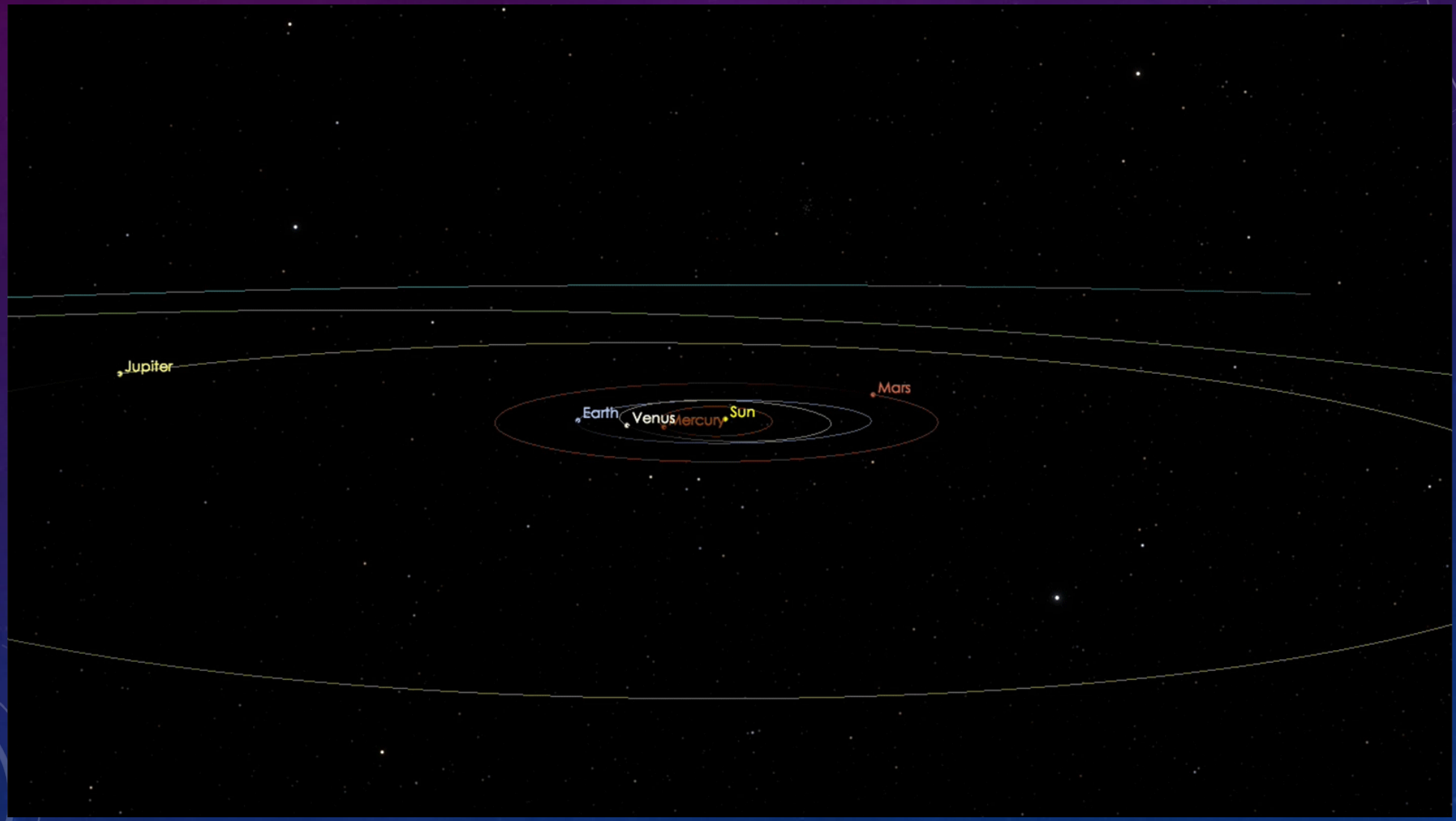
THE ~LARGEST TELESCOPE IN THE WORLD – THE VLT - AND THE HUBBLE SPACE TELESCOPE TOO – COULD FIND NO TRACE OF ANY OUTGASING, AND NO TRACE OF A TAIL OF EITHER GAS OR DUST.



THE TRAJECTORY OF OUMUAMUA PASSING THROUGH OUR SOLAR SYSTEM MADE FOR A RELATIVELY CLOSE ENCOUNTER WITH EARTH ON THE OUTBOUND SIDE, WHICH IS WHEN WE DISCOVERED IT.

- Yikes!– was that deliberate?? Or more likely merely a selection effect since it was so small.
- See this article and the animated GIF showing the orbital motion of our planets and Oumuamua
- https://solarsystem.nasa.gov/news/482/10-things-mysterious-oumuamua/

THE ORBITAL MOTION THROUGH THE ECLIPTIC PLANE, PASSING BY EARTH…

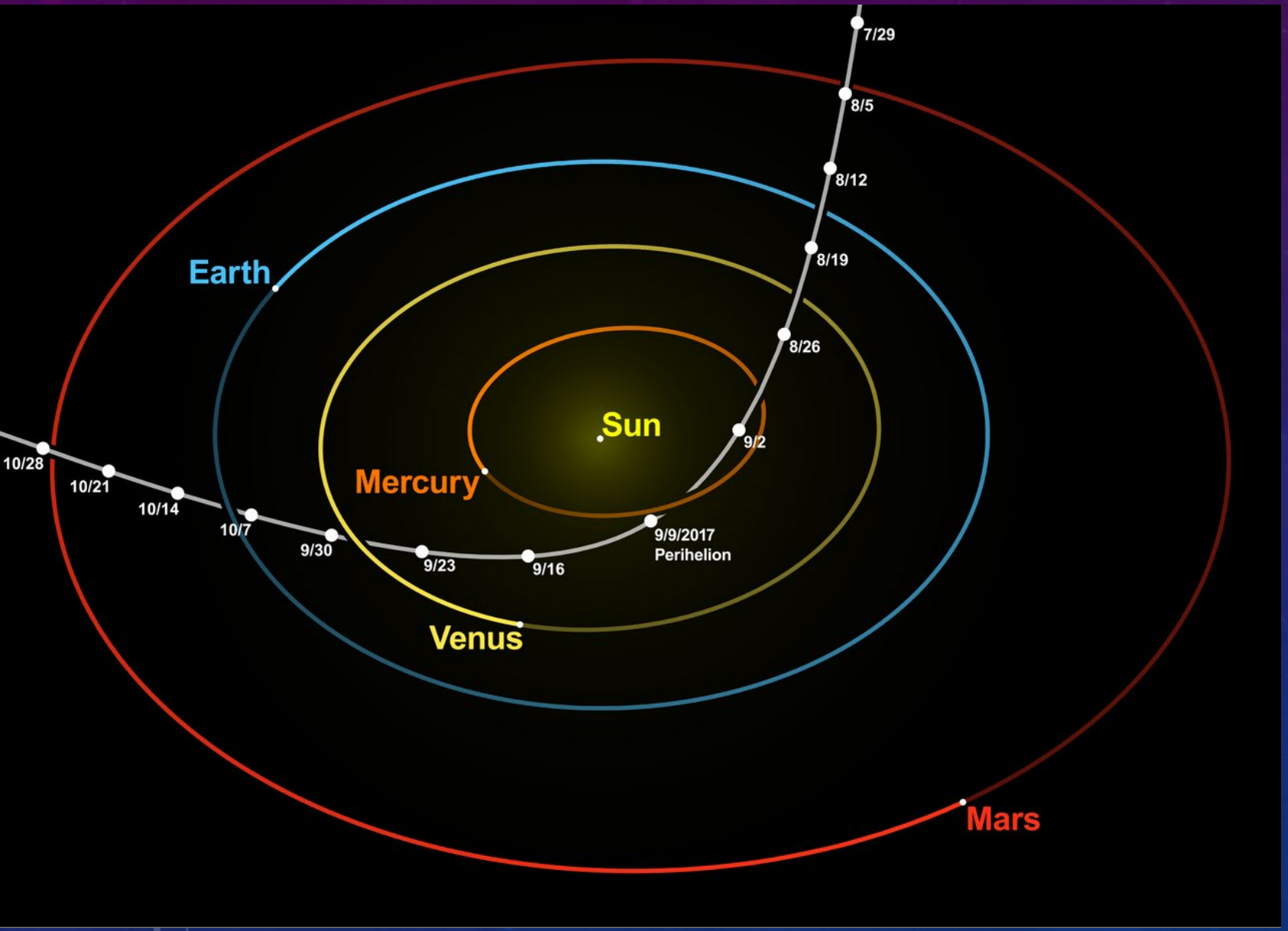


SO – THIS HAS BEEN THE CASE PUT FORWARD BY HARVARD'S AVI LOEB THAT OUMUAMUA COULD BE A DEFUNCT ALIEN SPACE CRAFT LAUNCHED TOWARDS OUR SOLAR SYSTEM

- Defunct, or a "ghost ship" because the object was tumbling, not spinning on a single axis. Tumbling motions are more chaotic.
- But it brings its own questions…

ISSUE #1: THE TRAJECTORY DOES NOT CLEARLY SHOW AN ORIGINATING STAR SYSTEM. OUR ASTROMETRY SHOW IT PASSING WITHIN A LIGHT YEAR OF A FEW STARS, BUT NONE LOOK LIKE THE ORIGINATOR

- How could it have been so precisely targeted to our solar system? Our Gaia astrometry data show it must have experienced several deflections by other stars in its long journey
- If alien artifact, could the aliens have used “slingshoting” like we do, to try to explore several stars with one launch?
- If they had extremely good astrometry of galactic stars – much better than we have - with their advanced technology – not impossible – they could have launched it long ago and this is not the first encounter with an interesting planetary system.



THE PATH THROUGH THE INNER SOLAR SYSTEM. SLIPPING INSIDE THE ORBIT OF MERCURY

ISSUE #2: YOU'D THINK THE ALIENS WOULD WANT TO GET ANSWERS RELATIVELY QUICKLY, NOT 10'S OF THOUSANDS OF YEARS LATER TRAVELING AT PEDESTRIAN SPEEDS

- Yet, Oumuamua arrived very nearly "at rest" with respect to the local Galactic standard of rest…
- Essentially, the Earth "ran into" a ~stationary Oumuamua in the local Galactic rotating frame of reference.

COULD “THEY” HAVE PLANNED ITS TRAJECTORY SO CAREFULLY AS TO USE GRAVITY AS A DECELERATOR TOO?

- With precise astrometry of all the stars and their planets along the way, and their masses and orbits in its first star system visited, it’s possible a proper trajectory could dissipate high interstellar velocities with careful targeting.
- We use “slingshot” techniques to use planetary orbital energy to add or subtract momentum from our spacecraft so they arrive at their Solar System targets at speeds to meet our goals.
- Why couldn’t another civilization do the same, using the stars in the local galactic neighborhood? Perhaps tough long-lived ion jets for fine tuning to “Target Earth”??

WHY TARGET EARTH? BECAUSE – ATMOSPHERIC OXYGEN AND METHANE TOGETHER TELL OTHER CIVILIZATIONS THAT PHOTOSYNTHETIC LIFE ABUNDANTLY COVERS EARTH.

- It would be a natural target, and easy to identify as such with technology hardly more advanced than our own today.
- However, aliens would not know we would have intelligent life at the time of arrival of their craft.
- Intelligent life here is only a few thousand years old at best, and their craft must have taken hundreds to thousands of millennia to make the trip.

IF INSTEAD IT WAS A COMET, COULD THE REQUIRED OUT-GASING STILL HAVE BEEN THERE, YET INVISIBLE?

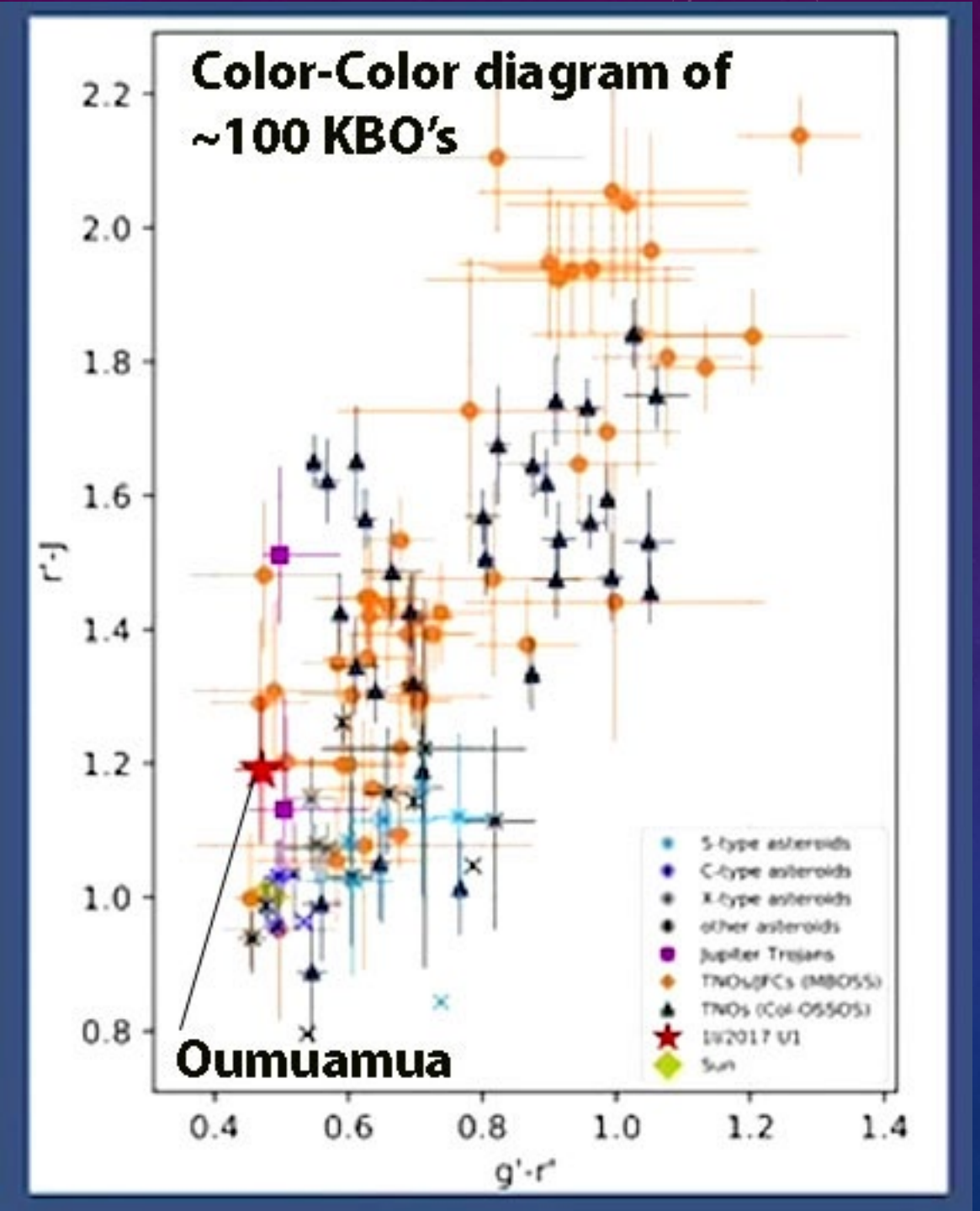
- If the gas were pure nitrogen N_2 molecules, then it has been suggested it could have been missed.
- Pluto, we know, has a nitrogen rich surface, as does Triton.
- But it would require the carbon to oxygen ratio for Oumuamua to be orders of magnitude less than for any known planet, KBO or comet, indeed anything in our own solar system or other stellar spectra, if Sekanina's outgasing reference is correct.

BUT OUTGASING HAS ANOTHER PROBLEM…

- Rafikov has pointed out (2018) that the observed acceleration, if caused by jets as we observe on comets, would not only accelerate the object, it would also cause its spin rate to change.
- We saw no such spin rate change, and no jets
- Laughlin, however, shows that if there were yet jet(s) not seen, and are free to migrate across the surface in just the right way, they can cause just about any light curve necessary to fit. But again, you need the jet(s) to behave this way.
- Laughlin also calculates that, on average and if natural, there should be an Oumuamua inside the Earth's orbit all the time. This, to me, suggests that the crater sized on our KBO's or even the lunar surface, could provide interesting limits.

KATZ (2021) POINTS OUT THAT A STELLAR SAIL CRAFT WOULD BE EXPECTED (STEPPING INTO ALIEN PSYCHOLOGICAL SHOES, IT SEEMS) TO BE DESIGNED TO BE MOVING AT HIGH VELOCITY

- After all, that's the point of a "sail"; to be able to accelerate a craft of low mass rapidly and get to another star system…. But then slowing it down is not going to likely be do-able.
- But Oumuamua instead is moving at a speed that is very close the Local Standard of Rest – the frame of reference at rest with respect to the stars in this part of the Galaxy.
- However, even Loeb does not argue that Oumuamua was still actively being controlled, but rather if it is of ET design, it was no longer functional. It may have been properly aimed towards the solar system by an ET civilization, but along the way, it lost control and/or contact.

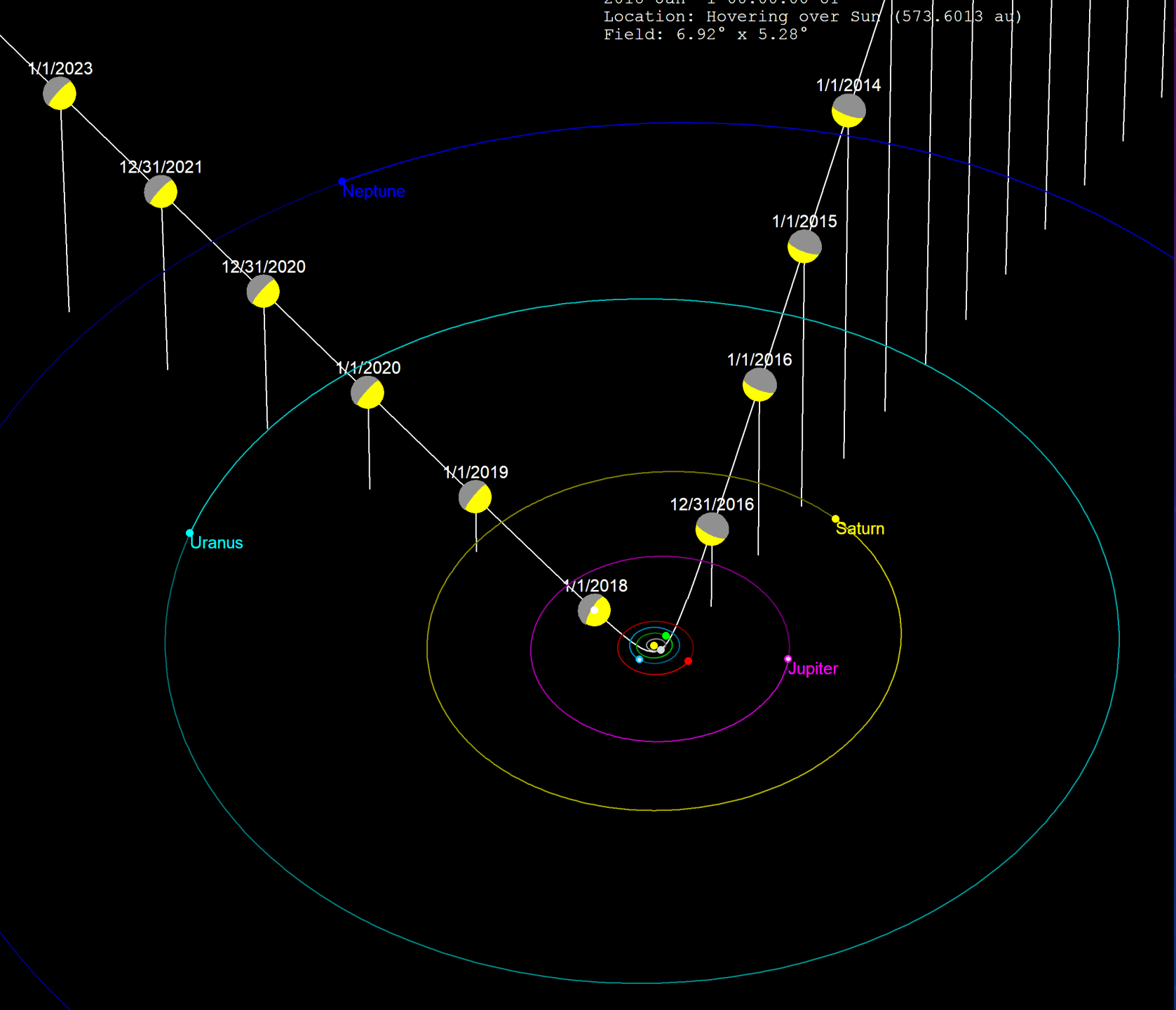


OUMUAMUA IS VERY RED, BUT THE COLOR IS NOT EXTREME COMPARED TO KBO'S WE KNOW.

COULD IT BE ONE OF OUR OWN KBO'S THAT GOT SWUNG INTO AN UNBOUND ORBIT?

EXTREMELY UNLIKELY…

- To give this kind of velocity, encounters with other KBO's would not provide enough energy
- But what about "Planet 9 from Outer Space"?... a ~super-Earth sized object inferred to be far out in the Kuiper Belt
- Yes, maybe… but ejections need to be 3-body interactions, so that one body can lose energy while the other gains it. But how likely is THAT? Have not seen the odds calculated.
- And worse….

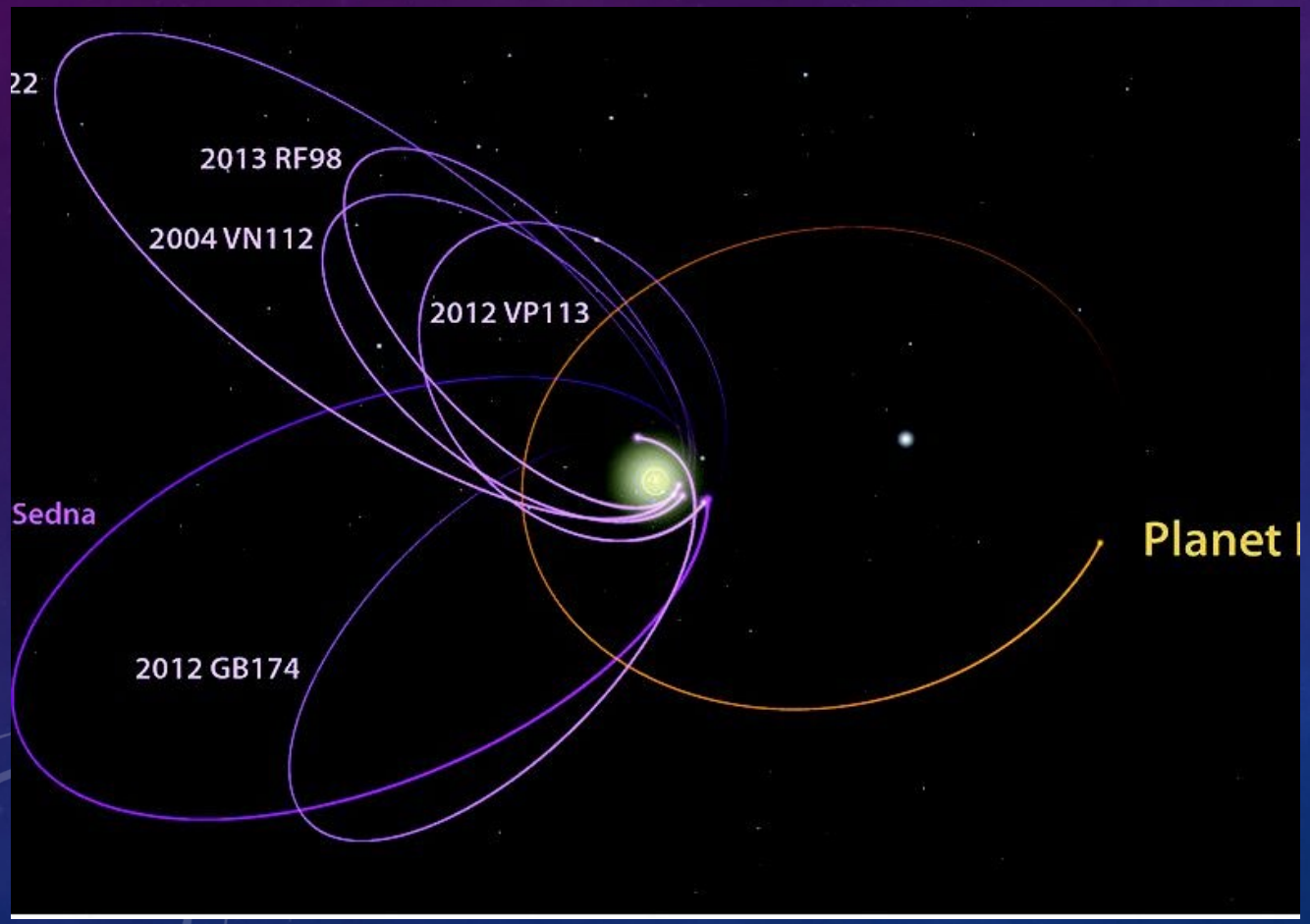


THE LINES HERE SHOW HOW FAR ABOVE THE ECLIPTIC PLANE OUMUAMUA'S PATH IS - CLEARLY A LOT!

BUT "PLANET 9" WOULD BE EXPECTED TO BE MUCH CLOSER TO THE ECLIPTIC.

SO, THIS THROWS A BIT MORE COLD WATER ON THE "PLANET 9" THESIS

WORSE: THE OBSERVATIONAL EVIDENCE FOR "PLANET 9" HAS RECENTLY EVAPORATED…

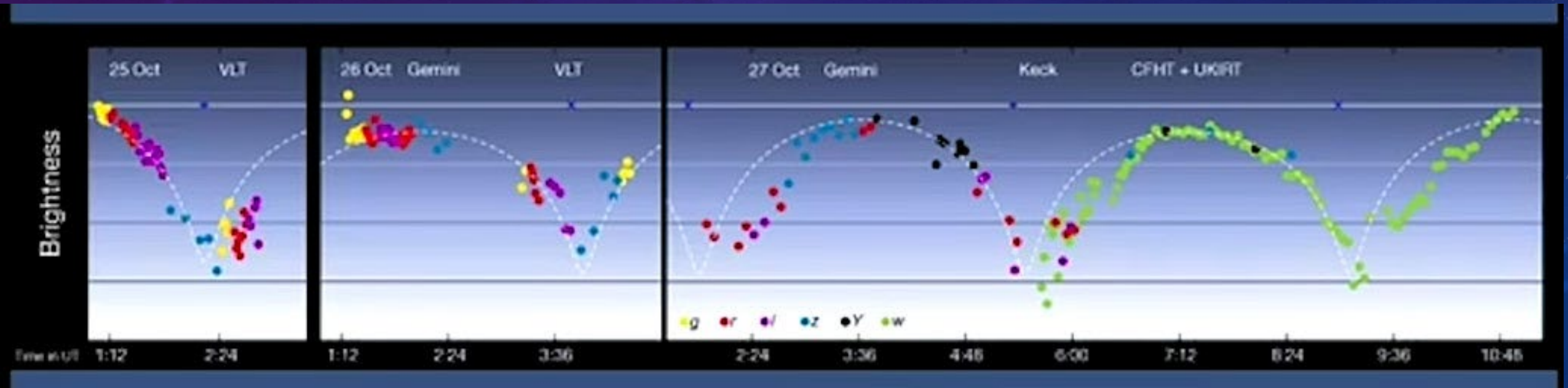


- The evidence *FOR* "Planet 9" was the clustering of the orbits of many of the discovered KBO's, with perihelia and inclinations that the authors (Batygin and Brown 2016) could explain by a hypothesized super-Earth sized planet

A MORE CAREFUL ANALYSIS OF THE SELECTION EFFECTS SAYS THE ORBITS ARE CONSISTENT INSTEAD WITH BEING RANDOM, REMOVING THE MOTIVATION FOR THE HYPOTHESIZED "PLANET 9"

- Napier *et al.* (2021) has now shown that carefully including the selection effects of the observatories discovering the KBO's that we know, that such selection effects bias towards discovery of objects with the unusual orbital statistics we see.
- He finds that now, instead of these orbits being a statistically very significant 3-sigma detection of the effect of a "larger perturber" (Planet 9), it shrinks to being only a 1-sigma suggestion, and could easily be random chance.
- Given that we've still not seen such a hypothesized large object, the most likely explanation now is that there IS no "Planet 9"

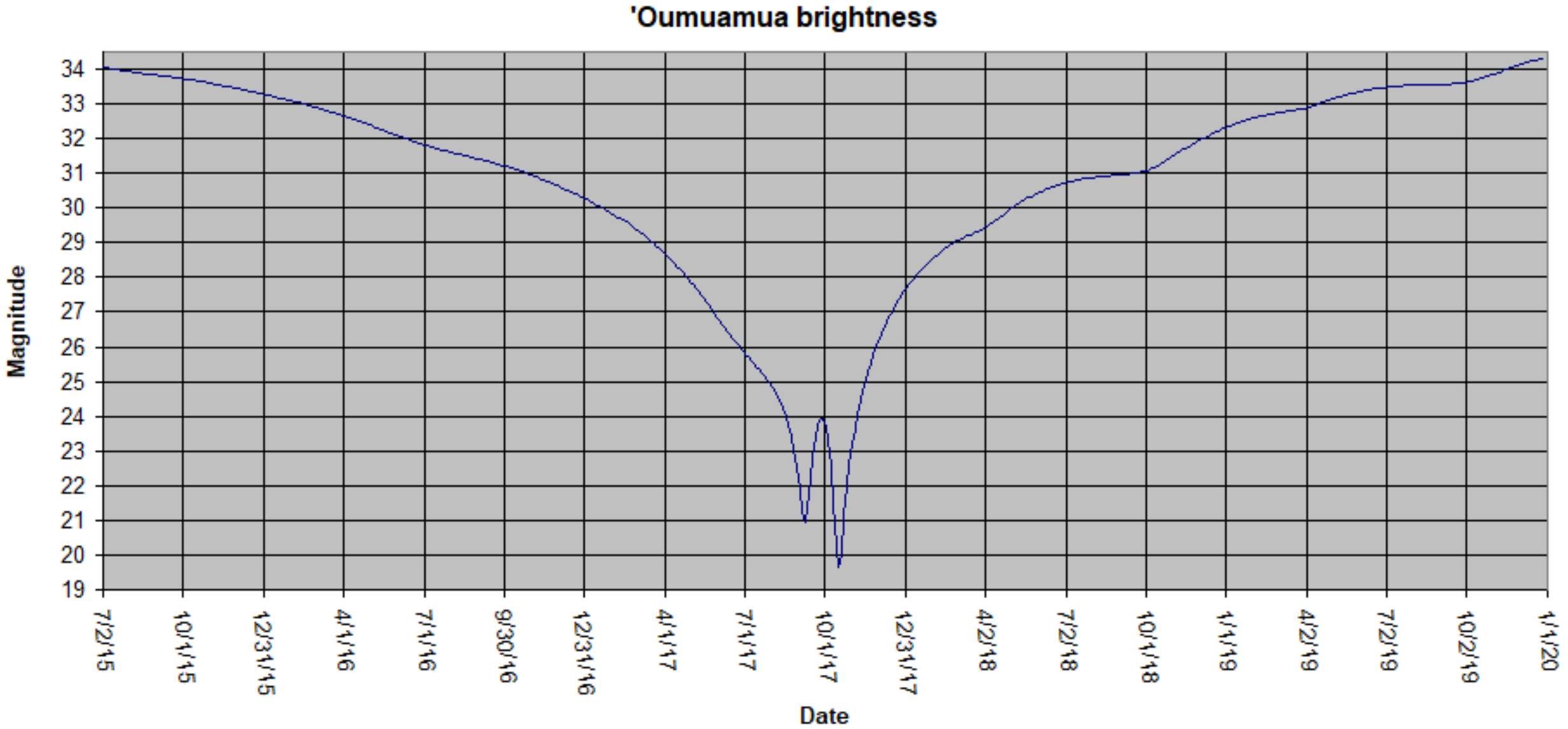
THE NON-REPEATING LIGHT CURVE SAYS OUMUAMUA IS “TUMBLING”. MEANING, IT DOESN’T HAVE A FIXED AXIS OF ROTATION



OUMUAMUA MUST HAVE SPENT A VAST AMOUNT OF TIME, HUNDREDS OF MILLIONS OF YEARS PERHAPS, OUT THERE SINCE "LAUNCH" OR ESCAPE FROM ANOTHER SYSTEM

- Tumbling will be damped out in any object that has any internal "degrees of freedom" – any internal movement, any dust or cracks to experience friction.
- So that argues STRONGLY, that this object is perfectly stiff and solid, and is not bendable, nor have any rocks or dust or pebbles or anything moveable on its surface or inside its internal structure.
- Else, it would not tumble, but instead have a fixed axis of rotation.
- It's either a solid ROCK, or solid ICE, or solid METAL like a very rigid solar sail.
- We have seen nothing like this in our solar system.

LIGHT CURVE RECONSTRUCTION; OF APPARENT BRIGHTNESS, UNCORRECTED FOR CHANGING DISTANCES.

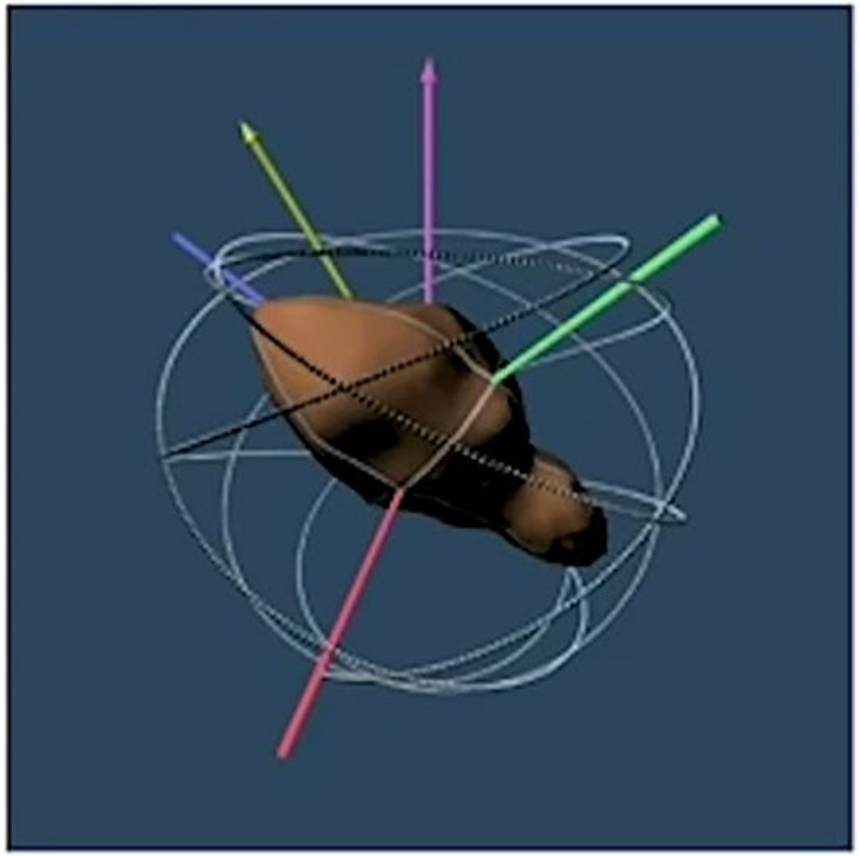


Asteroid tumbling

Most asteroids spin around shortest axis

Some asteroids tumble, like Apophis

Tumblers are usually very small or spin very slowly



In space, rotation lasts forever but tumbling damps over time

"rubble piles" damp tumbling much faster

Credits: Science/AAAS, KidKiddos Books

TUMBLING IS DAMPED BY INTERNAL MOTIONS; WHETHER FROM DUST, OR PEBBLES, OR SNOW, OR CRACKS. OUMUAMUA IS A VERY RIGID SOLID, WHATEVER IT IS.

SPEAKING OF MONOLITH'S…

- Photos of the Martian moon Phobos show a lit up "monolith"-like object.
- Fun! (or, "disturbing…") NASA is contemplating a mission to put a lander near this object for further exploration. Buzz Aldrin is in support (source)

THAT'S EERY.

DID "THEY" ALREADY SET UP AN OUTPOST ON THE MARTIAN MOON PHOBOS? THE NEAREST USABLE PLANET TO EARTH? (I'M JUST SAYIN'...)

INERT NATURAL OBJECT? OR ARTIFICIAL INTELLIGENCE DESIGNED, BUT ITS RADIO TRANSMITTERS LONG DEAD? WE DON'T KNOW. BUT IT'S "DISTURBING"

OTHER OUMUAMUA EXPLANATIONS HAVE TROUBLE…

- First proposal was that it might be made of pure hydrogen, and then it wouldn’t be so easy to see.
- Ionized hydrogen doesn’t have easily detected signals from such a small object
- But Huang and Loeb (2020) has shown that a pure hydrogen “comet” would not survive the long trip from another star system. It sublimates at only 4K temperature. Cosmic rays and star light alone would sublimate it to nothing before it arrived.

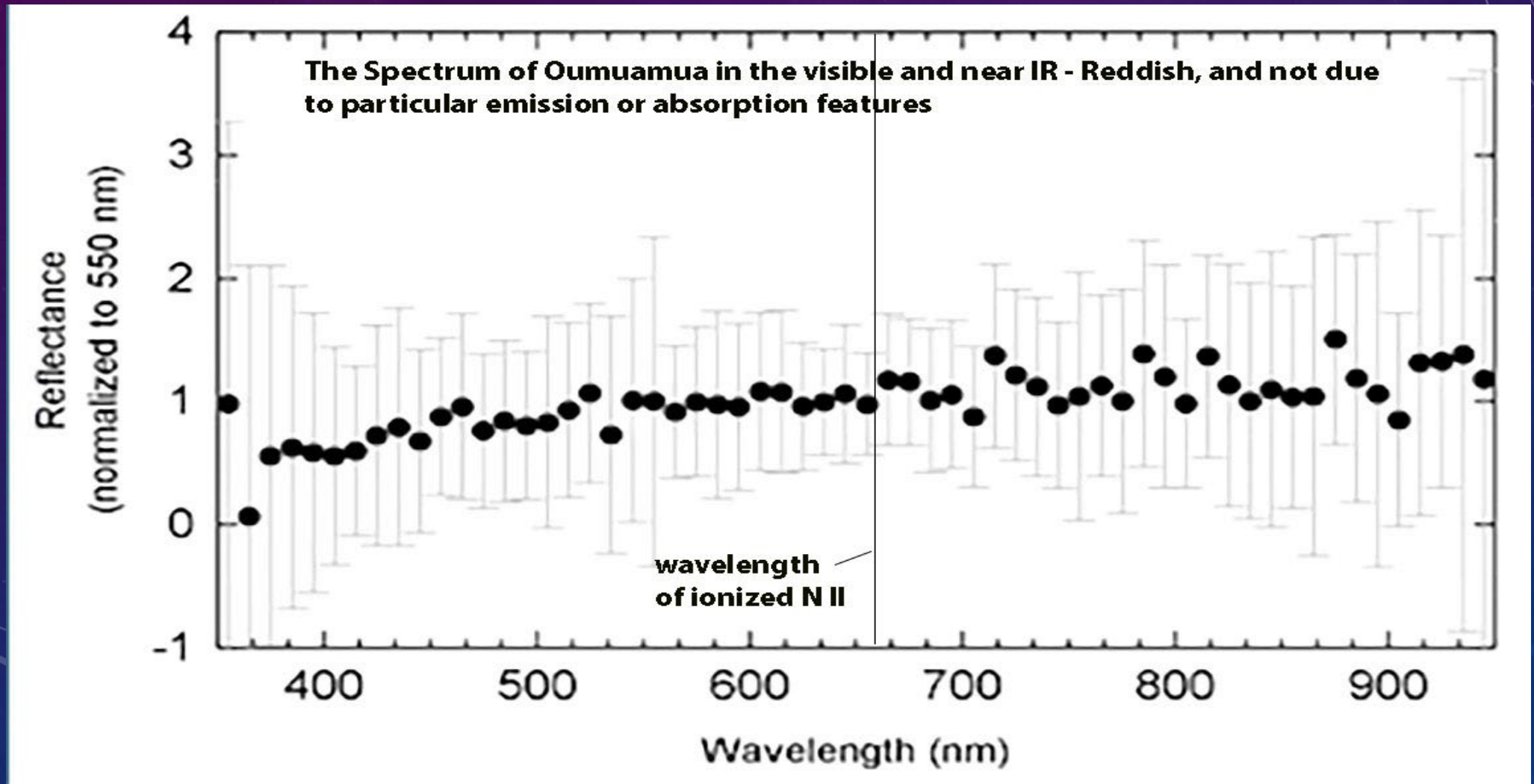
THEN, HOW ABOUT AN INTERSTELLAR "DUST BUNNY"?

- Jane Luu and co-authors suggest this. (Luu *et al.* 2020) and discussed in the media here
- The idea was to try to explain the large acceleration seen, which seems to require very low density.
- But this idea has the major problem that it would not be tumbling – dust bunnies are very fragile and easily excited internal motions, which would damp out the tumbling very rapidly.
- It's also problematic how it could survive the long journey from another star system in the high energy cosmic ray environment of the Galaxy. These are extremely high speed particle and would be expected to chew up such a fragile object rather quickly over time.

OK, THEN HOW ABOUT IF IT'S MADE OF PURE NITROGEN ICE?

- I wonder if we'd have seen, during its passage by the sun and the nitrogen sublimated off, that the N2 molecules would dissociate to N atoms, and a good fraction to be then ionized N II by the solar wind and UV.
- N II has a strong emission lines in the blue and red, in the red very close to the H-alpha line, at 660 nm wavelength
- The spectrum of Oumuamua was obtained, although of rather low signal to noise, and it shows no hint of any N II emission feature

THE SPECTRUM, SHOWS NO HINT OF AN EMISSION FEATURE AT THE IONIZED NITROGEN WAVELENGTH IN THE 660 NM AREA.



SO… A SAUCER SHAPED UTTERLY RIGID SOLID OBJECT, TUMBLING, UNCONTROLLED, PASSING BY EARTH.

- Where could it have come from?
- Bailor-Jones *et al.* (2020) traced the orbit and the Gaia Data Release #2 data to reconstruct its past trajectory, and find it was 0.6 pc away (a little over 1 light year, so not that close really) from the red dwarf star HIP 3757 1 million years ago.
- It is expected to pass within 1 pc of stars about 20 times every million years, or about 50,000 years between encounters.
- To arrive in our solar system and pass only 0.25 AU or 1.2×10^{-6} pc of our sun, is a remarkable bulls eye if these things are rare.
- On the outward journey, it passed only 0.27 AU from Earth on Oct 8, 2017. That's 25 million miles, and closer than either Mars or Venus ever get to Earth. Spooky.

BACK-TRACING THE ORBIT SHOWS 4 STARS CLOSE ENOUGH TO ITS TRAJECTORY TO BE POSSIBLE SOURCES OF OUMUAMUA, BUT ONLY JUST POSSIBLE, NOT LIKELY.

- The strong hyperbolic orbit and so the high velocity with which it entered our solar system argues, if natural and not alien artificial, that it most likely was ejected from a binary star system. Binary stars provide the extra body to absorb energy so other objects can be ejected.
- But none of these 4 stars are known binary star systems
- We don’t have a clear case for any originating stellar system at this moment.

THE BEST (AND MOST RECENT) NATURAL EXPLANATION SO FAR, STILL IS THAT OF DESCH AND JACKSON (2021)

- A chunk of nitrogen ice, like found on the surface of KBO's like Pluto, but with much less carbon.
- The color matches well, and the reflectivity and inferred size help match the outgasing quandry and minimize the needed mass.
- But it would have to be absolutely pure nitrogen with ~no carbon, which carbon molecules would be easily seen – and weren't.

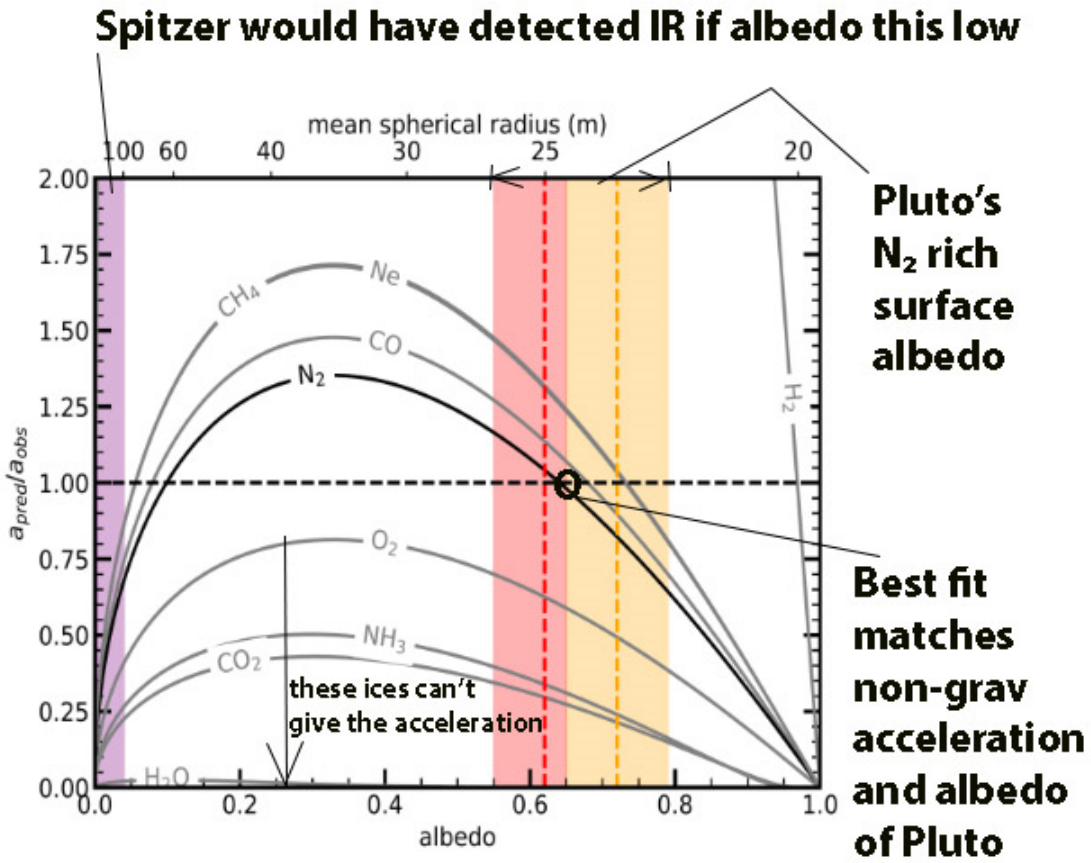


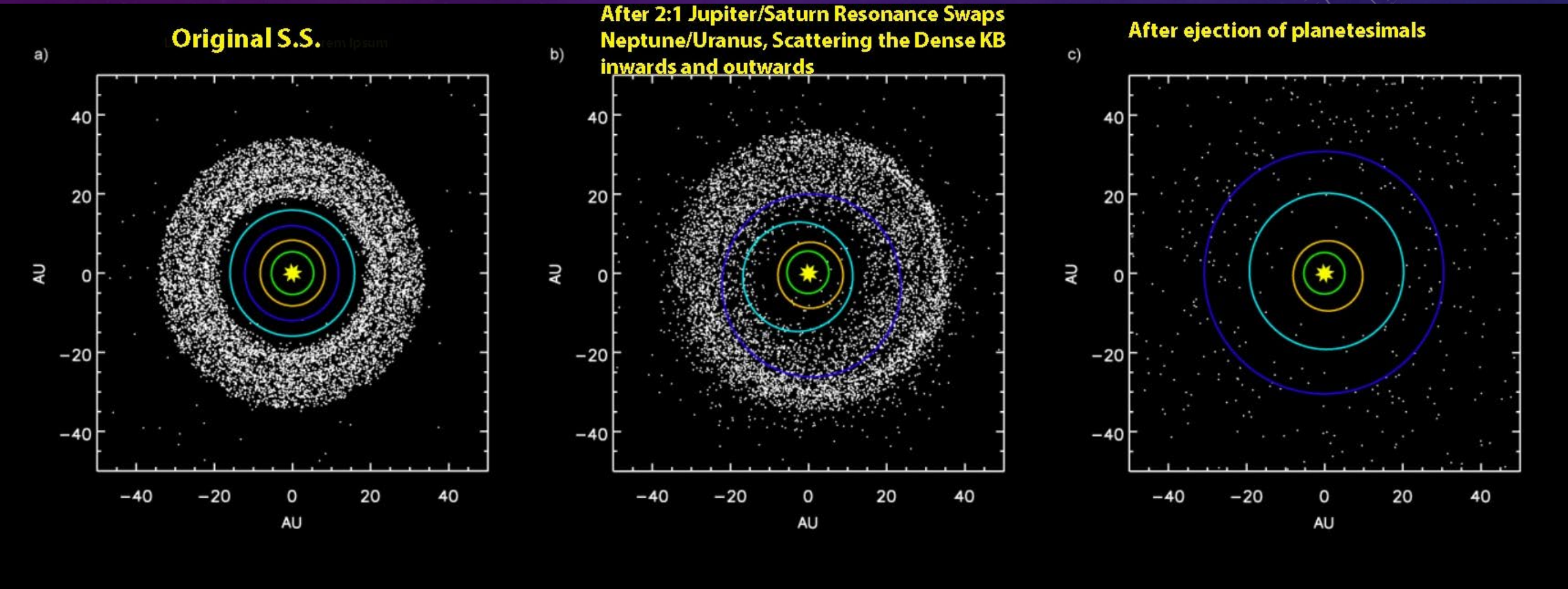
Fig. 1: Predicted non-gravitational acceleration at 1.42 au due to sublimation and jetting, relative to the observed value, assuming 'Oumuamua is an oblate ellipsoid of pure ice with the labelled compositions, for a range of values of the common geometric and bond albedo. The top axis converts albedo into mean spherical radius assuming a 6:6:1 axis ratio. Note that the H_2 curve extends far above the plotted range, peaking at ~13. The orange and red bands show the reported Bond and geometric albedos for Pluto respectively [11,12]. The purple band shows the range disallowed by the Spitzer non-detection.

PURE NITROGEN ICE, FOR A 45 M WIDE SAUCER, WOULD SUBLIMATE AT THE RATE NEEDED TO ACCOUNT FOR THE ACCELERATION OBSERVATIONS, AND IT ALSO FITS THE ALBEDO OF THE NITROGEN SURFACED OBJECTS PLUTO AND TRITON. BUT WHAT ABOUT THE LARGE ABUNDANCE NECESSARY?...

THEY POINT OUT THAT THE ABUNDANCE PROBLEM IS REALLY NOT AS BIG AS IT LOOKS AT FIRST GLANCE

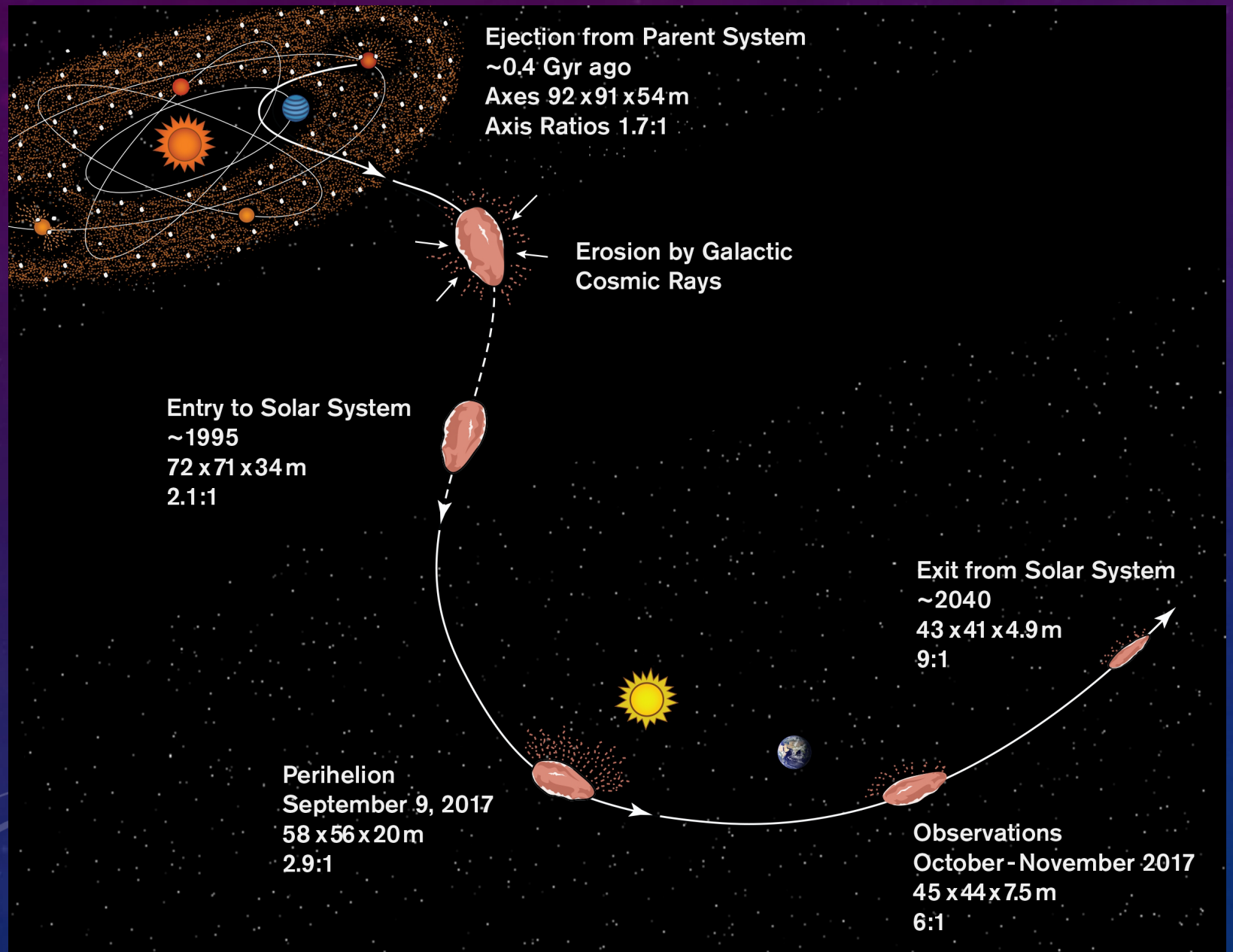
- Already, the inferred mass of the Kuiper Belt before Neptune / Uranus swapped places as inferred from the Nice Simulation can explain how the original Kuiper Belt could have had **~30 Earth masses** of total KBO material, not the 0.02 Earth's of today.
- See next slide…

A NUMERICAL SIMULATION (THE NICE SIMULATION) OF A PLAUSIBLE EARLY SOLAR SYSTEM WITH JUPITER AND SATURN NEAR A 2:1 RESONANCE, WOULD SCRAMBLE THE OUTER SOLAR SYSTEM, RESULTING IN LOSS OF MOST OF THE KUIPER BELT TO EJECTION, AND RESEMBLE TODAY'S RATHER WELL



THE DESCH & JACKSON IDEA THEN HYPOTHESIZES THAT…

- During this chaotic period, enough impacts on Pluto-like objects which they presume already had thick pure nitrogen ice crusts, would impact-liberate large numbers of N_2 ice fragments, some into interstellar space.
- Their inferred diameter to match the extremely high reflectivity of the pure N_2 surface of parts of Pluto, for Oumuamua shrinks to only 45m, not 200m. That gives a reduction in mass from our original calculation.
- Instead of needing 167 Earth's of material ejected, need only 167 x $(45/200)^3$ = 2 Earth's of mass ejected in this way, of N_2, per stellar system, to explain the probability of discovery, by my figuring.
- But best let's use their own numbers, which include different solar heating and interstellar cosmic ray erosion figures…



THE DESCH & JACKSON 2021 SCENARIO. AS PURE VERY REFLECTIVE N_2 ICE, IT MIGHT PERMIT THE VISIBLE ACCELERATION AND COLOR, AND EJECTION BY IMPACT ON PLUTO'S OF ANOTHER SOLAR SYSTEM LESS THAN ½ BILLION YEARS AGO. AS OBSERVED, IT WAS ONLY 3% OF ITS ORIGINAL EJECTION MASS, THEY SUGGEST

USING THEIR 3% FIGURE FOR THE OBSERVED *VS.* ORIGINAL MASS OF OUMUAMUA AT EJECTION ON THE LAST SLIDE…

- $6x10^{11}$ g/ 0.03 = 2 x 10^{13} g for Oumuamua at ejection.
- If 1.2 x 10^{16} per star system, as we saw from the discovery probability selection effect that was determined earlier, and in agreement with Loeb's calculation, that's still 2.4 x 10^{29} g in such ejected objects per star system
- **That's still 40 Earth's mass worth of Oumuamua's per star system. That's the number to remember.**

BUT THAT'S THE INFERRED MASS OF ALL OF THE ORIGINAL KUIPER BELT OF OUR SOLAR SYSTEM. AND YET IT ALL ENDS UP, SOMEHOW, AS UNBOUNDED N_2 FRAGMENTS? THAT MAKES OUR SOLAR SYSTEM VERY UNUSUAL.

- Yet even Jackson and Desch use prior research to quote that the nitrogen fraction should only allow nitrogen crusts that are a dozen or two km thick on large KBO's.
- A small fraction of the total mass in nitrogen, not ALL of it.
- So, this explanation, while I agree is the best we've got, is still extremely "surprising".

THE JACKSON/DESCH CALCULATIONS ALSO SAY

- That only about 4% of interstellar ejected objects should be nitrogen ice fragments
- So, it’s surprising that the very first one that we see is such a rare object
- But, not fantastically unlikely

Abstract

"The origin of the interstellar object 1I/'Oumuamua, has defied explanation. In a companion paper (Jackson & Desch, 2021), we show that a body of N_2 ice with axes 45 m × 44 m × 7.5 m at the time of observation would be consistent with its albedo, non-gravitational acceleration, and lack of observed CO or CO_2 or dust. Here we demonstrate that impacts on the surfaces of Pluto-like Kuiper belt objects (KBOs) would have generated and ejected ~10^{14} collisional fragments—roughly half of them H_2O ice fragments and half of them N_2 ice fragments—due to the dynamical instability that depleted the primordial Kuiper belt. We show consistency between these numbers and the frequency with which we would observe interstellar objects like 1I/'Oumuamua, and more comet-like objects like 2I/Borisov, if other stellar systems eject such objects with efficiency like that of the Sun; we infer that differentiated KBOs and dynamical instabilities that eject impact-generated fragments may be near-universal among extrasolar systems. Galactic cosmic rays would erode such fragments over 4.5 Gyr, so that fragments are a small fraction (~0.1%) of long-period Oort comets, but C/2016 R2 may be an example. We estimate 'Oumuamua was ejected about 0.4-0.5 Gyr ago, from a young (~10^8 yr) stellar system, which we speculate was in the Perseus arm. Objects like 'Oumuamua may directly probe the surface compositions of a hitherto-unobserved type of exoplanet: "exo-plutos". 'Oumuamua may be the first sample of an exoplanet brought to us."

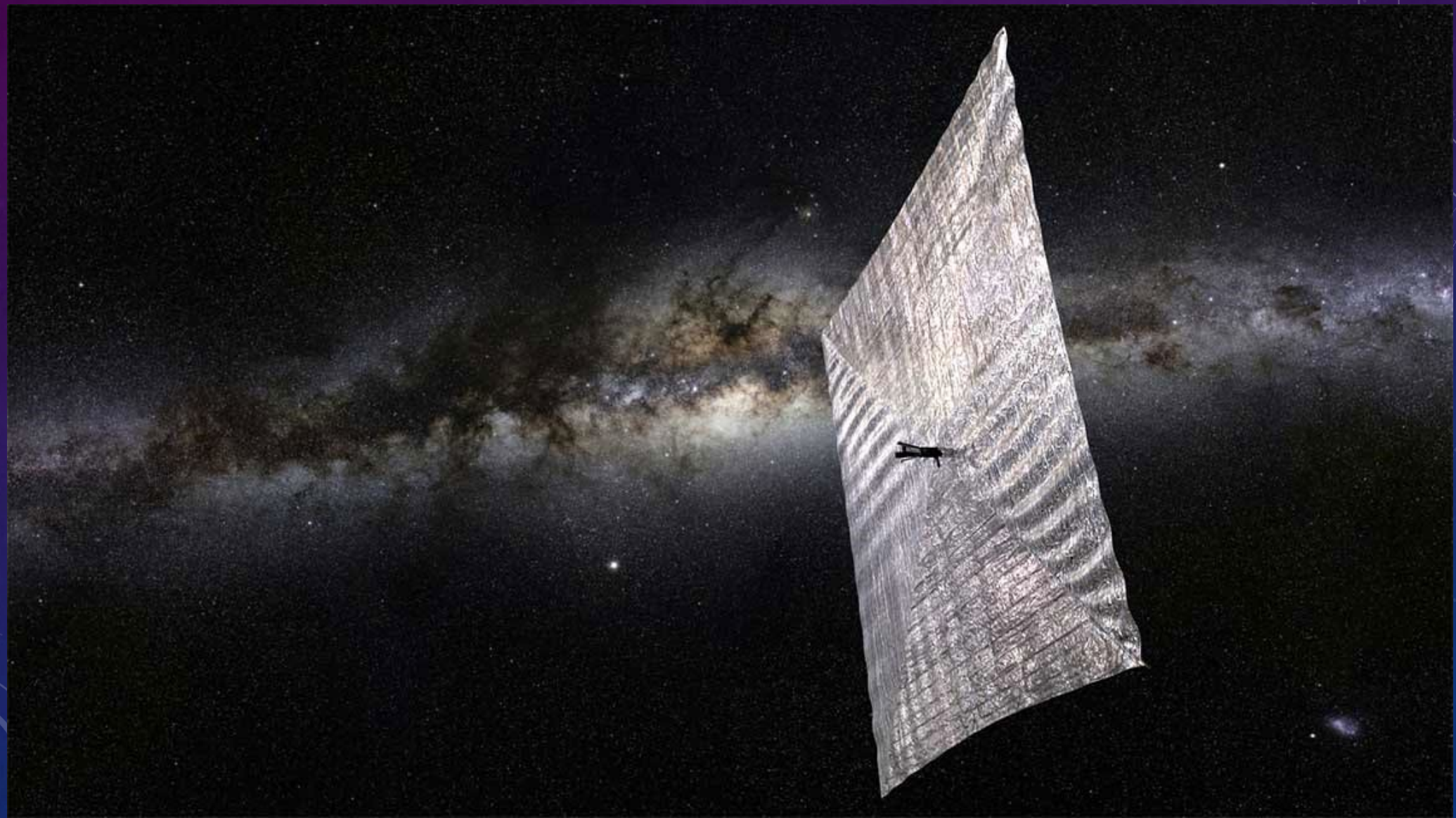
THE JACKSON AND DESCH ABSTRACT

- Reduces the required original mass by reducing the size as seen, to only ~45m across, requiring remarkably high albedo, higher than anything in our solar system, although parts of the surfaces of Pluto and Triton approach this.
- Regardless, this object is unlike anything we've yet seen. No straightforward explanations fit well.
- As Yale's Greg Laughlin observes *"There are no slam-dunk explanations for Oumuamua"*
- *Maybe we're arguing backwards… arguing that "typical" means "like our solar system".*

ARGUING INSTEAD FROM THE ANTHROPIC PRINCIPLE…

- It’s dangerously anti-Baysian to assume our Kuiper Belt is typical.
- After all, it’s the Kuiper Belt of a known intelligently inhabited solar system – quite a big factor to put into Baysian statistics when judging probabilities!
- Perhaps to have a livable inner solar system for billions of years, it is highly favorable to have a very light weight Kuiper Belt; so low mass that ours could indeed be very rare, and the “remarkable” other solar systems are actually typical.

NOW, TO COME BACK TO THE ALIEN SPACE CRAFT HYPOTHESIS AND LOOK FOR STRENGTHS AND WEAKNESSES



IF IT'S ARTIFICIAL INTELLIGENCE DESIGNED AS A STELLAR SAIL….

- There's another question – how did it survive the cosmic rays for X number of years and not dissolve?
- So what is a reasonable X years, being in interstellar space??
- Well, let's say it came from a star system about 100 pc or 300 light years away, maybe not impossibly unreasonable for the next nearest star system with intelligent life? So, it had to carom off probably several star systems to arrive here correctly, let's say 4 systems to pick a possibly reasonable number. You can't go too big or the aiming precision gets impossible…
- Say that results in a path length of 700 light years. Let's say it is travelling during that time at speeds roughly 1.3x escape velocity from typical Habitable Zone of a sun-like star, and we don't get captured by any of these 4 stars.
- So lets say…. 55 km/sec = 30 miles/sec avg speed.
- So the time in space is… 1000 lyr x $6x10^{12}$ miles/lyr -> $60x10^{14}$ miles/30 miles/sec = $2x10^{14}$ sec

SO THAT'S $2X10^{14}$ SEC / $3.15\ X10^{7}$ SEC/YR =

- …about 6×10^{5} years
- ~600,000 years drifting in space, till arrival here.
- That's a factor of 1000 quicker than ½ billion years for the Jackson and Desch proposal, which is so destructive for nitrogen ice.
- Can we devise tough metallic materials for a solar sail that could handle that much cosmic ray exposure? I'm guessing that's do-able

A TARGETING PUZZLE FOR THE “GHOST SAIL-CRAFT” HYPOTHESIS…

- If this object is a stellar sail, making use of gravitational sling-shots to arrive at Earth, as a sail it will also have to “tack” and “trim” expertly when in the neighborhood of any star, to insure its proper targeting at Earth; the force on the sail will be significant, and alter the path if not tacking and trimming perfectly.
- If the sling-shot’ing took several stars to accomplish the final destination target at the proper speed, it must have used highly precise expert sailor-ship skills or (very tough ion drives for mid-course corrections?) for each stellar maneuvering encounter…
- And yet then somehow, lost control after arriving finally at Earth? Tumbling out of control. This seems a bit unlikely and incredible bad luck for the Alien engineers.

OF COURSE, THERE'S ALWAYS THE POSSIBILITY…

- Maybe they WANTED us to believe it was out of control!... and no danger to us, and natural, so they initiated tumbling when still too far away for us to detect!
- This sounds entertainingly conspiratorial… but the big problem with this is – they could not possibly have known what would be the state of our civilization upon arrival in our solar system, if launched even just 1,000 years ago, let alone 100,000 years ago

IF STEALTH WERE THEIR GOAL, HOW COULD THEY KNOW WE'D BE UNPREPARED?

- Technology so far as been advancing so rapidly that (being optimistic we'll survive intact our current adolescent maturity phase) , then we would likely have sensors and perhaps defenses constructed on the surfaces of our own KBO's, like the Cold War era DEW (Distant Early Warning) line.

OR DID OUMUAMUA ACTUALLY LAUNCH FROM AN ALIEN AUTOMATED “BASE” IN OUR OWN KBO, SO THE LIGHT TRAVEL TIME WAS NOT A PROBLEM…

- Pre-programmed to notice when we became capable of planetary suicide, on this preciously ultra-rare planet, and monitor how we handled it…
- … and are not happy with the assessment…
- … and the decision is to eradicate the cancerous species so the rest of the planet may live…
- … and the Doomday Machine is just getting cranking up now, to arrive later
- …. Guns blazing!
- ….Or…

A SURGICAL STRIKE USING “NANO-DEATH-BOTS”!

IF AN ALIEN SPACECRAFT

- We could have been visited….
- What is “their” next step??
- Is the Mother Ship hovering out there, tuning up their big photon torpedoes, and readyin’g their armies of nano-death ‘bots! (like Keanu Reeves did in “The Day the Earth Stood Still”!)
- Only time will tell
- Where’s my agent? I need to submit this script to Hollywood!

NOW, LIKE ANY GOOD STORY, WE NEED OUR PLOT TWISTS AND SURPRISING ENDINGS

- We've made as good and generous a case for the ET Intelligence origin of Oumuamua as we can, and shown trouble with some of the early proposed and even newly proposed natural solutions.
- But there's another numerical simulation based variation we've saved for last… It's due to Zhang and Lin (2020).

TIDAL DISRUPTION OF DWARF PLANETS BY THEIR PARENT STAR, AND THEN SOMEHOW ACQUIRING INTERSTELLAR SPEEDS AND ESCAPING.

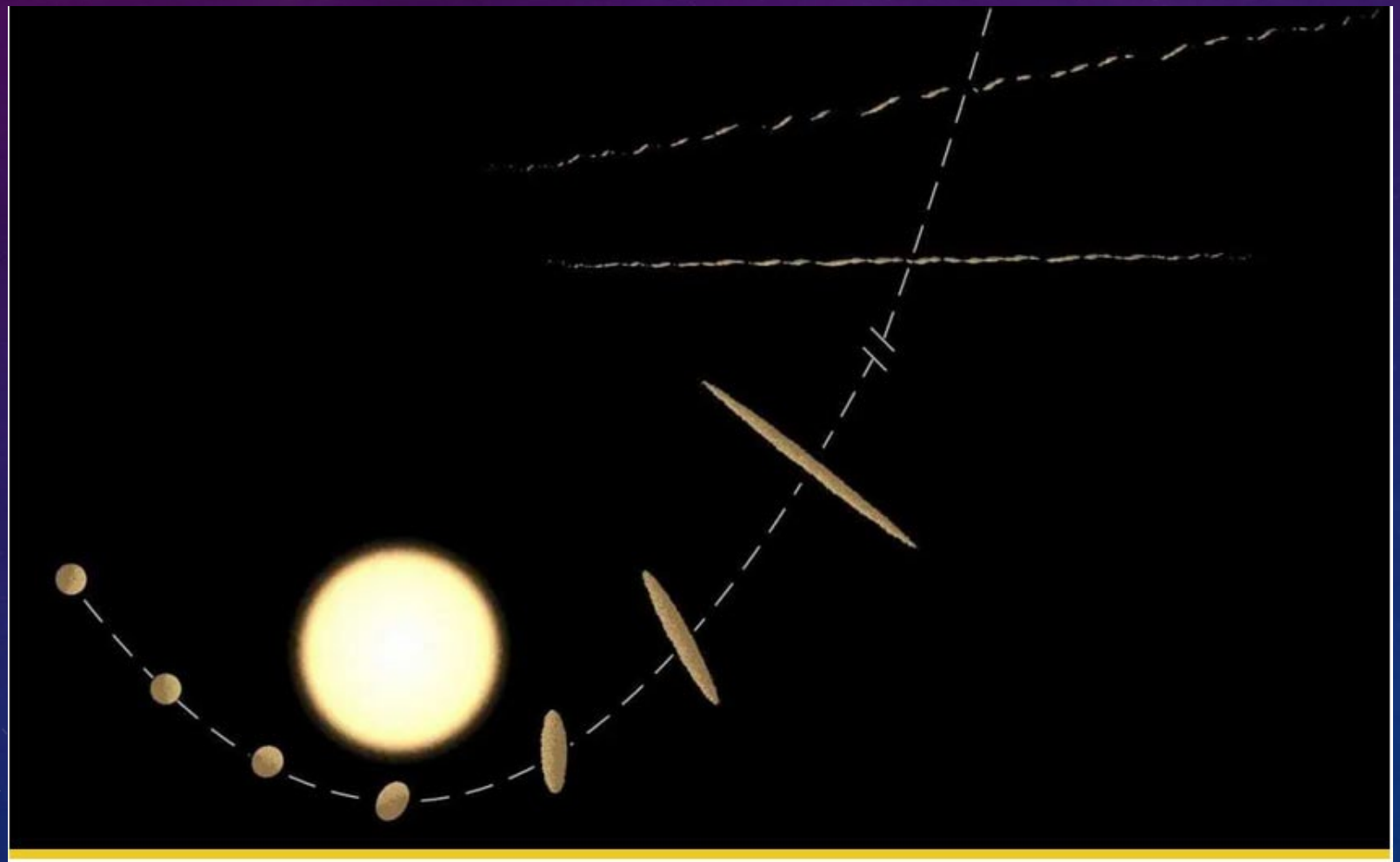


Illustration of stellar tidal disruption processes – Credit : ZHANG Yun

SOME PROBLEMS SOLVED…

- The huge mass estimate we got for the N_2 ice idea is reduced quite a bit because the idea is that these tidal fragments are pretty much unaltered since they left their parent system, so they're small to start with and small still.
- It means the scale up by ~ a factor of 30-100 to get to original mass, is not needed.
- That still leaves several Earth's worth of material, and our own Kuiper Belt has only an estimated .02 Earth's worth of mass.
- We could be wrong, and there's far more small material out there than we think, based on the small crater abundances on the few KBO's we've got close-up photos of. Maybe our solar system is unusual in having such a small population of such objects.

BUT WHERE TO ACQUIRE THE INTERSTELLAR ESCAPE VELOCITY?

- Tidal disruption takes orbital energy and converts it to internal disruption, dissipating energy and causing a loss of orbital speed, so the ejection must happen later, by some other way;
- Chance encounters with other planets?
- That’s an awful lot of material to get unbounded after close passage by parent star. But Zhang and Lin find it plausible.

AND THE ACCELERATION OBSERVED *VS.* BALLISTIC TRAJECTORY?

- The supposition is that there could be water beneath the surface of the crusty exterior, and outgasing that could provide the boost.
- But the estimates I've seen say that boost would require at least 10% of the mass of the object itself to be vaporized and outgased to provide the observed acceleration.
- Water outgasing is what provides comets with their tails – again we're back to the fact that deep images subtracting stellar point-spread-function photometry failed to show any coma or tail at all.
- Perhaps there's numerical explanations, but the paper is behind a firewall and the usual popular sources all look alike and don't address these questions.

BUT THE N_2 ICE IDEA WAS ATTRACTIVE BECAUSE IT ALLOWED OUMUAMUA TO BE SO SMALL AND MIGHT NOT SHOW A COMA OR TAIL, SINCE IT WAS LIGHT AND SO SHINY

- If we're back to it being a dark rocky rubble covered object, then the cost is that we need it to be larger again, such as ~500m in order to account for its brightness.
- And larger means it needs orders of magnitude MORE somehow invisible outgasing to account for the acceleration observed.
- I don't see discussion of calculations that address that. Perhaps Zhang and Lin did, but I'm frustrated by the failure of *e.g.* Physics.org and the UCSC media outlet, to ask these vital questions of the authors, or simply get them from the paper.

RESPECTED LONG TIME COMET EXPERT ZDENAK SEKANINA (2019) POINTS OUT THAT THE OBSERVED LACK OF OUTGASING PUTS AN UPPER LIMIT OF ONLY $4X10^{23}$ MOLECULES PER SECOND.

- This is about the amount of air contained in your milk carton after the milk is gone(!)
- The observed acceleration for such tiny outgasing then requires the bulk density to be less than 0.001 g/cm^3, or not much more than a dust bunny. Or a solar sail if averaging over a ~spherical volume.
- But such low densities are inconsistent with tumbling motion, which we pointed out would be rapidly damped out by the mechanically weak dust bunny natural structure.
- A well-designed solar sail, built for interstellar travel, could work though.

OUTGASING CANNOT EXPLAIN THE OBSERVED ACCELERATION, EITHER BY WATER ICE, NOR CO NOR CO_2 ICE SUBLIMATION

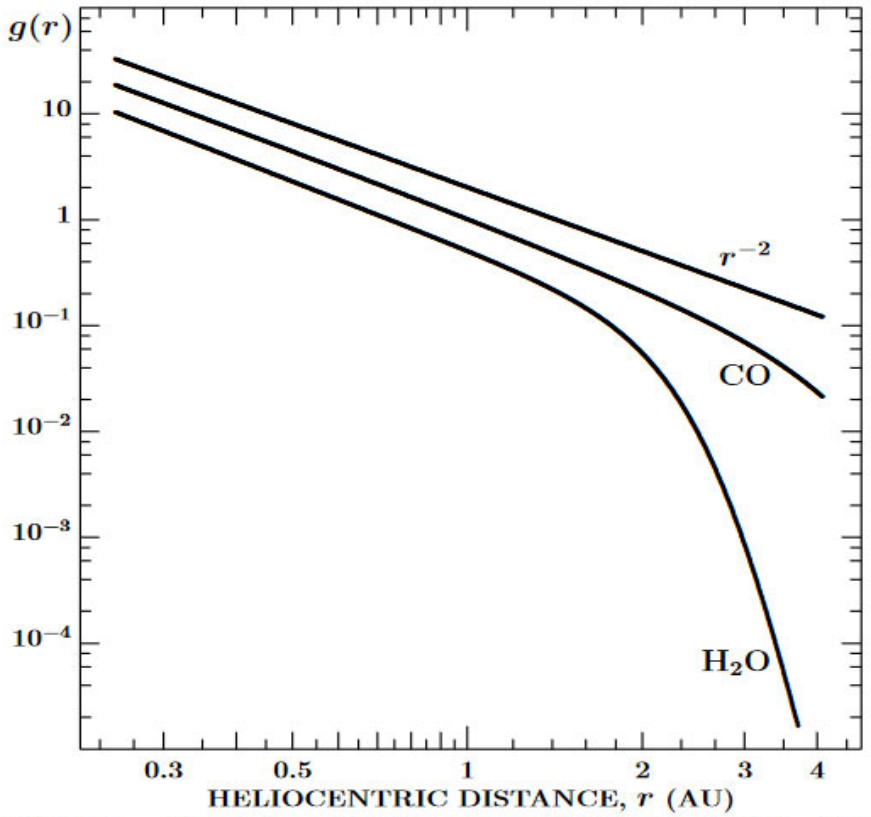


Figure 1. Comparison of three nongravitational laws $g(r)$. The H_2O curve is the standard Style II law by Marsden et al. (1973), describing the sublimation of water ice. The CO curve is the carbon monoxide law by Yabushita (1996), applied by Nakano to comet C/1998 P1. The r^{-2} curve is the inverse square power law of heliocentric distance employed by Micheli et al. (2018) for the nongravitational acceleration of 'Oumuamua. The three curves are essentially equivalent up to about 1 AU from the Sun; the H_2O law then diverges rapidly. The curves are vertically shifted for clarity.

- Sekanina's study (2019) adds additional arguments against water ice as causing the observed acceleration, from behavior *vs.* distance from sun.
- The observed acceleration was well fit by a r^{-2} law, not the much different trend from H_2O water ice sublimation (Micheli *et al.* 2018)
- N_2 ice isn't shown here, but would be well fit by the r^{-2} law, since it sublimates at a much lower temperature than either CO or H2O. So the Desch/Jackson idea survives here

TYPICAL COMET – SHOWING GREEN C2 EMISSION, AND BLUE ION TAIL WITH YELLOW DUST AS WELL, IN BLENDED COLORS… NOTHING LIKE OUMUAMUA

AVI LOEB HAS READ THE FULL ZHANG AND LIN PAPER – HE IS NOT CONVINCED BY THE STUDY.

- *"To account for Oumuamua as a member of a population of interstellar objects on random orbits, one needs each star to produce roughly a quadrillion (a thousand trillion) such objects, totaling roughly an Earth mass of rocky material per star. It is very unlikely that tidal disruption events will produce so many Oumuamua-like objects because these are rare events restricted to the region near a star, which is tens of millions of times smaller than the size of the planetary system around it," he explained.*
- (Zhang and Lin, and so Loeb here, is assuming now that as a dark rocky surfaced object, it wouldn't suffer so much from erosion by cosmic rays or solar heating, so the mass at parent system ejection is not 167 Earth's, but maybe 1 or 2 Earth's. But then, why no dust seen??)

SUMMARY

- We’re left with the highly improbable, or the fantastic, as explanations.
- The “ghost ship” alien space craft idea is wild, but hard to rule out, on the evidence.
- However, it does still have its own troubles…

THE JACKSON AND DESCH (2021) N_2 ICE IDEA…

- A nitrogen ice shard from impacts on Pluto-like KBO's in other solar systems, is the most recent paper and I think the most natural plausible explanation.
- The large amount of material required might be best explained in reverse – that our own solar system is unusually light-weight in KBO's
- The invisibility of any ionized N II emission is possibly another problem, but the paper does not address this, nor any other accounting I've read

THE DUST BUNNY IDEA OF LUU *ET AL.*

- Makes for a tiny mass easier to accelerate with just solar radiation pressure.
- But is still an object unlike any seen or reasonably argued prior to Oumuamua.
- And, it fails against the damped tumbling argument.
- It also would seem to be extremely fragile against the millions of years of peppering by speed-of-light relativistic cosmic rays and very unlikely to survive.

THE TIDAL DISRUPTION OF DWARF PLANETS THEORY, BY ZHANG AND LIN

- Well-done numerical simulations find gravitational tidal disruption events could be made at the rate needed to produce so many fragments.
- Has not explained, so far as I can tell, the non-gravitational acceleration, as water vapor has already been ruled out, as completely insufficient to power the observed acceleration.
- If its propellant (water) is buried and safe from interstellar cosmic rays, then we'd very much expect just a few jets of outgasing; this would cause varying spin rate. We saw no such spin rate change. Spin rate remained 8 hrs, for months. Also, the carbon fractional abundance would have to be orders of magnitude lower than for any other object in the solar system – including watery objects like Enceladus and Jupiter's moons. How could it have a dark rocky crust and not show any dust emission after solar passage, is not explained.
- And the mass of such rather more conventional and heavier objects makes worse trouble for explaining the significant acceleration and yet no outgasing.

THE ALIEN CIVILIZATION ARTIFACT THEORY OF LOEB

- It still requires the manufacture and regular launch of large numbers of these crafts, (since they couldn't know when we'll grow up enough to pay attention and notice them) to have just happened to find one so soon after PanSTARRs went online.
- But, not nearly as many at 10^{15} per system. Reduces the abundance problem by a factor of about 30 million according to Loeb (5 minutes into this interview), since it's directly targeted to our inner solar system and Earth.

WHY REDUCED BY A FACTOR OF 30 MILLION?

- Avi Loeb then figures that the odds of encountering it are improved by a factor of 30 million, since the inner solar system is the deliberate target, occupying a much smaller volume of space than random objects would occupy.
- **So instead of 10^{15} of these inside our Oort Cloud now, there are "only" 30 billion of them.**
- That's about the same number as automobiles that we've created just since 1900.

AT WHAT RATE DO ALIEN CIVILIZATIONS HAVE TO LAUNCH SUCH SAIL-CRAFT TO HAVE OUMUAMUA'S DISCOVERY BE REASONABLE?

- PanSTARRS was online taking science for 7 years when it discovered Oumuamua.
- Figure then, that PanSTARRS would encounter one every ~30 years, to not be unreasonable odds of our discovery
- Elsewhere (The Modern Drake Equation), we considered new understandings of how rare Earth's unique characteristics are in being well suited to carbon-based life for 4 billion years, to arrive at intelligence (us), to conclude there are very few in the Galaxy.
- That's good, and bad. It means that we are very special, and an alien civilization would more likely be highly interested in us, and worth perhaps a large investment.
- It's bad, because "they" are then likely to be thousands of light years away, and would likely only know that life existed on our planet, not that it was intelligent life.

WE'RE GOING TO ASSUME THAT SUCH CRAFT HAVE A "STANDARD" SIZE, AND OUMUAMUA IS IT: 100M OR SO IN DIAMETER, ABOUT LIKE A GOOD SIZED RADIO TELESCOPE DISH

LET'S ASSUME IT'S A SAIL CRAFT, AND SO MOVES THROUGH THE GALAXY FAIRLY SLOWLY, GIVEN THE MASS NEEDING ACCELERATION BY WEAK STARLIGHT.

- Assume there is just one civilization that is targeting Earth
- Assume this civilization is long past its adolescence, successfully, and has made the choice to invest heavily in trying to explore or signal Earth, to join their tiny **Civilizations of the Milky Way Galaxy Club.**
- The astronomical tragedies waiting to cause mass or total extinctions, only come along once every ~100 million years for our Earth, so assume their civilization has been launching these craft a long time. Thousands, maybe hundreds of thousands of years, hoping to get a 'return on investment'.
- What rate does a civilization have to create and launch such sail craft?

IT'S ACTUALLY A STRAIGHT FORWARD QUESTION

- If you assume they're expert marksmen (sailors!).
- The rate of launch is just the rate of discovery, or once every ~30 years.
- Say they have a failure rate of 80%, so only 20% get to arrive to within the PanSTARRS regime for discovery
- **So they need to build and launch one of these about once every 6 years.**
- That would seem a pretty do-able investment, and not unreasonable given the tiny odds that their craft would arrive at a time that *Homo Sapiens* became interesting and needing their attentions – for good or ill.
- If a team of civilizations took on this task, then it's cheaper still.

IF OUMUAMUA IS AN ALIEN CRAFT, IT RELIEVES SOME OTHER PROBLEMS…

- The outgasing problem is solved because solar radiation pressure explains the r^{-2} behavior. However, N_2 ice does as well, since it sublimates only at regions far beyond our observations.
- The thin, designed-to-be-tough low-mass solar sail idea solves the huge inferred original ice mass problems too. Now, the original mass was just the same mass, and thin and light weight, as we saw.
- We don’t know how many stars it may have sling-shot’d off of, but very likely very few if the sailor’ing was that good. Yet, upon arrival, it seemed out-of-control. Strange.

OF COURSE, WE CAN ALSO TILT OUR MINDS TO “THE DARK SIDE”…

- What if it was designed to LOOK like it was tumbling out of control, and so take us off guard??
- What if “they” set up an automated robot-controlled outpost in the outer solar system, to spy on us close range, without the speed-of-light delay problems. **Artificial General Intelligence**.
- Waiting …. For the moment we “came of age” and watched how we handled OUR adolescence as a technological species, perhaps knowing that most interstellar civilizations die young, by their own immaturity in handling their urges for eternal “growth”?

AND, SEEING US ON THE VERGE OF WRECKING OUR CLIMATE FOR MILLENNIA, THEN INITIATING THE LAUNCH OF OUMUAMUA TO SCOUT US CLOSER…

- …Perhaps sending back enough information to finalize setting in motion…
- **The Doomsday Machine (captain'ed by Keanue Reeves??)**

WILL WE NEED TO CALL ON JENNIFER CONNELLY TO MELT THEIR HEARTS AND CONVINCE “THEM” TO GIVE US A SECOND CHANCE?

OUMUAMUA MAY HAVE SOLUTIONS – IF WE JUST WAIT A FEW MORE YEARS

- When the Vera Rubin telescope goes on line, it should detect more such interstellar objects (if they exist in a natural distribution of sizes), and catch them before they reach the inner solar system, so we can have a launch mission ready to get a close up inspection.
- Unless we were just incredibly lucky to catch an incredibly rare object, and then… we may ~never know.

SUMMARY OF SUMMARIES…

- If Oumuamua was a very rare very lucky “hit”, the options are still wide open
- If it’s typical, then the most likely natural explanation is that of Desch and Jackson 2021 – a N_2 fragment from repeated impact peppering of KBO’s during a chaotic orbital migration phase in another stellar system.
- But it also suggests our solar system is unusual in still having had such an event, but the original Kuiper Belt was then unusually low massed.
- Unusual, but perhaps not if you apply the Anthropic Principle. Heavy bombardment by a much richer KB could have spelled doom too often for life in the inner solar system to grow to intelligence.
- If it’s an alien spacecraft, “they” must be a far older technological civilization that we are, and extremely interested in us to send so many spacecraft for so so many millennia, every few years, in hopes of whatever contact they’re wanting. But not unreasonable.


THE TRUTH IS OUT THERE