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1I/'Oumuamua and 2I/Borisov

the unexpected and the half-expected interstellar visitors

You May Have Seen This Picture

ESO Observations Show First Interstellar Asteroid is Like Nothing Seen Before
VLT reveals dark, reddish and highly-elongated object
20 November 2017
www.eso.org/public/news/eso1737/

Credit: ESO/M. Kornmesser

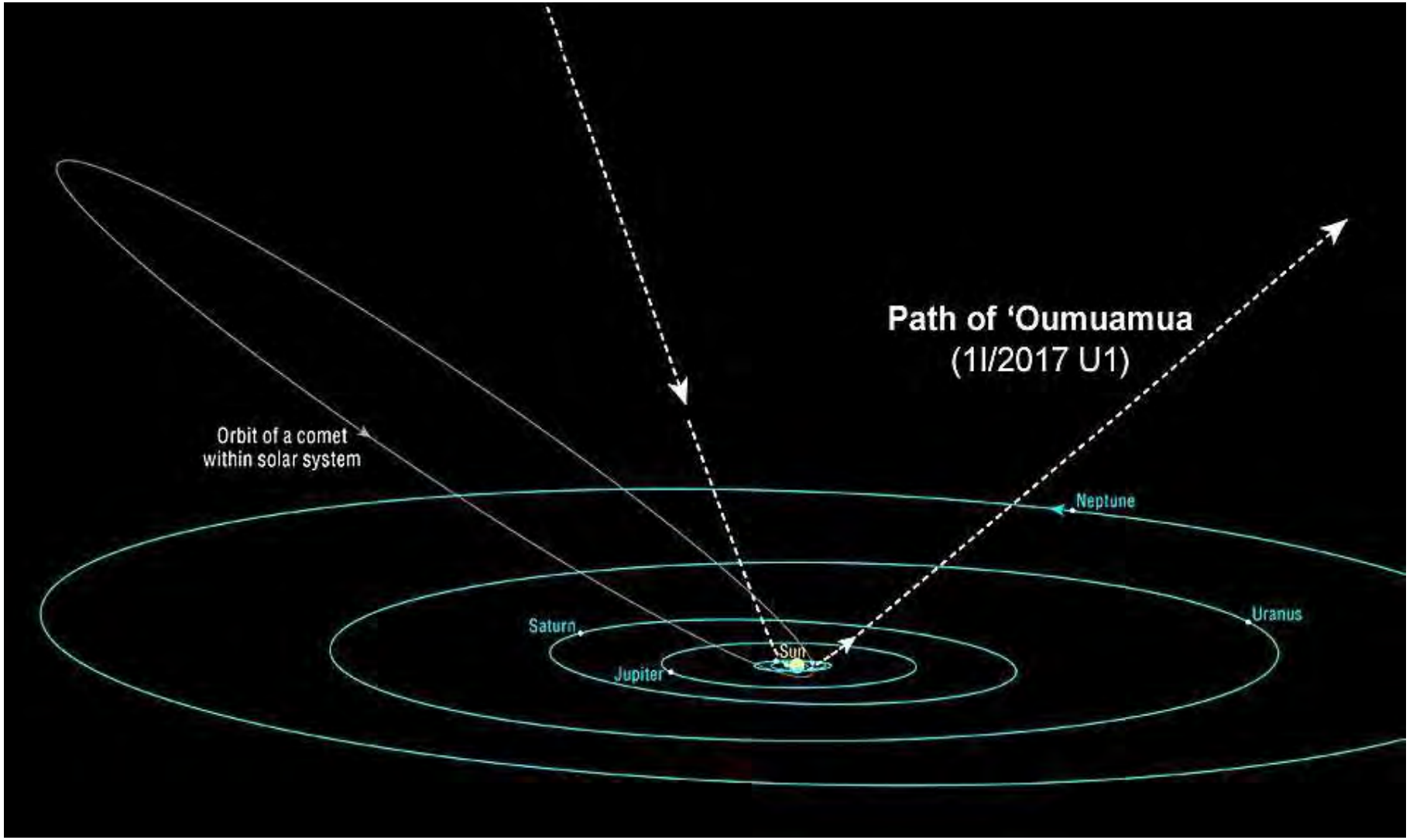
Asteroids and Comets –

the NASA/Caltech glossary

- “(a) A small rocky body that orbits a star. In the Solar System, most asteroids lie between the orbits of Mars and Jupiter.
  (b) A small planet-like body of the Solar System…”
- “A diffuse body of gas and solid particles which orbits the Sun. The orbit is usually highly elliptical or even parabolic “
- Both out of date – but add “or hyperbolic” – and are we OK?

NASA/Caltech glossary - ned.ipac.caltech.edu/level5/Glossary

Trajectory



discovered Oct. 19, 2017 by the University of Hawaii's Pan-STARRS1 telescope

An Astronomical Question: What is 1I/`Oumuamua?

- Long (about 5:1) and tumbling* but not breaking up
- Accelerating away from Sun but tumbling motion unchanged
- No associated meteors and no visible outgassing
- Who said (of another astronomical discovery) – “That’s funny….”?

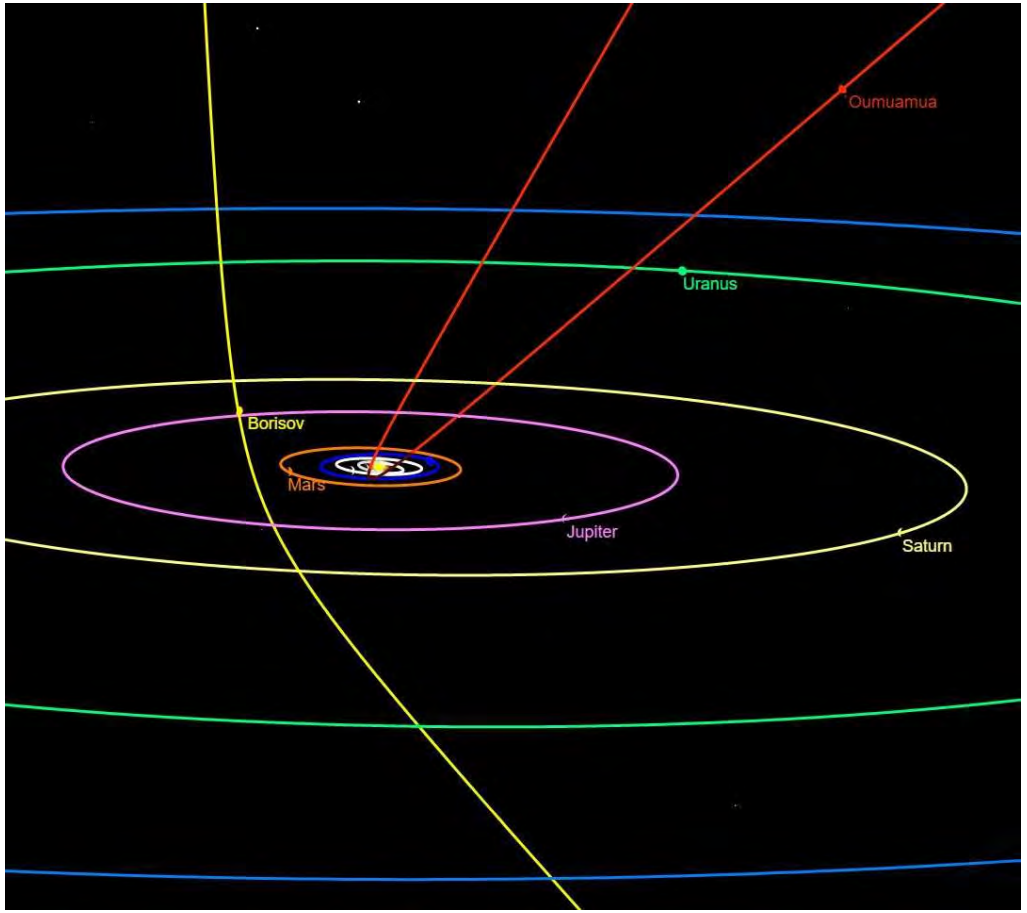
* jargon: “complex non-principal axis rotation”…

An Astronomical Question and Answer: What is 2I/Borisov?

- Coma and tail
- Breakup around perihelion?
- nothing “funny….” – apart from trajectory?

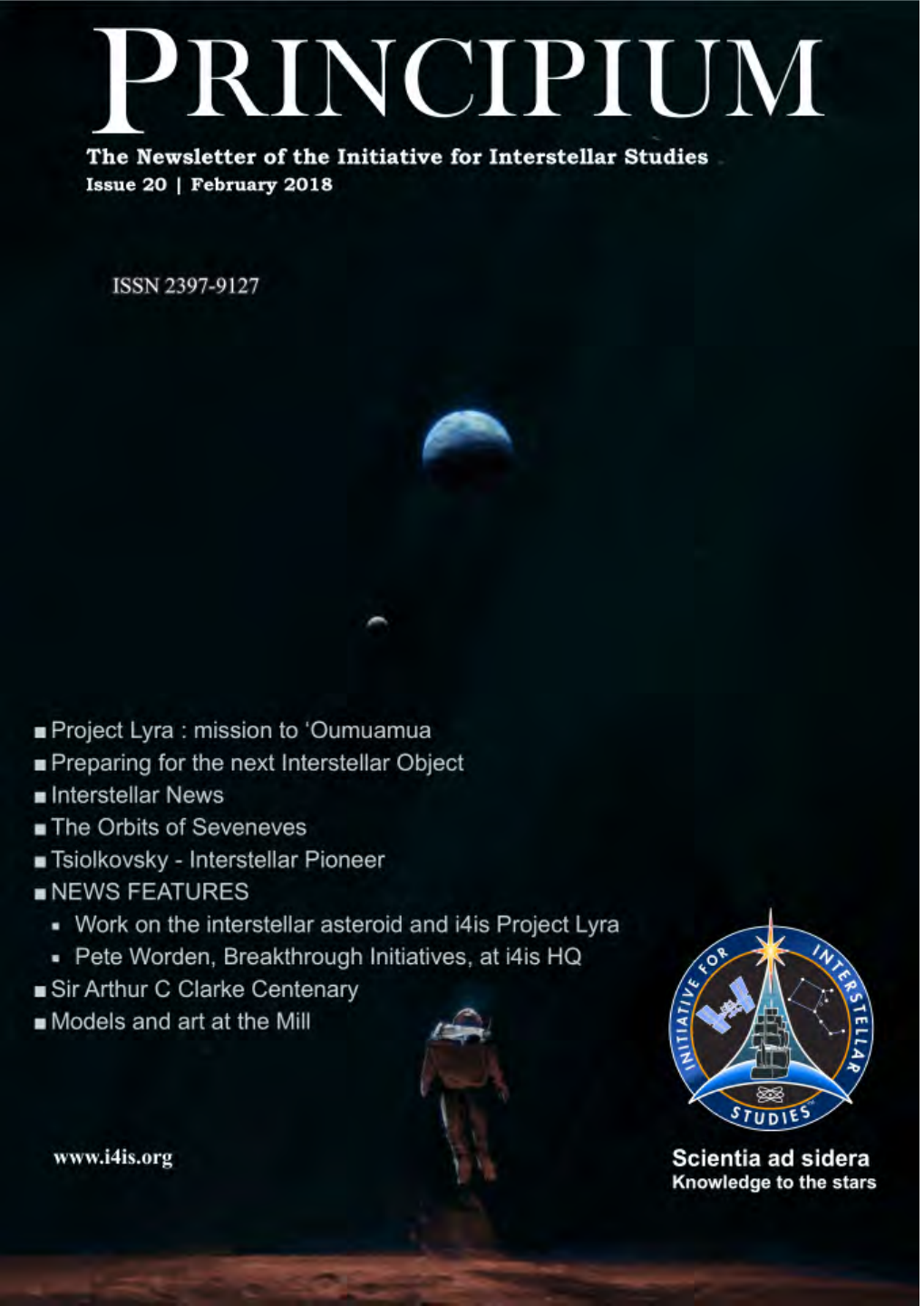
NASA/ ESA/
D. Jewitt

Trajectory



2I/Borisov

- Perihelion 2AU
- Classic comet



How close was 'Oumuamau?

approximately 0.1616 AU (24,180,000 km; 15,020,000 mi) from Earth
www.nasa.gov/planetarydefense/faq/interstellar

or 60 times apogee of the Moon (252,088 miles / 405,696 km)

Visualisation of astronaut hopping – Principium 20 cover
credit: Efflam Mercier (efflammercier.com)

Theories - 1I/`Oumuamua

- Low activity comet - *The Natural History of ‘Oumuamua*, Bannister et al
- Thin reflective sheet - possibly artificial - *Could Solar Radiation Pressure Explain ‘Oumuamua’s Peculiar Acceleration?* Bialy and Loeb
- Molecular hydrogen “iceberg” - *Evidence that 1I/2017 U1 (‘Oumuamua) was composed of molecular hydrogen ice* - Seligman and Laughlin (who also wrote *The Feasibility and Benefits of In Situ Exploration of 'Oumuamua-like Objects*)

Google Scholar is your friend! scholar.google.co.uk

The LGM factor –

lessons from Jocelyn Bell Burnell, Prof Geraint Evans (& the popular press!)

A new theory from some old hands - mystery

Evidence that 1I/2017 U1 (`Oumuamua) was composed of molecular hydrogen ice (arxiv.org/abs/2005.12932), Seligman & Laughlin (Yale and Chicago)

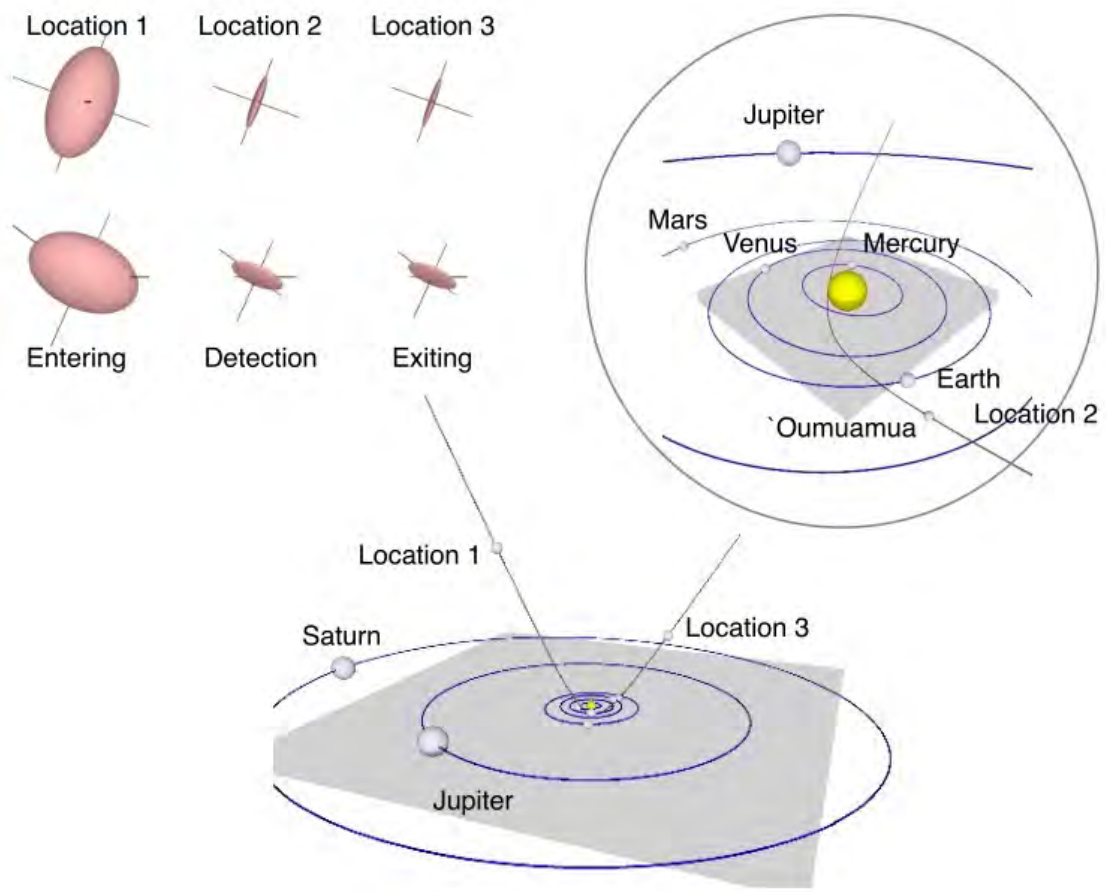
Not H_2O! - H_2O 51 kJ/mol enthalpy of sublimation* implies more energy input than 'Oumuamua received from solar irradiation –must provide sublimation enthalpy AND particle kinetic energy of the out-flowing molecules

Why not radiation pressure? Bulk density extremely low

So "'Oumuamua's acceleration presents a genuine mystery"

* internal energy+pressure*volume == energy required to convert solid to gas

A new theory from some old hands



- H_2 ice (very cold!) – much lower enthalpy of sublimation
- And gets thinner– like a bar of soap! - "Sublimation driven by uniform illumination generates a secular increase in the aspect ratio of the body"

Seligman & Laughlin

Seligman Figure 1. Schematic diagram showing 'Oumuamua's size and shape evolution due to H 2 sublimation and its trajectory through the Solar System. Pairs of orientations at three discrete points on the trajectory are shown in the upper left.

A new theory from some old hands – solution?

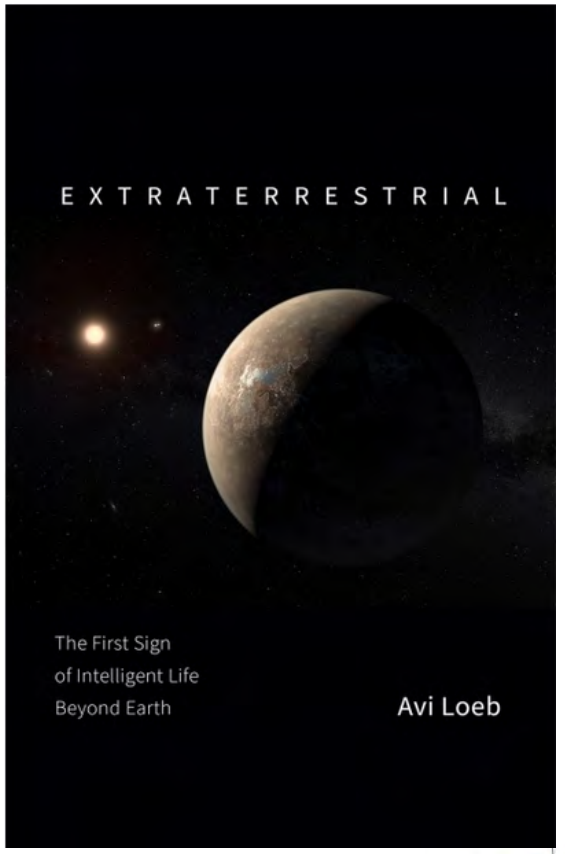
- But what about no secular change in tumbling?
- If net outgassing force is through centre of mass then no change in tumbling

My purely amateur opinion: Its weird - but it isn't ET!

Dissent continues – Loeb vs (almost) everyone

Loeb: *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth*, Houghton Mifflin Harcourt, 2020

www.hmhbooks.com/shop/books/extraterrestrial/9780358278146



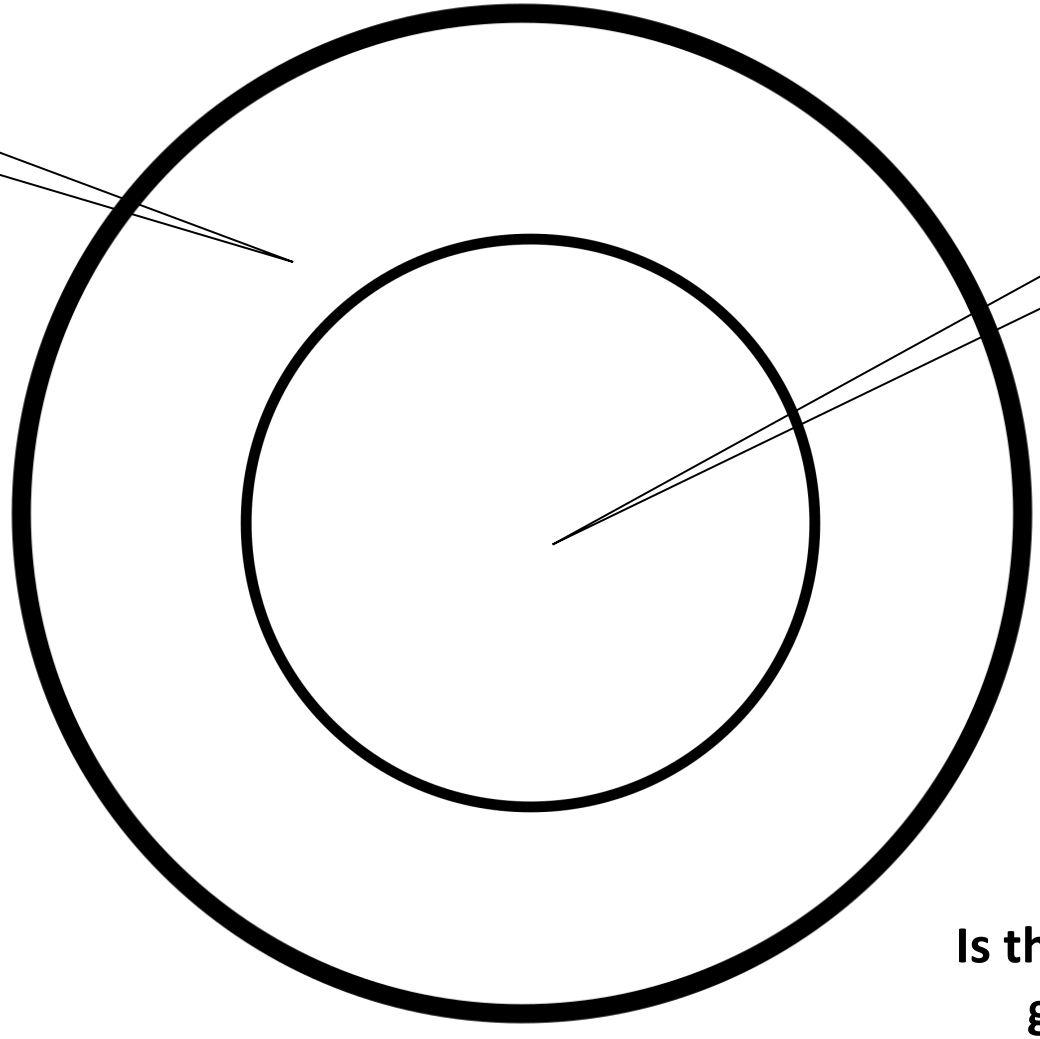
An Interstellar Visitor:
sorting the fact from the speculation
Alan Aylward, Professor Emeritus of Atmospheric Physics, UCL, Principium 32, February 2021, page 53

Book Review in next issue of Principium 33, May 2021

Why we need to visit 1I/‘Oumuamua

- Bannister et al “The Large Synoptic Survey Telescope is expected to begin full operations in 2022 and is predicted to discover on the order of one interstellar object per year…”
- But what if it does not discover an ISO like 1I?
- And recall that current telescopes have found one more ISO, a comet
- So Bannister et al “Thus, we will soon have a much better understanding of how common — or rare — the properties of ‘Oumuamua are.” may be sadly disappointed.
- And more cometary ISOs won’t tell much about 1I…..

The ‘Oumuamua probe wait calculation



February 2021

(a) =2

(b) =1

2025? – scenario 1

(a) =4

(b) =2

2025? – scenario 2

(a) =4

(b) =1

Is this a problem in games theory?

Getting to ISOs – the challenges

- Spotting Interstellar Objects (ISOs)
- DeltaV –
  - heavy launchers / gravity assist / Oberth
  - lurk at L2
  - maybe laser push or nuclear thermal
- Flyby or rendezvous (more DeltaV)

$$\Delta v = v_{ex} Ln\left(\frac{m_o}{m_f}\right)$$

Lyra: A Mission to ’Oumuamua

- The Lyra studies [Hein et al., 2019, Hibberd et al., 2020, etc] show a mission to 1I is possible using existing technology - and can provide a substantial science return.
- The outgoing v_∞ of 26.3 km s^{-1} - substantially faster than fastest spacecraft to date, Voyager 1, which has a v_∞ = 16.86 km s^{-1}.
- But 1I will be ~three orders of magnitude easier to reach and sample than any exoplanet for the remainder of this century.
- Could be combined with missions like JHU-APL proposed Interstellar Probe [Brandt et al., 2017] intending to explore out to 100’s of AU.

i4is Project Lyra – missions to ISOs

- Hein et al., *Project Lyra: Sending a spacecraft to 1I/'Oumuamua (former A/2017 U1), the interstellar asteroid*. Acta Astronautica, 161, 552-561. – first published Nov 2017 arxiv.org/abs/1711.03155
- Hibberd, Hein, Eubanks, *Project Lyra: Catching 1I/'Oumuamua-Mission Opportunities After 2024*. Acta Astronautica, 170, 136-144, May 2020 arxiv.org/abs/1902.04935
- Hibberd, Hein, Perakis, *Sending a Spacecraft to Interstellar Comet C/2019 Q4 (Borisov),* September 2019 arxiv.org/abs/1909.06348
- Hibberd & Hein, *Project Lyra: Catching 1I/'Oumuamua -- Using Laser Sailcraft in 2030*, June 2020 arxiv.org/abs/2006.03891v1
- Hein, Eubanks, Lingam, Hibberd, Fries, Perakis, Schneider, *Interstellar Now! Missions to and Sample Returns from Nearby Interstellar Objects*, Jan 2021, arxiv.org/abs/2008.07647

+ Eubanks, Hein, Lingam, Hibberd, Fries, Perakis, Kennedy, Blase, Schneider *Interstellar Objects in the Solar System: 1. Isotropic Kinematics from the Gaia Early Data Release 3*, March 2021 arxiv.org/abs/2103.03289

And others –
The Feasibility and Benefits of In Situ Exploration of 'Oumuamua-like Objects, Seligman and Laughlin (Yale) 2018, Astro J v55 #5, 2018 – first published April 2018 arxiv.org/pdf/1803.07022.pdf

A Lyra Mission

- Getting the velocity - Oberth Manoeuvre (at either Sun or Jupiter) - ΔV added to parabolic or hyperbolic velocity of a close approach.
- Oberth showed that adding a velocity change to a large velocity causes an even larger change, one that remains “at infinity” (when the original V will largely be removed by gravity). Clue: Kinetic Energy=$1/2mV^2$
- Default mission Lyra spacecraft mass 5745 kg, close to proposed SLS-launched Europa Clipper spacecraft, and similar Jovian transfer orbit.
- Two solid fuel stages firing sequentially close to Sun, delivering a total ΔV of 4.489 km s^{-1} for Oberth manoeuvre.
- Plus Saturn fly-by to get the Lyra probe out of ecliptic plane
- Third stage used for terminal encounter navigation

Another way to go - The lightsail equation

"The acceleration α of a vehicle of mass M and reflectance η driven by an incident laser power P is -

$$\alpha = \frac{2\eta P}{Mc}$$

where c is the velocity of light and the factor 2 comes from the double momentum transfer to the sail by the reflected photons. "

Forward 1984 *Roundtrip Interstellar Travel Using Laser-Pushed Lightsails*-
arc.aiaa.org/doi/abs/10.2514/3.8632
pdfs.semanticscholar.org/25b2/b991317510116fca1e642b3f364338c7983a.pdf

What is 1I/`Oumuamua?

Other suggested missions to ISOs

- Seligman and Laughlin
- Breakthrough Starshot
- ESA Comet Interceptor

What is 1I/`Oumuamua?

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i4is Project Lyra – how its done – the authors

- Hibberd (UK) – astrodynamics, developed OITS*
- Eubanks (USA) – ex JPL, US Naval Observatory
- Hein (France/Germany) – i4is technical lead

Google Scholar search: i4is lyra hein

* Example animations from OITS –

https://drive.google.com/file/d/1Pgcdl4kuz7rxSJ30PDkafvohbg2G63P8/view

https://oits.justinhui.com/runs/

How to reach Interstellar Visitors: Optimum Interplanetary Trajectory Software, Adam Hibberd, Principium Principium | Issue 27 | November 2019

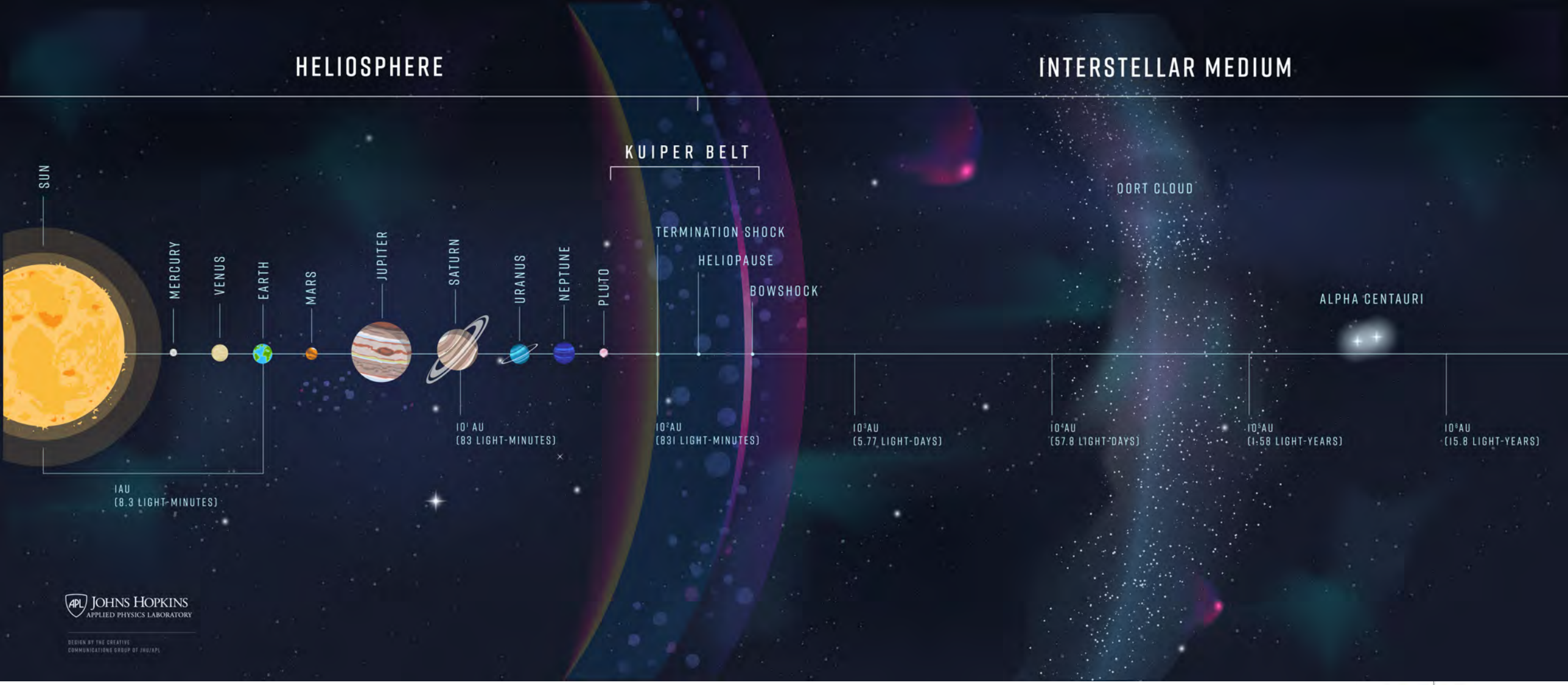
Practicalities and Difficulties of a Mission to 'Oumuamua , Adam Hibberd, publishing Principium 33, May 2021 (**preprint for members now**)

What else do we do?

- Long term ambition to enable robotic and human exploration - and eventually settlement of nearby star systems –
  Projects Dragonfly, Andromeda, Lyra, Glowworm (& Pinpoint ChipSat)
- Education (schools, universities), outreach (as today) and R&D (from studies to demonstrators)
- Team in UK, France, Germany, USA and other countries
- Working with other organisations – BIS, TVIW, Tau Zero Foundation, Breakthrough Starshot, Limitless Space, Icarus Interstellar, ISU, NASA & ESA

Astronomy: for example, Exoplanets

- Which stars can see Earth as a transiting exoplanet? MNRAS Letters academic.oup.com/mnrasl/article/499/1/L111/5931805 tviw.us/2018/12/tviw-updates/
- Can we detect orientation of stellar axis of rotation, thus ecliptic and therefore likelihood of transits?
- We need more astronomers in Interstellar Studies
- Join us!

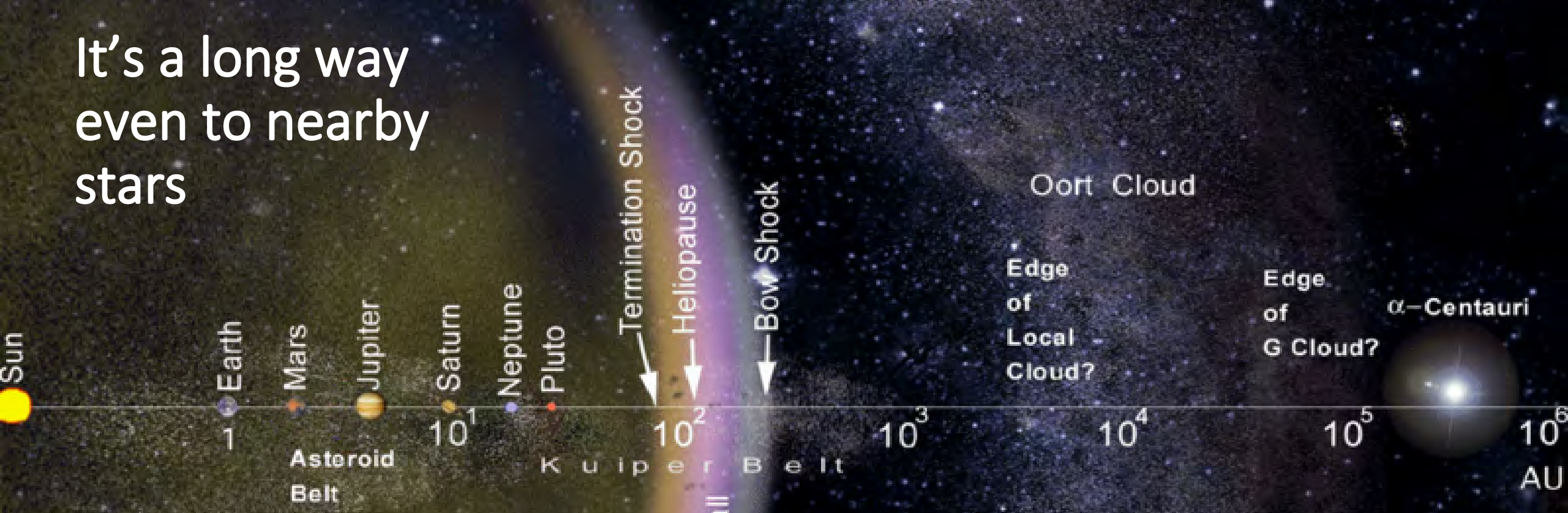


The Scale of the Problem

A Johns Hopkins University Applied Physics Laboratory (JHU-APL) perspective on the interstellar neighbourhood

Credit: Pontus Brandt. JHU-APL

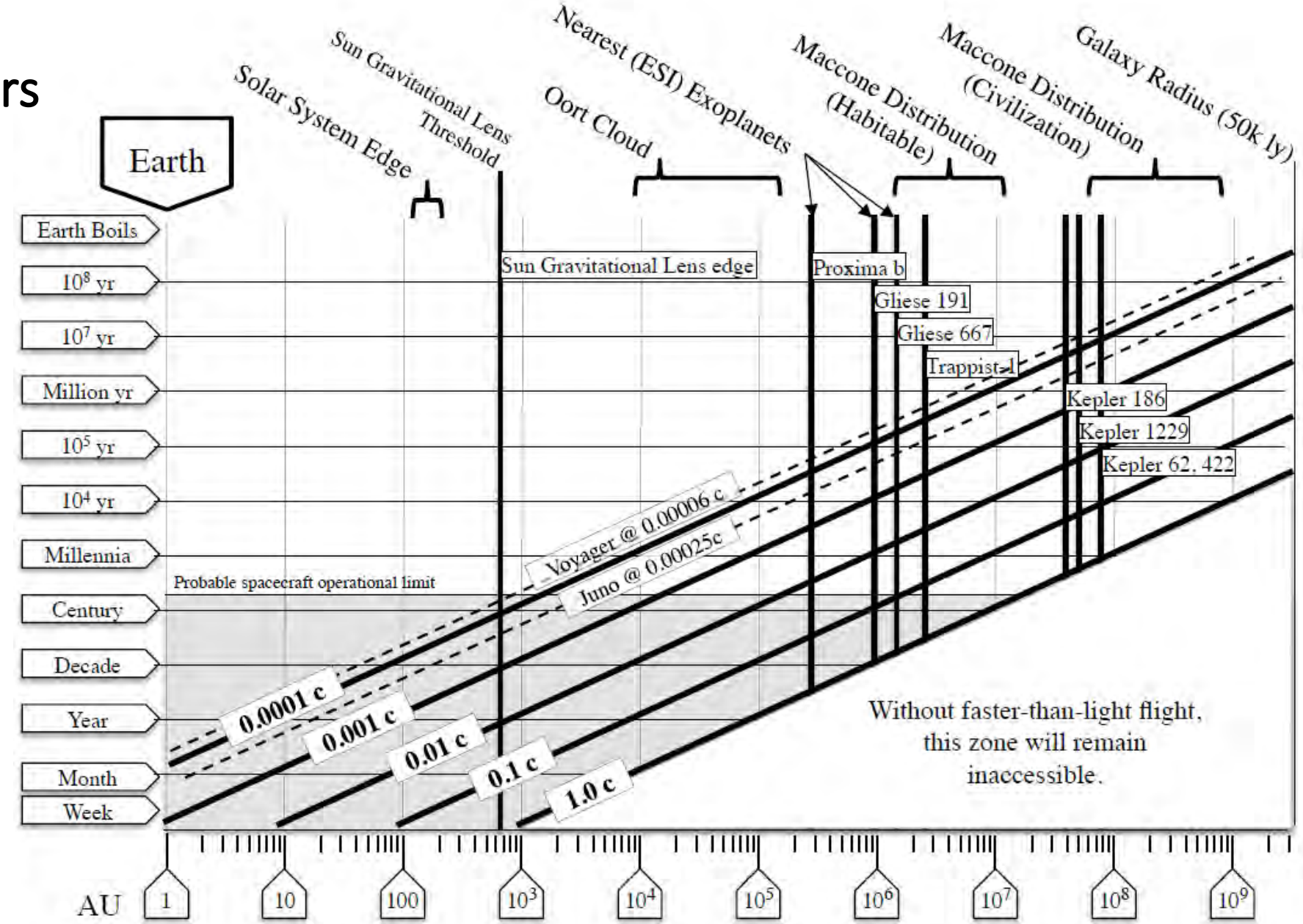
It’s a long way even to nearby stars



Log scale of astronomical units

-but we can get there !

A probe to nearby stars
Scaling the problem



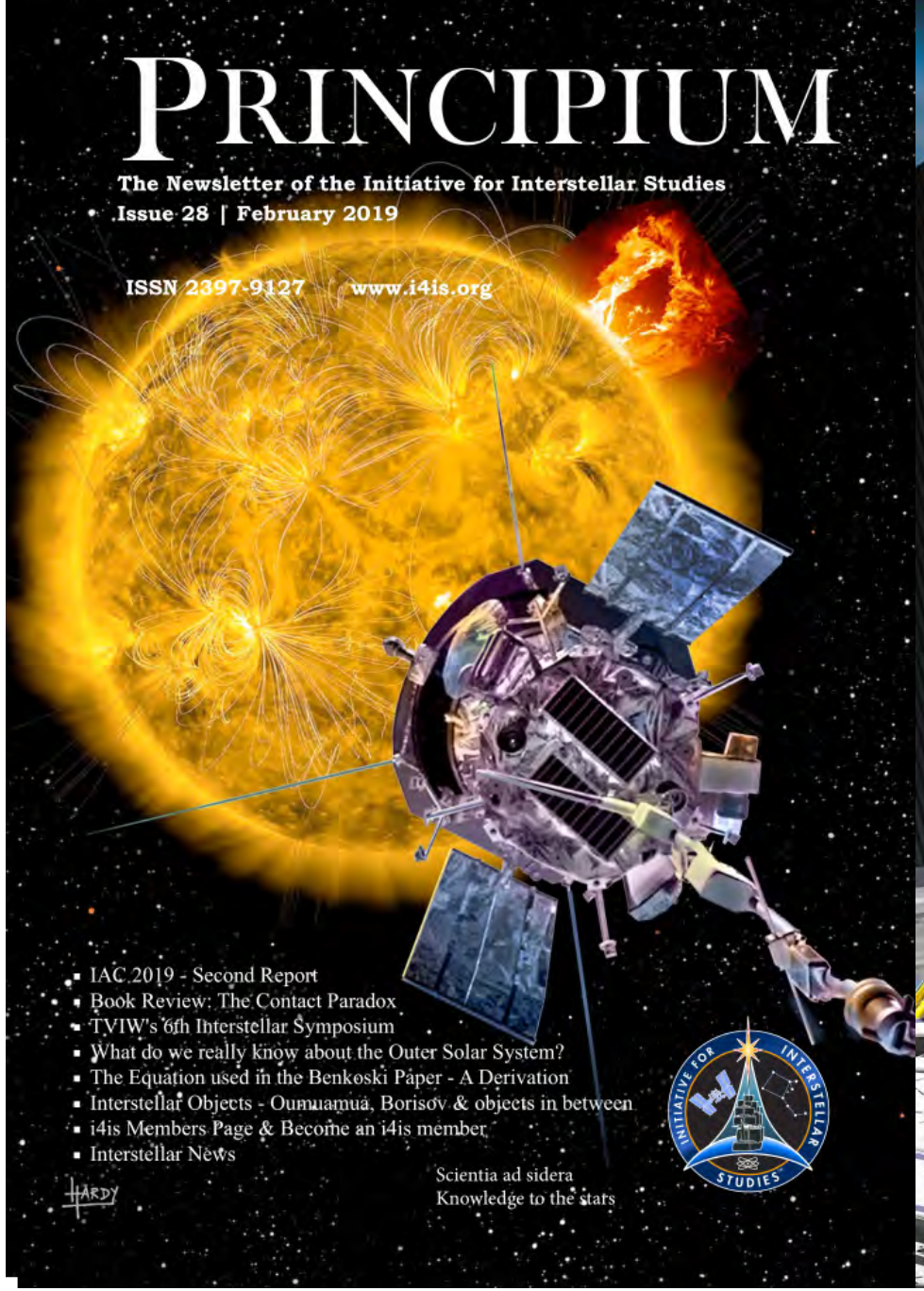
credit - Tau Zero Foundation - NASA Breakthrough Propulsion Study 2018

for “Maccone Distribution” see C. Maccone, “The Statistical Drake Equation,” 59th International Astronautical Congress, Glasgow, 2008

approx light years	8min	1hr	10hr	100hr	1	10	100	10k

Find out more….

PRINCIPIUM magazine is free!



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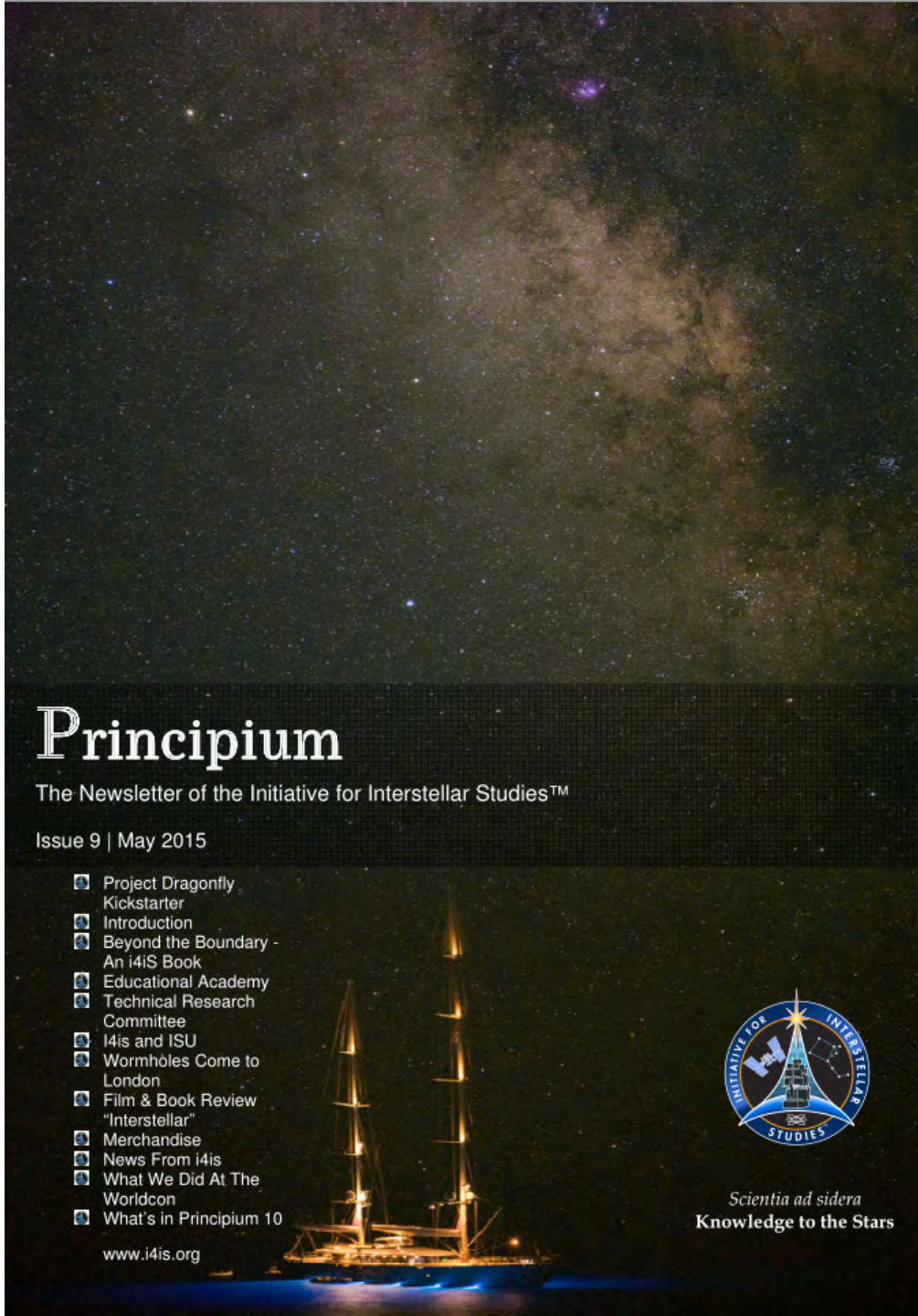

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