Rotational state and shapes of Ryugu and Bennu

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Introduction

At first glance, the asteroids (162173) Ryugu and (101955) Bennu look very similar. Images acquired by the Hayabusa2 [1] and OSIRIS-REx missions [2,3], respectively, reveal that both are rocky worlds covered in rubble, including numerous boulders with diameters up to tens of meters. Both bodies have low albedos and spectra consistent with a carbonaceous chondrite-like composition with low albedos [1,2] and to first order, both are "top-shaped" rapid rotators.

A more detailed analysis of the shapes and spin states of these asteroids, however, reveals a number of differences between the two, and their unique topographic characteristics may point to differences in their internal structures. The geologic evolution of rubble-pile asteroids is driven in large part by downslope migration of surface material [4], which may be dislodged by Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) -induced spin-up [5, 6]. Thus, the rotational states and shapes of these bodies is key in understanding their histories and predicting future dynamic evolutions.

YORP Spin-up

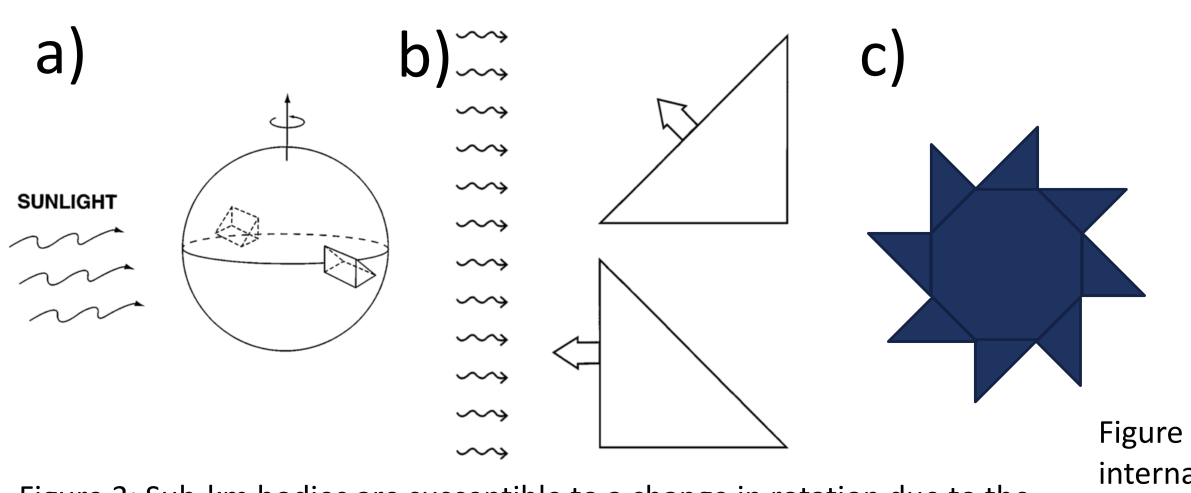

Figure 3: Sub-km bodies are susceptible to a change in rotation due to the YORP effect [5, 6, 13], in which asymmetric reflection and re-emission of solar radiation from the surface (a). The magnitude of the YORP-induced torque is sensitive to the orientation of blocks on the surface (b). We hypothesize that the longitudinal ridges observed on Bennu may act like blades on a windmill (c) to promote spin up. Panels a, b adapted from [5] .

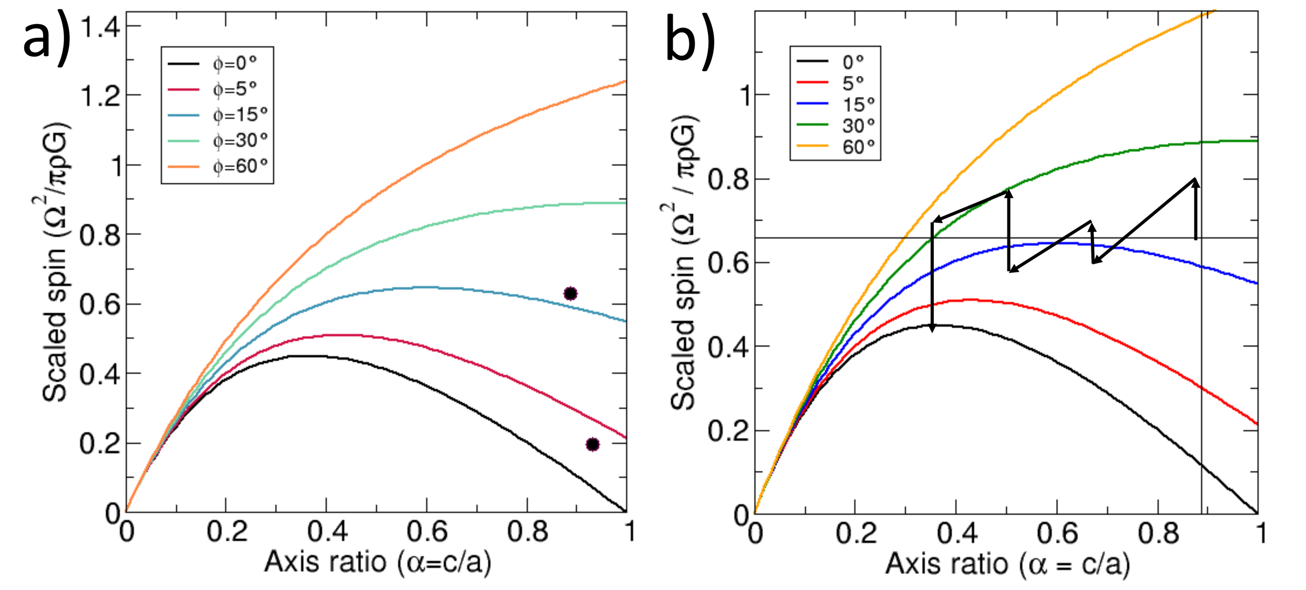

Figure 4: Maximum stable spin rates as a function of the oblateness of the body for various angles of internal friction (without cohesion). The curves mark the limits of rotational stability for cohesionless bodies with a given angle of internal friction. Ryugu's and Bennu's present rotation rates and shapes are indicated by the circles (a). Our goal is to understand the possible evolutionary paths of these bodies in spin-shape space. The arrows mark a possible path for Bennu (b). As Bennu spins up, it may eventually fail and begin to flatten out until it reaches a stable state. Spin-up may resume and the cycle can repeat. Alternatively, redistribution of rubble on the surface could reverse the effect of YORP, allowing it to spin down.

Shapes

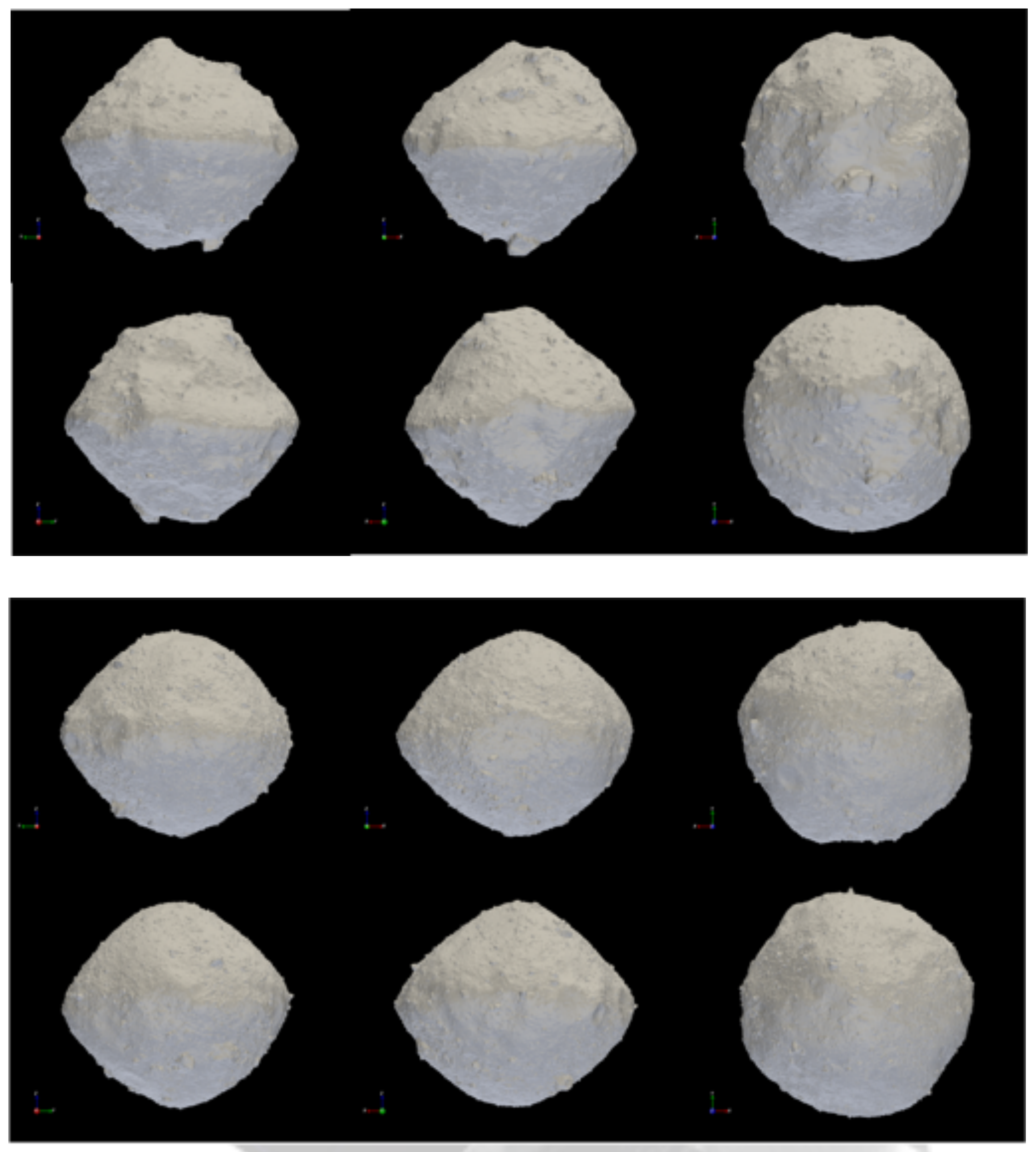

Figure 1: Shape models of Ryugu (top) and Bennu (bottom) viewed from each principal axis. Model with ~800k plates shown for each body. Ryugu model is determined from imaging data using stereophotoclinometry [7]. Bennu model is from OSIRIS-REx Laser Altimeter [8].

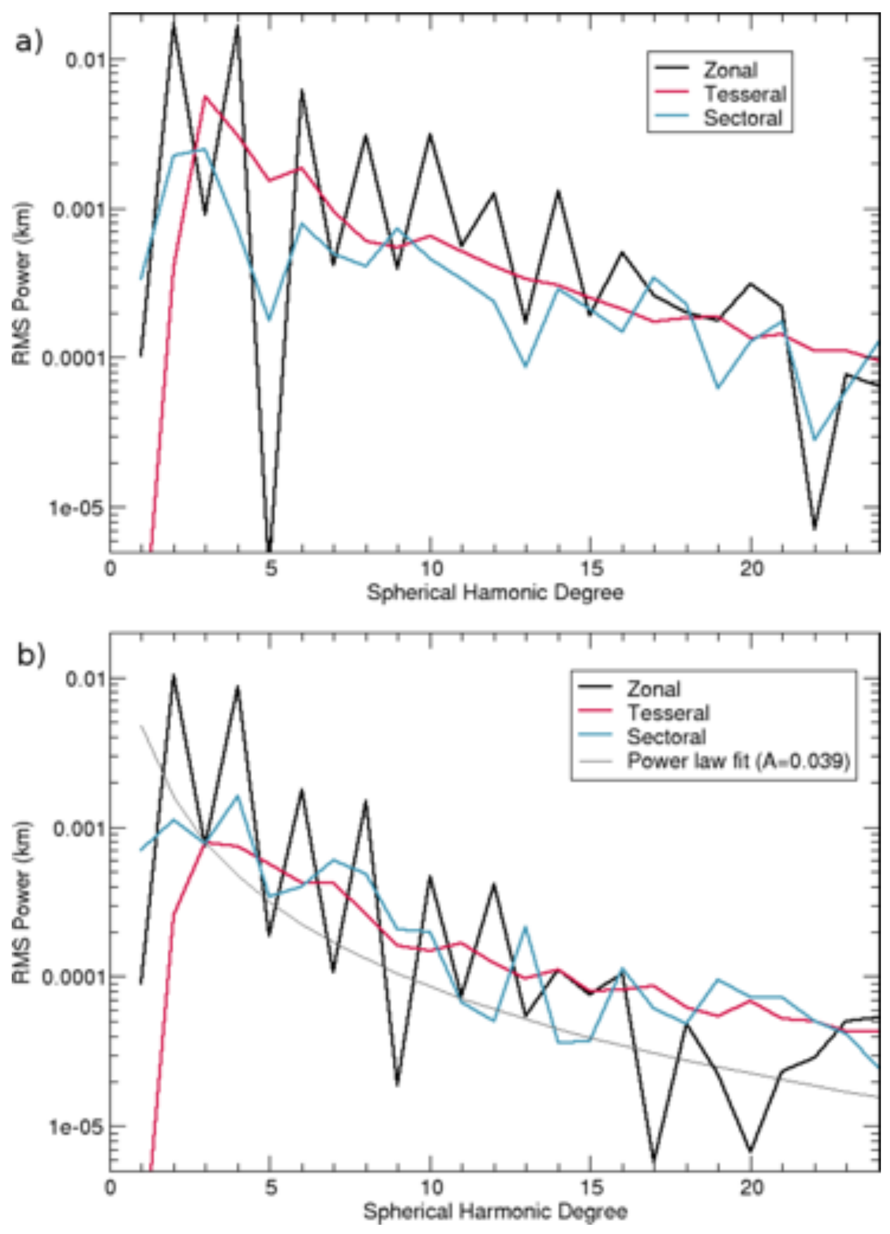

Figure 2: Spherical harmonic decompositions of the shapes of Ryugu (a) and Bennu (b). On both bodies, the zonal terms are particularly strong at degrees (ℓ) 2 and 4, due to the equatorial ridge characteristic of top-shaped asteroids. On Bennu, the power at ℓ = 6 and 8, are indicative of terraces [9]. The strong sectoral terms at ℓ = 4 reflects high-standing longitudinal ridges, which are most obvious as a "squarish" outline as viewed from the poles [10] and (Figure 1). Apart from the top-shape, Ryugu differs significantly from Bennu. The ℓ = 4 sectoral component is much weaker, and longitudinal ridges are not observed [11]. Viewed from above the pole, the profile of Ryugu is far more circular. The strongest non-zonal contribution are the tesseral terms at ℓ = 3, indicating some large-scale asymmetry, which is prominent in topography relative to a reference shape model constructed from the even zonal harmonics [11]. The Tokoyo/Horai Fossae system in the southern hemisphere and the large plain in the northwestern mid-latitude [1] may be responsible for this shape. At smaller scales, terraces are not evident; instead, regolith run-ups and imbricated boulders are observed [12].

Torque

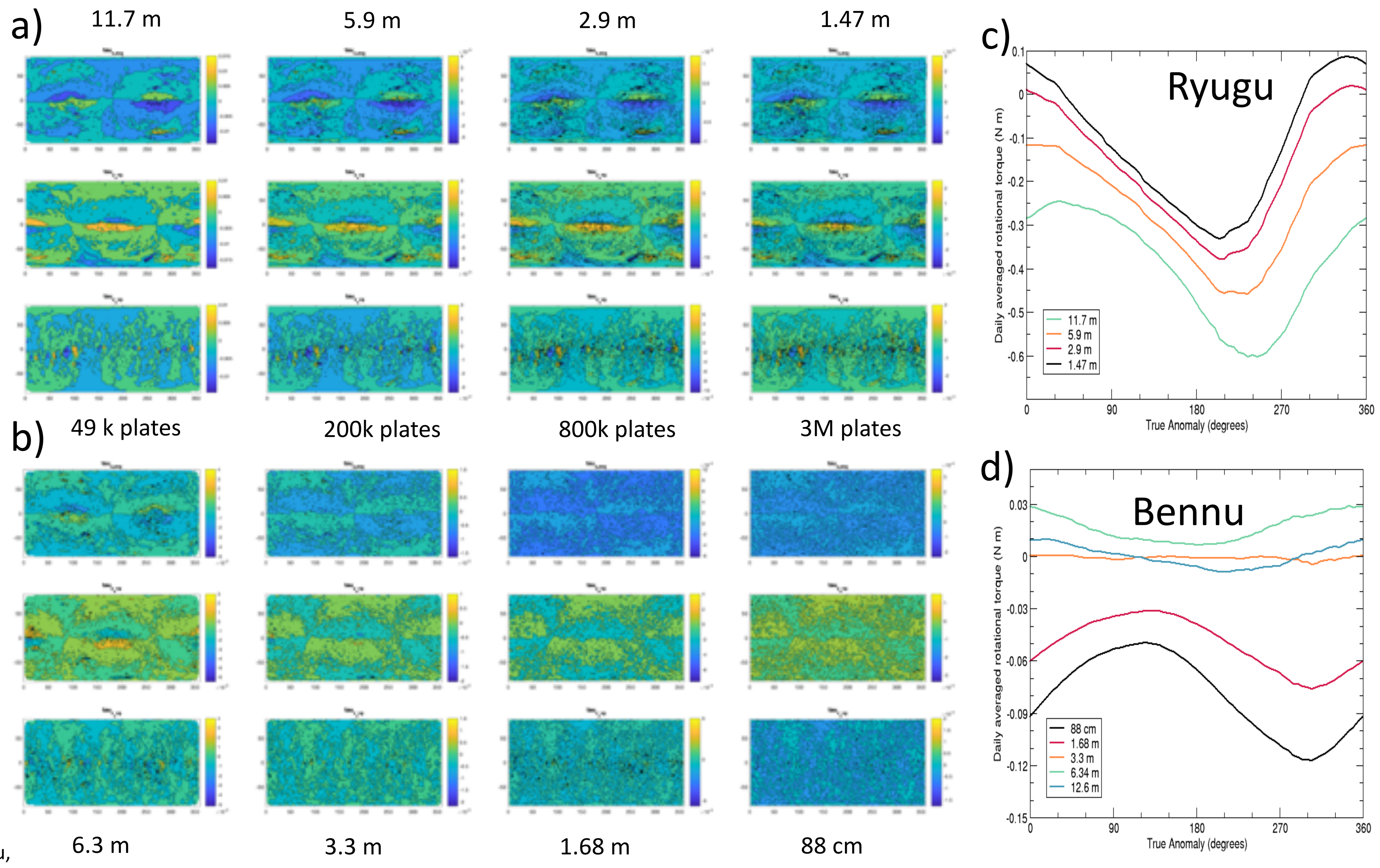

Figure 5: Daily averaged YORP torque computed at each plate of the shape model for Ryugu (a) and Bennu (b) at progressively higher resolution shape models at a True Anomaly of 180°. Note that Ryugu is roughly twice the size of Bennu resulting in larger ground-sample distances at the same plate number. Globally-averaged torque over the course of an orbit.

Conclusions

- Some degree of internal friction or cohesion necessary to maintain current shape
- YORP-induced spin-up may result in episodes of mass movement
- Terraces and longitudinal ridges may be indicators of partial failure and may themselves enable YORP spin-up (or spin-down)
- Small-scale topography (< 15 m) is important-- Even the sign of the net torque on the body is influenced by it.
- We don't even start to get convergence until ~1 m resolution. This complicates our ability to predict future spin-shape evolution.

References

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