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Constraining Neptune's Migration: Cold Classicals in the 2:1 Resonance?

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Abstract

The small bodies in the outer Solar System, called trans-Neptunian objects (TNOs), have a variety of surface types and orbital classifications. The cold classicals, which formed in situ, and the dynamically excited objects, which were likely scattered into their current locations, have distinct surface types. These surface types can be robustly identified using photometry in the combination of g, r, and z bands. We investigate the 2:1 resonance, which is located just outside the cold classical belt, to see whether this resonance harbors trapped cold classical surfaces. These would have been captured during a period of smooth sweeping migration by Neptune. We have acquired photometry of 17 of our 34 targets in 2018, and our results exclude a slow smooth sweeping of the entire cold classical region by Neptune's 2:1 resonance.

1. Introduction

There is significant evidence that the early Solar System underwent a period of dynamical instability, during which the giant planets migrated and scattered/swept small bodies from their formation locations into their current orbits in the outer Solar System [e.g., [5]; [6]]. The specifics of this instability are preserved in the surface properties and orbital characteristics of the TNOs, particularly those in resonance with Neptune. The recent large characterized TNO surveys with carefully recorded discovery biases (Canada-France Ecliptic Plane Survey: CFEPS [8, 9]; Outer Solar System Origins Survey: OSSOS: [2]; and Alexandersen 2016 [1]; collectively referred to hereafter as the OSSOS+ surveys) now provide a tool for testing the specifics of planetary migration scenarios.

The current cold classical TNOs are generally thought to be the remnants of a population which formed in situ; they have semimajor axes between $\sim$42–47 AU with low inclination and low eccentricity orbits. The cold classical TNOs have physical properties that distinguish them from other TNO populations, including albedos [3, 11], binarity [7], and colors [10]. **The critical recent discovery of the unique surface color reflectance of cold classical surfaces in g, r, and z bands (see Figure 1) [10]** means it is now possible to use photometry to securely identify TNOs with cold classical surfaces in other regions of the Kuiper belt, emplaced during planetary migration.

2. Planetary Migration

As Neptune migrated outward to its current location, its 2:1 resonance swept, jittered, or jumped across the cold classical region of the Kuiper belt. A smooth, sweeping migration would trap cold classical objects into the 2:1 resonance). Some period of smooth migration is necessary to produce the 'blue binary' population [4]. 2:1 objects captured by smooth resonance sweeping of the cold classical belt will have surface reflectances in the red region of Figure 1. In contrast, if the 2:1 is dominated by objects which scattered into the resonance, their surface properties would match the dynamically excited populations in the Kuiper belt, the black points in Figure 1. Thus, the g-r and r-z color distribution of the objects in Neptune's 2:1 mean motion resonance will place a robust constraint on how much Neptune's 2:1 resonance smoothly swept over the cold classical Kuiper belt during planetary migration, hence providing a limit on the distance and nature of Neptune's final stages of migration.

2.1. Results and Conclusions

We combine migration simulations with photometry of a sample with known discovery biases (OSSOS+) to measure the intrinsic fraction of cold classical objects trapped in the 2:1 resonance. We have acquired g, r, and z band photometry of 17 of our 34 targets on the Large Binocular Telescope (LBT), using the Large Binocular Camera (LBC Red and Blue) and the multi-object double imager (MODS 1+2). Our results already exclude the most efficient sweeping scenario: a slow sweeping migration across the entire cold classical region. Our team will be observing the 6 remaining A-semester targets in May 2019, and we have applied for time in 2019B to complete the project and determine the intrinsic fraction of cold classical surfaces trapped in Neptune's 2:1 resonance.

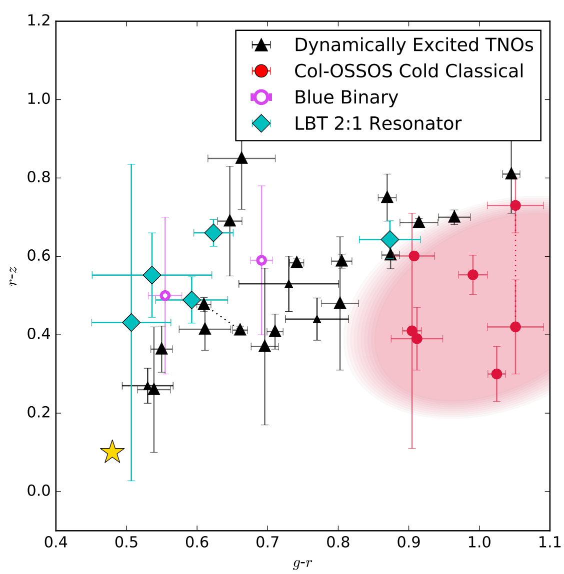

Figure 1: Figure: Colors of dynamically excited TNOs (black triangles), cold classical TNOs (solid red circles), and blue binary cold classical objects (pink circles) which were implanted into the cold belt. Figure is adapted from Pike et al. 2017, with additional data from the 2:1s from LBT (cyan diamonds). Solar colors are indicated by the star. The cold classical objects clearly occupy a separate clump, indicated by the red shaded area, and can be identified using grz photometry.

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