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

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

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

During Grand Tack and Nice model migration, ejection of 5-40 M\(_{\text{Earth}}\).

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

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

But - numbers ejected heavily dependent on system architecture.
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)
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 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
‘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° 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)
Perihelion 9 September
Discovery 19 October
$e=1.197$
$q=0.25$ au
$i=122.6^\circ$
$H=22$
(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

Brightness

Time
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)
P = 7.34 hours, $\Delta m \approx 2.5$ mag  (Meech et al. 2017)
H=22.4 implies D~200m
Amplitude implies elongated body, axial ratio 10:1!
Spin Period & Shape

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

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)
Belton et al. (2018) found long axis precession period of $8.67 \pm 0.34$ 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
McNeil et al. (2018) Calculated constraints on the bulk density. If completely strengthless \((s=0)\) then \(1500 < \rho < 2800 \text{ kg/m}^3\). If has non-zero cohesive strength, the density is lower and \(s \sim 10\) Pascals.
Optical+IR colours

Large amplitude lightcurve means colours need careful measurement!

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: $S'=17\pm2\%/1000\AA$
October 27.0UT  VLT+X-Shooter: $S'= 9\pm1\%/1000\AA$

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 $\sim 10^8$ yr to form $\sim 50$ 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)
We have found one ISO. Guess the size distribution, albedo, velocity distribution…

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