First Contact: Understanding the nature of Interstellar Object 1I/‘Oumuamua

QUEEN'S UNIVERSITY BELFAST
Alan Fitzsimmons
Astrophysics Research Centre

First Contact: Understanding the nature of Interstellar Object 1I/‘Oumuamua

- The origin of ISOs
- Discovery, orbit and observation constraints
- Lightcurve period and amplitude
- Colour measurements and interpretation
- Spectroscopy and interpretation
- Questions and future directions

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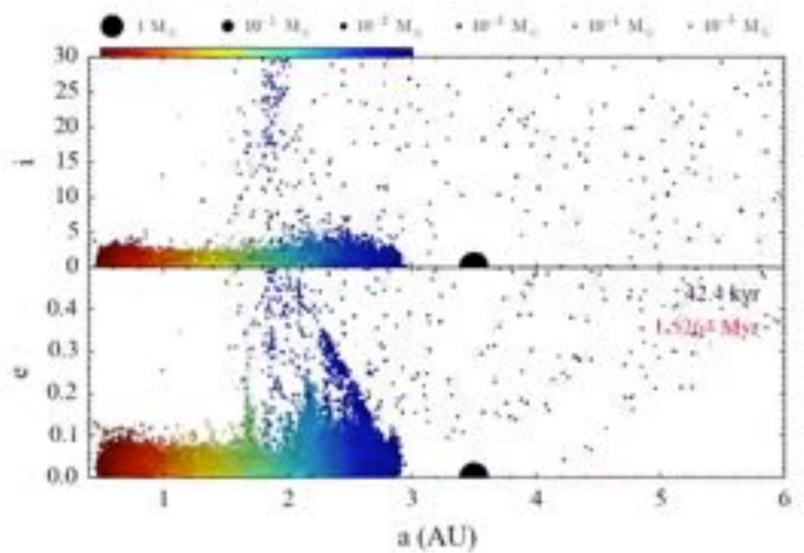
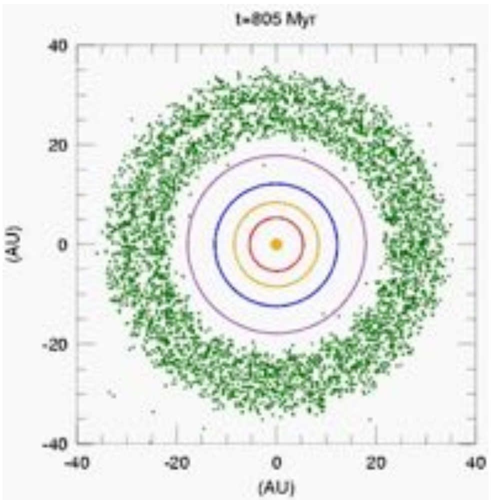
ISOs before ‘Oumuamua





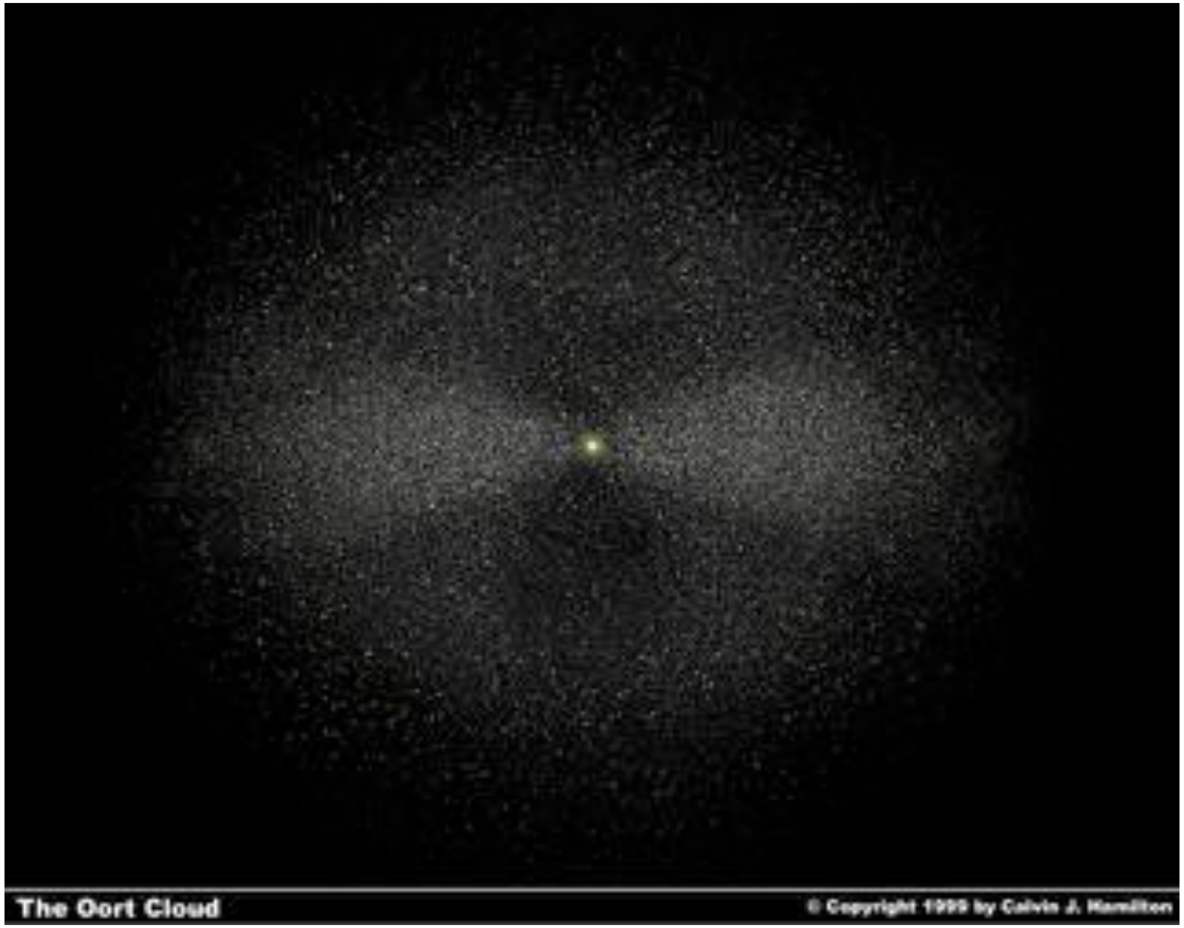
During Grand Tack and Nice model migration, ejection of 5-40 M_{Earth}.

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

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

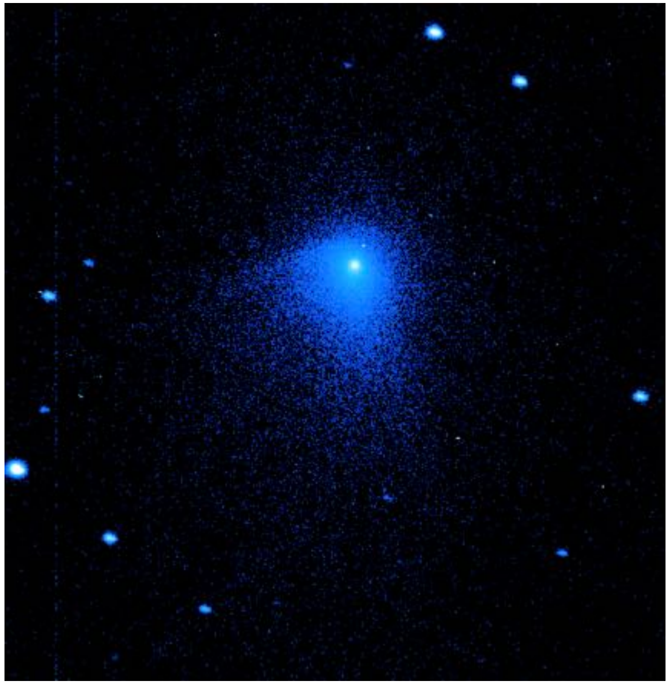
<u>But</u> - numbers ejected heavily dependent on system architecture.

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).

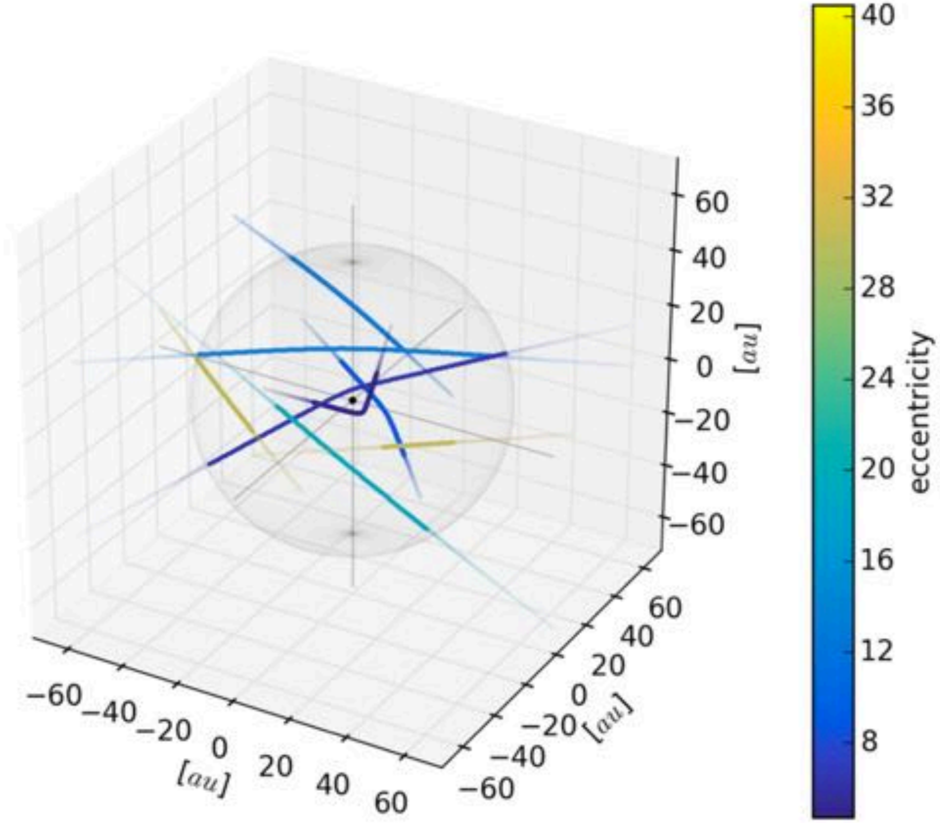
ISOs before ‘Oumuamua



Probable cometary appearance

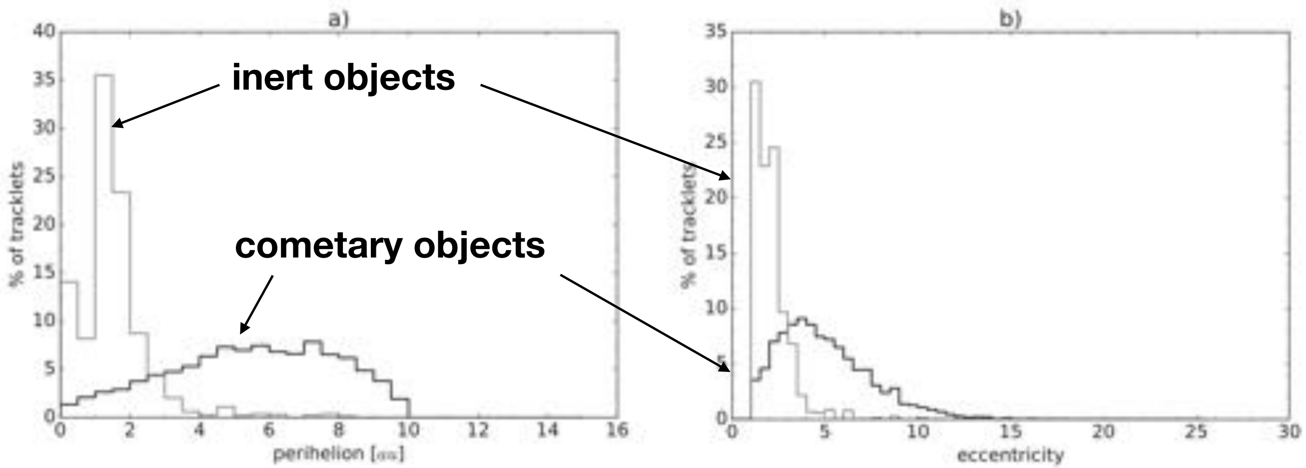
$$\frac{n(icy)}{n(rocky)} \sim 10^2 - 10^4$$

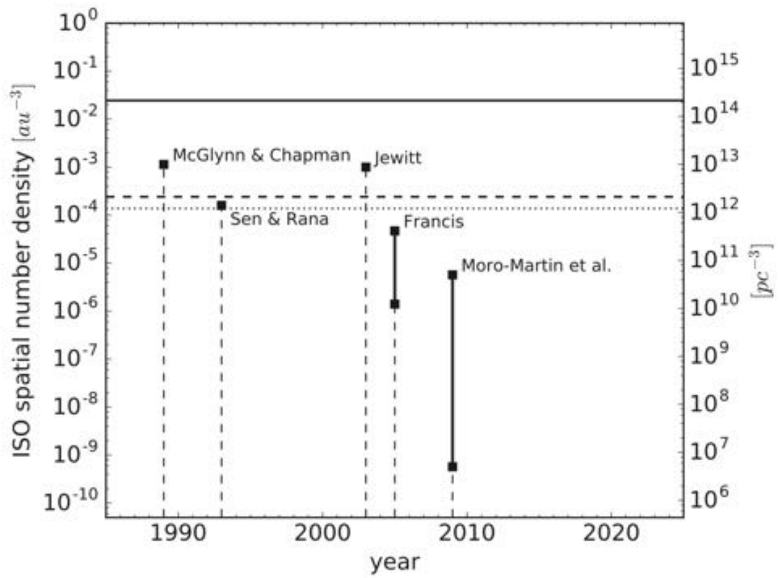
(e.g. Shannon et al. 2015)



Hyperbolic Orbit
(Engelhardt et al. 2017)

ISOs before ‘Oumuamua

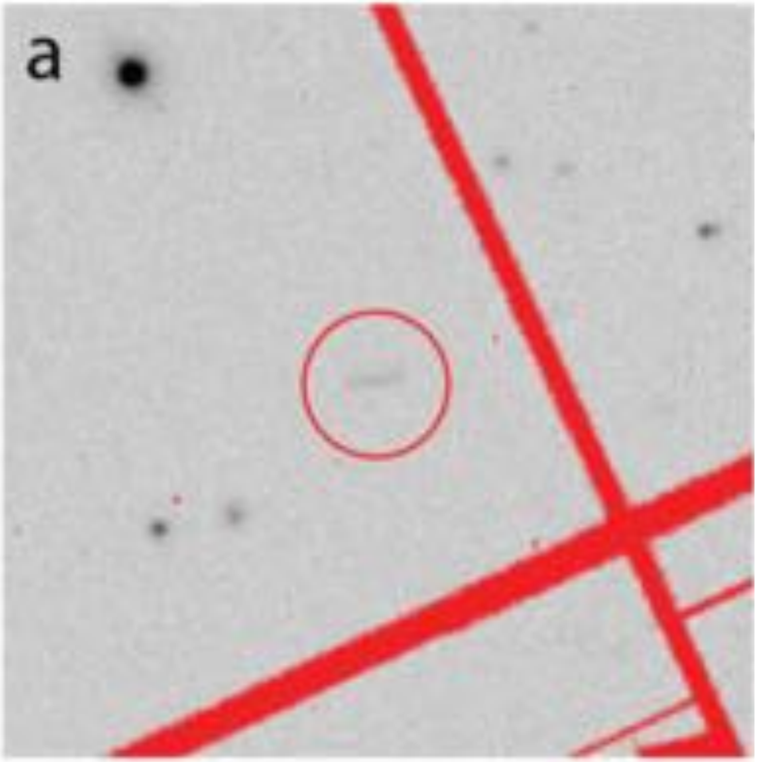




Engelhardt et al. (2017) simulations of detected orbits and upper limits for H=19 (D~1km):

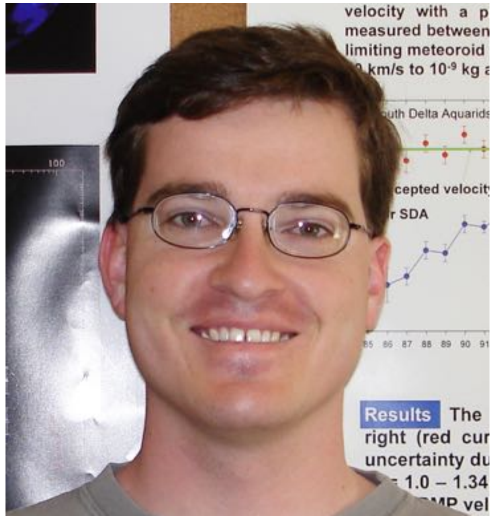
$n<2\times10^{12}$ pc^{-3} for cometary ISOs
$n<2\times10^{14}$ pc^{-3} for inert ISOs

19th October 2017



Pan-Starrs 1

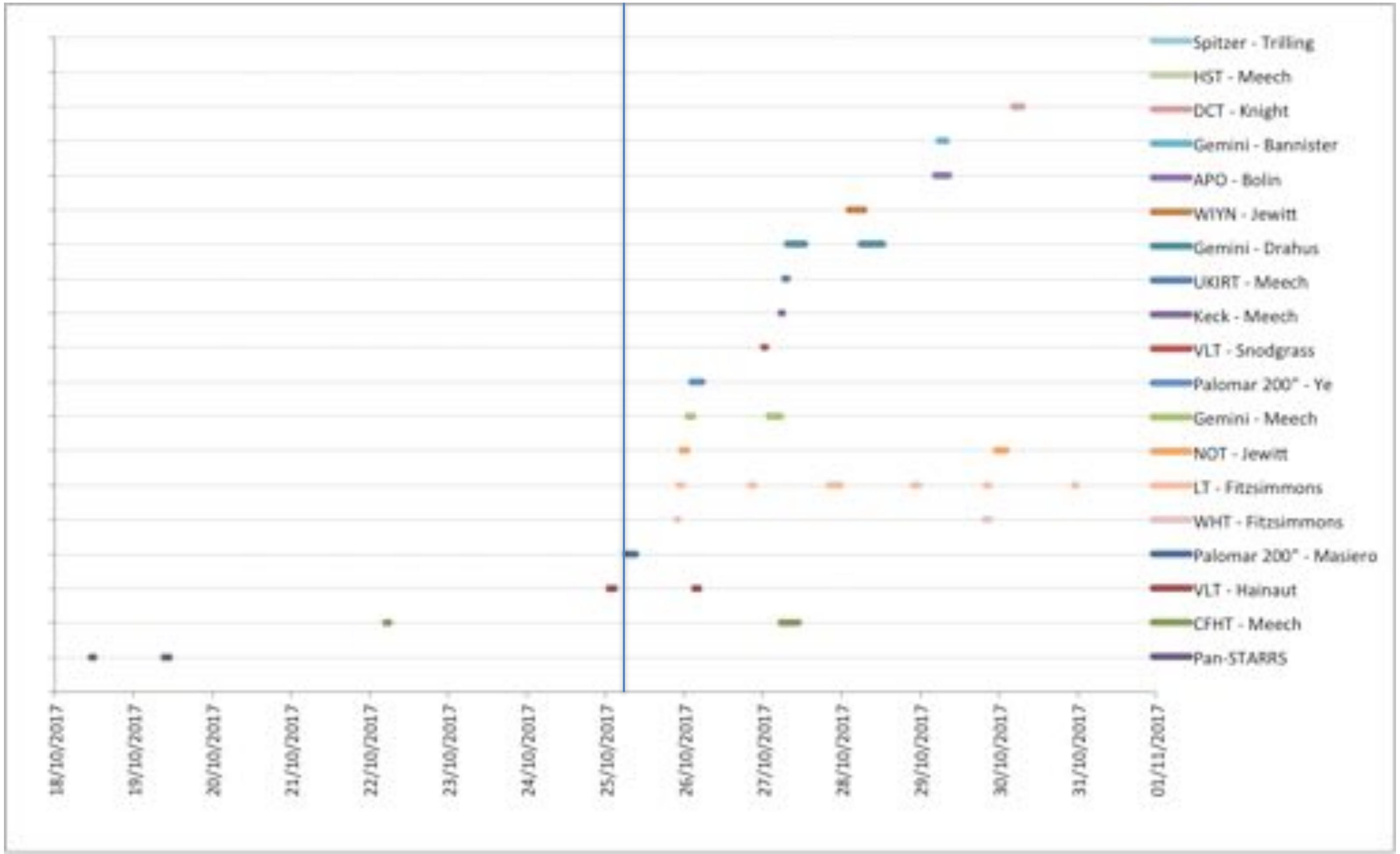
Fast Moving Object P10Ee5V
15 acseconds/minute



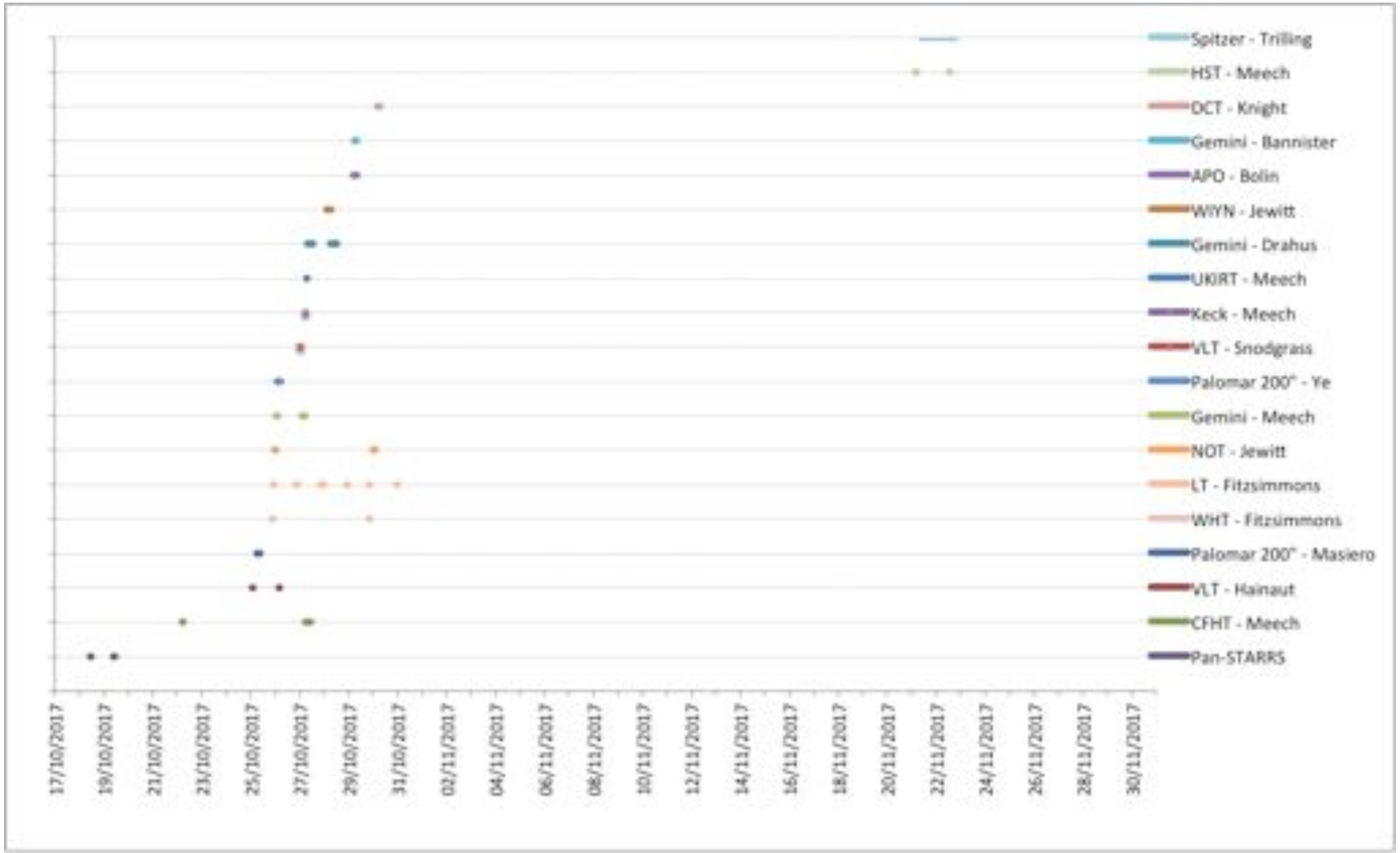
Rob Weyrk

Marco Micheli

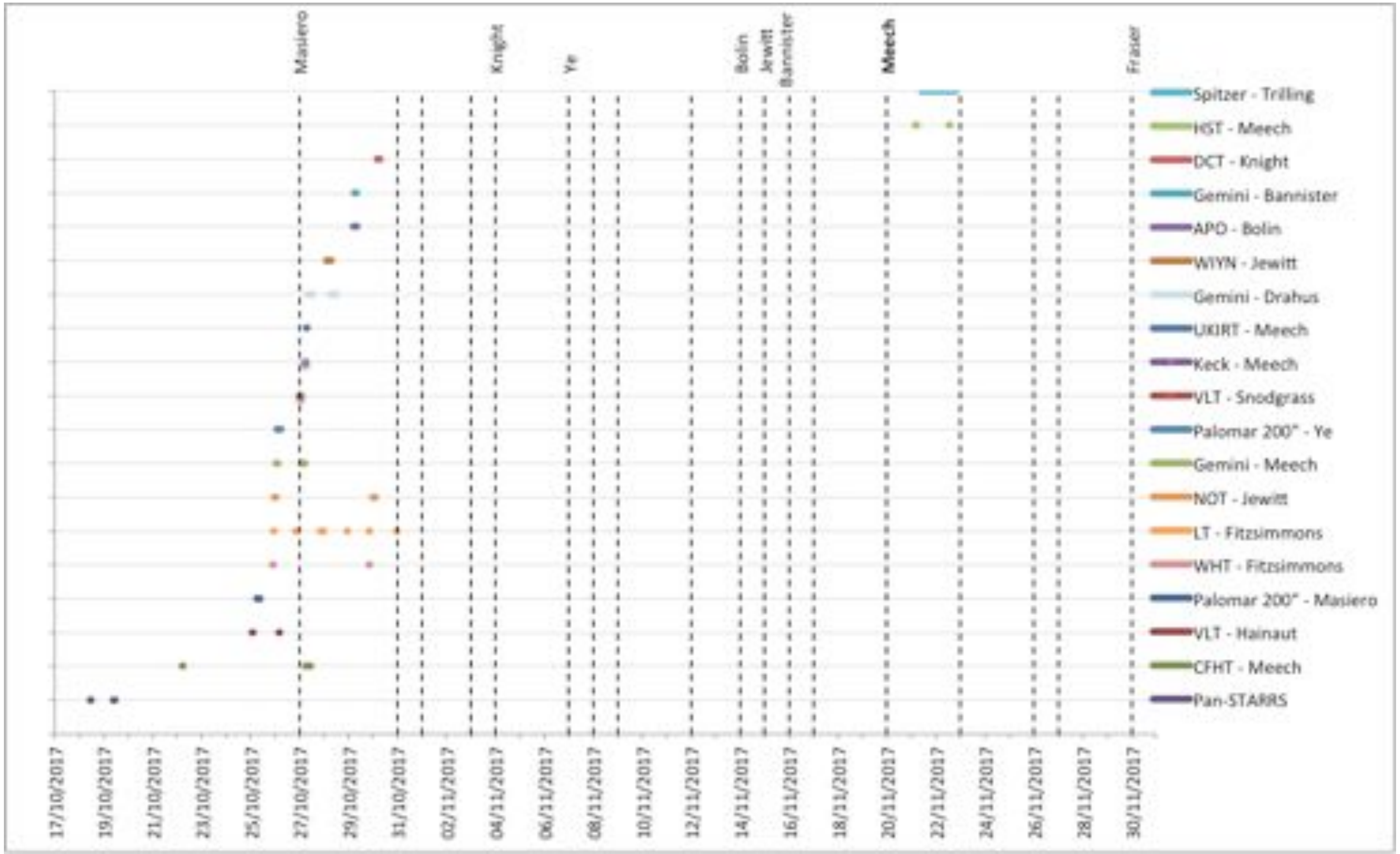
Rapid Reaction (1)



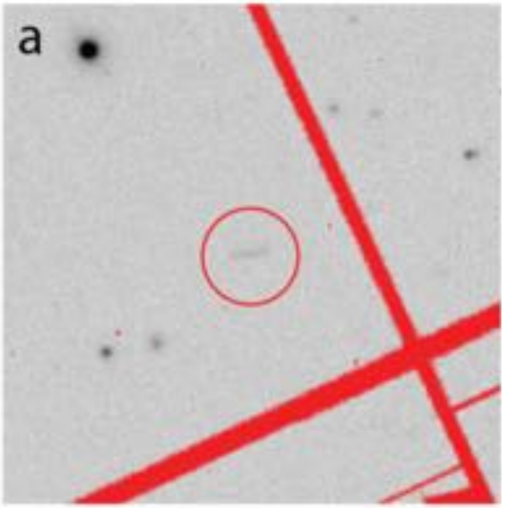
Rapid Reaction (2)



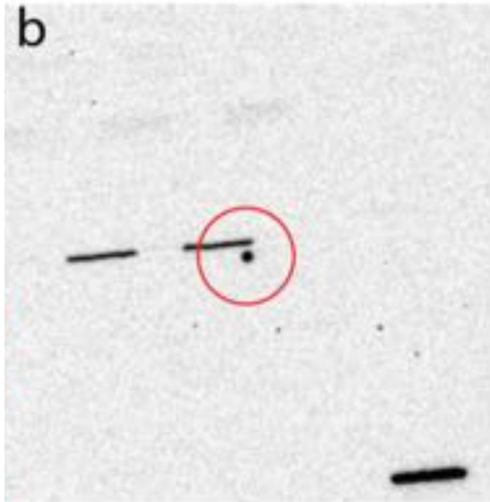
Rapid Reaction (3)



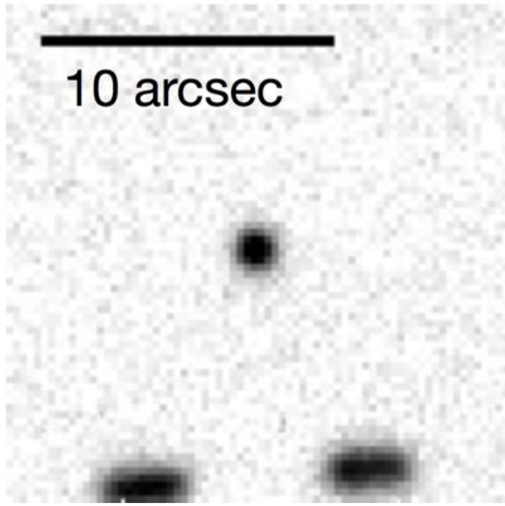
19th October 2017 **22nd October 2017** **25th October 2017**



Pan-Starrs 1

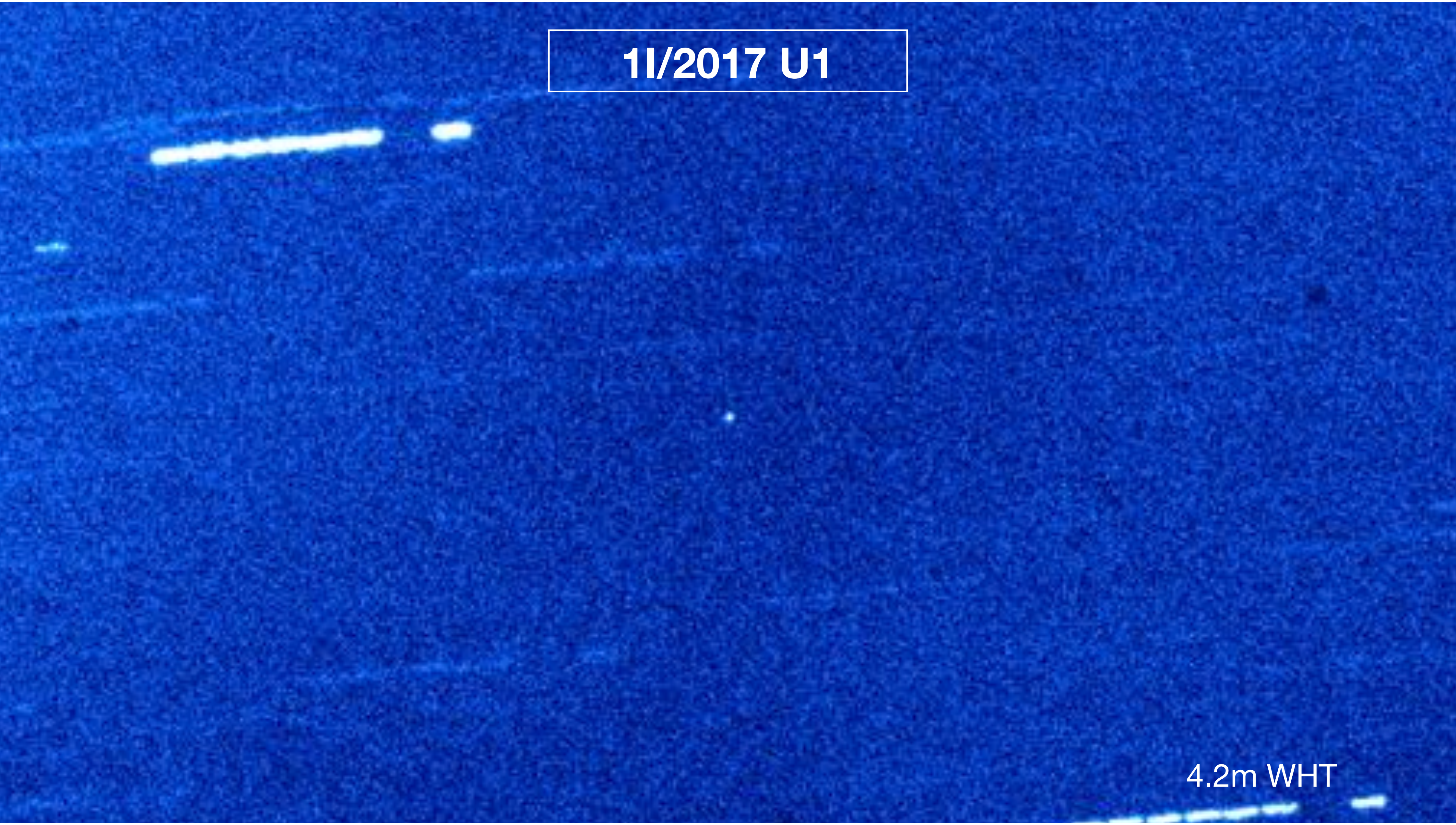


CFHT

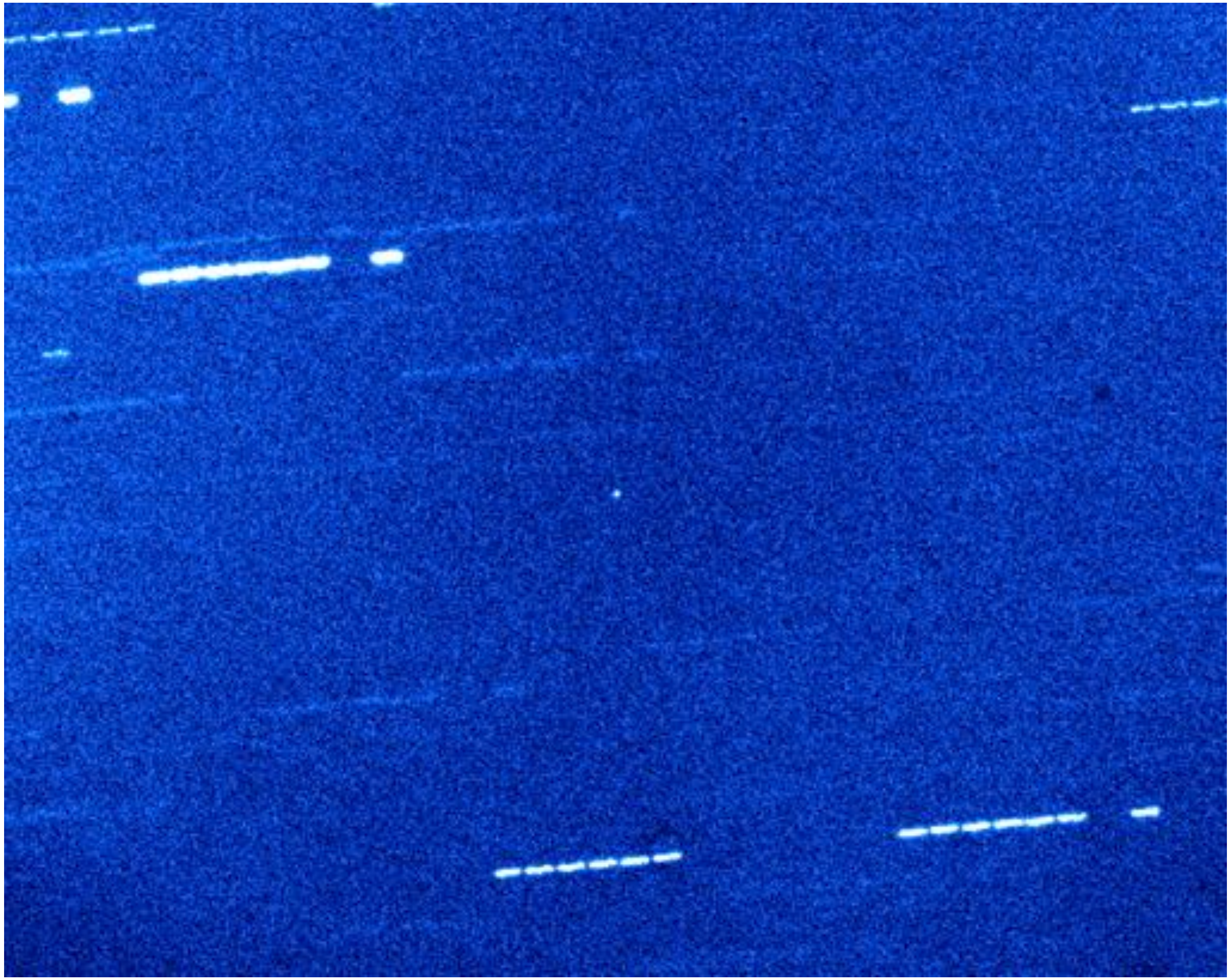


VLT+Gemini-South

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


1I/2017 U1
4.2m WHT

‘Oumuamua

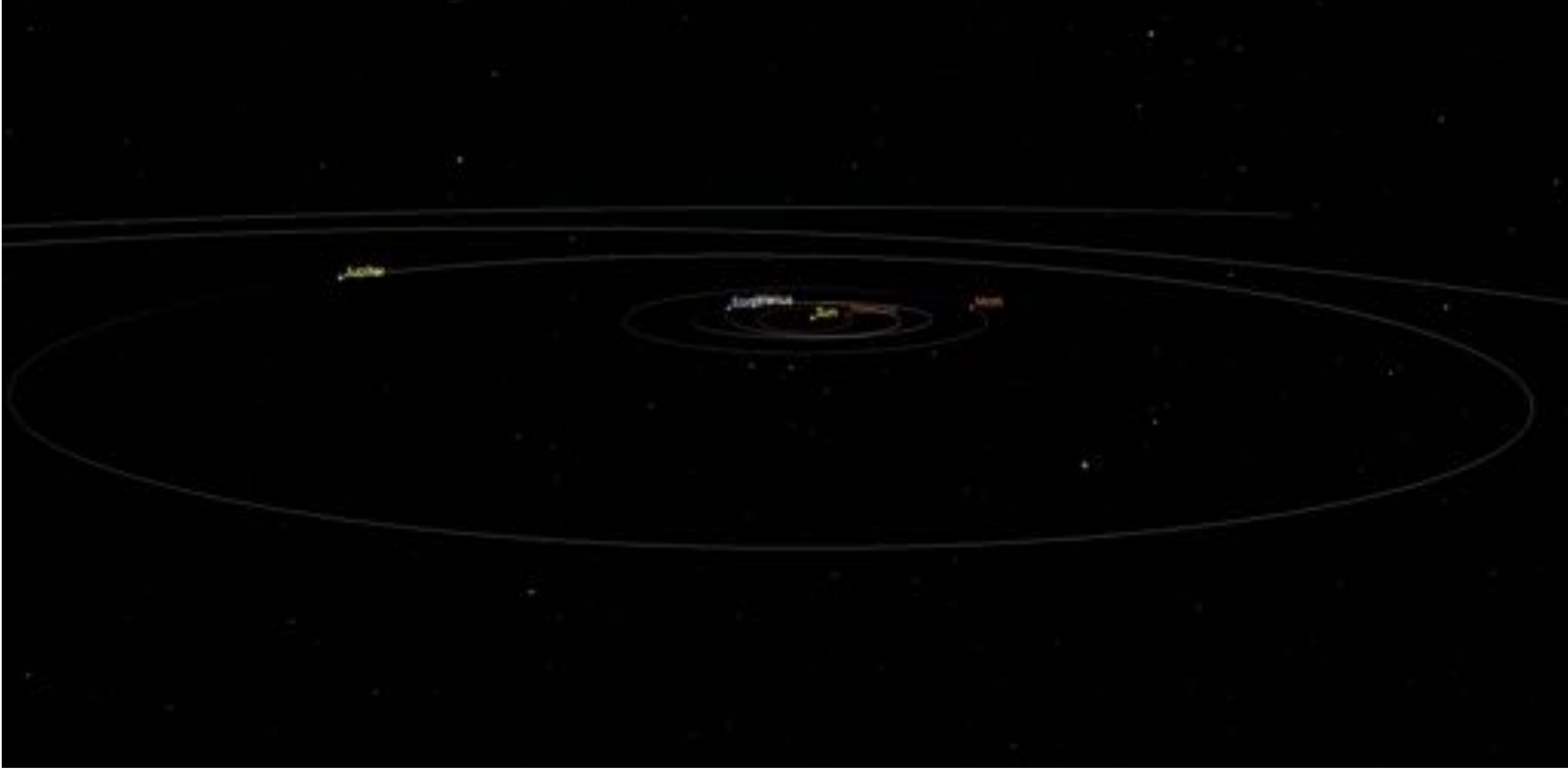


(Oh - moo - ah - moo - ah)

“A messenger from afar arriving first”

Humuhumunukunukuapua'a

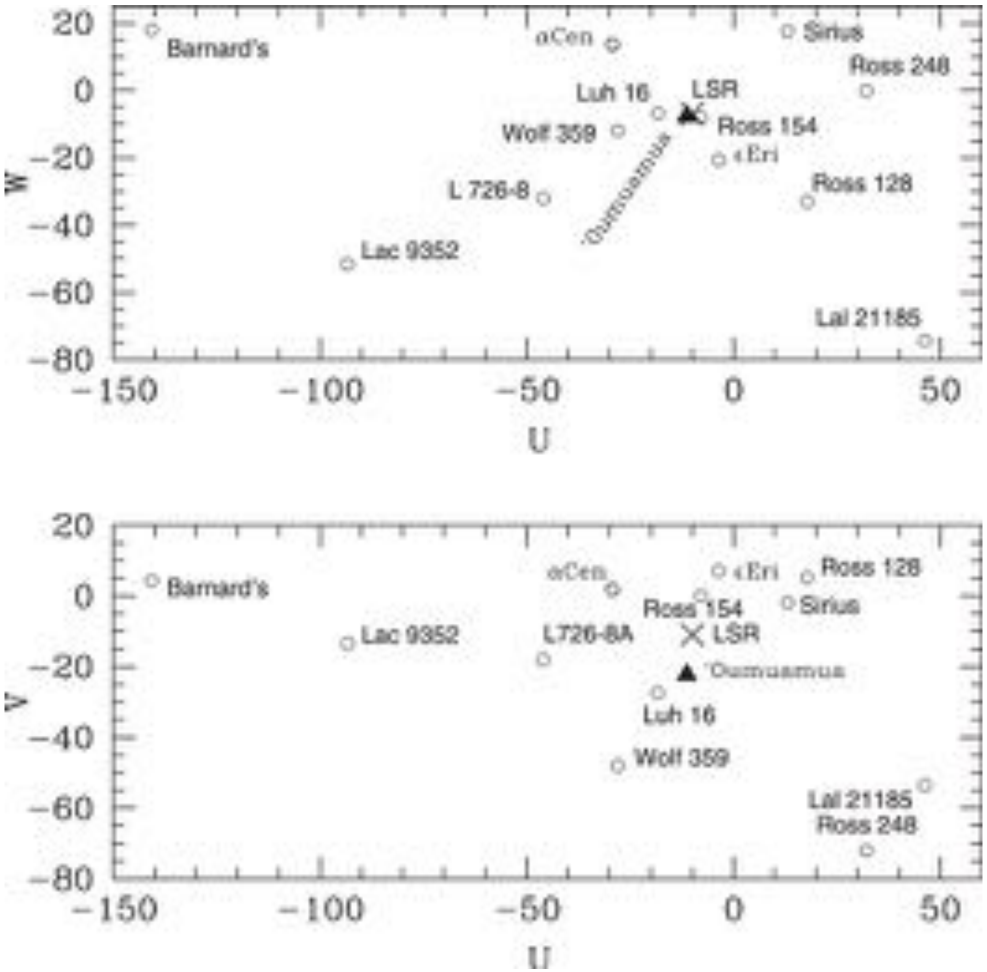
Orbit of ‘Oumuamua



I/2017 U1 Origin

alpha=18h 40.6m dec=34^{o} 9’
~6 degrees from Solar Apex

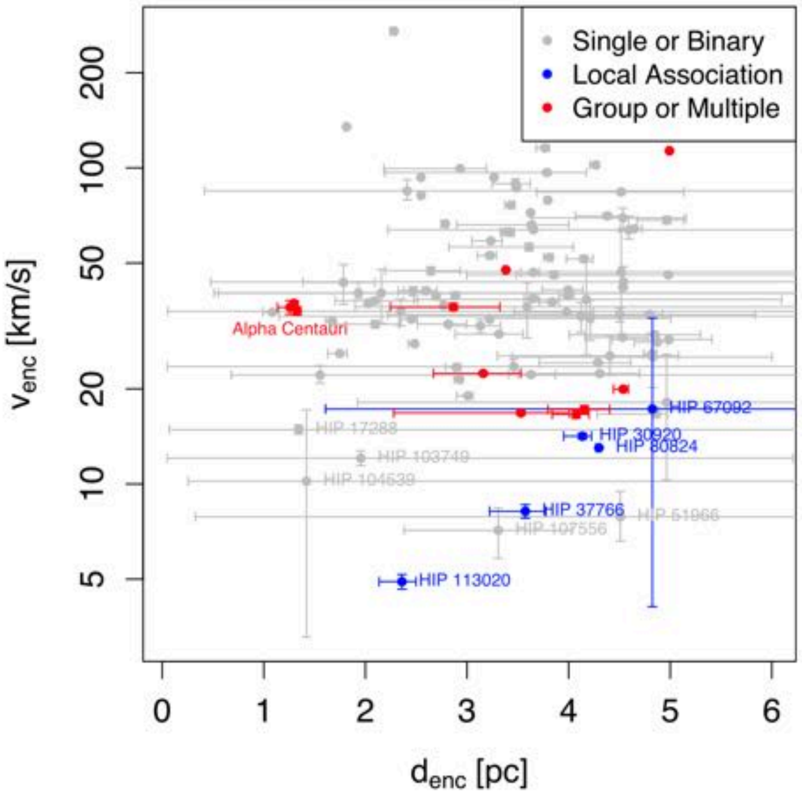
Where did it come from?



Mamajek (2017)

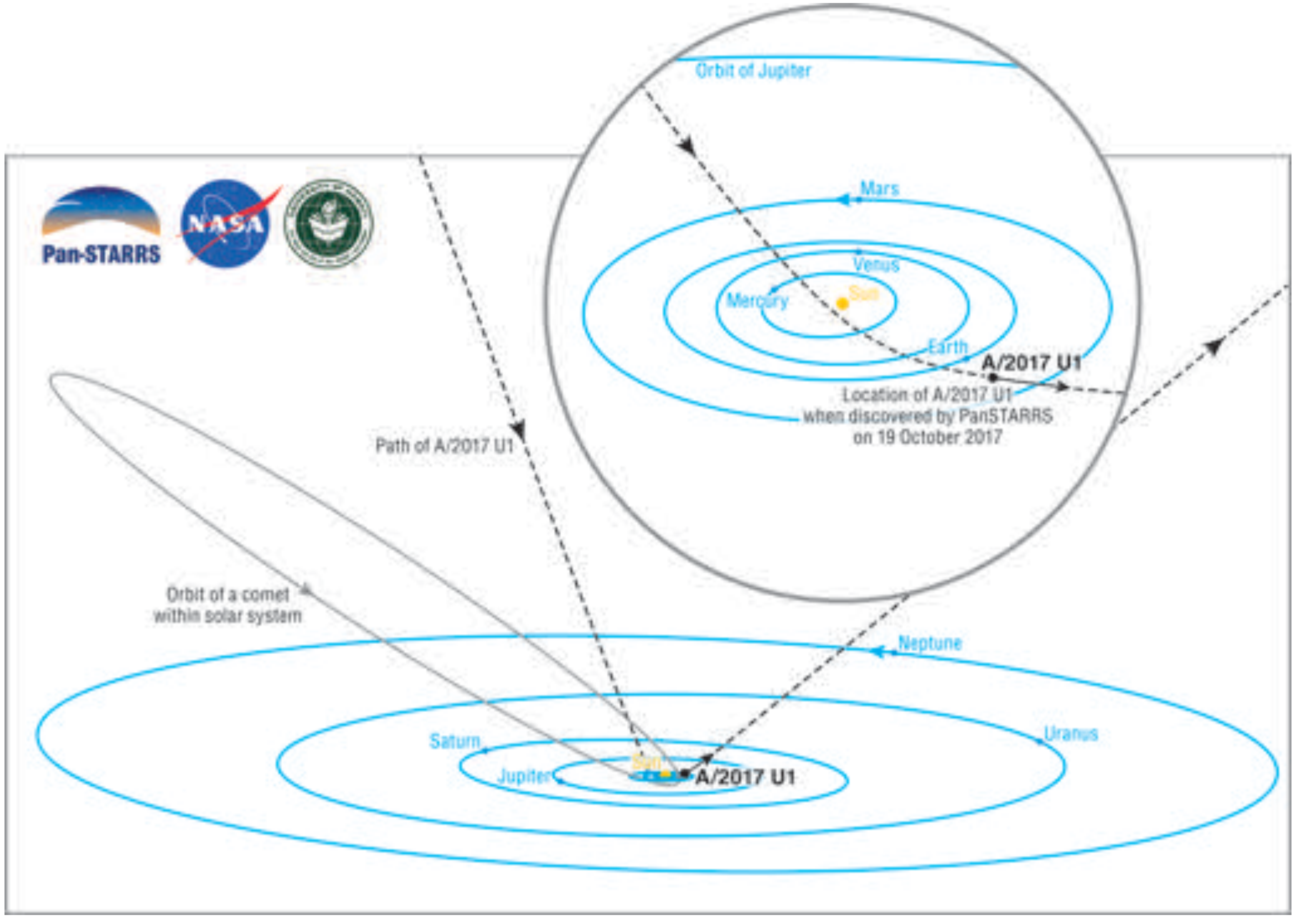
V= 26.2 km/s

V= 26.6 pc/Myr



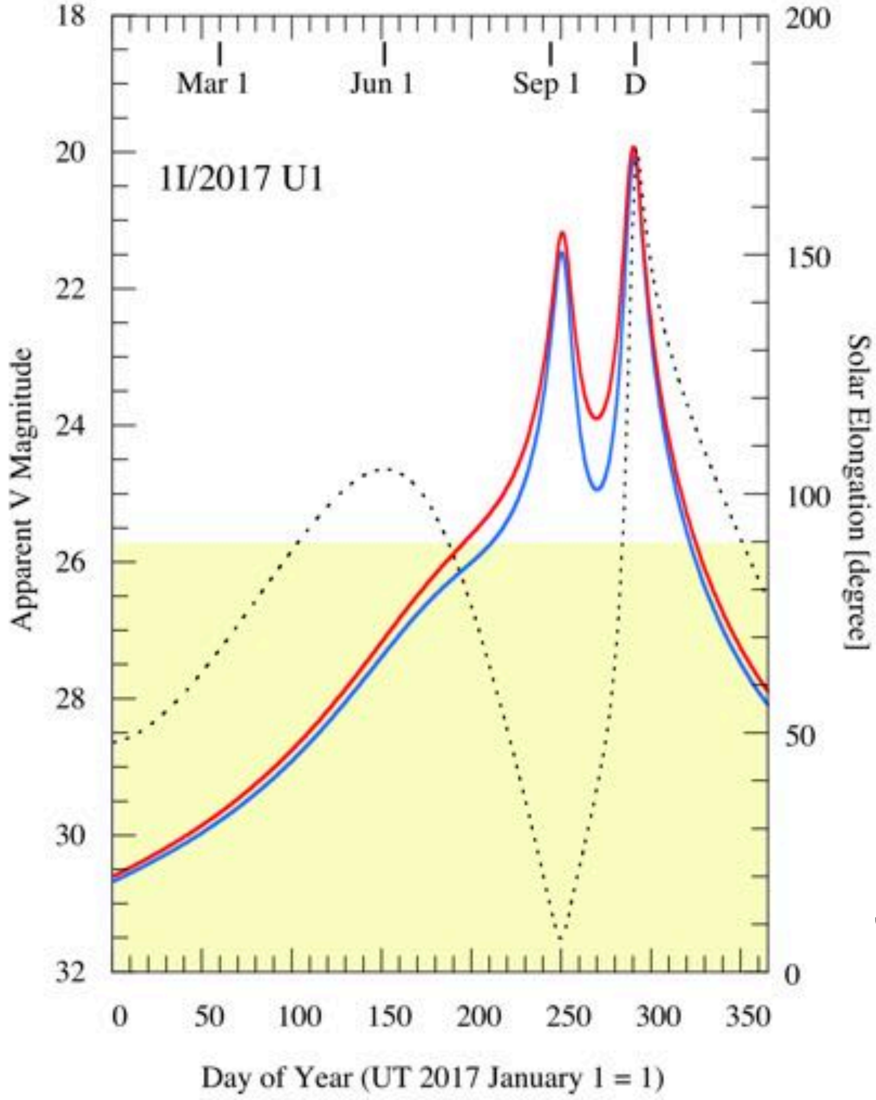
Feng & Hugh (2018)

Orbit of ‘Oumuamua



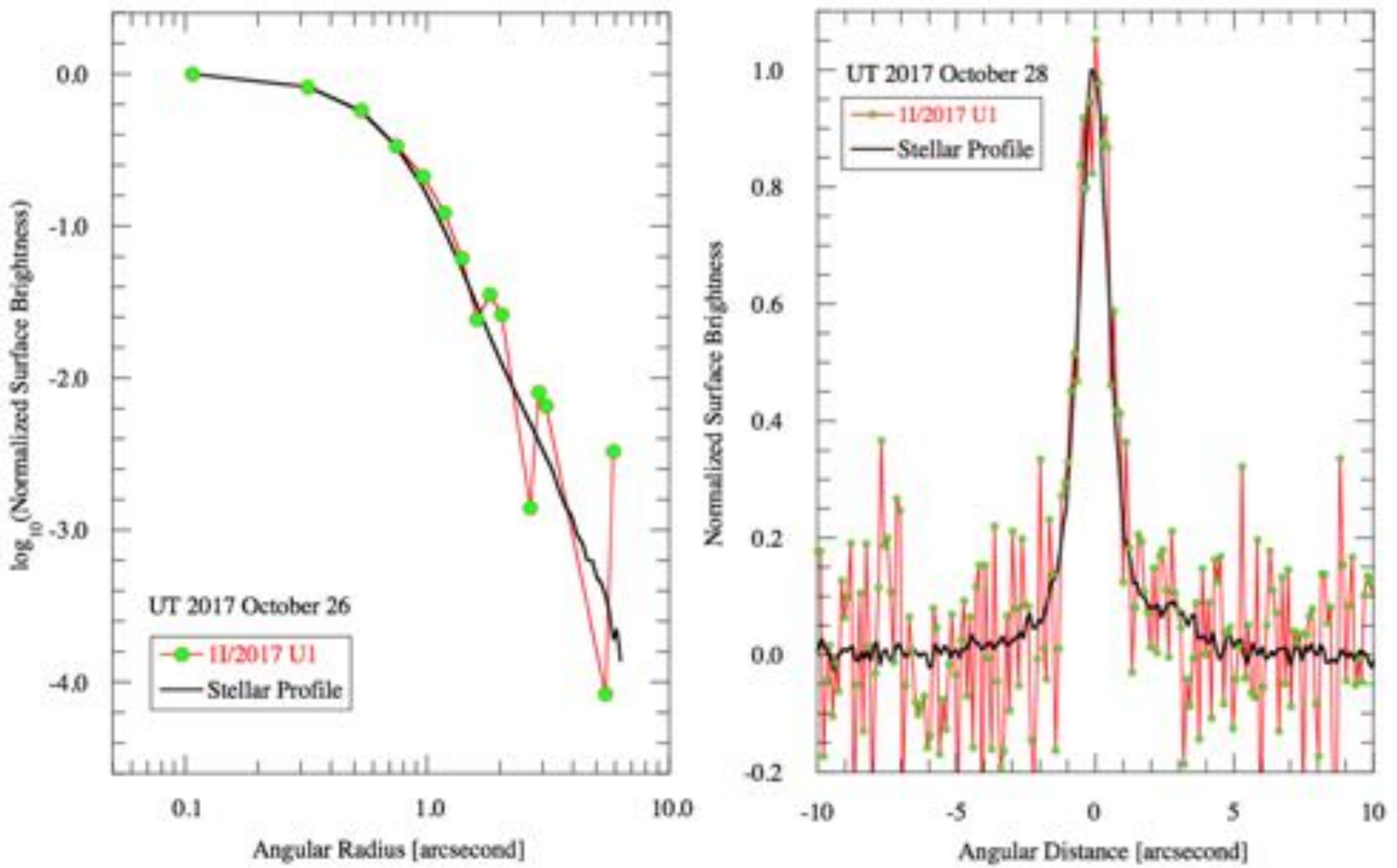
Perihelion 9 September
Discovery 19 October
e=1.197
q=0.25 au
i=122.6^{o}
H=22
(D~200m-300m for low albedo)

I/2017 U1 Visibility



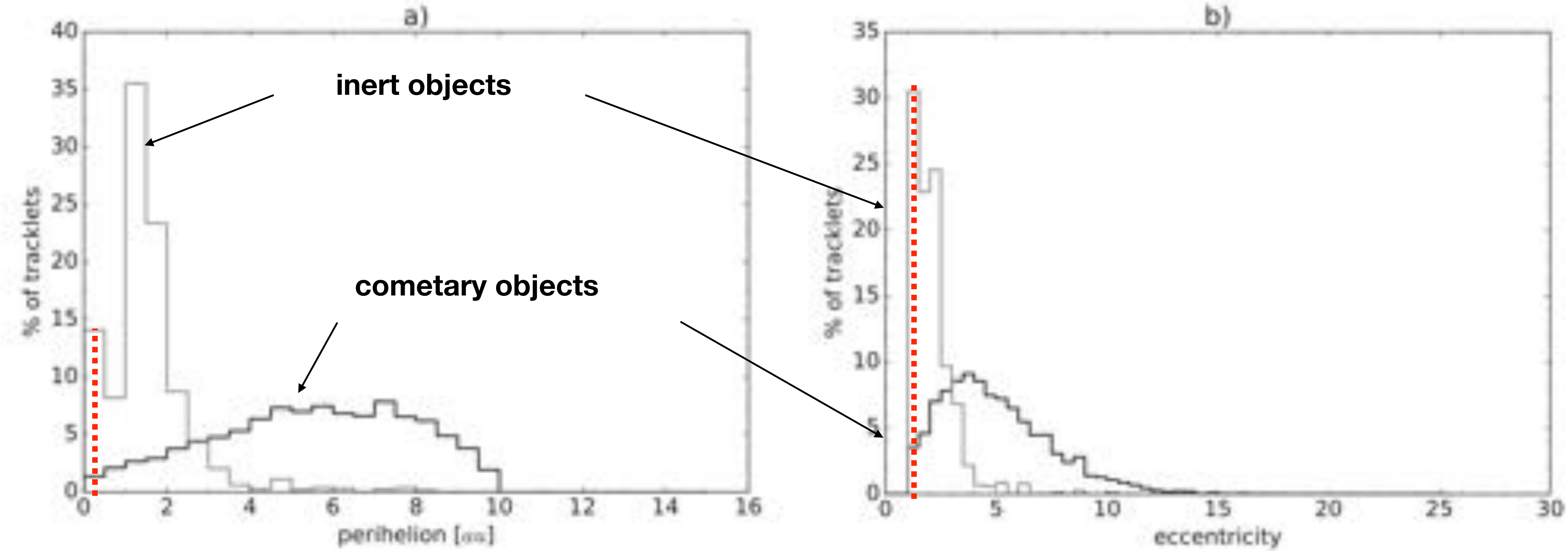
Jewitt et al. (2017)

No activity in profile – asteroid?



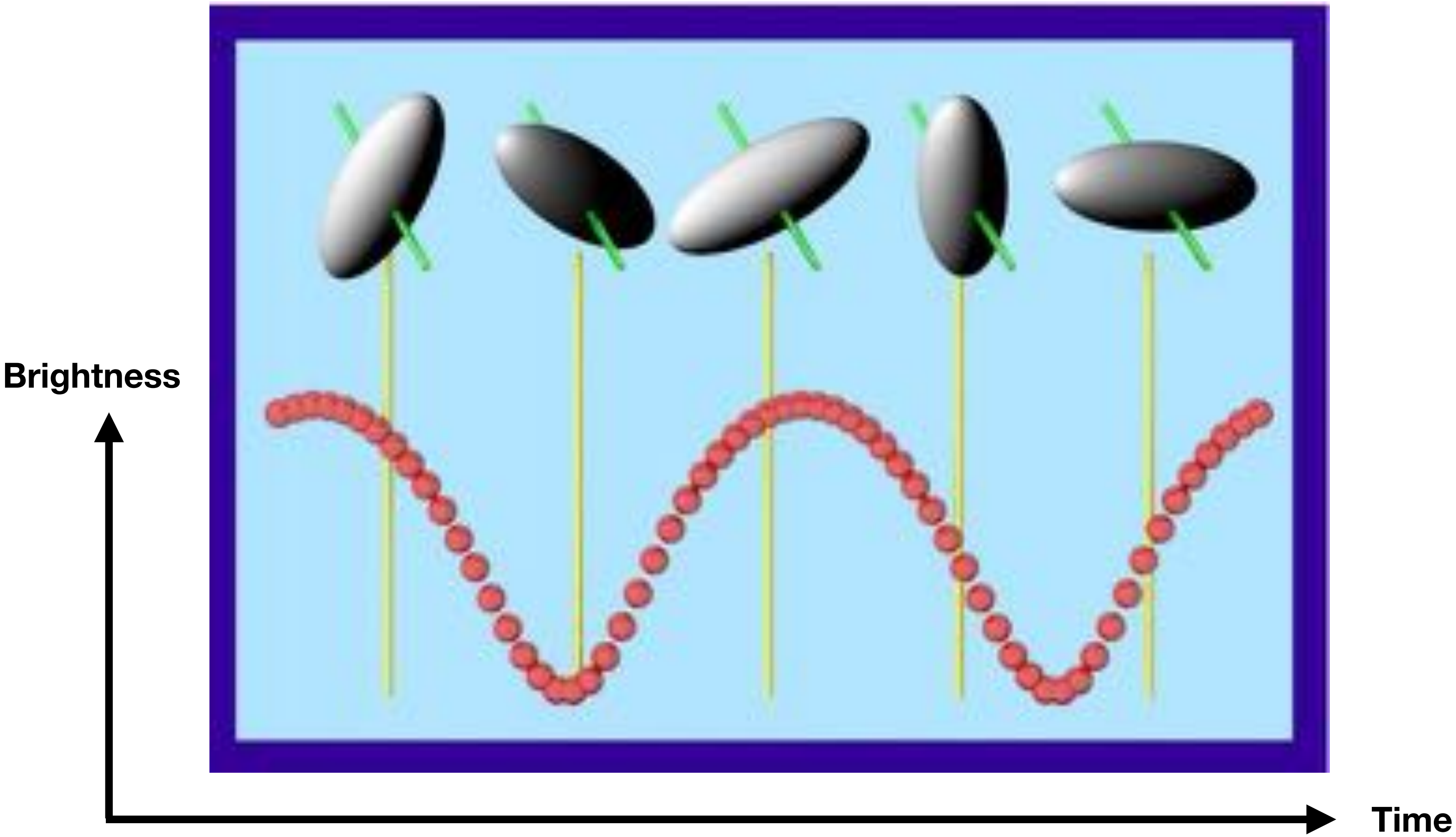
Jewitt et al. 2017

No activity in profile – asteroid?

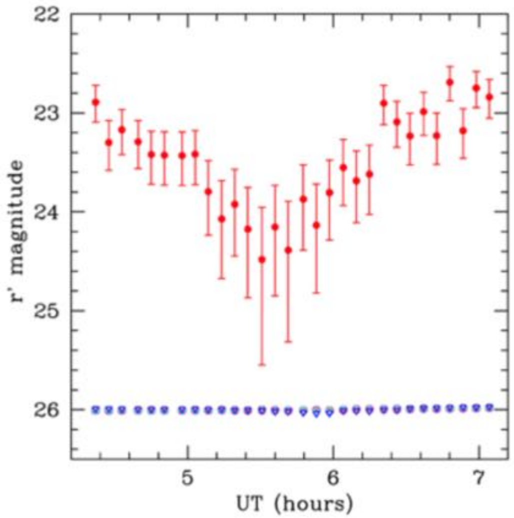


Engelhardt et al. (2017)

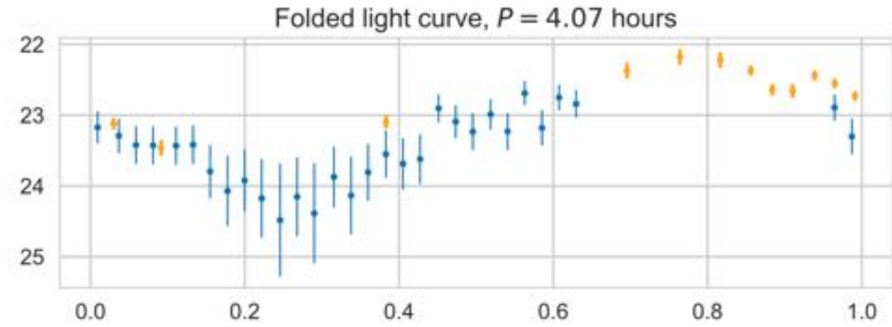
Small Body Lightcurves



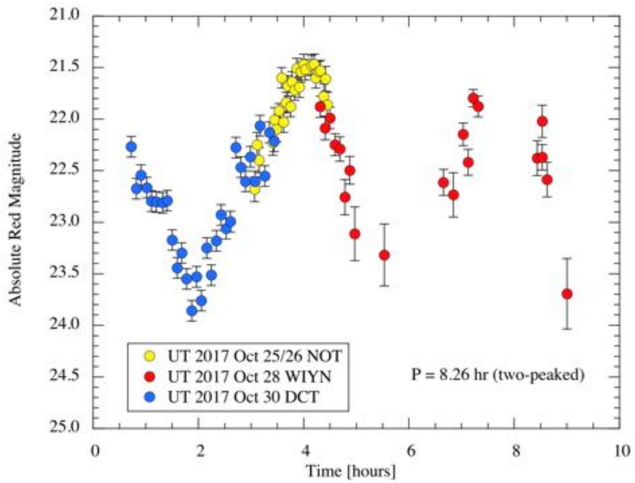
Spin Period & Shape



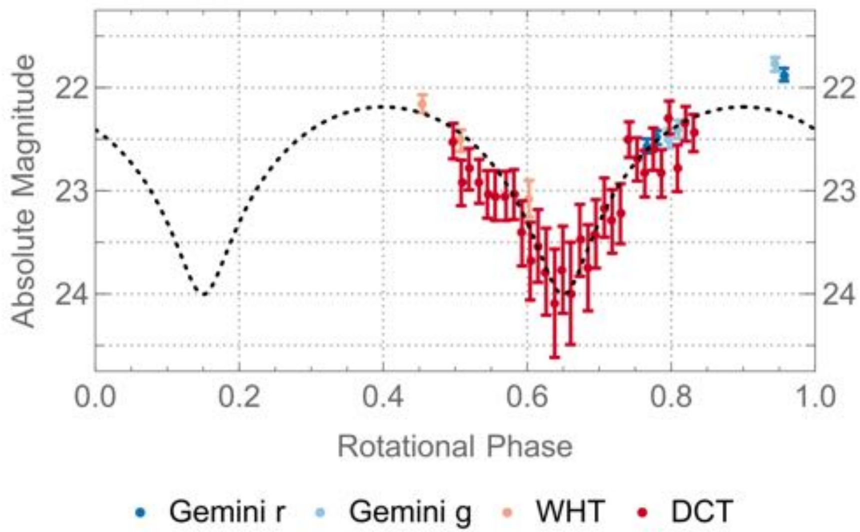
P > 5 hours Knight et al. (2017)



P=8.1 hours Bolin et al. (2017)

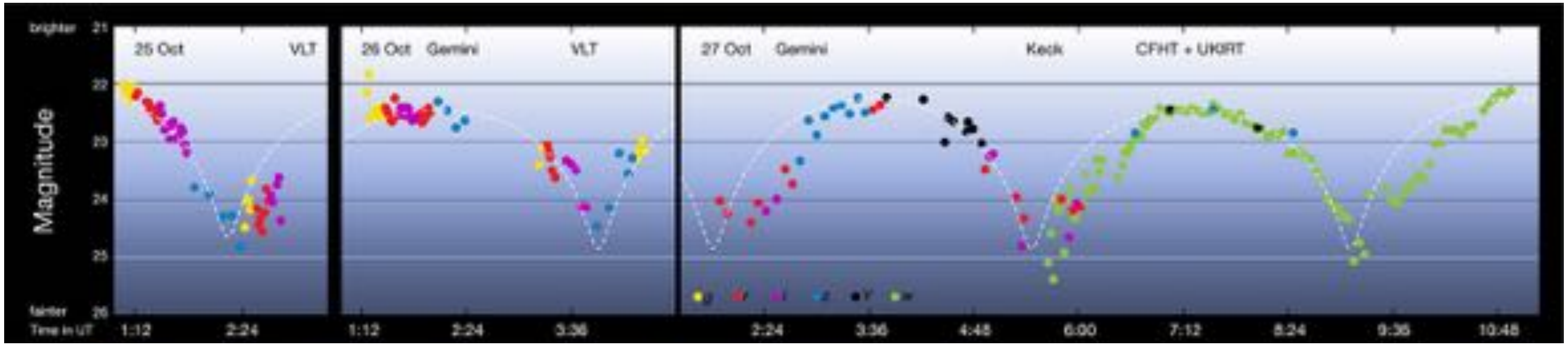


P=8.26 hours Jewitt et al. (2017)



P=8.10 hours Bannister et al. (2017)

Spin Period & Shape

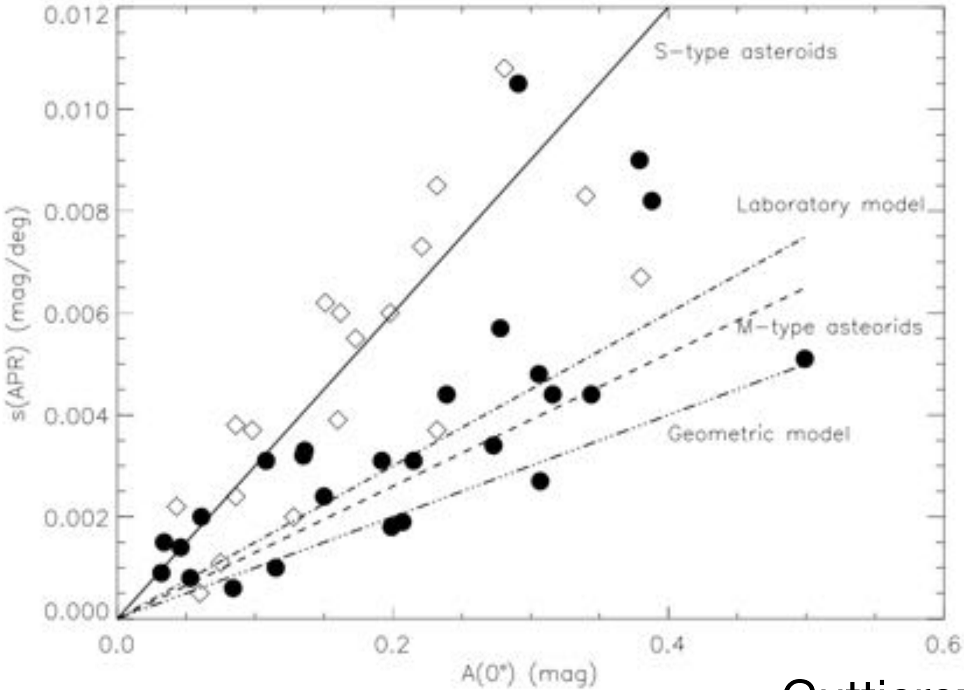


$\mathrm{P} = 7.34$ hours, $\Delta m \simeq 2.5$ mag (Meech et al. 2017)

H=22.4 implies D~200m

Amplitude implies elongated body , axial ratio 10:1!

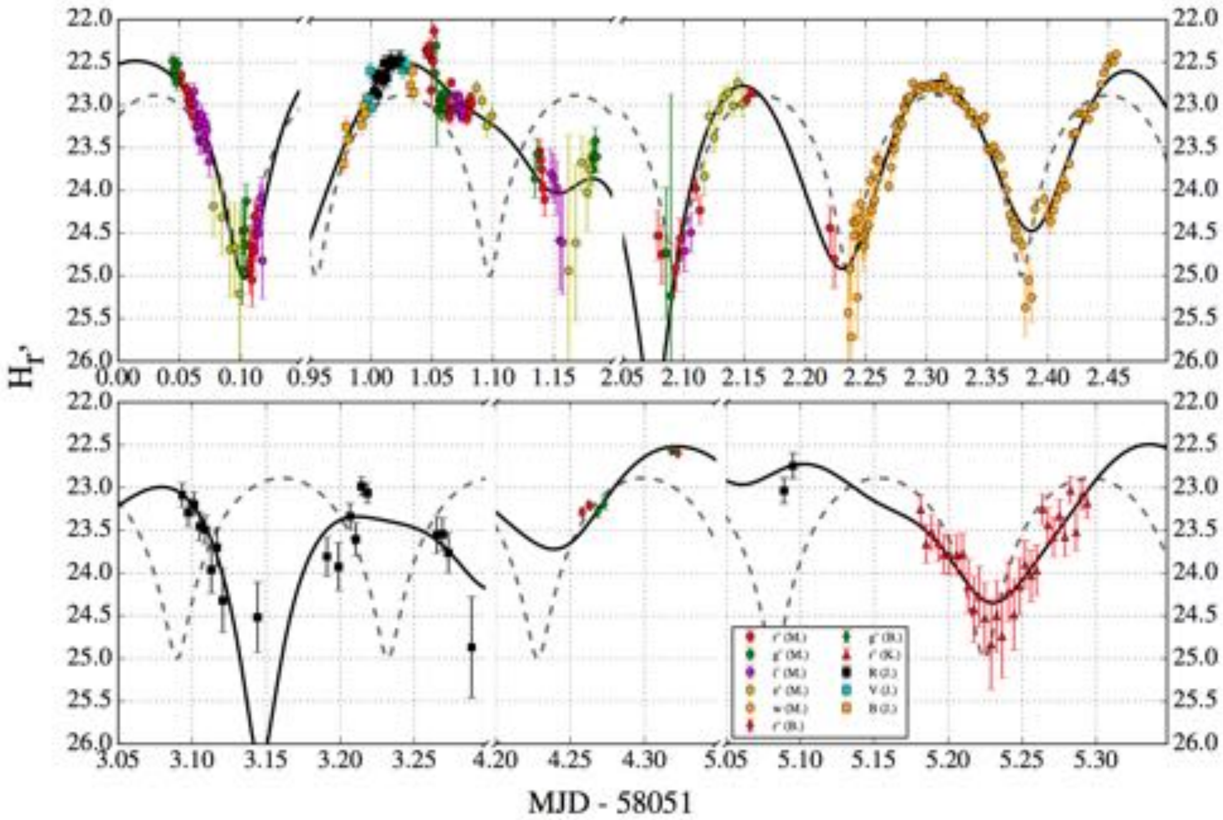
Spin Period & Shape

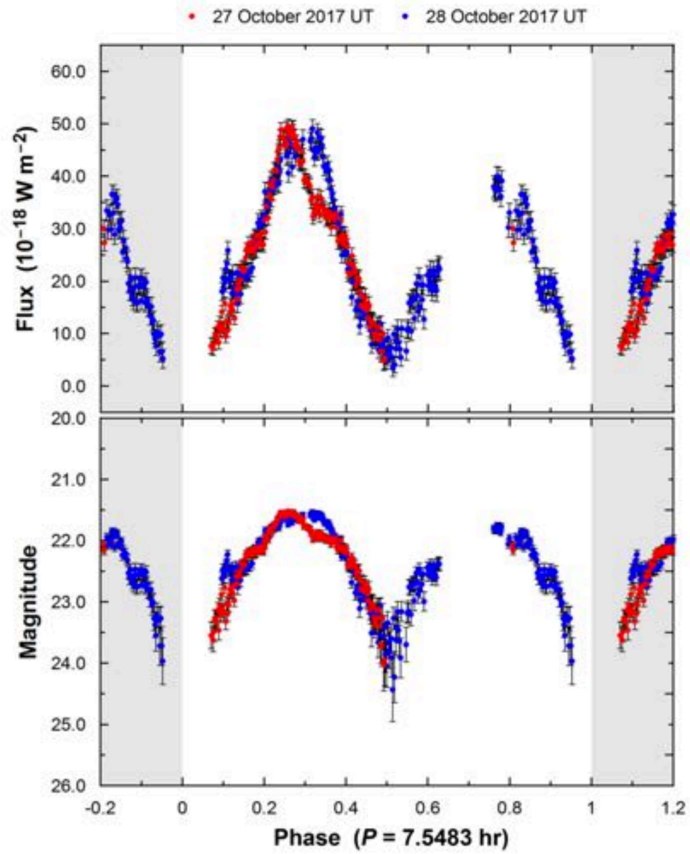


Guttierez et al. (2006)
Zappala et al. (2000)

Lightcurve amplitude is a function of phase angle (scattering angle).
Probable minimum elongation 5:1 for α= 20-24 degrees.

Non-Principal Axis rotation

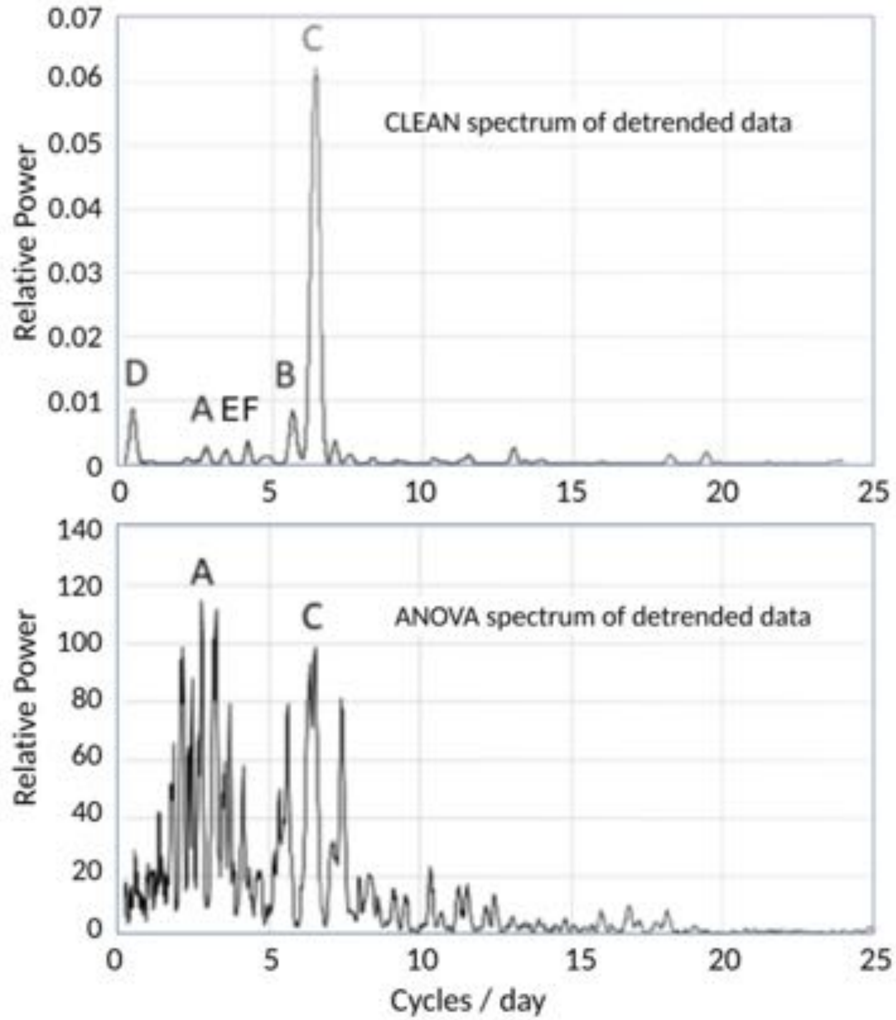


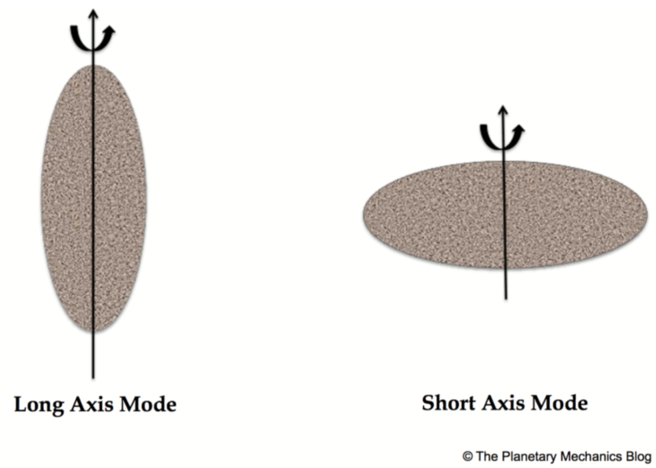


P=7.41 hours and P=7.94 hours
(Fraser et al. 2018)

P=7.5483 hours
(Drahus et al. 2018)

Non-Principal Axis rotation



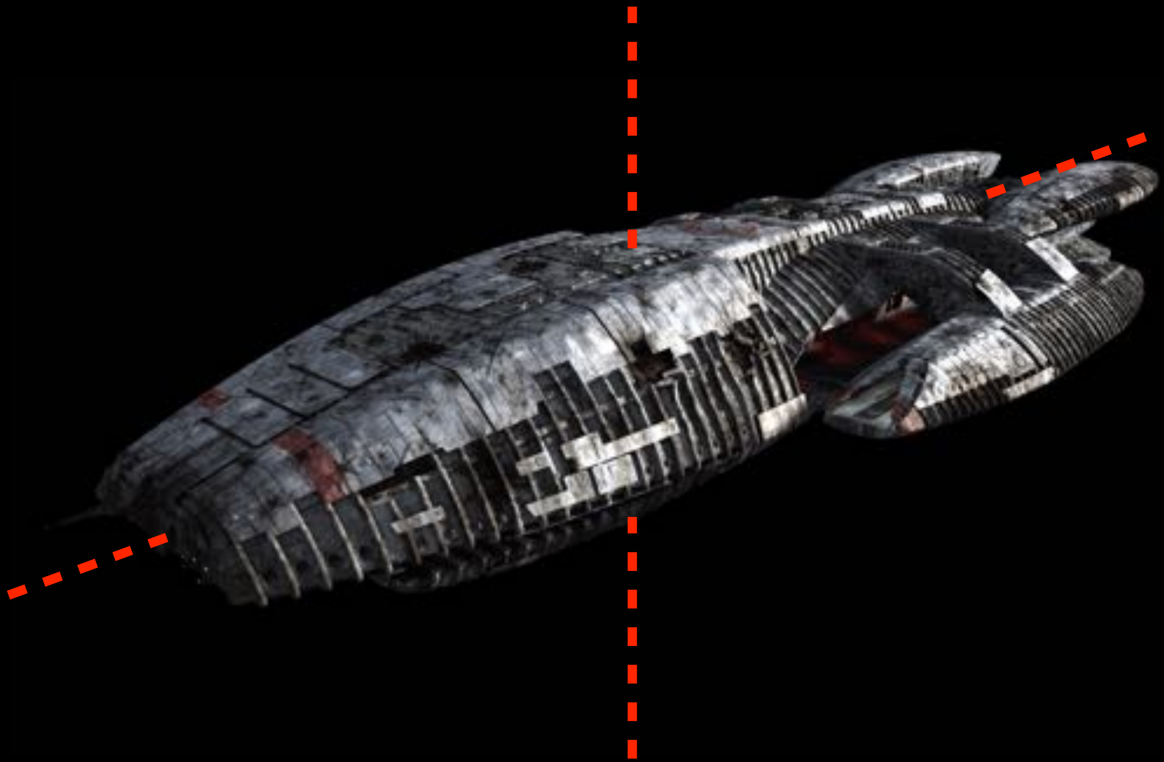


Belton et al. (2018) found long axis precession period of **8.67+/- 0.34** hr.

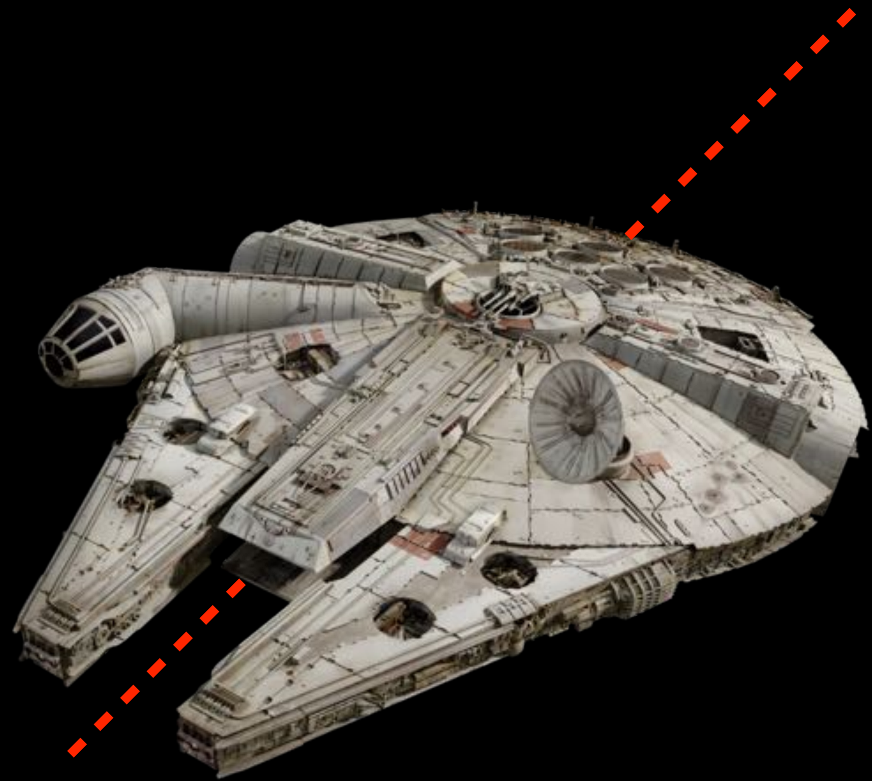
Long-Axis Mode rotation of 6.58 hr, 13.15 hr, or **54.48** hr

Short-Axis Mode rotation of 13.15 hr or 54.48 hr

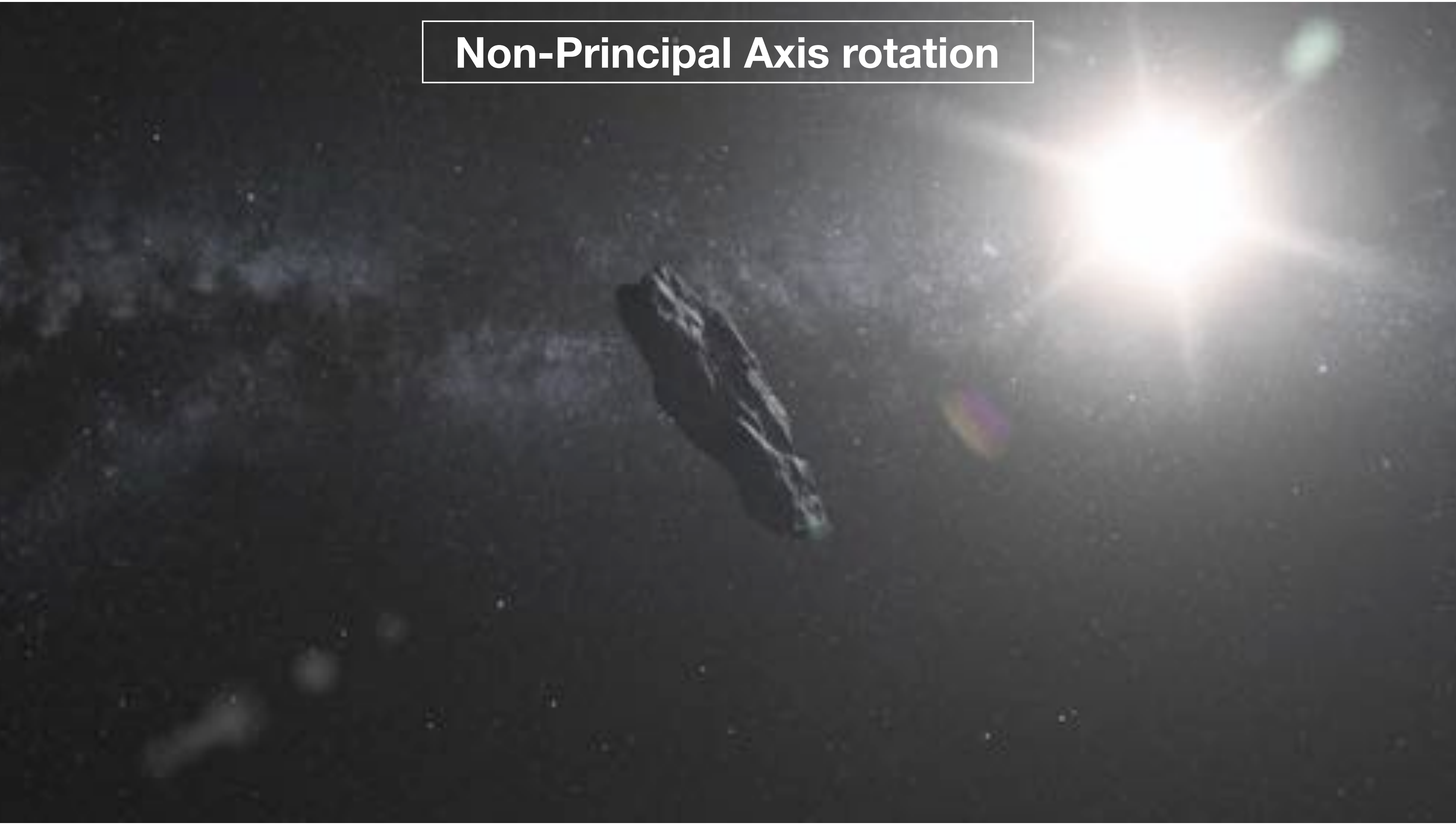
Lowest Energy State
SAM or LAM



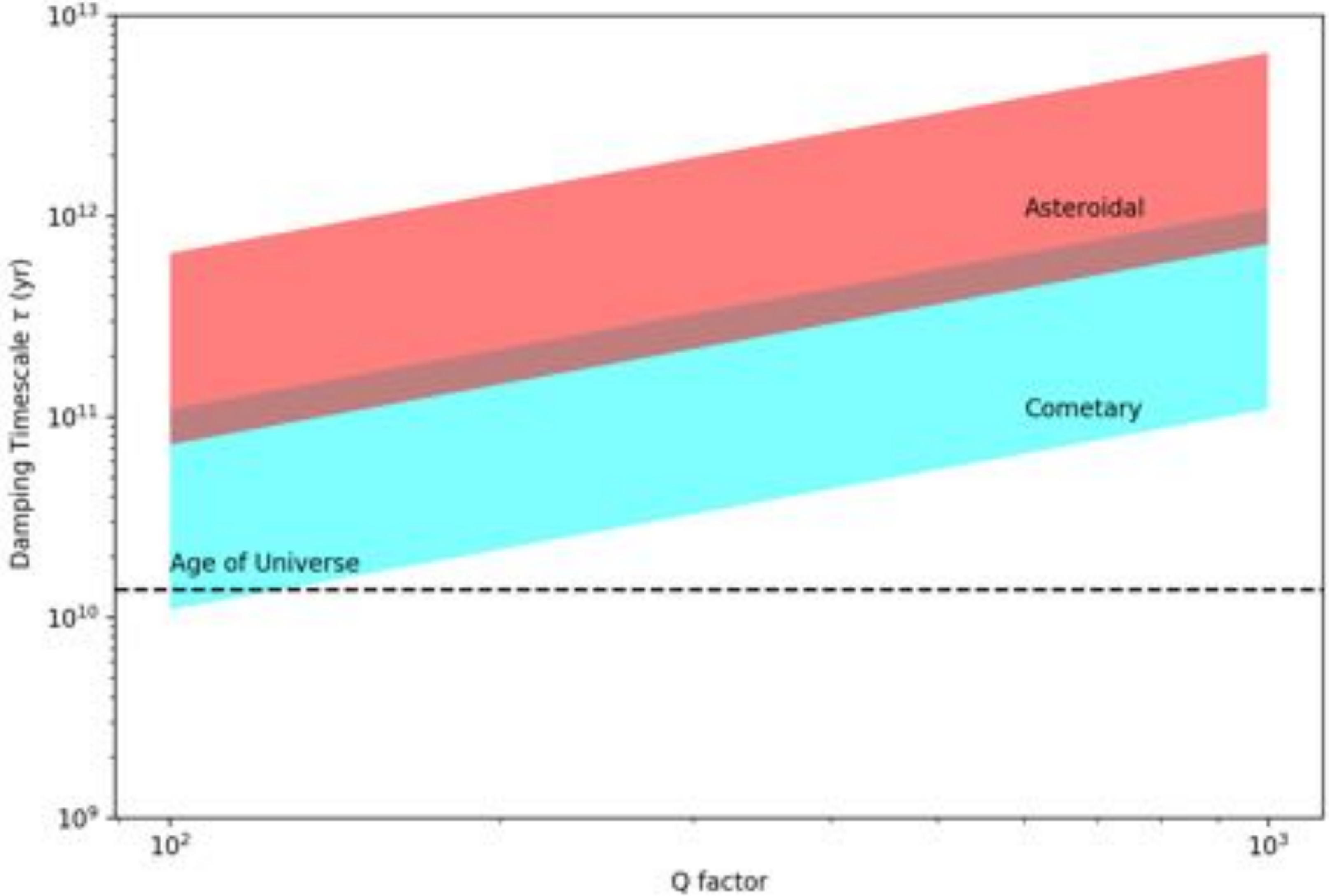
Highest Energy State
LAM



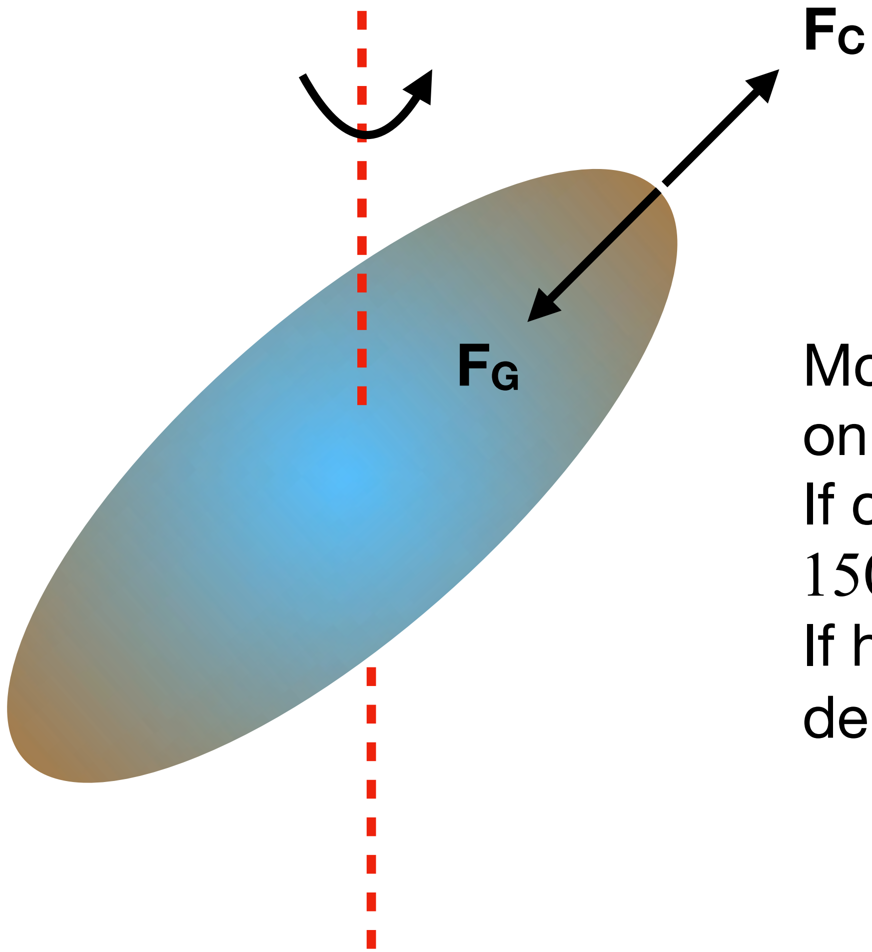
Non-Principal Axis rotation



Time needed to stop NPA rotation



Internal Density Constraints



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

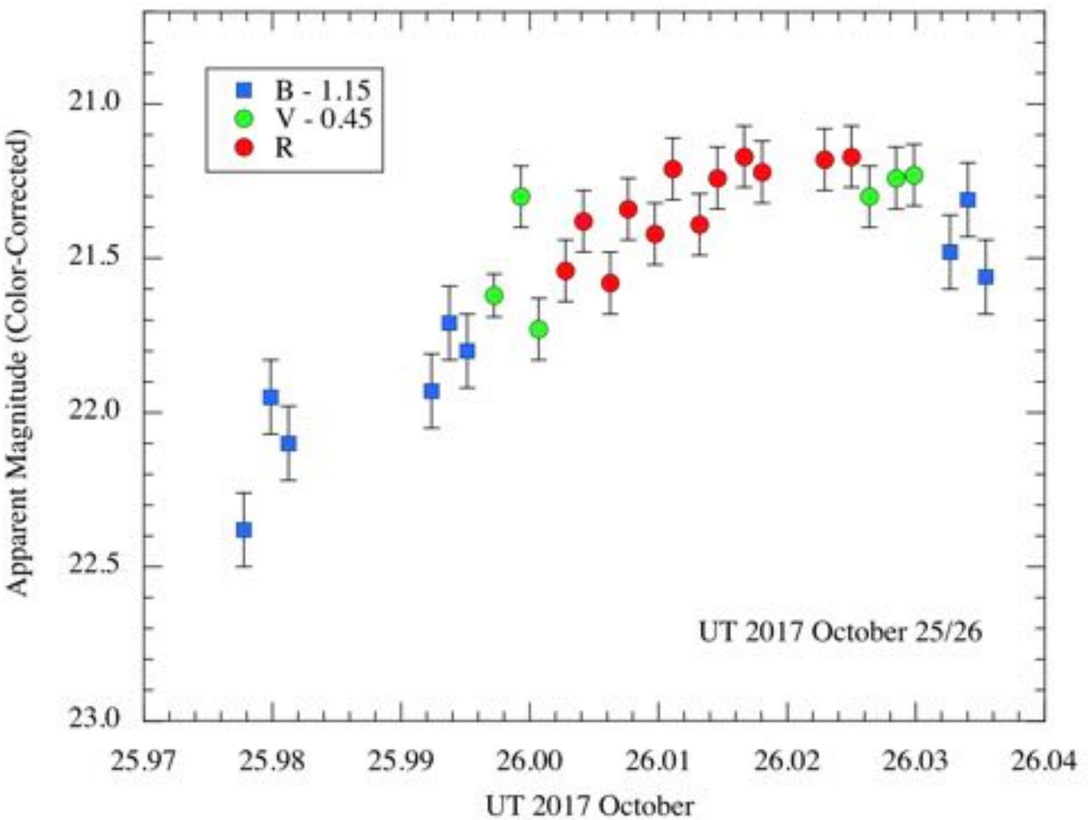
If completely strengthless (s=0) then

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

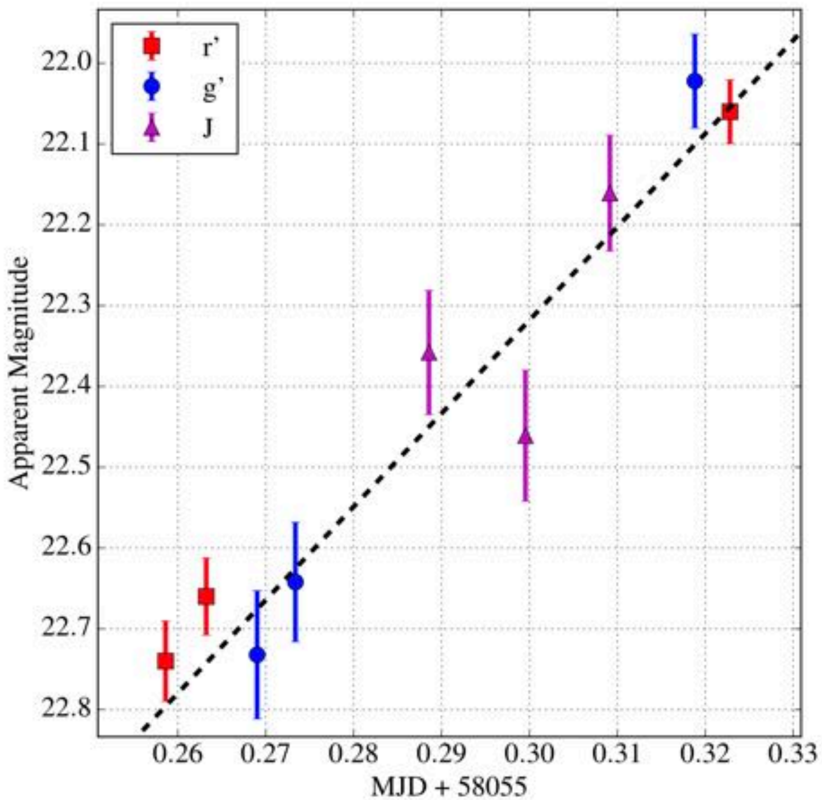
If has non-zero cohesive strength, the density is lower and s~10 Pascals.

Optical+IR colours

Large amplitude lightcurve means colours need careful measurement!

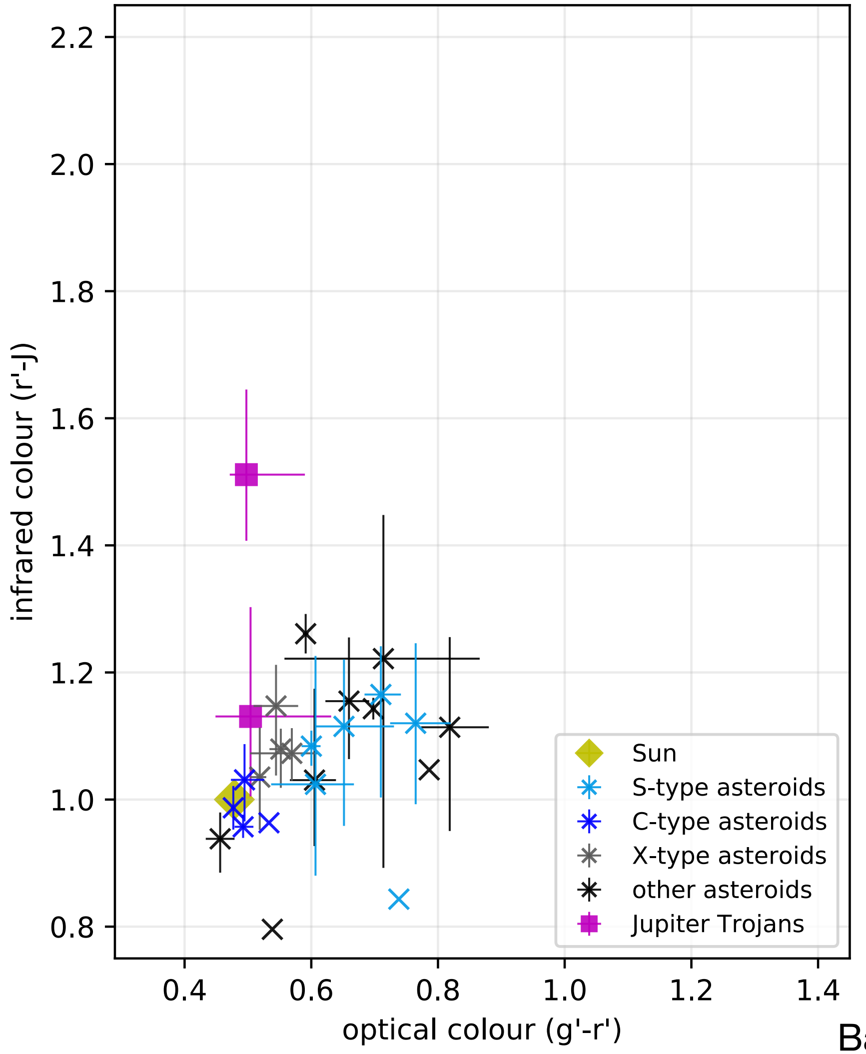


Jewitt et al. (2017)



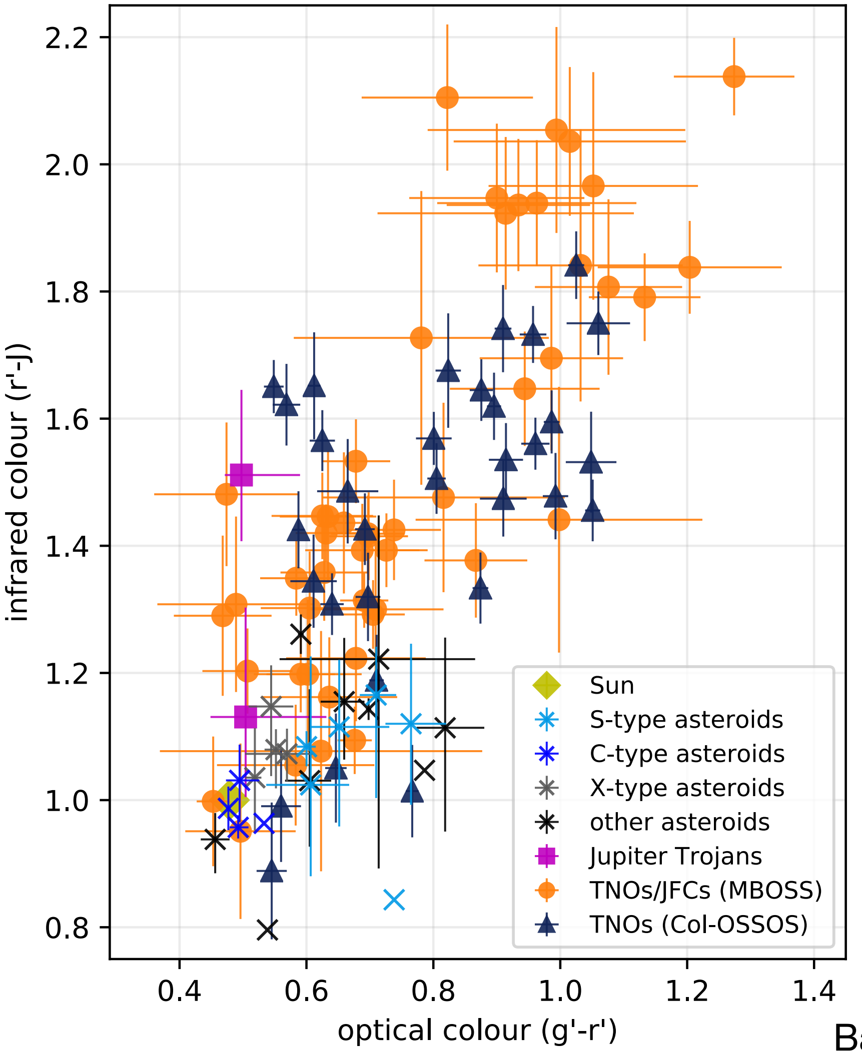
Bannister et al. (2017)

Optical+IR colours



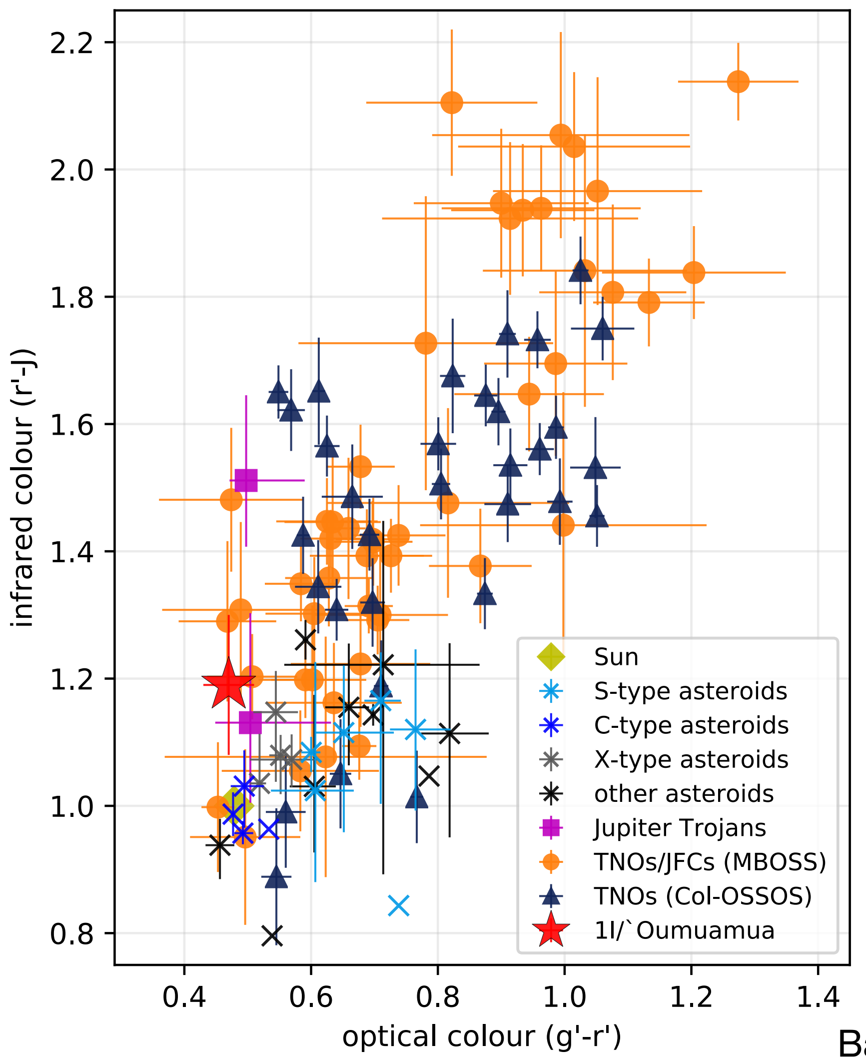
Bannister et al. (2017)

Optical+IR colours



Bannister et al. (2017)

Optical+IR colours

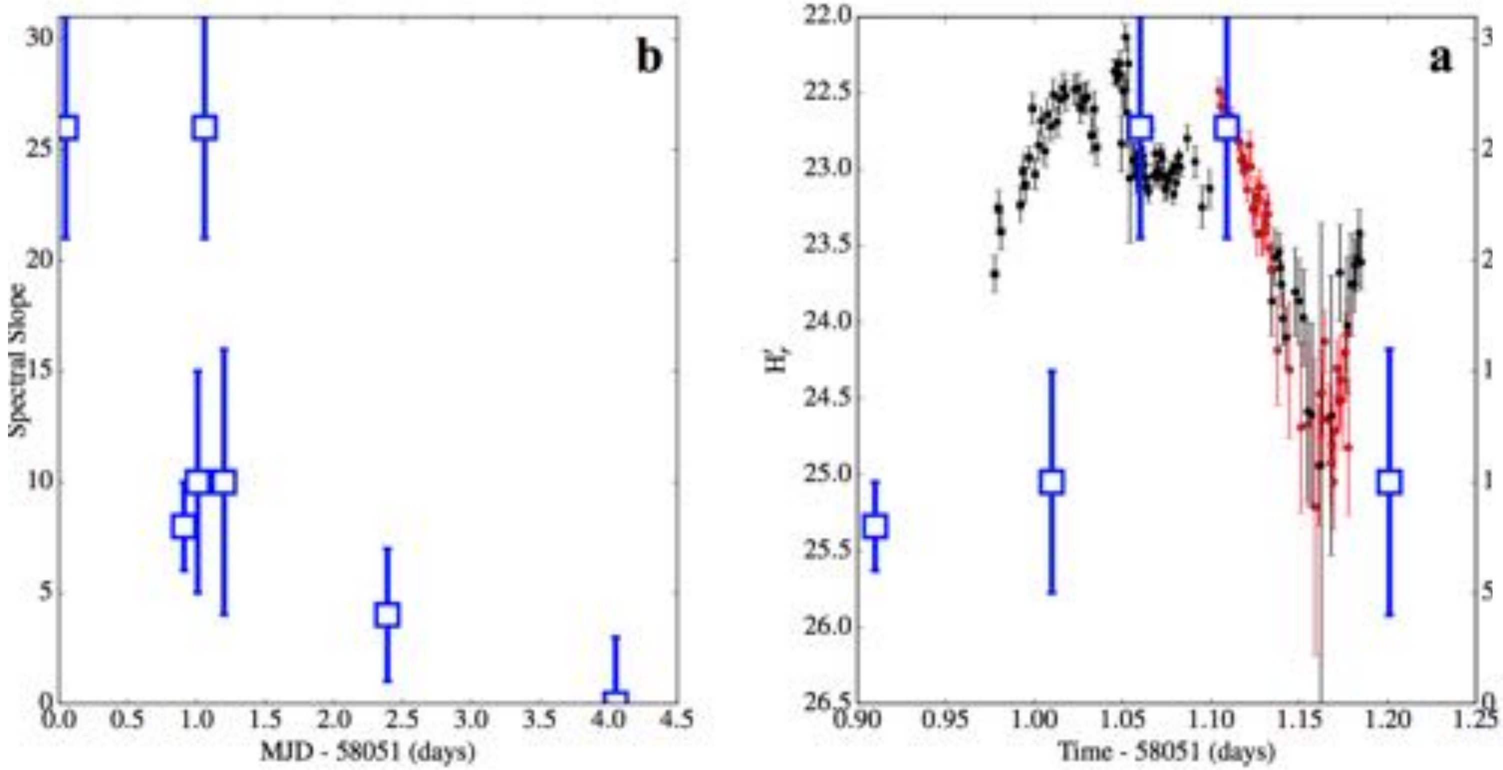


Bannister et al. (2017)

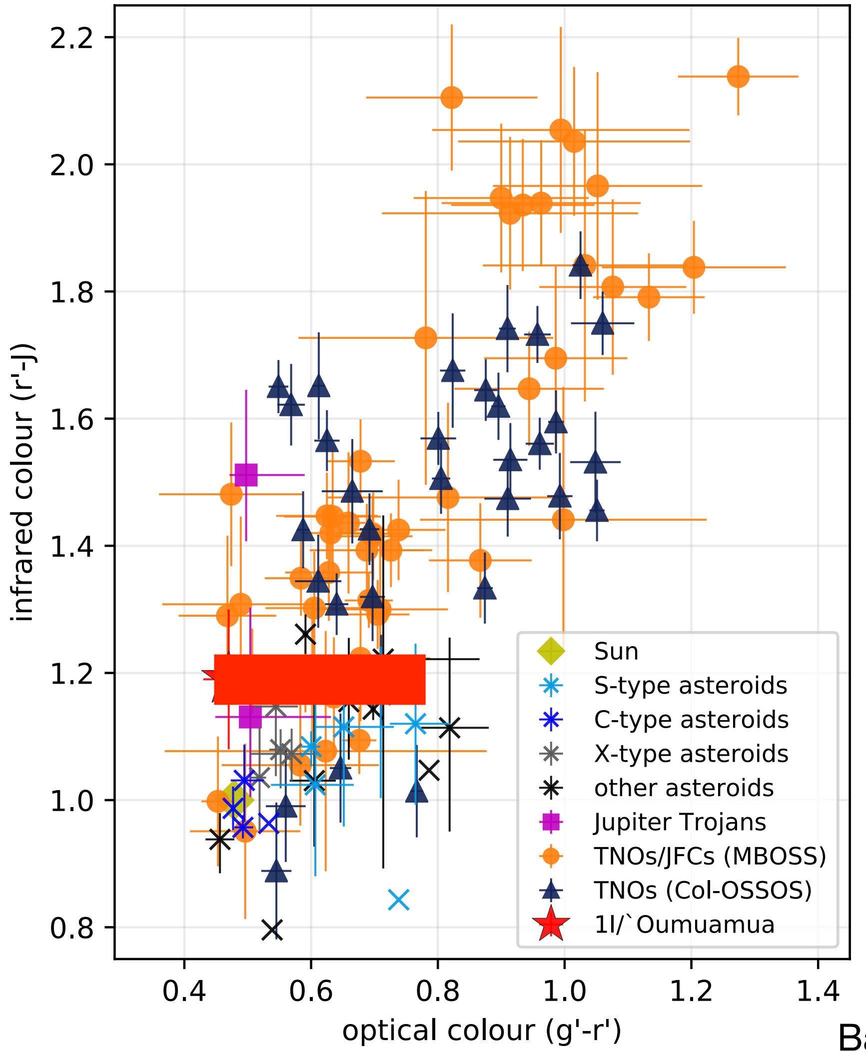
Optical+IR colours

Colour variations not secular but linked with lightcurve phase.

Fraser et al. (2018)

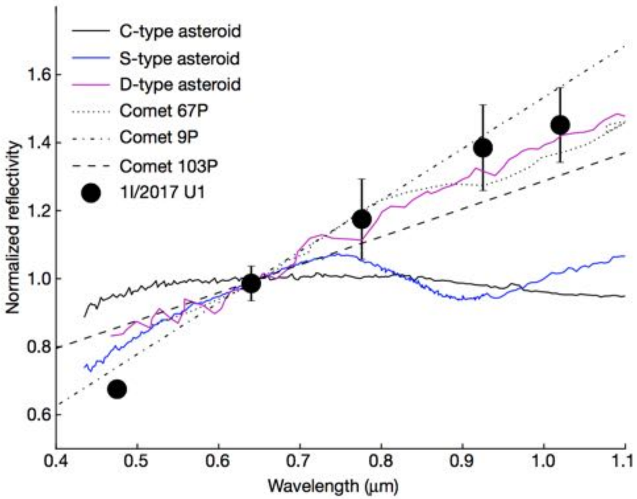


Optical+IR colours

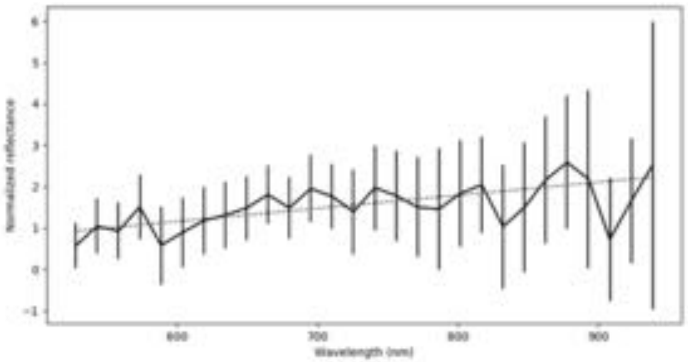


Bannister et al. (2017)

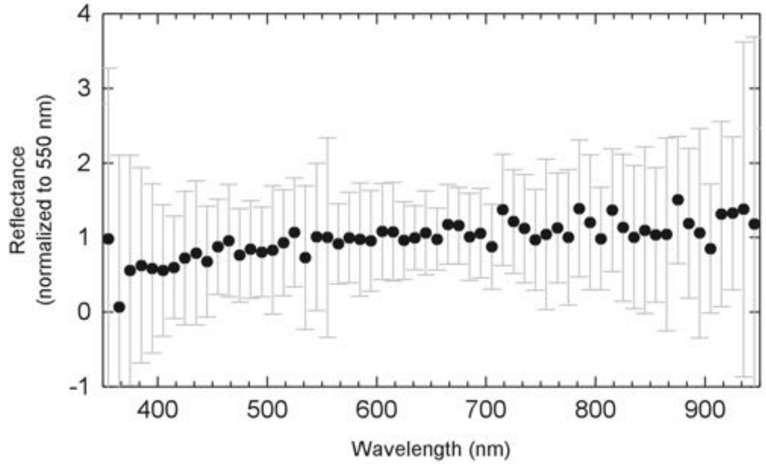
Optical Spectroscopy



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)

Spectroscopy

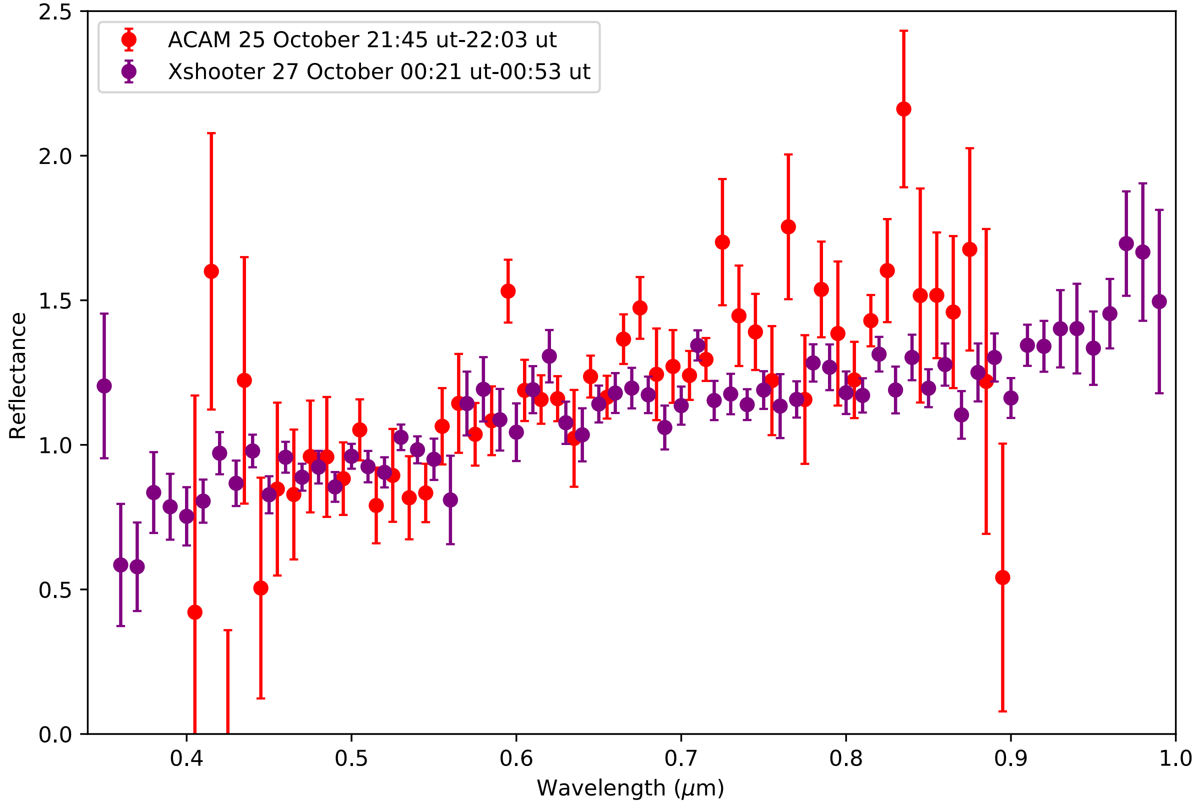
October 25.9 UT

4.2m William Herschel Telescope
+ ACAM

October 27.0 UT

8.2m Very Large Telescope UT2
+ X-Shooter

Optical Spectrum

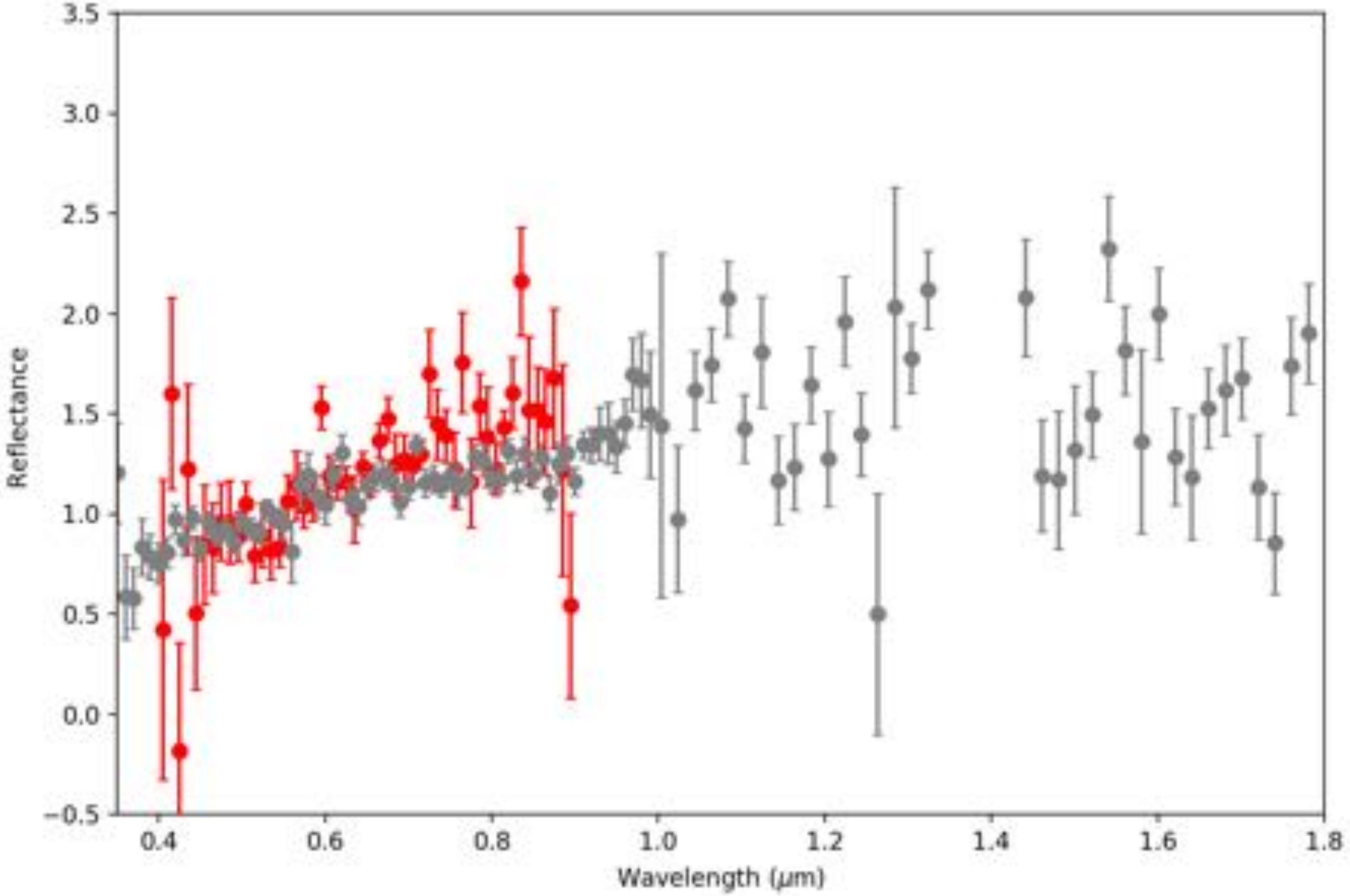


October 25.9UT WHT+ACAM: S'=17±2%/1000Å

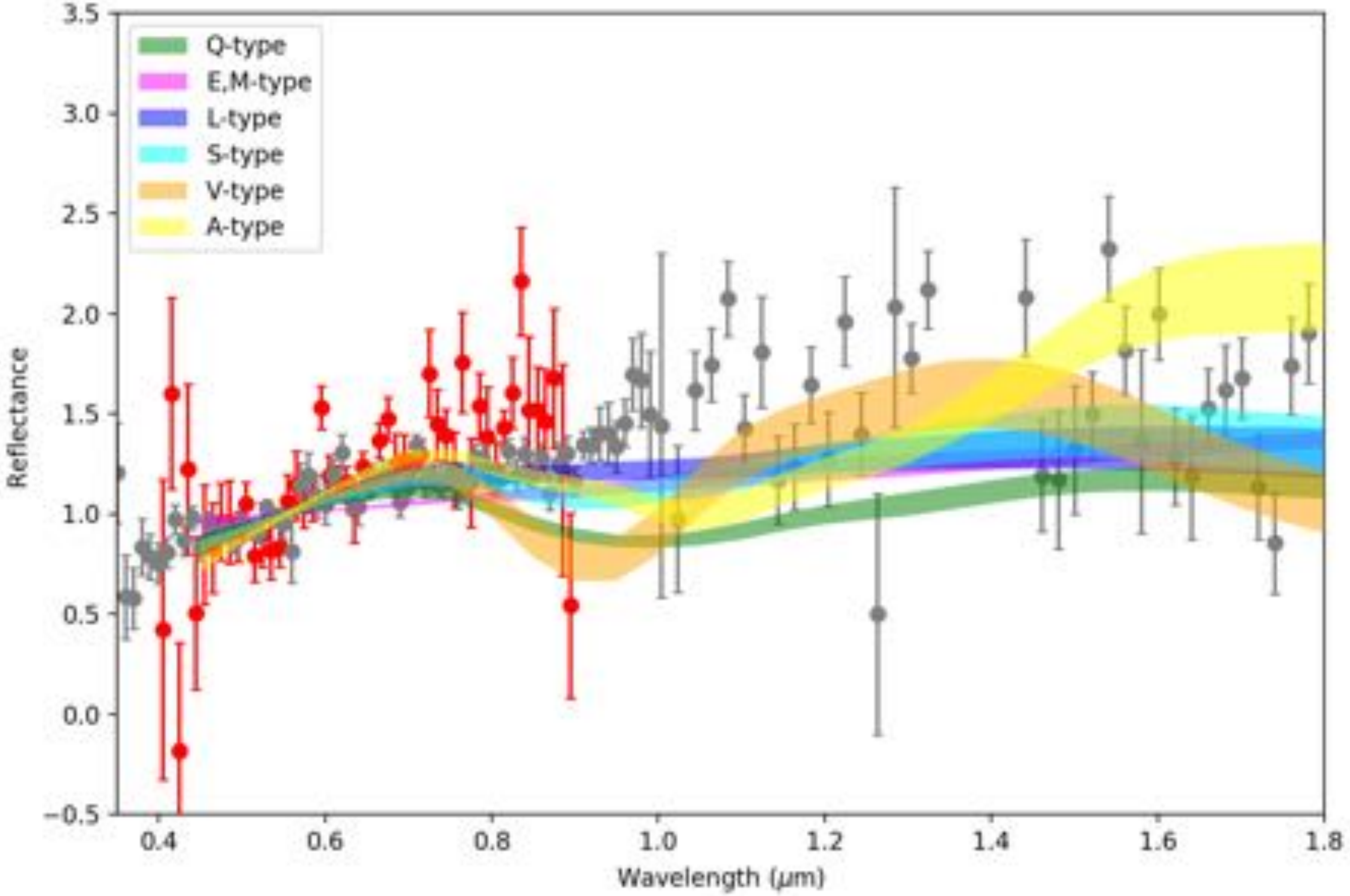
October 27.0UT VLT+X-Shooter: S'= 9±1%/1000Å

Fitzsimmons et al. (2017)

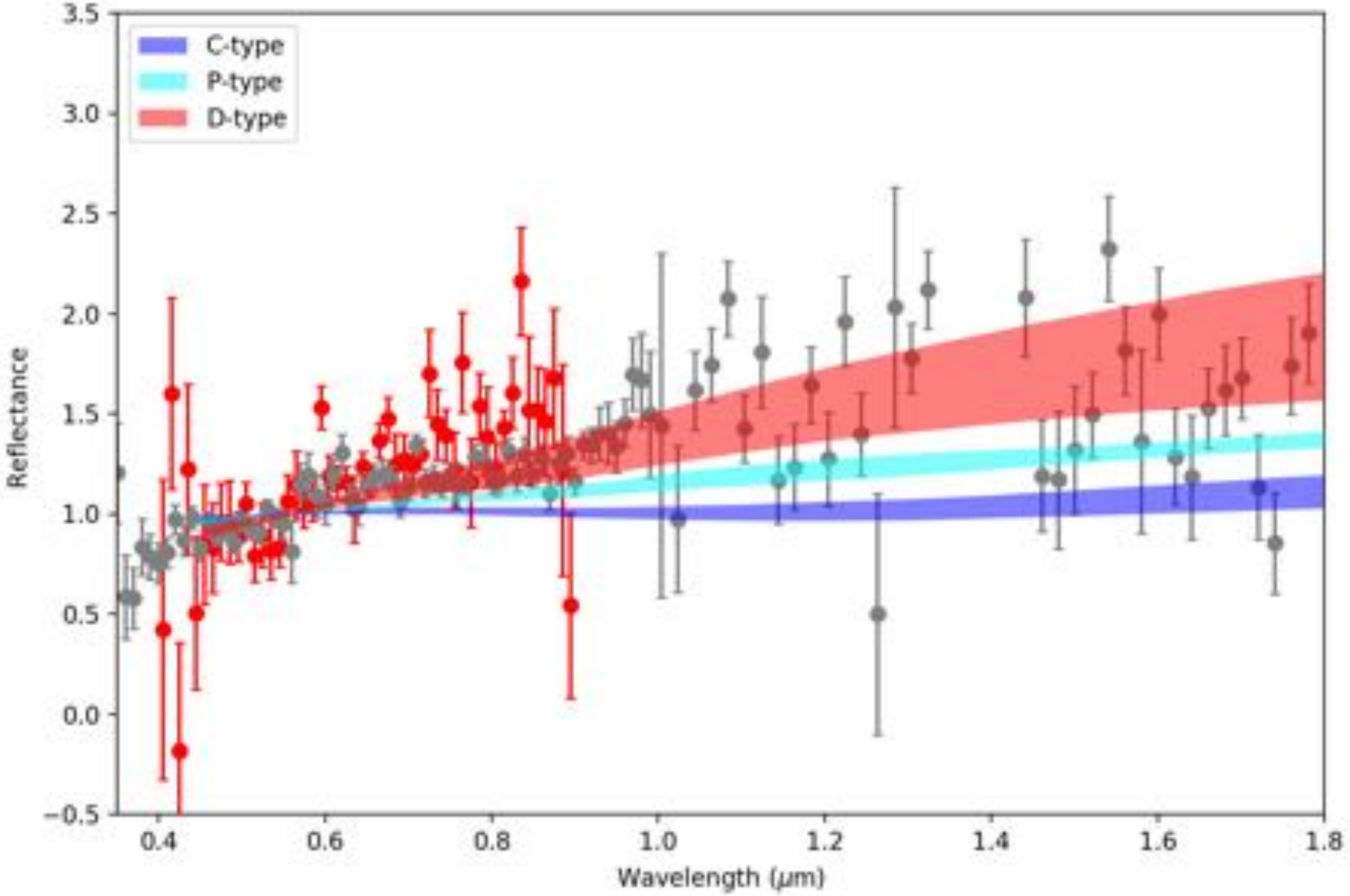
Optical + Near-Infrared Spectrum



Optical + Near-Infrared Spectrum

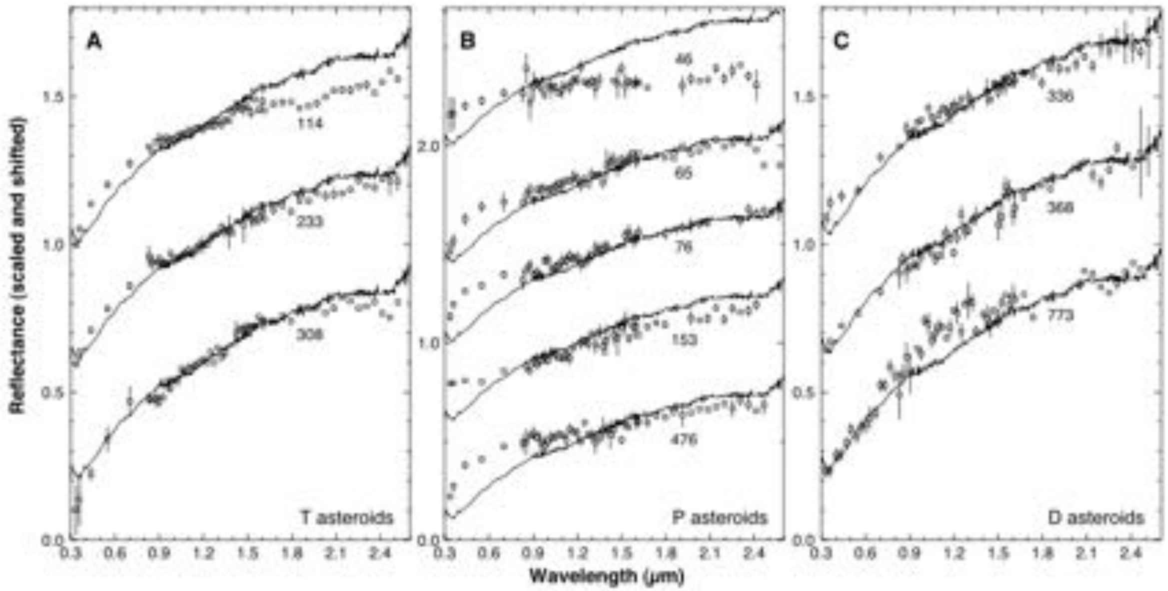


Optical + Near-Infrared Spectrum



D-type Asteroid?

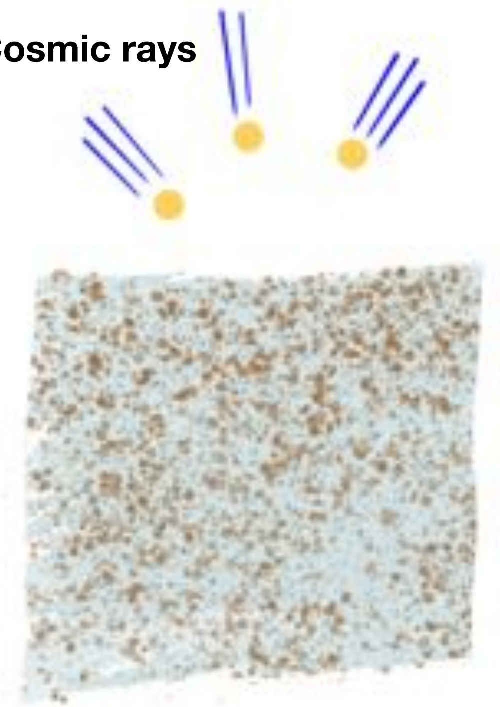
Tagish Lake Meteorite



Bulk Density ~1.7 gm/cm3
(Ralchenko et al. 2014)

Comparison with primitive asteroids
(Hiroi et al. 2001)

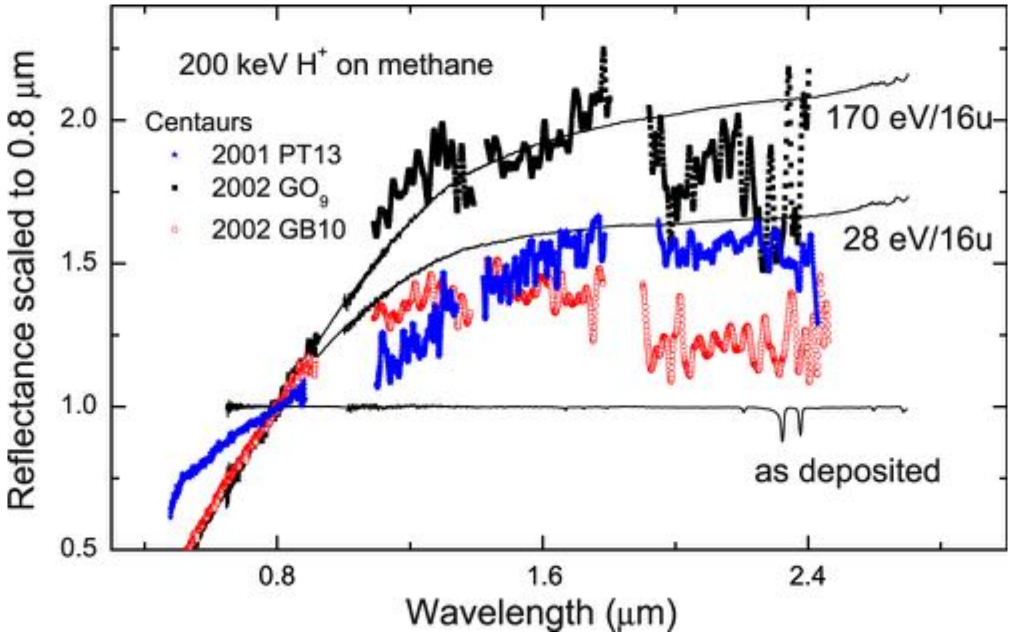
Irradiation ice mantles



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

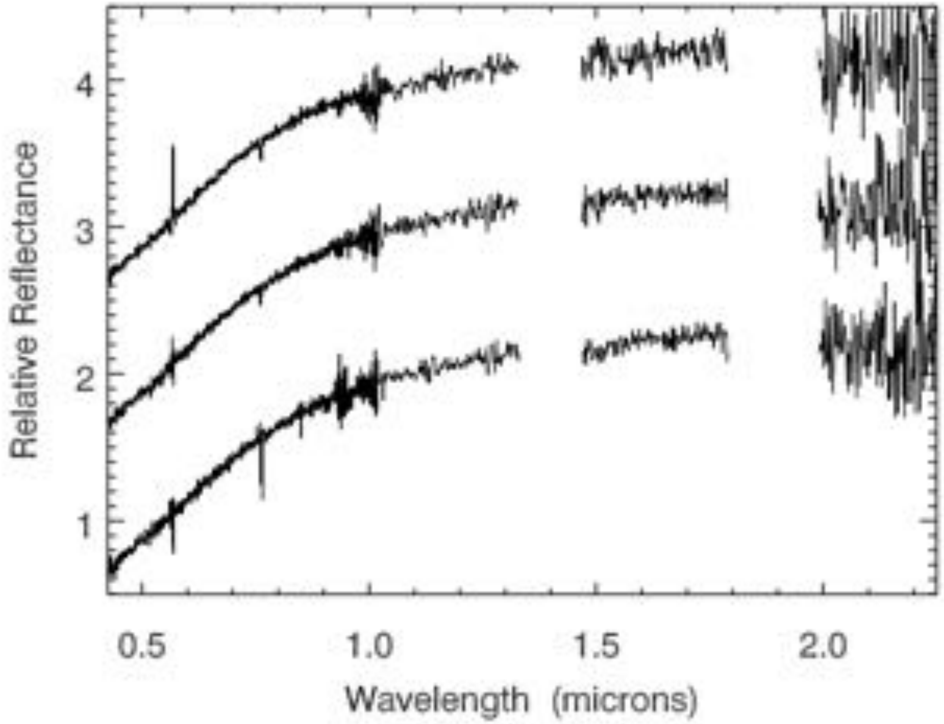
Irradiated comet?

200 keV H^+ onto CH_4 ice



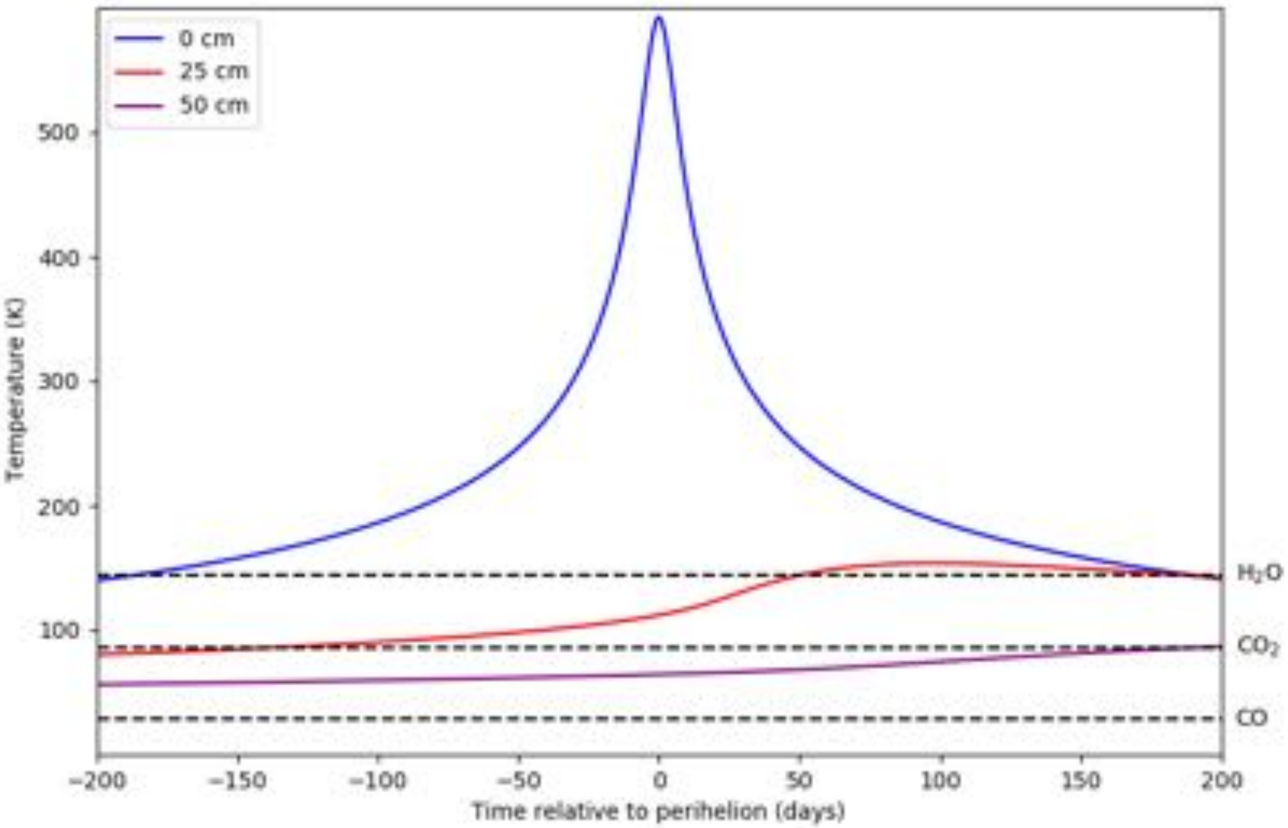
Rothard et al. (2017)

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

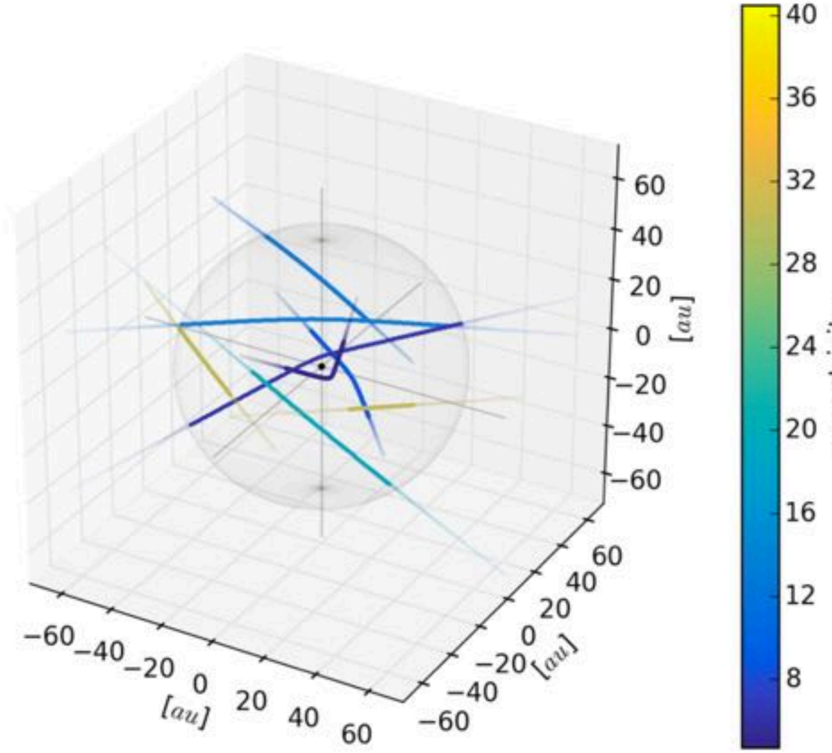
Fitzsimmons et al. (2018)

number density

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

Number per cubic parsec	Reference
< 2×10^{15}	Englehardt et al. (2017)
~10^{15}	Meech et al. (2017)
~10^{15}	Trilling et al. (2017)
~2×10^{15}	Do et al. (2018)

Number density in Solar system
~0.2 au^{-3}



number density

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

Number per cubic parsec	Reference
< 2×10^{15}	Englehardt et al. (2017)
~10^{15}	Meech et al. (2017)
~10^{15}	Trilling et al. (2017)
~2×10^{15}	Do et al. (2018)

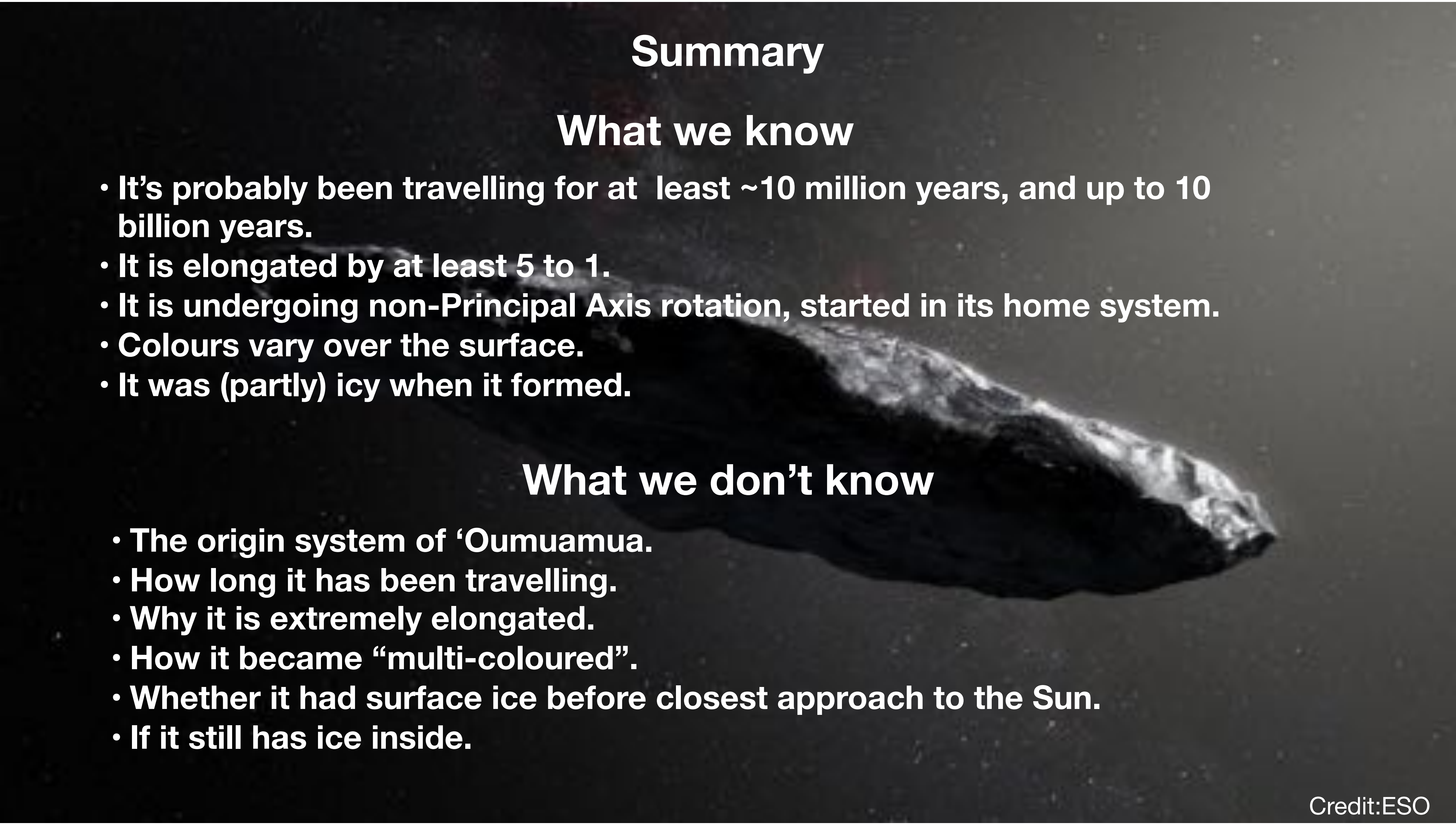
Number density in Solar system
~0.2 au^{-3}

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)
- Tidal disruption of terrestrial planets? (Cuk 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 5 to 1.
- It is undergoing non-Principal Axis rotation, started in its home system.
- Colours vary over the surface.
- It was (partly) icy when it formed.

What we don’t know

- The origin system of ‘Oumuamua.
- How long it has been travelling.
- Why it is extremely elongated.
- How it became “multi-coloured”.
- Whether it had surface ice before closest approach to the Sun.
- If it still has ice inside.

Credit:ESO