# Herschel Open Time Key Programme:
# TNOs are Cool: A Survey of the Transneptunian Region

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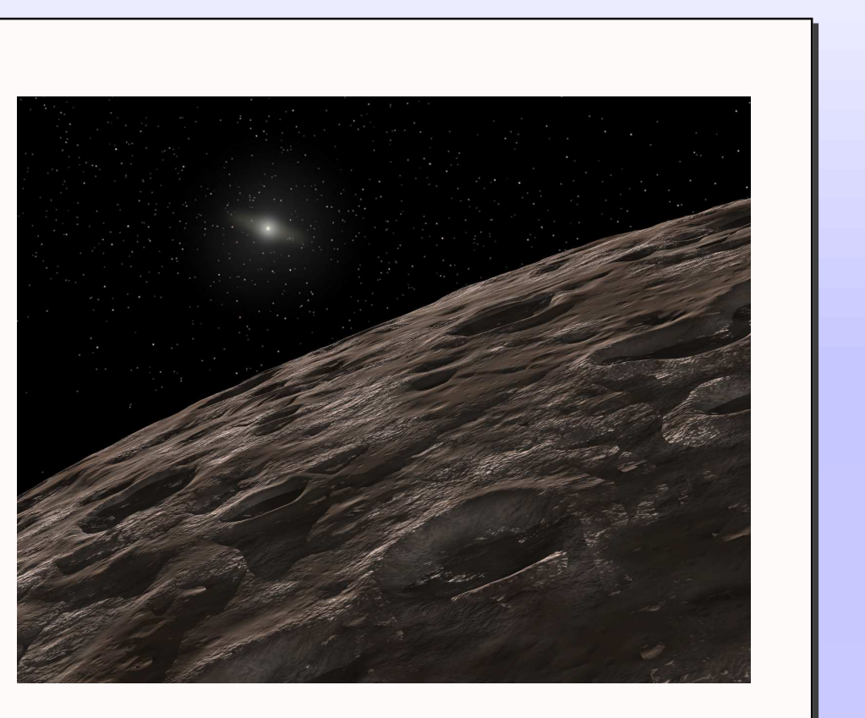
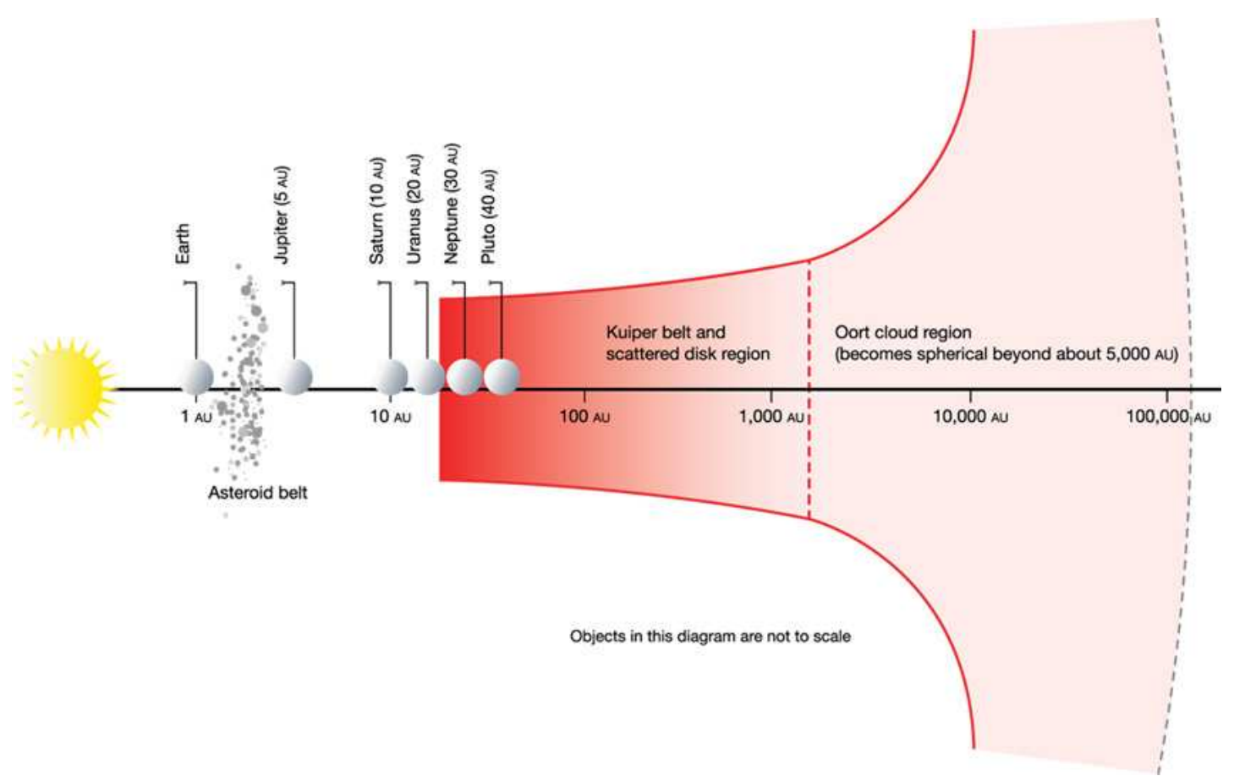


Credit: NASA/JPL-Caltech/T. Pyle (SSC)

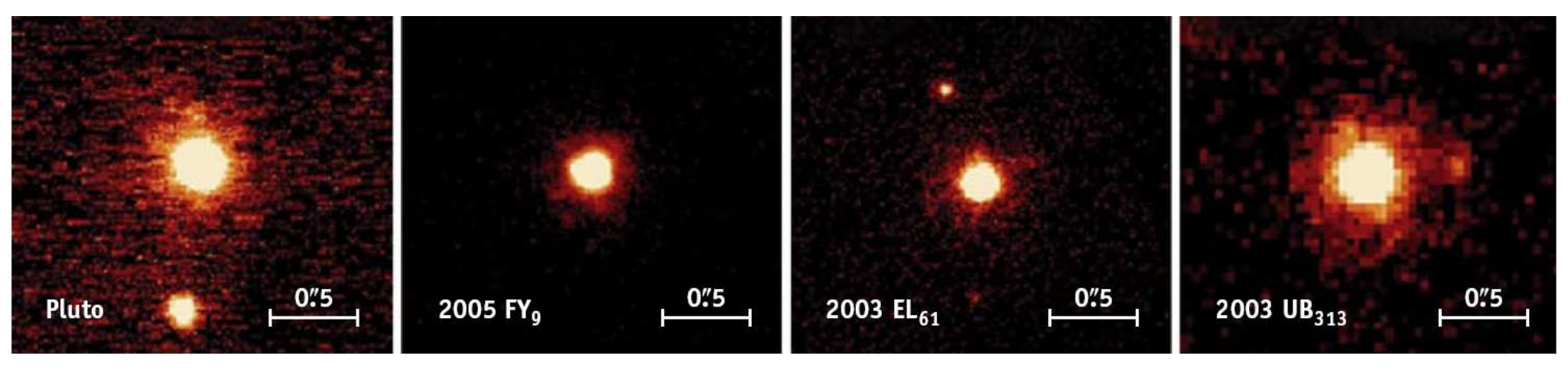
**Over one thousand objects have been discovered orbiting beyond Neptune. These trans-Neptunian objects (TNOs) represent the primitive remnants of the planetesimal disk from which the outer planets formed, and is an analog for unseen dust parent-bodies in debris disks observed around other main-sequence stars. The dynamical and physical properties of these bodies provide unique and important constraints on formation and evolution models of the outer Solar System. While the dynamical architecture in this region (also known as the Kuiper Belt) is becoming relatively clear, the physical properties of the objects are only beginning to be revealed. In particular, fundamental parameters such as size, albedo, density and thermal properties are difficult to measure. Measurements of their thermal emission, which peaks at far-IR wavelengths, offer the best means available to determine those physical properties. While Spitzer has provided the first results, notably revealing a large albedo diversity in this population, the increased sensitivity of Herschel and its wavelength coverage will permit profound advances in the field.**

**Within our accepted project we propose to perform radiometric measurements of 139 objects, including 25 known multiple systems. When combined with measurements of the dust population beyond Neptune (e.g. from the New Horizons mission to Pluto), our results will provide a benchmark for understanding the Solar debris disk, and extra-solar ones as well.**



A. Stern 2003, Nature

## Multiple TNO-systems



M. Brown et al. 2006, ApJ

## Main goals

**(i) A determination of the size distribution of the large (> 200 km) objects, thought to have remained unchanged from the accretion phase.**

**(ii) Systematic searches for correlations between size, albedo, and other physical and orbital parameters, diagnostic of formation and evolution processes.**

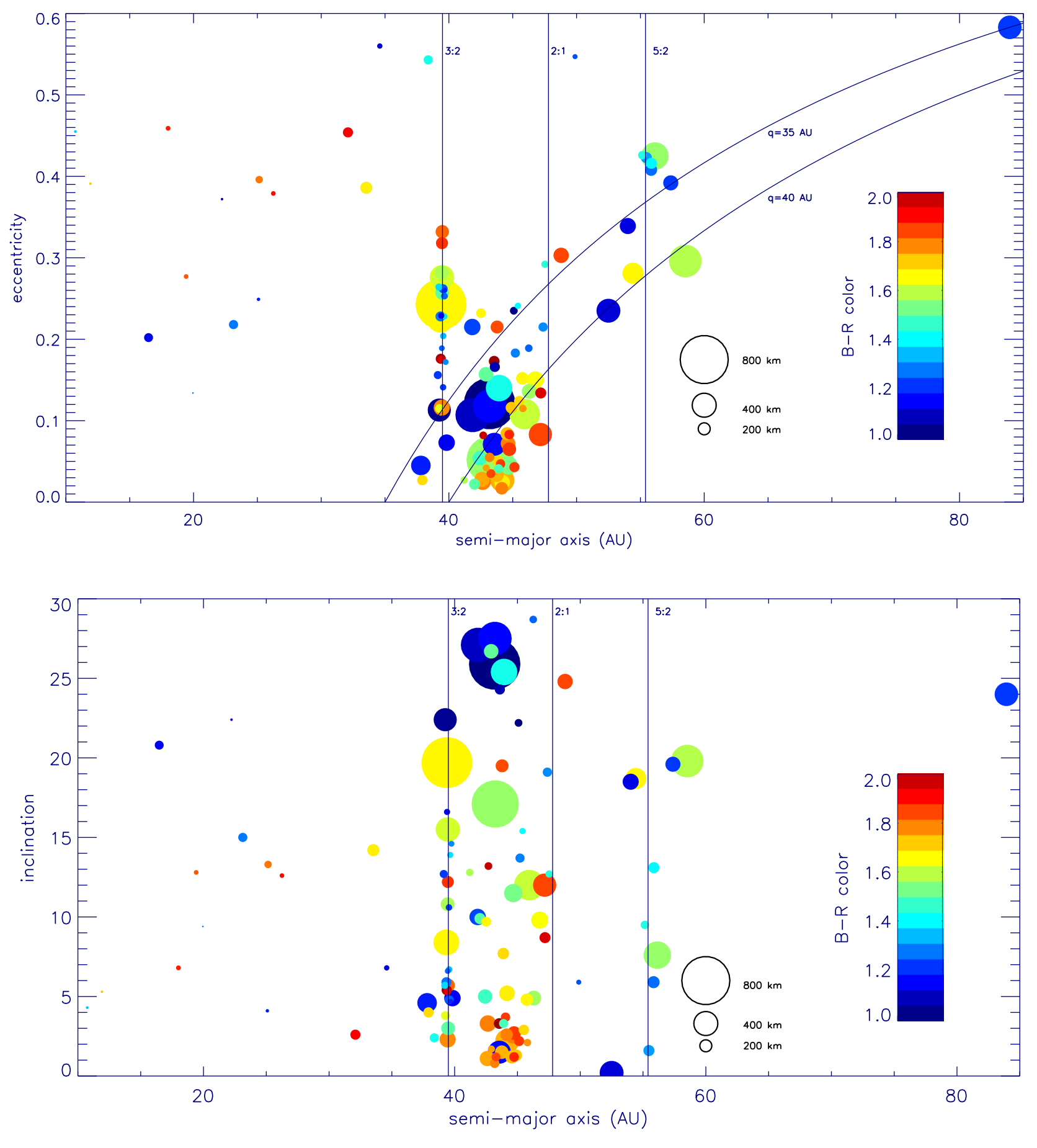
**(iii) Determination of mass-density for at least 20 binary TNOs, diagnostic of nebular chemistry and interior structure.**

**(iv) The first study of their thermophysical properties, including thermal inertia and surface emissivity.**

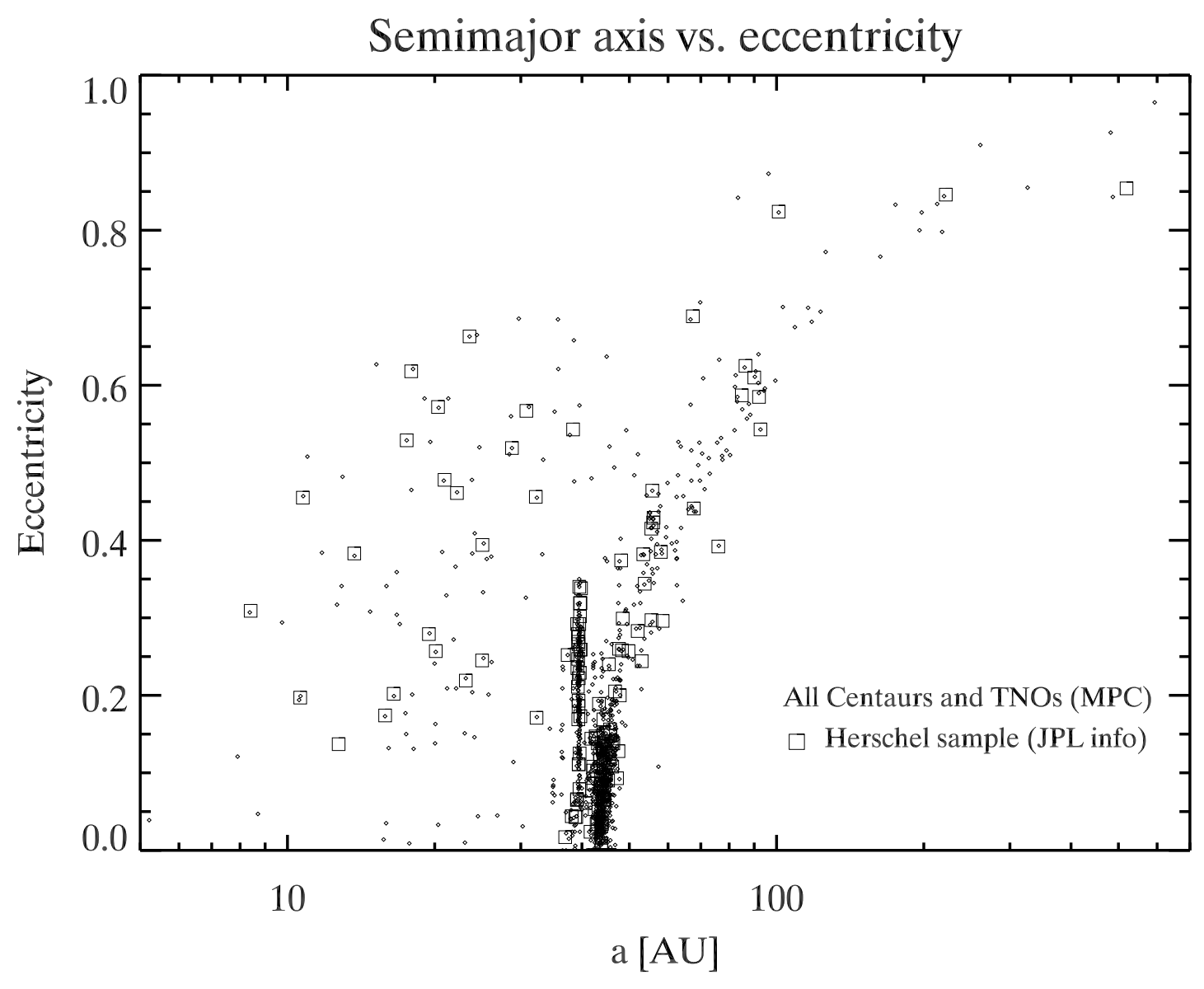
**→to "color" the picture of the outer regions of our solar system**

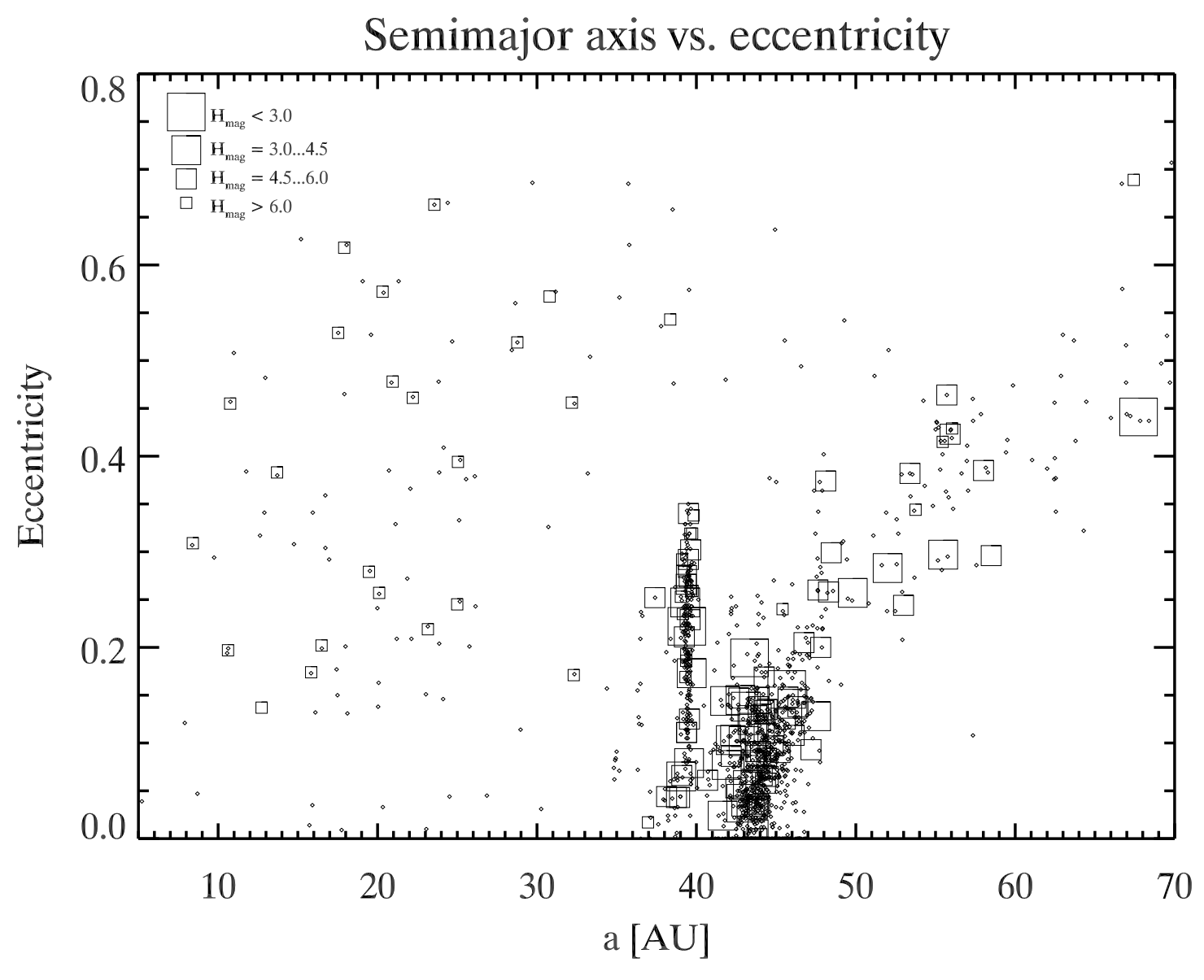
## Herschel TNO/Centaur Sample

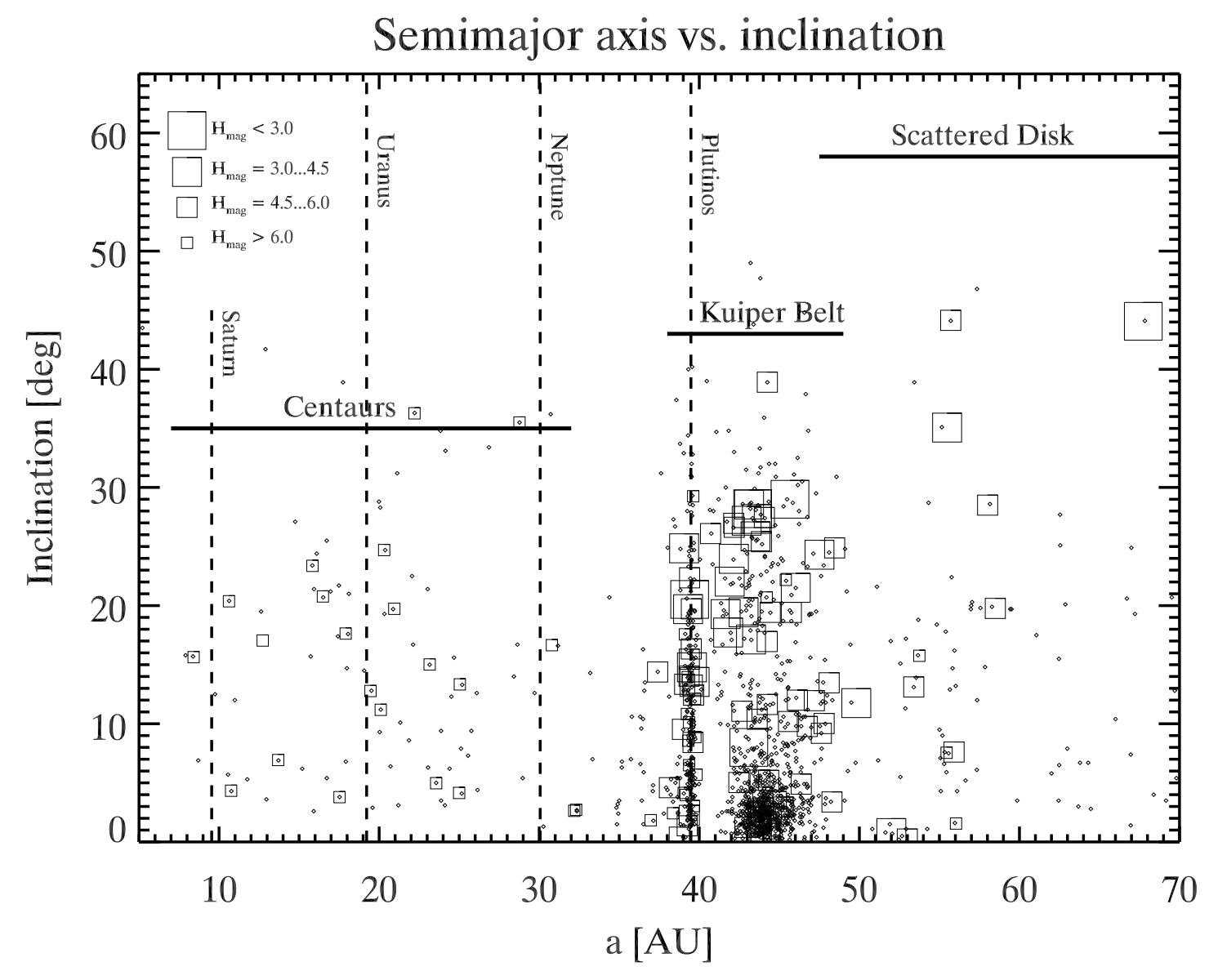
- 19 Centaurs (a < 30.1 AU)
- 118 TNOs (Classical & Resonant KBOs, SDOs)
- 2 planetary satellites (captured TNOs)



- Colors of TNOs and Centaurs (more than 100 objects) in the orbital eccentricity (top) and orbital inclination (bottom) vs. semi-major axis plane.
- The sizes of the symbols are proportional to the corresponding object's diameter (an average R geometric albedo of 0.09 has been assumed).
- Colors: B-R=1.0 (coded as dark blue) to B-R=2.0 (coded as red), the Sun has a value of 1.03 and 5145 Pholus about 2.
- 3:2 (a∼39.5 AU), 2:1 (a∼48 AU) and 5:2 (a∼55.4 AU) resonances with Neptune are marked, as well as the q=40 AU perihelion curve.
- A wide color diversity characterizes the outer solar system objects: objects with perihelion distances around and beyond 40 AU are mostly very red, classical objects (mostly between the 2:3 and 1:2 resonances) with high eccentricity (and also inclination) are preferentially neutral/slightly red, cold classical disk objects are red (low inclination, low eccentricity).
- No clear trend is obvious for SDOs (a > 50 AU) nor for the Plutinos (Doressoundiram et al. 2007, AJ 134, 2186).







## Herschel Observations/Modes/AORs

- 404 AORs: 374 × PACS-Photo & 30 × SPIRE-Photo, all observations are in *solar system tracking mode* (apparent Herschel-centric sky motion 0...21″/h)
- All AORs are *time-constrained* to schedule them when the targets are in low-confusion sky regions

### PACS (all targets)

- Chopped-nodded point-source photometry (3.5′ × 1.75′ FOV) in 2 categories: targets with estimated flux densities above and below 10 mJy
- 70/160 μm and 100/160 μm photometry are separated in time to limit risk of source confusion
- PACS concatenated point-source photometry (up to 21 AORs) for 6 selected TNOs to obtain dual-band thermal lightcurves (at 70/160 or at 100/160 μm)
- Expected S/N values > 10 (assuming a *5σ-1 hour point source detection limit* of ∼3 mJy) even for the faintest targets

### SPIRE (15 brightest targets)

- Large scan-map photometry at 250, 350 and 500 μm, array FOV 4′ × 8′
- Two concatenated scans, nominal speed (30″/s), 4′ length, 0′ hight
- Map orientation: *Array* (no sky constraint)
- Expected 5σ sensitivity for mapping (28...47 repetitions of A&B scans): <10 mJy in all 3 bands (targets have between 15 and 300 mJy at 250 μm)

## Sizes and Albedos

There are several fundamental motivations for measuring the size and albedos of a large sample of TNOs:

**First** , a detailed modelling of surface spectra requires a knowledge of the absolute albedo.

- ▷ without albedo, spectrscopy provides only semi-qualitative information on the presence of surface compounds
- ▷ pure ices are usually bright, a low albedo is indicative of a dark surface material (e.g. tholin, dark carbon) which is otherwise spectrally neutral.
- ▷ Modelling techniques (e.g. models by Hapke, Shkuratov and Muinonen) of surface spectra are available, potentially allowing a determination of the relative abundances of surface materials, grain size, and the state of mixing, but these can be applied only if the absolute reflectance is known.

**Second** , the observations will allow to establish the original size distribution in the Kuiper Belt and therefore provide constraints for formation models.

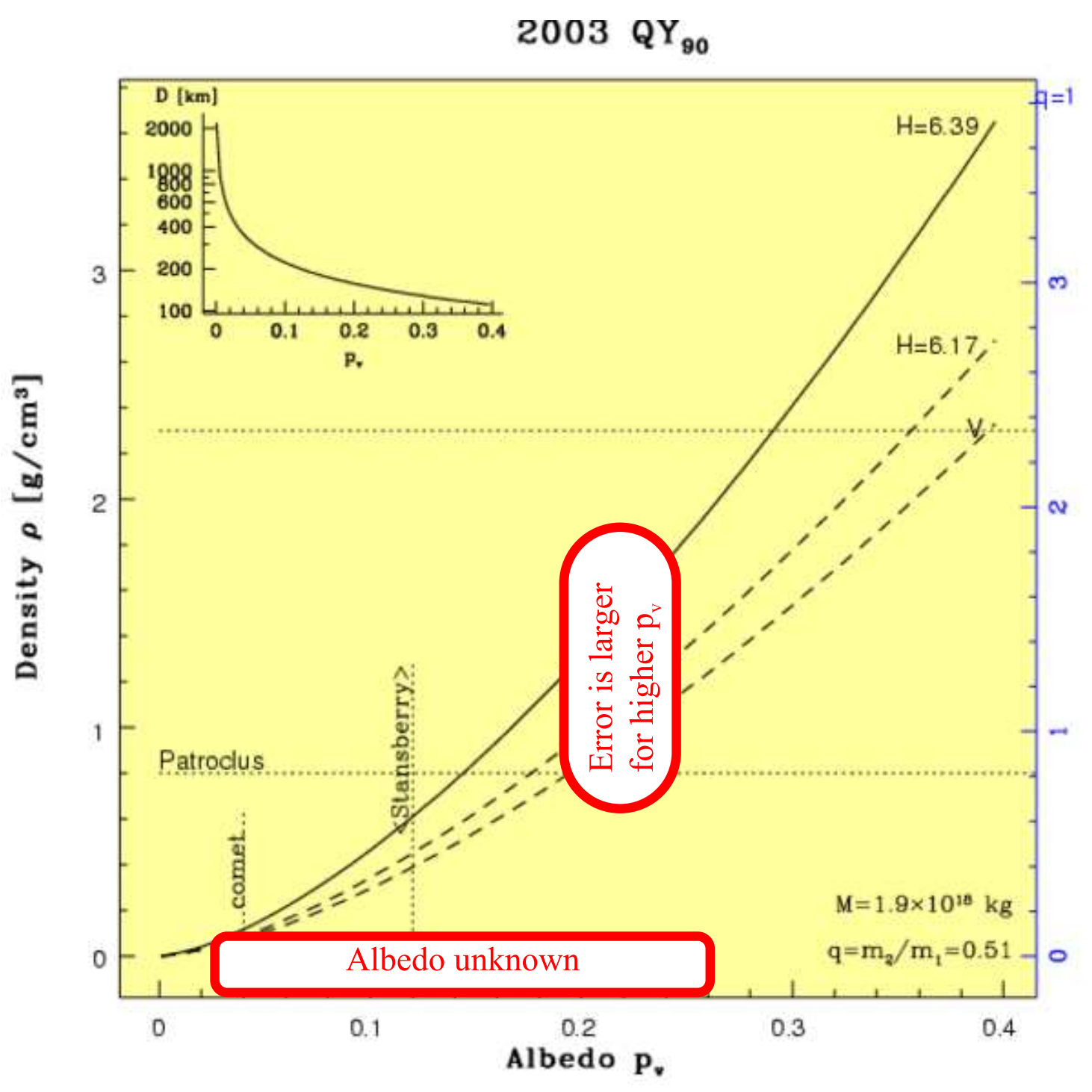
- ▷ Objects detectable with *Herschel* will be typically 100 km or more in diameter.
- ▷ These larger TNOs should reflect the primordial-size distribution, in contrast to objects smaller than ∼100 km which are slowly eroded by collisions (Stern & Colwell 1997; AJ 114, 841).

**Third** , correlations between size, albedo, colour, composition, and orbital parameters will be diagnostic of evolution processes.

- ▷ red objects may be expected to be dark, as the red colour is thought to be associated with space weathering, which also darkens surfaces if acting for long enough (order of 10 Myr).
- ▷ Objects that have experienced a higher impact rate, or recent impacts, may be intrinsically brighter (and bluer), since collisions may excavate fresh, un-weathered material from below the surface.

## Binaries

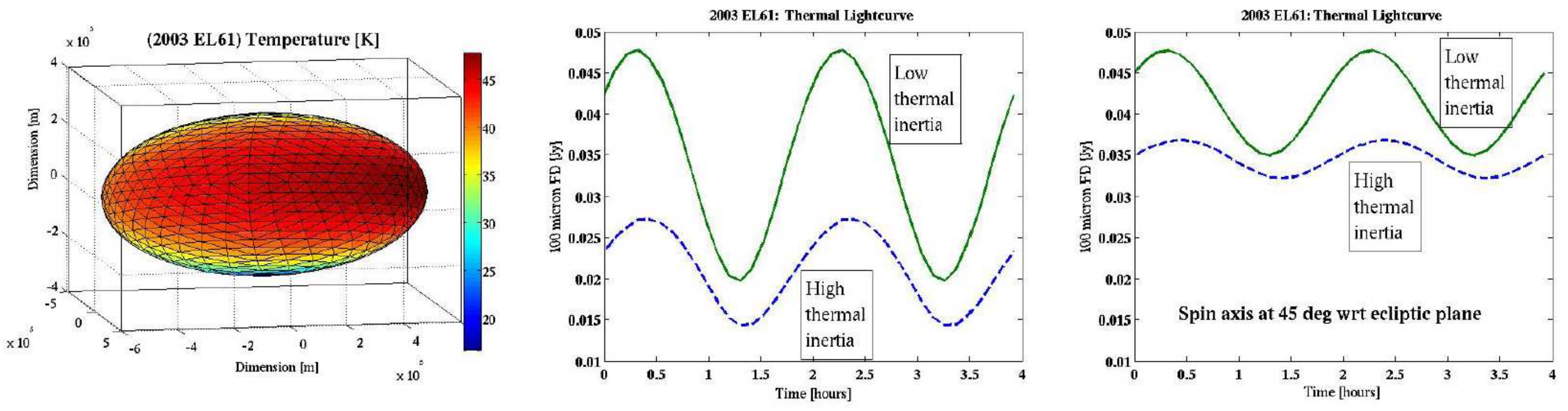
- Binary systems are common among TNOs, they are of particular interest:
  - ▷ (Herschel size) + (mass) ⇒ (system's average **bulk-density** $\rho$)
- At present this fundamental parameter $\rho$ is either uncertain, or unknown:
  - ▷ size and albedo are known for only the few largest TNOs (Spitzer)
  - ▷ density should not be derived from hypothetical hydrostatic equilibrium model
  - ▷ size is estimated from H, but in strong error ⇒ bad volume guess
  - ▷ at best we are left with a poor albedo-density relation
- With Herschel 25 systems in different populations will be observed. It will shed light to the composition and possibly the interior of these distant bodies.
- Herschel will bring information of the formation and evolution of TNOs. What is the fraction of icy bodies? are higher densities (sillicates) common for large bodies? is there any difference between the various dynamical populations?



**Caption:** Large uncertainty on bulk-density. The total mass of the system is known from the binary orbit, the mass ratio q is derived from the flux ratio between the components. Without Herschel, the diameter, volume and bulk-density are next derived from the D=D(H, $p_v$) relation, where the absolute magnitude H in the IAU (H,G) system can be severely wrong, and where $p_v$ is unknown. Herschel can provide the actual size needed to accurately derive the density.

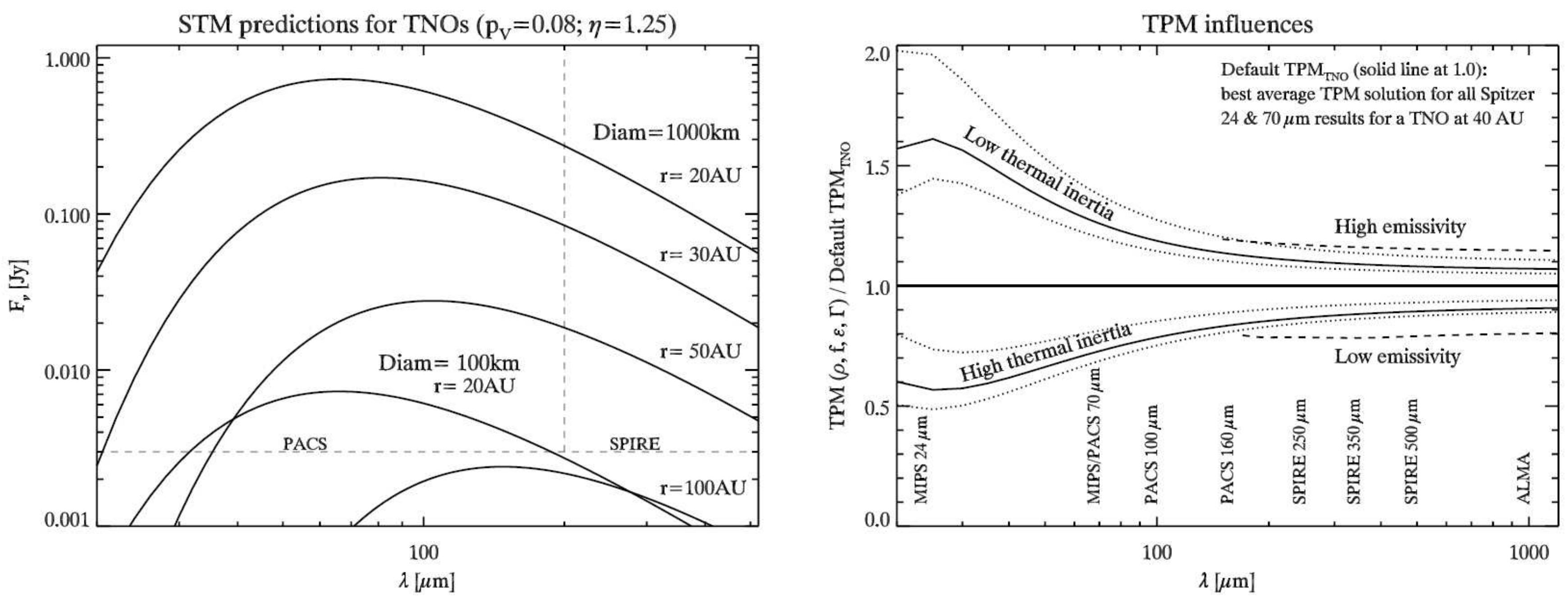
## Thermal Lightcurves

- About 25 TNOs exhibit measured lightcurves, i.e. repeatable variations of their visible magnitude with rotational phase
- With the exception of Pluto, which is spherical and has a lightcurve due to albedo spots, and a couple of bodies believed to be eclipsing contact binaries, these lightcurves are attributed to shape effects, and the degree of elongation is inferred from the amplitude of the lightcurves.
- Possible albedo variations on the surface are usually not accounted for when interpreting lightcurves
  - ▷ This may influence the determination of the axis ratios and induces an ambiguity in the rotation period.
  - ▷ This has important implications notably because constraints on the density can be derived from rotation periods and axis ratio.
- thermal lightcurves will provide, in addition to disentangling shape vs. albedo, constraints on thermal inertia



**Caption:** Left: Thermophysical temperature calculation for 2003 $EL_{61}$, as seen from *Herschel*. Thermal properties are based on Spitzer data (Stansberry et al. 2007; astro-ph/0702538), the shape information was taken from Rabinowitz et al. (2006; ApJ 639, 43). Based on such a model, thermal lightcurves can be predicted and the influences of surface properties, spin vector orientation and wavelength can be studied. Corresponding thermal 100 μm lightcurves for 2003 $EL_{61}$ are shown in the middle (spin vector perpendicular to the ecliptic plane) and right figure (spin axis at 45°).

## Thermal Modeling



**Caption:** STM and TPM predictions for a range of sizes, distances and thermal properties, model defaults are based on the best fit to all Spitzer TNO results. The thermal inertia causes major uncertainties at wavelengths below the emission peak, while the unknown emissivities affect mainly the sub-mm/mm range, the influence of extreme surface roughness conditions is indicated by dashed lines.

- Beaming factors of TNOs as a function of heliocentric distance, as measured by Spitzer
- The dotted curves are model calculations for a fast rotating (period = 2 hr) object with thermal inertia of 2, 5, 10, 20, and 100 $Jm^{-2}s^{-0.5}K^{-1}$, and a rotation axis perpendicular to the solar direction
- The long-dashed line indicates $\eta = 0.756$, which applies to objects with zero thermal inertia and a surface roughness similar to large MBAs

**Herschel observations at 70, 100 and 160 μm (+ 250, 350 and 500 μm for the brightest targets) will constrain the SED and therefore determine thermal inertia, surface roughness, emissivity, ....and provide reliable albedo and size solutions.**