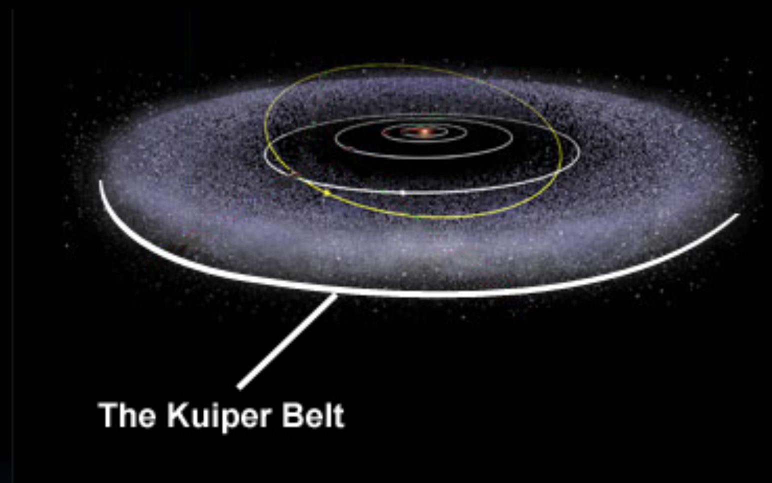
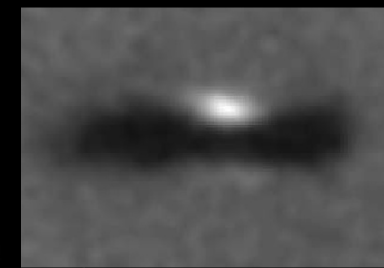
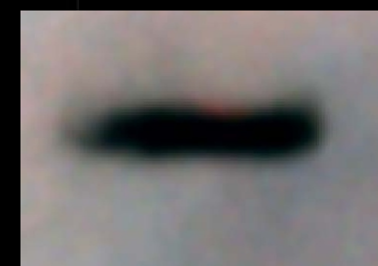
Herschel's view on the cool TNOs





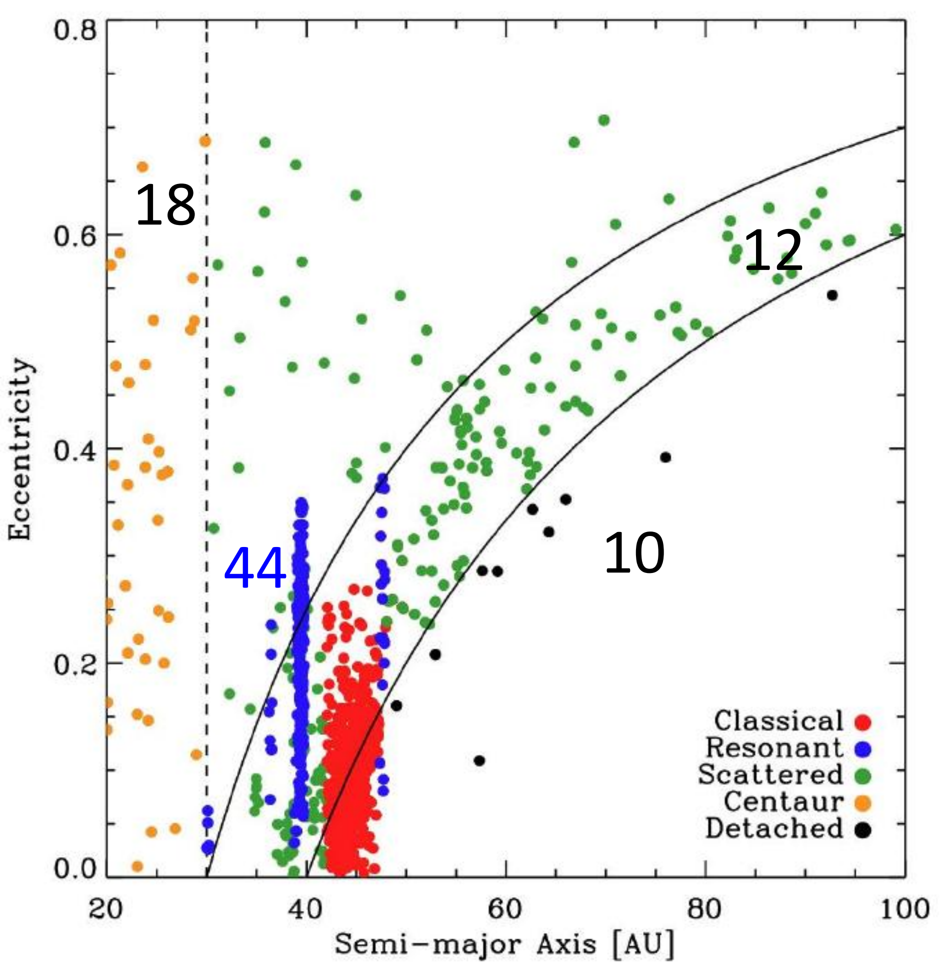
Edge-On Disks in Orion (HST)

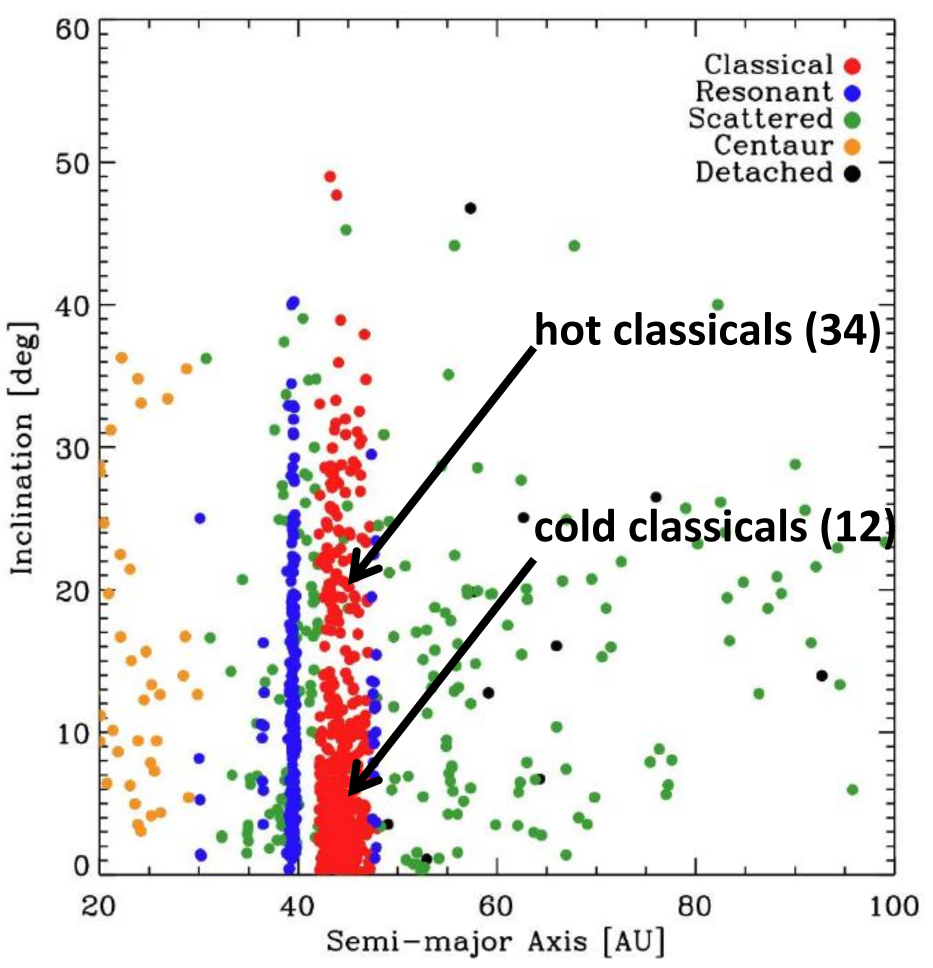


McCaughrean & O'Dell 1995

Thomas Müller (MPE Garching)
& the "TNOs are Cool" KP team

The trans-Neptunian Region & "TNOs are Cool" Sample

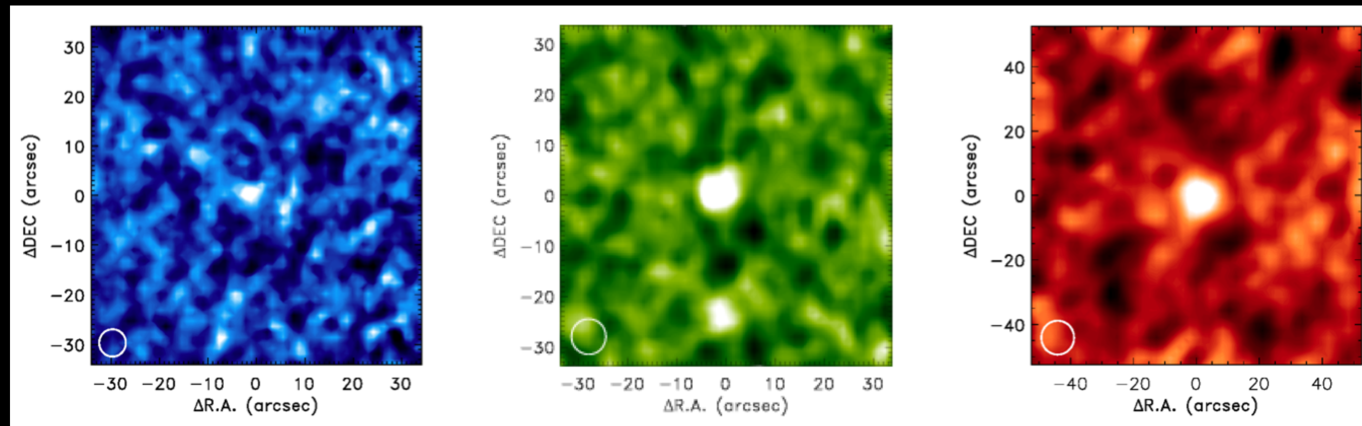


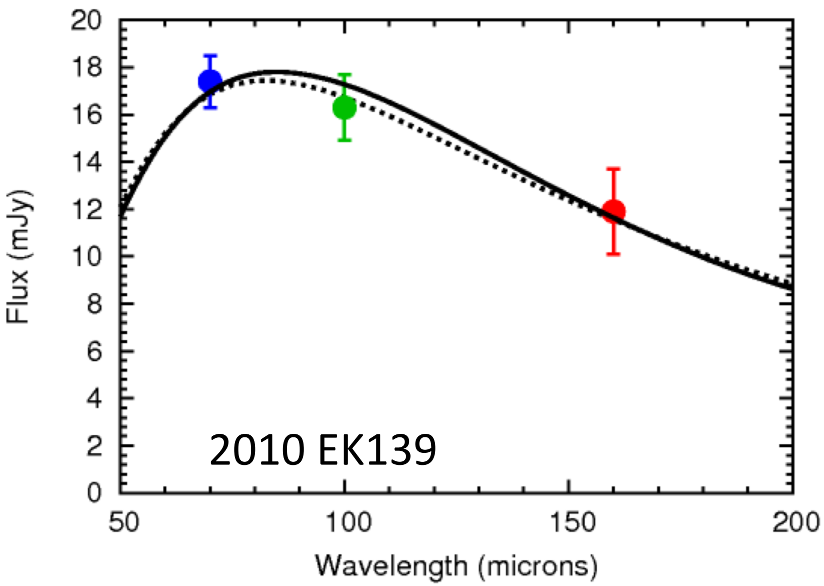


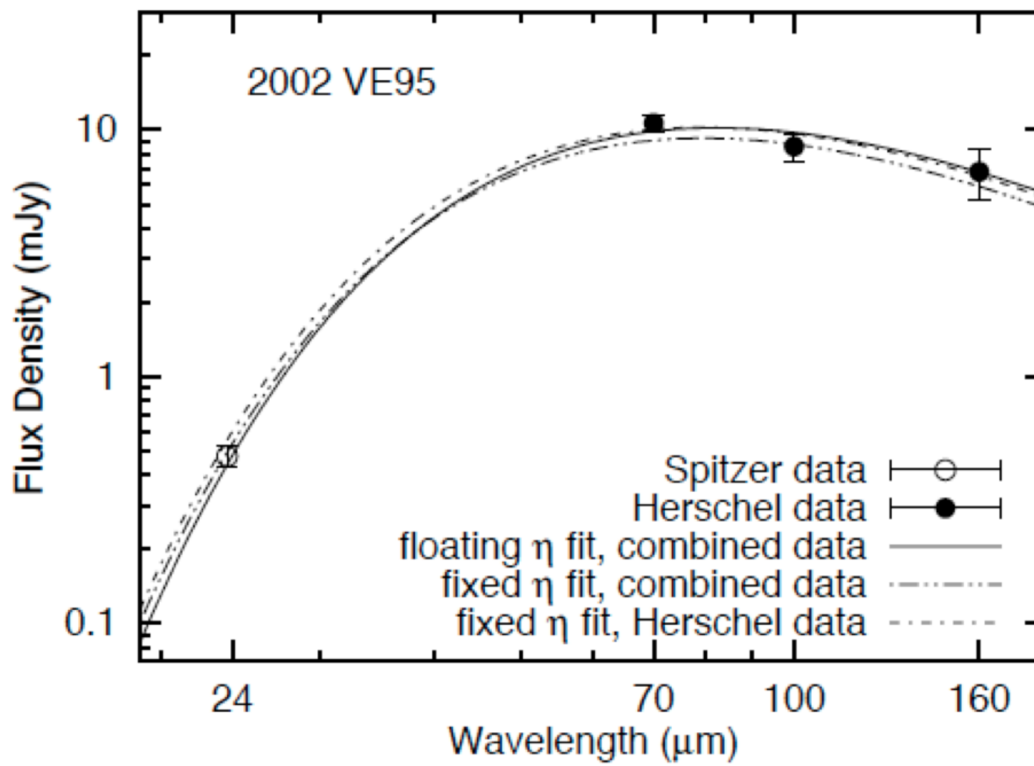
Jewitt et al. 2008

Fundamental Properties: Size & Albedos

130 TNO/Centaurs
>90% detections
with Herschel,
partially detected
by Spitzer



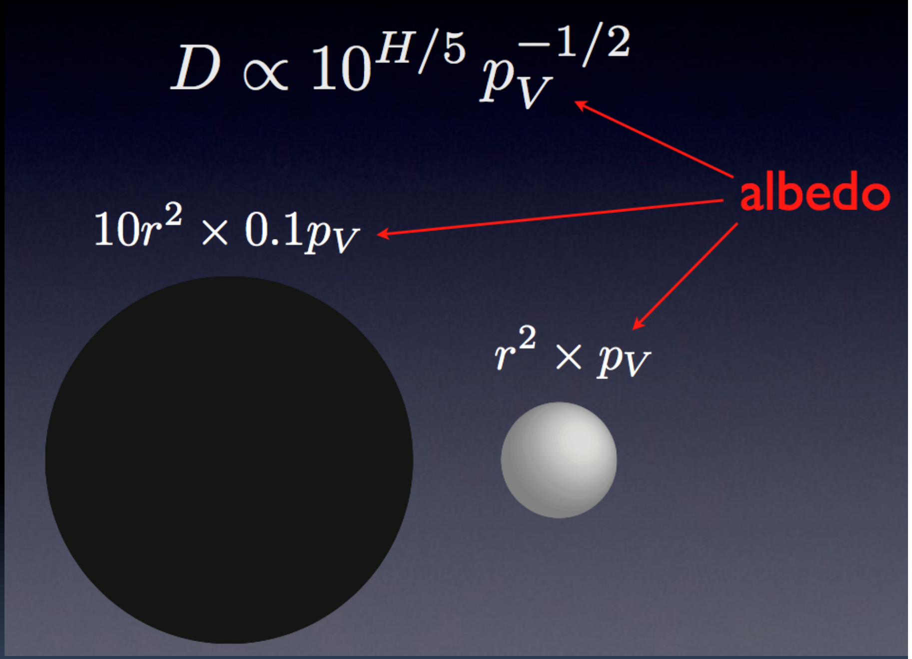


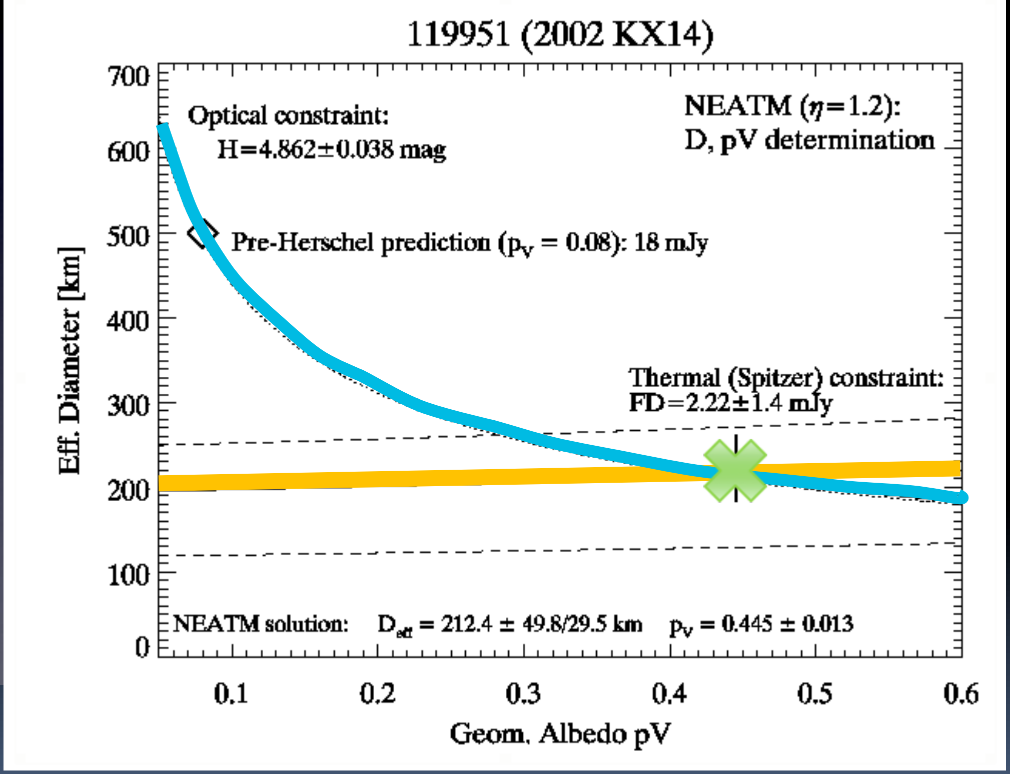


Different thermal models

Fundamental Properties: Size & Albedos

- groundbased support to characterize the reflected light
- careful determination of error bars
- well-established (and calibrated) model setups

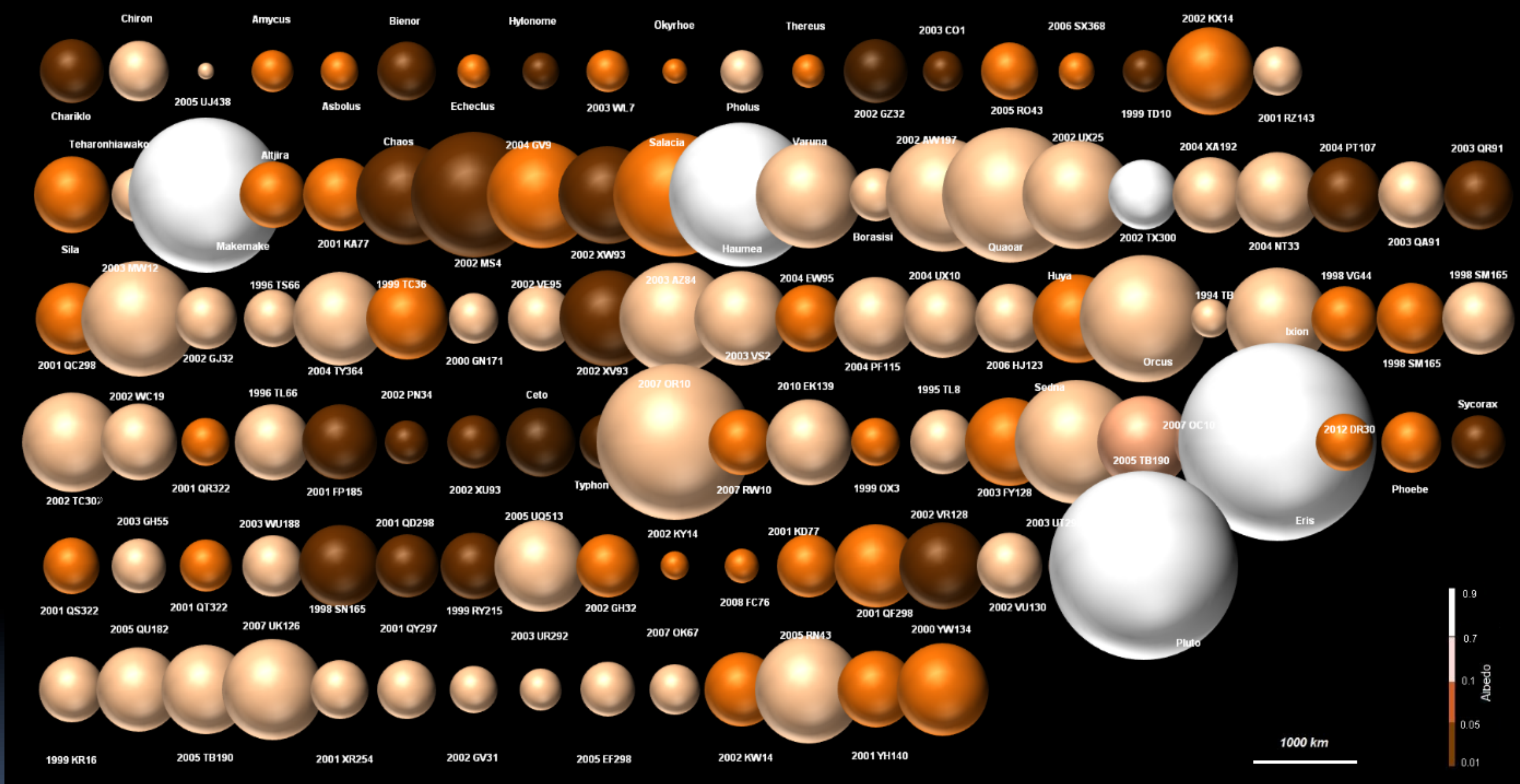




Radiometric method:

- solving for size & albedo
- reflected light: absolute magnitude H
- thermal emission: as measured by (Spitzer)/Herschel

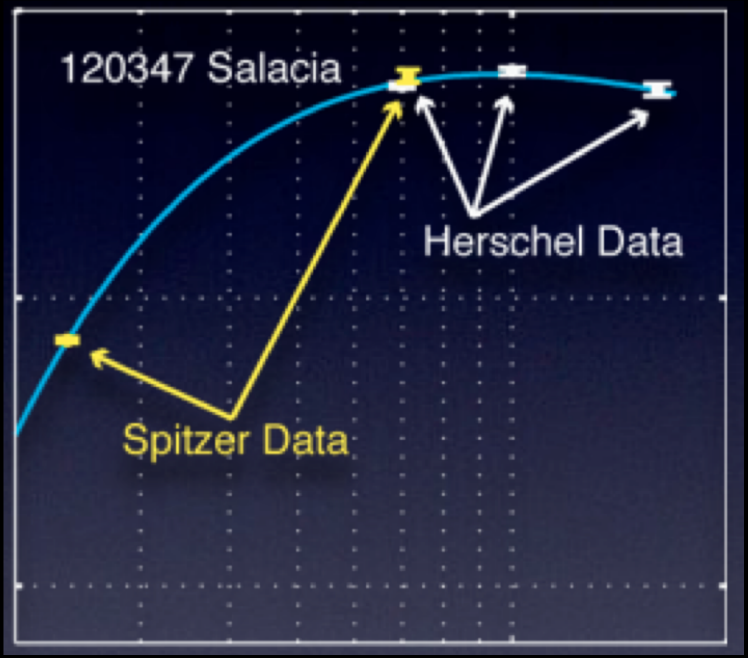
Fundamental Properties: Size & Albedos

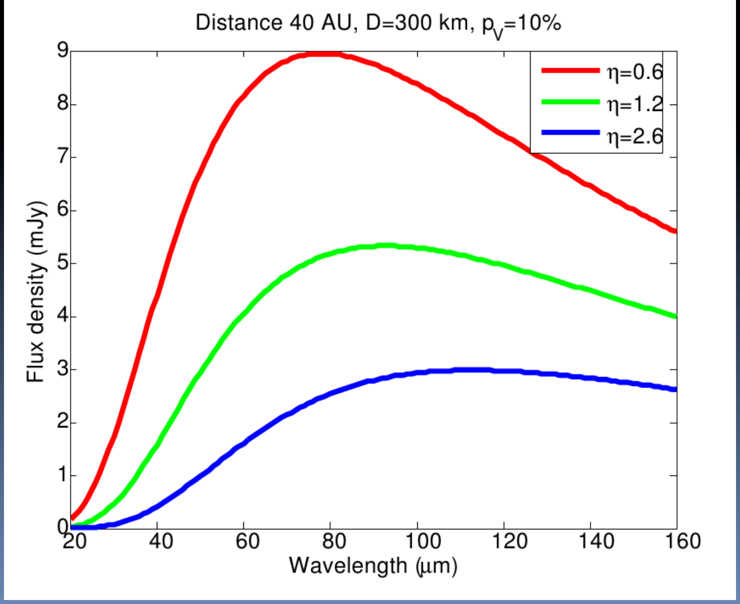


Müller et al. 2010, Lellouch et al. 2010, Lim et al. 2010
Mommert et al. 2012, Vilenius et al. 2012, Santos-Sanz et al. 2012
Fornasier et al. 2013, Duffard et al. 2013, Vilenius et al. 2013

Thermal properties of Centaurs/TNOs

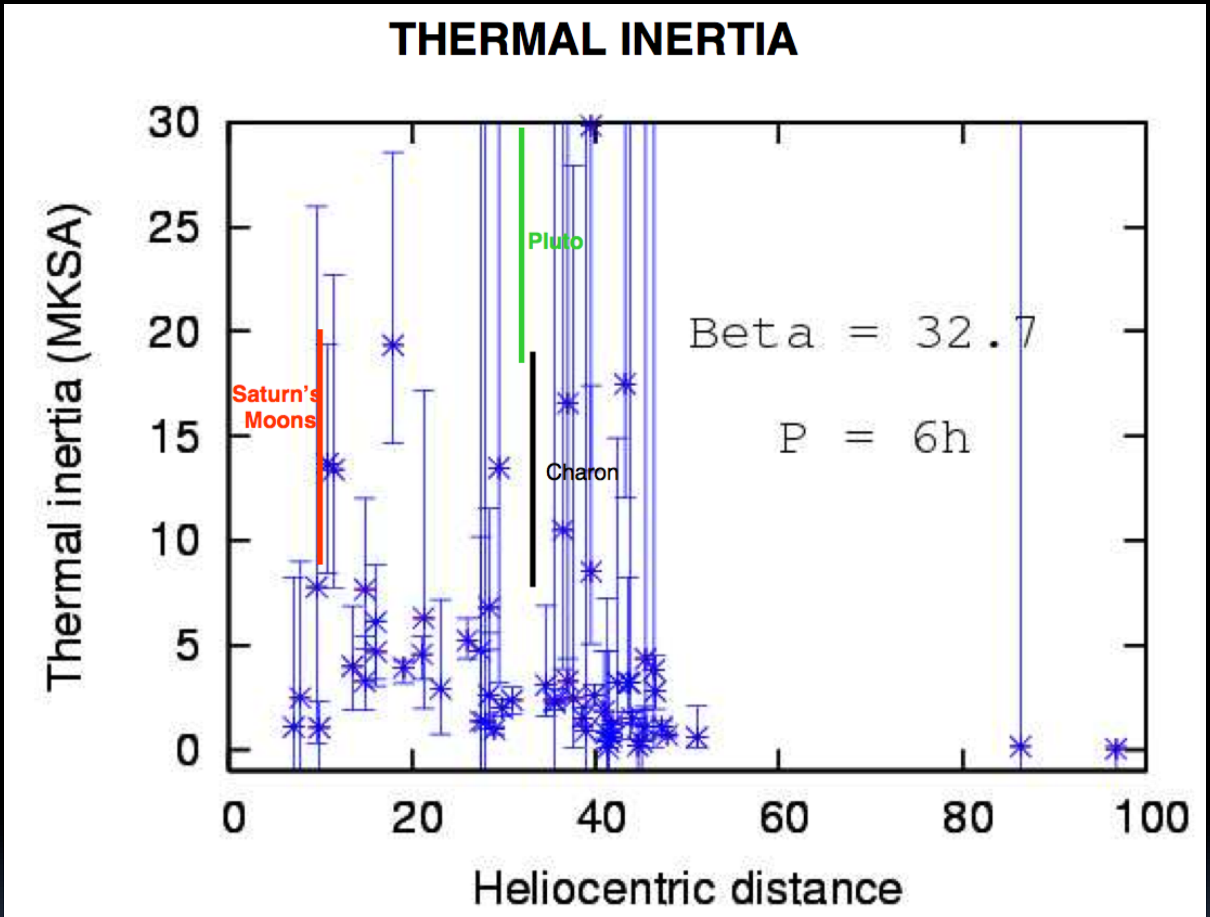
- Surface temperature distributions are derived from multi-band Herschel (+ Spitzer) thermal measurements (30-100K; insolation: 0.1 - 3 W/m²)
- Shape of thermal SED is characterized by the beaming parameter η
- The temperature distributions (η) include the combined effects of thermal inertia Γ, rotational properties, and surface roughness
- thermal inertia Γ can be derived via statistical spin properties





Thermal properties of Centaurs/TNOs

- Mean thermal inertia is 2.5 ± 0.5 $Jm^{-2}s^{-1/2}K^{-1}$
- only rough surfaces can explain the SED
- Γ-values are 2-3 orders lower than for compact ices and smaller than on Saturn's icy satellites or in the Pluto/ Charon system



- Most high-albedo objects are found to have unusually low Γs
- The results suggest extremely porous surfaces, significantly affected by radiative effects within pores (based on the decrease of Γ with heliocentric distance)

Lellouch et al. 2013 + Poster P97

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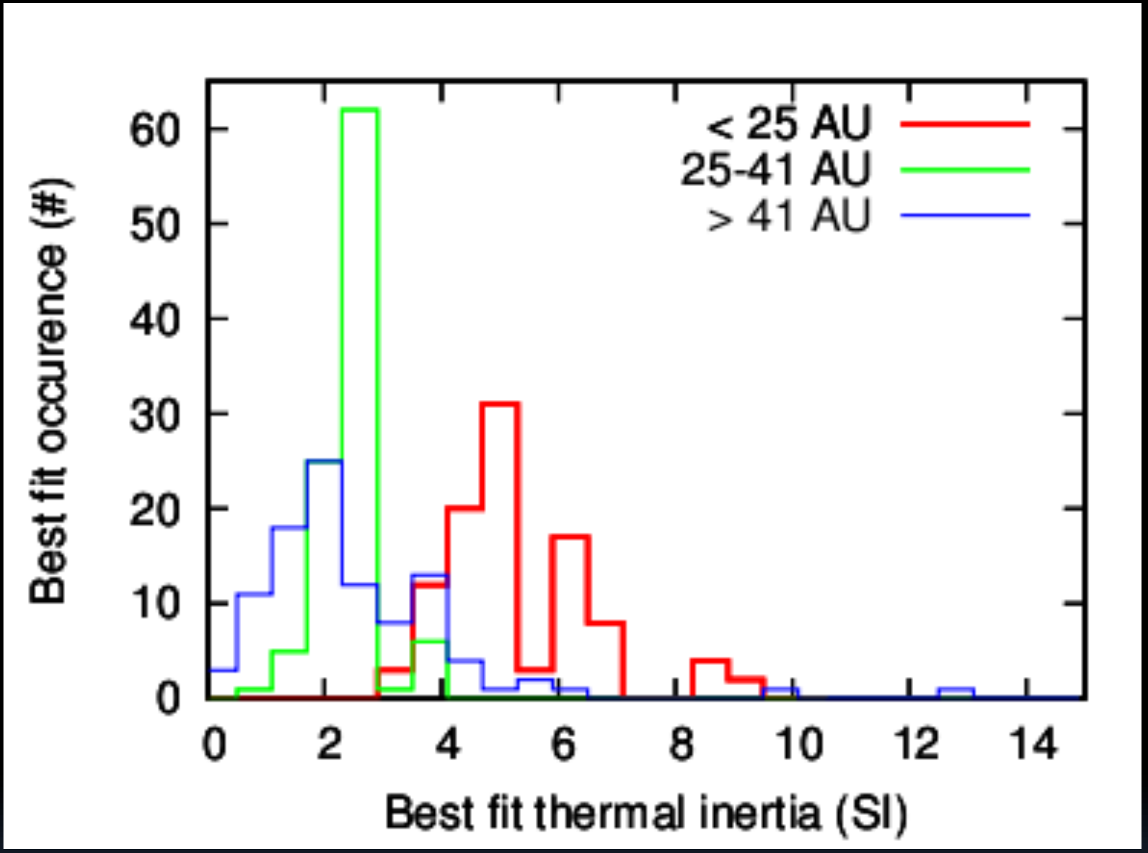

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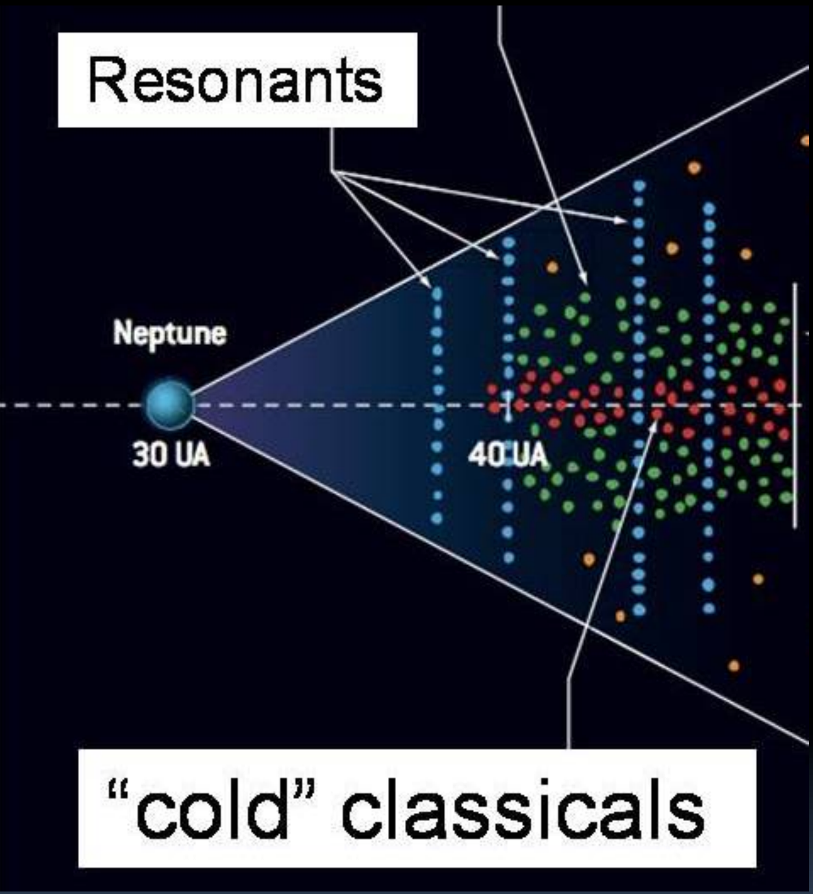
Lellouch et al. 2013 + Poster P97

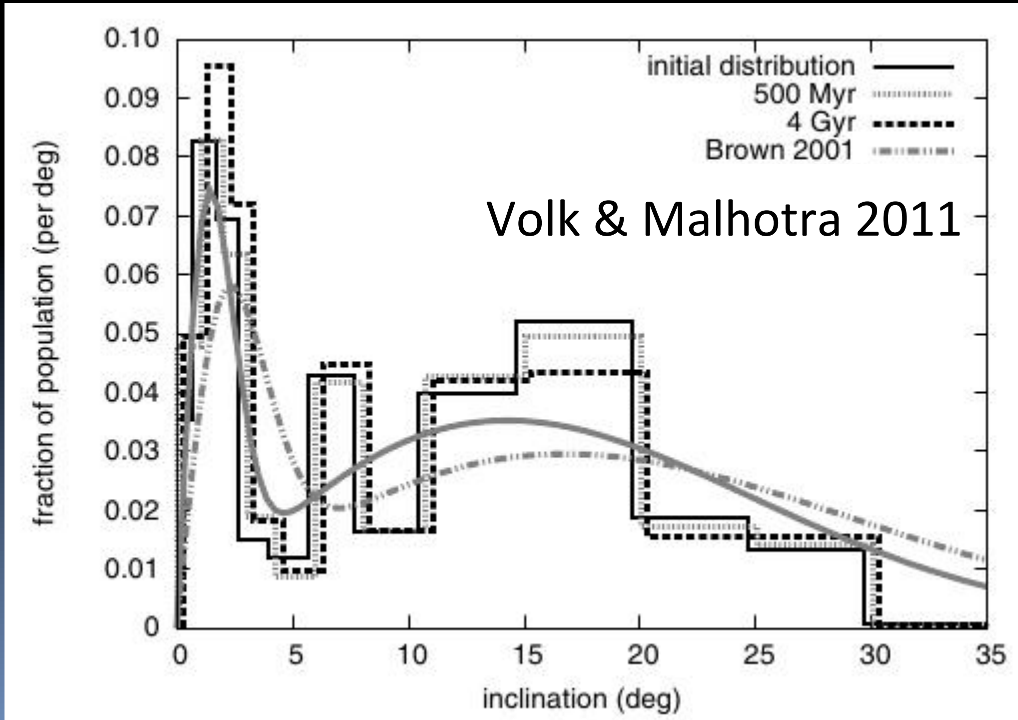
Dynamically cold and hot belt objects



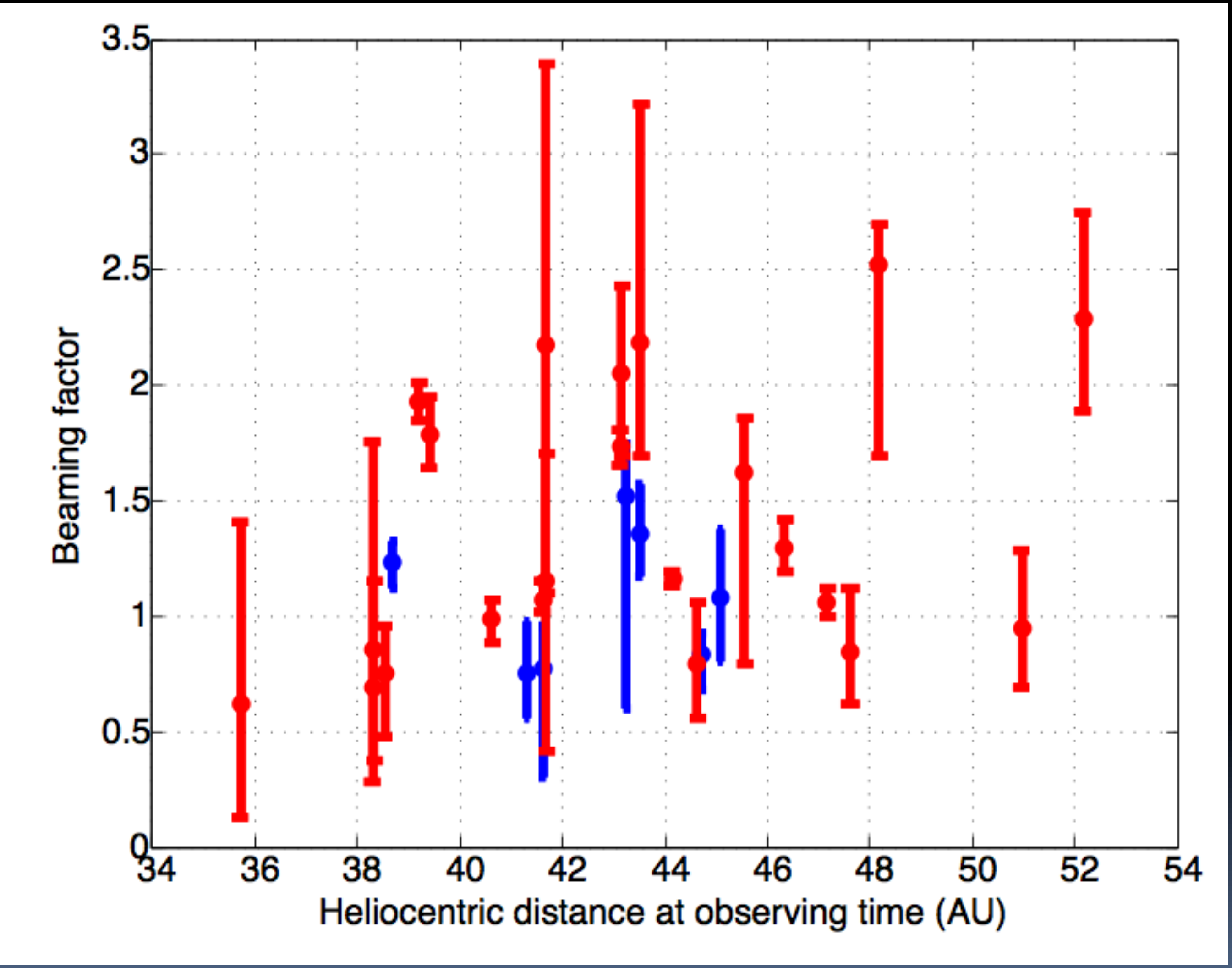
Credit: A. Doressoundiram

- cold classicals have a uniform red color
- high abundance of binary systems (especially in the cold population)
- Solar system evolution models: cold classicals may have formed in-situ, other classes closer to the Sun

(Tegler & Romanishin 2000, Levison & Stern 2001, Brown 2001)



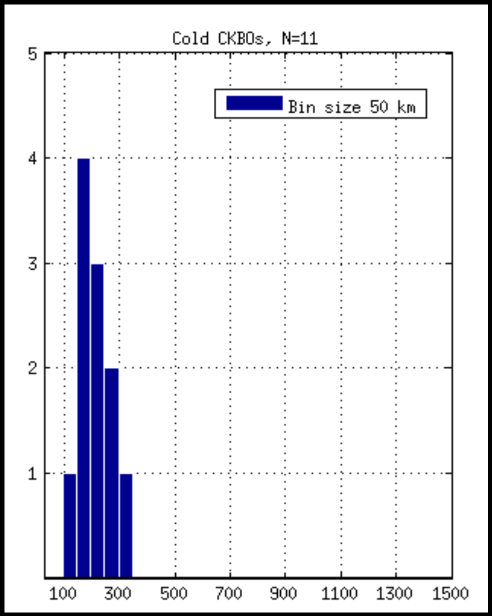
Hot and cold classicals: different thermal properties

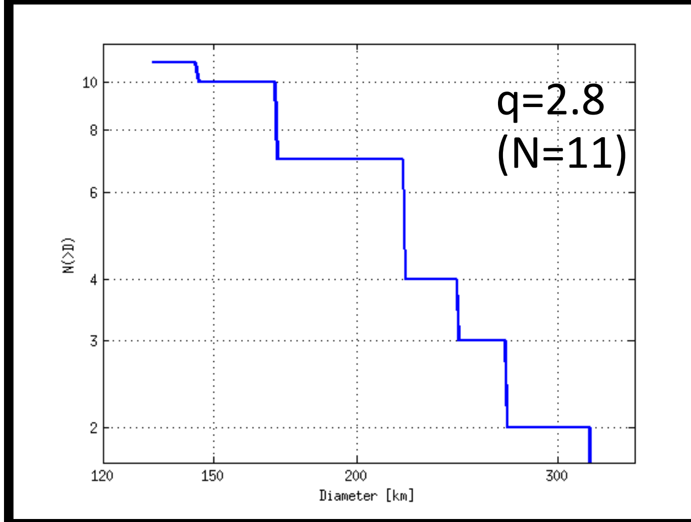


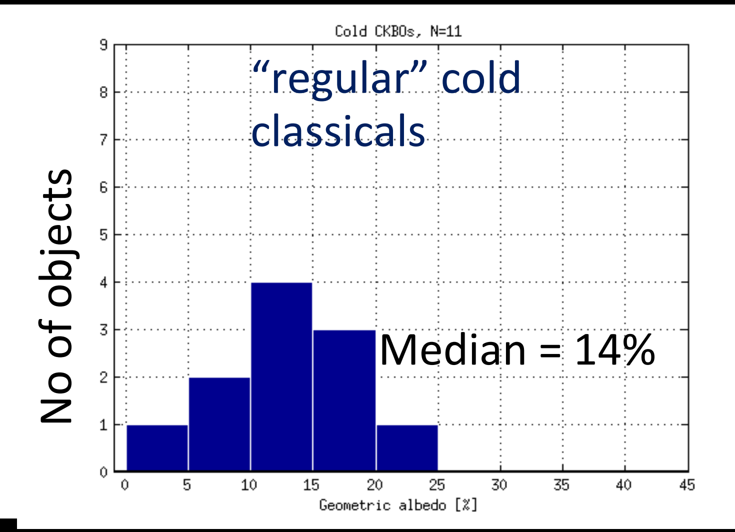
Indications for a different origin?

Hot and cold classicals: Size & Albedo

Dynamically cold

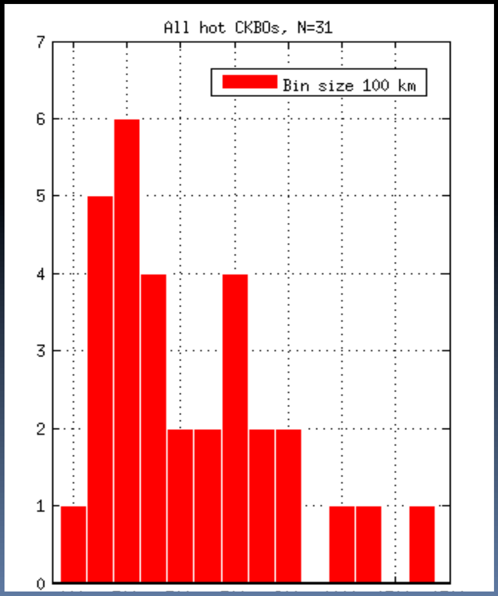


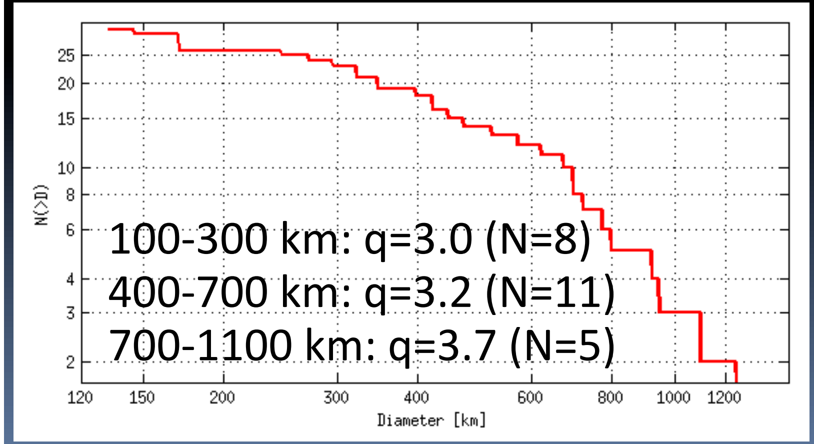


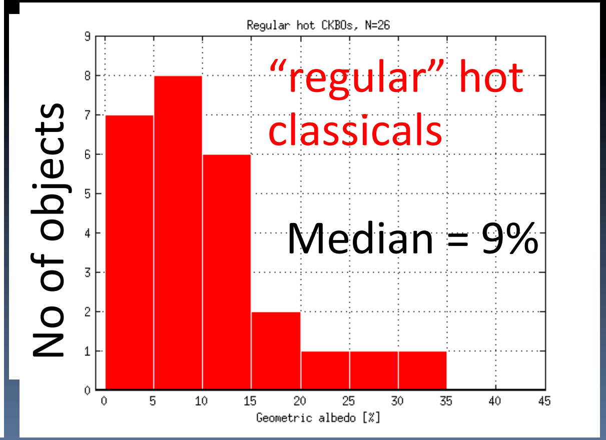


$$N(>D) \propto D^{1-q}$$

Geometric albedo [0-45%]





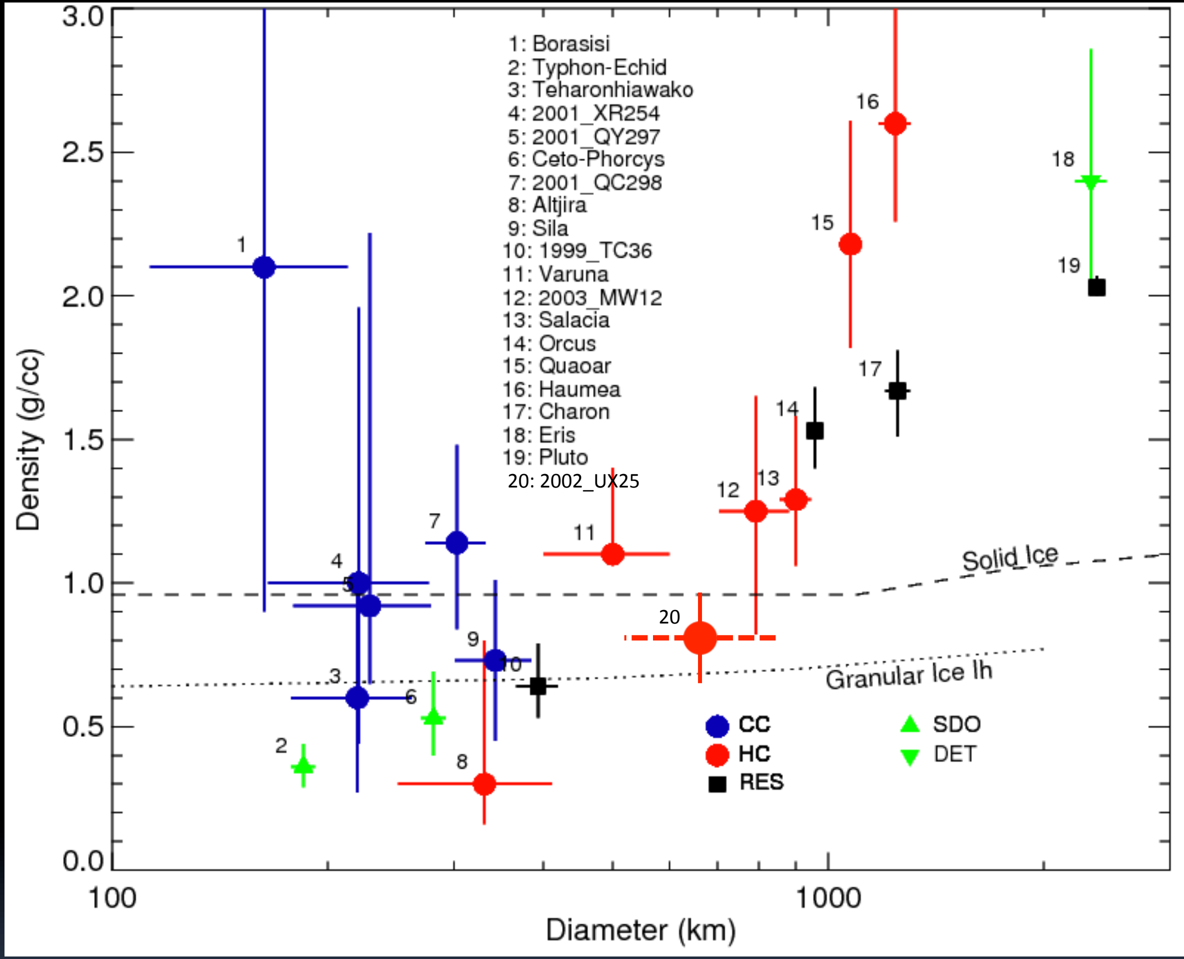


Diameter [100-1500 km]

Dynamically hot

Vilenius *et al.* 2013 submitted

TNO Densities: derived from binary systems



pure H2O < ≈1 g/cm^3
methane ice 0.5 g/cm^3

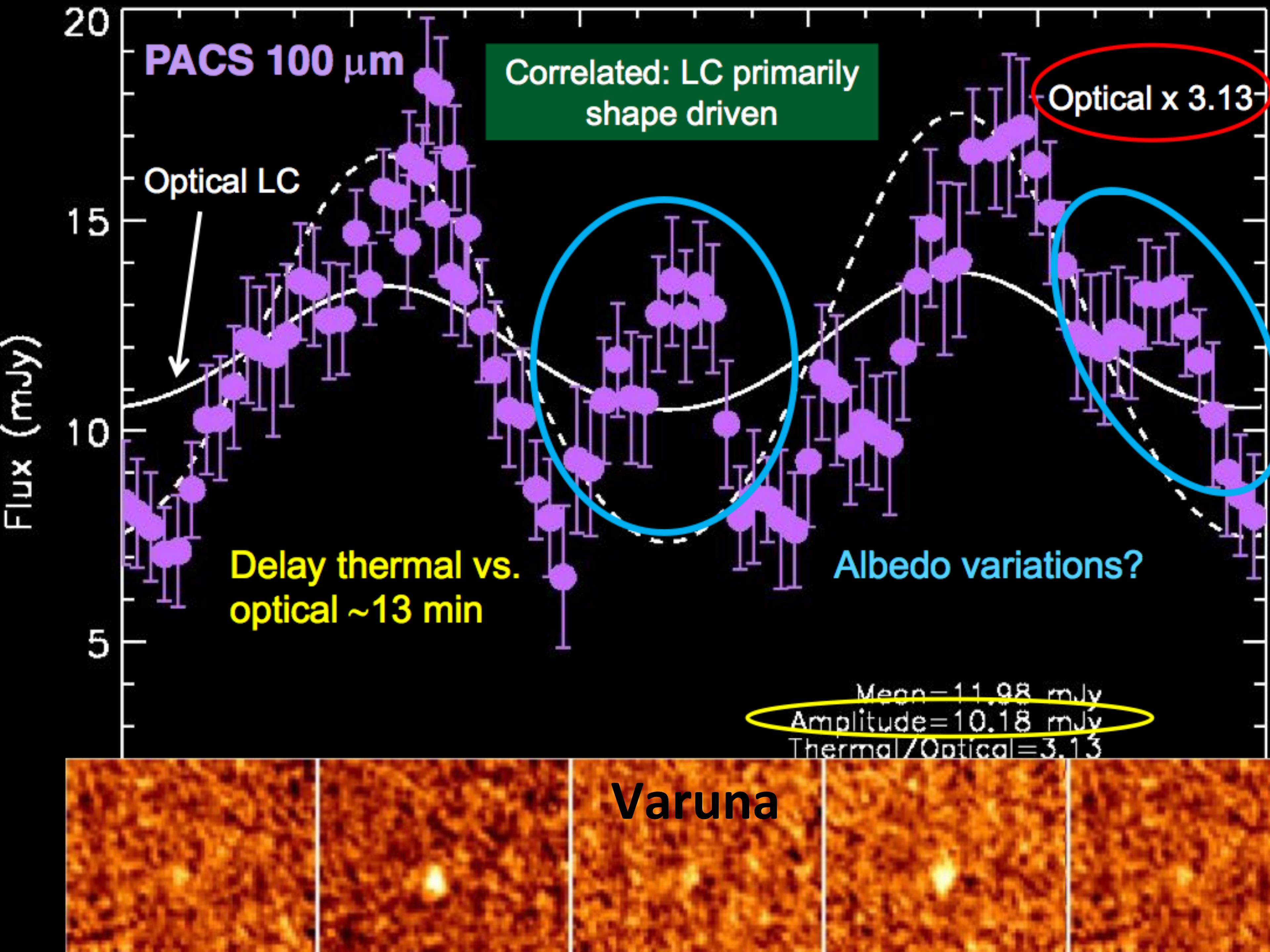
densities <1 g/cm^3 require
macro-porosity and/or
very high ice/rock ratios

objects > ≈500 km all have
densities above ≈1 g/cm^3
(Eris ≈2.5 g/cm^3, Pluto 2 g/cm^3)

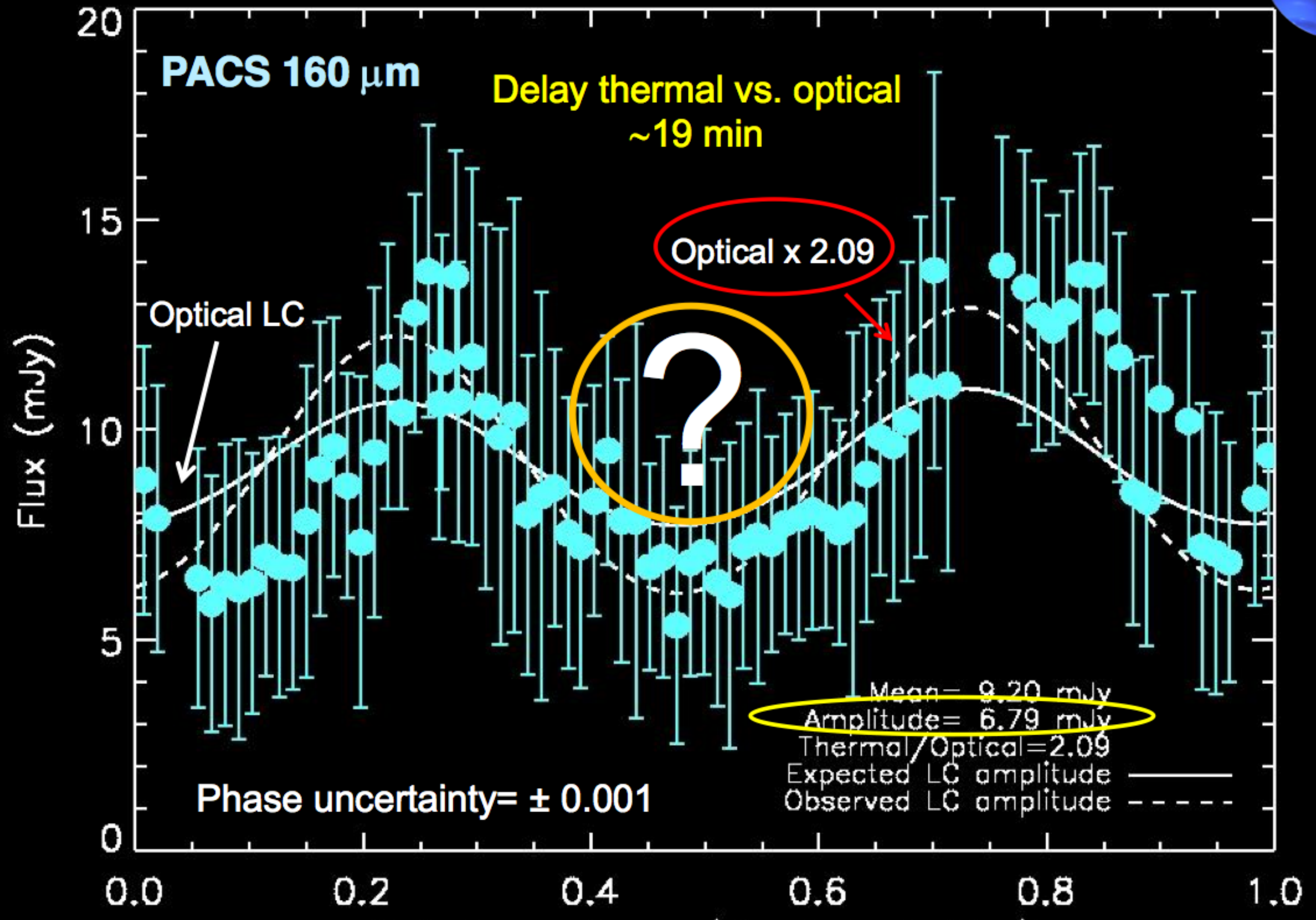
most of the smaller objects
have densities below ≈1 g/cm^3

another 5-10 densities are
still missing

Increasing density with diameter for large objects:
→ gravitational self-compaction, less macroporosity (water in higher density phase)
Different formation scenarios for large and small TNOs:
→ dwarf planets: direct collapse from over dense regions of the disk?
→ smaller TNOs: standard pairwise accretion?



PACS 100 μm
Correlated: LC primarily shape driven
Optical x 3.13
Optical LC
Delay thermal vs. optical ~13 min
Albedo variations?
Flux (mJy)
20
15
10
5
Mean=11.98 mJy
Amplitude=10.18 mJy
Thermal/Optical=3.13
Varuna

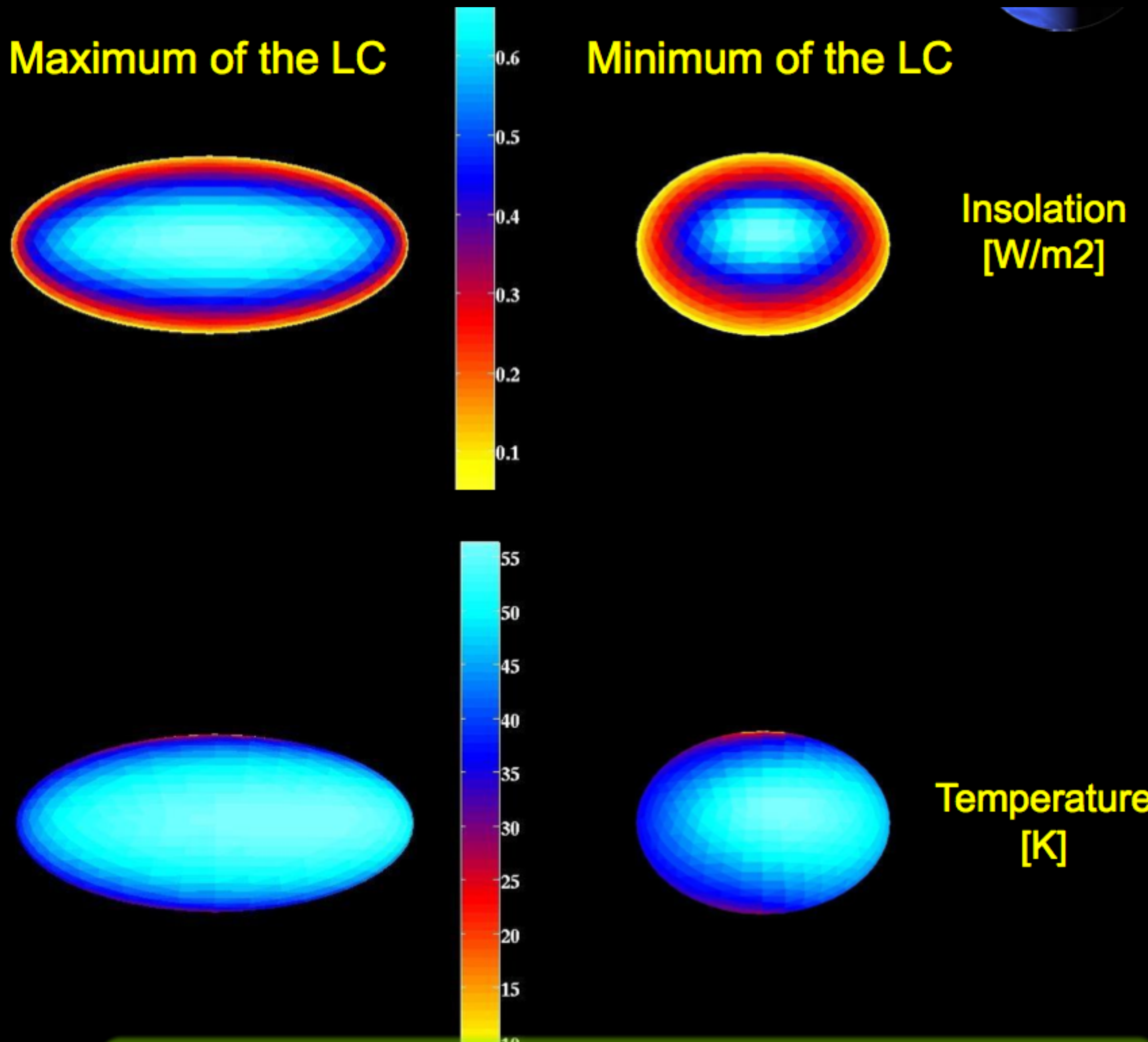


Santos-Sanz, in prep.

Varuna: extreme shape, strange lightcurve effect

Physical model

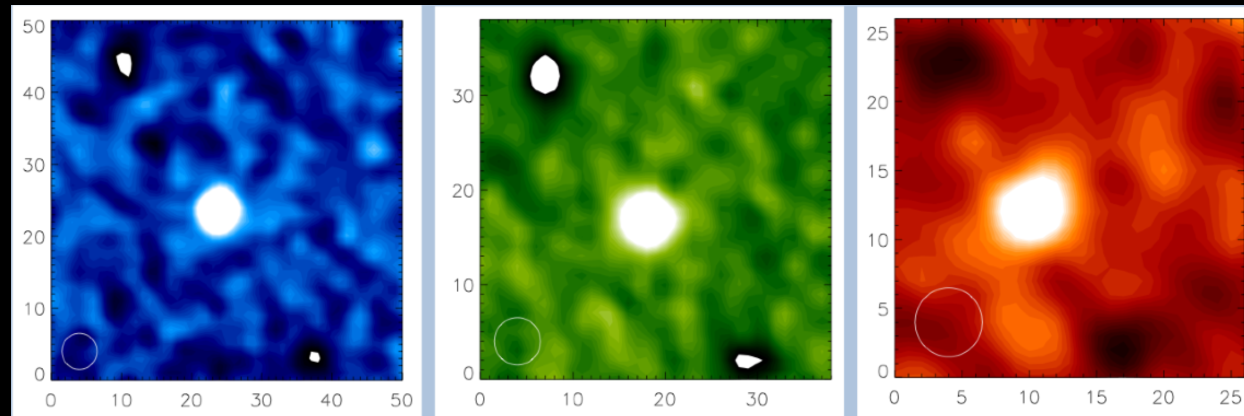
D_{eff}= 540 km
a/b= 1.60
b/c= 1.40
P= *6.3435674±0.0000005 h*
p_V = 0.18
Spin-axis from optical LCs
Γ= 1 S.I.
Default roughness



Santos-Sanz et al. in prep. + Poster P102

Makemake: Cryovolcanos on the surface?

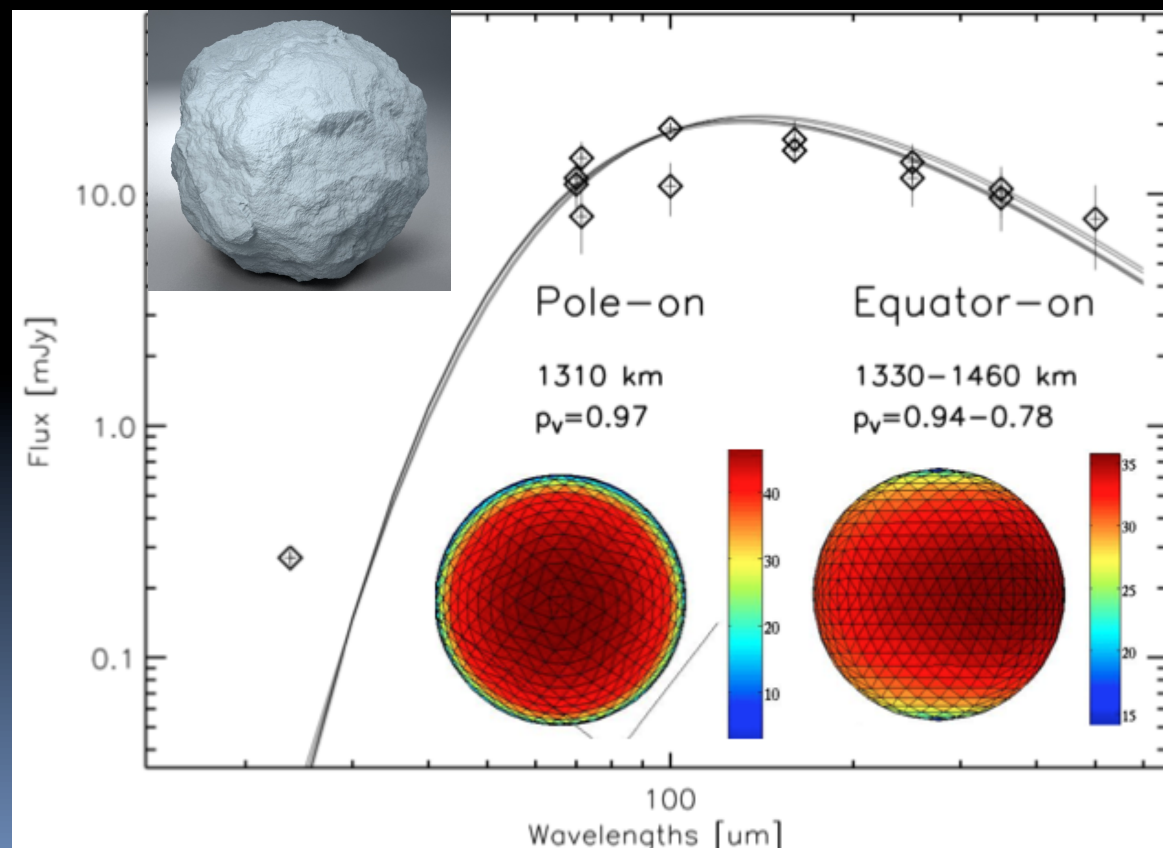
- hot classical
- methane ice
- no satellite
- a= 45 AU, i=29°
- Spitzer & Herschel
- very shallow lightcurve



strong IR-excess at 24µm

↓

very hot terrain needed without producing a noticable lightcurve!



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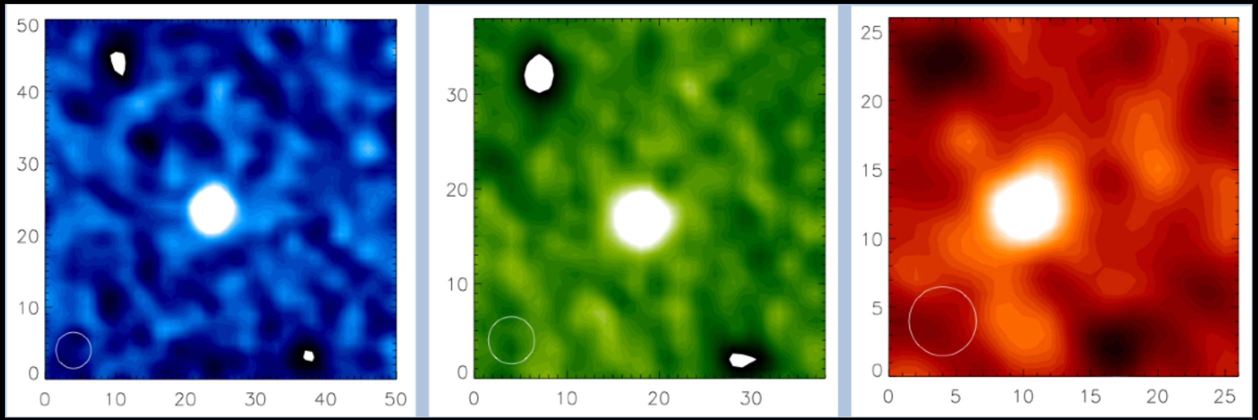

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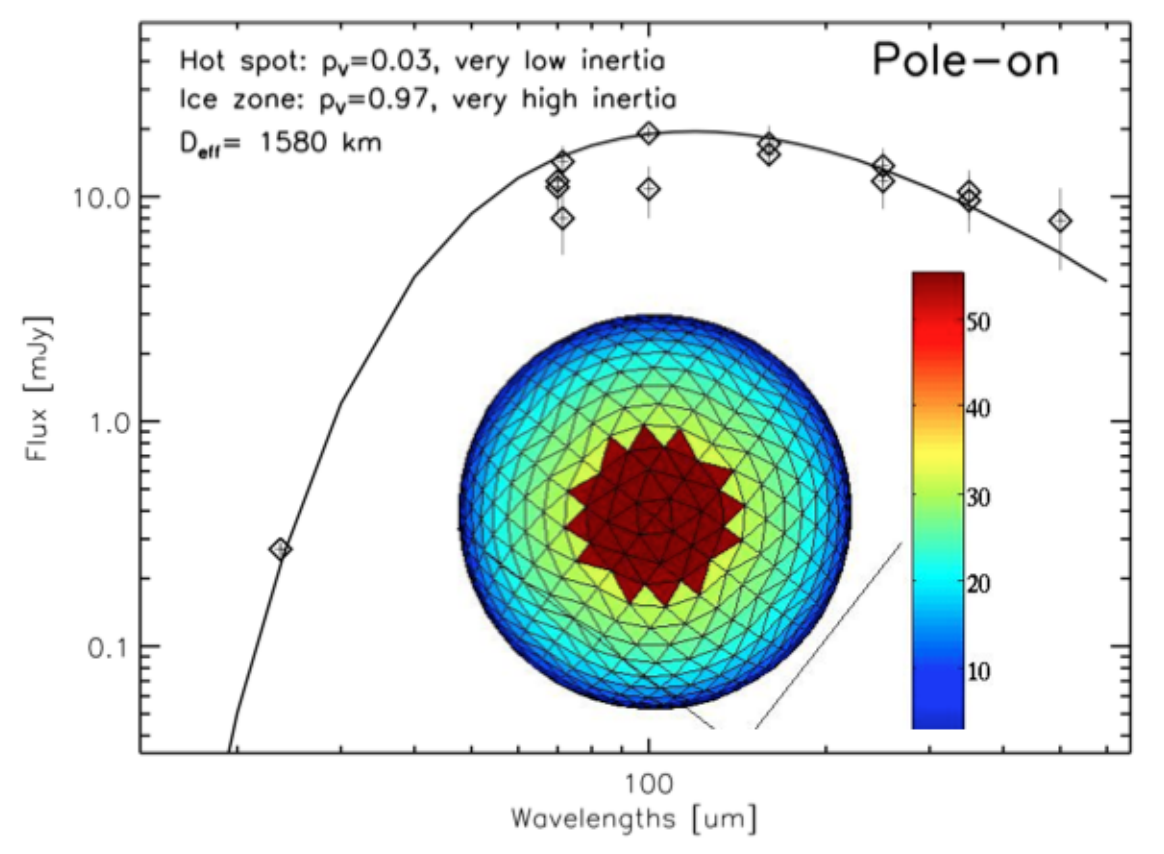

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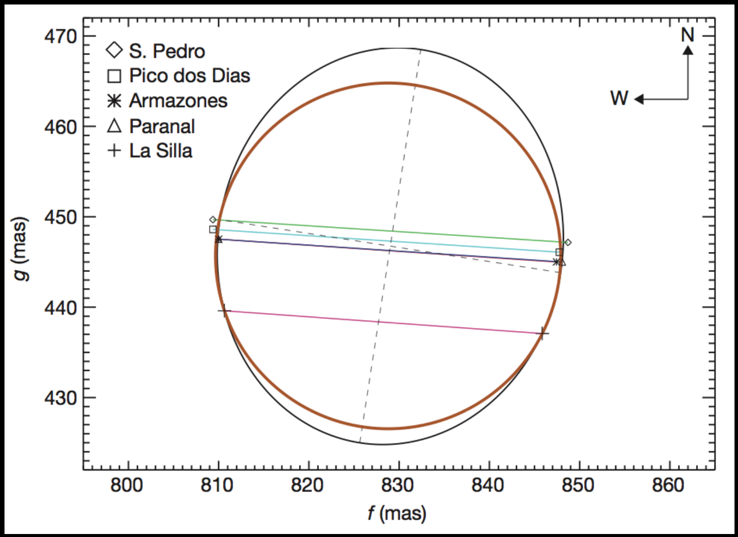

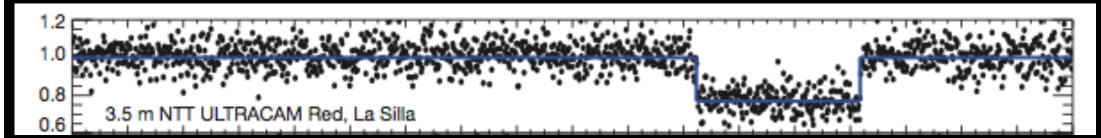

<u>Results from an occultation event:</u>

Object's size: $1430^{+/-9}$ x $1502^{+/-45}$ km

p_V=0.77 $^{+/- 0.03}$, no global atmosphere

(Ortiz et al. 2012, Nature)

<u>combined with Herschel/Spitzer:</u>

- very low thermal inertia
- dark band/spot are not very likely
- hot-spot(s) must have a similarly high albedo

→ cryovolcanism? (Müller et al., in prep.)

Summary: TNOs are Cool!

- new sizes and a wide variety of albedos (>110 TNOs/Centaurs)
- densities for about 25 objects in binary systems
- significantly lower emissivities found at submm wavelengths: → problems for "ALMA-only targets" (talk by S. Fornasier)
- thermal properties (for 81 targets) indicate surfaces with very low thermal conductivities → extremely porous surfaces
- thermophyiscal characterization of several prominent large TNOs (Makemake, Eris, Orcus, Sedna, 2012 DR30, Haumea, Varuna, ...): strange worlds: multiple systems, ice/rock ratios decreasing with size, fresh icy surfaces → cryovolcanism?
- thermal lightcurves: rotationally deformed objects, mixture of size and albedo driven effects, unknown lightcurve effects?
- dynamical class properties: testing Nice model predictions and Brown (2012) surface composition concepts (hot and cold classicals, volatiles lost/retained, density and size distributions, correlations with colours, orbital parameters, ...)

Herschel "TNOs are Cool" KP Team

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Olivier Hainaut, ESO
Alan Harris, DLR Berlin
Paul Hartogh, MPS
Miriam Rengel, MPS
Esa Vilenius, MPE

France
Emmanuel Lellouch (Co-PI), Meudon
Antonella Barucci, Meudon
Jacques Crovisier,Meudon
Audrey Delsanti, Marseille
Alain Doressoundiram, Meudon
Sonia Fornasier, Meudon
Olivier Groussin, Marseille
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Pedro Gutiérrez, Granada
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Tanya Lim, RAL
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Silvia Protopapa, Maryland
David Trilling, Flagstaff

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Aurelie Guilbert, ESTEC
Migo Mueller, SRON

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Australia
Jonathan Horner, Sydney

Switzerland
Nicolas Thomas, Bern