ROTATION PROPERTIES OF NEUTRAL TRANS-NEPTUNIAN OBJECTS.

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Introduction: Trans-Neptunian Objects (TNOs) are a belt of small bodies with orbits that lie beyond Neptune. Because of their large heliocentric distances and relatively small sizes, TNOs are remarkably well-preserved compared to other small body populations. Despite being supposedly isolated and inactive over their lifetimes, roughly 1/3 of TNOs have neutral colors typically indicative of fresh surfaces, giving them the most diverse color distribution in the solar system so far measured [e.g., 1,2]. Some theories addressing the cause of the neutral colors predict that resurfaced TNOs should have heterogeneous surfaces - e.g., the collisional resurfacing theory, in which impacts excavate the fresh subsurface [e.g., 3]. Other color diversity theories predict globally neutral colors - e.g., initial composition differences, in which TNOs form on either side of certain ice condensation lines, producing long-term irradiation products with differing colors [e.g., 4].

To help discern between these competing theories, we conducted a search for surface homogeneity in neutral TNOs by looking for variation in the color as the object rotates. We divided this campaign into two surveys: (1) the Brightness Variation Survey (BVS) – sparse, single-band lightcurve sampling of neutral TNOs to determine which have detectable variation and can therefore be meaninigfully explored for color variation; and (2) the Color Variation Survey (CVS) – dense, two-band lightcurve sampling of targets chosen for follow-up through from the BVS. Determining color variation through lightcurves also allowed us to identify binaries (which have unique lightcurve features) and constrain the TNO shape and spin distributions (which can be used to infer collisional history). Here, we describe the surveys, present the results, and compare them to other small body populations.

The Surveys: We obtained 50 usable nights of *V* and *R* band photometry on the University of Hawaii 2.2-meter Telescope using both the Tek CCD camera and the imaging capabilities of the Wide Field Grism Spectrograph 2. The observations began in August 2009 and concluded October 2012. We observed 38 neutral TNOs during the BVS and 9 during the CVS. Photometry was performed using the tphot algorithm described in [5] and magnitude calibration was done using Sloan Digital Sky Survey (SDSS) magnitudes for field stars, when available. When SDSS data were not available for the target fields, magnitude calibration was done using observations of Landolt standard stars.

Analysis and Results:

Updated Amplitude Distributions. We used the Kolmogorov-Smirnov (KS) test to show that neutral and red TNOs have statistically similar amplitude distributions (Fig. 1). We confirmed the size-amplitude correlation described in [6], [7], and [8] and found that at some diameter larger than 200-400km, TNOs become notably more spherical. The amplitude distribution for all TNOs is statistically different from that of Trojan and Main belt asteroids (MBAs) to greater than 3σ, regardless of the size regime explored, with Trojans and MBAs typically having higher amplitudes than TNOs (Fig. 1).

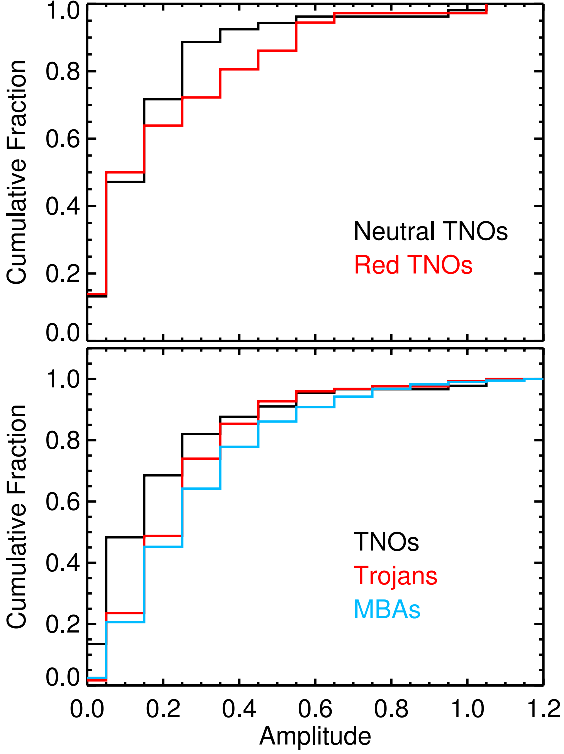

Figure 1: Updated cumulative fraction distributions for neutral vs. red TNOs (top) and all TNOs vs. Trojans and MBAs (bottom).

Updated Spin Distributions and Color Variation. Another KS test showed that neutral and red TNOs have statistically similar spin distributions, in agreement with the updated amplitude distribution and suggesting that neutral and red TNOs share the same primary rotation properties. Our results also showed that TNOs have weakly similar spin distributions to Trojans and MBAs (with the probability of dissimilarity being 2.6σ and 1.4σ, resp.), with TNOs generally having shorter rotation periods. However, this result could be affected by a strong observational bias against detecting slowly spinning TNOs. We did not find evidence of a size-spin rate correlation. We were able to constrain rotation periods for 7 of the 9 objects observed in the CVS, one of which (2003 OP_{32} – a Haumea collisional family member) has the fastest rotation period measured for an outer solar system object at 2.4 or 2.6 hours (Fig. 2). From this rotation period, we calculate a minimum density of 1900 kg/m^3, corresponding to a maximum ice fraction of 55%.

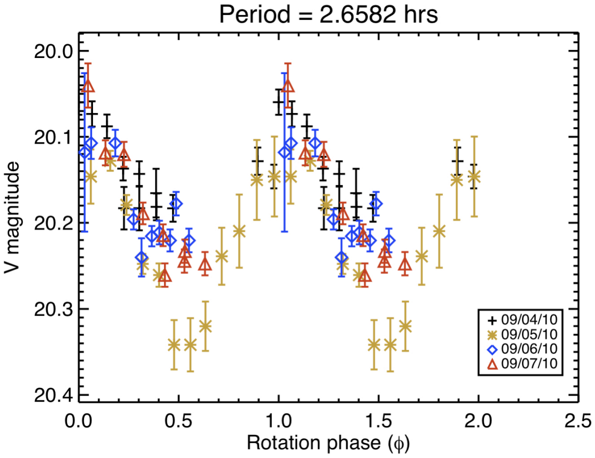

Figure 2: Phased lightcurve of 2003 OP_{32} from data taken over 4 consecutive nights, showing one of two possible solutions, the other being ~2.4 hrs.

Binary Discoveries. We did not detect any close or contact binaries during the BVS, though our survey efficiency for contact binary detection was only ~6%. In the CVS, however, lightcurves of 4 of the targets showed multi-day offsets from the primary rotation signature, which can only be explained by either an asynchronous or eclipsing binary system. Of these four binary detections, two were previously known to be binaries, and the remaining two are Haumea family members, making them the first binaries detected within an outer solar system collisional family. From this, we calculate a debiased TNO binary fraction of >24% for binary component separations of 0.04 ± 0.02″.

Color Variation. We detected color variation to ≥ 3σ on 5 of our 9 CVS targets. For 3 of these 5, however, the variation corresponds to the multi-day offset attributed to a companion, thereby implying that the companion is a different color from the primary, rather than the primary having a variegated surface.

Conclusions: The rotational similarities (in amplitude and spin period) between red and neutral TNOs suggest that they had a common collisional history, thus refuting collisional resurfacing as a mechanism for producing neutral TNOs. The dissimilarities in rotation properties between TNOs and Trojans/MBAs suggests different collisional histories. If TNOs do not share a collisional history with these two populations, then TNOs and Trojans/MBAs had different origins, assuming subsequent dynamical evolution for those small body populations was negligible compared to the turbulent environment of the early solar system. Such a finding would provide evidence against Trojans being TNOs that were scattered during early dynamical evolution and then captured by Jupiter.

Our detection of another fast rotator (2003 OP_{32}) and inference of two asynchronous or eclipsing binaries within the Haumea family provides interesting constraints on the dynamical environment that must have existed while the family was forming. The binary fraction computed for separations to which we were sensitive in the CVS was in agreement with the trend found by [9] of an increased binary fraction toward smaller component separations. The binary fraction distribution including our results is, as before, mostly consistent with the [10] binary formation model using dynamical friction.

We detected color variation associated with the primary object in 2 of the 9 CVS targets. Therefore, we cannot draw definitive conclusions from color variation as to the mechanism responsible for the neutral colors observed on some TNOs.

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