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Reality and origin of the Kernel of the classical Kuiper Belt

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Abstract

The Canada-France Ecliptic Plane Survey (CFEPS) obtained characterized observations of 321 sq.deg. of sky to depths in the range g ∼23.5 - 24.4 AB mag, providing a database of 169 trans-neptunian objects (TNOs) with high-precision dynamical classification and known discovery efficiency. Using this database, we find that the main classical belt (a=40–47 AU) needs to be modeled with at least three components: the ‘hot’ component with a wide inclination distribution and two ‘cold’ components (stirred and kernel) with much narrower inclination distributions.

The existence of the kernel poses strong constraint on models of the early solar system. We will present a sequence of events that can lead to the presence of the observed dynamical structure.

1. Introduction

The discovery component of the CFEPS project [1, 2] imaged 321 square degrees of sky, almost all of which was within a few degrees of the ecliptic plane. Discovery observations were acquired using the Canada-France-Hawaii Telescope (CFHT) MegaPrime camera which delivered discovery image quality (FWHM) of 0.7 - 0.9 arc-seconds in queue-mode operations.

We characterized the magnitude-dependent detection probability of each discovery block by inserting artificial sources in the images and running these images through our detection pipeline to recover these artificial sources. The TNOs in each block that have a magnitude brighter than that block’s 40% detection probability are considered to be part of the CFEPS *characterized sample*.

Tracking during the first opposition was done using the built-in followup of the CFEPS project. Subsequent tracking, over the next 3 oppositions, occurred at a variety of facilities, including CFHT.

Of the 196 TNOs in our CFEPS characterized sample 169 have been tracked through 3 oppositions or more (ie. not lost) and their orbits are now known to a precision of $\Delta a/a < 0.1\%$ and can be reliably classified into orbital sub-populations [3].

2. The Kernel

Our data demand that the main classical Kuiper belt (a=40–47 AU) is represented by at least three components. These components are a population with a wide inclination distribution (the *hot* population) superposed on top of a *cold* population with narrow inclination component. With the qualifier that there will be mixing from the low-i tail from the hot component, we must split the ‘cold’ population of the main classical belt into two sub-components to account the transition in the e/i distribution beyond a ≃44.4 AU clearly visible in Fig. 1. The *stirred* population have orbits with a narrow-inclination distribution with semi-major axes starting at a=42.5 AU and extending to $a \simeq 47$ AU, with a range of eccentricities that increases as one goes to larger a. There are more low-i and moderate-e TNOs per unit semimajor axis at $a \sim 44 - 44.5$ AU than at smaller and larger semi-major axis, indicating that a third component is required. To model this component we insert a dense low-inclination concentration, which we call the *kernel*, near a=44 AU to account for this intrinsic population.

3. Discussion

We favor the idea that this cold component is primordial (the objects formed at roughly their current heliocentric distances), although this is not required.

The primordial distance range of the cold population is difficult to constrain. The inner boundary at a=42.4 AU may have been eroded via scattering by massive bodies and resonance migration; an important condition is that any sequence of events cannot allow

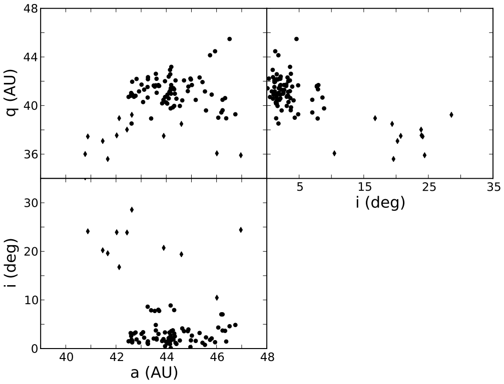

Figure 1: Multiple 2D projections of (a, q, i) orbital elements of the CFEPS main classical belt objects. (a, q): upper left; (a, i): lower left; (i, q): upper right. Solid circles are for objects with $i < 10°$. Solid diamonds are for $i \geq 10°$. This cut is introduced only to allow identification of large-i TNOs in the (a, q) plot.

either the inner belt, or the mean-motion and secular resonances that probably migrated through it, to have preserved a cold component today. The coincidence of the stirred population's outer edge with the 2:1 resonance suggests to us that the kernel marks the original outer edge and that the larger-a cold objects have either (i) been dragged out of the $a < 44.4$ AU region via trapping and then drop-off in the 2:1 as it went past or (ii) due to weak scattering out of the $40 < a < 44.4$ AU region. Perhaps the edge of the original cold population around 45 AU may be explained by the global evolution of solid matter in turbulent protoplanetary disks [4], although an even-more extreme density contrast may be needed at ∼30 AU to prevent Neptune's continued migration outward [5]. Sharp drops in surface density are commonly observed in protoplanetary disks at about this 30–50 AU scale [6].

There is an issue with a primordial origin of the cold population at this location. The on-ecliptic mass density of this population is extremely low and it would be difficult to form multi-hundred km TNOs in a low surface density environment. This may not be impossible due to recent work on forming planetesimals big [7], which can be favored by external photoevaporation [8], and may be supported by the fact that it appears that there are simply no cold objects larger than $H \sim 5$; all the larger objects are in the other populations which may come from closer to the Sun where the mass density was higher.

We will present preliminary dynamical simulations detailling the previous sequence of events, showing what are the required order and direction of motion of hte various mean motion and secular resonances that allow the existence of the kernel.

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