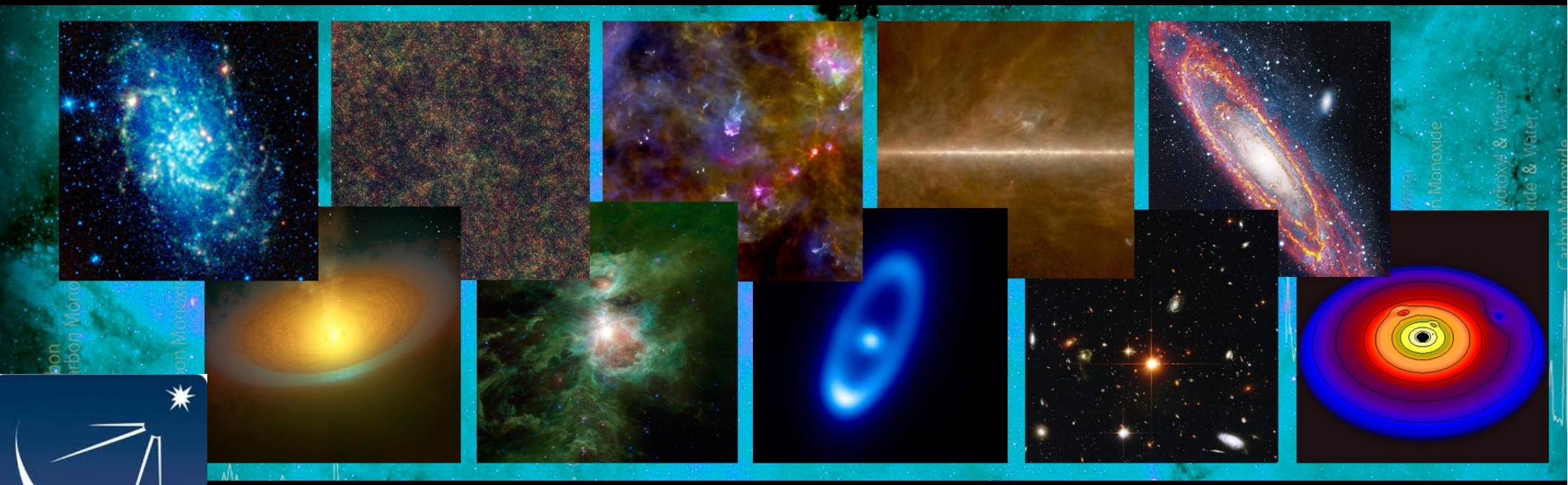
Size and albedo distribution in the Kuiper Belt

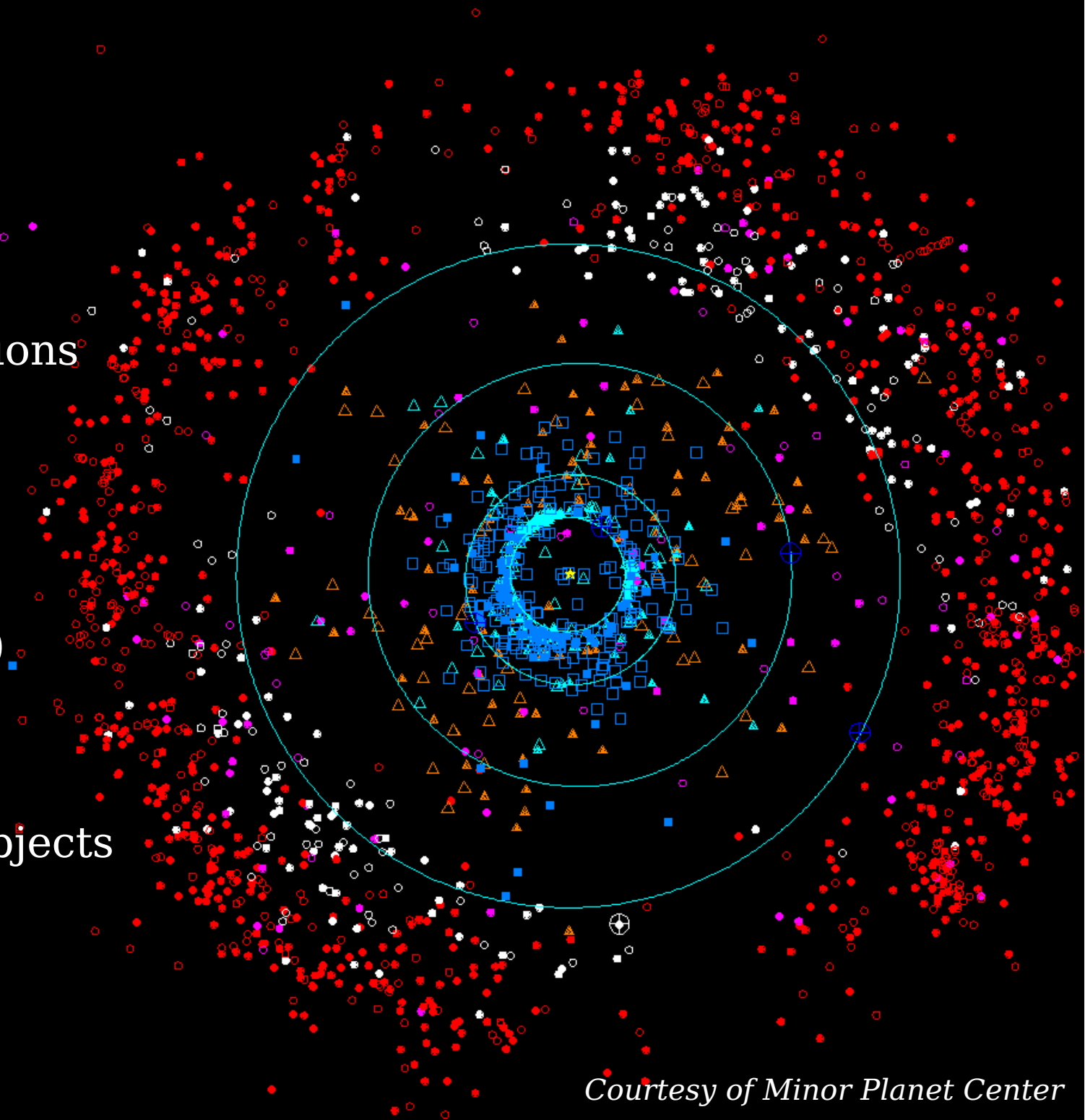
Arielle Moullet, NRAO



Far-IR community Workshop, May 12-13, 2014

~**1400 KBOs** and associated populations

- 1000 KBOs (classical, Plutinos)
- 200 Centaurs
- 200 Scattered objects



Courtesy of Minor Planet Center

Nasa Images Center

+2012 VP-113 ('Biden') `

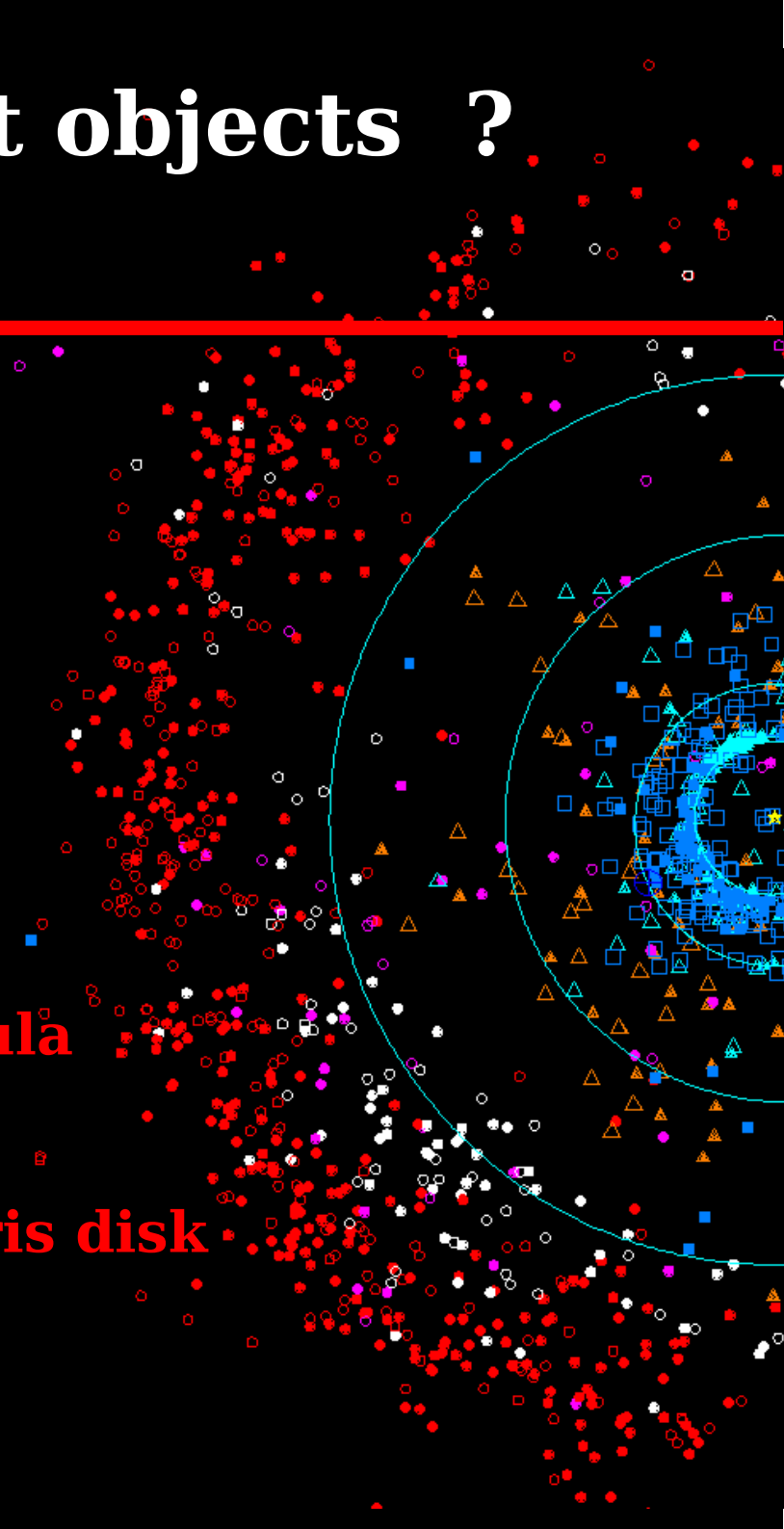
~20 large objects (diameter 300-2000 km)

Icy surfaces (H_2O, N_2, CH_4)

Moons, rings, atmospheres

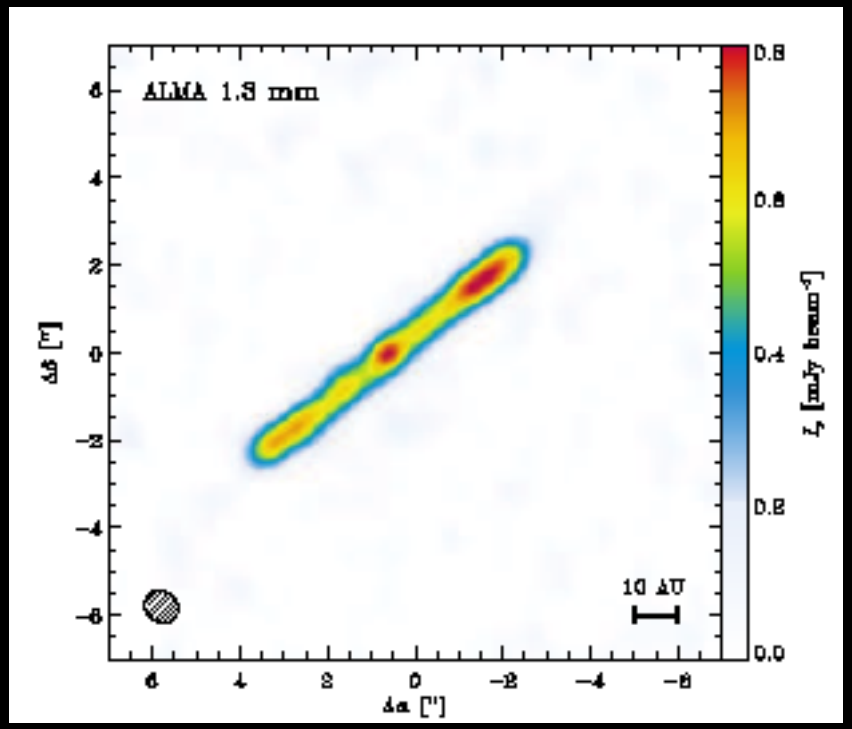
Why study Kuiper Belt objects ?

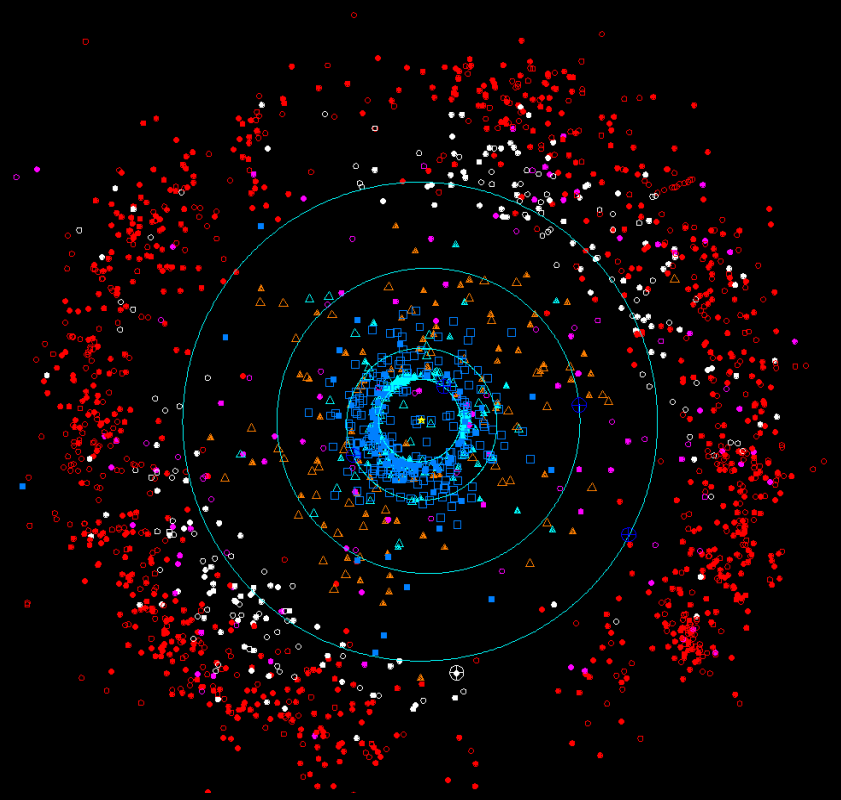
(and related populations)



- **Physics and chemistry** of cold surfaces (atmospheres)
- Pristine objects: information on the conditions in the **primitive Solar nebula**
- Analog of planetesimals in stellar **debris disk**

McGregor et al., 2012:
Au- Mic Imaged with ALMA





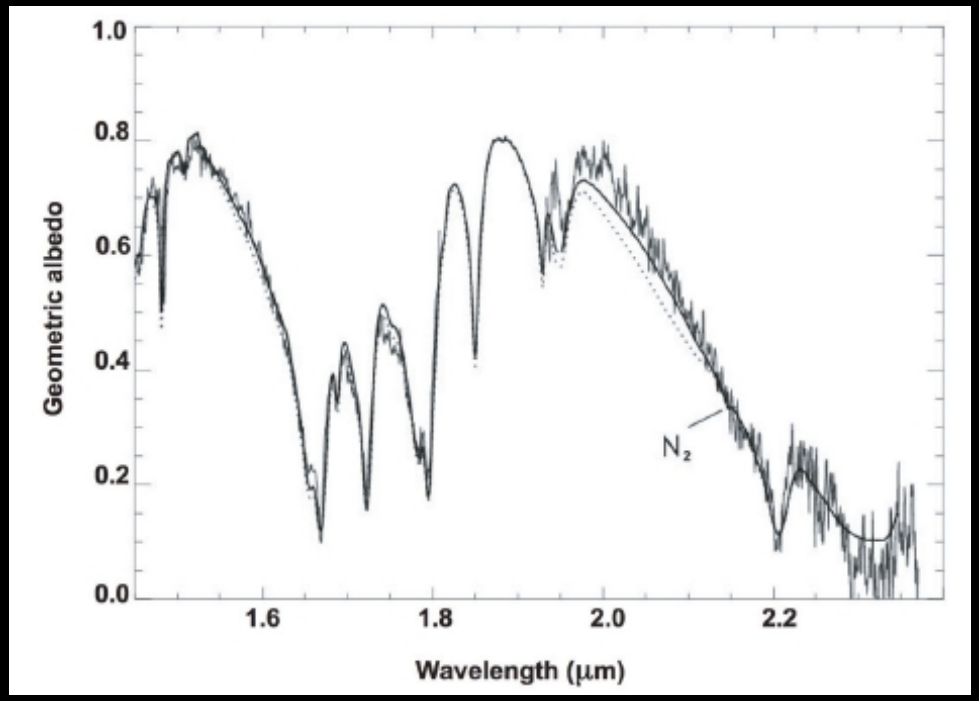
- optically thin **dust emission**
- cold dust (far-IR – mm): >10 AU
- planetesimals undetectable

- dust ~ transparent
- **planetesimals** detectable

Measuring KBOs's properties

Opt. – NIR photometry
→ **orbital** parameters,
spectral index

Opt. – NIR spectrosocopy
→ **icy/mineral bands**

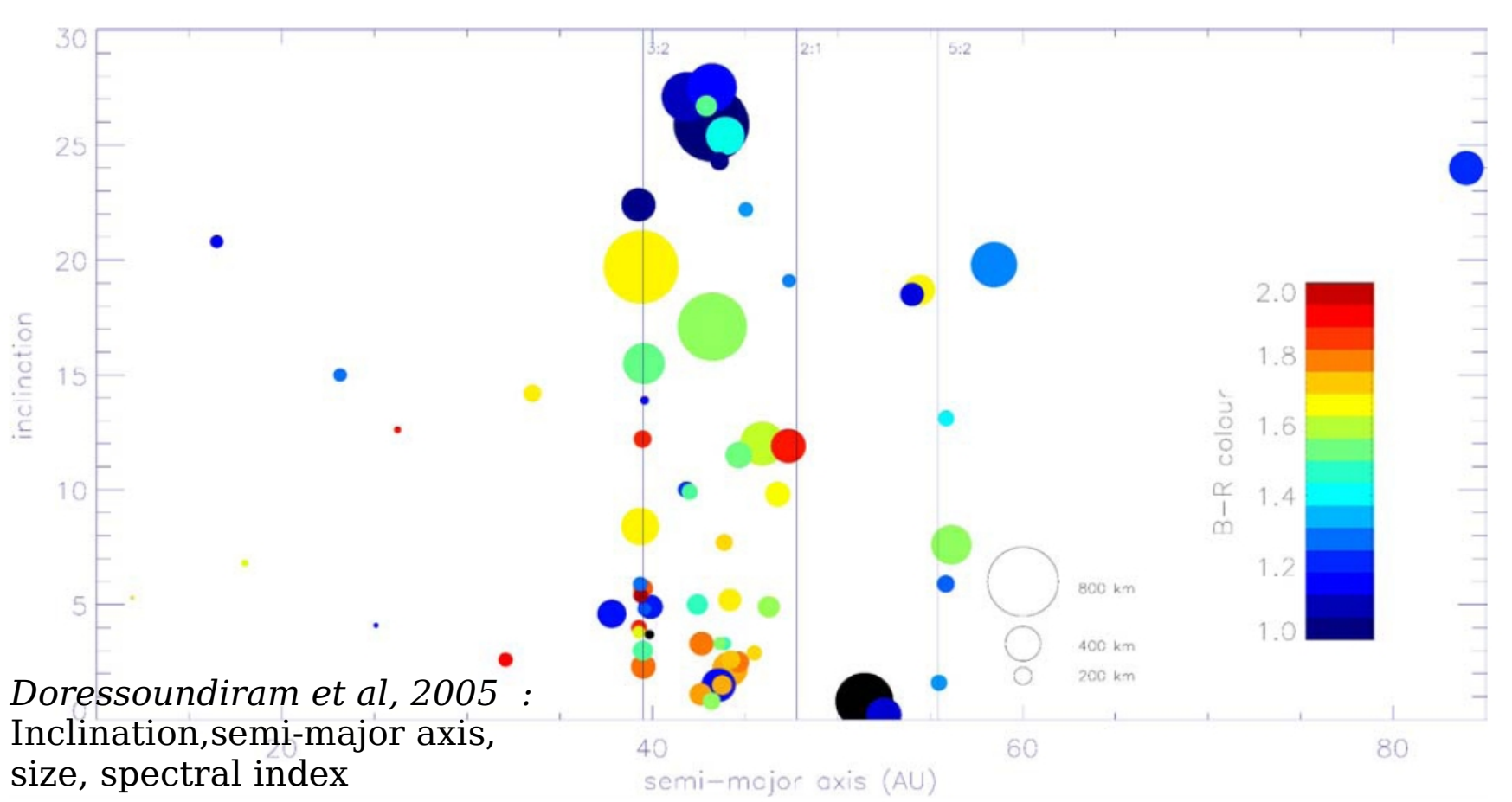


Dumas et al., 2007 :
Eris spectra with water/tholin/methane/ nitrogen ice model

HST Imaging
→ multiple systems

Occultations
→ sizes, shape, atmospheric height

Correlations between spectral/physical/orbital properties:
Identification of **families/groups/processes**



Doressoundiram et al, 2005 :
Inclination,semi-major axis,
size, spectral index

Spectral index (colors):
~400 objects

Only ~120 **albedos & sizes**

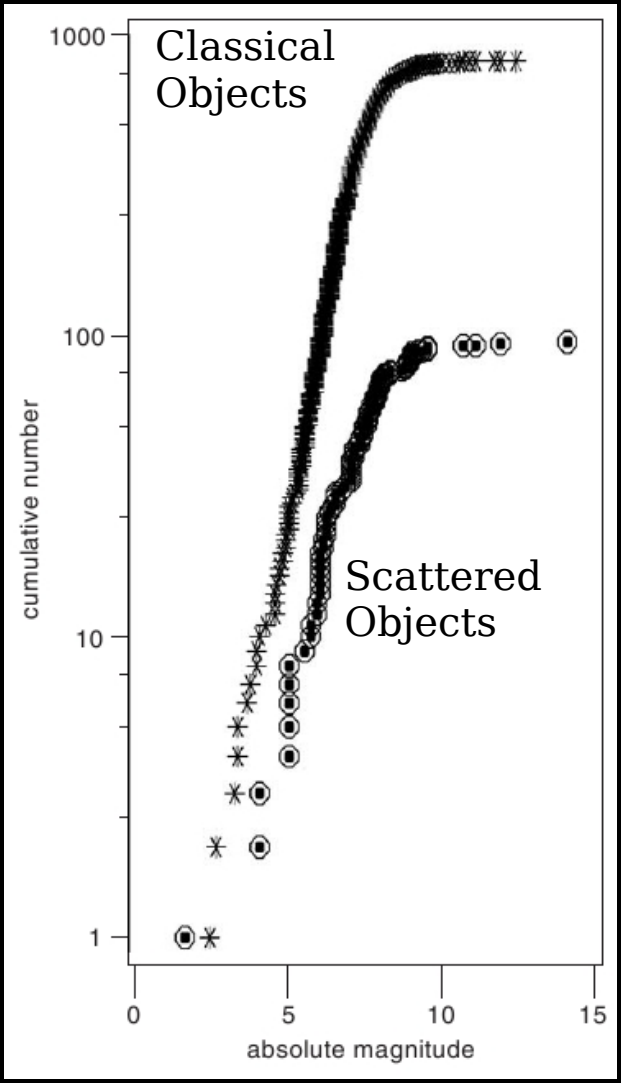
Size distribution

Distribution >30 km may be ~ primordial (Schlichting et al., 2013)

→ internal cohesion (**porosity**)

→ comparison to formation models : **coagulation, accretion, collisions, runaway growth**

Proxy for size: absolute magnitude



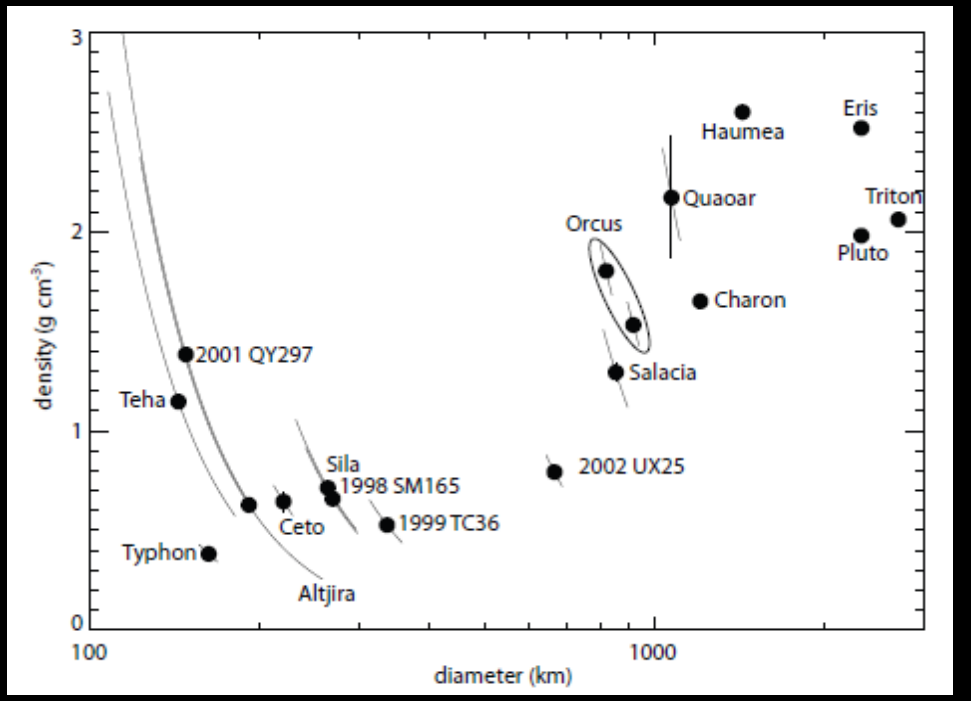
Donnison et al., 2006

Bulk densities

Mass measurements only possible on binary systems (Kepler, 1609)

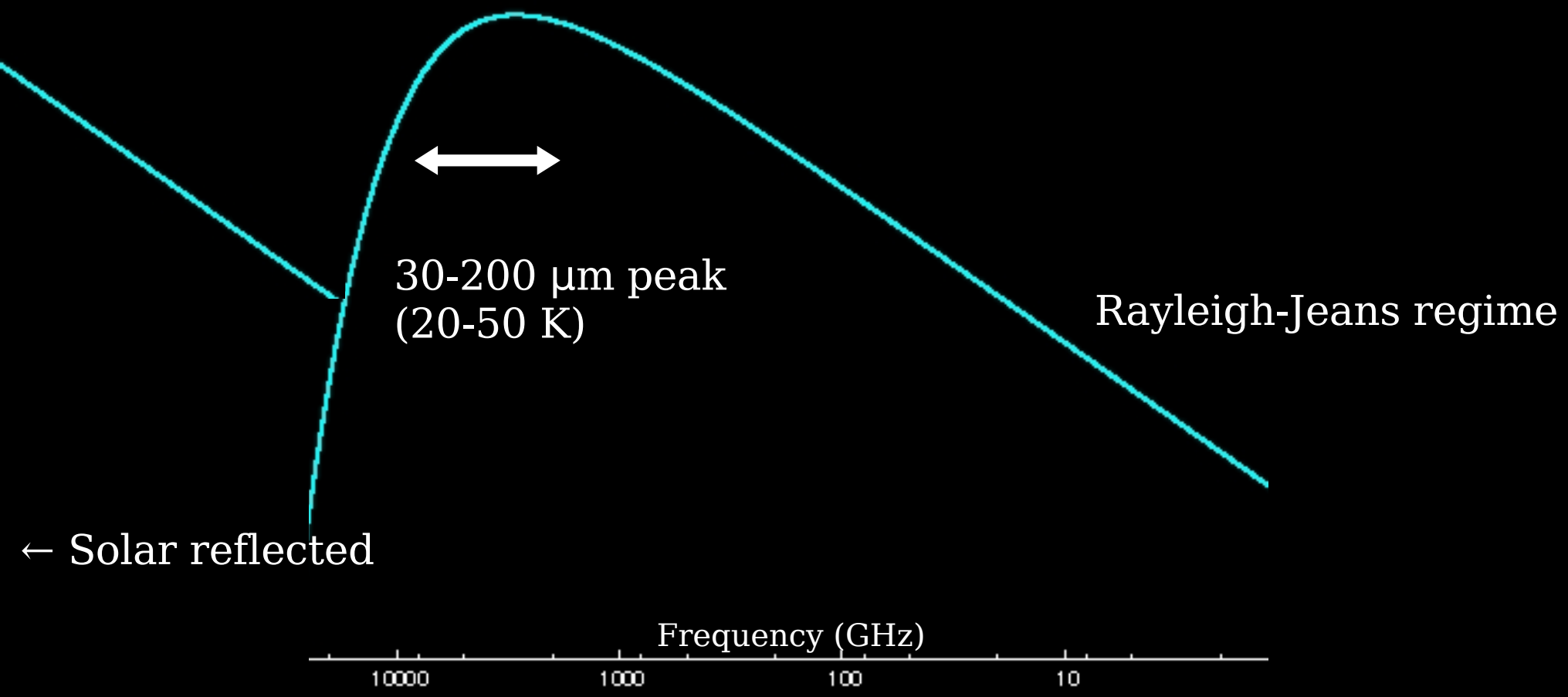
Great **variety of bulk densities**

→ inhomogeneous ice/rock ratio in disk?
→ collisions on differentiated bodies?
→ density varying w mass (porosity)?



Brown et al., 2013 :
Densities and diameters

Thermal emission: access to size/albedo



Thermal emission : **Area (∅²)** x Brightness temperature

Temperature and object properties

Brightness temperature $T_b = \varepsilon$ Tsurface (ε : emissivity)

Emissivity depends on **refraction index, surface roughness**

$$T_\phi = \left[\frac{(1-p_{bolo})F}{r_h^2 \varepsilon_{bolo}\sigma}\right]^{1/4} \Omega_{\Theta,i}(lat, long, z) = T_{SS}\Omega_{\Theta,i}(lat, long, z)$$

geometric properties :
shape, rotation rate

orbital properties
hel. Distance, pole direction

surface properties :
albedo, thermal inertia

The radiometric method

Morrison et al., 1977

Optical magnitude

$\sim a \cdot D^2$

Assuming thermal model

albedo and effective size

Thermal emission

$\sim B(\nu, T((1-aq)^{0.25})) \cdot D^2$

Fitting thermal model

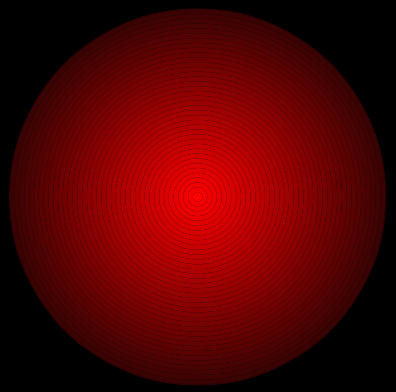
albedo and effective size, Thermal inertia
(or thermal inertia proxy)

Thermals models adjusted through **beaming parameter η**

Low inertia → High inertia

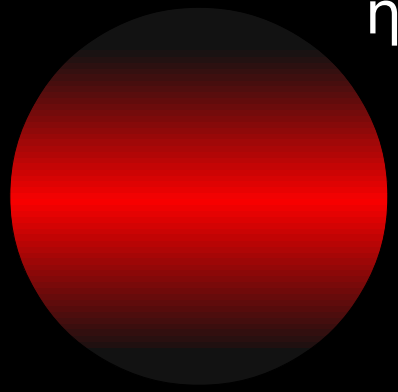
Varying η

η=1



Slow Rotator model

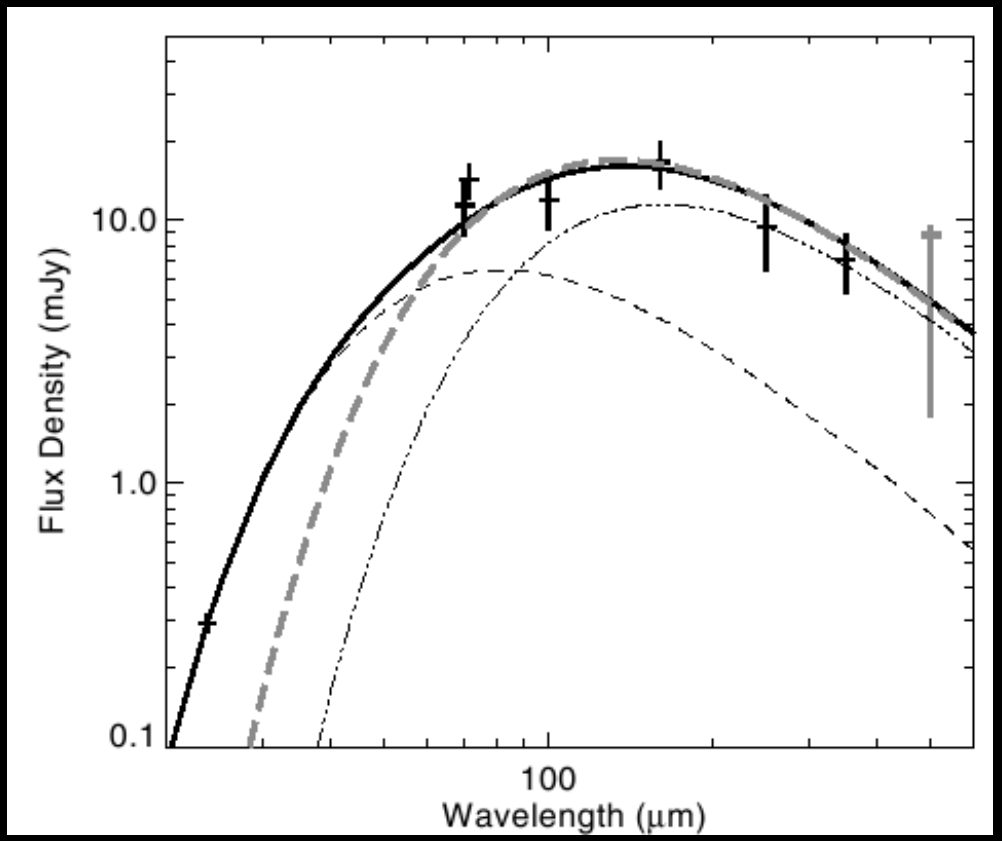
η=2



Quick Rotator model

'STM' 'NEATM' 'TPM'

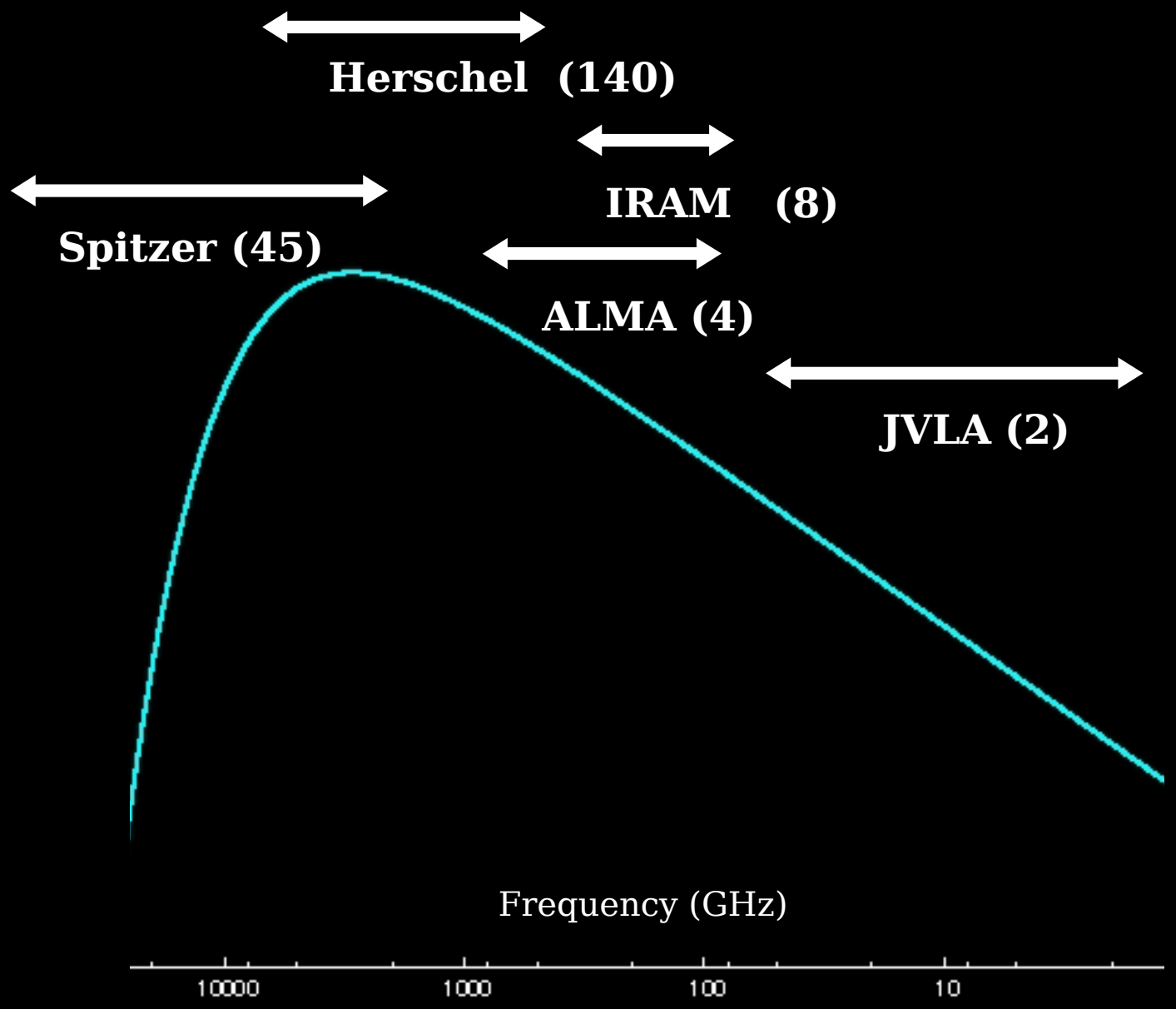
Most constraining method for thermal model fit: measurements on **each side of the peak**



Lellouch et al., 2010: Makemake modeling based on Herschel and Spitzer measurements

Far-IR is the best access to thermal properties, size and albedo

Past measurements

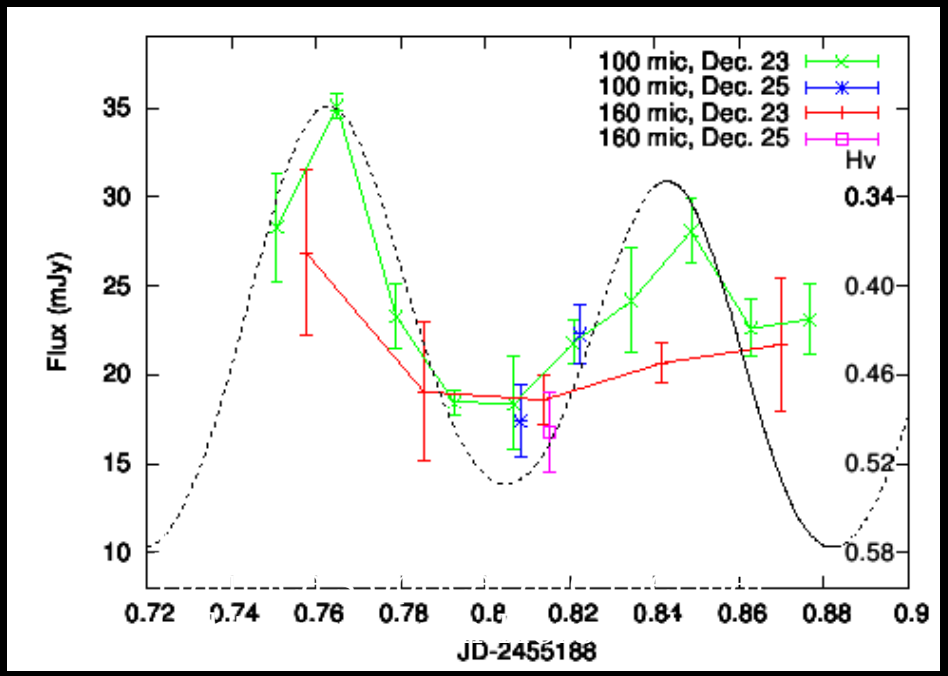


The Herschel Large Program : "TNOs are cool"

370 hours awarded (PIs Mueller and Lellouch)

- 140 targets at 60, 100 and 160 µm (PACS), 17 targets at 250 µm (SPIRE) : **sizes (>150 km) / albedos**

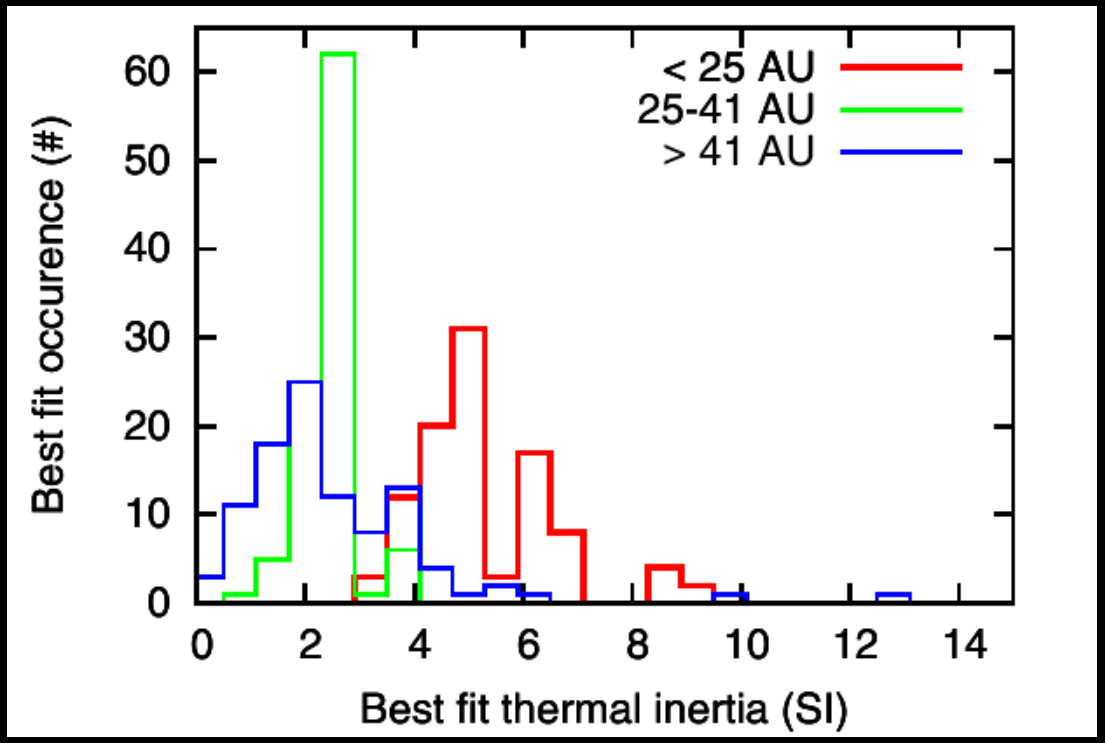
- 25 binaries : **densities**
- 25 lightcurves : **shapes**



Lellouch et al, 2010:
Haumea's optical and thermal lightcurves with Herschel

Surface properties

Measurement of average thermal inertia (~2.5 MKS):
Lower than moons and ice.



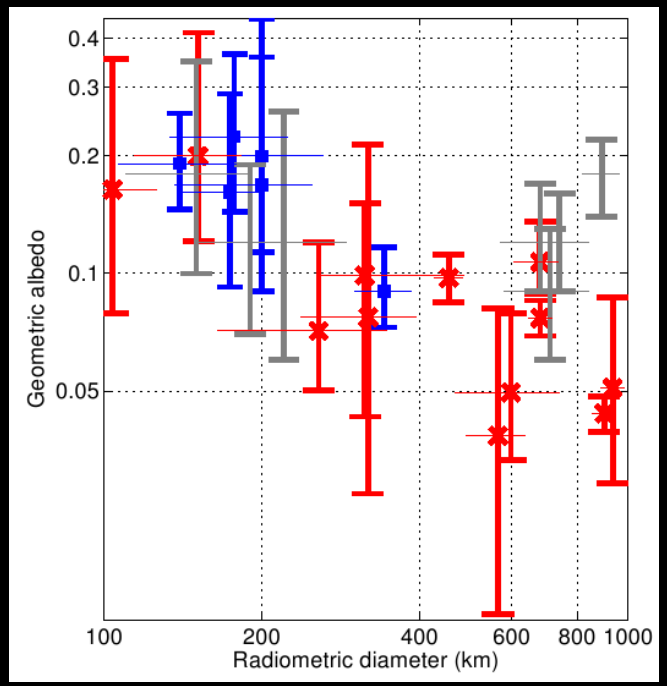
Lellouch et al., 2013

high porosity / regolith above ice (*on 85 bodies*)

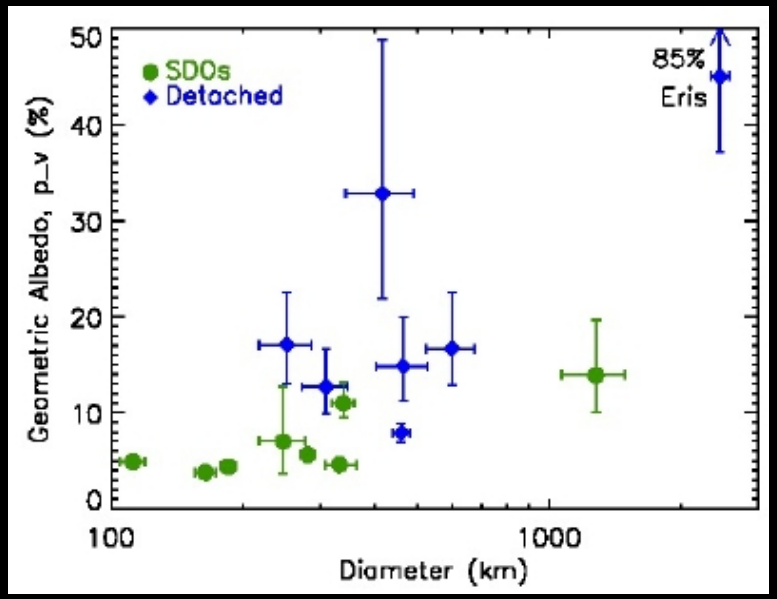
Correlations

Search for correlations on different dynamical groups.

Albedo Vs diameter:
- anticorrelated on 'main belt' KBOs
- correlated on scattered/detached (halo)



Vilenius et al, 2012



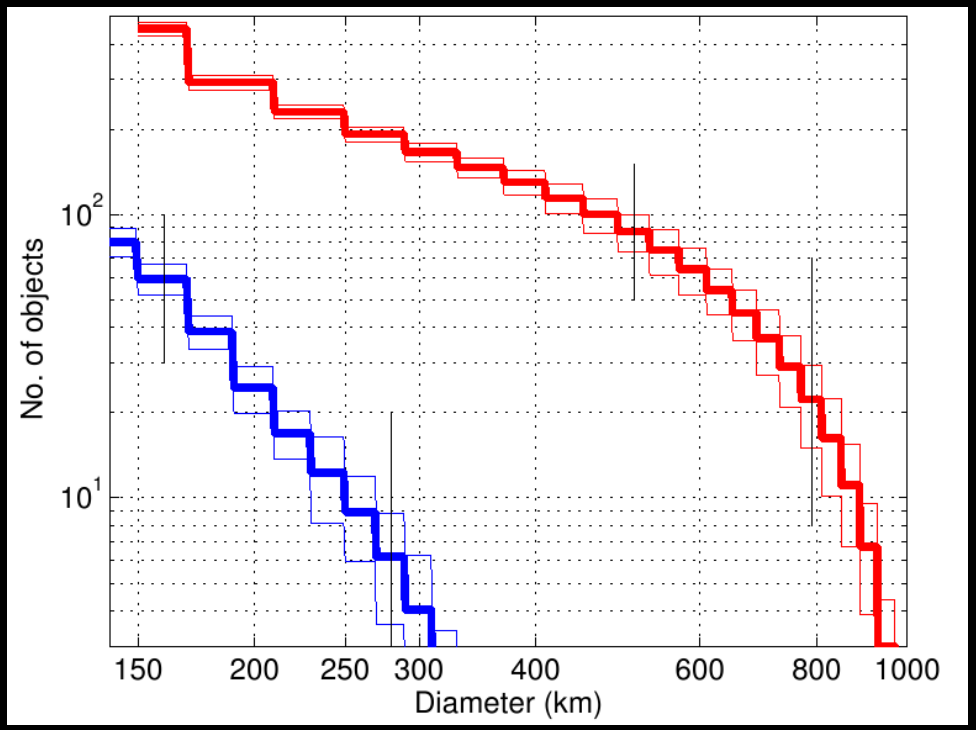
Santos-Sanz et al, 2012

Albedo error: 10-25%

Low-level correlations

Size distribution

Size distribution slope varies with population:
between dynamically excited ('hot') and little excited ('cold') populations in the main Kuiper belt



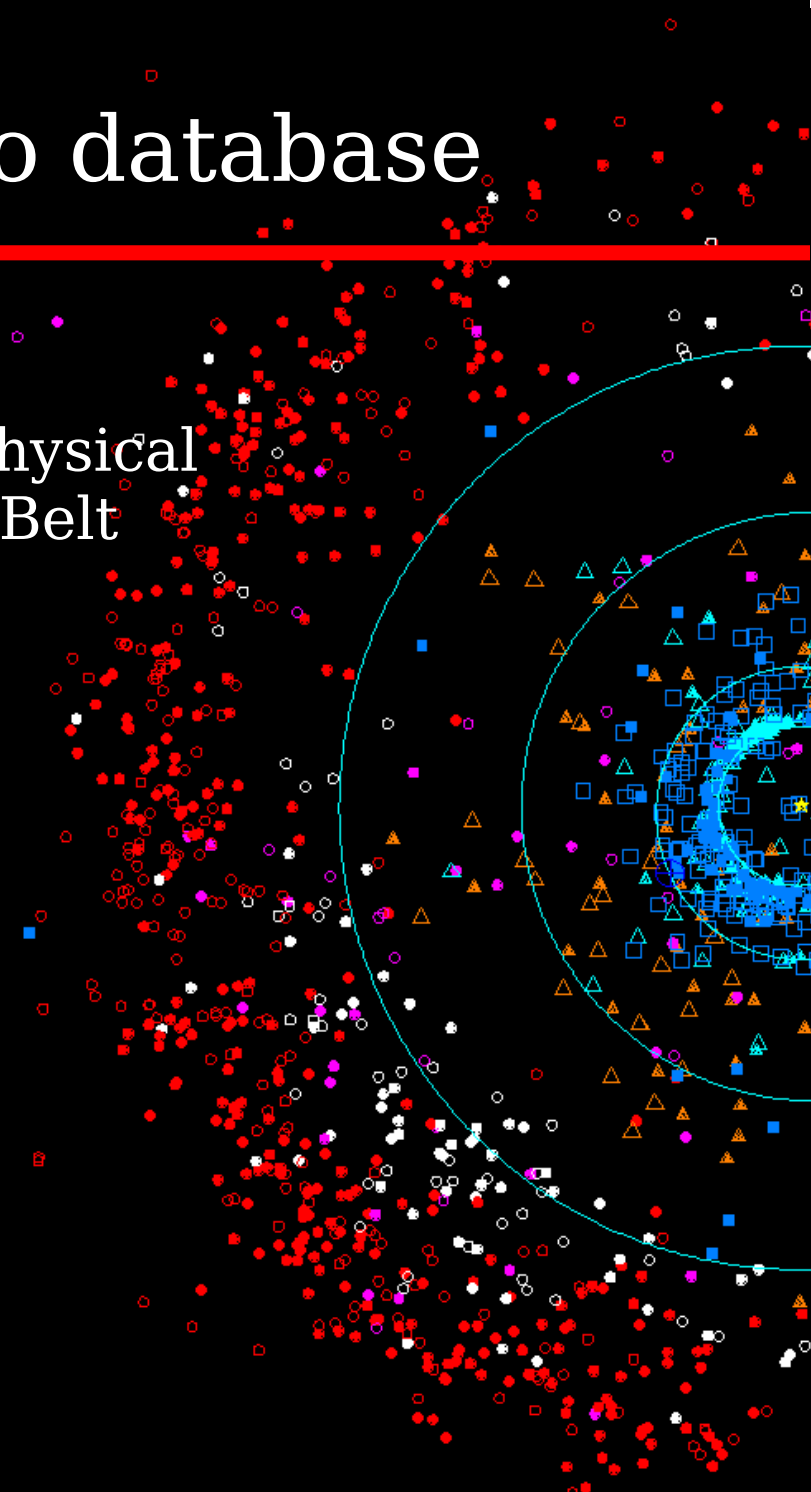
Down to 150 km
In diameter

Missing the collision/fragmentation/ gravitational accretion transitions

Vilenius et al., 2014

The next step:
expanding the size/albedo database

Constrain dynamical, collisional and physical processes and evolution in the Kuiper Belt

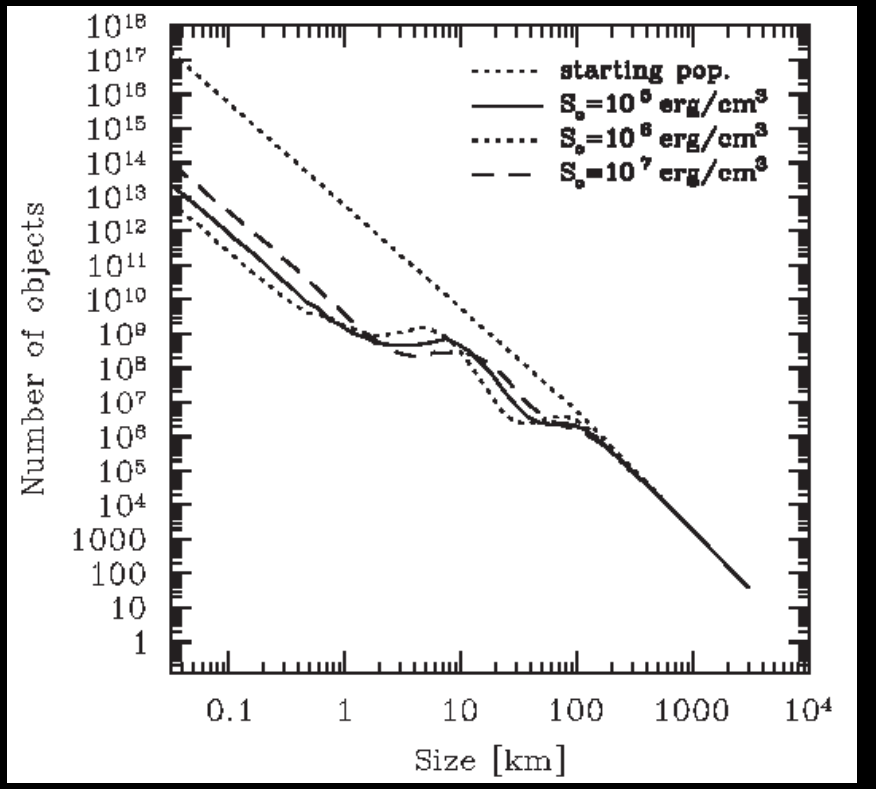


<u>Science Objectives:</u>

- Size distribution near accretion/fragmentation threshold
- Orbital/physical correlations using size, density and albedos
- New collisional families
- Composition/thermal properties knowledge of larger KBOs

Measurement goals

- Size/albedo on **100 objects/population** (Doressoundiram et al., 2005)
- albedos **error bars <10%**
- reach objects of **~50 km**



Campo-Bagatin et al., 2009

<u>Strategy</u>:
High sensitivity **SED sampling** around thermal peak (50 - 200 μm) + RJ point (ALMA) on **> 500 objects**

30 AU, 50 km: 150 μJy/190 μJy (60/160 μm)
50 AU, 50 km : 18 μJy/ 19 μJy (160/200 μm)

Desired measurement capabilities

Parameter	Units	Value or Range
Wavelength range	μm	50-200
Angular resolution	arcsec	n.r. (point sources)
Continuum sensitivity	μjy/h (5σ)	~20 (150 μm)
Instantaneous FoV	arcmin	Any
Number of target fields	dimensionless	> 500

Sensitivity ~CALISTO (SPECS)

- Tracking capabilities: a few “/ hour
- Good absolute and relative calibration
- Background confusion strategy
- Need for optical support campaign

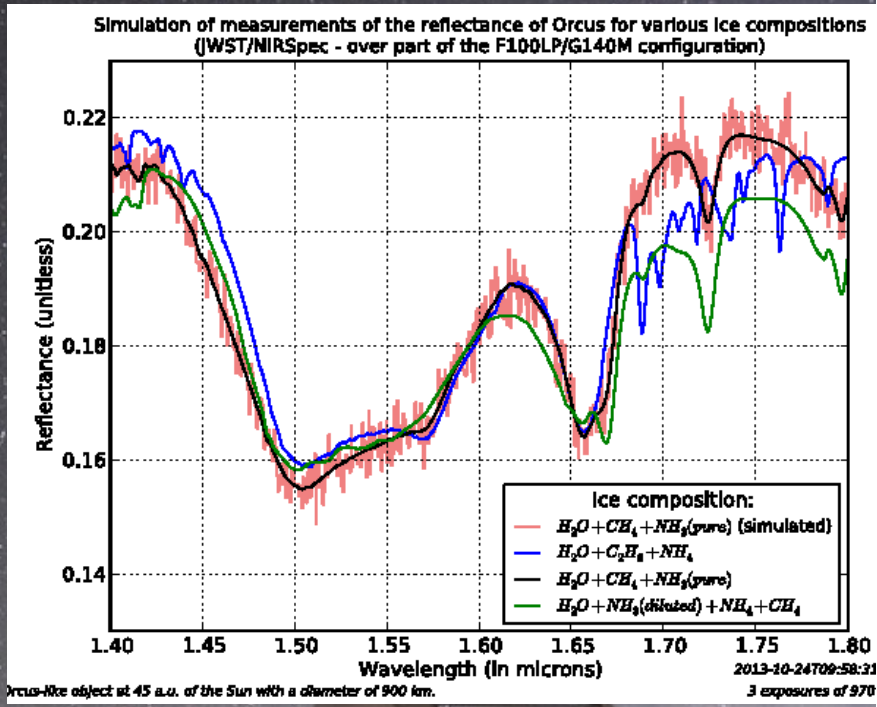
A new era for KBOs with multi-λ approach

Optical (Pan-Starrs/JWST): detection

Near-IR (JWST): spectroscopy

Thermal (ALMA + FarIR mission): size/albedo

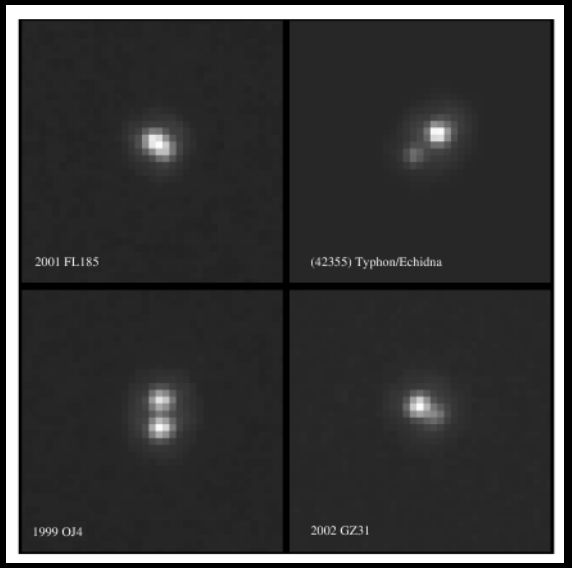
Norwood et al., 2014



Resolved studies

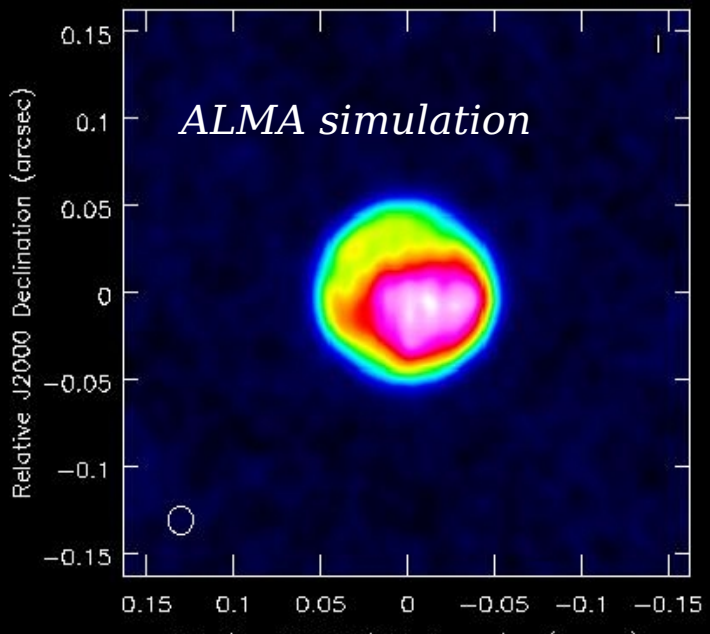
Objects unresolved by single-dish Instruments (size < 0.1”)

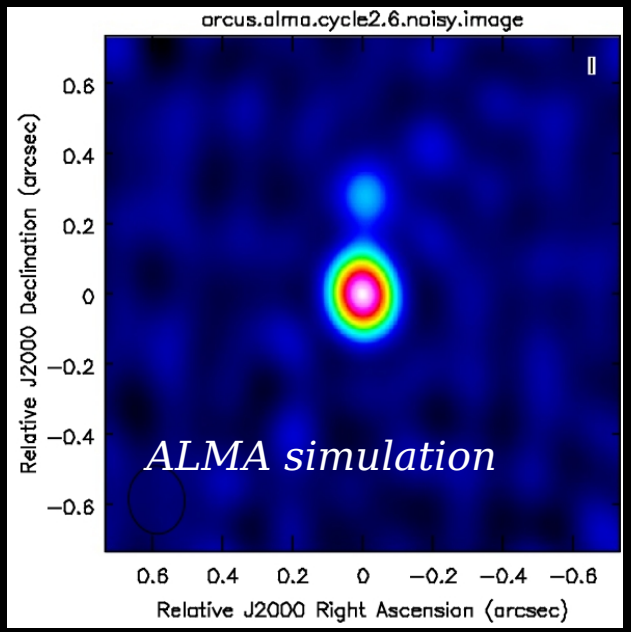
Interferometry (Far-IR or ALMA):
→ First thermal maps of large KBOs
→ separation of contact binaries



Noll et al., 2008

Resolving power must be ~0.01” (~ALMA)



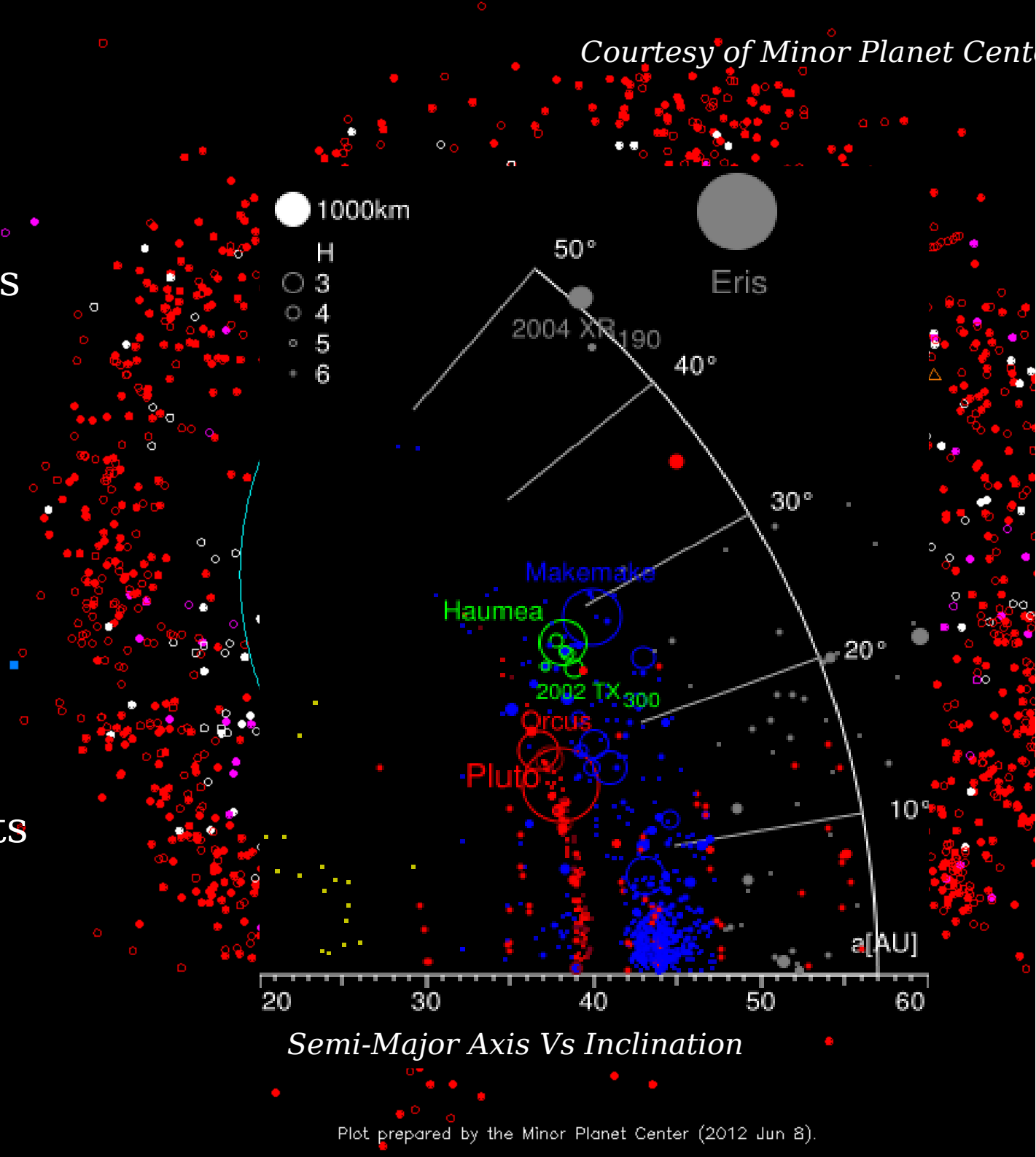


~ 1400 KBOs and associated populations (V ~ 22-28)

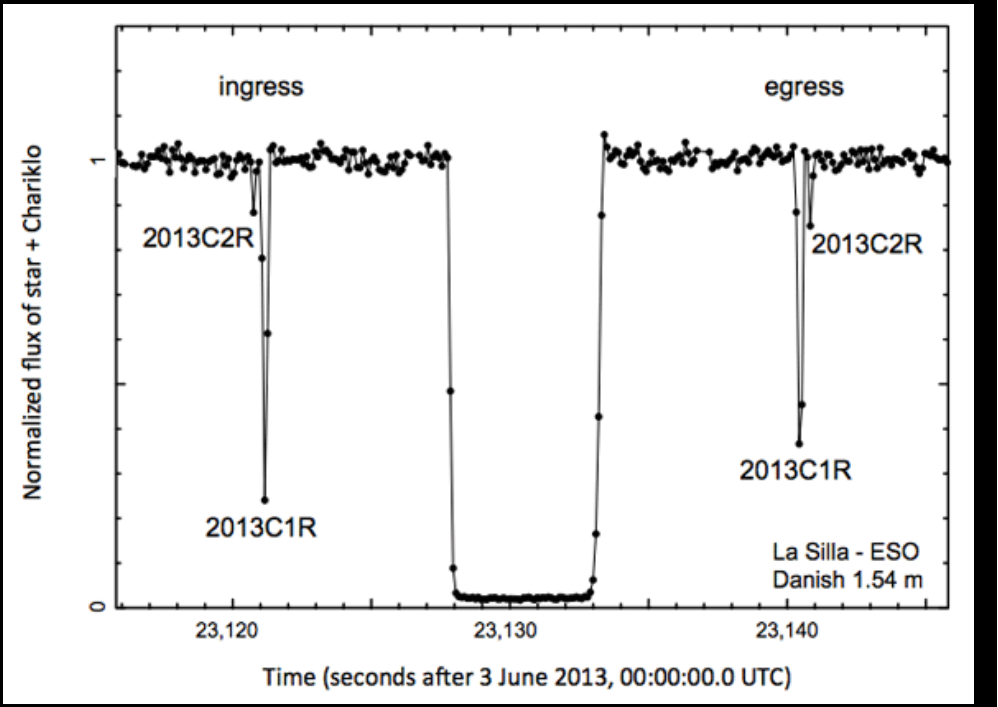
- 1000 KBOs (classical, Plutinos)

- 200 Centaurs

- 200 Scattered objects



Haumea, Hi'iaka and NASA/ESA



Chariklo rings
Braga-Ribas et al., 2014

Moons (multiple systems) in up to 30% of KBOs

Rings

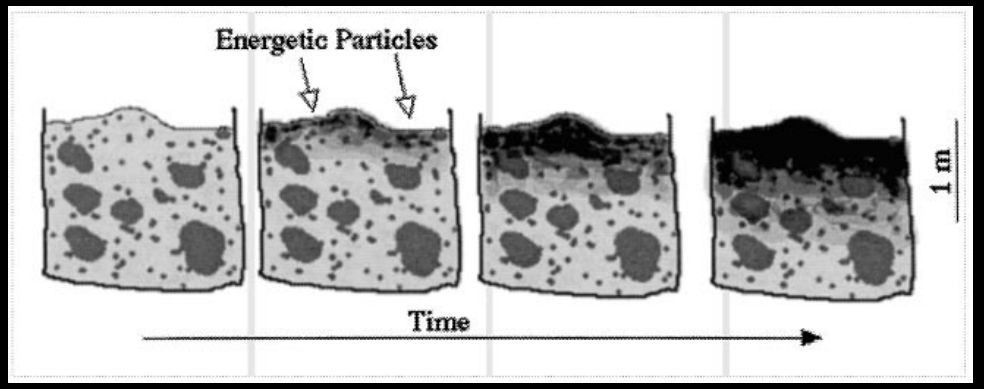
Possibly atmospheres (N_2, CH_4)

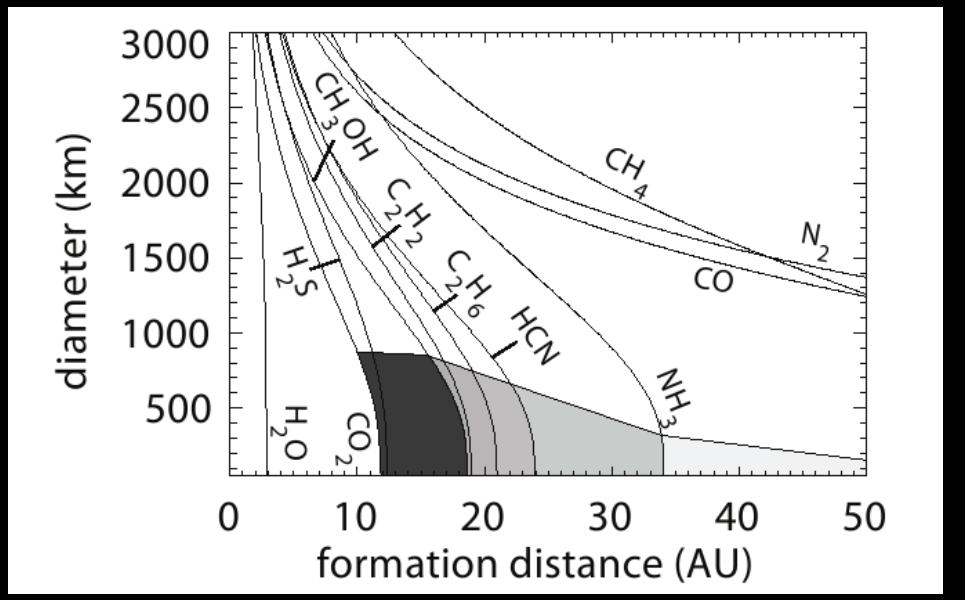
Surface altering

Wide variety of surface composition (volatiles/organics), reflect **surface alteration processes** :

- Collisional excavation
- Space weathering
- Volatile loss
- Thermal alteration
- Cryovolcanism
- Radiogenic heating...

Jewitt et al. : Space-weathering





Brown et al., 2010 : Model of volatile retention on surfaces