Herschel’s view on the cool TNOs

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/Centaur detections with Herschel, >90% 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

$$D \propto 10^{H/5} p_V^{-1/2}$$

$$10r^2 \times 0.1 p_V$$

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
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 $\eta$
- The temperature distributions ($\eta$) include the combined effects of thermal inertia $\Gamma$, rotational properties, and surface roughness
- Thermal inertia $\Gamma$ can be derived via statistical spin properties
Thermal properties of Centaurs/TNOs

- Mean thermal inertia is $2.5 \pm 0.5 \text{ Jm}^{-2}\text{s}^{-1/2}\text{K}^{-1}$ only rough surfaces can explain the SED
- $\Gamma$-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 $\Gamma$s
- The results suggest extremely porous surfaces, significantly affected by radiative effects within pores (based on the decrease of $\Gamma$ with heliocentric distance)

Lellouch et al. 2013 + Poster P97
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Lellouch et al. 2013 + Poster P97
Dynamically cold and hot belt objects

- 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


Resonants

“cold” classicals

Credit: A. Doressoundiram

Volk & Malhotra 2011
Hot and cold classicals: different thermal properties

Indications for a different origin?
Hot and cold classicals: Size & Albedo

Dynamically cold

- 100-300 km: \(q=2.8\) (\(N=11\))
- 400-700 km: \(q=3.2\) (\(N=11\))
- 700-1100 km: \(q=3.7\) (\(N=5\))

Geometric albedo [0-45%]

- Median = 14%

Dynamically hot

- 100-300 km: \(q=3.0\) (\(N=8\))
- 400-700 km: \(q=3.2\) (\(N=11\))
- 700-1100 km: \(q=3.7\) (\(N=5\))

Geometric albedo [0-45%]

- Median = 9%

Vilenius et al. 2013 submitted
TNO Densities: derived from binary systems

- Pure H2O: < \( \approx 1 \text{ g/cm}^3 \)
- Methane ice: 0.5 g/cm\(^3\)
- Densities <1 g/cm\(^3\) require macro-porosity and/or very high ice/rock ratios
- Objects > \( \approx 500 \text{ km} \) all have densities above \( \approx 1 \text{ g/cm}^3 \) (Eris \( \approx 2.5 \text{ g/cm}^3 \), Pluto 2 g/cm\(^3\))
- Most of the smaller objects have densities below \( \approx 1 \text{ g/cm}^3 \)
- 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 160 µm

Delay thermal vs. optical
~19 min

Optical x 2.09

Optical LC

Phase uncertainty = ± 0.001

Mean = 9.70 mJy
Amplitude = 6.79 mJy
Thermal/Optical = 2.09
Expected LC amplitude
Observed LC amplitude

Santos-Sanz, in prep.
Varuna: extreme shape, strange lightcurve effect

Physical model

$D_{\text{eff}} = 540 \text{ km}$
$a/b = 1.60$
$b/c = 1.40$

$P = 6.3435674 \pm 0.0000005 \text{ h}$
$
u = 0.18$

Spin-axis from optical LCs
$\Gamma = 1 \text{ S.I.}$
Default roughness

Santos-Sanz et al. in prep. + Poster P102
Makemake: Cryovolcanos on the surface?

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

Strong IR-excess at 24$\mu$m

Very hot terrain needed without producing a noticable lightcurve!
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Results from an occultation event:
Object’s size: $1430^{+/-9} \times 1502^{+/-45}$ km
$p_V=0.77^{+/-0.03}$, no global atmosphere
(Ortiz et al. 2012, Nature)

combined with Herschel/Spitzer:
• very low thermal inertia
• dark band/spot are not very likely
• hot-spot(s) must have a similarly high albedo
$\rightarrow$ 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, ....)
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