PHYSICAL STUDIES OF TRANS-NEPTUNIAN OBJECTS AND CENTAURS: RECENT PROGRESS.

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Introduction: Discovery of a population of small bodies beyond Neptune opens new horizons in the Solar system study. At present more than 1300 objects beyond the orbit of Neptune have been discovered. Trans-Neptunian objects (TNOs) are considered to represent one of the oldest and most primordial populations in the Solar system. Understanding of their origin is impossible without knowledge of physical properties of these bodies which put important constraints on the formation and evolution history of the early Solar system environment. Thanks to using very large ground-based (8-m VLT, 10-m Keck) and space telescopes (Hubble, Spitzer) the number of TNOs for which information on physical properties is available has essentially increased last years. A review on methods of physical study of these remote objects, their limitations and obtained results is given.

Photometry: It is the only technique which can be applied to the majority of discovered TNOs. Broadband BVR color indices were measured for more than 200 objects. They revealed a great color diversity and made possible to search for statistically significant correlations between colors and orbital properties of TNOs. A classification of TNOs and Centaurs based on their broadband colors has been proposed using the same approach as for asteroid taxonomy [2].

Observations of the short-term photometric variability are the main source of information on rotation and shapes of TNOs. Reliable data on rotation periods have been obtained for about 30 objects. A wide range of rotation periods and lightcurve amplitudes has been found.

Study of magnitude phase dependences is restricted by the small phase angle range of ground-based observations which is typically less than 2° for TNOs increasing to 7°–8° for Centaurs. The first phase curve observations have shown considerable opposition brightening with a steep phase slope and a narrow opposition surge at extremely small phase angles below 0.1°. These data together with polarimetric phase curves give a first look into the microscopic properties of the surface layers and suggest different surface properties of TNOs as compared to less distant small Solar system objects.

Polarimetry: Measurements of the linear polarization degree were made for about 10 TNOs and Centaurs. The observational data show a noticeable negative polarization varying from –0.3% to –1.4%. The minimum of the negative polarization branch measured for the Centaur Chiron occurs at small phase angles less than 2° [1]. A possible trend is found between the negative polarization degree and the geometric albedo resembling that for asteroids.

Spectroscopy: About 50 objects have been observed spectroscopically but high-quality spectra were obtained only for brightest of them. The visible and the near-infrared spectra of TNOs and Centaurs vary from the featureless to that having rather strong absorptions due to water ice. Signatures of the presence of other ices such as methane, methanol and nitrogen have been also found. The interpretation of spectral data is typically based on comparison with a synthetic reflectance spectra calculated for mixtures of several different components with various grain sizes. Such modeling can give very similar fits to the data however the result is not unique strongly depending on assumption of grain sizes, albedo etc. [3].

Radiometry: Measurements of thermal emission are widely used to determine sizes and albedos of small bodies. Due to low temperatures of TNOs surfaces (30–50 K) their thermal emission is very weak and reaches the blackbody peak at about 100 μm. First radiometric measurements of brightest TNOs using ground-based telescope were not able to give reliable size estimations. Considerable improvement in the applying of the radiometric method to determine sizes of TNOs has been achieved with the Spitzer Space Telescope. The thermal emission at 24 and/or 70 μm has been measured for more than 40 objects. To derive their diameters and albedos the modified standard thermal model is applied in which the beaming parameter is considered as a free parameter. The obtained data demonstrate a wide range of albedos of TNOs and suggest possible correlations of their albedo with orbital distance and size [5].

High-resolution imaging: This technique has been applied to search for satellites of TNOs. At present more than 50 binaries have been found among TNOs which is about 15-20% of the studied objects [4]. The most part of these discoveries were made using the Hubble Space Telescope. Study of binaries gives a possibility to determine the total mass of the system and to derive object's density when an independent size estimation is available.

Conclusions: Despite the difficulties in study physical properties of TNOs and Centaurs due to their remoteness and faintness a progress in this field is impressive. The obtained data gives a first look into the chemico-physical structure of the Kuiper belt.

References: [1] Bagnulo S. et al. (2006) *Astron. Astroph. 450*, 1239-1248. [2] Barucci A. et al. (2005) *Astron. J. 130*, 1291-1298. [3] Barucci A. et al. (2008) *In: The Solar System Beyond Neptune* (A. Barucci et al., eds.), Univ. Arizona Press, Tucson, 143-160. [4] Noll K. et al (2008) *Icarus 194*, 758-768. [5] Stansberry J. et al. (2008) *In: The Solar System Beyond Neptune* (A. Barucci et al., eds.), Univ. Arizona Press, Tucson, 161-179