Observing water in our Solar System

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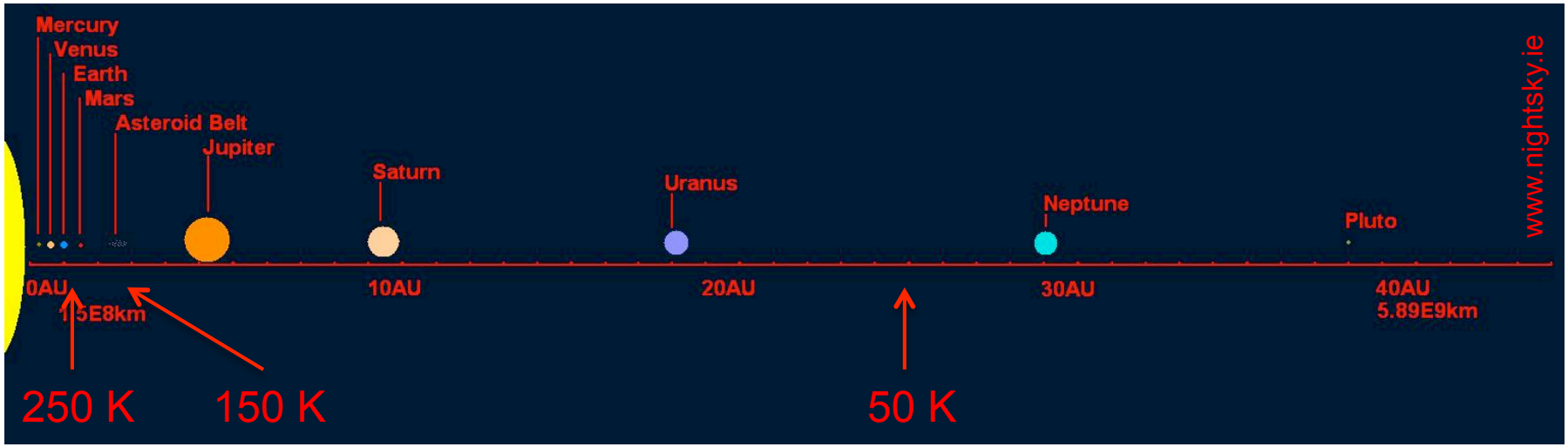
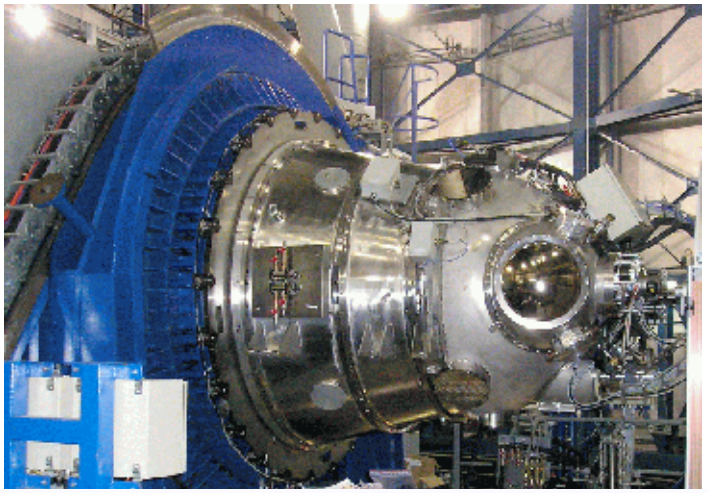
Ice in our Solar System

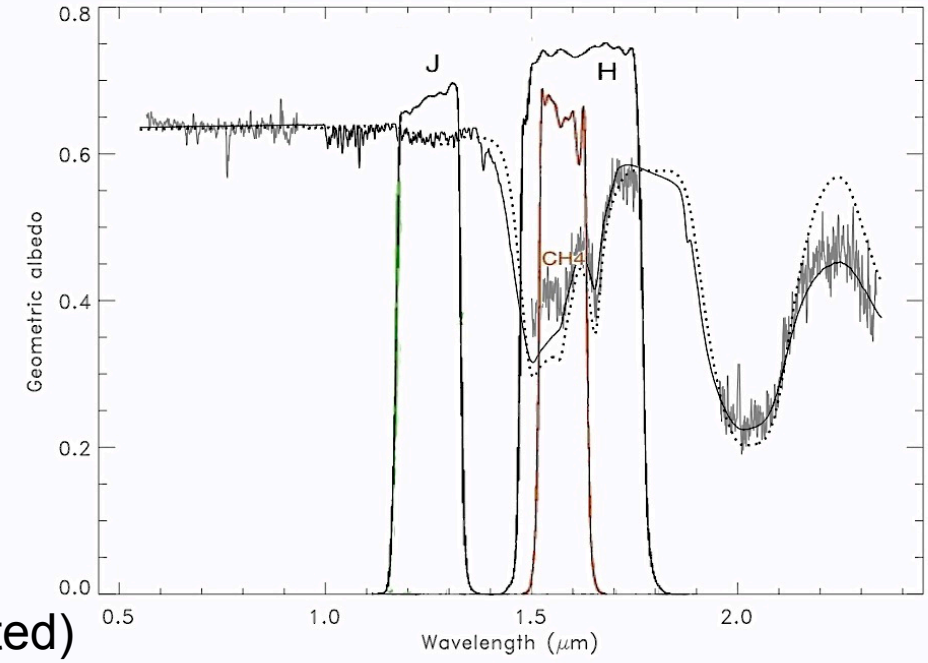


- Equilibrium temperature drops with distance ($d^{-1/2}$)
- Present day snow line is at ~2.7 AU from Sun, in asteroid belt.
- Ice exists on surfaces in Kuiper Belt.
- In inner solar system, sublimation drives cometary activity.

Kuiper Belt Objects – Haumea

- Spectroscopy of KBOs, particularly in the NIR, reveals differences in their surface ices.
- Haumea 'family' have spectra that match almost pure water ice.
- Remains from a collision.
- We used the VLT+Hawk-I to identify ices on potential family members using photometry.





Snodgrass et al 2010, Carry et al (submitted)

Further Family Members

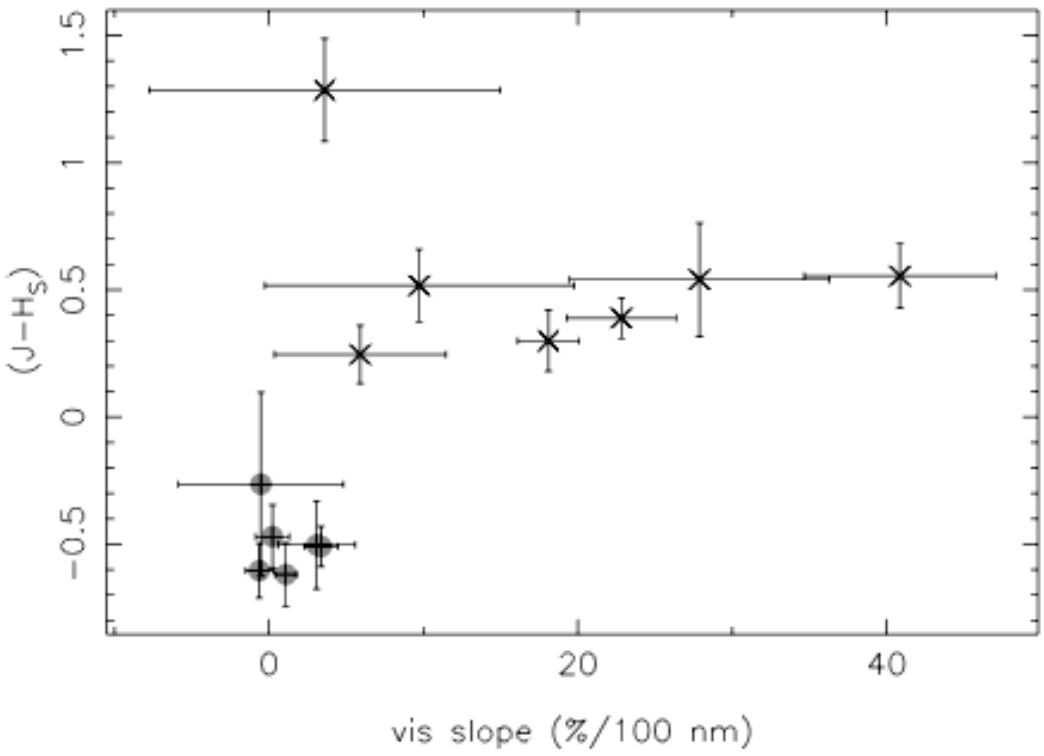
- Ragozzine & Brown (2007, AJ 134, p2160) published a list of further family member candidates selected on dynamical grounds.
- The orbits in the TN region (and interactions with resonances) make this difficult to do.
- Need to confirm that they share the same water ice surface to be true family members.
- However, most are too faint for the NIR spectroscopy that can unambiguously detect water ice.

Water Ice Detection

- We use HAWK-I at the VLT to perform J and CH_4 band photometry, using the CH_4 band as a narrower H band.
- We confirm that our measurements of ($J-H_s$) are sensitive to water ice.
- We measured this colour for 18 objects.
- 6 are objects previously claimed as family members - they have strongly negative ($J-H_s$).
- 2 other objects are confirmed as family members, 2003 SQ_{317} and 2005 CB_{79}.
- The remaining 10 (including non-candidate Eris, observed for comparison) have positive values and we rule out water ice surfaces.

Optical colours

- Comparison with visual colours from NTT (EFOSC2) observations.
- Those objects with water ice also have flat visible spectra.
- Very red colours (large slope) rule out strong water ice.
- Blue colours do not necessarily imply ice.

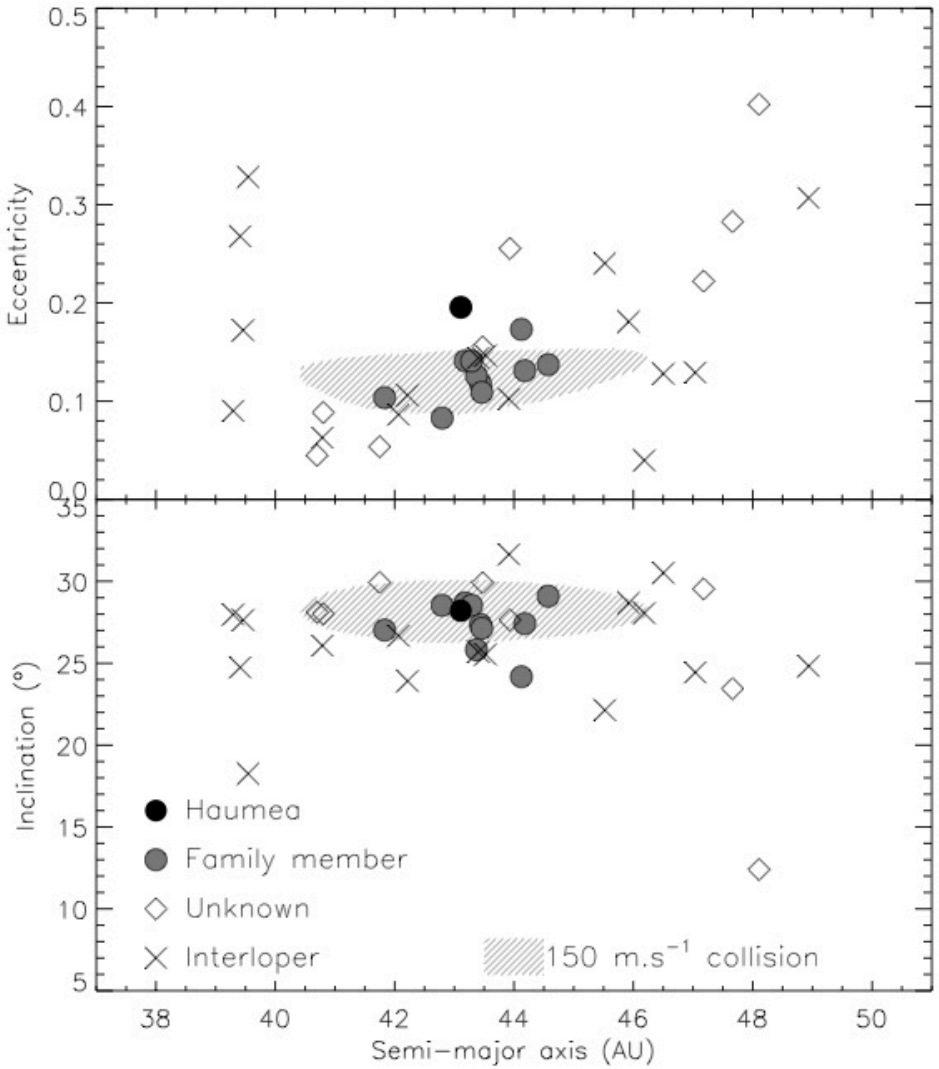


Family Members?

- We can confirm membership of only 2 more of the candidates, and rule out 7 using NIR photometry.
  - 2003 SQ_{317}, 2005 CB_{79} confirmed
- Of those where we only have optical photometry, 5 more have steep spectral gradients and are inconsistent with water ice.
- Of the 36 candidates selected dynamically, it seems that a large proportion do not match the criteria of matching surface properties to be considered family members.
  - 11 confirmed (31%)
  - 17 rejected (47%)

Orbital element space

- Confirmed family members all near centre of distribution.
- Implies family is real.
- Rejected candidates everywhere.
  - It is necessary to get physical properties to confirm any object is really a family member.
- All members have low velocities (<150 m/s).
  - Collisional fragments expected with ~1000 m/s.



Real collisional family?

For

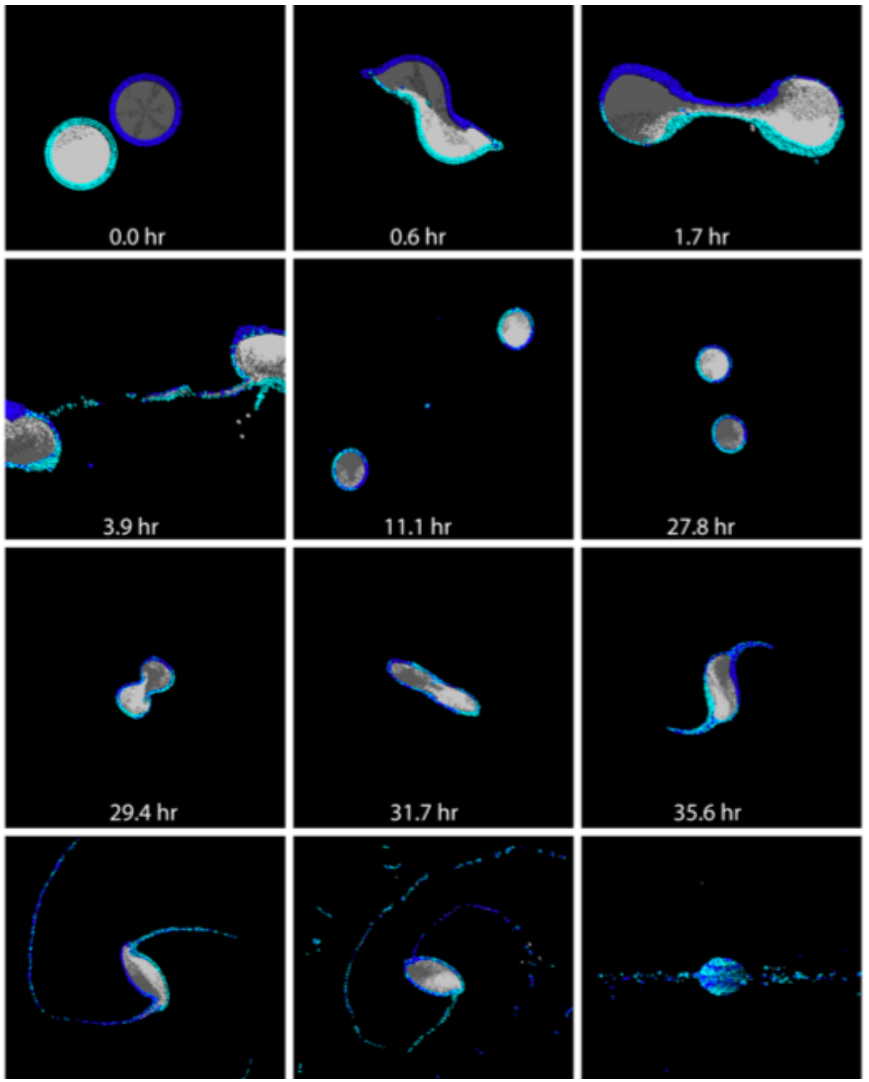
- Clustering suggests this is a real family.
- 'Pure' water ice objects not seen anywhere else
  - Trujillo et al Gemini survey
  - Fraser & Brown HST survey

Against

- Velocity dispersion much lower than expected.
- Mass in fragments only ~1% of Haumea.
- Collision in Kuiper belt unlikely.

Graze and merge

- Leinhardt, Marcus & Stewart (2010) suggest a 'graze and merge' collision.
- Explains lower velocities, forms satellites and family.
- Predicts original population ~7% of proto-Haumea mass.

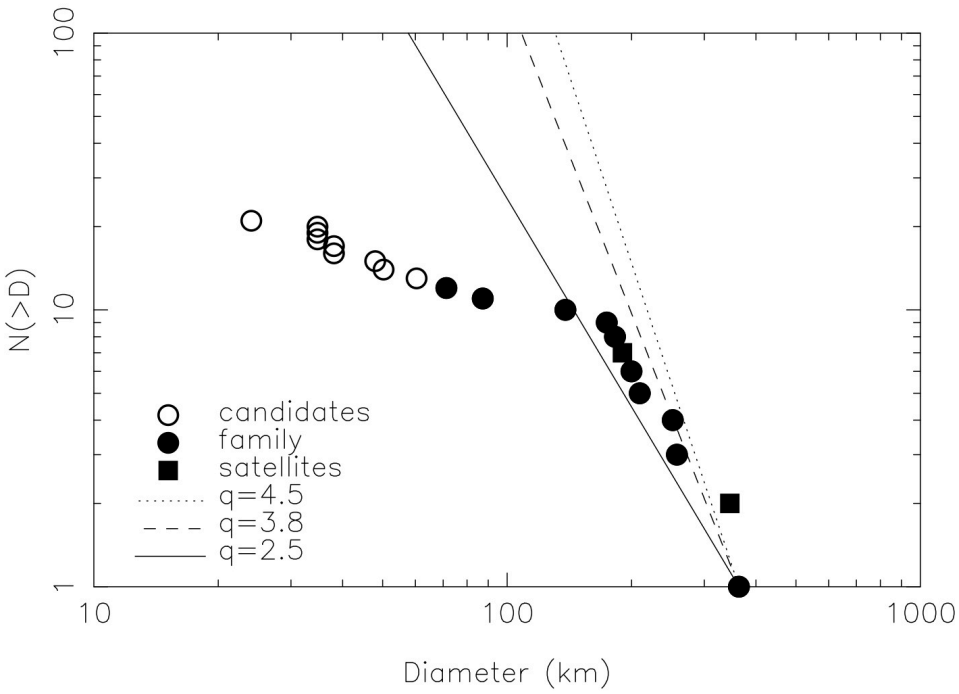


“Black sheep”

- Cook, Desch & Rubin (2011) suggest that collision could also produce non-icy fragments.
- Means water ice criteria too restrictive for finding family members.
- Difficult to tell true family from interlopers in this case.
- If all ‘candidates’ actually members, total mass too high (> Haumea).
- Where do fragments from mantle / crust go?
- Differentiation of pre-collision body into multiple layers?

Missing mass?

- Possibly there are more icy fragments to find.
- If steep size distribution, some D ~300 km bodies still to be found, can get reasonable fraction of Haumea with only icy bodies.
- If shallow, next biggest ones to find have D ~140 km, but most of mass already known, and black sheep required.



Inner solar system

- Ice not stable on surfaces
- Sublimation drives comet activity
- Interesting recent results suggest that water ice exists buried in the asteroid belt (MBCs).
- Direct detection required!

Ice in the asteroid belt

- P/2010 A2 and Scheila were shown to be the result of collisions.
- Why do other MBCs have to be 'real' comets?

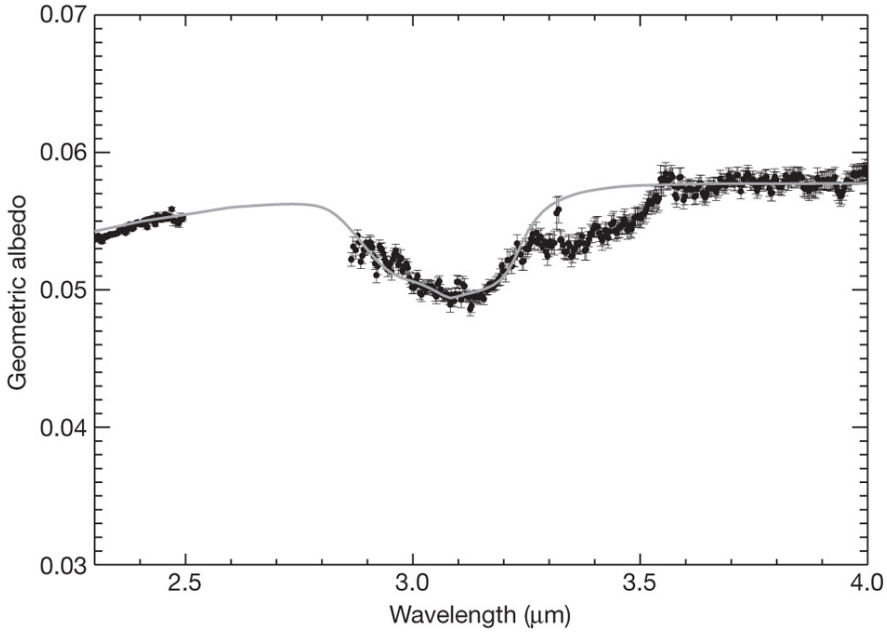
- They are more likely sublimation driven as they show repeated activity, at the same point in their orbit.
- So far, two MBCs have been seen to have repeating activity: 133P/Elst-Pizarro and 238P/Read.
- Others are expected to repeat, but have not been known long enough to complete an orbit (5-6 years).

Ice in the asteroid belt

- So far, the presence of ice in MBCs is inferred, as sublimation driven activity is the most reasonable explanation for the observed dust tails.
- There have been no direct detections of gas (from the sublimation of ice) in their comae.
- Limits placed on the water production rate based on non-detections of CN, and assumption of JFC-like CN/H_2O ratio.
- Newer physical models suggest that only H_2O ice will be present, no more volatile ices (so no CN gas expected).
- Need direct detection of OH.

Ice in the asteroid belt

- Campins et al. and Rivkin & Emery claimed detection of water ice frost on asteroid 24 Themis in 2010.
- Based on weak absorption at 3.1 micron.
- No absorption features seen at 1.6 micron, or other major water ice bands.
- We have data from VLT on more large C-types.



NACO programme

- L-band grism spectroscopy with NACO.
- AO assisted (asteroids bright enough to use as natural guide stars).
- Combined with H+K spectra from IRTF, or NACO H+K.
- Observations of Themis, Themis family members, and other large C-types.
  1. Ice is found on Themis only – unique asteroid (late delivery, or found only in largest fragments of collisions)
  2. Ice is found in family, not others – revealed by collision.
  3. Ice is found everywhere – can expect all C-types to have some ice.

Targets

Object	Wavelength	Category
24 Themis	L	Themis family
10 Hygiea	L	control
21 Lutetia	H+K, L	control, Rosetta target
48 Doris	L	control
52 Europa	L	control
90 Antiope	L	Themis family
95 Arethusa	H+K, L	control
104 Klymene	H+K, L	Themis family
120 Lachesis	H+K, L	control
171 Ophelia	L	Themis Family

Meanwhile

- Beck et al suggest mineral Goethite as alternative explanation of the feature.
- Rivkin et al find similar feature on 21 Lutetia, but only southern hemisphere (which Rosetta didn't see).
- Licandro et al find it on 65 Cybele (outer asteroid belt object, could come from further away?)
- Jewitt & Guilbert-Lepoutre publish limits on gas sublimating from any ice (assuming CN & water ratios are comet like) on Themis & Cybele.

Summary

- Direct observations of water ice in Kuiper belt are used to identify Haumea family members.
  - Family formation is still a puzzle, that will tell us about the early history of planetesimals in outer solar system.
- Indirect inference of the presence of water in the outer asteroid belt, from comet-like activity.
  - Important constraints on past/present snow line, but direct detection of water the next big challenge.
- Claimed direct detection of water ice on surface of large asteroids.
  - Remains controversial, ongoing project to search for signatures on other large asteroids.