Cosmogonic constraints from densities in the Pluto system and rotational and tidal figures of equilibrium for Pluto and Charon

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A byproduct of the discovery of Nix, Hydra, Styx, and Kerberos, and the detailed study of their orbits, has been a relatively precise determination of the system barycenter, and thus the Pluto/Charon mass ratio [1]. Coupled with precise determinations of Charon's size by multiple stellar occultations [2,3], Charon's mean density is now relatively well-determined (1.72 ± 0.02 g cm^{-3}), both in an absolute sense and with respect to that of Pluto (1.89 ± 0.06 g cm^{-3}) [1]. The latter's precise size remains uncertain due to the effects of its atmosphere on stellar occultations [e.g., 4] and of limb darkening on mutual events [5]. Both Pluto and Charon are relatively rock-rich, but Charon is somewhat icier, which is consistent with impact origin scenarios in which one or both precursor bodies were at least partially differentiated (rock separated from ice under the action of gravity) [6,7]. Ice-rich ejecta is also the preferred route for forming a particle disk outside of Charon's initial post-giant-impact orbit, such as would lead to accretion of the small satellites [8]. In this regard, the upper limits on the densities of the brightest and presumably largest of the small satellites (Nix and Hydra) are – even at the 3σ level — consistent with very icy and porous bodies. Icy rubble-pile bodies are predicted by the initial conditions of the giant impact as presently understood (conditions necessary to give an icier Charon). The small satellites will thus offer an interesting cosmogonical test during the 14 July 2015 *New Horizons* encounter, as good constraints will be placed on satellite volumes from imaging and improved satellite masses should result from optical navigation and orbital simulations.

The fly-through of the Pluto-Charon system by *New Horizons* also offers the first opportunity to determine both the total system mass and the individual masses of Pluto and Charon by direct Doppler tracking (although the spacecraft will not pass close enough to any of the small satellites to measure their gravitational accelerations). Simulations of the encounter by the REX Radio Science experiment indicate the potential accuracies of the combined and individual mass determinations of Pluto and Charon are on the order of 0.1 % [9,10], a substantial improvement in precision (especially for Charon). This will put to rest a long-standing limitation on modeling and understanding Pluto and Charon's internal structure and evolution [11]. It is notable, from the densities quoted above, that the "density gap" between Pluto and Charon appears to be narrowing, and at the 3σ level and considering the effects of porosity, this gap could even be zero. If Pluto and Charon were close in density after all, it could change our view as to how the binary formed [12].

Refinement at the next level, that is, determining Pluto's or Charon's internal structure, specifically their degree of differentiation (or even the presence or absence of oceans), will not be easy. *New Horizons* will not pass close enough to measure the degree-2 gravity field for either body (nor was such an original measurement requirement or mission objective), but shape determination from imaging offers the possibility of determining differentiation state. For this to be successful, however, Pluto or Charon must be in hydrostatic equilibrium. For all hydrostatic models of these two bodies, the differences between the lengths of the principal axes of their figures are predicted to be less than 1 km, and the differences between differentiated and undifferentiated models smaller still [13]. Thus, discriminating between the two cases will be challenging. Furthermore, either Pluto or Charon may choose not to cooperate, if they retain fossil hydrostatic figures from earlier in their mutual tidal evolution [14], in the manner of Iapetus [e.g., 15]. These fossil figures would be larger (more biaxial in the case of Pluto, and more triaxial for Charon), and thus much easier to measure, and could provide important clues to Pluto's thermal and structural evolution [16].

References: [1] Brozović M. et al. (2014) Icarus, in press. [2] Person M.J. et al. (2006) AJ 132, 1575. [3] Sicardy B. et al. (2006) Nature 439, 52. [4] Young E.F. et al. (2008) AJ 136, 1757. [5] Tholen D.J. & Buie M.W. (1997) in Pluto & Charon, UAP, 193. [6] Canup R. (2005) Science 307, 546. [7] McKinnon W.B. et al. (2007) in TSSBN, UAP, 213. [8] Canup R. (2011) AJ 141, 35; [9] Tyler G.L. et al. (2008) SSRev 140, 217. [10] Paetzold M. et al. (2013) DPS 45, abs. 310.06. [11] McKinnon W.B. et al. (1997) in Pluto & Charon, UAP, 295. [12] Nesvorný D. et al. (2011) AJ 140, 785. [13] McKinnon W.B. (2013) abs. Pluto Conf. [14] Dobrovolskis A.R. et al. (1997) in Pluto & Charon, UAP, 159. [15] Singer K.N. & McKinnon W.B. (2011) Icarus 216, 198. [16] Robouchon G. & Nimmo F. (2011) Icarus 216, 426.