National Aeronautics and Space Administration

Provenance of the Plutinos

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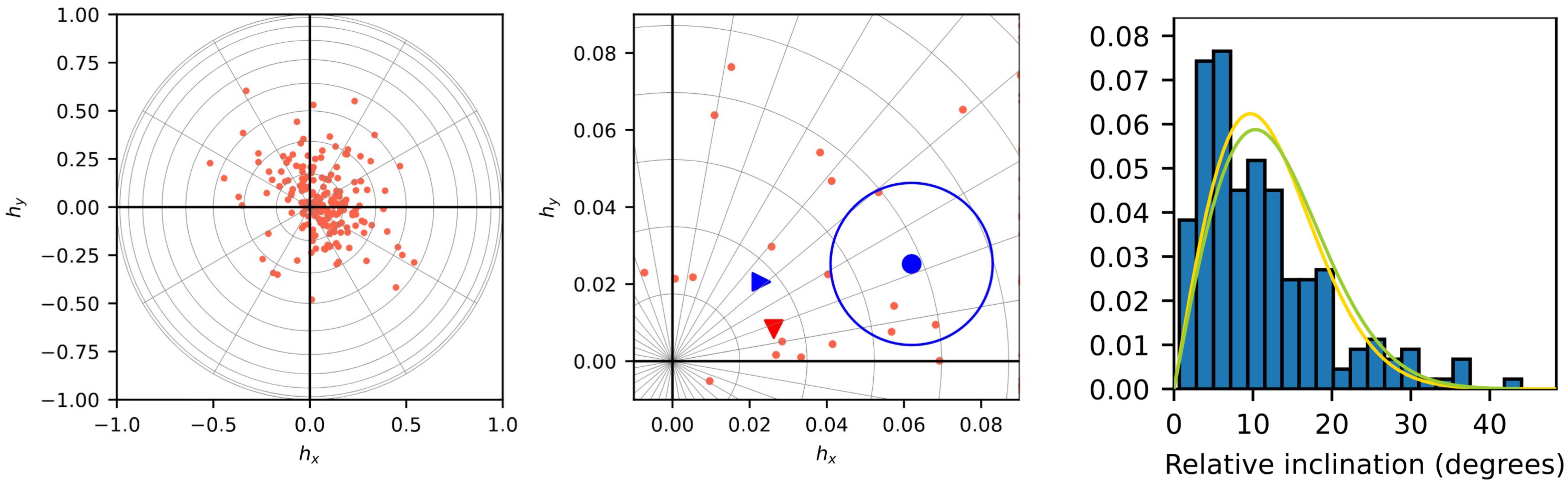
Strategic Focus Area: Solar system origin, structure and evolution

Objectives: The "Plutinos" are a prominent dynamical subgroup of the Kuiper belt, locked in the 3/2 mean motion resonance (MMR) with Neptune. Plutinos are thought to have been captured by a migratory Neptune in the early history of the Solar system. In this project, we investigate the distribution of orbit poles of the Plutinos.

Background: The Kuiper belt hosts the largest population of primordial planetesimals and is a source of short period comets. It is hypothesized that the planetesimals beyond Neptune that survived the giant planet migration epoch in the early history of the Solar system, more than ~4 Ga, and should be found piled up in eccentric orbits in external mean motion resonances (MMRs) with Neptune, particularly in the 3/2 and the 2/1 MMRs. The observed high abundance of Kuiper belt objects in Neptune's resonances, especially the "Plutinos" in the 3/2 MMR, has been interpreted as proof of Neptune's outward migration and has led to the wide acceptance of the hypothesis of giant planet migration as a core part of the history of the Solar System. Moreover, this migration is implicated in the bombardment history of the terrestrial planets, including the Earth and Moon. Thus, understanding the origins of the Plutinos will inform theoretical models of the dynamical history of the solar system. The distribution of the orbital and physical parameters of the Plutinos are only now becoming amenable to more detailed study with discoveries of statistically significant numbers of Kuiper belt dynamical subgroups, making this a timely investigation.

Approach and Results: Small bodies in the solar system have a wide dispersion of orbit pole orientations, posing a challenge to dynamical models of solar system origin and evolution. To characterize the distribution of orbit poles of dynamical groups of small bodies it is useful to have a functional form for a model of the distribution function. Previous studies have often used the small-inclination approximation and adopted variations of the normal distribution to model the dispersion of orbital inclinations. Because the orbital plane orientation is a directional random variable, orbit pole distributions can be more appropriately and accurately modeled with directional statistics. We describe the von Mises-Fisher (vMF) distribution on the surface of the unit sphere for application to solar system small bodies' orbital plane distributions. We apply it to model the orbit pole distribution of the observed sample of the Plutinos. We find a mean pole given by μ=[0.062,0.025,0.998] (in the J2000 reference frame). The 95% confidence cone of the mean pole has a half-angle of 1.2°. This vMF distribution is similar to a Rayleigh distribution of the inclinations relative to the mean pole, with width parameter of about 10°. Unlike previous models, the vMF model naturally accommodates the full—and only the full—range of inclinations, whereas Rayleigh or Gaussian models must be truncated to the physically limited inclination range 0–180°. Further work is needed to harmonize the vMF model with methods of mitigating systematic error in the mean pole measurement.

Significance/Benefits to JPL and NASA: This research will expand the expertise of the JPL small bodies research group to the study of the dynamics of the Kuiper belt. This work also extends JPL leadership in the study of the outer Solar system, which is a field that will soon experience rapid growth in the era of LSST/Vera Rubin Observatory and other upcoming large astronomical surveys. KBOs are a foundational destination for potential future JPL missions, and the University Arizona has extensive experience with spaceflight missions making this partnership both natural and strategic for capturing future Discovery and New Frontiers proposals. The University of Arizona is a longstanding strategic partner for JPL.



Left: Plutino orbit poles projected in the ecliptic plane. Longitude lines are drawn at 30° intervals and latitude circles are drawn at 10° intervals from the ecliptic pole to the equator. **Middle:** Detail near the origin. Longitude lines are drawn at 10° intervals and latitude circles are drawn at 1° intervals starting from the ecliptic pole. Orbit poles of individual Plutinos are indicated with the red points. The vMF mean pole is the blue point, surrounded by a blue 95% cone. The invariable pole of the solar system is the red downward-pointing triangle. The orbit pole of Neptune is the blue rightward-pointing triangle. The ecliptic pole is at the origin. **Right:** Histogram of the Plutino orbit inclinations relative to their vMF mean polei s shown in blue, with a bin size of 2.2°. The vMF relative inclination probability distribution function is shown as the yellow curve, and the truncated Rayleigh probability distribution function of is shown as the green curve

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