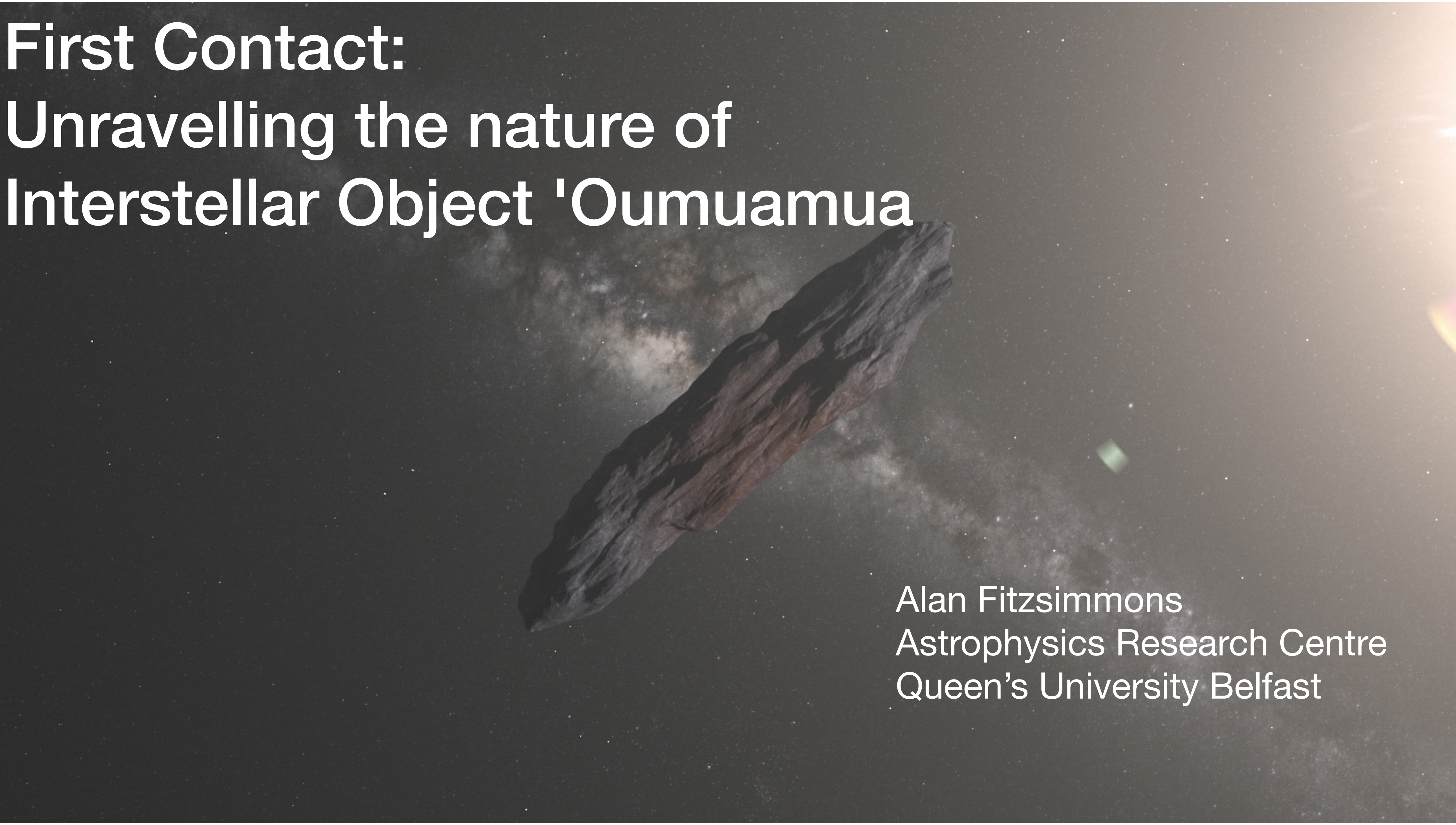
First Contact: Unravelling the nature of Interstellar Object 'Oumuamua

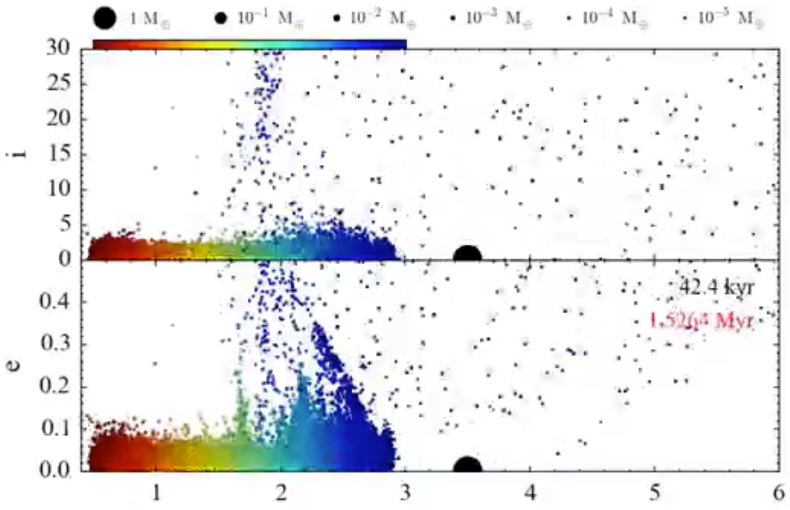


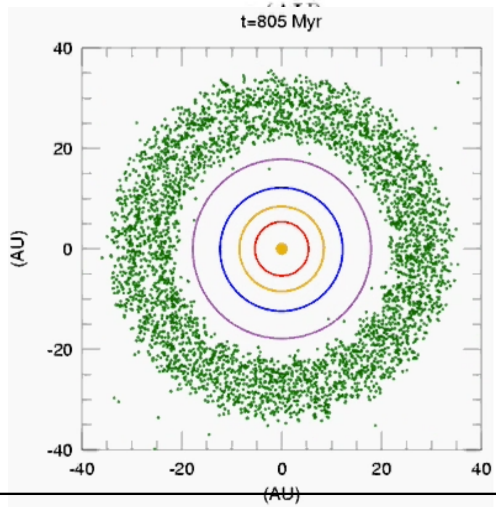
Alan Fitzsimmons
Astrophysics Research Centre
Queen’s University Belfast

First Contact: Unravelling the nature of Interstellar Object 'Oumuamua

- The origin of ISOs
- Discovery and orbit
- Lightcurve period and amplitude
- Colours & Spectroscopy
- Thermal-IR constraints
- Non-gravitational forces
- How “alien” is ‘Oumuamua?
- Questions and future directions

ISOs before ‘Oumuamua





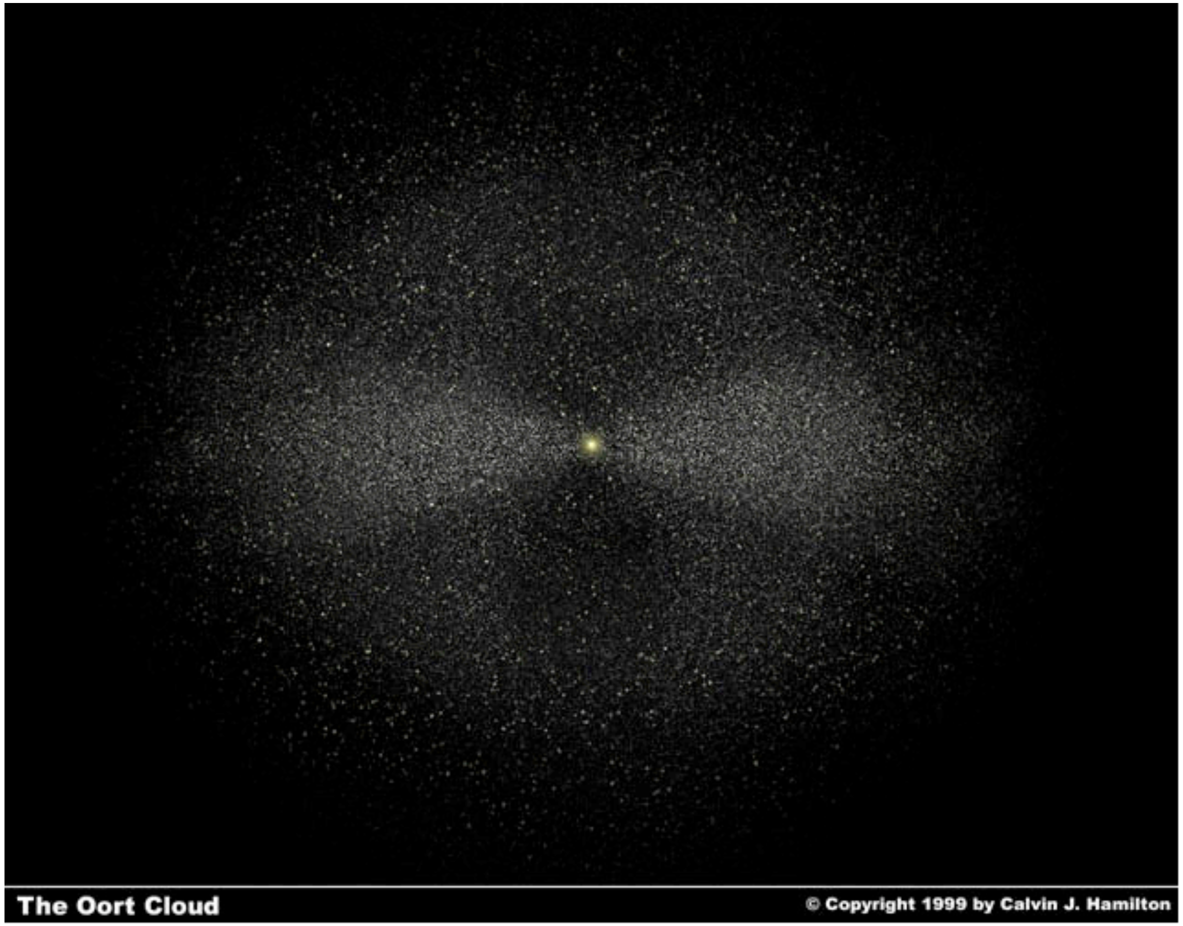
During Grand Tack and Nice model migration, ejection of 5-40 M_{Earth}.

Most ejected bodies come from beyond snowline and hence contain significant ice.

Similar exoplanet evolution around all stars would give a local density of $n(1\text{km}) \sim 10^{14}$ pc^{-3}.

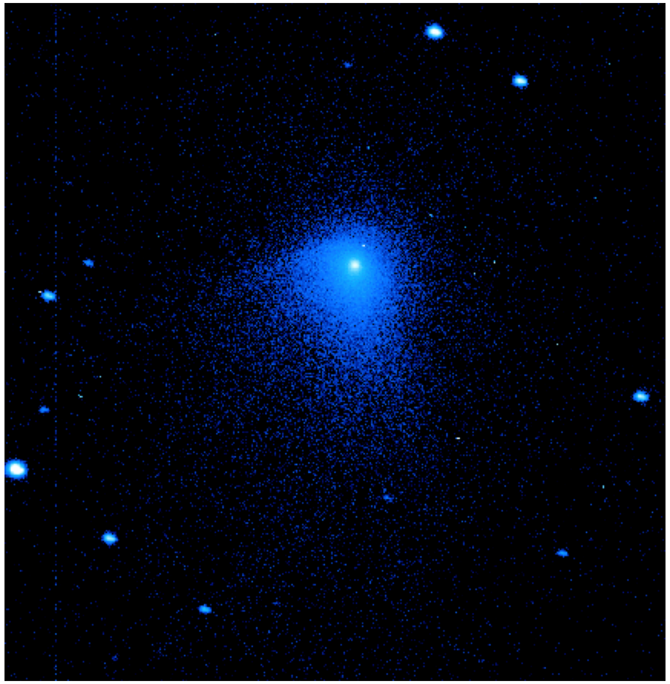
<u>But</u> - numbers ejected heavily dependent on system architecture and size distribution

ISOs before ‘Oumuamua



Oort Cloud erosion due to stellar encounters and Galactic tides results in a loss of 10^{11} - 10^{12} comets (Brasser & Morbideli 2013; Hanse et al. 2018).

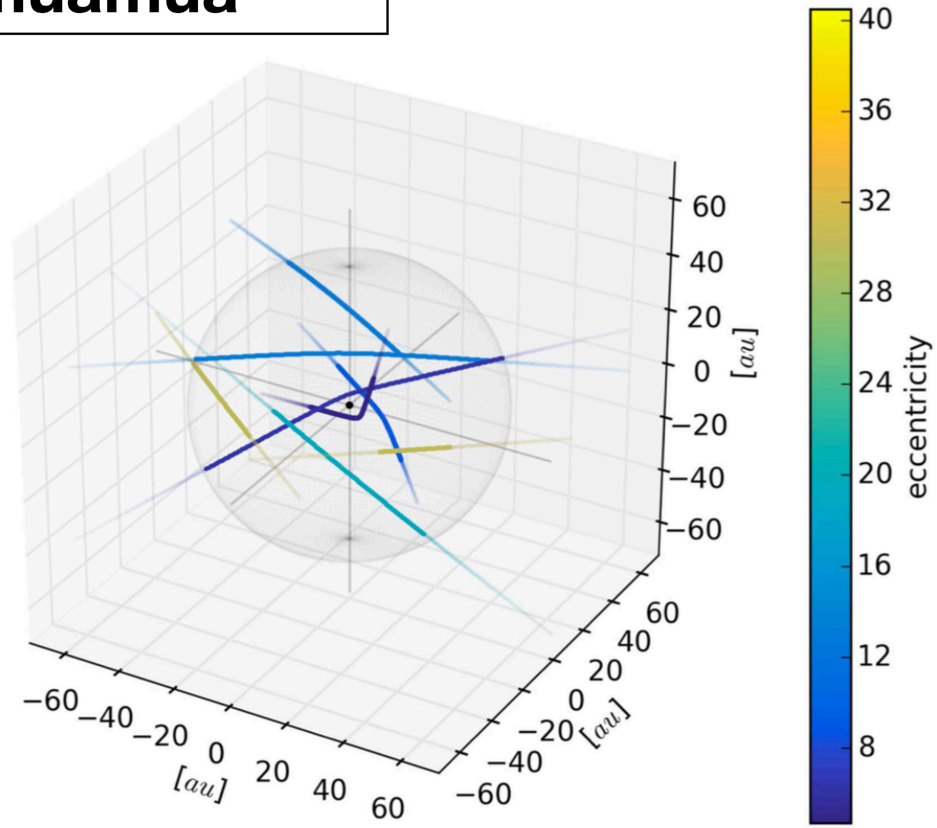
ISOs before ‘Oumuamua



Probable cometary appearance

$$\frac{n(icy)}{n(rocky)} \sim 10^2 - 10^4$$

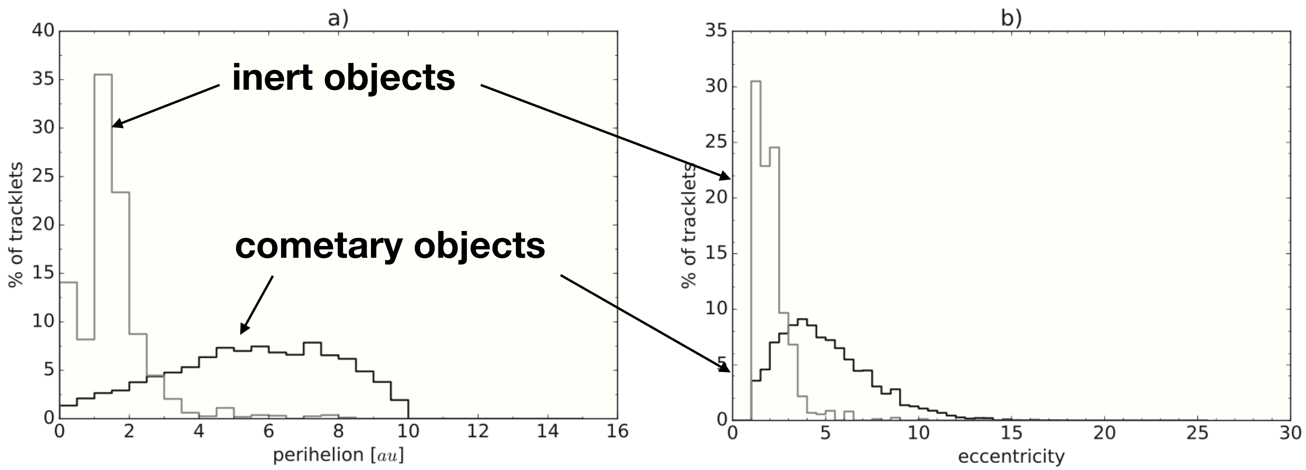
(e.g. Shannon et al. 2015)

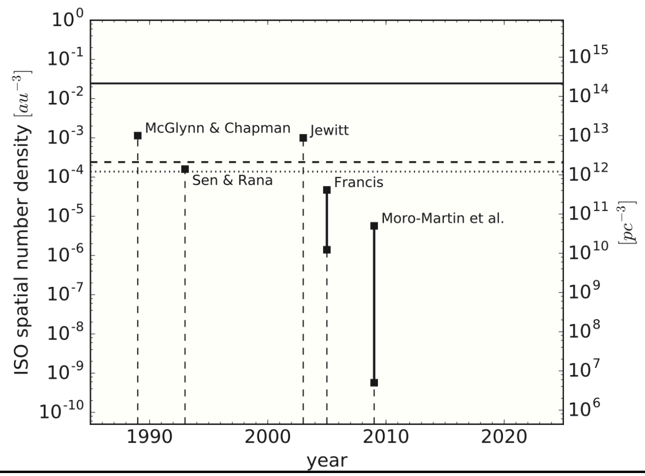


Hyperbolic Orbit

(Engelhardt et al. 2017)

ISOs before ‘Oumuamua

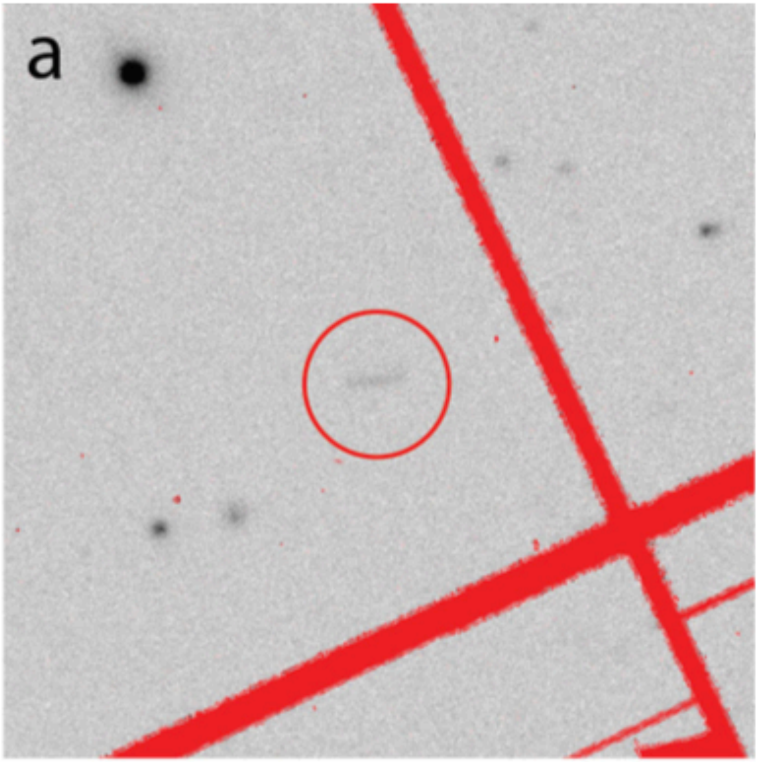




Engelhardt et al. (2017) simulations of detected orbits and upper limits for H=19 (D~1km):

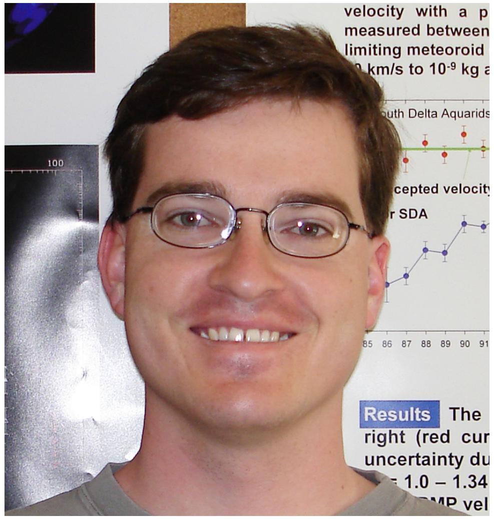
$n<2x10^{12}$ pc^{-3} for cometary ISOs
$n<2x10^{14}$ pc^{-3} for asteroidal ISOs

19th October 2017



Pan-Starrs 1

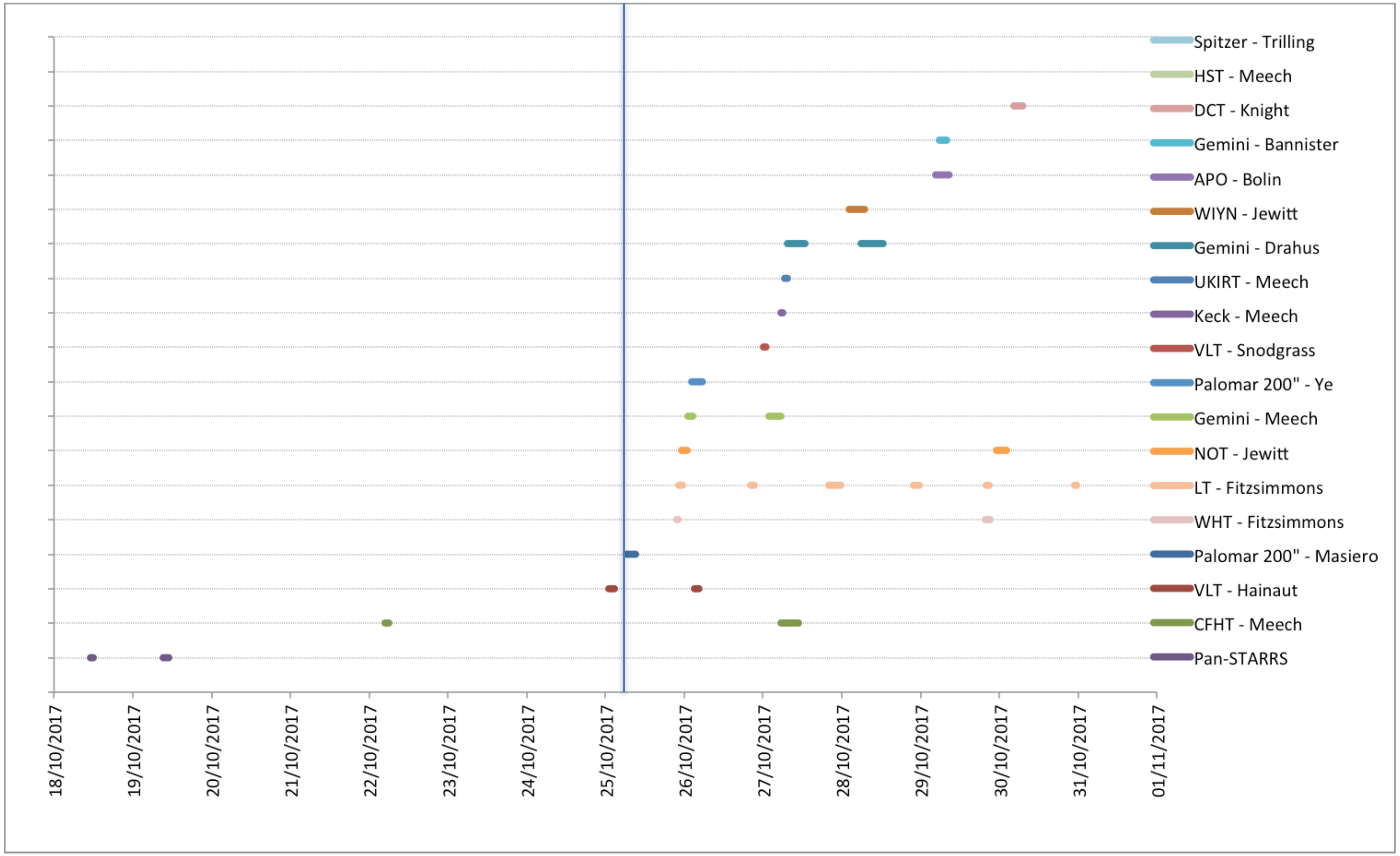
Fast Moving Object P10Ee5V
15 acseconds/minute



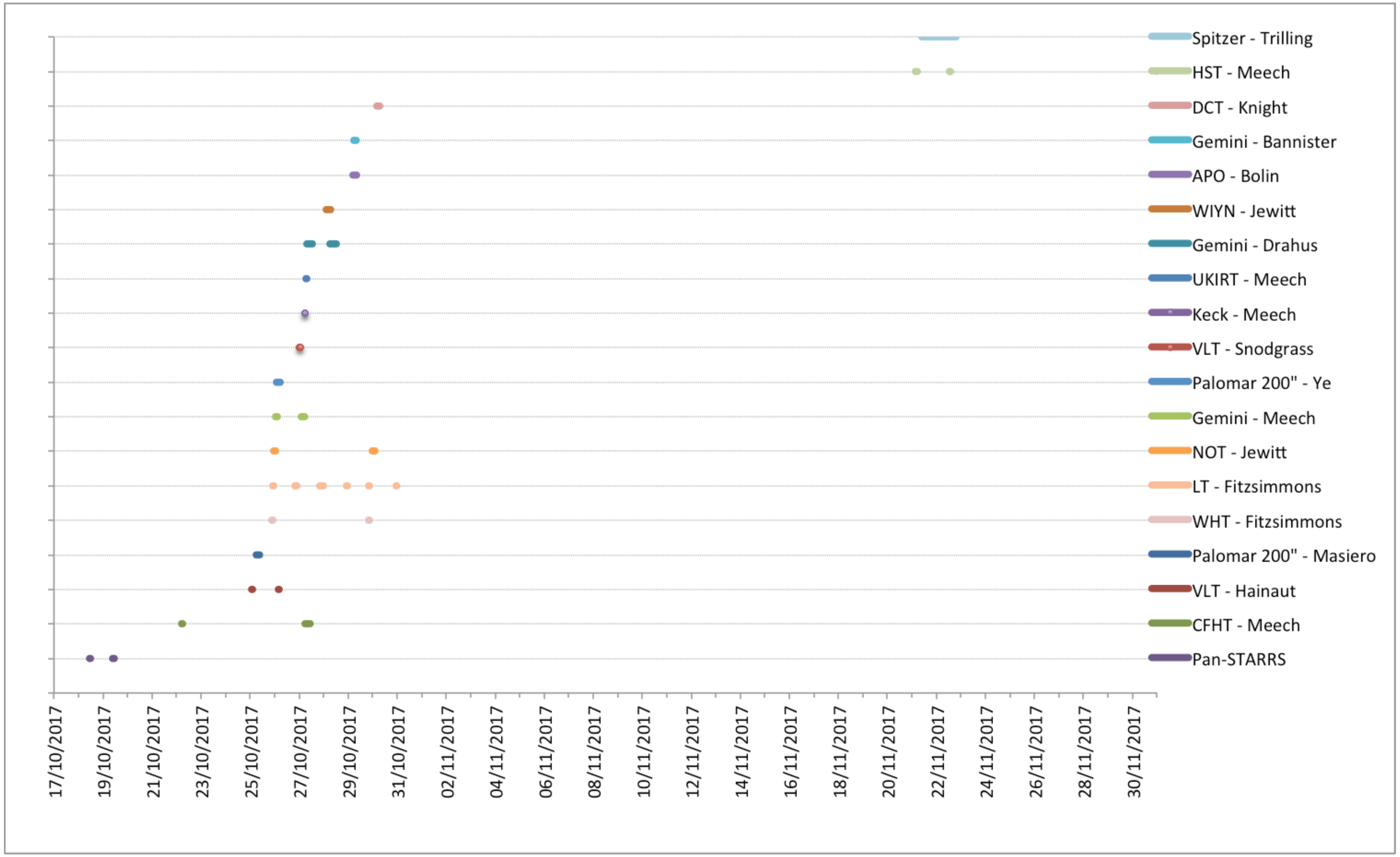
Rob Weyrk

Marco Micheli

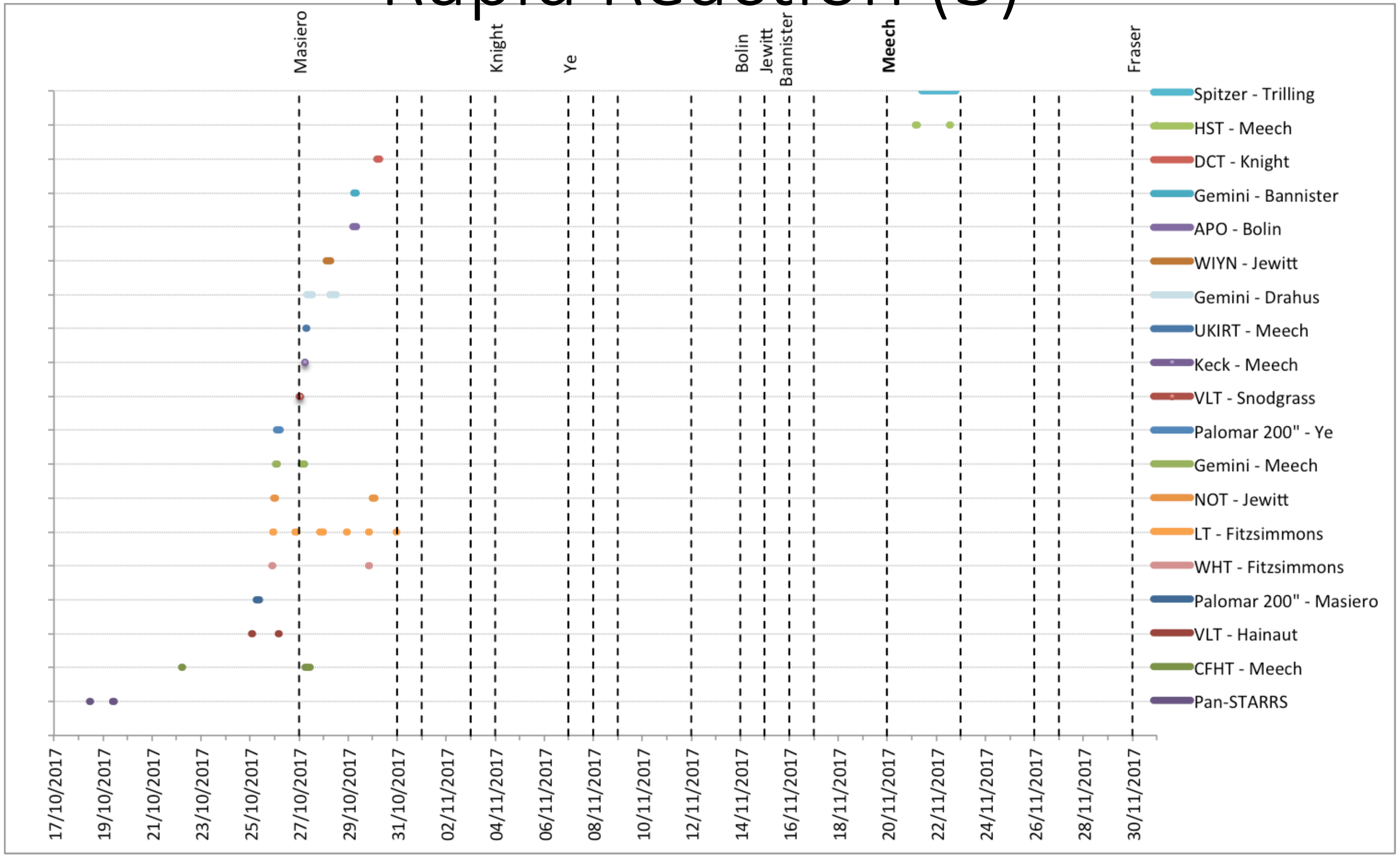
Rapid Reaction (1)



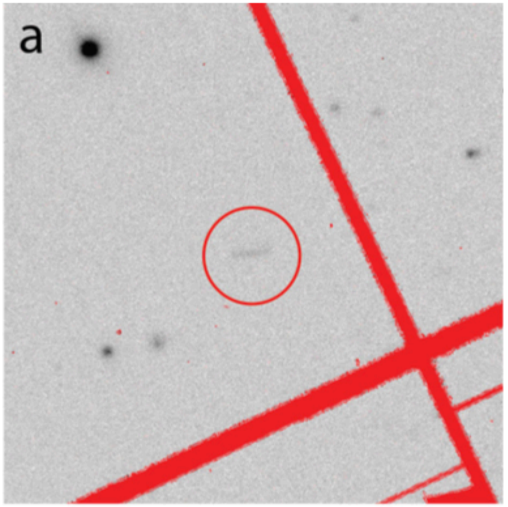
Rapid Reaction (2)



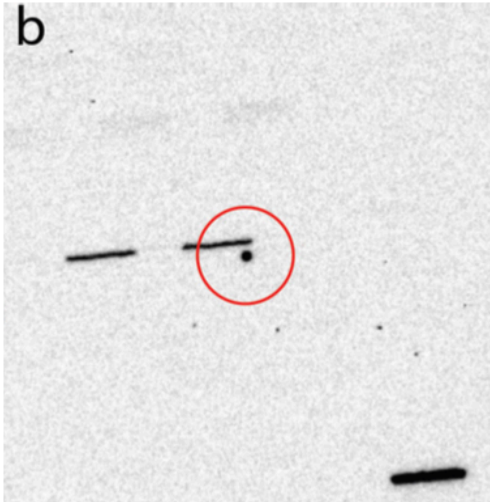
Rapid Reaction (3)



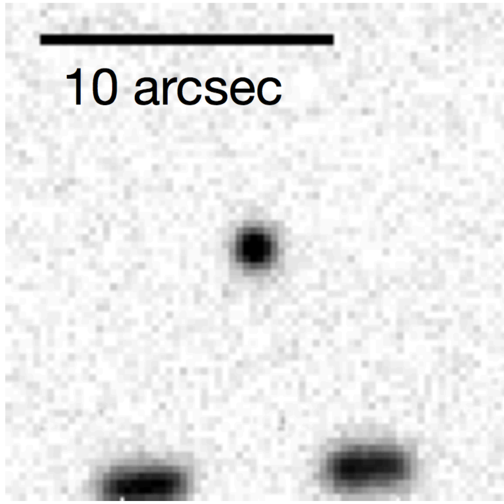
19th October 2017 | 22nd October 2017 | 25th October 2017



Pan-Starrs 1

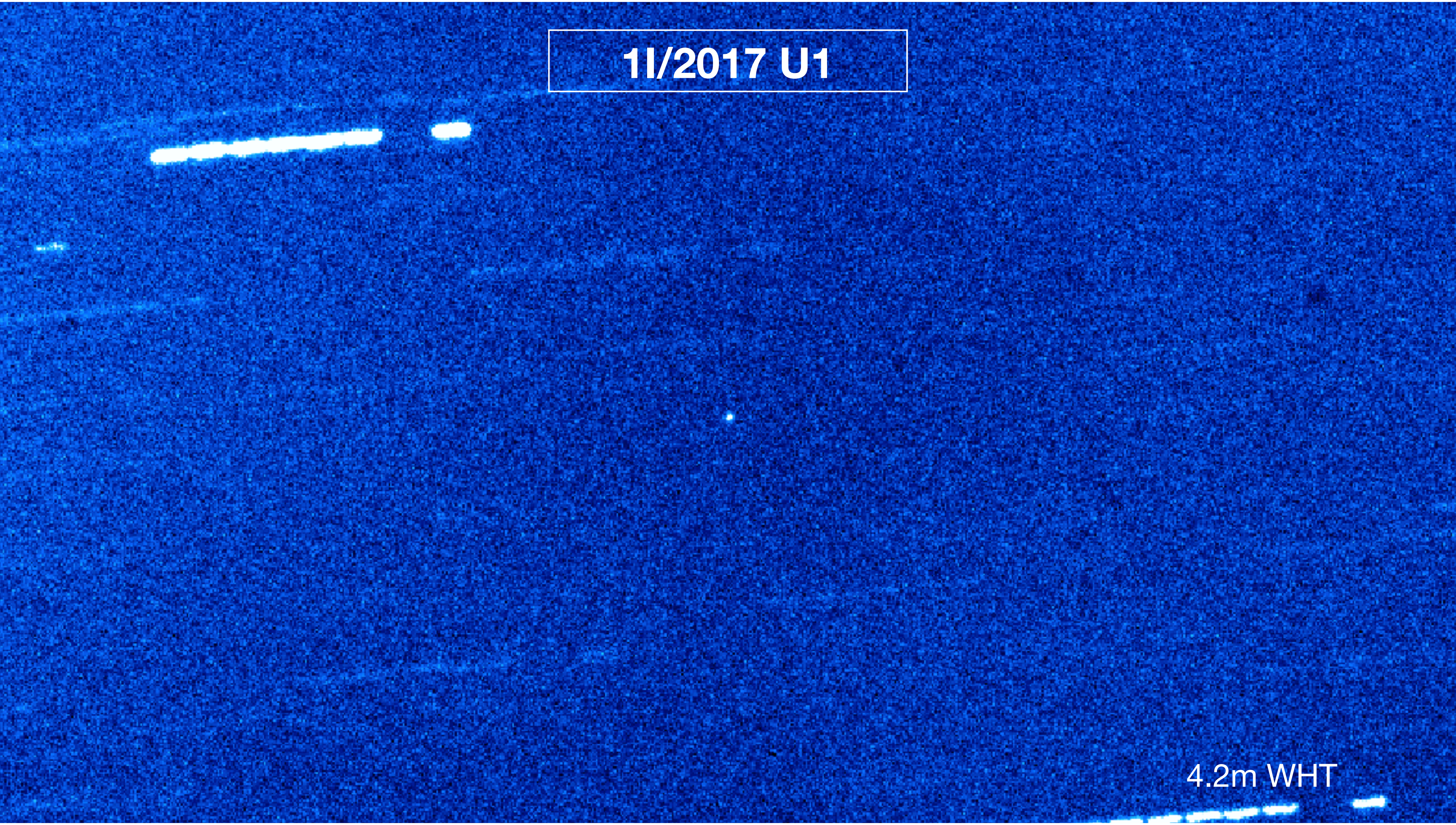


CFHT

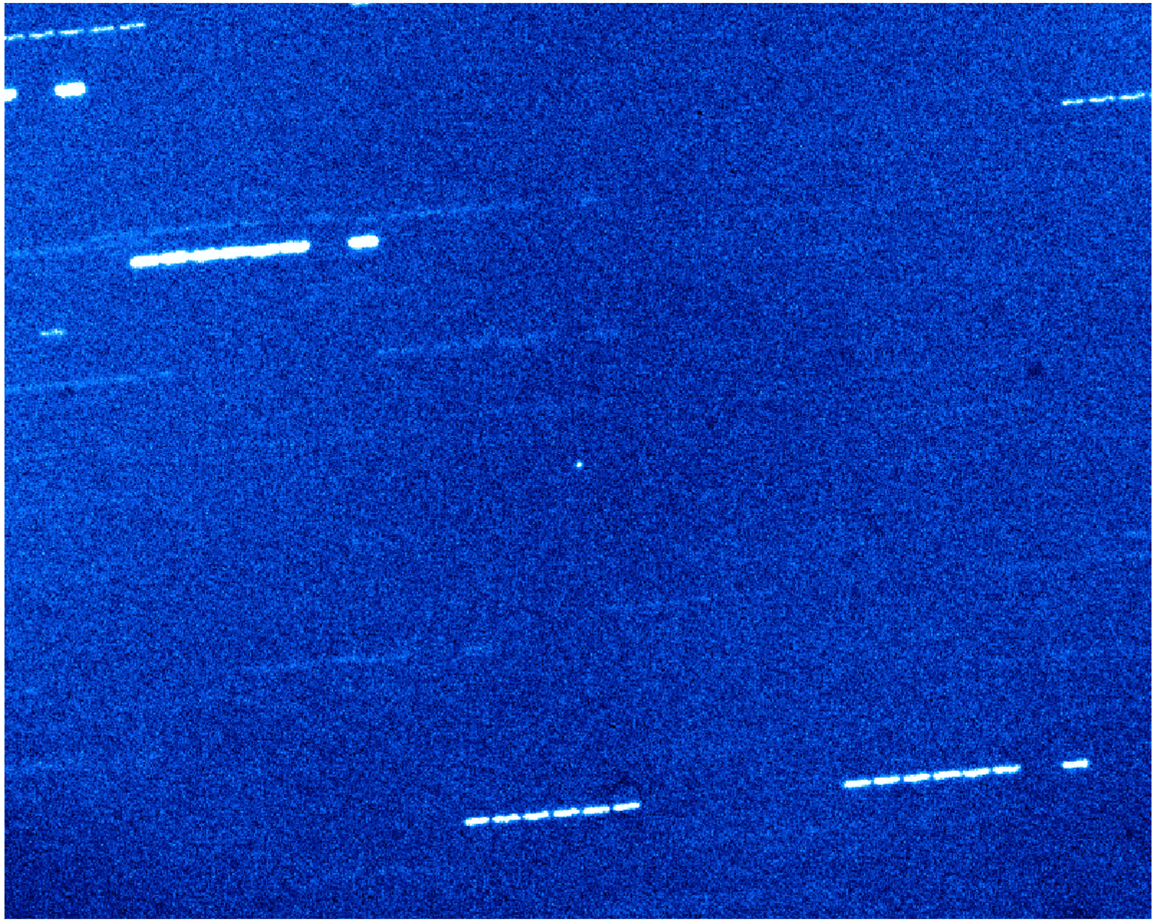


VLT+Gemini-South

25th October: C/2017 U1
26th October: A/2017 U1
6th November: 1I/2017 U1


1I/2017 U1
4.2m WHT

‘Oumuamua

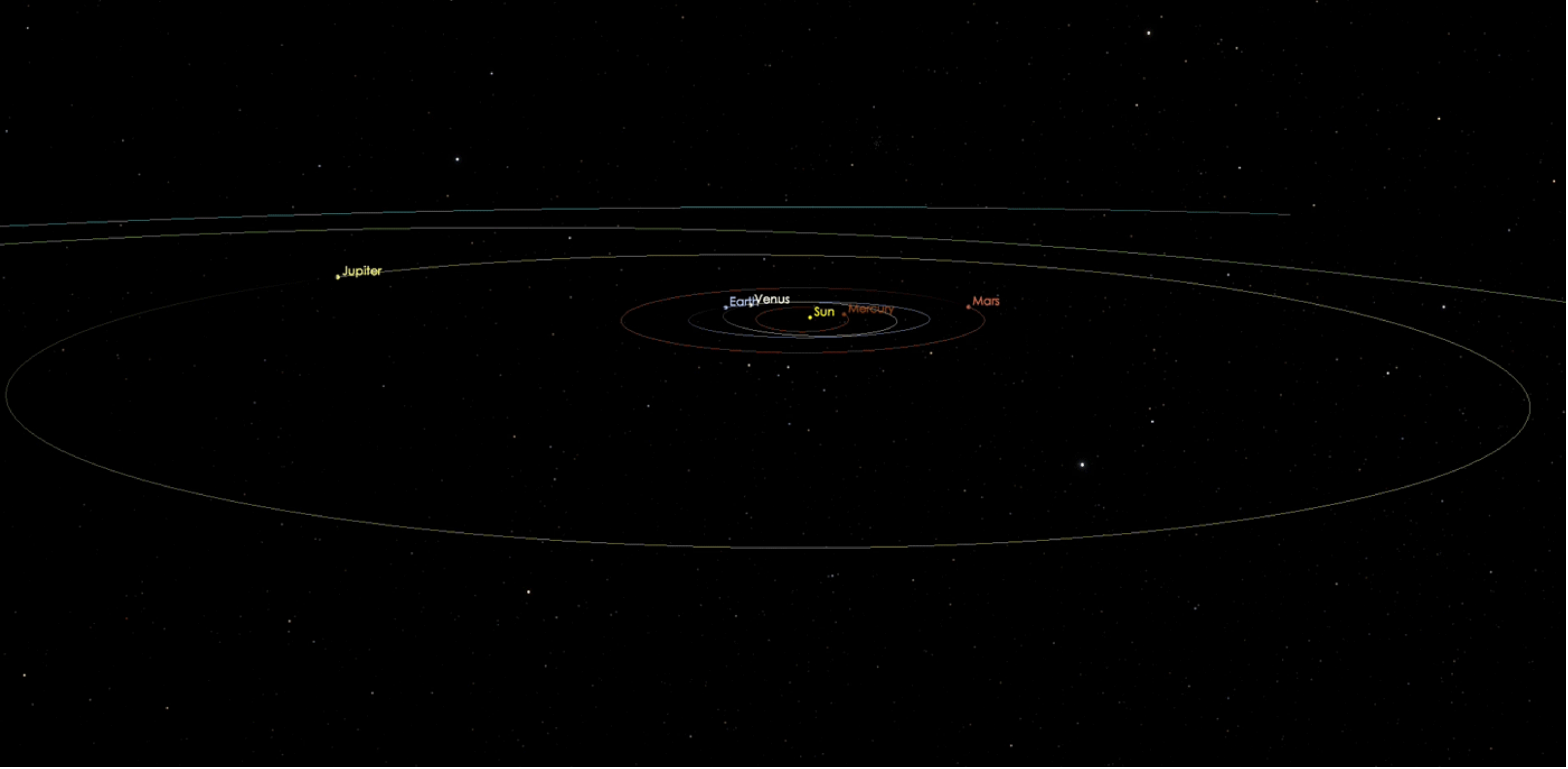


(Oh - moo - ah - moo - ah)

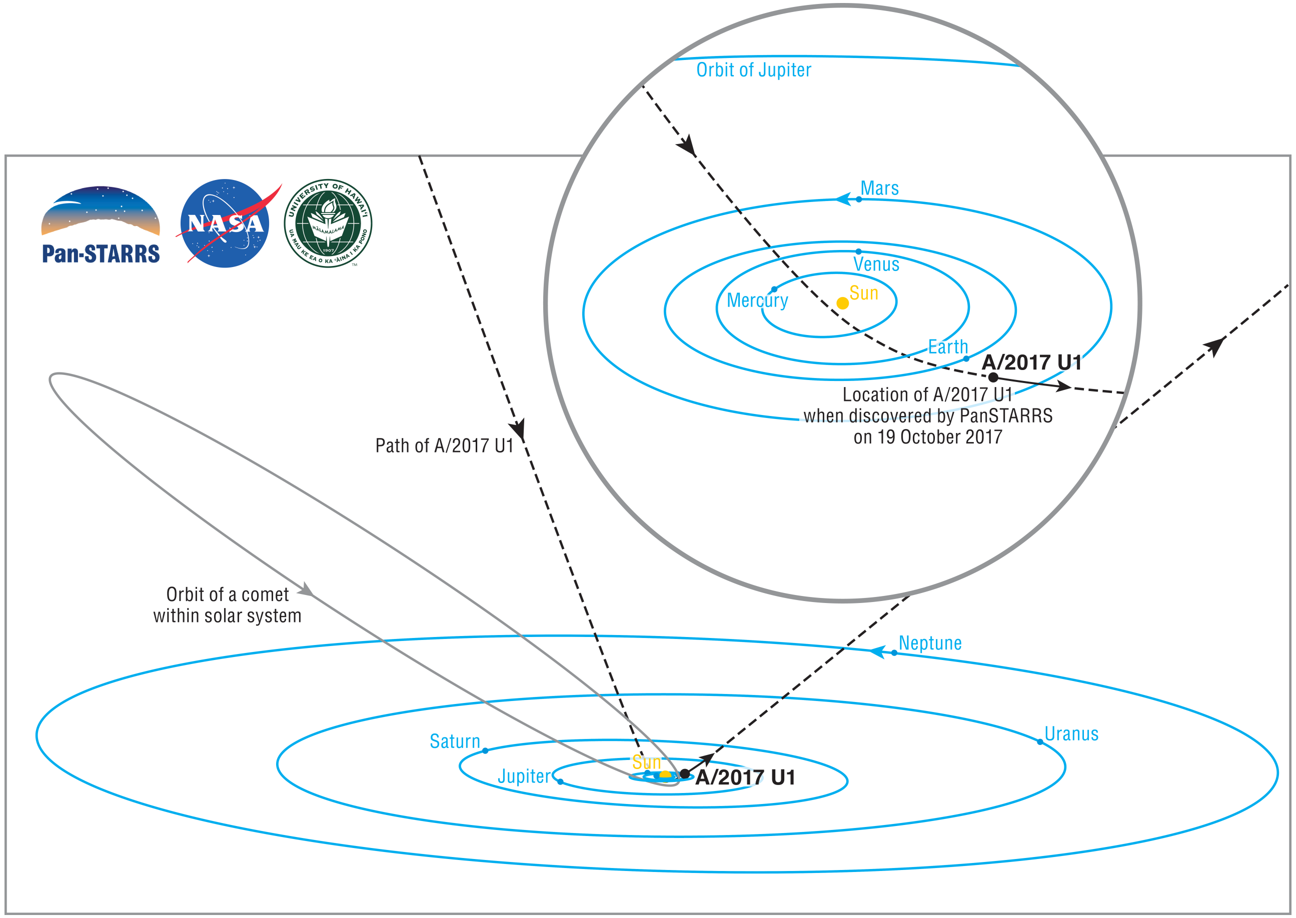
A messenger from afar arriving first

Humuhumunukunukuapua’a

Orbit of ‘Oumuamua

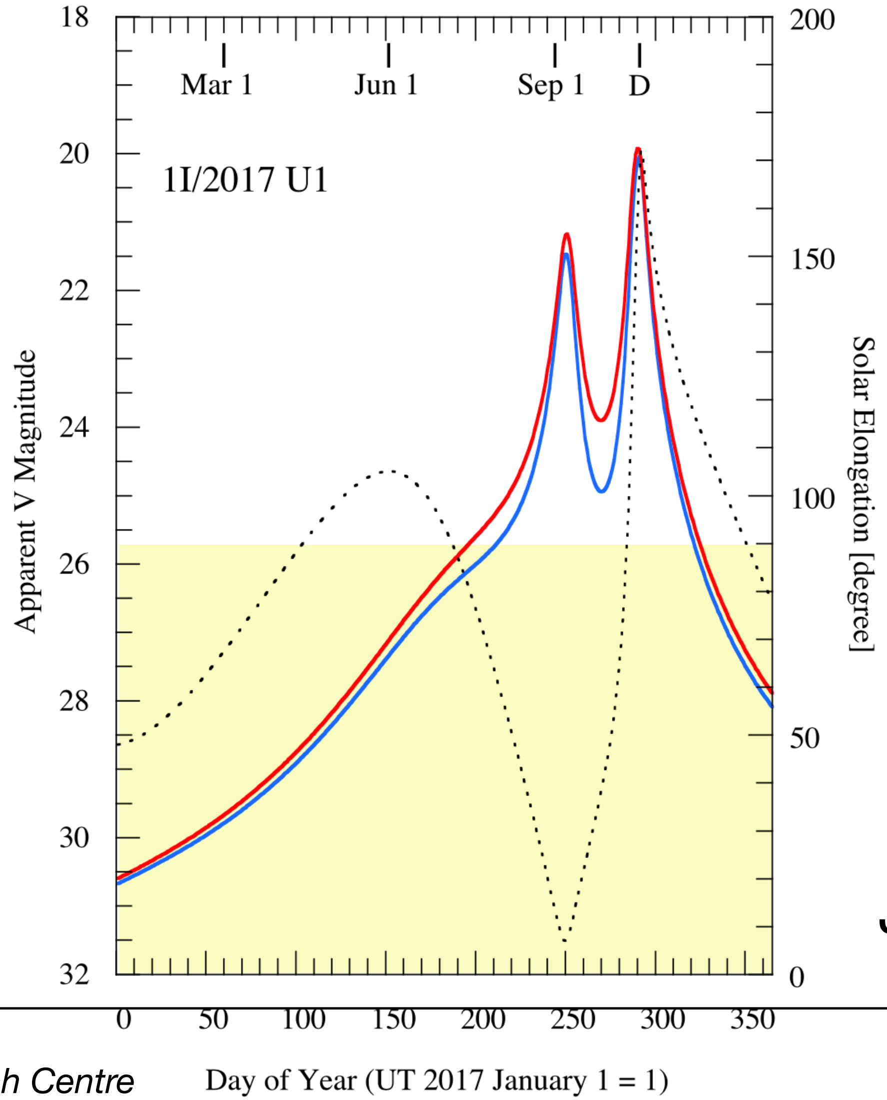


Orbit of 'Oumuamua



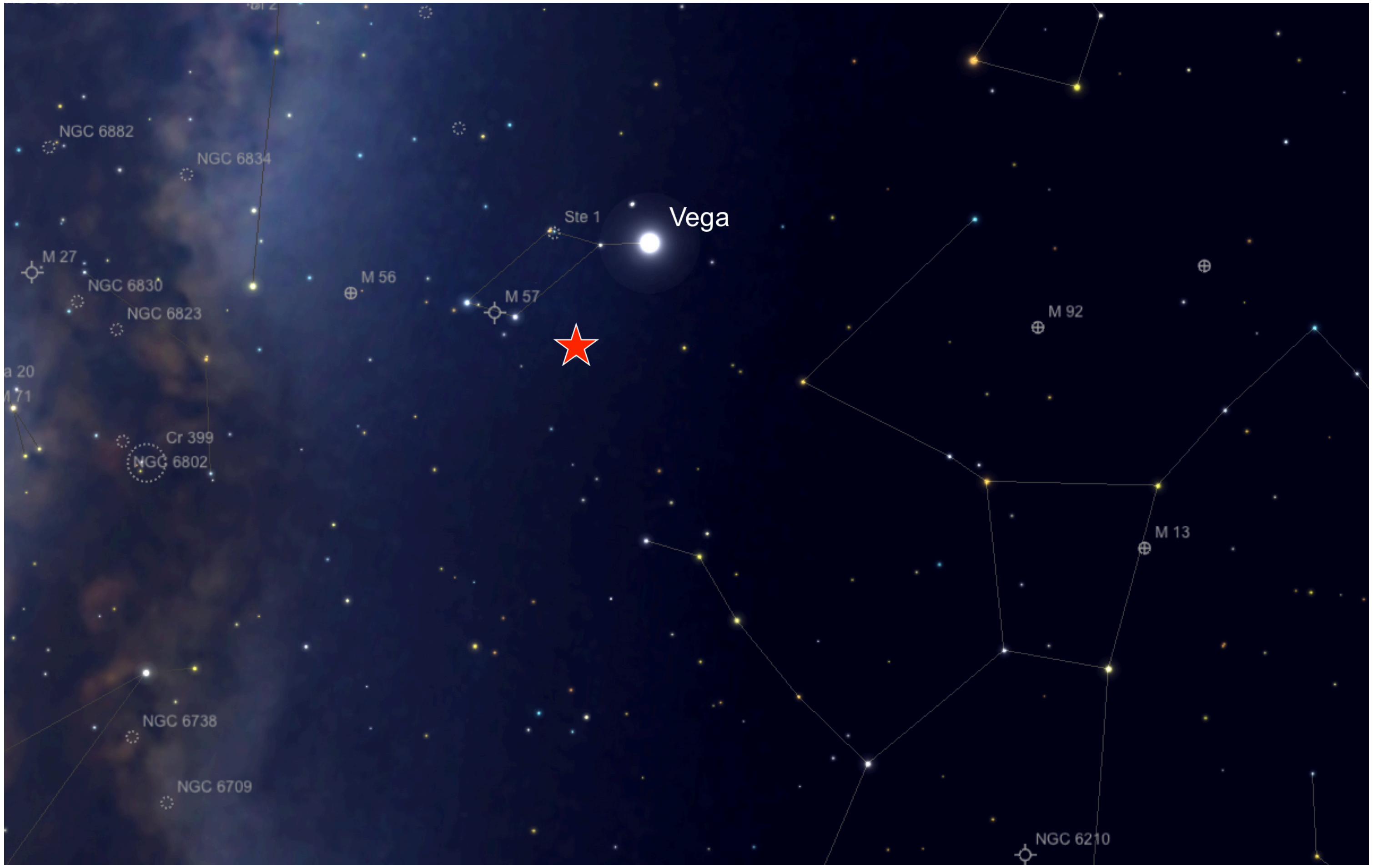
Perihelion 9 September
Discovery 19 October
e=1.197
q=0.25 au
i=122.6^{o}
Hv=22.4
(D~200m-300m for low albedo)

I/2017 U1 Visibility



Jewitt et al. (2017)

I/2017 U1 Origin

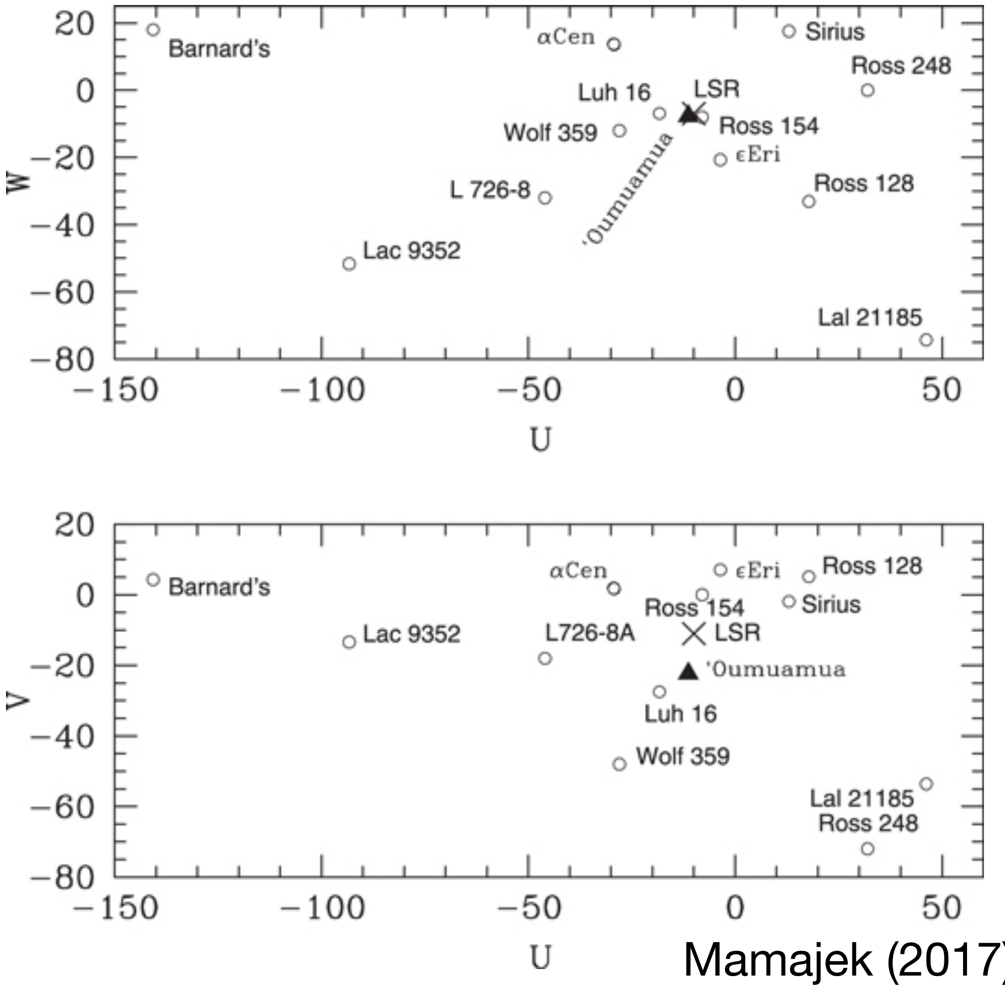


$\alpha \simeq 18\text{h}\ 40.6\text{m}\ \delta \simeq 34^\circ\ 09'$

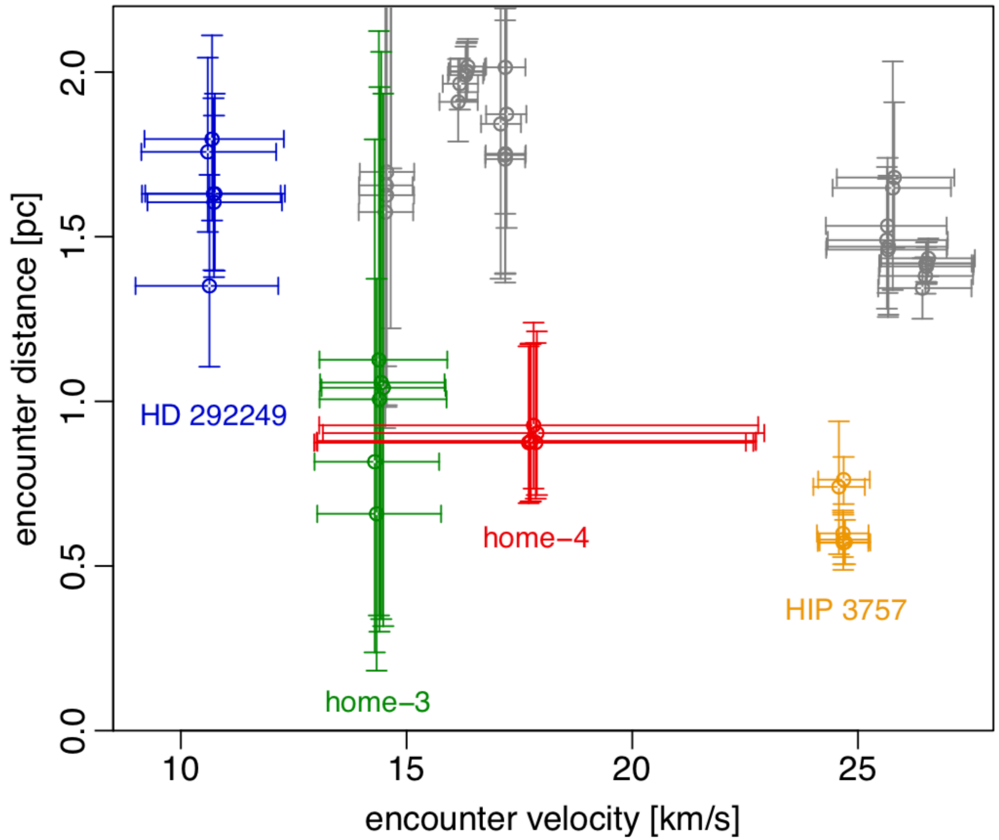
~6 degrees from Solar Apex

V= 26.2 km/s= 26.6 pc/Myr

Where did it come from?

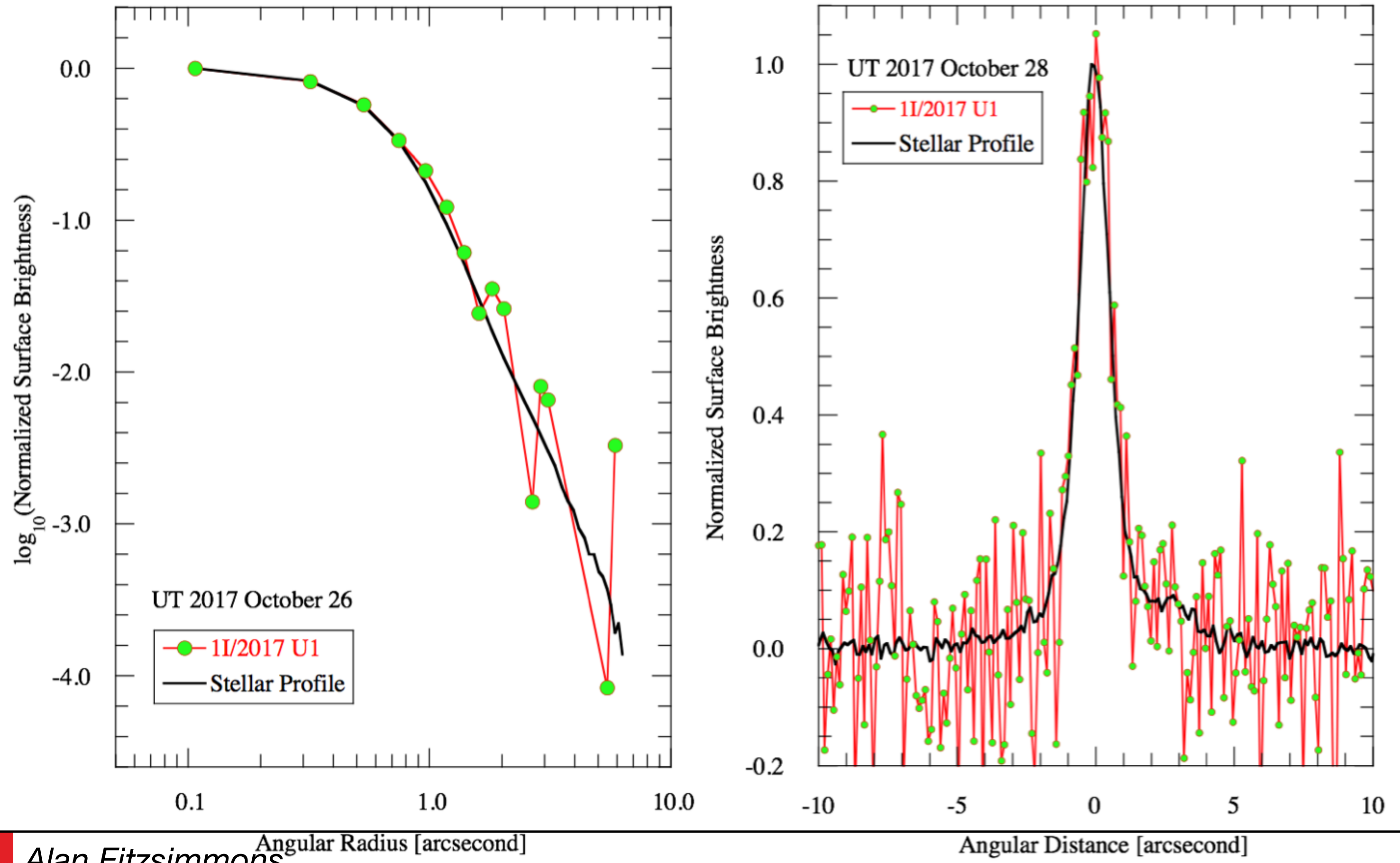


Mamajek (2017)



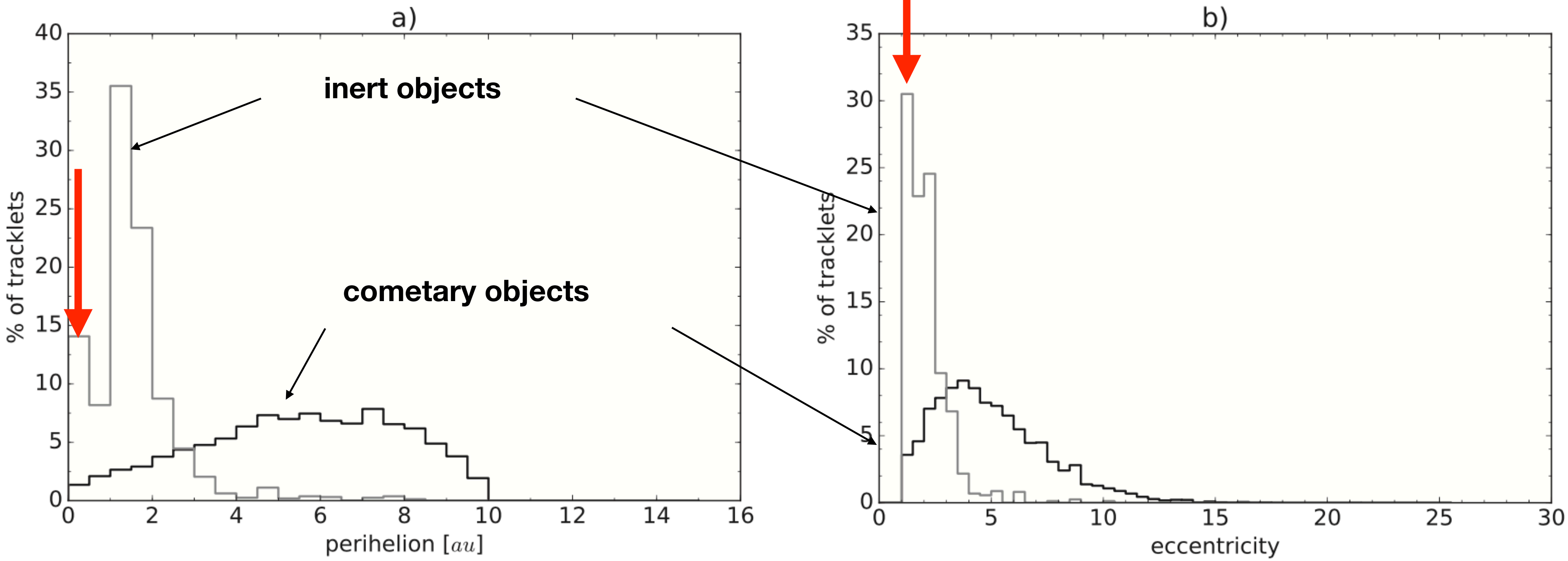
Bailer-Jones et al. (2018)

No activity in profile



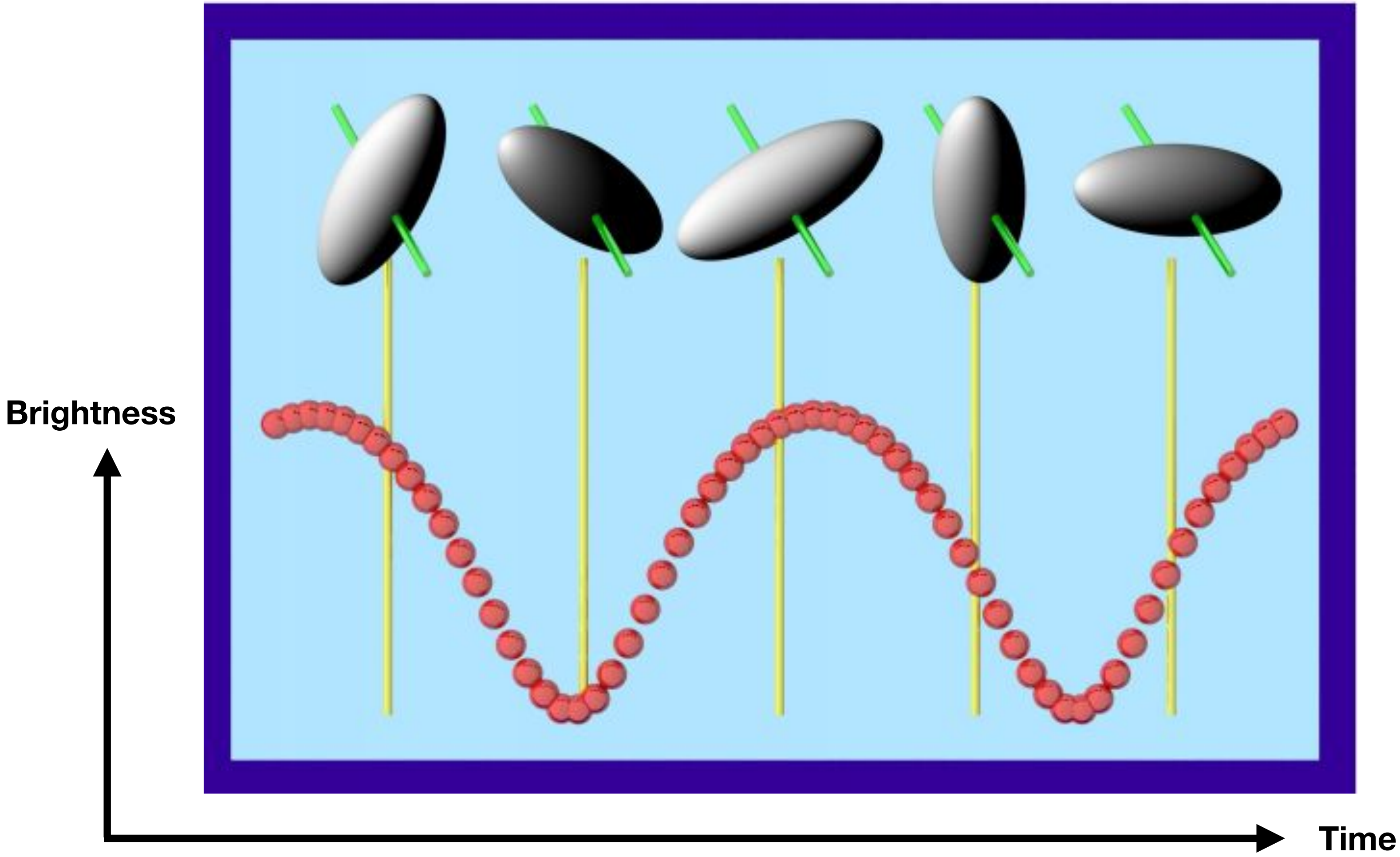
Jewitt et al. 2017

No activity in profile

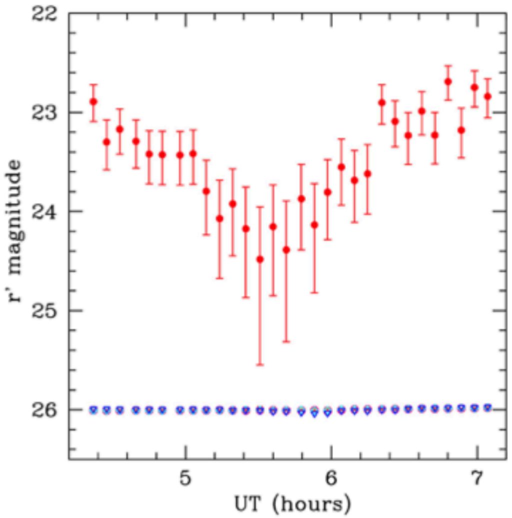


Engelhardt et al. (2017)

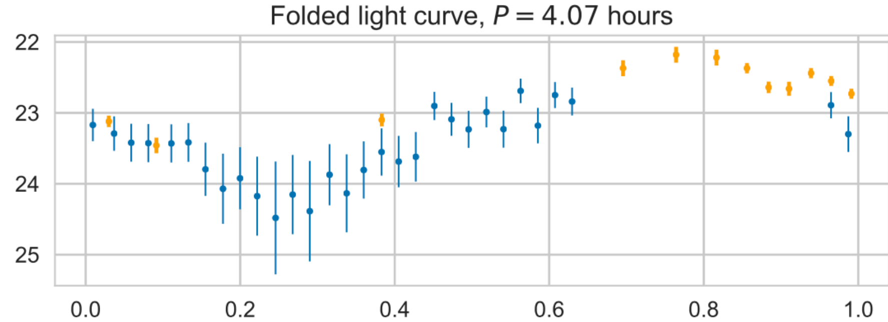
Small Body Lightcurves



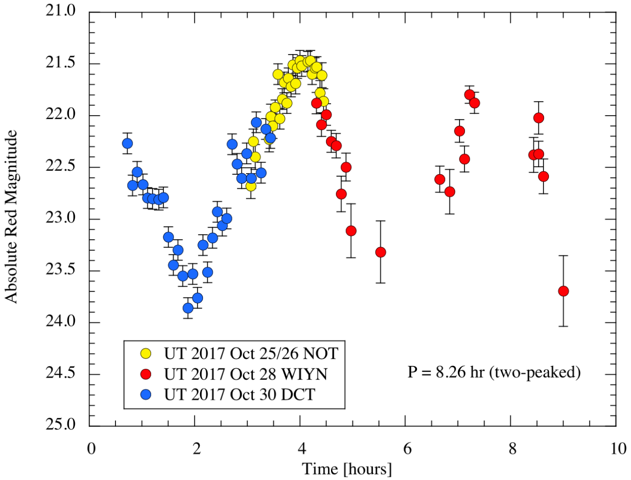
Spin Period & Shape



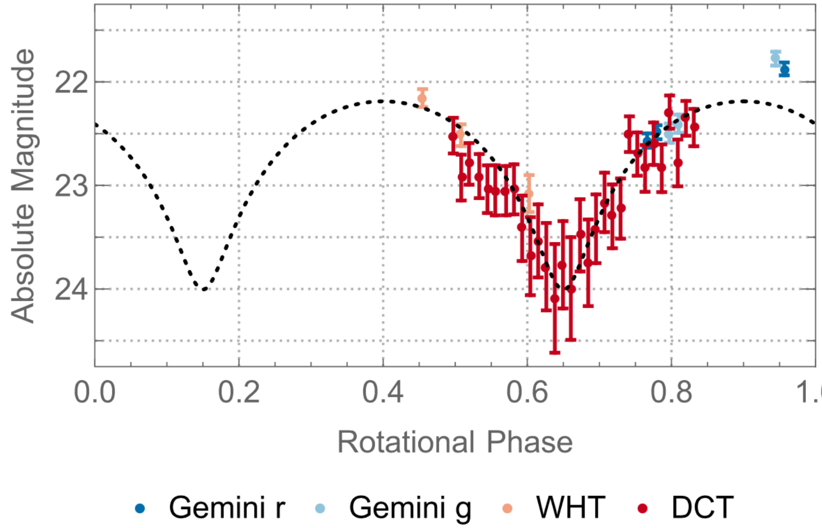
P > 5 hours Knight et al. (2017)



P=8.1 hours Bolin et al. (2017)

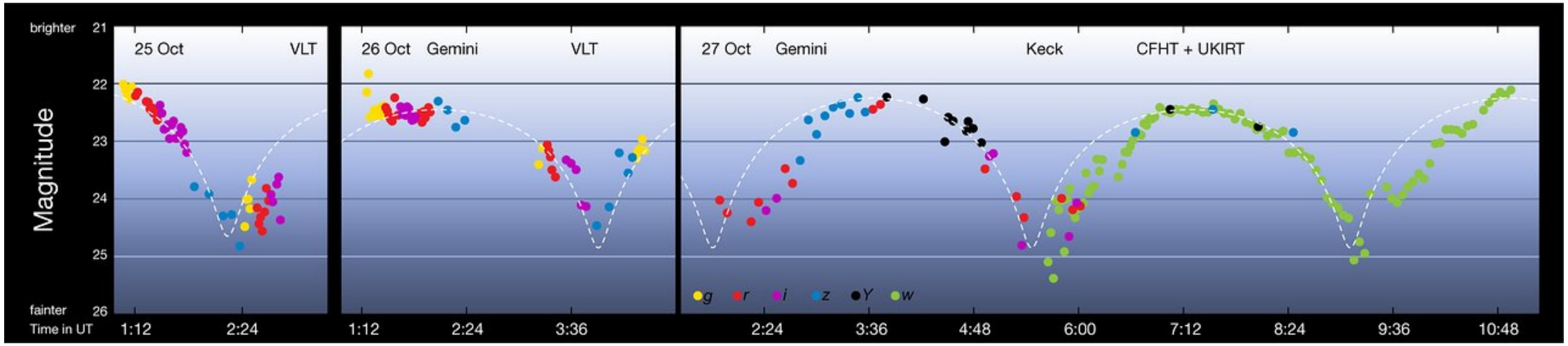


P=8.26 hours Jewitt et al. (2017)



P=8.10 hours Bannister et al. (2017)

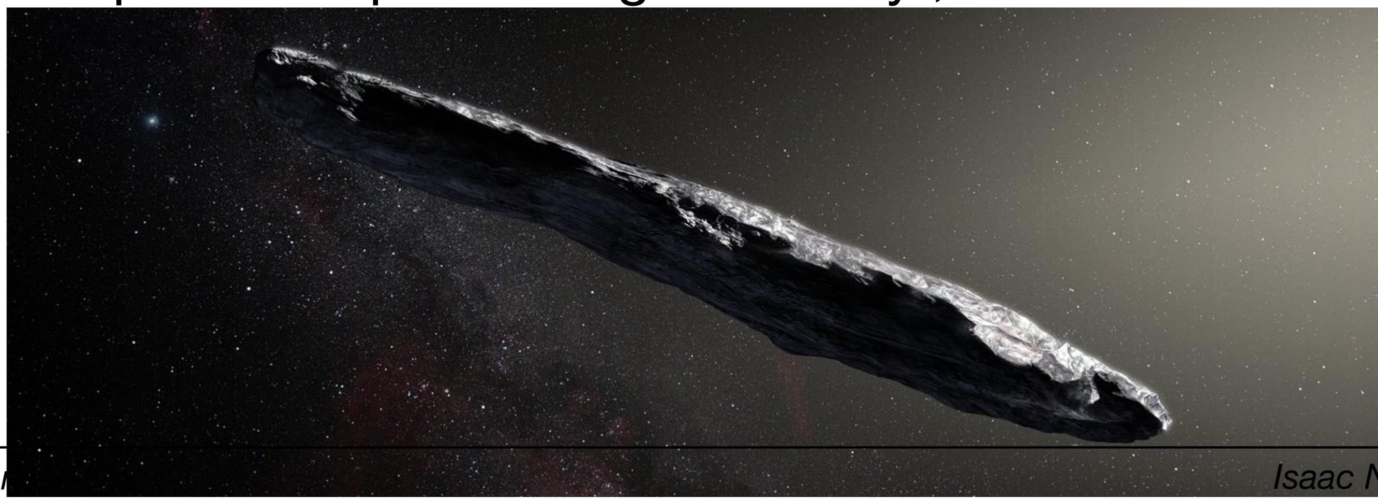
Spin Period & Shape



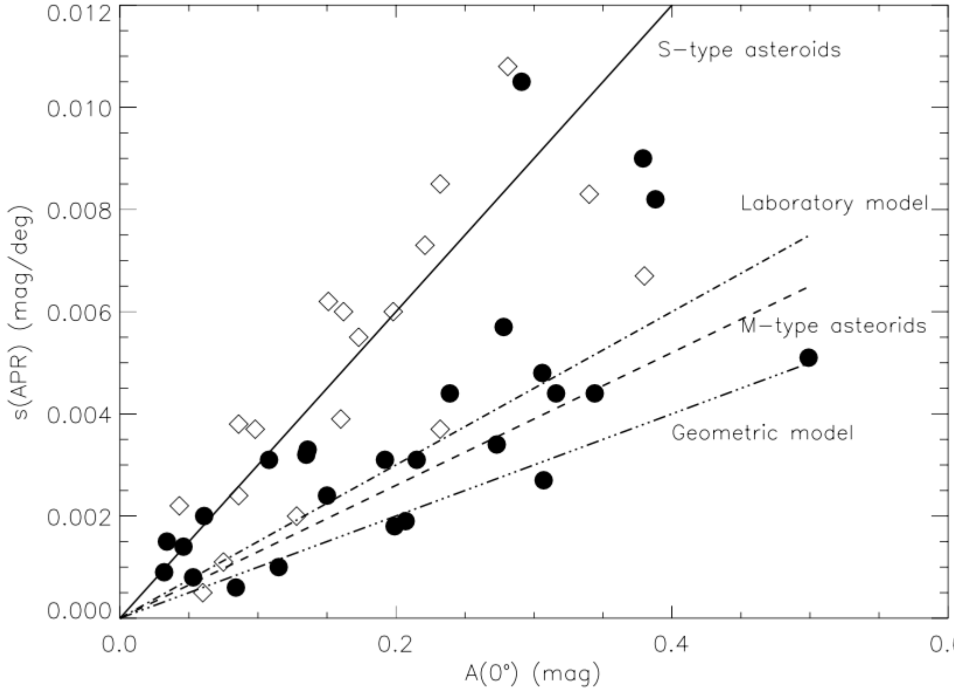
$P = 7.34$ hours, $\Delta m \simeq 2.5$ mag (Meech et al. 2017)

H_V=22.4 implies D~200m

Amplitude implies elongated body , axial ratio 10:1!



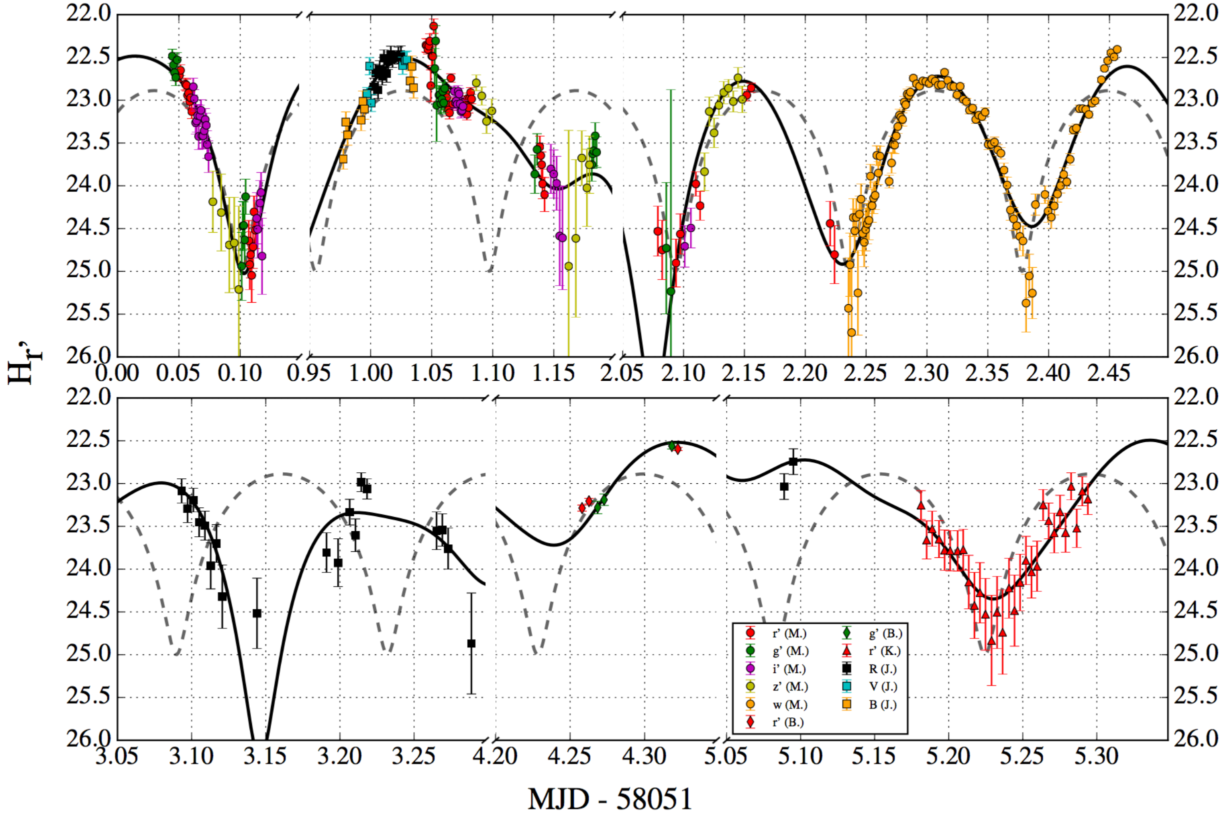
Spin Period & Shape

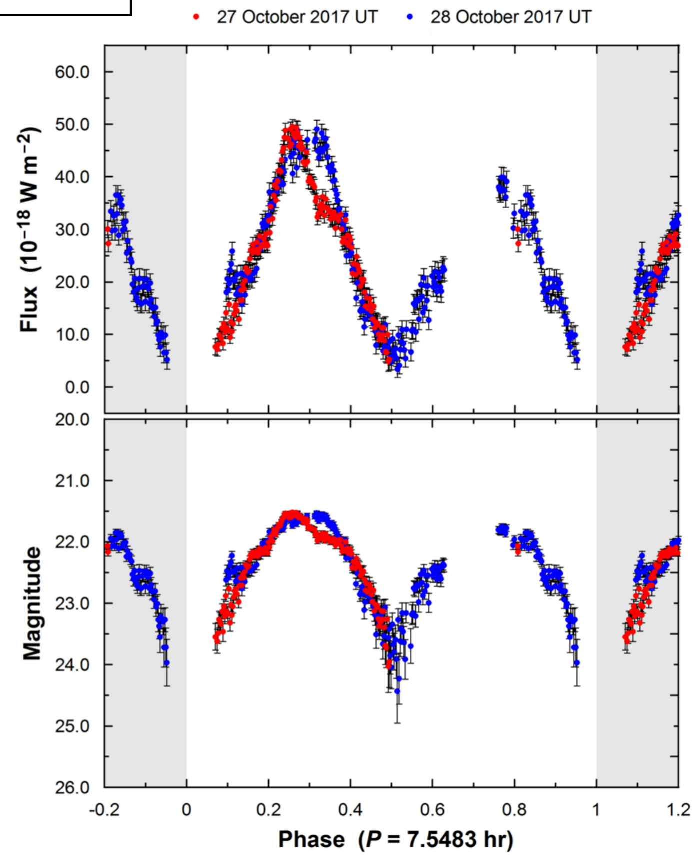


Guttierez et al. (2006)
Zappala et al. (2000)

Lightcurve amplitude is a function of phase angle (scattering angle).
Probable minimum elongation 6:1 for α= 20-24 degrees (NcNeil et al. 2018).

Non-Principal Axis rotation

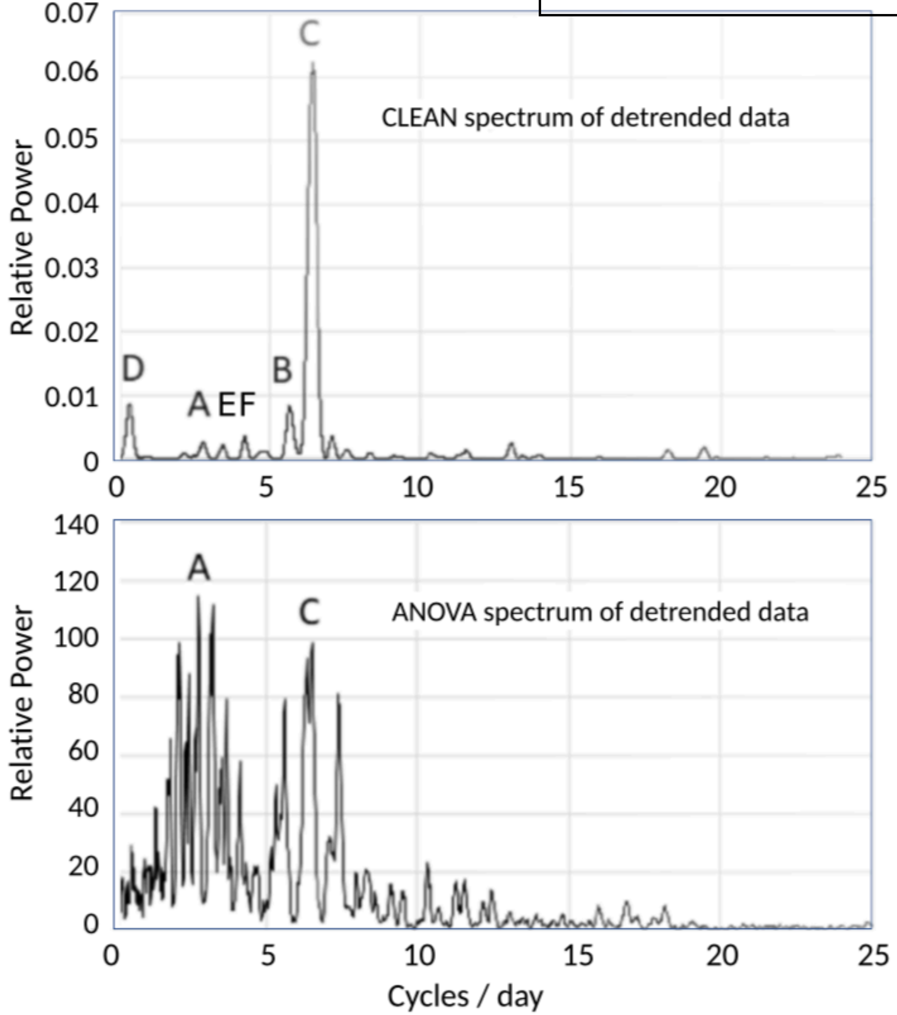


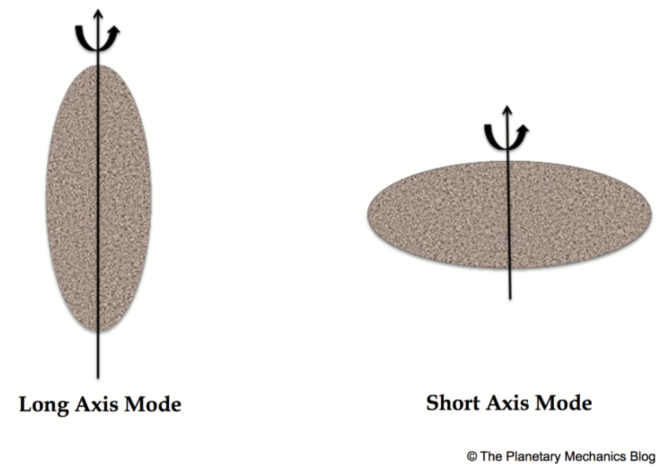


P=7.41 hours and P=7.94 hours (Fraser et al. 2018)

P=7.5483 hours (Drahus et al. 2018)

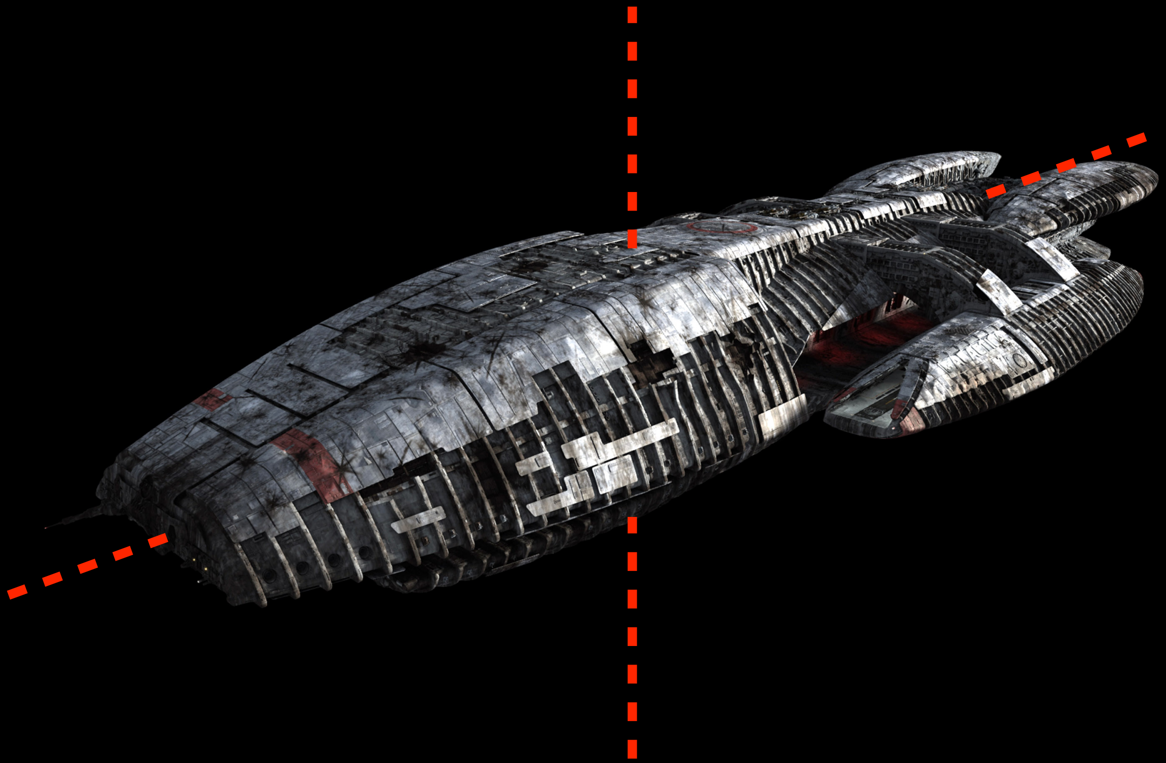
Non-Principal Axis rotation



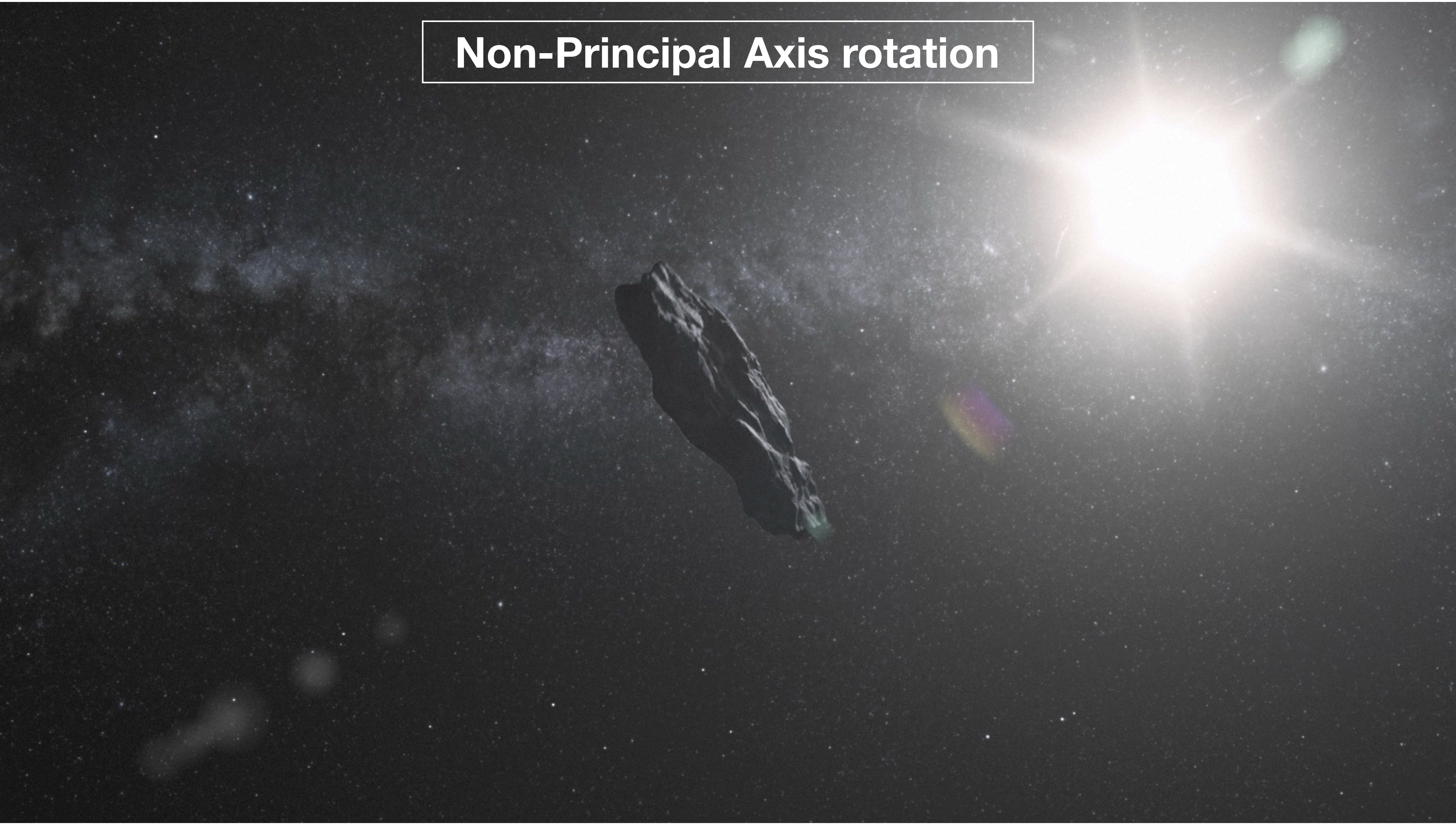


Belton et al. (2018) found long axis precession period of **8.67+/- 0.34** hr.
Long-Axis Mode rotation of 6.58 hr, 13.15 hr, or **54.48** hr
Short-Axis Mode rotation of 13.15 hr or 54.48 hr

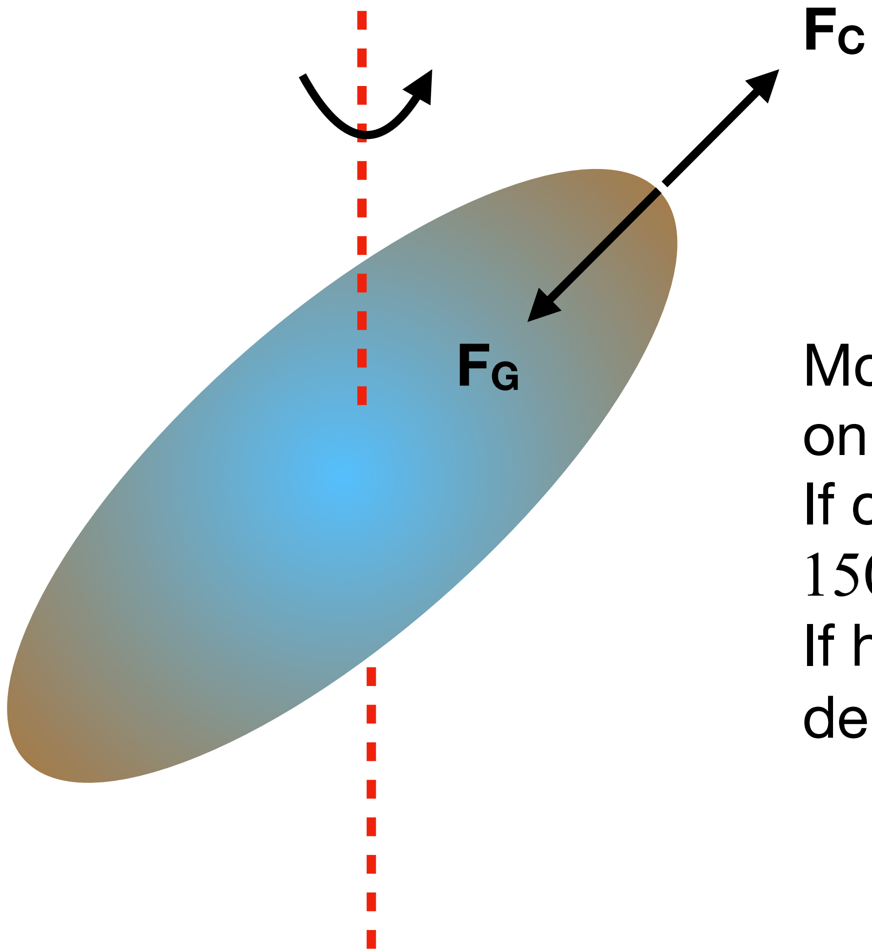
Lowest Energy State
SAM or LAM



Highest Energy State
LAM


Non-Principal Axis rotation

Internal Density Constraints



McNeil et al. (2018) Calculated constraints on the bulk density

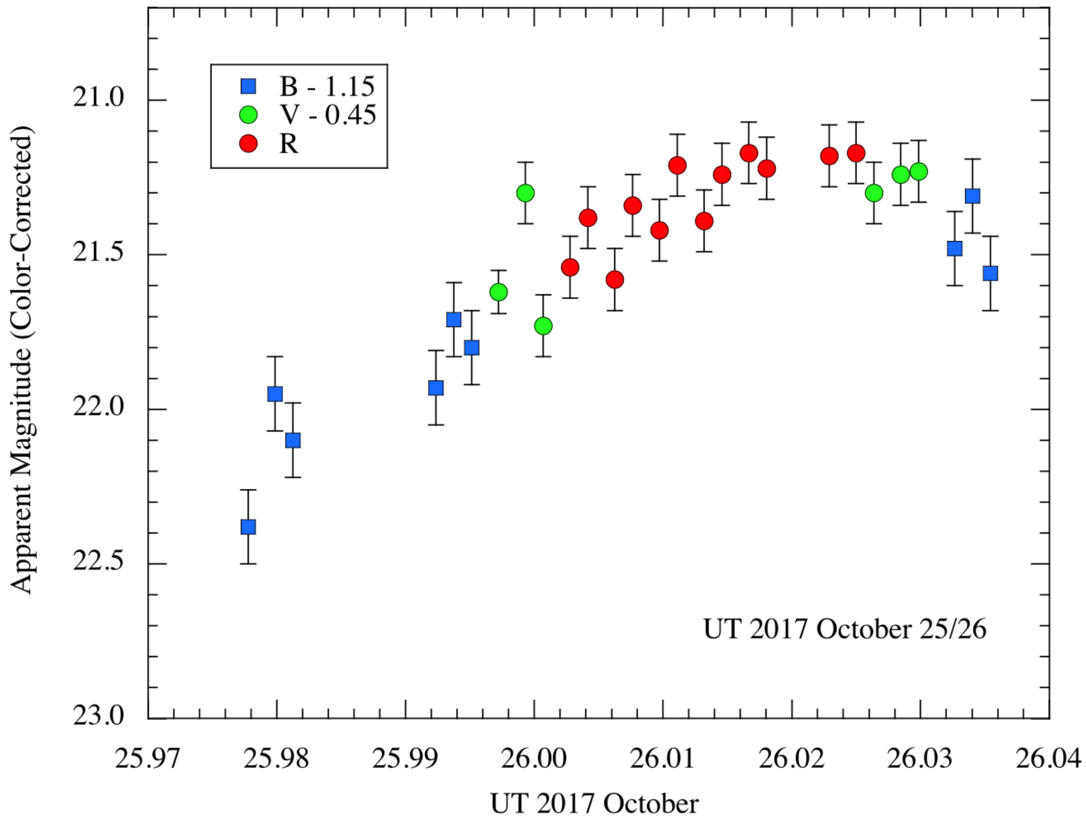
If completely strengthless (s=0) then

$$1500 < \rho < 2800\,\mathrm{kg/m^3}$$

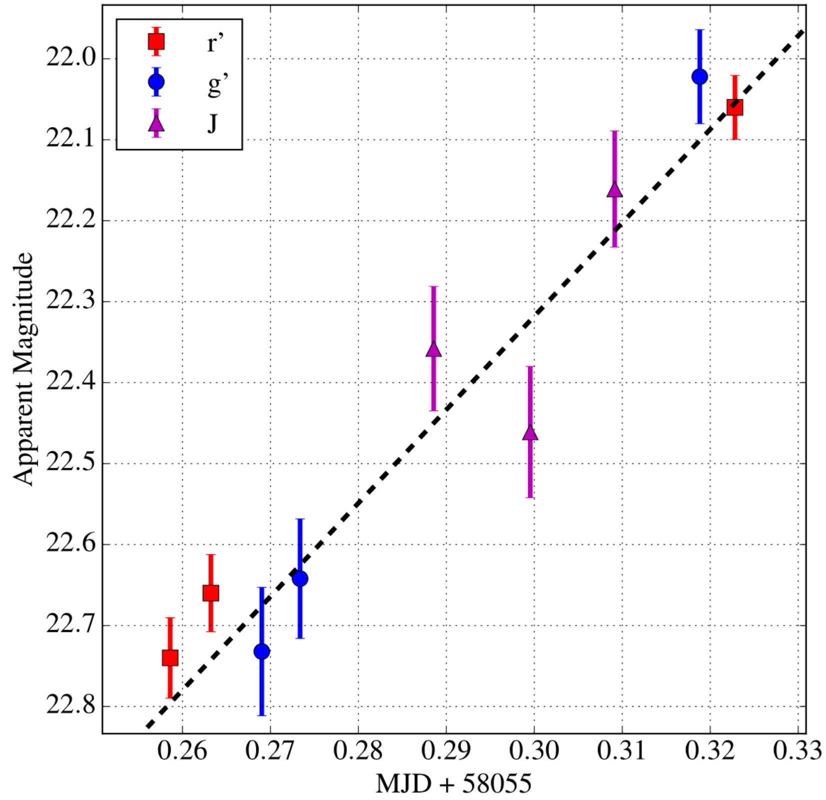
If has non-zero cohesive strength, the density is lower and s~10 Pascals.

Optical+IR colours

Large amplitude lightcurve means colours need careful measurement!



Jewitt et al. (2017)

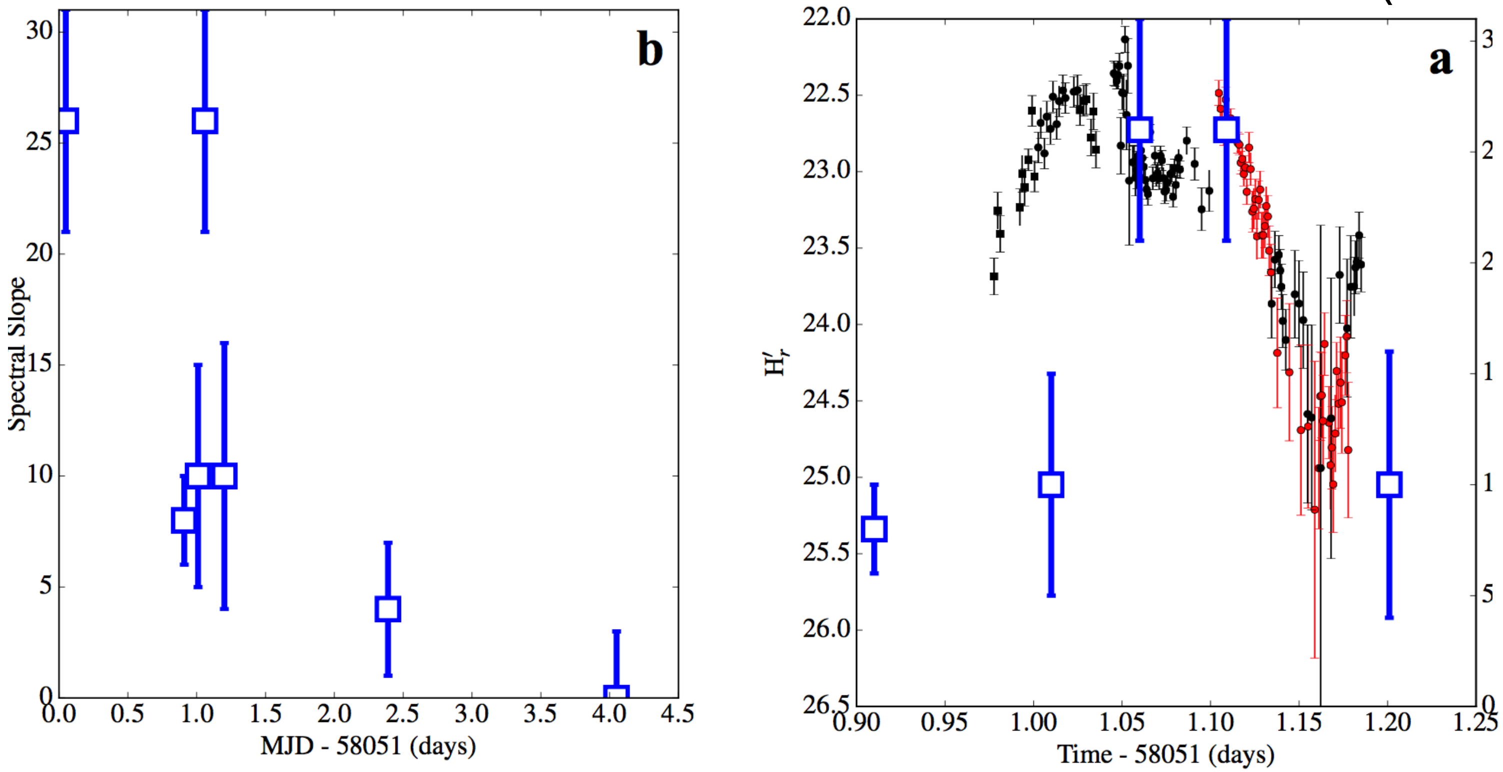


Bannister et al. (2017)

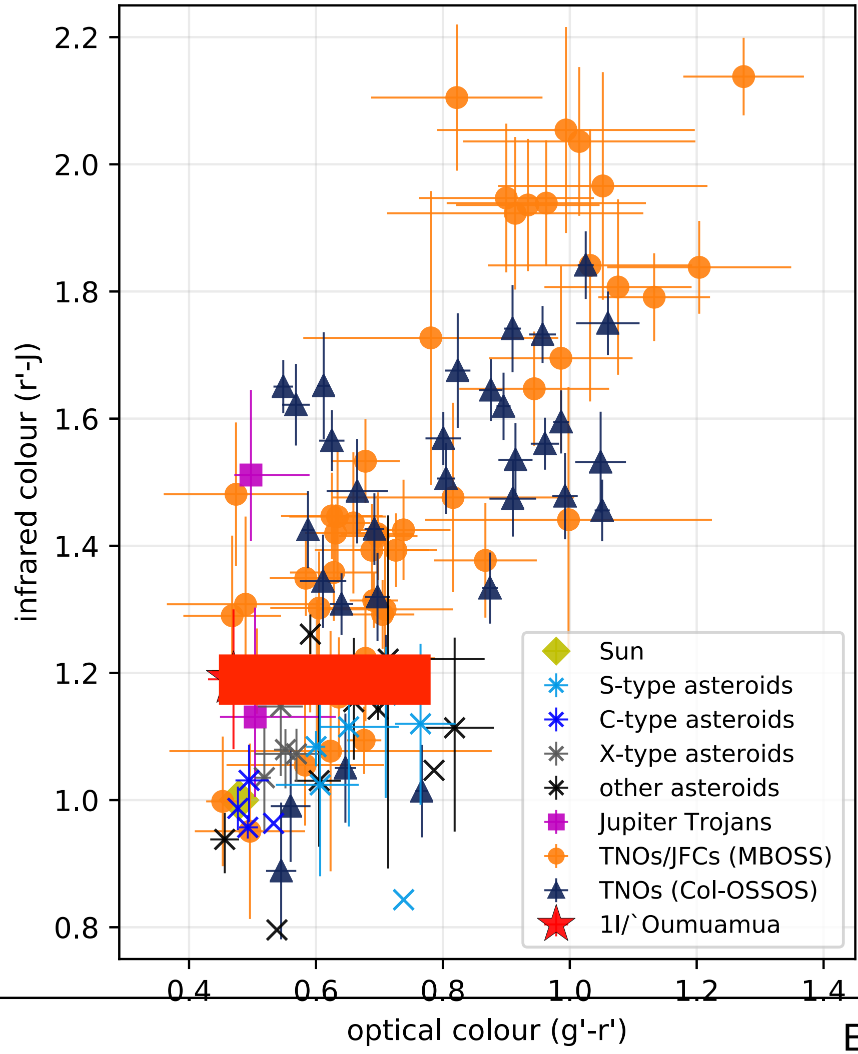
Optical+IR colours

Colour variations not secular but linked with lightcurve phase.

Fraser et al. (2018)

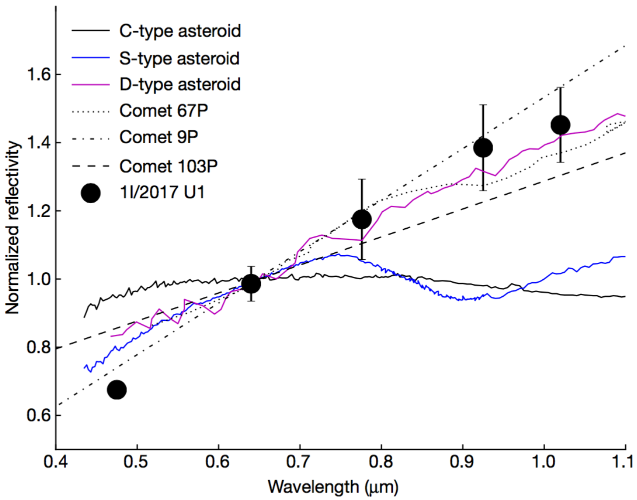


Optical+IR colours

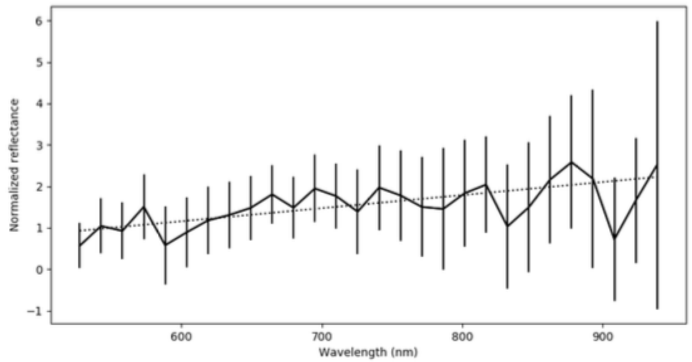


Bannister et al. (2017)

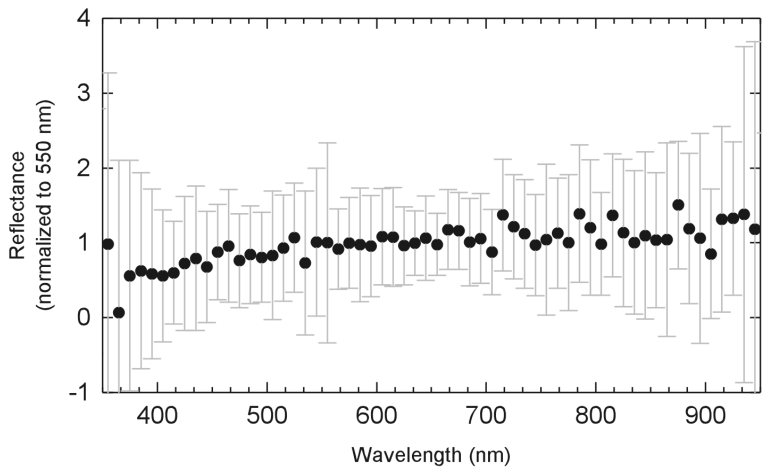
Optical Spectroscopy



VLT+Gemini-S, October 25-26
S'=23±3%/1000Å
Meech et al. (2017)



Palomar 5.0m, October 25.3 UT
S'=30±15%/1000Å
Masiero (2017)



Palomar 5.0m, October 26.2 UT
S'=10±6%/1000Å
Ye et al. (2017)

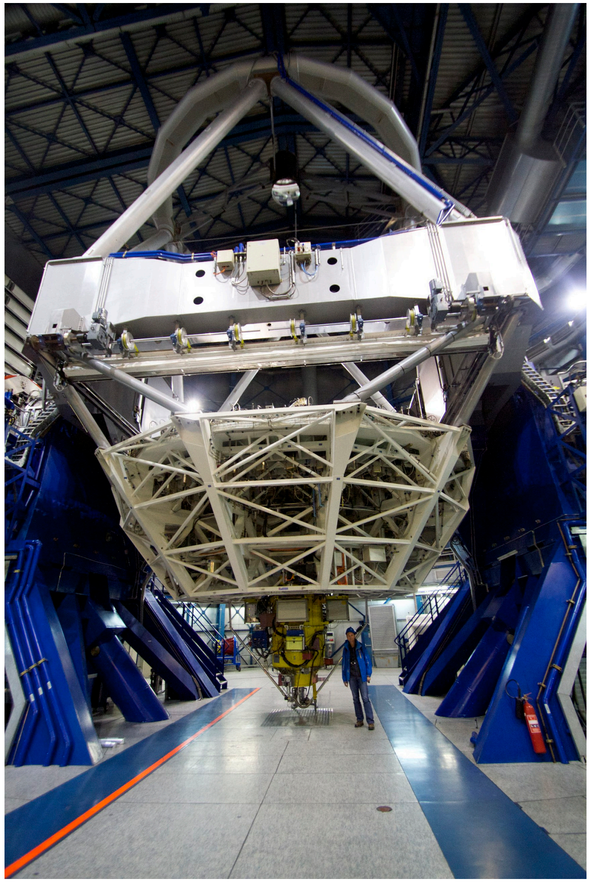
QUEEN'S UNIVERSITY BELFAST
Alan Fitzsimmons
Astrophysics Research Centre

Spectroscopy

October 25.9 UT

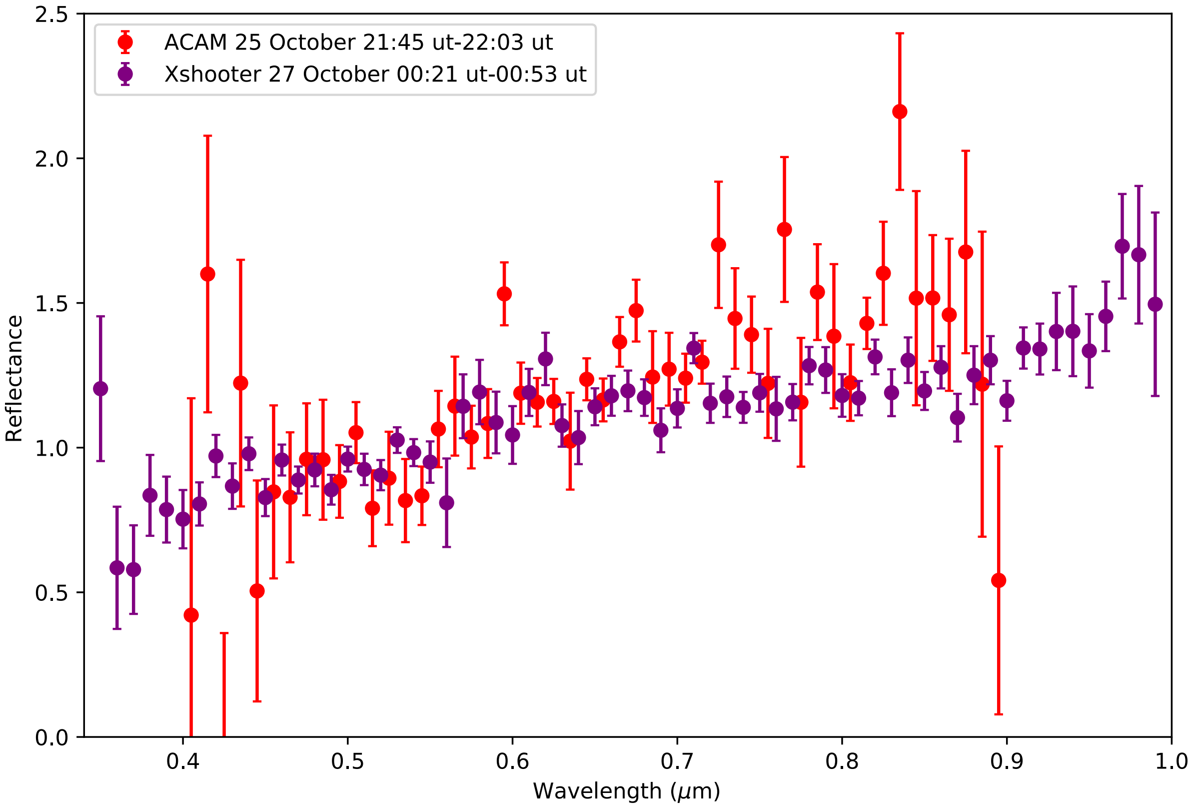
4.2m William Herschel Telescope + ACAM

October 27.0 UT



8.2m Very Large Telescope UT2 + X-Shooter

Optical Spectrum



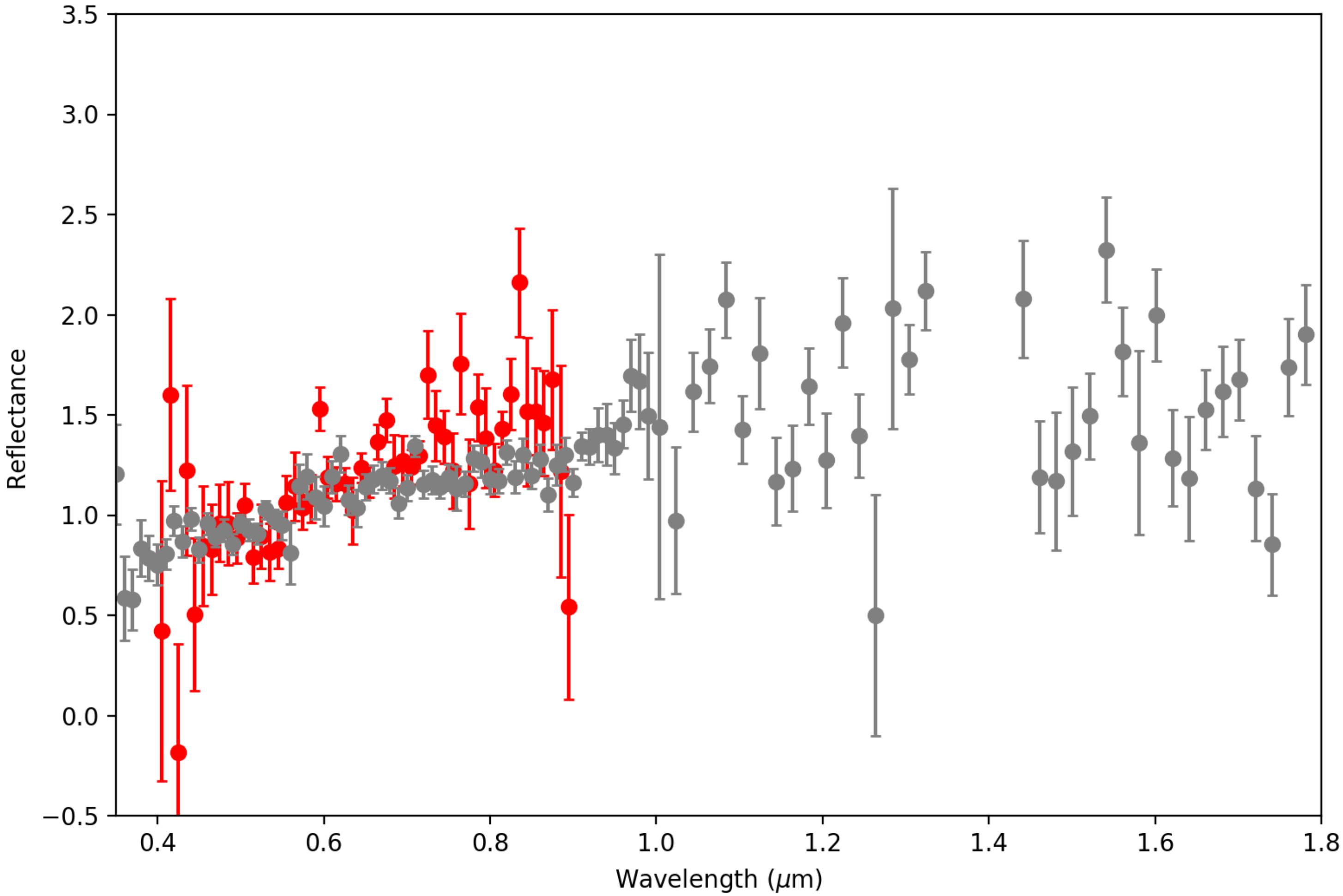
WHT+ACAM: S'=17±2%/1000Å

VLT+X-Shooter: S'= 9±1%/1000Å

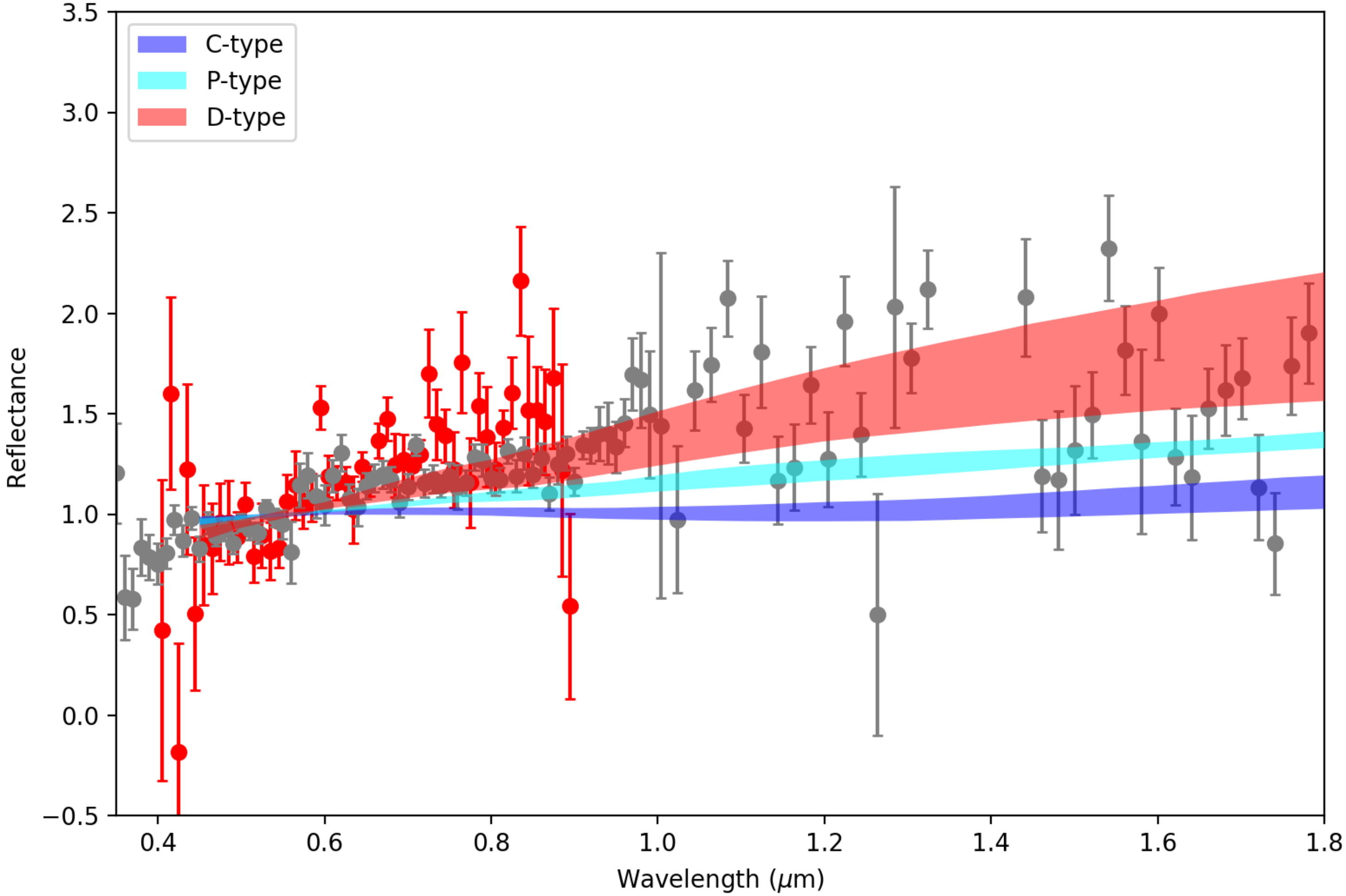
R. Ashley, C. Fariña and I. Skillen (Isaac Newton Group)

G. Beccari, B. Haeussler and F. Labrana (European Southern Observatory)

Optical + Near-Infrared Spectrum



Optical + Near-Infrared Spectrum

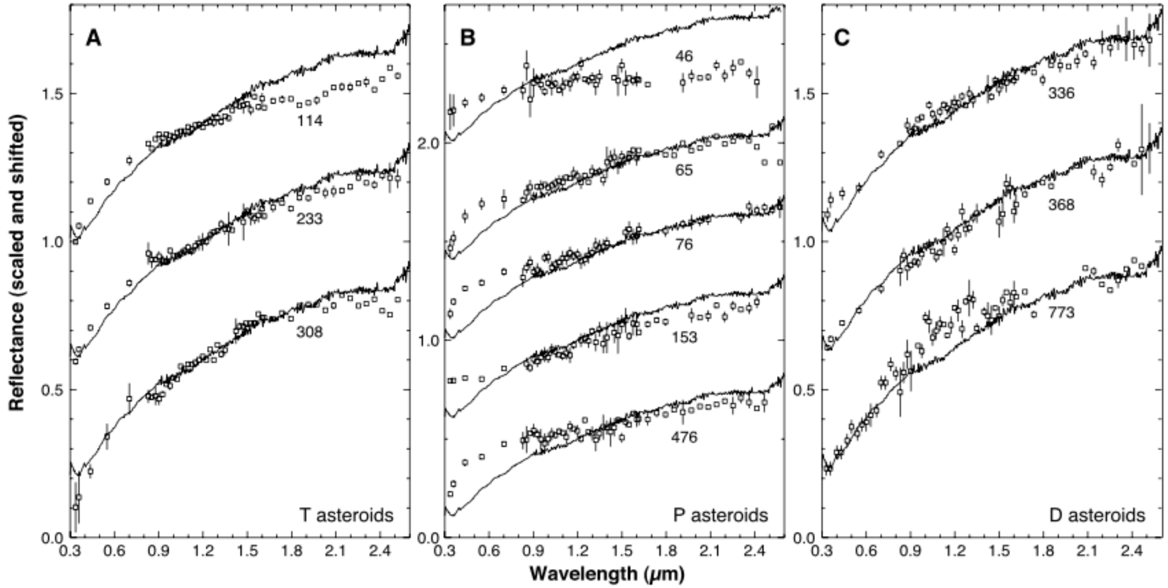


D-type Asteroid?

Tagish Lake Meteorite

Bulk Density ~1.7 gm/cm3

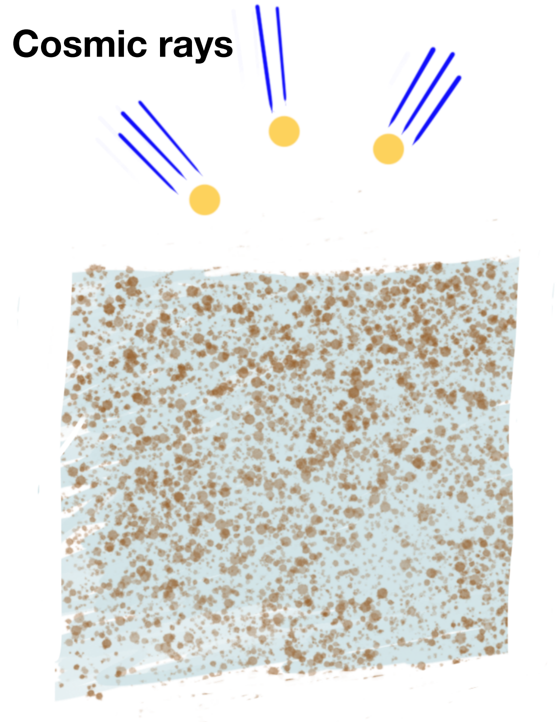
(Ralchenko et al. 2014)



Comparison with primitive asteroids

(Hiroi et al. 2001)

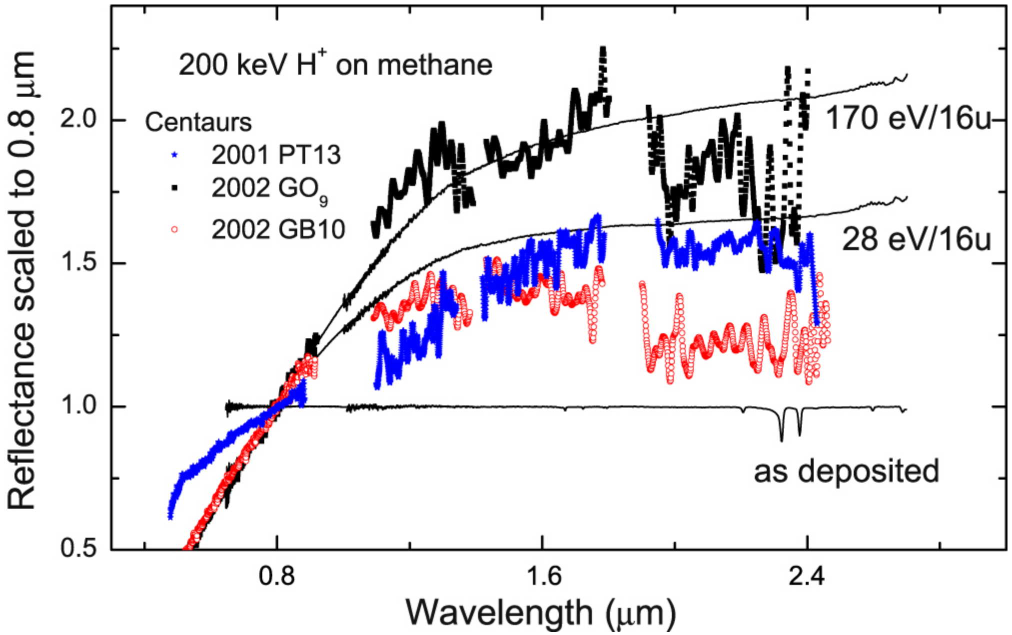
Cometary Irradiation ice mantles



Irradiation mantle requires ~10^8 yr to form ~50 cm thickness
(Guilbert-Lepoutre et al. 2015)

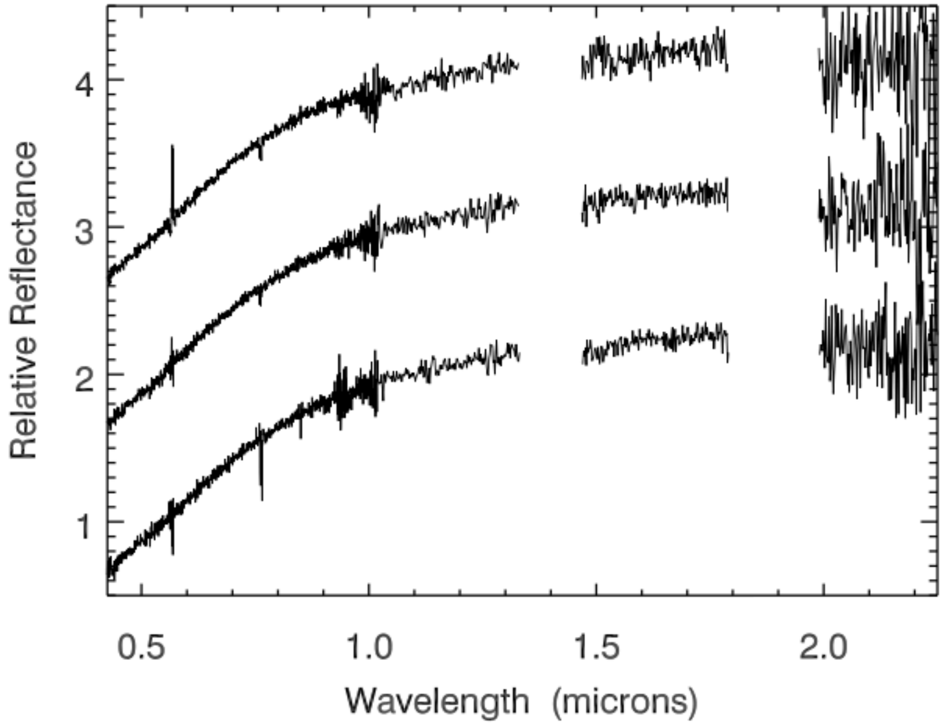
Cometary Irradiation ice mantles

200 keV H^+ onto CH_4 ice



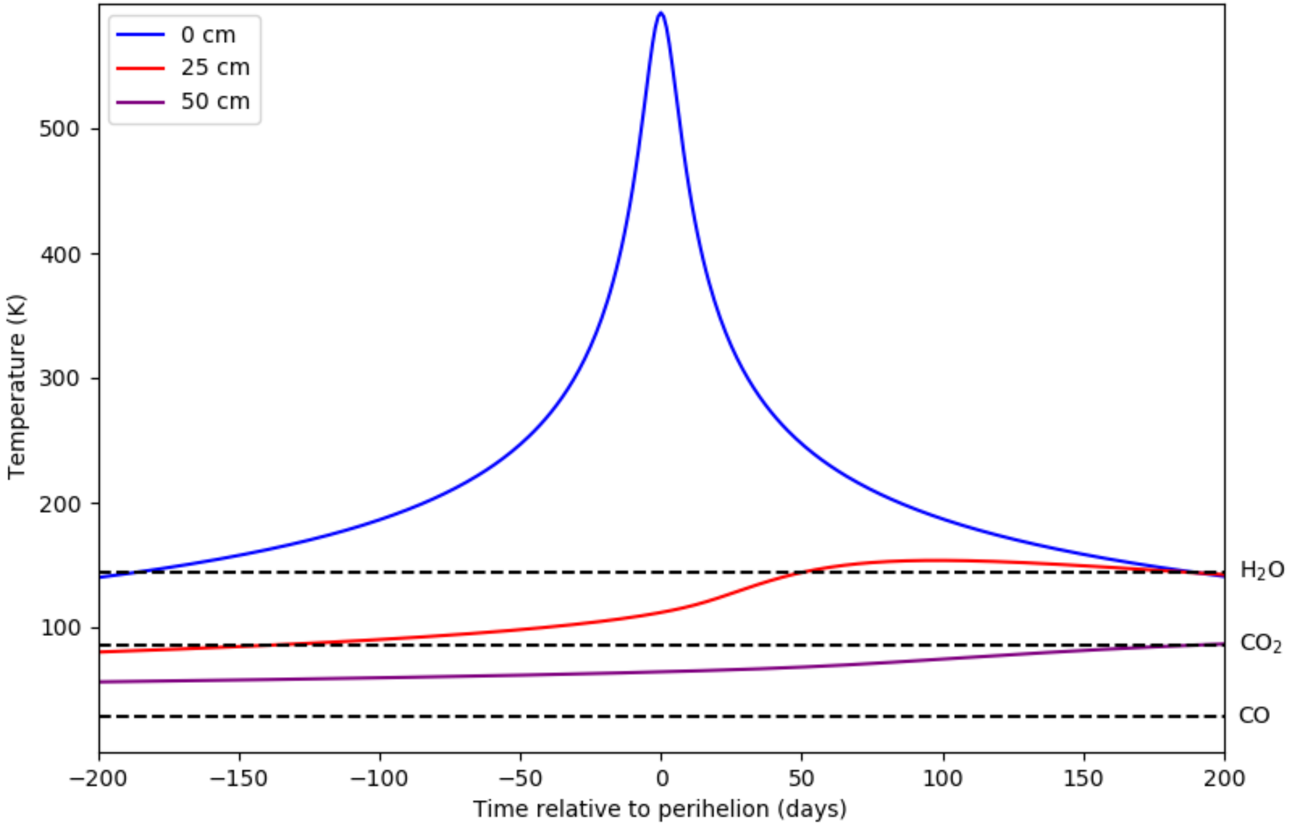
Rothard et al. (2017)

TNO (38628) Huya



Merline et al. (2017)

Ice survival



Irradiation mantle requires ~10^8 yr to form ~50 cm thickness (Guilbert-Lepoutre et al. 2015)

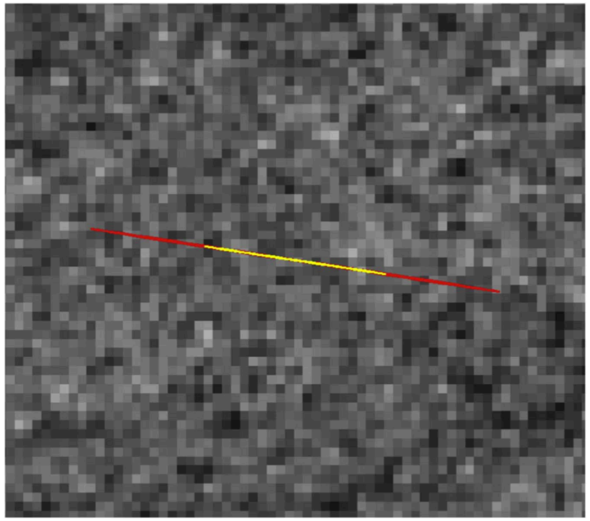
Assume albedo & thermal properties similar to cometary surfaces.

H_2O stable at > 25cm depth

CO_2 stable at > 50cm depth

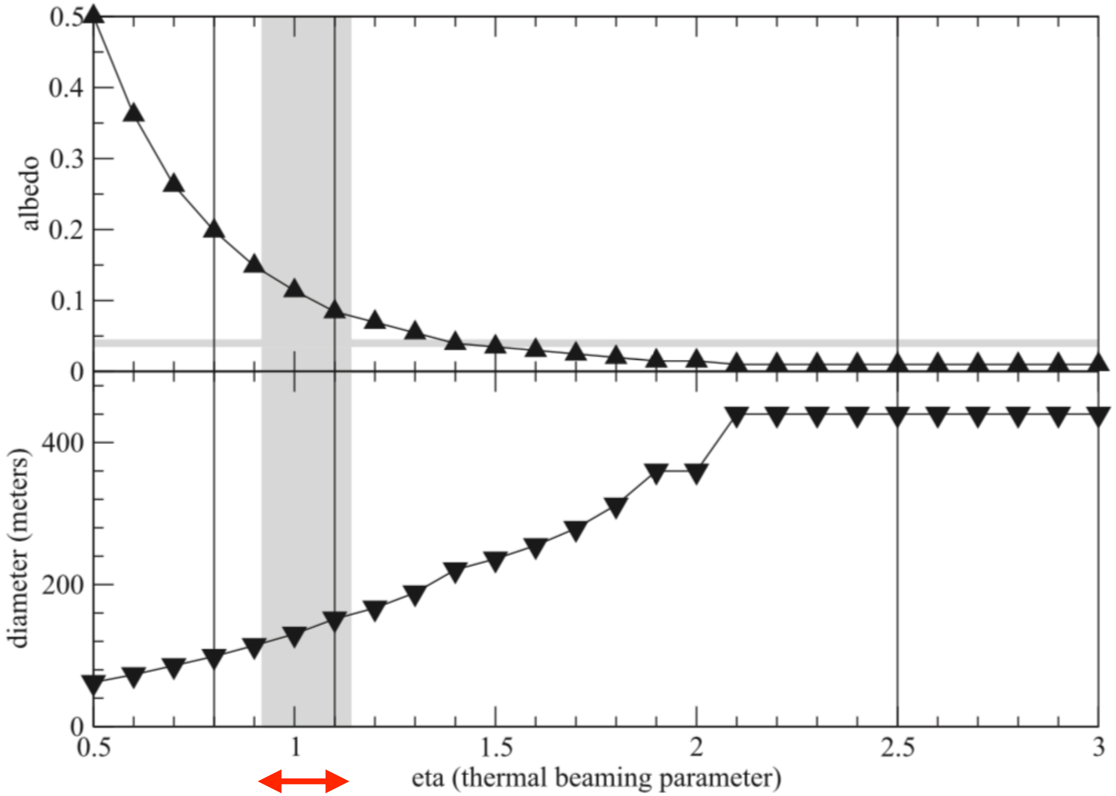
Fitzsimmons et al. (2018)

Spitzer Observations @ 4.5 um



IRAC 30.3 hours exposure
No detection

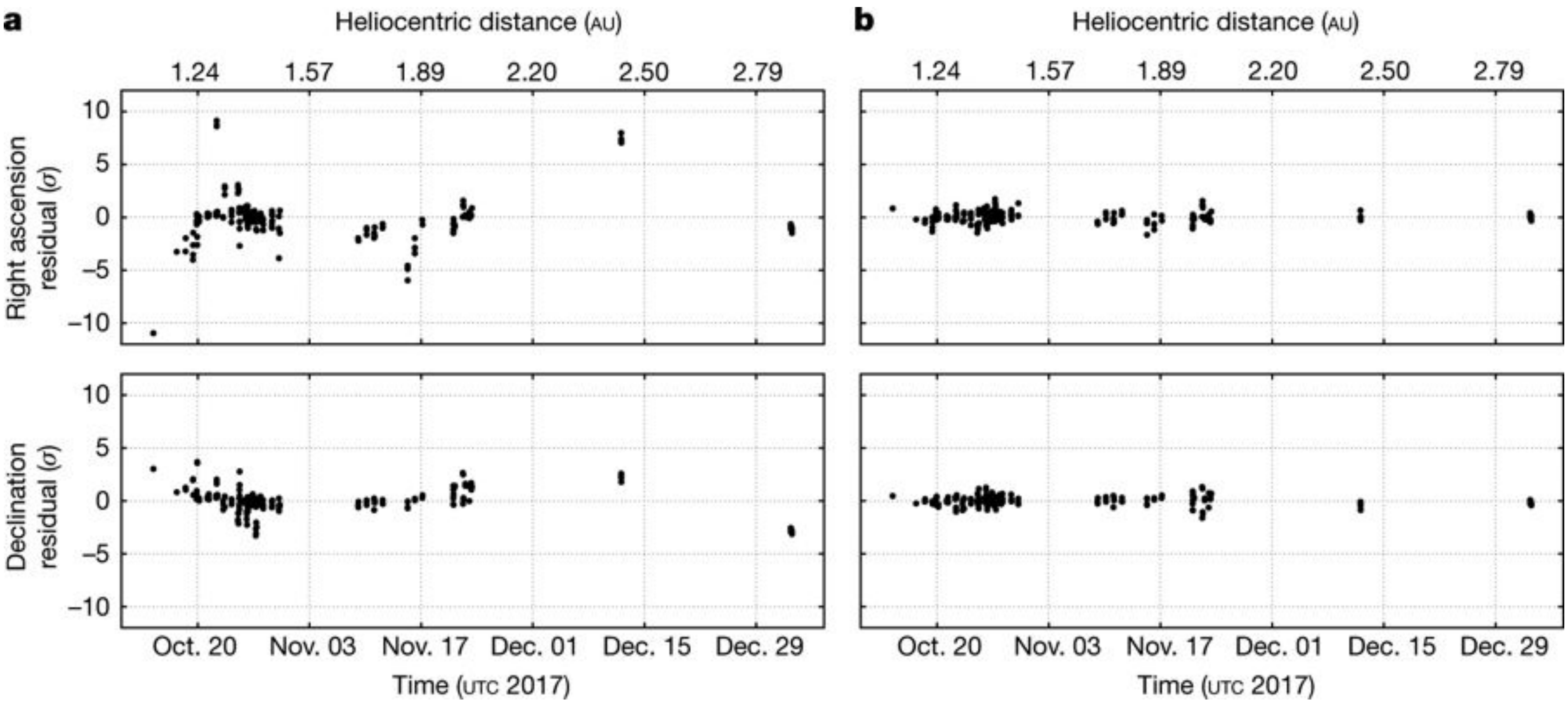
Trilling et al. (2018)



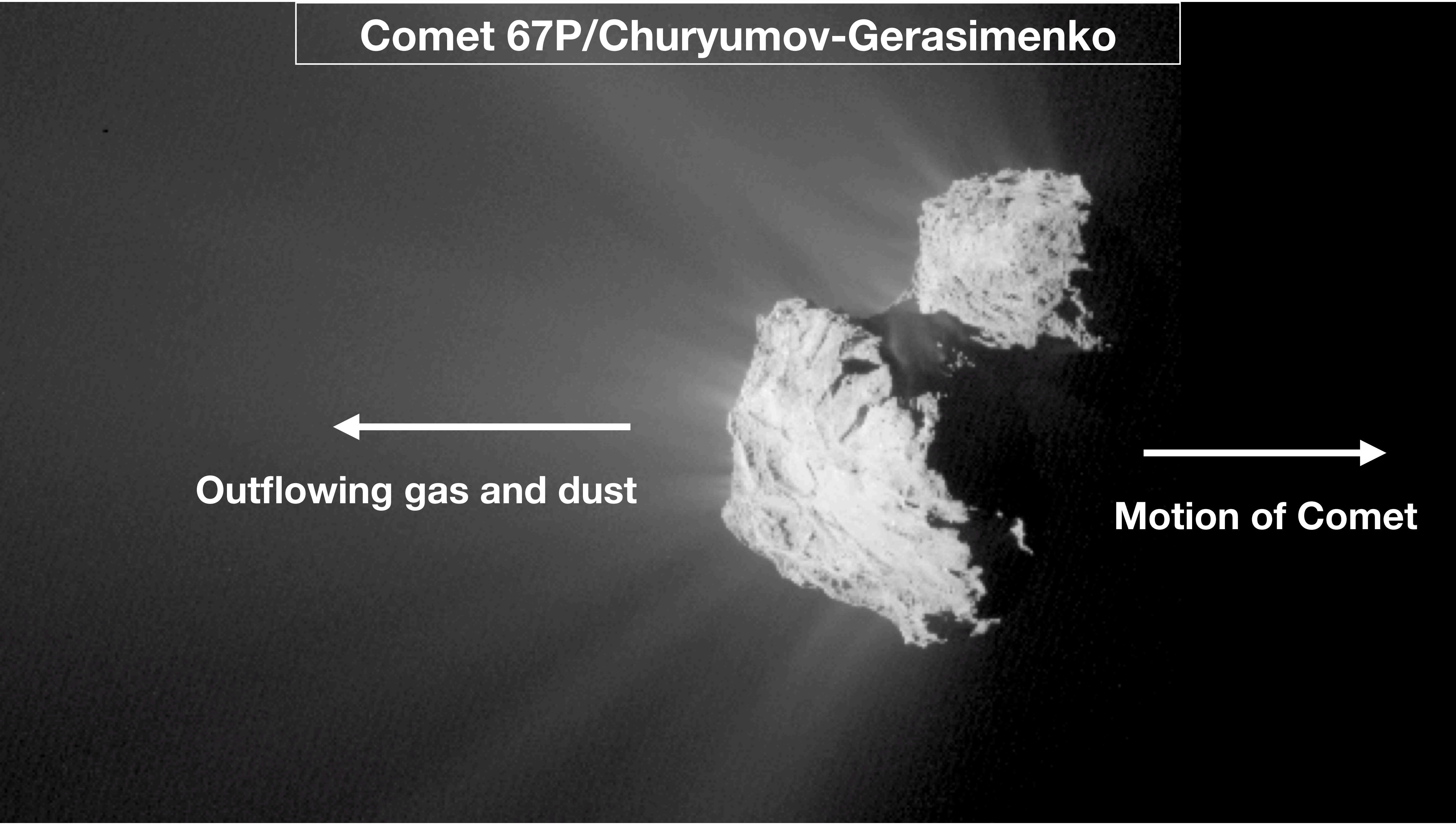
Typical Comet Values

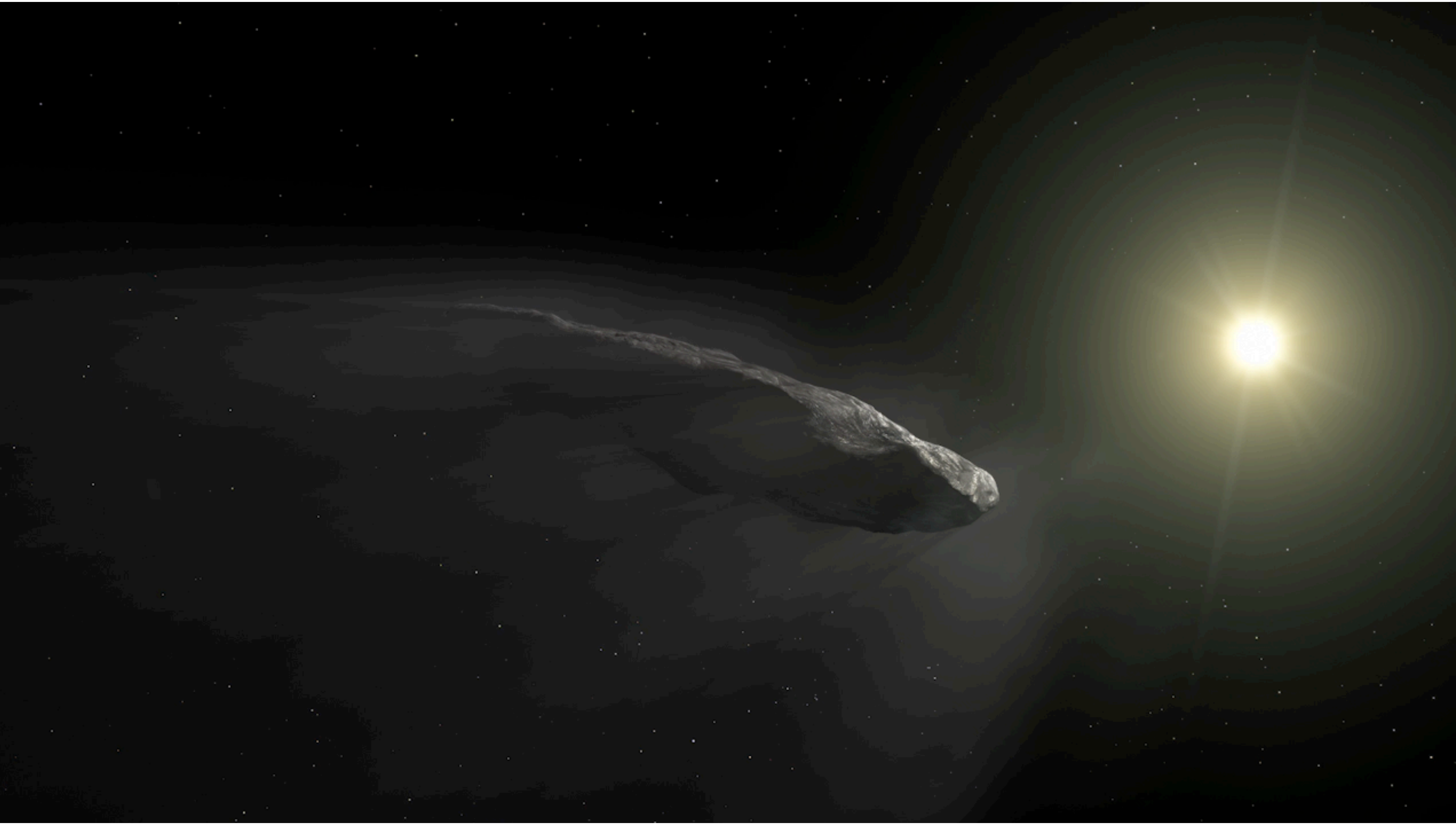
Albedo ~0.1 if a cometary surface.

Non-Gravitational acceleration of ‘Oumuamua

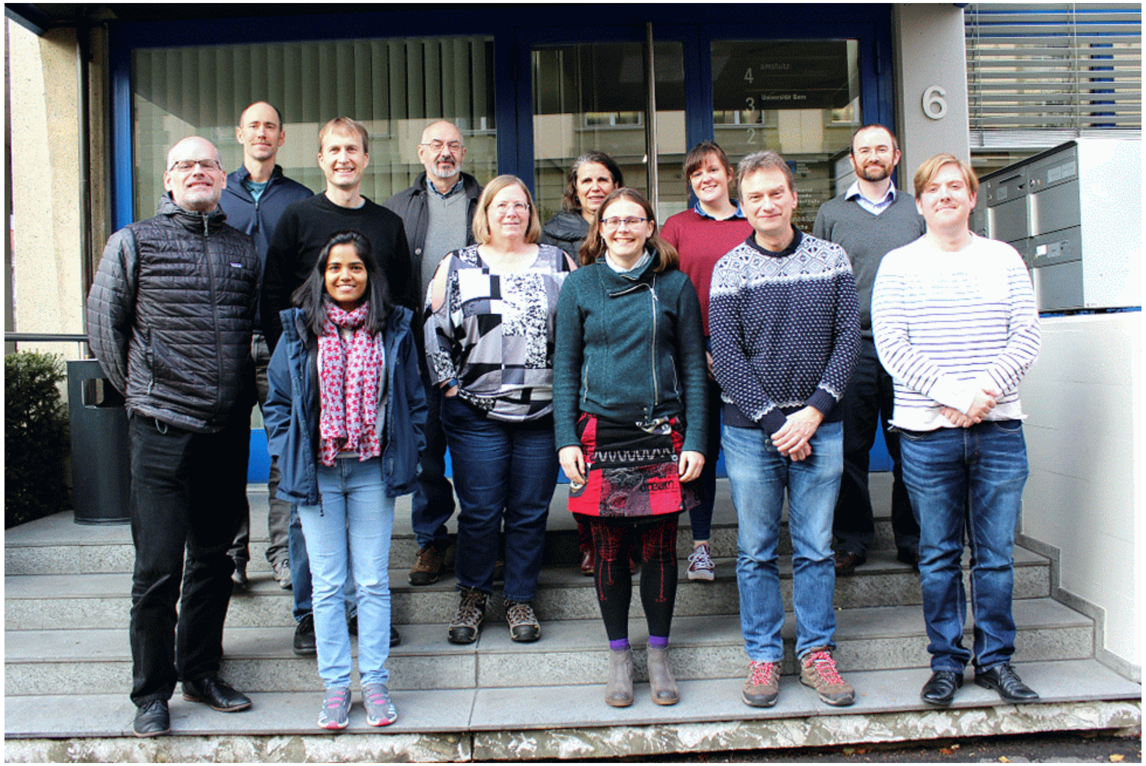


Micheli et al. (2018)


Comet 67P/Churyumov-Gerasimenko
Outflowing gas and dust
Motion of Comet



Next steps: A Coherent Picture?



The ISSI 'Oumuamua Team

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How Alien is ‘Oumuamua?

COULD SOLAR RADIATION PRESSURE EXPLAIN ‘OUMUAMUA’S PECULIAR ACCELERATION?

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Draft version November 1, 2018

Hypothesis: A lightsail could explain the non-gravitational acceleration.
Answer: This is understandable by standard cometary physics acting on a small object.
Hypothesis: Observed spectrum is caused by accretion of ISM carbon dust particles.
Answer: Carbon has a low albedo, and it’s tumbling, so it’s not a very good lightsail!
Hypothesis: Inferred interstellar number density not explainable by current planetary science.
Answer: Multiple methods of creating ISOs, and planet formation theories predict wide range of mass ejected, but not size distribution.

Number Density

We have found <u>one</u> ISO.
Guess the size distribution, albedo, velocity distribution…

Number per cubic parsec	Reference
$< 2 \times 10^{15}$	Englehardt et al. (2017)
$\sim 10^{15}$	Meech et al. (2017)
$\sim 10^{15}$	Trilling et al. (2017)
$\sim 2 \times 10^{15}$	Do et al. (2018)

Number density in Solar system
~ 0.4 au^{-3}

Outstanding Problems

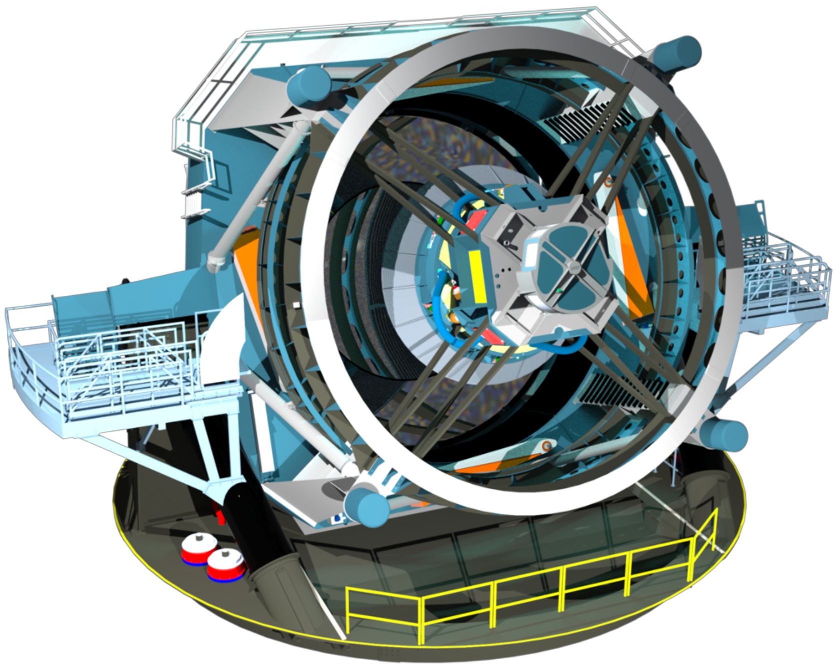
1. How did ’Oumumua obtain it’s elongated shape?
   - Tidal disruption in home system?

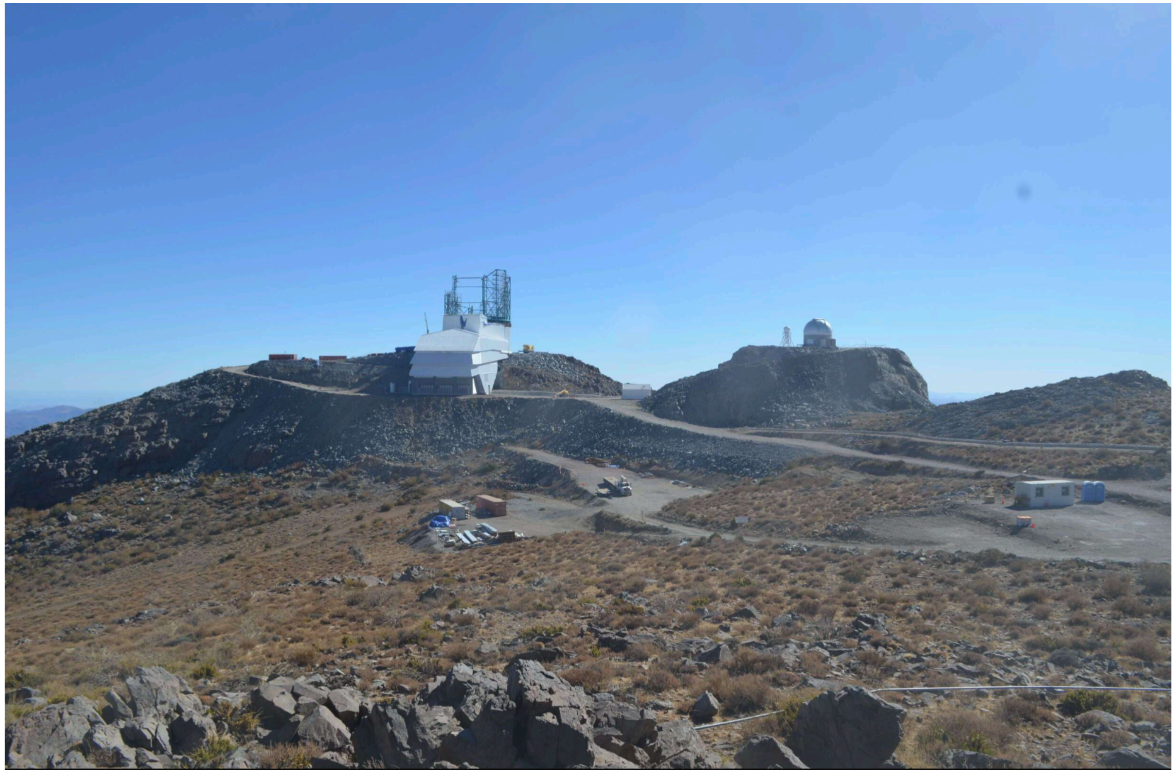
2. Are the colour variations real, and if so how were they formed?
   - Close approach to the Sun?

3. Why wasn’t mass-loss detected in deep imaging?
   - Abundance of large dust grains and water-rich outgassing?

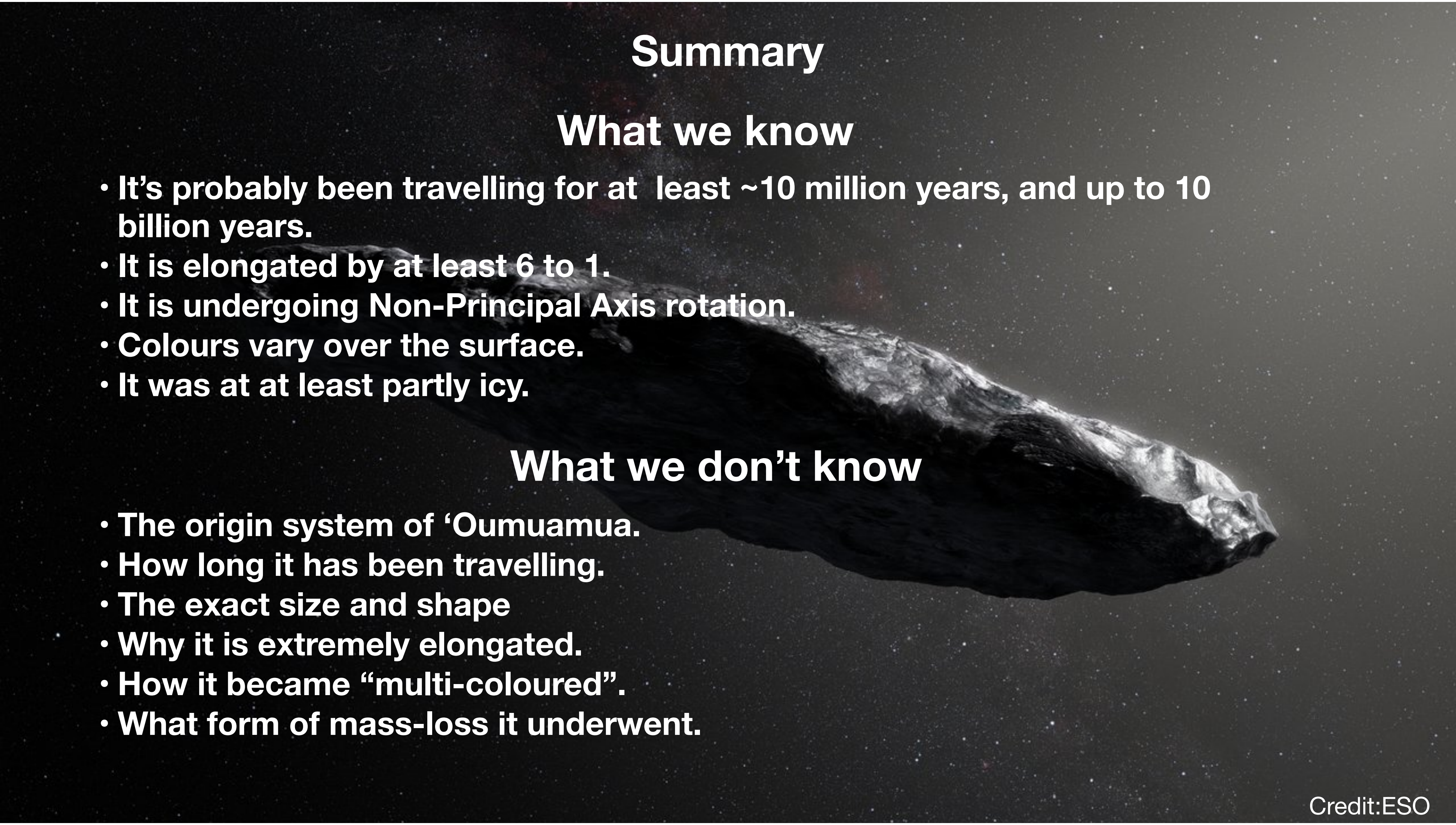
4. Implied number densities requires ~10^{15}–10^{16} bodies ejected per star.
   - Efficient ejection by giant planets? (Raymond et al. 2018)
   - Post-AGB phase ejection of Oort Clouds? (Do et al. 2018)

Large Synoptic Survey Telescope





Sky Surveys start 2022
Should find ~1 per year (Trilling et. al. 2017)



Summary

What we know

- It’s probably been travelling for at least ~10 million years, and up to 10 billion years.
- It is elongated by at least 6 to 1.
- It is undergoing Non-Principal Axis rotation.
- Colours vary over the surface.
- It was at at least partly icy.

What we don’t know

- The origin system of ‘Oumuamua.
- How long it has been travelling.
- The exact size and shape
- Why it is extremely elongated.
- How it became “multi-coloured”.
- What form of mass-loss it underwent.

Credit:ESO