The Kuiper Belt as the Context for Pluto. S. Fornasier[1] , M.A. Barucci[1] and M. C. Dalle Ore[2], [1] LESIA, Observatoire de Paris, Université PSL, CNRS, Univ. Paris Diderot, Sorbonne Paris Cité, Sorbonne Université, 5 Place J. Janssen, 92195 Meudon Pricipal Cedex, France (sonia.fornasier@obspm.fr); [2] SETI Institute, Mountain View, CA

Introduction: The Kuiper belt is populated by the Transneptunians Objects (TNOs), frozen leftovers from the formation period of the outer Solar System. More than 3000 TNOs have been discovered, including the dwarf planets Pluto, Eris, Makemake and Haumea. The investigation of the TNOs's physical properties is essential for understanding the formation and the evolution of the Solar System, and sheds light on the composition of the primordial protoplanetary disk, and, by extension, of other exoplanetary systems. The Kuiper Belt is sculpted in a complex manner as indicated by the presence of bodies with highly inclined and/or very eccentric orbits and the existence of distinct dynamical classes including classical, resonant, scattering, and detached objects [1]. The Kuiper Belt region seems to be the source both of short period comets and of Centaurs, thought to have been injected into their present unstable orbits by gravitational instabilities and collisions.

In this work we will give a state of the art overview of the physical properties of the Transneptunians and Centaurs, including composition, size, albedo, bulk density, and rotational and thermal properties.

Size, albedo and Thermal Properties: Knowledge of TNOs albedos and sizes is important to constrain the surface composition and understand the dynamical evolution of the outer Solar System. Size and albedo values, mostly derived from radiometric modeling of the thermal observations performed with Herschel, Spitzer and Wise, and a few from occultations, are available for a total of ~170 TNOs and Centaurs [2].

TNOs show a huge variation in geometric albedo (p_V) , including both extremely dark surfaces (p_V = 2-3%) and high reflective bodies (p_V > 50%). Globally, excluding the volatile rich bodies, transneptunians have dark surfaces with a mean albedo value of ~10%.

The size of TNOs ranges from a few tenths of a km to ~ 2380 km for the dwarf planet Pluto. The size distribution is affected by discovery and selection biases in thermal observations affecting the smallest TNOs, hard to detect and to characterize. Centaurs sizes range from ~1 km to ~240 km for Chariklo, but most of them are smaller than 120 km.

Average values for size and albedo have been analyzed for the different populations [3, 4, 5, 6]. Centaurs and Scattered Disk objects have both dark surfaces with similar albedo values (7%). In the Classical population the cold objects, i.e., those having inclination lower than 5°, have an higher albedo and a steeper size distribution than the hot classicals (i.e., those having higher inclination orbits). All cold classicals are smaller than 400 km, while the hot ones show a wider size distribution.

Models of the TNOs thermal emission permit to constrain surface properties such as thermal inertia, spin state, surface roughness, and emissivity. The so-called "beaming factor" (η), a proxy for the combined effect of thermal inertia, spin state and surface roughness, show a relative variability ranging from 0.34 to ~2.5, with an average value of 1.07 [7]. The thermal inertia derived from the η value using a statistical approach on the bodies spin rate and surface roughness is 2.5 ± 0.5 J m^{-2} $s^{-0.5}$ K^{-1} [7], that is 2-3 orders of magnitude lower than expected for compact ices. The TNOs emissivity has been found to decrease with wavelength in the submm and mm range from Herschel and Alma observations [8, 9]. This, together with the low thermal inertia value, indicates that TNOs have highly porous surfaces with absorption coefficients much stronger than those of pure water ice.

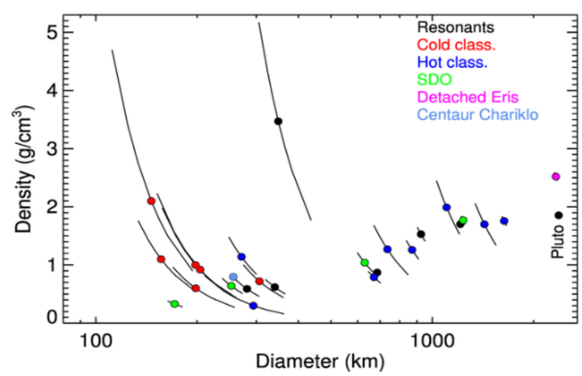

Figure 1*: Bulk density versus the effective diameter for 26 TNOs and the Centaur Chariklo [9, 10,11].*

Density : Density measurements are available for 27 binary/multiple systems, showing a clear dichotomy between relatively small and big objects (Fig. 1) : transneptunians smaller than 400 km have densities lower than that of water ice (with median value of 0.79 g cm^{-3}), while those bigger than ~750 km have all density higher than 1 g/cm^3 , indicating a larger rock to ice ratio and less porosity. The huge variation in density, by a factor of ~5, between small and large bodies may be related to different formation location/times/processes of large TNOs and dwarf planets compared to smaller bodies.

Composition: Good spectra in the visible and near-infrared are available for a limited number of objects and only about 50 of them (TNOs and Centaurs) show clear or possible absorption features. Others show almost featureless spectra, which make any attempt at deriving surface compositions particularly challenging.

The visible part of the spectrum is generally featureless, with the exception of methane enriched bodies and of a few TNOs showing absorption bands attributed to aqueously altered minerals [12, 13]. The presence of hydrated minerals is intriguing. They may have been produced by post-accretional heating processes such as cryovolcanism or impacts on ices, or they may have condensed directly in the solar nebula, considering that they are also observed on debris disks and in the interplanetary dust.

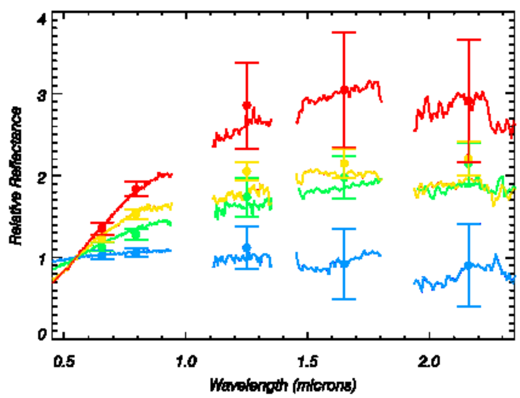

***Figure 2**: Four mean TNOs spectra, normalized at 0.55 µm, corresponding to the BB (in blue), BR (in green), IR (in yellow) and RR (in red) taxonomical classes [14], with the associated mean photometrical data in reflectance [15].*

The visible spectral gradient has huge variations from neutral to steep spectral slopes, making some of these objects among the reddest in the solar system. This indicates a variety in the surface composition of the outer Solar System bodies. Red spectral slopes can be associated with the presence of organic or other irradiated compounds. On the basis of the colors four main taxonomical classes have been identified, the BB, BR, IR and RR classes with increasing color values from BB, almost neutral-sloped surfaces, to the RR, the reddest objects [14, 15].

The near-infrared observations in the range 1-2.4 micron are the most diagnostic to detect the presence of ices and volatiles. Three main kind of surfaces have been detected [16]:

(i) water-ice rich (about 30 objects) showing absorption bands at ~1.5 and 2 micron. Most of those having high S/N ratio also show the 1.65 micron band indicating that the water ice is in the crystalline state. This requires temperatures T > 100 K, well beyond the environmental temperature of the Kuiper belt. The heating could have occurred by impacts or generated in the deep interiors. Water ice rich objects are found in all the dynamical classes, and the abundance of water ice is correlated with the objects size.

(ii) volatile-rich bodies including methane and/or nitrogen or methanol. Pluto, Eris, Makemake and Sedna all show spectra dominated by methane ice, pure or diluted in nitrogen. Methanol has been detected in ultrared bodies like (5145) Pholus, (55638) 2002 VE_{95}, and Sedna. The methanol signature is considered an indication of a chemically primitive surface and methanol is an abundant component of active comets and of the interstellar medium. Orcus and Charon show the ammonia band at 2.25 µm. The presence of ammonia has been suggested to be the result of a flow of ammonia-rich interior liquid water onto the surface.

(iii) featureless bodies, with different spectral gradient, indicating surfaces enriched in carbon or in organics. Irradiation processes are thought to be responsible for these properties as all these objects are supposed to have been originally composed of ices.

Correlations between physical and orbital parameters and compositions have been investigated and will be presented. The lesson learned by Pluto for the other TNOs will be also discussed.

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