BUILDING A SNOWMAN IN SPACE. Alan W. Harris. MoreData! 4603 Orange Knoll Ave., La Cañada, CA 91911, USA. harrisaw@att.net

Bilobed shapes are numerous among small Near-Earth asteroids, main belt asteroids, and especially TNOs. In the past, it has been assumed that the YORP effect was the driving mechanism of both formation, by spinning up a single "rubble pile" body to the point of fission, and possibly also the mechanism by which some such bodies slow down, when the new shapes have a reversed YORP torque, resulting in a shrinking separation and perhaps re-joining of the two bodies to produce a bilobed single body spinning more slowly than the 'spin barrier" limit. Scheeres [1] has investigated the fissioning of various shape configurations, and Pravec et al. [2] have examined outcomes, including escape of secondaries to produce "asteroid pairs" in very similar heliocentric orbits that certainly represent escaped components of previously bound pairs or multiple objects.

This tidy picture was challenged recently by the imaging of 2014 MU69 by the New Horizons mission. An object larger than ~10 km at a distance of around 40 AU cannot possibly have experienced any significant alteration in its spin characteristics from YORP, and has a distinct bilobed shape suggesting a fissioned and re-merged binary body [3]. As noted by Stern et al. [3], the deformation of the pair of ellipsoids is so minor that even the impact velocity of the two coming from zero velocity "at infinity" would be expected to cause more deformation, thus the chance slow collision of two bodies from separate heliocentric bodies seems impossible. The conclusion is that they must be a re-merged binary. But the current rotation period, 15.92 hours, is well below the fission limit for these two bodies, so how did they form, and how did they re-merge?

In this preliminary work I demur entirely on how the binary may have formed, and how the two components might have achieved their rather regular flattened ellipsoid shapes, but consider only the re-merging, taking as constraints the current shapes and contact configuration of the two bodies and the current angular momentum. The momentum and energy transfer mechanism that should still work out in the TNO zone, and obviously has with the Pluto-Charon system, is tidal friction. Thus we can trace backward from the present contact configuration to investigate the orbits and spins of the two bodies before they merged.

Given the current rotation period of the single body, three-dimensional shapes of the two lobes, the center-to-center separation, and that they are connected nearly equatorially with the same axis direction [3], the only unknown is the mean density, which New Horizons was not able to measure due to the fast flyby of the encounter. Stern et al. [3] note that the minimum density possible for zero strength would be 0.28 gm/cm^3; I find 0.29 for the model parameters I have adopted, but well within uncertainties of the measures. A more expected density of 0.5 indicates that the current spin is well under the fission limit and the two bodies are in a state of compression at their point of joining.

In Figure 1 on the next page, I plot the spin period of the primary as a function of separation of the pair as a detached binary, assuming the secondary is synchronized with the orbit frequency. Also plotted is the spin frequency (period) for the given separation. I plot these spin frequencies for various assumed densities of the two bodies, assumed equal and homogeneous. I caution that this work is preliminary and needs to be checked carefully before accepting any of the following results as conclusive.

The first thing to notice is that for the minimum density, 0.29 gm/cm^3, the orbit frequency is less than the primary spin frequency in the range from 1.6 to about 2.4, where a second synchronous state exists. In this range tidal evolution would be outward, not inward, so the current configuration would be unstable, the slightest nudge separating the two would leave the satellite tidally receding from the primary and settling at the outer synchronous point around 2.4 radii. If the binary formed further out than 2.4 radii, tides would evolve the pair into the outer synchronous point, but no further in, leaving a detached binary. So a density as low as 2.9 is ruled out. A density of only 0.30 is not entirely ruled out, as the "snowman" would be stable in contact, but if it existed as a binary any farther than ~1.9 radii it would become "stuck" as a very close binary at about that distance. Densities any higher than that would evolve from more distant binary configuration into contact and result in the present form, although with increasing density, the primary would have to be spinning retrograde with respect to the binary orbit, for example at a density of 0.5, the nominally expected density, the primary would have to be spinning retrograde as the secondary spiraled in, and would be nearly non-rotating at the point of merger, so that the secondary would arrive with a horizontal velocity of about its orbital velocity with respect to the surface of the primary, not much less than the "fall from zero v_∞". A modestly lower density of say, 0.4 or 0.35, could lead to an acceptable inward evolution of a binary and merger at a more modest horizontal velocity.

References: [1] Scheeres, D. (2007). *Icarus* **189**, 370-385. [2] Pravec, P., *et al*. (2010). *Nature* **466**, 1085-1088. [3] Stern, S.A., *et al*. (2019) *Science* **364**, eaaw9771.

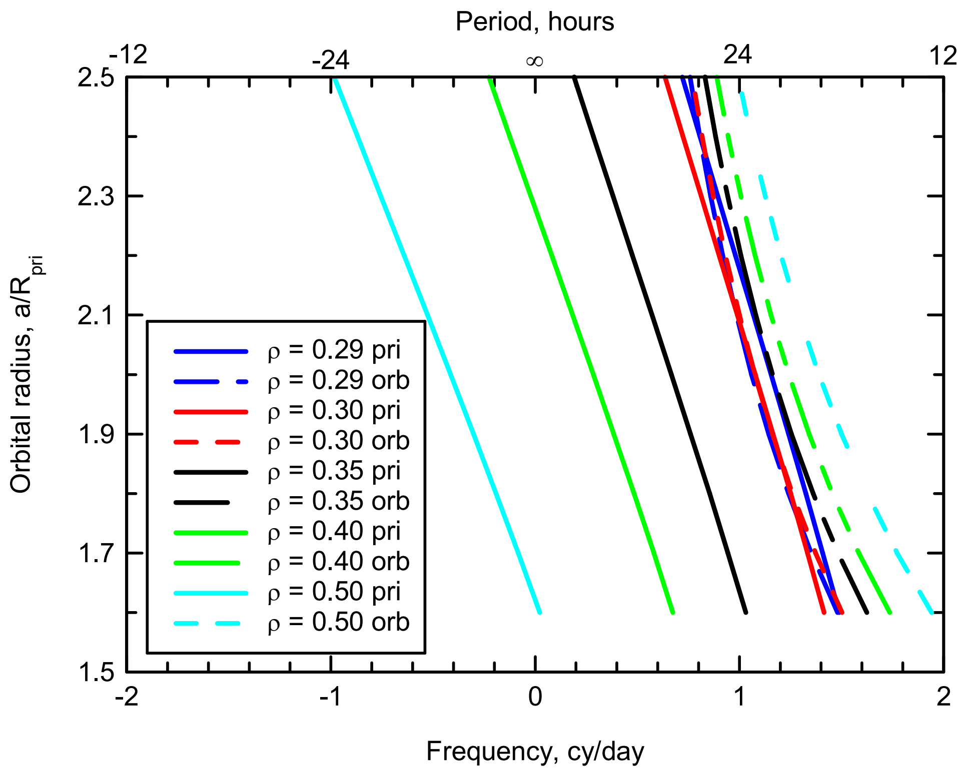

Figure 1. Orbit frequency and corresponding primary spin frequency for constant angular momentum of the system, assuming the secondary is spinning synchronously with the orbit frequency. The primary spin frequency (or period, top labels) is plotted for each density in solid colored lines; the orbit/secondary spin frequency (period) is plotted in dashed lines of the same color for each density. A negative spin frequency (period) corresponds to retrograde rotation compared to the orbital direction.