PROBING THE INTERNAL STRUCTURE AND HABITABILITY OF ICY WORLDS USING HAUMEA.

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Introduction: The habitability of mid-sized (R~ 400-800 km) icy satellites depends on whether subsurface ocean liquids exist inside them, and whether that liquid can circulate through a radiogenically heated, porous core. Constraining the density of an icy world's core would indicate whether the core was unaltered, and likely non-porous olivine (~3.3 g cm^{-3}) or aqueously altered, porous clays (~2.9 g cm^{-3}). The cores of most icy worlds are not accessible, but it may be possible to constrain the density of the core of the unique Kuiper belt object Haumea.

Based on its rapid rotation (3.92 hr), multiple satellites, and the presence of a collisional family, it is inferred that Haumea suffered a major impact [1]. Haumea's mass and mean radius of about 718 km [2] imply a high mean density of 2.58 g cm^{-3}, but its surface is spectrally pure (> 98%) water ice [3,4]. This suggests Haumea is differentiated into a rocky core and icy mantle, and that the impact stripped the outermost layers, revealing a core and thin veneer of ice.

Despite its uniform icy surface, Haumea's light curve shows a large (Δm~0.3) photometric variation over its rotation period [2,5,6]. Haumea's light curve and thermal emission have been successfully modeled assuming Haumea is a triaxial ellipsoid [2,5-7]; the most recent study [9], which resolved Haumea from its moons, found radii 960x770x495 km, and axis ratios b/a = 0.80 and c/a = 0.52. These ratios and Haumea's rotation period are consistent with a Jacobi ellipsoid of homogeneous density ~ 2.6 g cm^{-3} [2,5-7]. However, the fact that Haumea has a rocky core and icy mantle violates the assumption of homogeneous density.

We present preliminary results of our numerical modeling of Haumea's shape and axis ratios for various core densities and ice shell thicknesses, constrained by Haumea's size and mass. By matching the axis ratios against its light curve, we aim to set upper limits to Haumea's core density; if ~ 2.9 g cm^{-3} or less, Haumea's core would have to be cracked and aqueously altered.

Methods: Using the pkdgrav *N*-body code [8,9]. we modeled Haumea as a gravitationally bound aggregate of 10,000 particles with no tensile strength (rubble pile). We allowed the aggregate to gravitationally settle, then adjusted the masses of the particles to create rocky interiors and icy mantle matching Haumea's total mass (4.006×10^{21} kg [10]) and density. The aggregate was then spun to Haumea's rotation period.

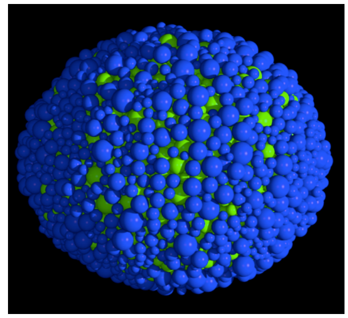

Figure 1 Simulated model of Haumea (S2); rocky core (ρ~3 g cm^{-3}, green particles) and an icy crust (ρ=0.917 g cm^{-3}, blue particles). The aggregate evolved from a sphere to this oblate spheroid. This view is looking down the b axis, the axis ratios are b/a = 0.99, and c/a = 0.75.

We determined the aggregate's axis ratios in three scenarios, to test whether its shape is a Jacobi ellipsoid.

***Scenario 1**:* Homogeneous aggregate of density 2.6 g cm^{-3}, to be certain we can reproduce a homogeneous Jacobi ellipsoid like [2,5-7].

***Scenario 2**:* 30 km crust of ice I_h (density 0.917 g cm^{-3}), and core density ~3 g cm^{-3}, to test the scenario proposed by [11,12].

***Scenario 3**:* Core of density 3.5 g cm^{-3}, the remaining portion of the body is ice I_h (thickness ~80 km).

Preliminary Results and Discussion: So far we have completed simulations of the three different scenarios. Slowly increasing the rotation period leads to Maclaurin spheroids, not Jacobi ellipsoids, but interestingly the c/a ratios of the aggregates differ for each scenario. From the homogeneous scenario (S1), the c/a ratio increases by 11% to the thin ice scenario (S2) while the ratio decreases by 11% to the thicker ice scenario (S3). We conclude that the proportion of ice composing Haumea influences its shape, and that the axis ratios inferred from Haumea's light curve can constrain its core density and the extent of aqueous alteration, and therefore past habitability.

References: [1] Brown M.E. et al. (2007) *Nature 446*, 294-296. [2] Rabinowitz D.L. et al. (2006) *ApJ 639*, 1238-1251. [3] Pinilla-Alonso N. et al. (2009) *A&A 496*, 546-556. [4] Trujillo C.A. et al. (2007) *ApJ 655*, 1172-1178. [5] Lacerda P. and Jewitt D.C. (2007) *AJ 133,* 1393-1408. [6] Lockwood A.C., Brown M.E., and Stansberry J. (2014) *Earth, Moon & Planets 111*, 127-137. [7] Lellouch E. et al. (2010) *A&A 518*, L147-151. [8] Richardson D.C. et al. (2000) *Icarus 143*, 45-59. [9] Schwartz S.R., Richardson D.C., and Michel P. (2012) *Granular Matter 14*, 363-380. [10] Ragozzine D. and Brown M.E. (2009) *AJ 137*, 4766-4776. [11] Probst L.W. et al. (2015) *LPSC XLVI*, Abstract #2183. [12] Desch S.J. and Neveu M. (2015) *LPSC XLVI*, Abstract #2082.