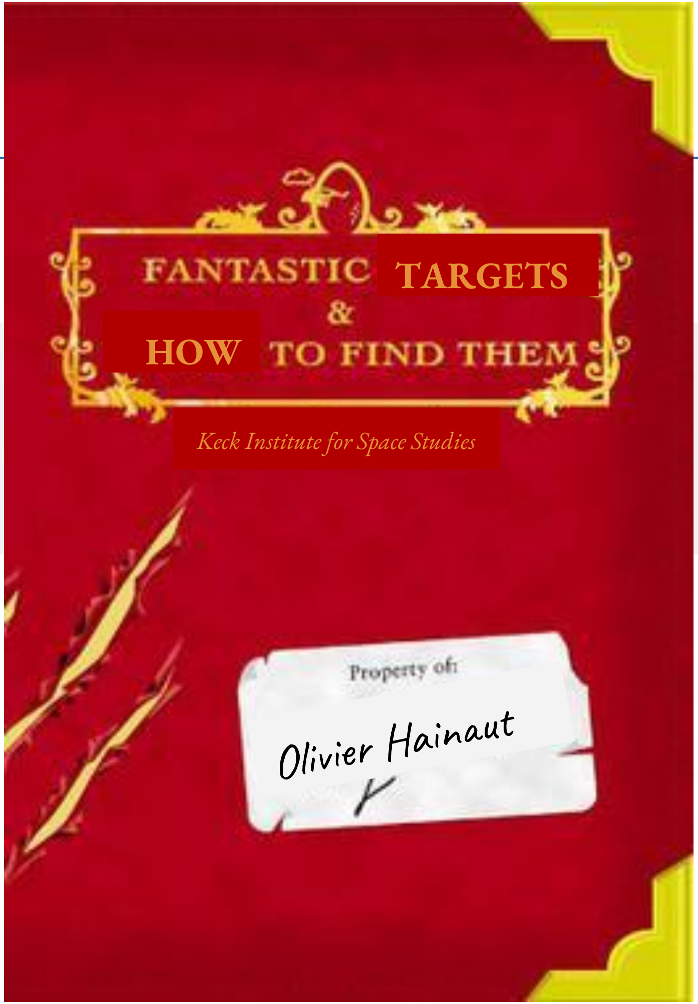
Exploring Once-in-a-Lifetime Targets



Olivier Hainaut

ESO

http://bit.ly/FantasticTargets

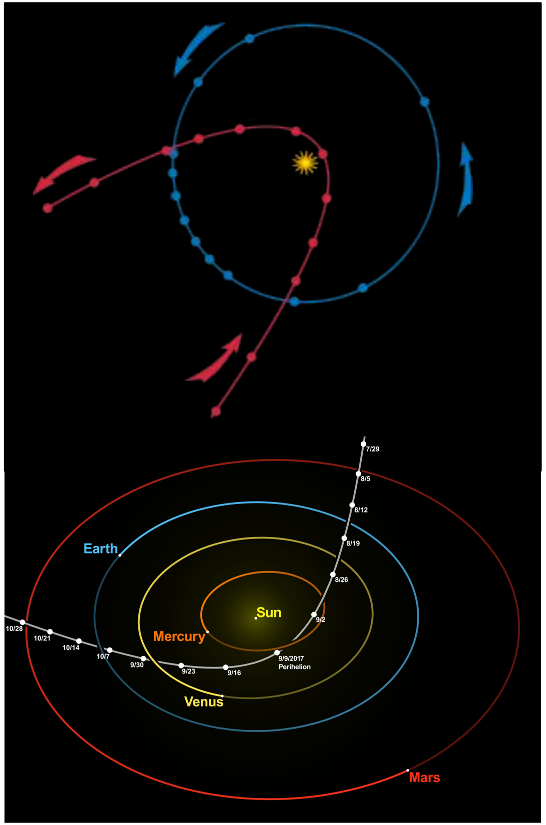
What is a Once-in-a-lifetime *Targets*

What?

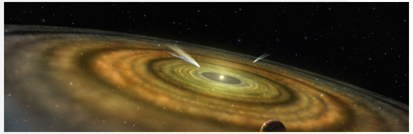
Minor bodies in the Solar System,
on extremely eccentric orbits

- Hyperbolic (e>1)
- Parabolic (e~1)
- Elliptic (e<1, a>>, P>>)

or: Objects that will never return [in civilization's life time]



Origin



Early Solar System:

Planet migration (or other model)

→ composition reshuffle

→ ejection of planetesimals to

- **Oort Cloud**

→ some will eventually come back

- **Interstellar space**

→ we get the neighbour's

Grand Tack

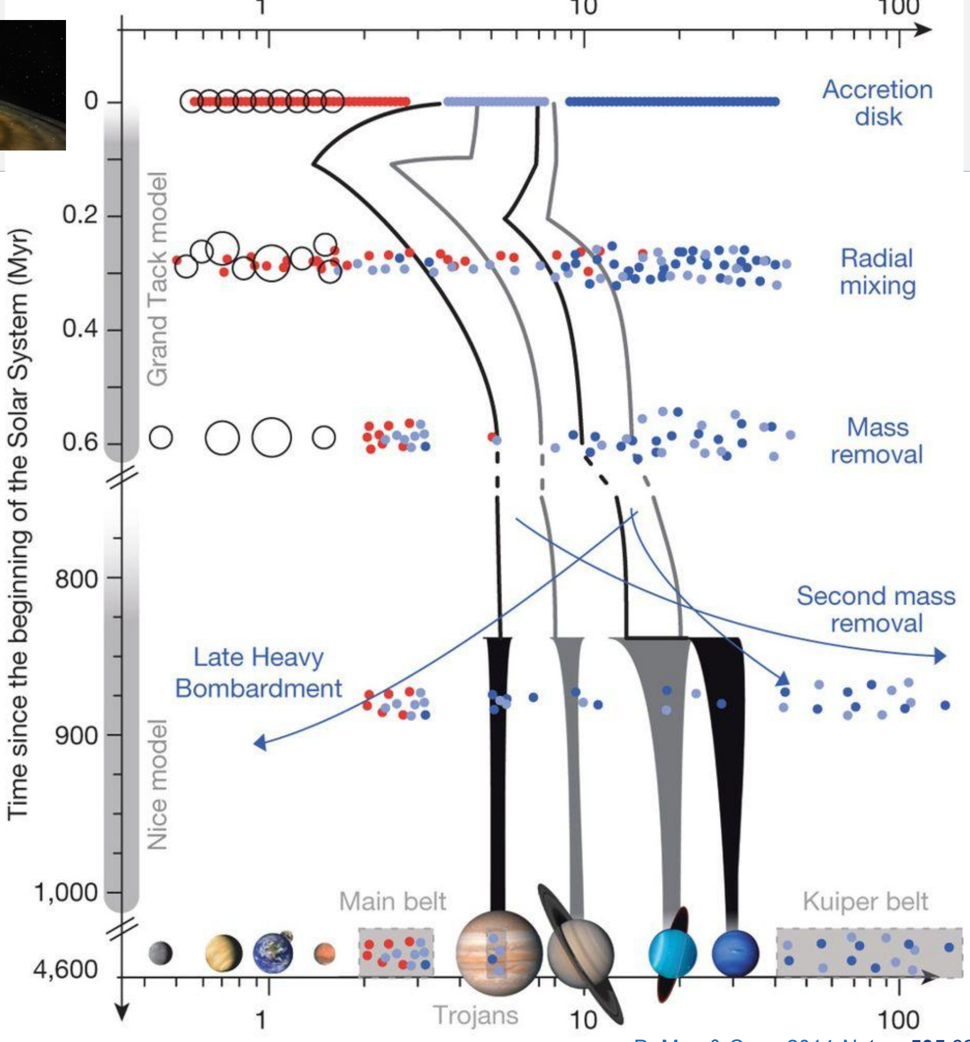
Walsh+ 2011. "A low mass for Mars from Jupiter's early gas-driven migration". *Nature*. **475** (7355): 206

Nice Model

Gomes + 2005. "Origin of the cataclysmic Late Heavy Bombardment period of the terrestrial planets". *Nature*. **435** 466

Tsiganis+ 2005. "Origin of the orbital architecture of the giant planets of the Solar System". *Nature*. **435** 459

Morbidelli+ 2005. "Chaotic capture of Jupiter's Trojan asteroids in the early Solar System" (PDF). *Nature*. **435** 462



DeMeo & Carry 2014 *Nature* **505** 629

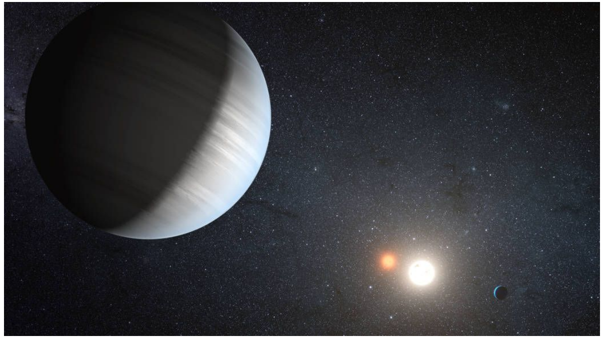
Collision, impacts and ejection

Collision between (proto-) planets:

- Numerous high-velocity fragments → ejection
- Example: Earth/Moon formation

Circum-binary systems:

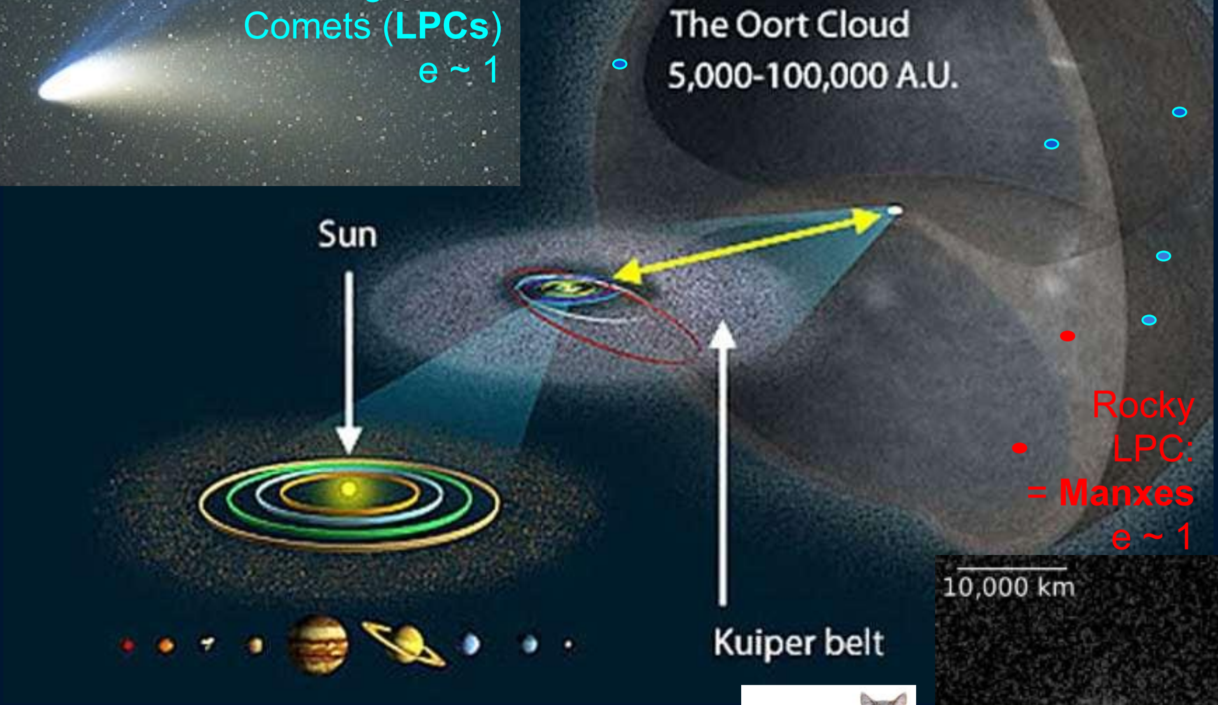
- Possible, but unstable → ejection



NASA Ames/JPL Caltech/T. Pyle
Bromley & Kenyon 2015 *ApJ* **806** 98
Sutherland & Fabrycky 2016 *ApJ* **818** 6

NASA | JPL | CalTech
Hartmann & Davis 1975 *Icarus* **24**, 504
Jacobson+ 2014 *Nature* **508**, 84

Interstellar Objects (**ISOs**)
e >> 1



LPCs + Manxes:

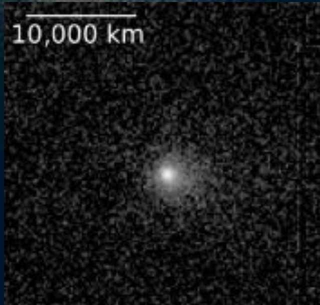
- Planetesimal from early Solar System
- Preserved from heating since their formation

ISOs

- Insight in other solar systems

We *really* want to study them

Manx Cat Breed | Purina



Manx: **C/2014S3** | Meech +16 | Science Adv **2** e160038

Orbit

Conservation of energy: $(\frac{1}{2}\, m\, \mathbf{v}^2) - (\mathbf{GM}\, m/\, \mathbf{r})$ $= cst$

$= \frac{1}{2}\, m\, \mathbf{v}_{\mathbf{inf}}^{\mathbf{2}}$

Target: **e~1** $\Rightarrow$ cst ~ 0, v_{inf} ~0

i >>

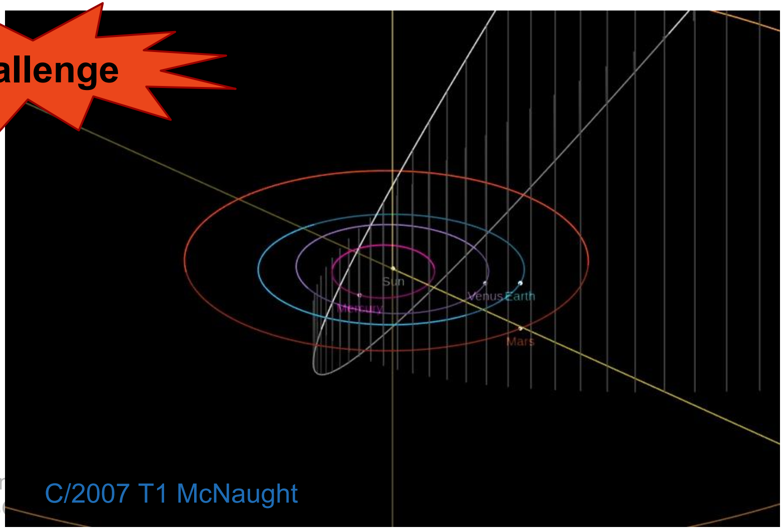
v_{1AU} = 42 km/s

v_{max}(1I) = 87 km/s

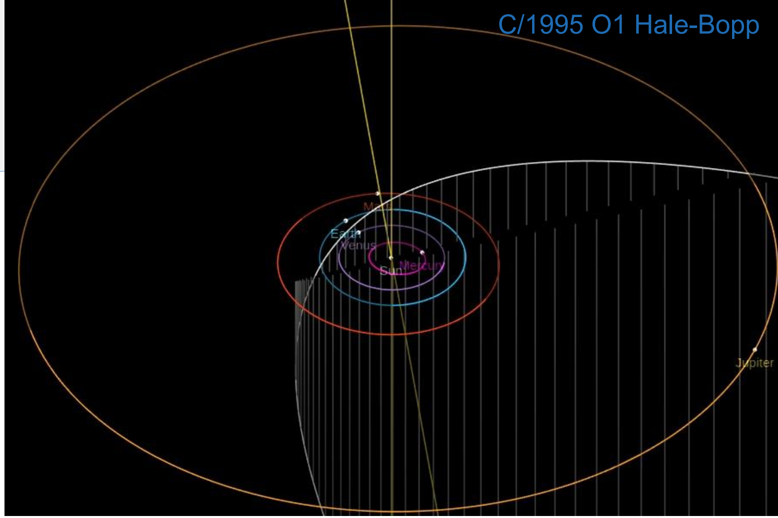
v_{earth} = 30 km/s

Huge Delta-v (see Hope's talk for the consequences)

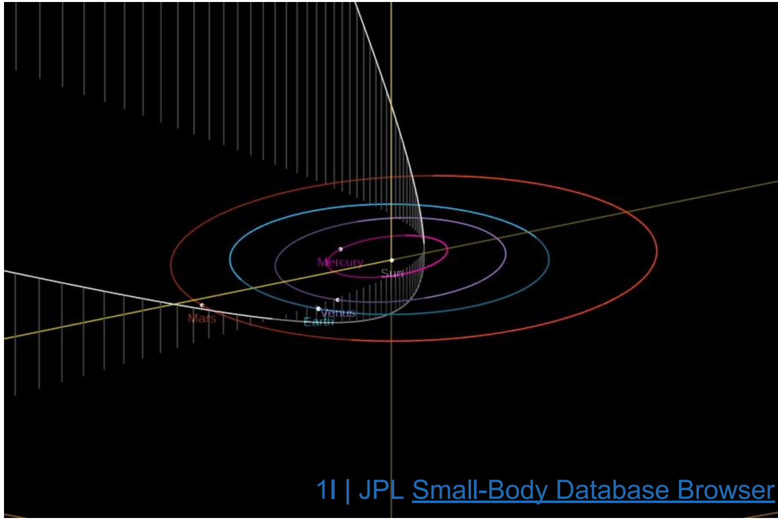
Challenge



C/2007 T1 McNaught



C/1995 O1 Hale-Bopp



1I | JPL [Small-Body Database Browser]

What do we want / need for a space mission

Fantastic Targets: shopping list

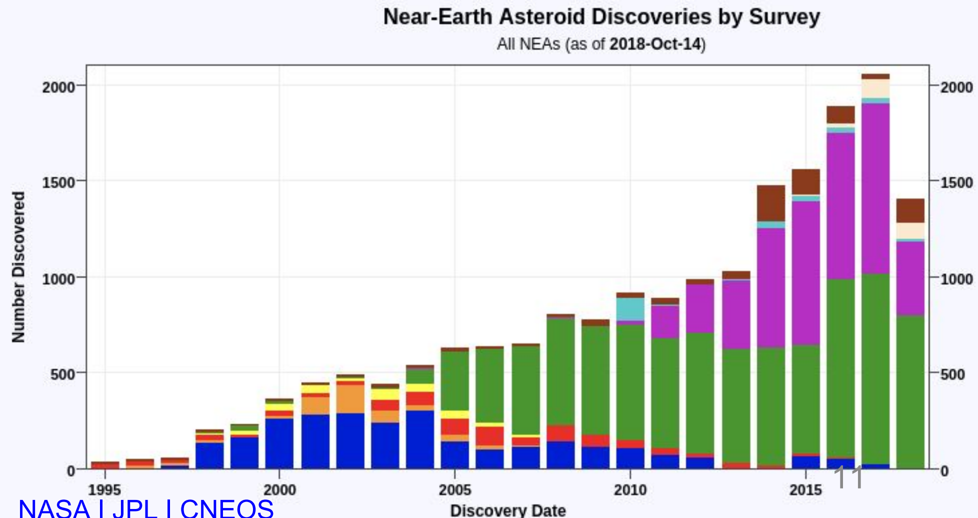
- Discovery
- Orbit
- Size
  - Shape
- Rotation
  - Stable: Period, orientation
  - Unstable: characterized
- Surface
  - Albedo
  - Composition
- Surroundings
  - Cometary activity
    - Dust production rates
    - Dust size distribution
  - Satellites
- Mass, density
- Interior structure

Targets in Hiding: How to discover them?

How?

Wide-field telescope

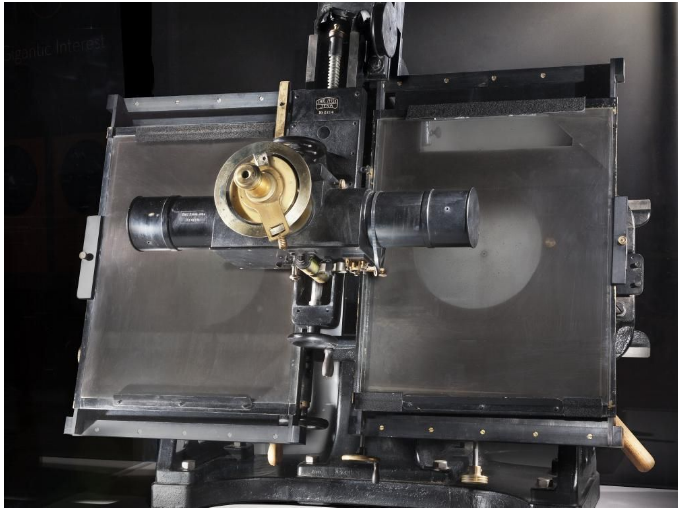
- \+ Excellent site
- \+ Huge camera
- \+ Powerful pipelines



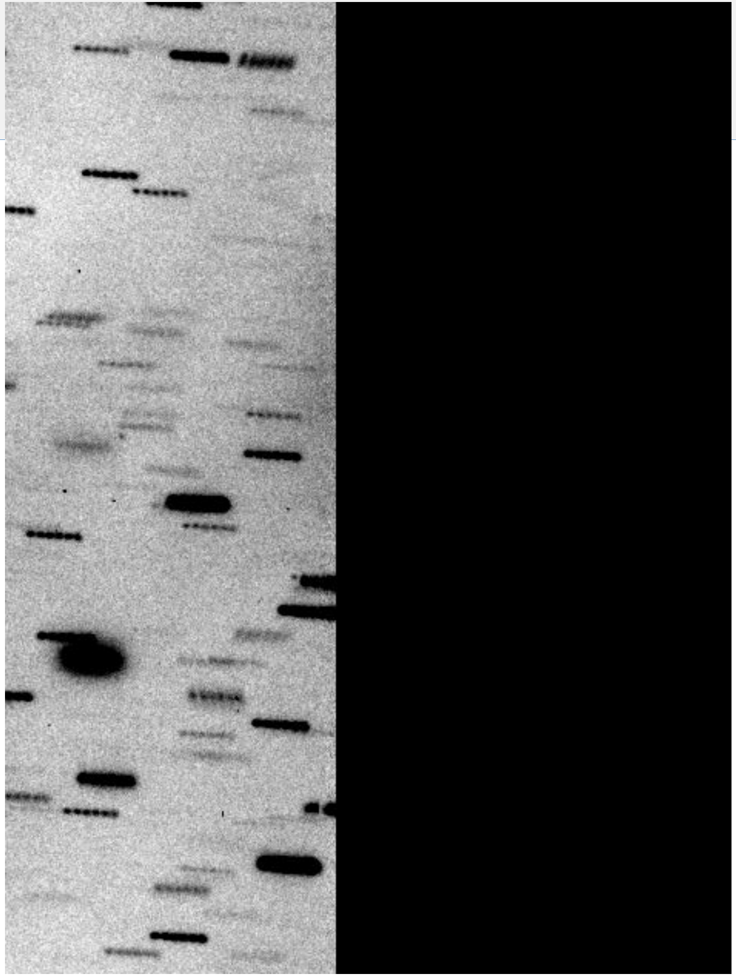
How?

Blink

Visual blink:
Extremely good,
but does not scale well

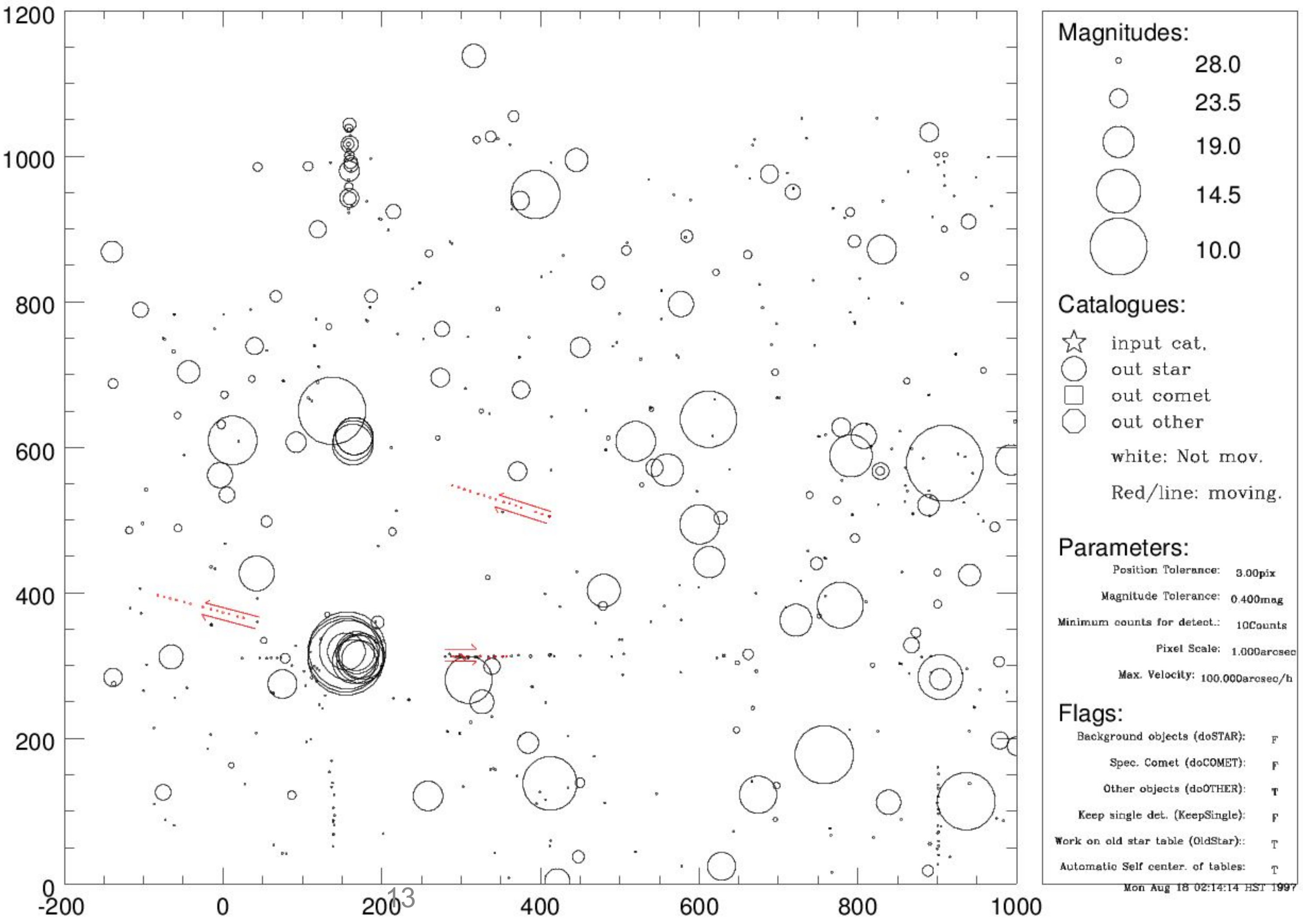


Pluto's blink comparator | Lowell Obs | photo Smithsonian Air & Space Museum



1991VG (recovery, mag=26.5) | Hainaut, Micheli, Kochny 2017

How?



1200
1000
800
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200
0
-200
0
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400
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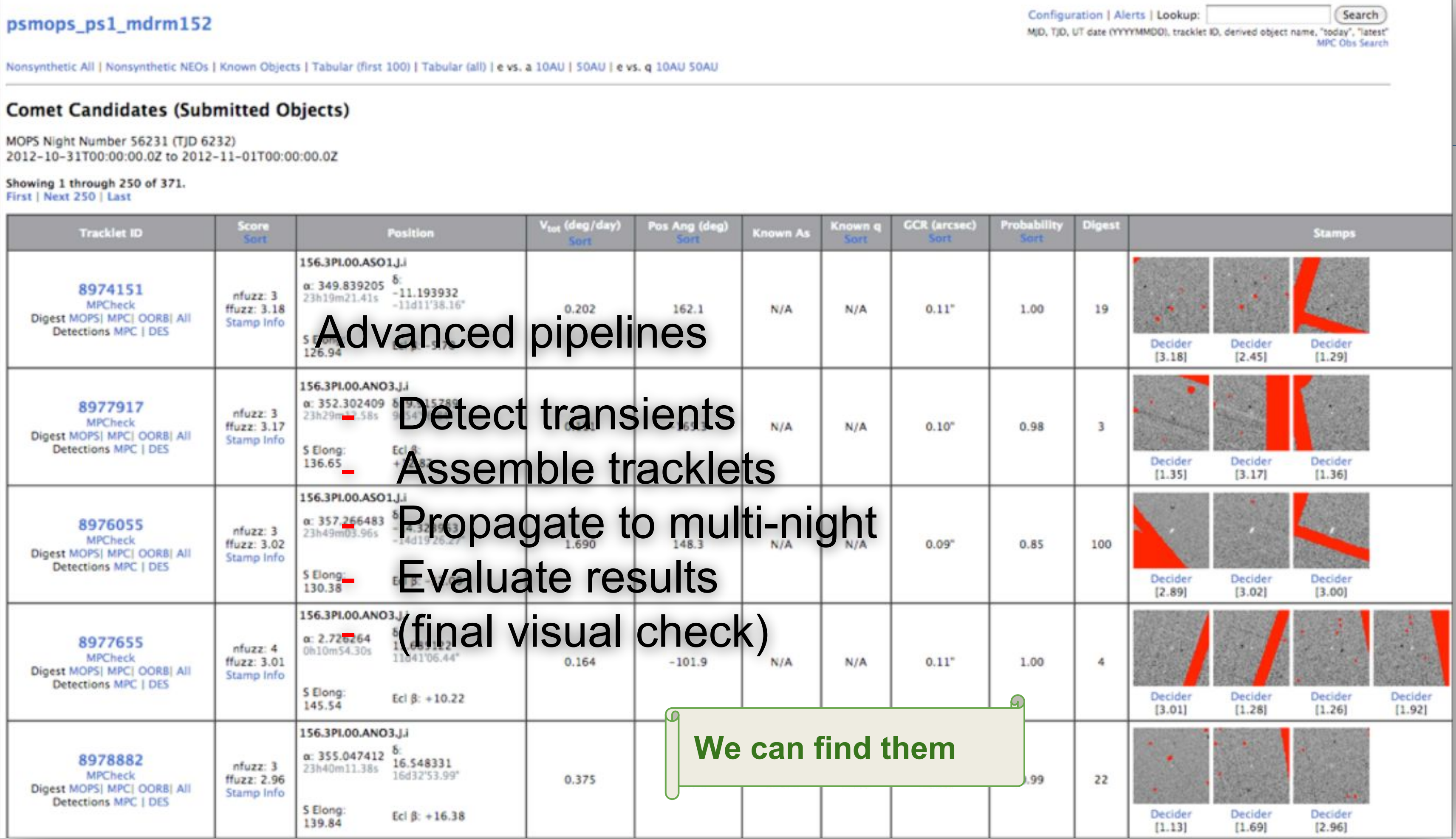
800
1000
Magnitudes:
28.0
23.5
19.0
14.5
10.0
Catalogues:
input cat.
out star
out comet
out other
white: Not mov.
Red/line: moving.
Parameters:
Position Tolerance: 3.00pix
Magnitude Tolerance: 0.400mag
Minimum counts for detect.: 10Counts
Pixel Scale: 1.000arcsec
Max. Velocity: 100.000arcsec/h
Flags:
Background objects (doSTAR): F
Spec. Comet (doCOMET): F
Other objects (doOTHER): T
Keep single det. (KeepSingle): F
Work on old star table (OldStar):: T
Automatic Self center. of tables: T
Mon Aug 18 02:14:14 HST 1997



Tracklet ID	Score Sort	Position	V_{tot} (deg/day) Sort	Pos Ang (deg) Sort	Known As	Known q Sort	GCR (arcsec) Sort	Probability Sort	Digest	Stamps
8974151 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 3.18 Stamp Info	156.3PI.00.ASO1.J.i α: 349.839205 23h19m21.41s δ: -11.193932 -11d11'38.16" S Elong: 126.94 Ecl β: [illegible]	0.202	162.1	N/A	N/A	0.11"	1.00	19	Decider [3.18] Decider [2.45] Decider [1.29]
8977917 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 3.17 Stamp Info	156.3PI.00.ANO3.J.i α: 352.302409 23h29m[illegible] δ: [illegible] S Elong: 136.65 Ecl β: [illegible]	[illegible]	[illegible]	N/A	N/A	0.10"	0.98	3	Decider [1.35] Decider [3.17] Decider [1.36]
8976055 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 3.02 Stamp Info	156.3PI.00.ASO1.J.i α: 357.266483 23h49m03.96s δ: [illegible] -14d19'26.27" S Elong: 130.38 Ecl β: [illegible]	1.690	148.3	N/A	N/A	0.09"	0.85	100	Decider [2.89] Decider [3.02] Decider [3.00]
8977655 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 4 ffuzz: 3.01 Stamp Info	156.3PI.00.ANO3.J.i α: 2.726264 0h10m54.30s δ: [illegible] 11d41'06.44" S Elong: 145.54 Ecl β: +10.22	0.164	-101.9	N/A	N/A	0.11"	1.00	4	Decider [3.01] Decider [1.28] Decider [1.26] Decider [1.92]
8978882 MPCheck Digest MOPS| MPC| OORB| All Detections MPC | DES	nfuzz: 3 ffuzz: 2.96 Stamp Info	156.3PI.00.ANO3.J.i α: 355.047412 23h40m11.38s δ: 16.548331 16d32'53.99" S Elong: 139.84 Ecl β: +16.38	0.375	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].99	22	Decider [1.13] Decider [1.69] Decider [2.96]

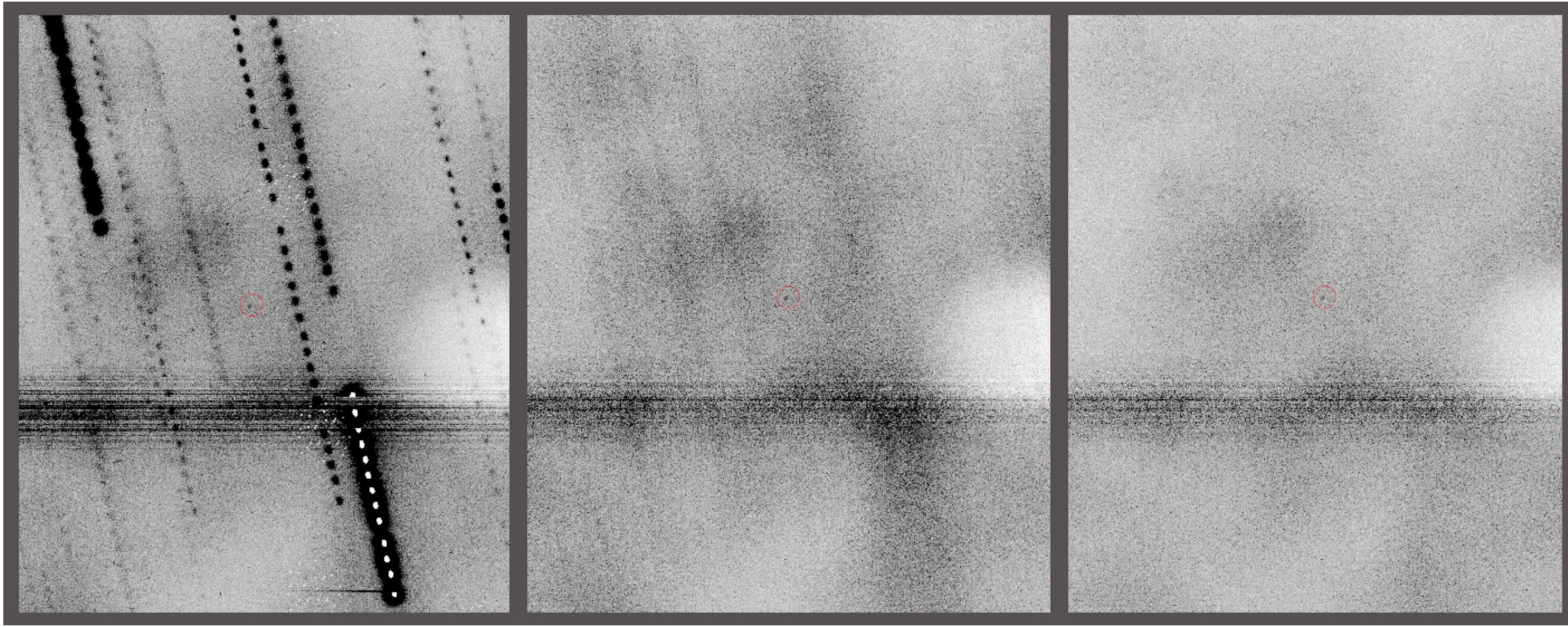
Advanced pipelines

- Detect transients
- Assemble tracklets
- Propagate to multi-night
- Evaluate results (final visual check)

We can find them

Pan-STARRS | MOPS | Denneau +13 PASP **125** 926

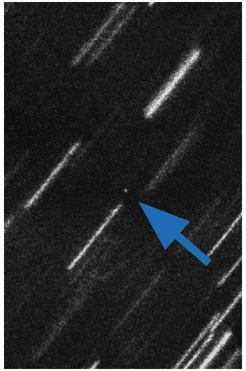
How? More advanced processing



Hainaut

Discovery

Comet 21P Sep.2018 | GL.Masi



2012TC4 | Hainaut Micheli

Active comets

vs

Inactive object

(~ same size, ~ same distance)

Challenge

How?

LSST

8.4m

3.5 sq.deg

3.2 Gpix

→ x10 - 100

Soon (~2021)

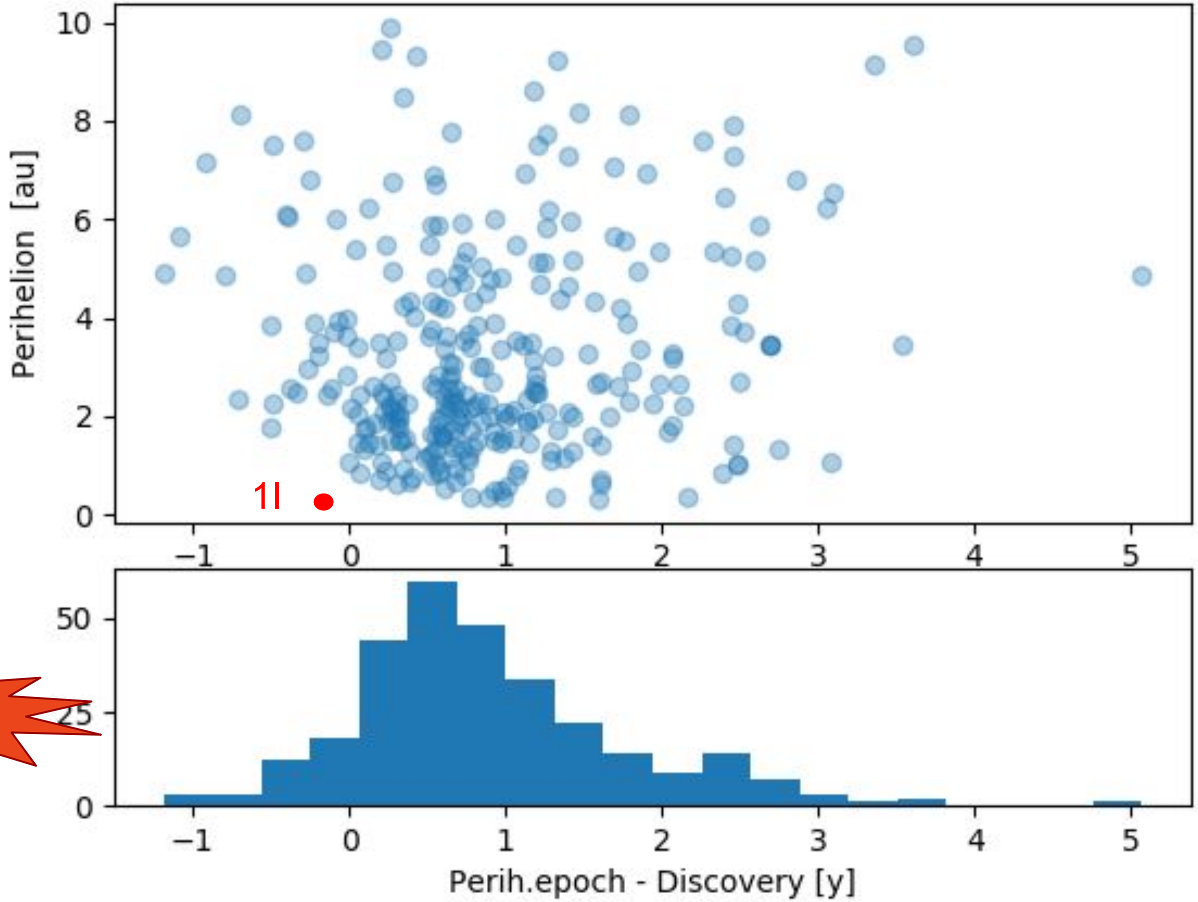
LSST

When?

Long Period Comet

Discovery vs Perihelion

How early is too late?



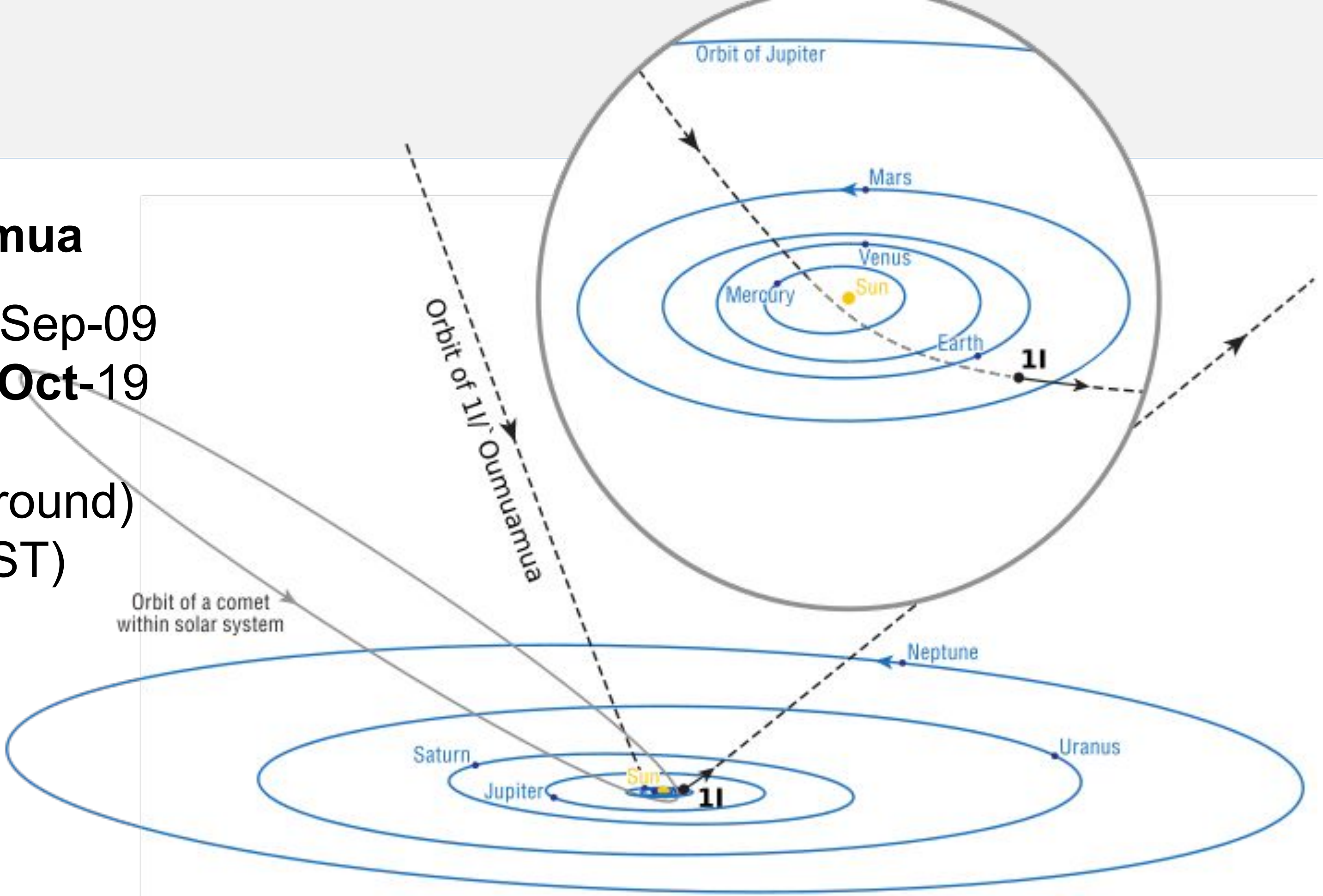
Challenge

Data from MPC, LPCs in 2010-2018

ISO: 1I/`Oumuamua

Perihelion: 2017-Sep-09
Discovery: 2017-**Oct**-19
Too faint after
  2017-**Nov** (ground)
  2018-Jan (HST)

⇒ fast response



Meech +17 Nature **552** 378 | Brooks Bays | SOEST Publication Services | UH Institute for Astronomy

How to Study them

Study them FAST

- **Normal telescope proposal**: year / semester cycles, **6-12m. in advance**
- **On-going proposal**, including LPC/ISOs: **instant response**
  - + Squeeze new object in program
  - - Can jeopardise the remainder of the program
- **Pre-approved Target of Opportunity**: normal proposal without target
  - + Ready to go, **instant response**
  - - Difficult to organize for very rare object (< 1/cycle)
- **Fast turnaround proposal:** 2-6w. in advance
  - + Can be tuned to target
  - - Too slow
- **Director Discretionary Time:** **1-4d** response time
  - Limited to very rare, exceptional objects
  - Limited to short/small projects

Study them fast! Where?

	Response	NOAO	KecK	ESO	HST
Normal proposal	6-18 months	yes	yes	yes	yes
Fast turnaround	4-6 weeks	@ Gemini	no	Soon (2019)	no
Pre-approved ToO	Instant!	Yes, esp. Gemini	Very limited (no queue)	OK - very few restrictions	Disruptive: 24-48h Non-disruptive: 13-25d
DDT	2-3 days	yes	some	yes	yes

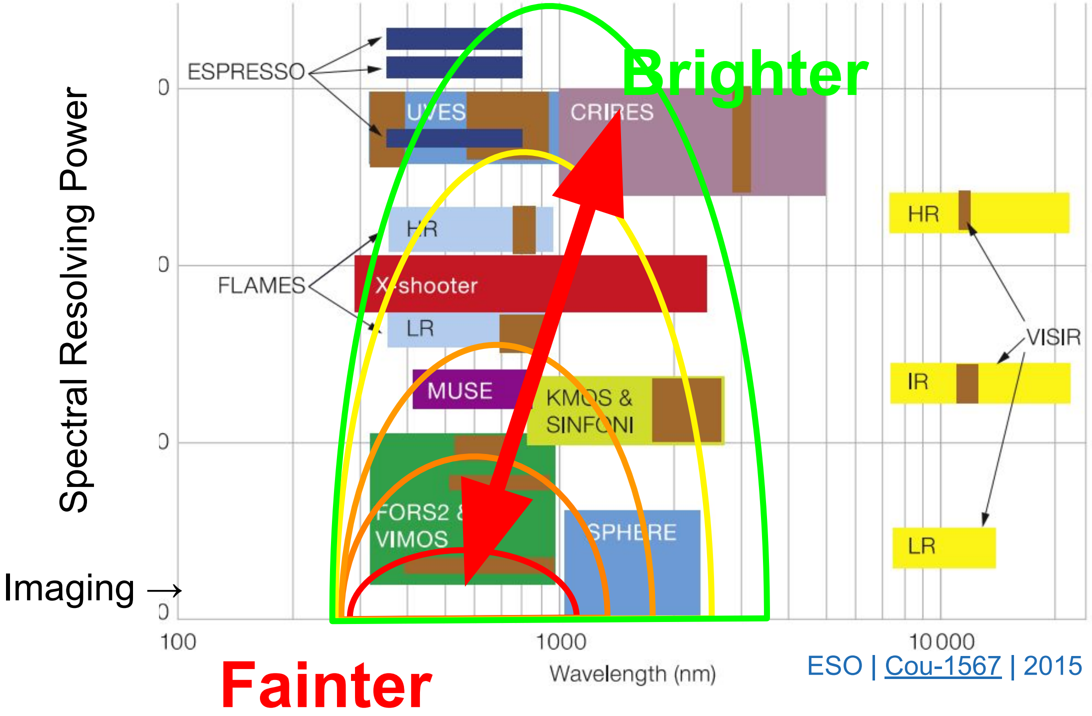
- Strong advantage for
  - ➢ the queue-driven telescopes (no visitor in the way...)
  - ➢ the multi-instrument facilities (easy change to the right instrument)

What?

Science requirements

vs

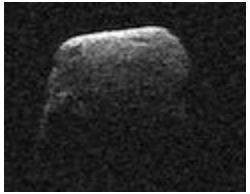
Instrument capabilities



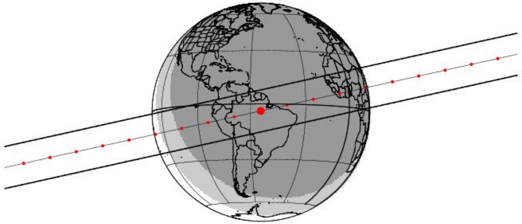
ESO | Cou-1567 | 2015

Orbit

- **Secure/refine the orbit** ⇐ Astrometry
  - For further observations (few arcsec)
  - To detect non-gravitational forces (few tens of arcsec)
  - To prepare space navigation (few hundredth of arcsec)
- How?
  - Imaging
    - Ground-based (including archive precovery mag ..26)
    - Space-based (HST, mag ..28)
  - Radar (strong constraints on size/distance and position)
  - Occultation (need very good orbit)



P/2016 BA14 | L. Benner | Echo | JPL | CalTech



Eris | M.Brown

Size (R)

- Visible Photometry:
  Assume albedo p (comet, primitive asteroids: 0.04, rocky: 0.2):
  $\text{Mag} = M_{sun} + 5 \log (r\,\Delta) + 2.5 \log (\mathbf{p}\,\mathbf{R}^2)$

  Visible alone: very good, easy, rough estimate (mag ..28)

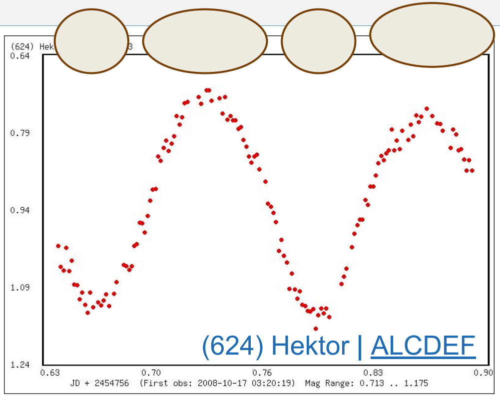
- Thermal IR: $F = \pi\,\mathbf{R}^2\,(\mathbf{1 - p}q)\,S_{sun} = \varepsilon\sigma\,T^4$ ← Lebofsky + 1986 *Icarus* **68** 239 (simplified for illustration)
  Requires big/bright object, fairly complex modelling
  Thermal IR + Visible: very good measurement

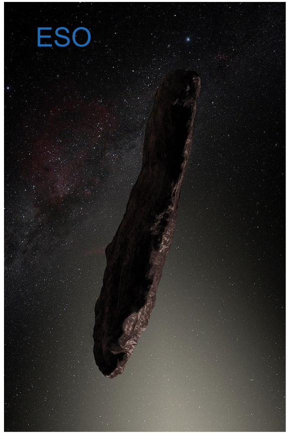
- Occultation
  Requires good orbit, work well for large object (>100km)

(462) Hippo | euraster.net

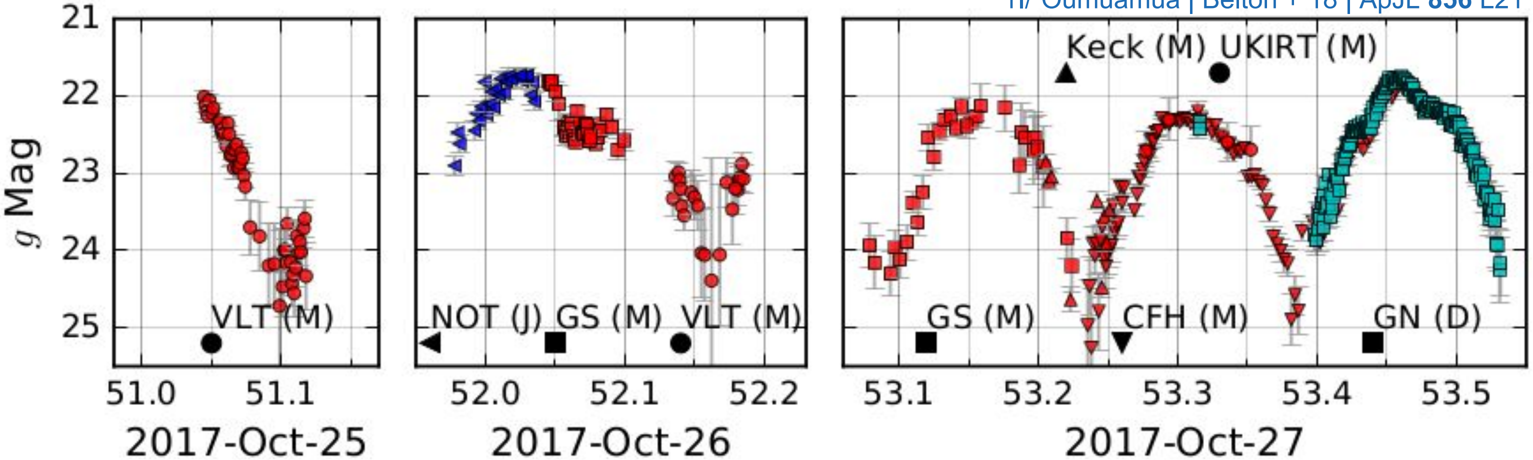
Rotation

- **Rotational light curve** ⇐ visible photometry
  - ➢ Rotation period // Rotation state
  - ➢ Some constraints on
    - Shape
    - density/cohesion
    - Pole orientation (needs coverage over the orbit)





1I/`Oumuamua | Belton + 18 | ApJL **856** L21

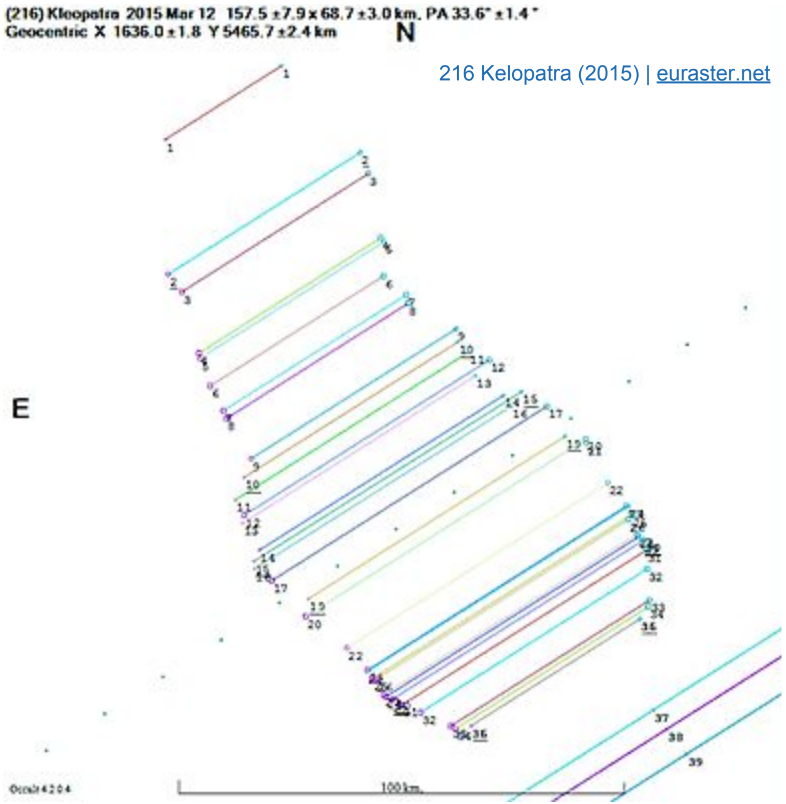


Shape

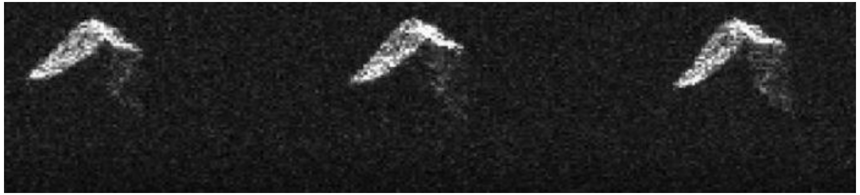
- Lightcurve (mag ..24) ⇒
  - ➢ Single → elongation
  - ➢ Multiple over various geometries → full 3D
- Occultation ⇒ 2D snapshot

  Requires
  - ⇐ good orbit
  - ⇐ Good star position (GAIA)
  - ⇐ Fairly large object
- Radar ⇒ 3D snapshot

  strong constraints on size/distance and position



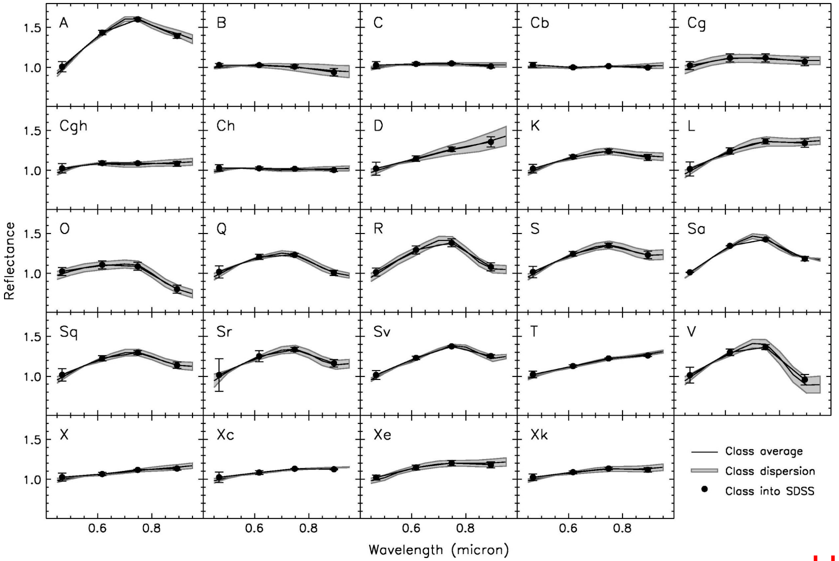
216 Kelopatra (2015) | euraster.net



2017BQ6 | Echo | NASA /JPL-CalTech/GSSR

Surface composition

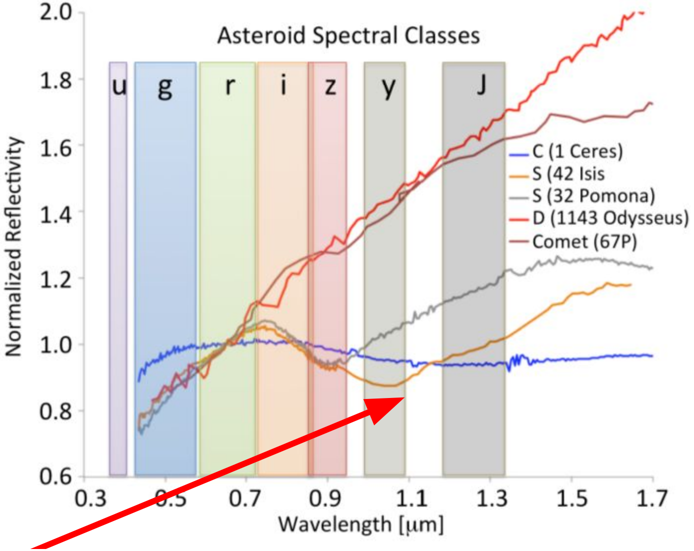
Proxy to **composition**
Taxonomic class via
Spectrophotometric reflectivity
Mag ..25



DeMeo & Carry 2013 *Icarus* **226** 723

Composition:

Reflectivity spectrum
Visible -- Near IR (Mag ..23)

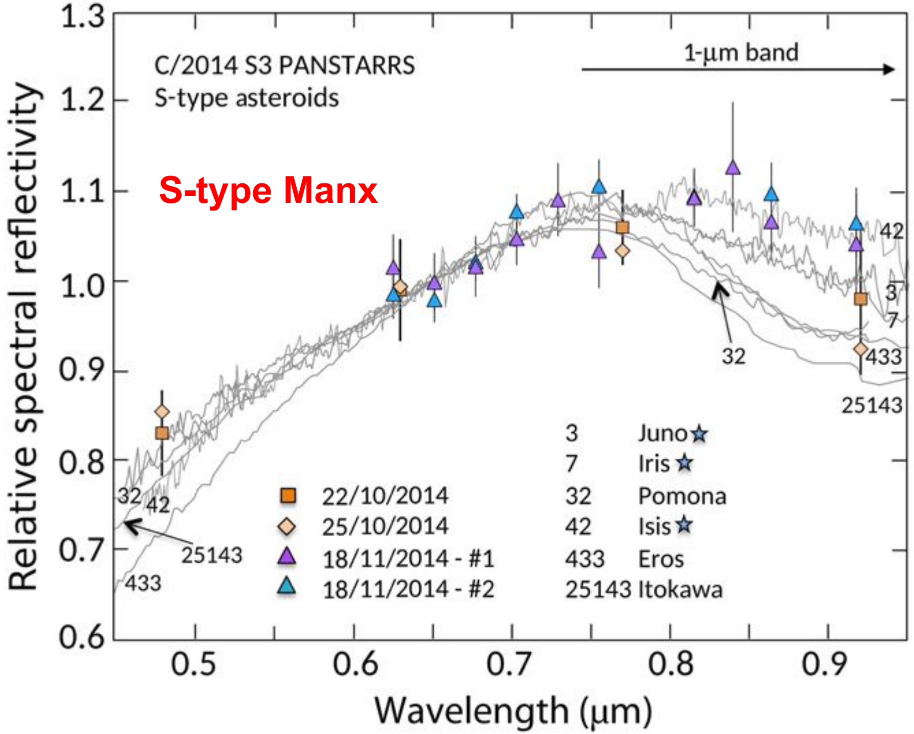


Highly diagnostic 1-1.5 micron region

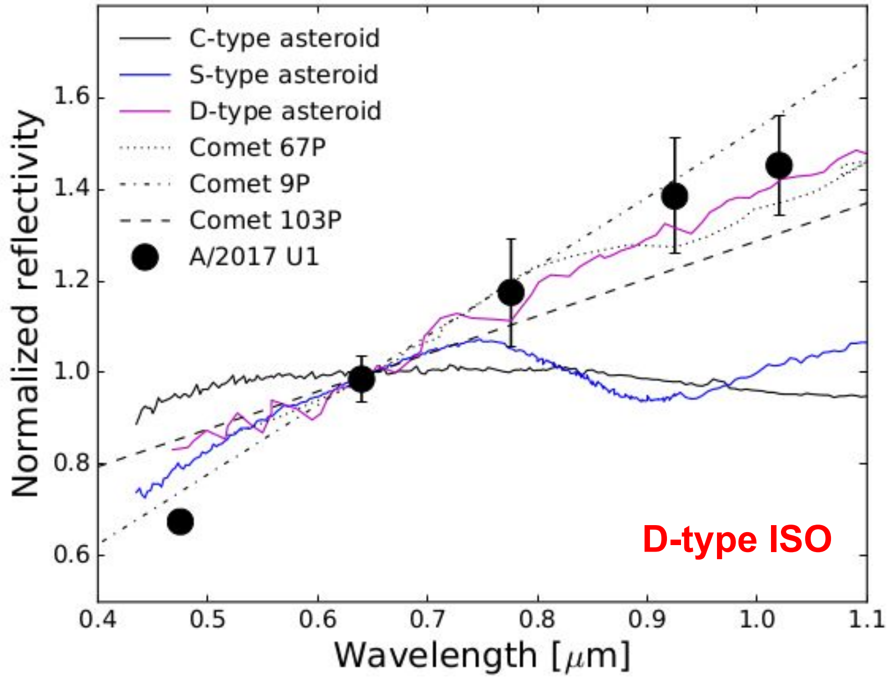
Meech priv.comm.

Surface composition

Examples...



Manx C/2014 S3 | Meech +16 | Science Adv **2** e160038



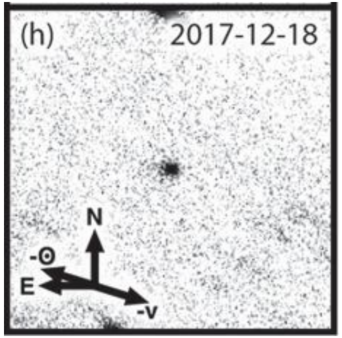
1I/`Oumuamua | Meech +17 Nature **552** 378

Cometary activity

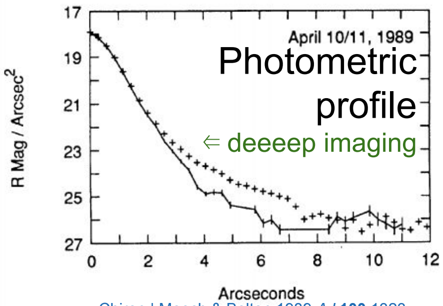
Bright, strongly active

21P | GL.Masi

Faintly active



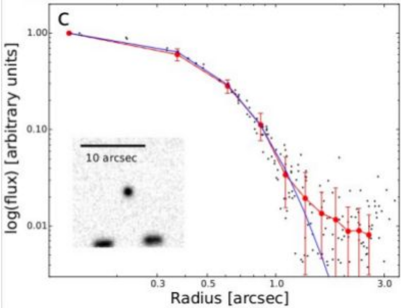
358P | Hsieh+ 2018 *AJ* **156** 39



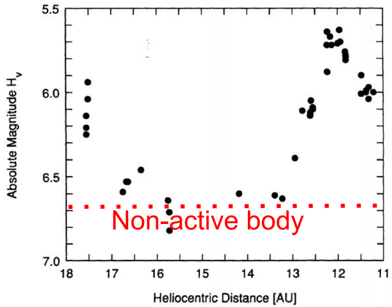
Photometric profile
⇐ deeeep imaging

Chiron | Meech & Belton 1989 *AJ* **100** 1323

Not active?



1I/`Oumuamua | Meech +17 Nature **552** 378



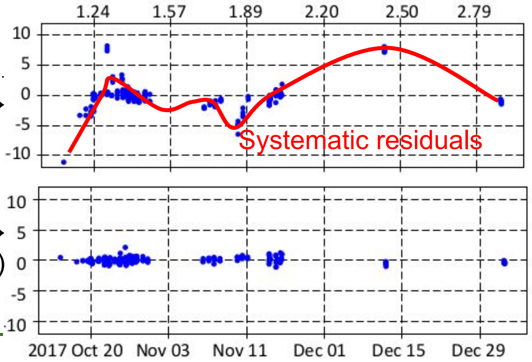
Chiron | Meech & Belton 1989 *AJ* **100** 1323

Heliocentric Lightcurve
⇐ long photometric monitoring

Orbit residuals:
Plain gravitational orbit →

With r^{-2} non-grav. →
(cometary activity)

⇐ long astrometric monit.

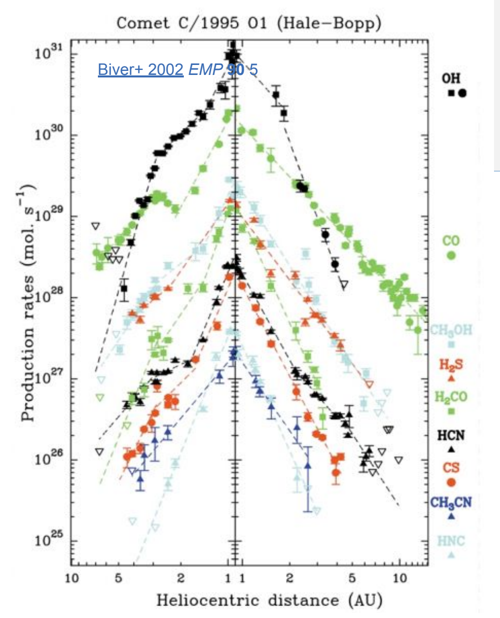


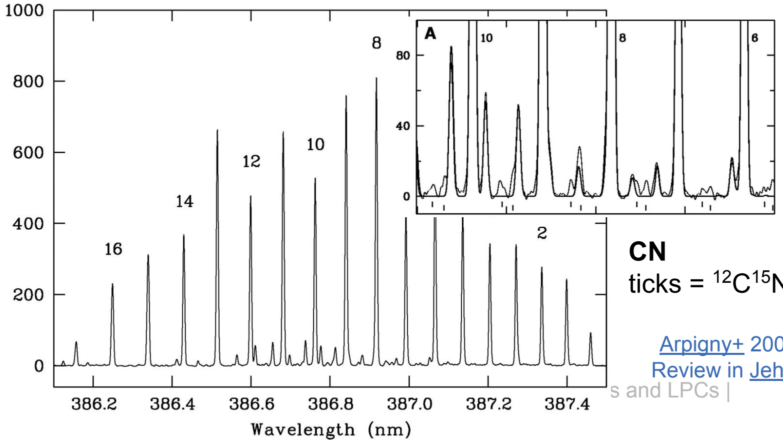
1I | Micheli+ 2018 *Nature* **559** 223

Interior composition

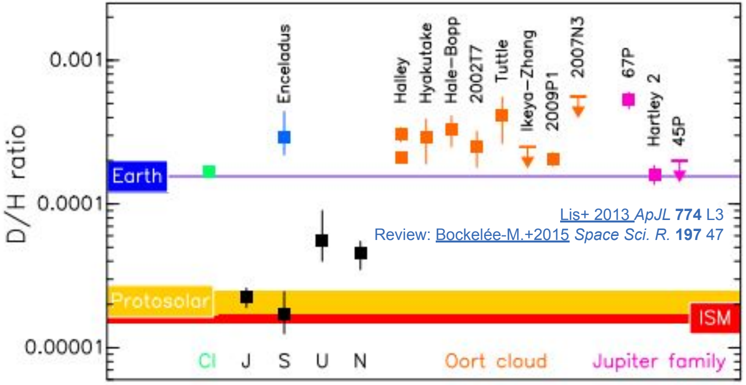
Cometary activity = sublimation of **ice from interior** (0..few m)
→ release of “mother” molecules → UV Photodissociation
→ Observed “Daughter” molecules ⇐ mm - radio, visible

Isotopic ratio ⇐ high-resolution spectroscopy (⇐ very bright)
→ D/H, $^{14}N/^{15}N$, $^{16}O/^{18}O$, $^{12}C/^{13}C$, and $^{32}S/^{34}S$
→ cosmogonical info.

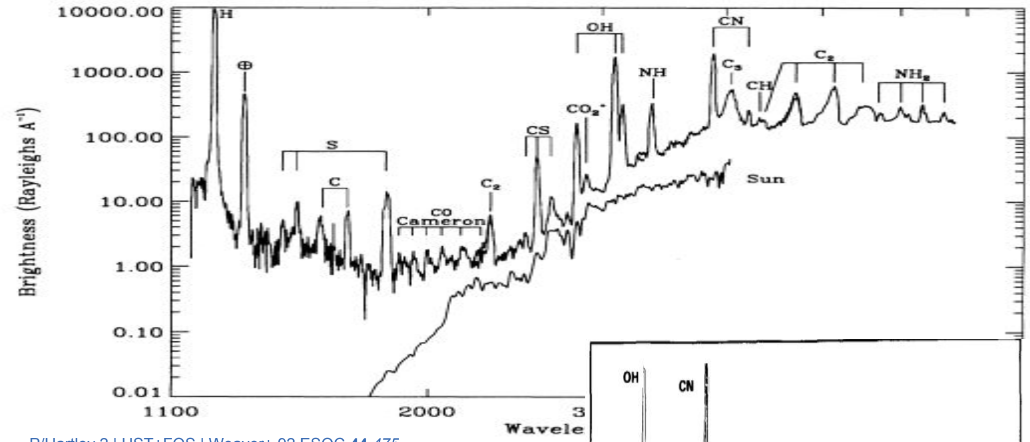




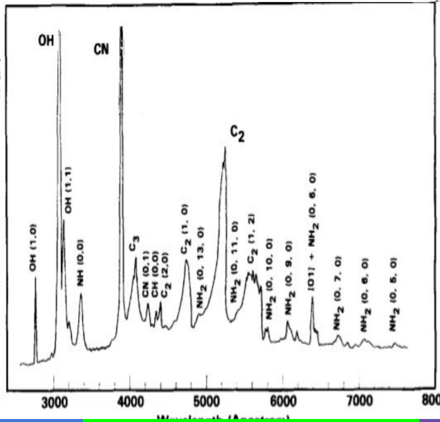
CN
ticks = $^{12}C^{15}N$, $^{13}C^{14}N$
C/2000 WM1
Arpigny+ 2003 *Science* **301** 1522
Review in Jehin+ 2009 *EM&P* **105** 167



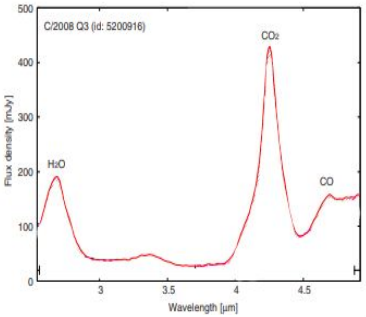
...help from space needed



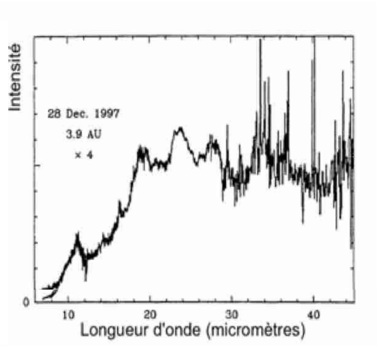
P/Hartley 2 | HST+FOS | Weaver+ 92 ESOC **44** *475*



C/1980XIII | Osborn+1990 *Icarus* **88** 228



C/2008Q3 | AKARI | Ootsubo+ 2012 *ApJ* **752** 15



C/1985O1 Hale-Bopp | ISO |
Crovisier+ 1999 ESASP **427** *147*

UV	Visible	IR

Dust Size Distribution

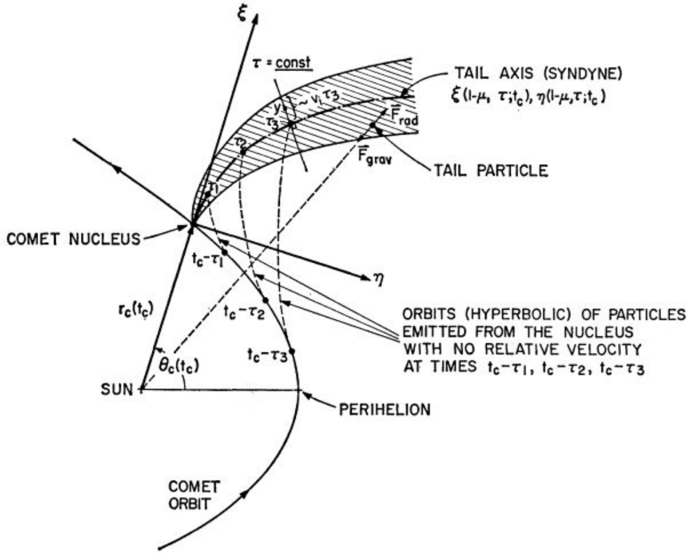
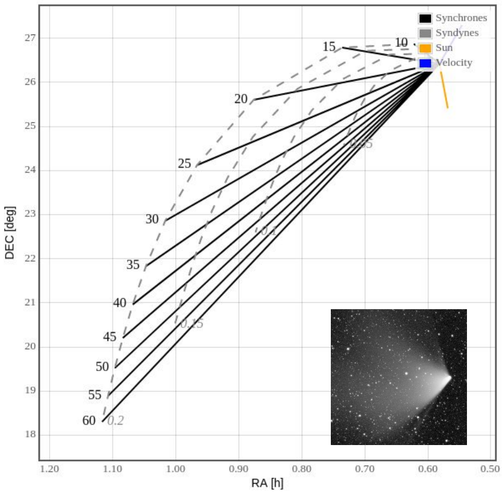


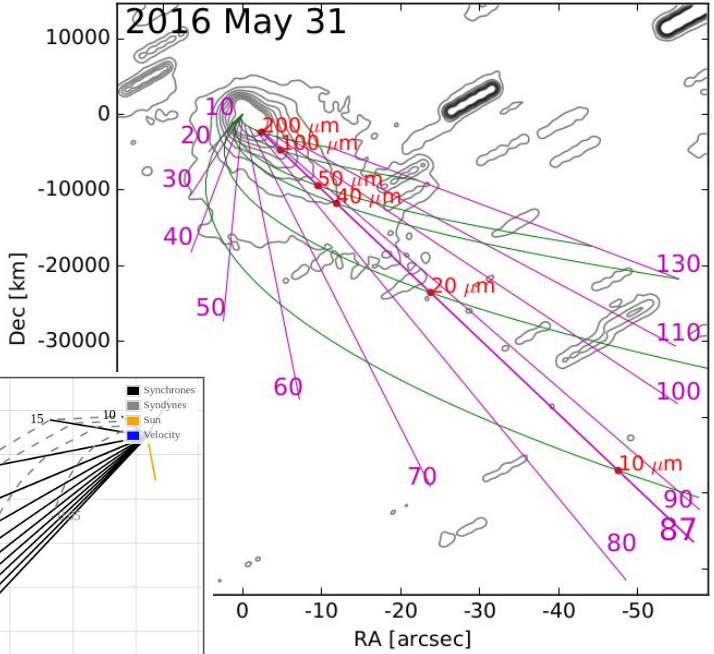
FIG. 1.—Comet tail and particle orbits

$\beta = F_{rad} / F_{grav} \rightarrow$ Synchrone + Syndyne curves

[Finson & Probstein 1968](#) *ApJ* **154**, 327
[Finson & Probstein 1968](#) *ApJ* **154**, 353



Kleyna | Priv.Comm.



comet-toolbox
www.comet-toolbox.com

Fantastic Targets: shopping list

- Discovery OK Surveys, LSST
- Orbit OK small + large telsc.
- Size ~OK (guess p, or with ThIr)
  - Shape ~OK (elongation)
- Rotation P: OK
  - Stable: Period, orientation
  - Unstable: characterized
- Surface
  - Albedo OK if Th.IR.
  - Composition
    - OK TaxoClass
    - HighRes Spectro/Radio

- Surroundings
  - Cometary activity OK deep Img.
    - Dust production rates
    - Dust size distribution
  - Satellites OK deep Img
- Mass, density no, need sat./SC
- Interior structure no

Summary

Manx, LPC, ISO:

Messengers from early solar system(s)

Achievements and assets

- We can discover them (with caveat)
- We can study them

Challenges

- Discover them early (including not active ones…)
- React fast to characterize them
  - (pre-approved programs ToOs, DDT)
- Be prepared to visit them
  - KISS workshop
  - Deal with huge Delta-v