EPSC Abstracts
Vol. 13, EPSC-DPS2019-2041, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

On the Origins of Haumea's Collisional Family

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Abstract

The Kuiper Belt Object Haumea is a dynamical and geophysical challenge. Its observed elongated shape, rapid rotation rate, and high density despite a pure water ice surface composition suggest a complex evolutionary history. Haumea belongs to a collisional family whose origin is poorly understood, and whose orbits are inconsistent with current formation models. Based on recent modeling including Haumea's internal differentiation, we propose a new hypothesis for the origin of Haumea's collisional family.

1. Introduction

The Kuiper Belt Object (KBO) and dwarf planet Haumea has a mass of 4.006 x 10^{21} kg [1], and its shape is a nonaxisymmetric, triaxial ellipsoid with its semiaxes estimated at a = 1161±30 km, b = 852±4 km, and c = 513±16 km with a mean density estimated at 1885 kg m^{-3} [2], despite having a pure water ice surface [3]. It also rotates remarkably fast P=3.91531±0.00005 hours [4] making it the fastest-rotating large (>100 km) body in the solar system. Because of this rapid rotation and its association with a collisional family [5], Haumea is thought to have suffered a large collision [5] >3 Gyr ago [1]. That created its collisional family of pure water ice fragments [1], and its two modern satellites [6].

The sequence of events that led to Haumea's current state and collisional family are poorly understood, One model suggests that there was a large impact event with a similarly-sized object early in proto-Haumea's history that stripped away its ice mantle [5]. This model accounts for the Haumea's rapid spin rate, the 12:7 resonance with Neptune, and the spectral similarities of the Haumea family members ("Haumeans"), but cannot account for their small velocity dispersion (140 m s^{-1}) [5]. Another model suggests the initial impact with Haumea created a large, temporary proto-satellite of Haumea that tidally migrated outward before being disrupted by another impact that formed the Haumeans [7]. In this model the proto-satellite's orbital velocity is likely to move the collision center to the point where Haumea's 12:7 resonance becomes unlikely, and it does not predict the number-size-velocity distribution of the observed Haumeans [8]. Finally, the graze-and-merge model [9] posits that a KBO similar in size to proto-Haumea collided with it, remained gravitationally bound, and then they reimpacted at a slower velocity and merged with proto-Haumea. The high rotation rate caused material to spin off that eventually became the Haumeans. Although this model could use updating, it can reproduce the number-size-velocity distribution of Haumeans [8,9]. The orbital elements of the Haumeans don't match any model in detail, even after accounting for interlopers, or ejecting Haumeans over the course of its heliocentric period [8]. Our purpose here is to present a new hypothesis for the origin of Haumea's collisional family.

2. Recent Results

2.1 Shape and Structure

In recent work [10] we used the kyushu code to model the internal structure of Haumea as a rapidly rotating, differentiated fluid in hydrostatic equilibrium, constrained by Haumea's occultation shadow [2]. We constrained Haumea's axes to be a≈1050 km, b≈840 km, and c≈537 km, with mean density 2018 kg m^{-3} and constrained Haumea's core to have axes a_c≈833 km, b_c≈723 km, and c_c≈470 km, with a core density of ρ_c= 2680 km m^{-3}. This also implies that Haumea's ice mantle ranges from 71 to 170 km in thickness and accounts for roughly 17% of Haumea's mass [10].

2.2 Haumea's Thermal Evolution

We have previously modeled the thermal evolution of KBOs similar to proto-Haumea and post-impact Haumea [7]. Assuming that Haumea formed from the graze-and-merge scenario [9], differentiation would begin after ~70 Myr and would be complete after several hundred Myr. If the bodies merged during this time, their cores and mantles would merge with some loss (~13%) of ice, and post-impact further differentiation would grow Haumea's core and decrease its moment of inertia. The ice mantle would then nearly completely melt, and hydrothermal circulation of this water would fully hydrate the rocky core within ~40 Myr [11]. Assuming a pyroxene / olivine core, serpentinization would lead to an 8% decrease in density (to around 2900 kg m^{-3}) and an expansion in core size radius to 673 km, increasing Haumea's moment of inertia.

3. Collisional Family Formation

Based on these results, we suggest the following series of events that could explain the formation of the Haumeans and reconcile the observations of Haumea's axis ratios, mass, and spectral signature with the Haumeans' orbital properties (Fig. 1):

1. A partially differentiated proto-Haumea endured a large impact event that spun it up to a high angular velocity.
2. Haumea continued to differentiate, which increased its high angular velocity.
3. Fragments spun off from Haumea's equator eventually formed the ring, its moons, and the collisional family members.
4. After ~10^8 yr, Haumea's core serpentinized and expanded, slowing Haumea's spin to its current state.

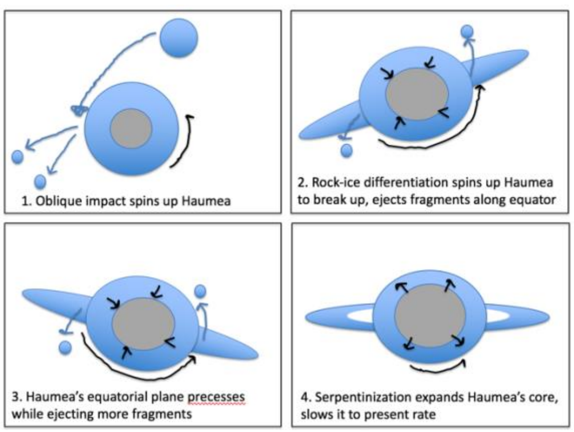

Figure 1: Series of events in our suggested model of Haumea's collisional family's formation.

Briefly: once an impact places Haumea near break-up, internal geophysically-driven changes in its moment of inertia may be sufficient to induce mass shedding. If this shedding ejects objects episodically and/or over long timescales, it could potentially match the observations in a way not considered by [9].

4. Future Work

We will use the IcyDwarf code [11] to investigate whether post-impact Haumea can undergo thermal evolution consistent with the proposed hypothesis. We intend to present details on how much Haumea can slow down after serpentinization. In addition, we will estimate whether it was near breakup in the past.

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