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Dynamical evolution of Haumea collisional family: Clues on the collision physics, new family members and implications for the outer solar system

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Abstract

Recently, the first collisional family consisting of Haumea and other nine trans-neptunian objects (TNOs) was identified in the trans-neptunian belt. Here, we modeled the long term orbital evolution of an ensemble of family fragments over 4 Gyr. We obtained collisional families (with ~60-75% survival rate) that reproduced the currently known Haumea's family. These objects concentrated in wide regions of orbital elements in the belt and populated the four main dynamical classes of TNOs (classical, detached, resonant and scattered). In addition, the great majority of fragments displayed negligible long term orbital variations, implying that the orbital distribution of the intrinsic Haumea's family can constrain the orbital conditions and physics of the collision that created the family billions of years ago.

1. Introduction and Methods

Trans-neptunian objects (TNOs) orbiting in the trans-neptunian belt (or Edgeworth-Kuiper belt) carry precious information about the origin and evolution of the solar system. More recently, the first collisional family was identified in the belt, thus providing evidence of the importance of collisions between TNOs. The family consists of the dwarf planet (136108) Haumea (formerly 2003 EL61) located at semimajor axis, a ~ 43 AU (currently locked in the 12:7 mean motion resonance), and at least nine other ~100 km-sized TNOs located around a = 42-44.5 AU. Haumea is also one of the largest TNOs known to date, with an estimated diameter of ~1500 km. The nine family members concentrate in orbital elements at a = 42-44.5 AU, q = 37-39 AU and i = 24-29° and share the peculiar C-depleted and H_2O ice rich surface spectra with Haumea's. Here, based on current knowledge of the family and asteroidal collision physics, we modeled the long term orbital evolution of an ensemble of fragments with varied sizes after the collision that created Haumea's family over 4 Gyr. Three realistic scenarios of kinetic energies carried by the fragments were considered, represented by mean ejection velocities v_{eje} = 200, 300 and 400 m/s. Each theoretical family of fragments was modeled with 1600 particles, whose orbits were evolved for 4 Gyr under the gravitational perturbation of the giant planets and the most massive family members in supplementary calculations). We also tested other model parameters.

2. Main results

First, we obtained collisional families that reproduced the currently known family even for varied initial conditions. In particular, ninety percent of the fragments survived the integrations concentrated in wide regions of orbital elements about the initial impact location: Δa ~ 6-11 AU, Δe ~ 0.1-0.17 and Δi ~ 7-11°, where the particular size of the spread was proportional to the v_{eje} used in the model. Most of the survivors populated the so called classical and detached regions of the trans-neptunian belt, whilst a minor fraction entered the scattered disk reservoir (<1%) or was captured in Neptunian resonances (<10%). In addition, except for fragments located near strong resonances (such as the 5:3 and 7:4 resonances), the great majority of fragments displayed negligible long term orbital variations. This implies that the orbital distribution of the intrinsic Haumea's family can constrain the orbital conditions and physics of the collision that created the family billions of years ago. We also estimate that approximately 25-40% of the original Haumea family was lost due to planetary ejections or collisions over the age of the solar system.

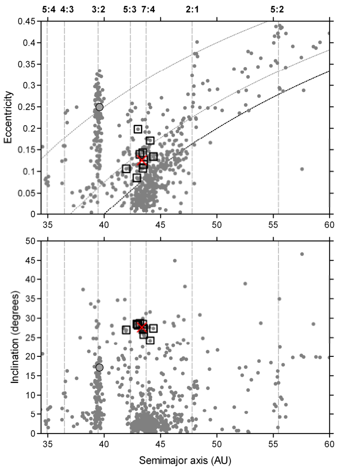

Figure 1: The orbits of 759 TNOs (gray circles) with small orbital uncertainties taken from the Asteroids Dynamic Site, AstDyS. Pluto is the gray closed circle. Currently known members of the Haumea collisional family are denoted by squares. The supposed location of the giant impact that originated the family is marked by the red cross. The location of Neptunian mean motion resonances are indicated by vertical dashed lines. The 12:7 resonance is located at ~43.1 AU, between the 5:3 and 7:4 resonances.

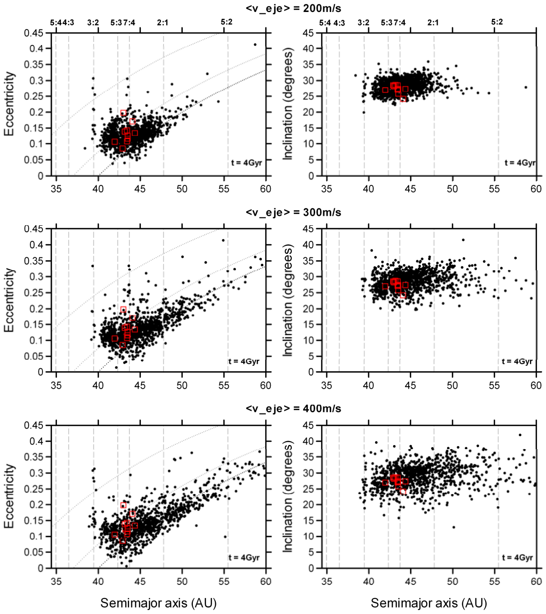

Figure 2: The orbital distributions in *a*-*e*-*i* element space of representative theoretical Haumean collisional families after 4 Gyr for the three main scenarios considered in this work, modelled with ejecta fragments following a mean ejection velocity of 200, 300 and 400 m/s. Currently known Haumea collisional family members are shown with red squares.

3. Summary and Conclusions

- We can reproduce the orbital distribution of the currently known members of the Haumean collisional family. However, the model suggests that the family fragments appear spread over a wide range of orbital elements: Δa ~ 6-11 AU; Δe ~ 0.1-0.17; Δi ~ 7-11°. This provides predictions for new family members with future observations.

- The orbital diffusion of the stable theoretical family fragments over 4 Gyr is extremely small. Therefore, the observed orbital distribution of Haumea's family can be used to draw conclusions about the nature of the collision that originated the family.

- The theoretical family fragments were found to populate all four dynamical classes within the trans-neptunian belt: classical and detached (majority), resonant (<10%), and scattered (<1%). In particular, the fraction of resonant fragments is sensitive to the timing of the collision and orbital history of Neptune.

- If the ejection velocities of the fragments are strongly dependent on their size, the larger fragments will likely be more tightly clustered in orbital element space than their smaller counterparts within the trans-neptunian belt.

- Approximately 25-40% of the fragments acquired unstable orbits, and were subsequently lost from the solar system. However, we do not expect slowly diffusing unstable fragments to contribute significantly to the currently known populations of Centaurs and short period comets.

Acknowledgements

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