RUBBLE PILE ASTEROID SHAPING DUE TO PARTICLE EJECTIONS. Leonard D. Vance[1] , Erik Asphaug[2] , University of Arizona, Jekan Thangavelautham[3] , University of Arizona

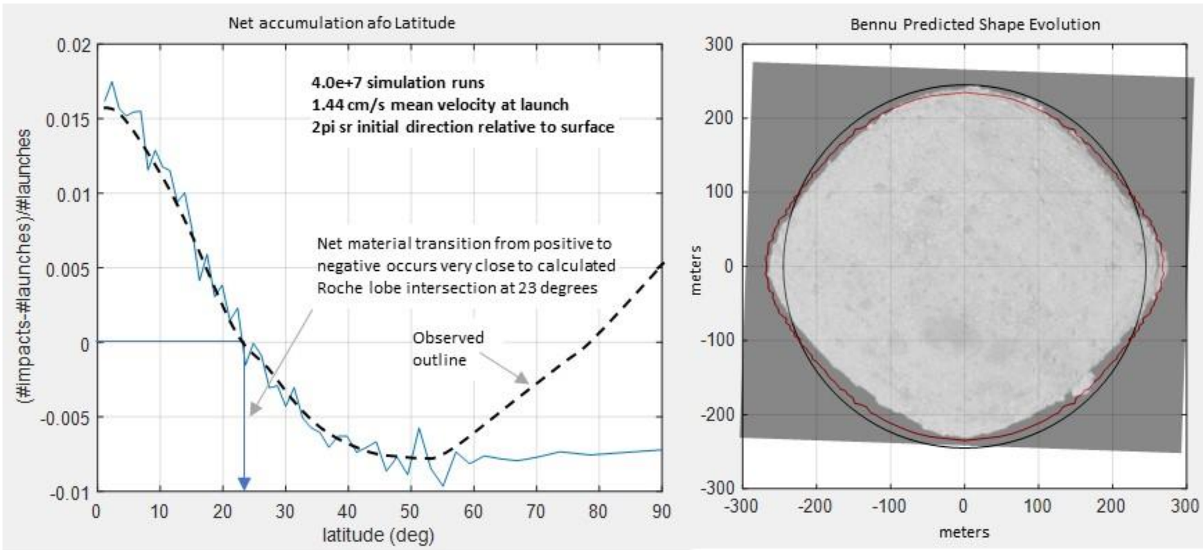

Figure 1: Net accumulation of material as a function of latitude, and the resulting shape compared to Bennu

Introduction: The recent discovery of regular particle ejections from Bennu begs the question of whether these ejections have a role in forming the distinctive 'top' shape of rubble pile asteroids. Simulations are performed which establish the evolution of these shapes and then compared to recent work by Scheers et al predicting the net accumulation transitions of material at the Roche Lobe intersection latitudes. Shape predictions are made for Bennu and Ryugu and compared to measured results, as well as the time periods necessary to reach the observed shapes.

Particle Ejection Shaping: It is possible that the particle ejection events recently observed by the OSIRIS-REx serve as a transport method resulting in Bennu's distinctive 'top' shape. A numerical experiment is executed on a rotating sphere with Bennu's size mass and rotation rate where particles are ejected from the surface at from a random location and with a randomly selected velocity/direction. The landing points of these objects are then tabulated over the course of 10-100 million simulation runs to establish a statistical basis for relative volume gain/loss as a function of latitude. The result is effectively the time derivative of the asteroid's radius as a function of latitude as a departure from an initial sphere.

Particles ejected from the mid latitudes go into sub-orbital trajectories which tend to land nearer the equator. Particles launched from the poles migrate lower towards the equator, and particles launched near the equator tend to stay there.

For 40 million simulations using these assumptions, the relative movement of material as a function of latitude are calculated, and this is shown in figure 1, showing a close match both to the projected shape of Bennu. The net transition from material depletion to accumulation occurs almost precisely at 23 degrees latitude. When the vertical scale of the predicted accumulation is matched to the actual (the blue curve is a prediction of the relative *rate* of accumulation), the resulting prediction matches both the Roche lobe prediction and the asteroid's actual shape.

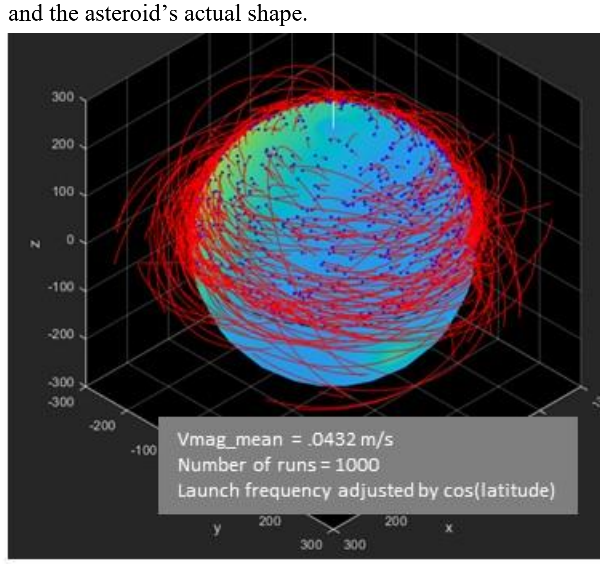

Figure 2: A plot of the first thousand trajectories with diurnal/latitude compensated launch frequency

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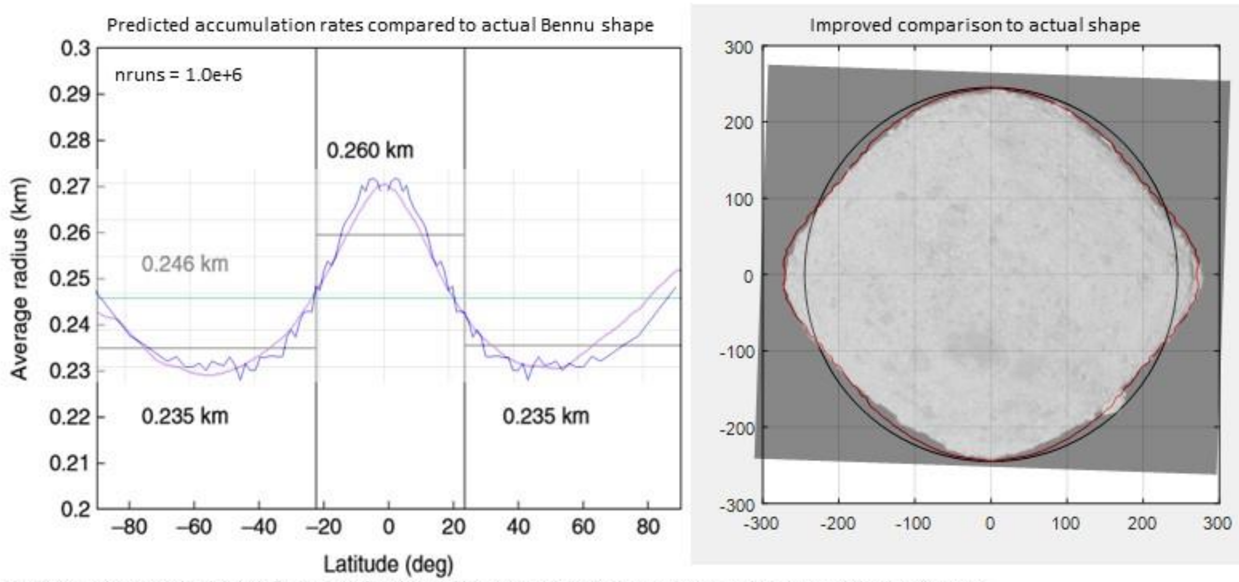

Figure3: Adjusting the launch frequency for diurnal heating produces mass shaping close to overall observations.

The actual increase in radius seen at very high latitudes is an interesting effect not predicted by this simple model, leading to the below prediction that particle ejections may be related to diurnal thermal transients, and therefore more probable near the equator

Incorporating diurnal heating into ejection probability: If we assume that the probability of particles erupting off the surface is related to diurnal heating, then the first order effect would be a reduction in the frequency of particle ejections as latitude increases. Assuming that diurnal heating cycle is proportional to the cosine of the latitude, the simulation is modified to incorporate this effect and rerun (figure 2). This produces a significantly better match to both the Roche lobe boundaries as well as the rise in altitude towards the poles, and with particle velocities a factor of about 3 times higher than before.

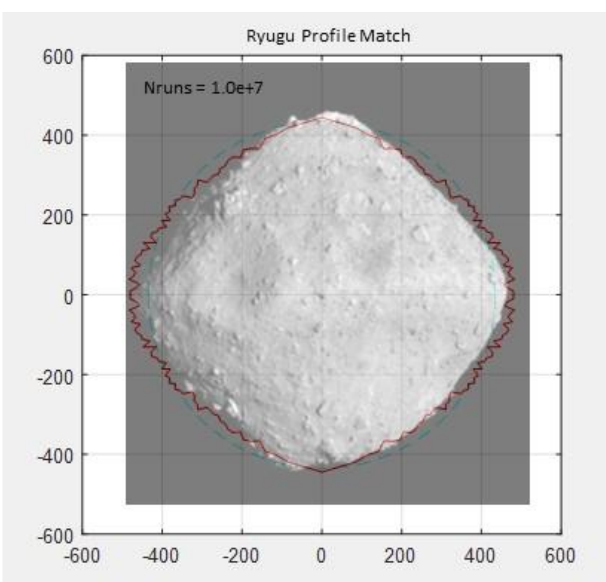

Figure 4. Ryugu shape matching. The same particle launch velocities used for Bennu match Ryugu's actual profile

Lowering the probability of launches from the polar reg ions produces the net effect of accumulating materials at the poles, since material landing there tends to stay. This becomes more pronounced as the energy of the ejections increases. Assuming a mean launch velocity of about 4.9 cm/s results in net volume movement which matches Bennu's observed profile, even at the poles. Figure 3 shows the resulting improved profile match overlaid on an image of the asteroid.

Ryugu shape matching: Updating the model to include the physical size and rotation parameters produces a reasonable prediction (figure 4) of Ryugu's shape using the identical particle velocity distribution (mean launch velocity = 4.9 cm/s) used for Bennu, and therefore suggests that Ryugu may experience similar particle ejections which have not yet been observed.

Summary: observed aspects of Bennu and Ryugu's 'spinning top' shape can be reproduced by assuming that the observed particle ejections by OSIRIS-REx are accompanied by a larger volume of lower energy ejections which at this time remain undetected because of their proximity to the surface of the asteroid. If this is true, then the displacement of material over time is possibly part of the answer as to how and why rubble pile asteroids evolve to the classic 'spinning top' shape.

References: [1] Dan Scheeres et al: Nature Astronomy pp 352-361 , *(March 2019*). "The dynamic geophysical environment of (101955) Bennu based on OSIRIS-REx measurements" [2] D.J. Scheeres et al, Icarus 276 (2016) pp 116-140. "The geophysical environment of Bennu". [3] AlanW. Harris, Eugene G. Fahnestock, Petr Pravec. Icarus 199 (2009) pp 310-318. "On the shapes and spins of "rubble pile" asteroids