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Surface Properties of neutral TNOs

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Abstract

Trans-Neptunian Objects (TNOs) are important as early solar system relics that can tell us about dynamical and chemical processes in the disk and in the population of small bodies in the solar system. TNOs are expected to be isolated and inactive (because activity has never been seen at such large heliocentric distances), which leads to very red optical colors compared to the Sun. However, a surprisingly large fraction of TNOs have neutral colors characteristic of resurfaced bodies. To investigate the resurfacing mechanism and better understand the physical and chemical processes of the early solar system, we are conducting a survey to determine surface properties of these neutral TNOs. Here, we present preliminary results from five of our survey targets.

1. Introduction

Trans-Neptunian Objects (TNOs) are remnant planetesimals orbiting beyond Neptune which formed in the ice-rich outer solar system. TNOs are important relics that have preserved information about early solar system processes and environment [1]. Dynamical, compositional, and physical information (size, albedo, density, porosity, surface colors, and spectra) from observations of these bodies has already reshaped our understanding of early solar system dynamics [2, 3] and allowed dynamical models to be compared to the current planetary architecture, chemical disk models, and disk observations. TNO studies also provide critical information on interrelations between small solar system bodies and may eventually be applicable to extrasolar planetary systems [4].

2. Peculiar Colors

As of May 2011, there are ~ 160 TNOs with measured visible photometric colors. TNOs are expected to become red with time due to irradiation of ices and organics by cosmic rays and high energy EM radiation [5, 6]. However, the current distribution shows that $\sim 13\%$ of these targets possess neutral colors [$V - R < 0.52$; 7, 8].

There are two leading theories that address the cause of unusually neutral TNO colors: collisional resurfacing and comet-like outgassing. In collisional resurfacing, impactors excavate and expose the icy, pristine subsurface; uncontaminated ices have blue spectral reflectances. In comet-like outgassing, solar radiation gradually penetrates the regolith and reaches subsurface water ice, then excess energy causes structural rearrangement (annealing) which releases gases trapped since TNO formation [9].

3. Our Survey

To help reveal key surface properties of neutral TNOs, we are conducting a survey for surface homogeneity by looking for rotational variation in color of neutral TNOs. Our color variation survey is a powerful diagnostic in many ways:

1. The presence or lack of color variation helps discern between competing theories that address the cause of the unusually blue and neutral colors. Presence of color variation suggests a nonhomogeneous resurfacing event, which could be either an impact crater or a cometary jet, while lack of color variation on a blue object implies a uniformly fresh surface, which is most likely due to global outgassing. Collisional studies provide key constraints and direct observational comparisons to dynamical models. Cometary activity at the large heliocentric distances in the Trans-Neptunian belt has never before been detected and would have immense implications about the TNO environment and their formation. Both explanations of neutral TNO colors offer unique insights into their formation, nature, and environment.

2. To determine color variation over rotation, the spin period must be measured. The shape of the spin period distribution carries TNO structural implication. For example, if collisions are

important in TNOs' dynamical history, and if TNOs have a low density and a rubble-pile structure, their spin periods are expected to cluster around the critical period, below which objects spin apart. Only 20 TNO spin periods have been measured to date (Fig. 1), so the true shape of the distribution is poorly determined [10]. Our data will assist in determining the light curve distribution's shape.

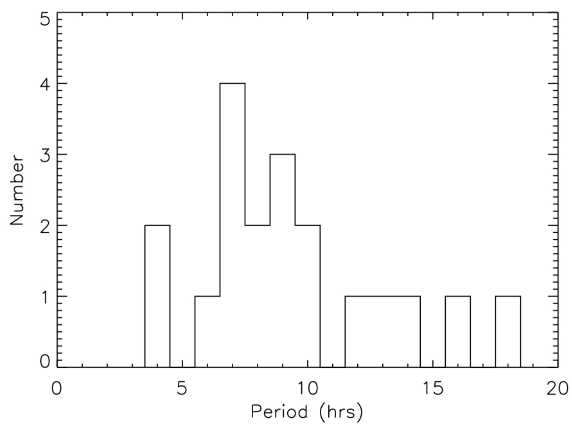

Figure 1: Distribution of 19 of the 20 known TNO rotation periods [excluding Pluto with a period of 153 hours; 9]. Poor sample size makes statistical analysis concerning rotation periods unreliable.

3. If a blue patch caused by collisional events is detected, we can use techniques of [11] to determine the size of the patch. Determining the patch size allows us to infer the impactor size and the object's collisional history. Because these objects are likely to have blue patches (both resurfacing theories can produce this phenomenon), we can construct the first distribution of impactor sizes. Dynamical formation models predict a specific distribution of impactor sizes, and an observational counterpart to the theorized distribution would provide checks on these dynamical models [*e.g.,* 2, 3].

4. Additional data from our survey at diverse phase angles in multiple broadband filters will help determine the phase curves. By determining the phase curve's shape at different wavelengths, especially within the opposition surge at very small phase angles ($\alpha < 0.5°$), one can constrain key surface properties such as porosity, texture, grain size, and complex refractive index [12, 13]. To date, only 22 TNOs optical phase coefficients for the linear part of the phase curve (β) have been determined, very few in the blue regime [14, 15, 12, 16].

Here, we present preliminary color curves and light curves for five objects in our sample: Cubewano 2002 MS_4, Plutinos 2001 QF_{298} and 2004 EW_{95}, and Haumea family members 2002 TX_{300} and 1995 SM_{55}. Our data suggest that 1995 SM_{55} may exhibit color variation. We also comment on the updated phase curves of each object including our data.

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