Interior Structure of Asteroids: Current Understanding and Open Questions I

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Small bodies records the solar system formation and evolution and are sources of planet formation.

- In the protoplanetary disk, accretion processes build larger bodies.
- Small bodies are leftovers of these objects and/or those that separated from them due to catastrophic disruptions.
- Depending on the location of formation, these bodies may have different compositions initially. However, they have been transported to other locations dynamically.
- Smaller sizes (< a hundred kilometers diameter) may be disrupted significantly because hypervelocity collisions likely disrupted these bodies.
- A series of disruption and reaccumulation have contributed to the formation and evolution of rubble piles bodies and their internal structure.

A small body's internal structure strongly controls kinetic impact cratering processes.

Airless bodies

- A mechanically strong body can give a target surface a kinetic energy more efficiently than a weak body such as a rubble pile body.
- The kinetic energy increases with the bulk density, leading to a larger impact crater.

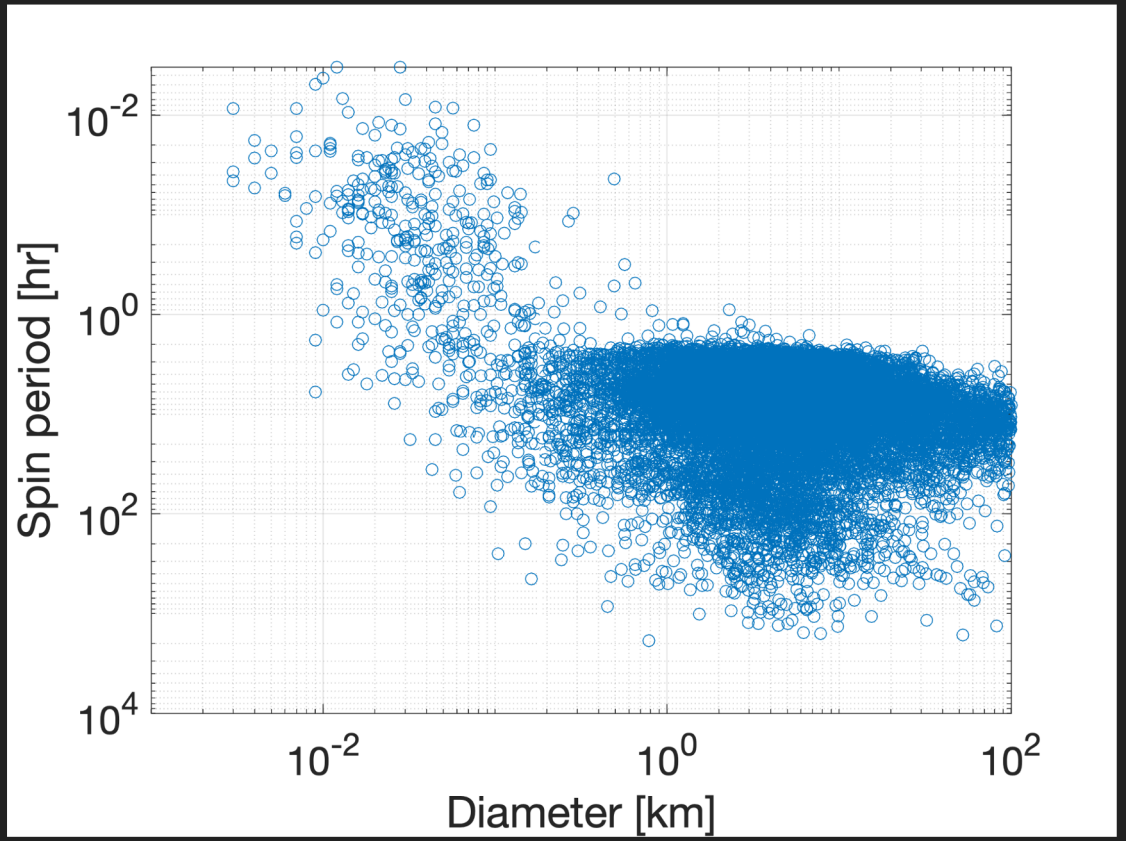
Atmospheric interactions

- Highly porous materials may be burned when an asteroid enters the atmosphere. Only the part of the body reaches the ground, but it causes a fireball event.

Lightcurve observations show small bodies' unique spin condition.

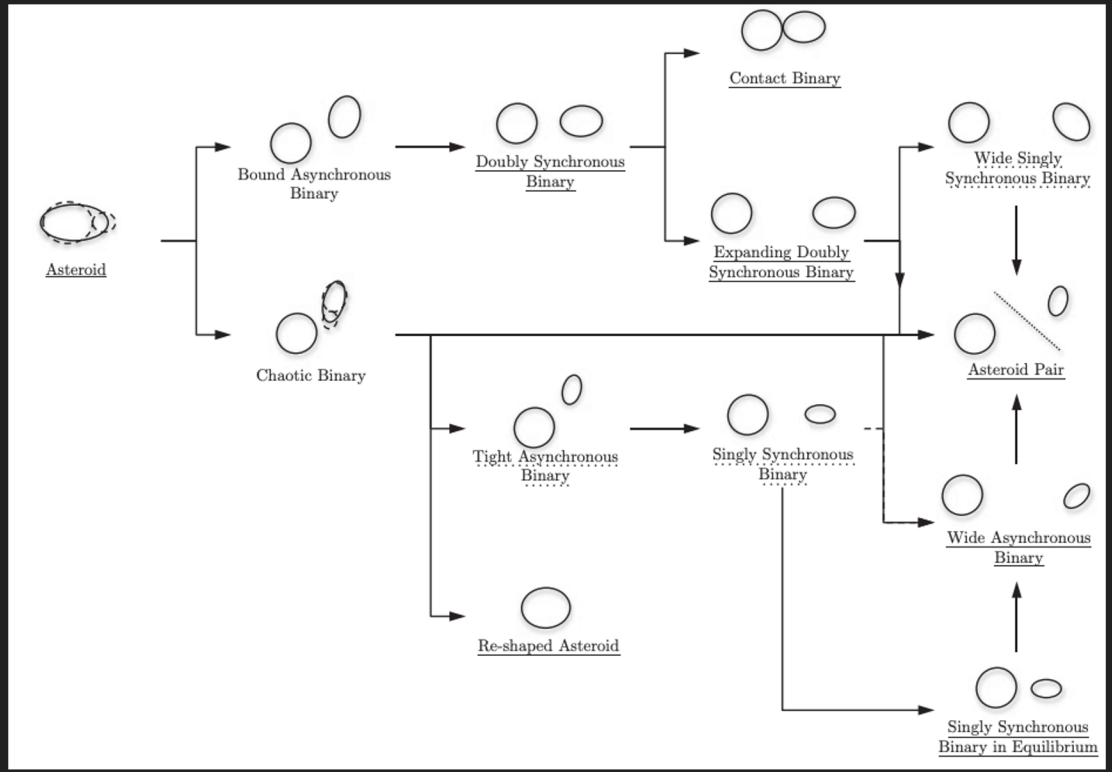
- There is a clear boundary at ~2.2 h for objects larger than ~200 m diameter.
- Objects smaller than that widely have a wide range of shorter spin states.
- This indicates possible evidence of having cohesion.
- One explanation of this distribution may be driven by YORP (vertical transition).
- Another explanation is impact-driven disruption (horizontal transition).

Waner et al. (2009) (LCDB, Aug 2019).



Small bodies (less than a few km) evolve dynamically overtime due to YORP, BYORP induced perturbations.

- YORP and BYORP gradually add an angular momentum to a small body (system) to dynamically change its configuration.
- This configuration changes creates binary, contact binaries, etc.

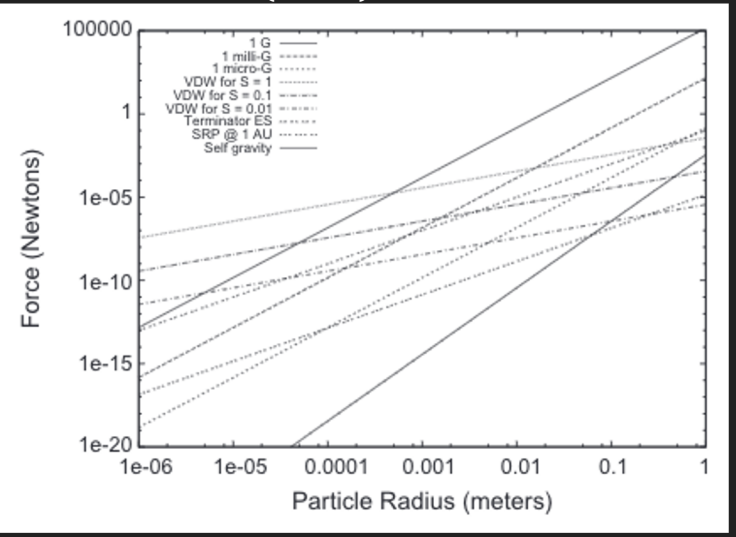


Jacobson (2014)

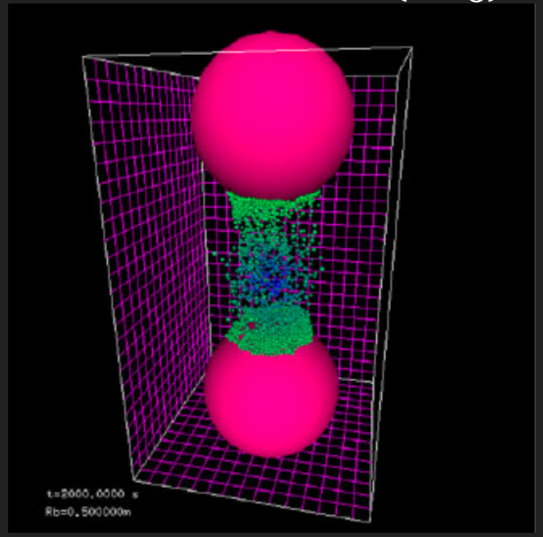
Cohesion may play a significant role in structural resistance against failure.

- Large boulders can be supported by a bridge of small micron-sized particles affected by cohesion.
- Rubble pile bodies could be mechanically strong because of bridges.

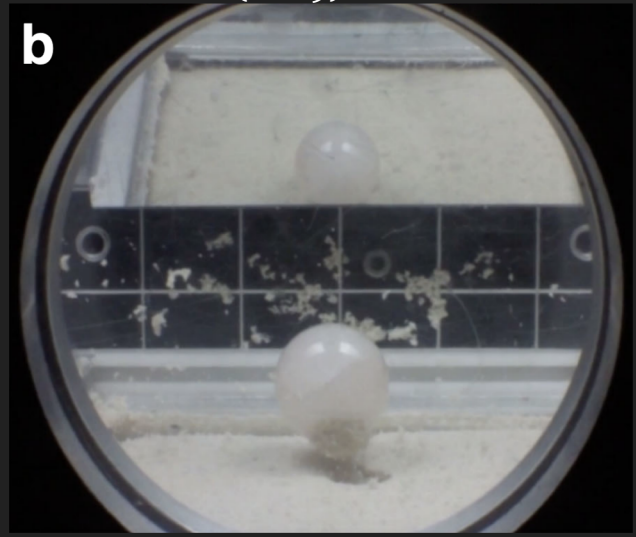
Scheeres et al. (2010)



Sanchéz and Scheeres (2015)

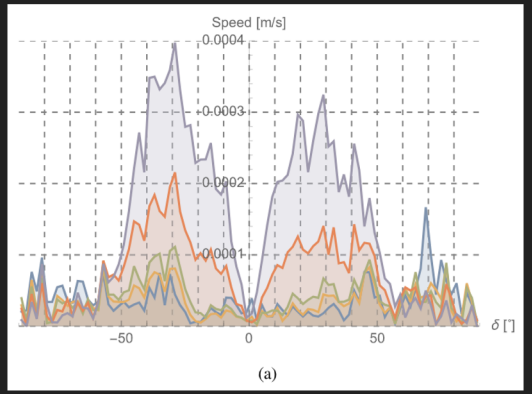


Brisset et al. (2019)

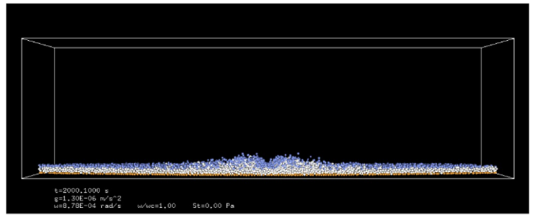


Granular models predict different reshaping modes, depending on the internal structures.

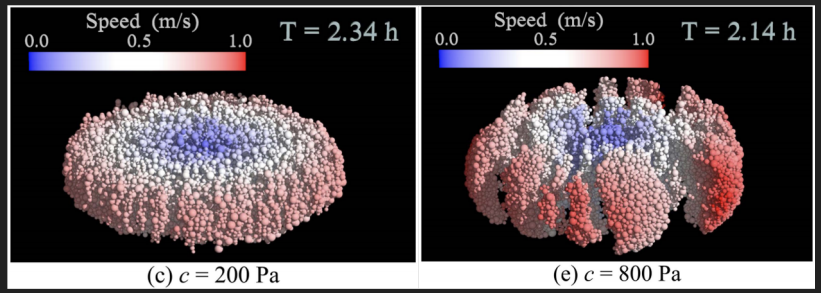
Sanchéz and Scheeres (2020)



(a)

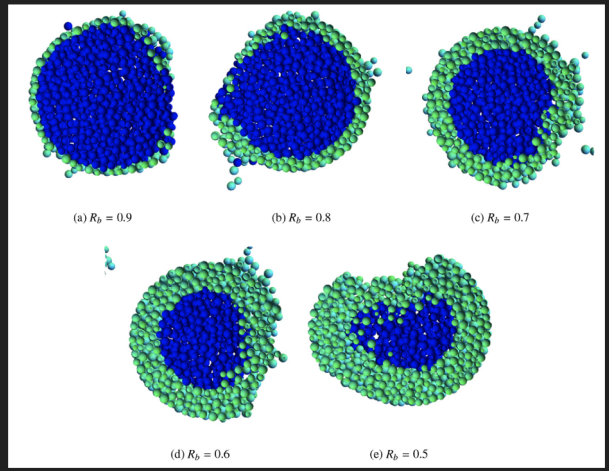

(b) t=2000 s

Zhang et al. (2018)

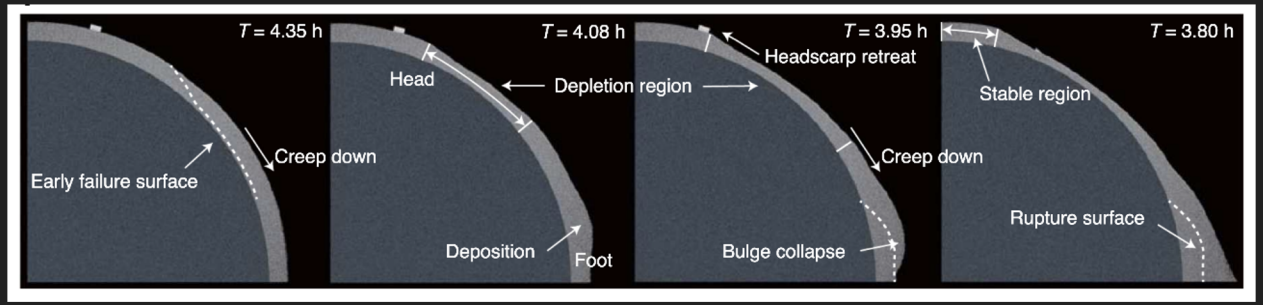


(c) c = 200 Pa (e) c = 800 Pa

Sanchéz and Scheeres (2018)



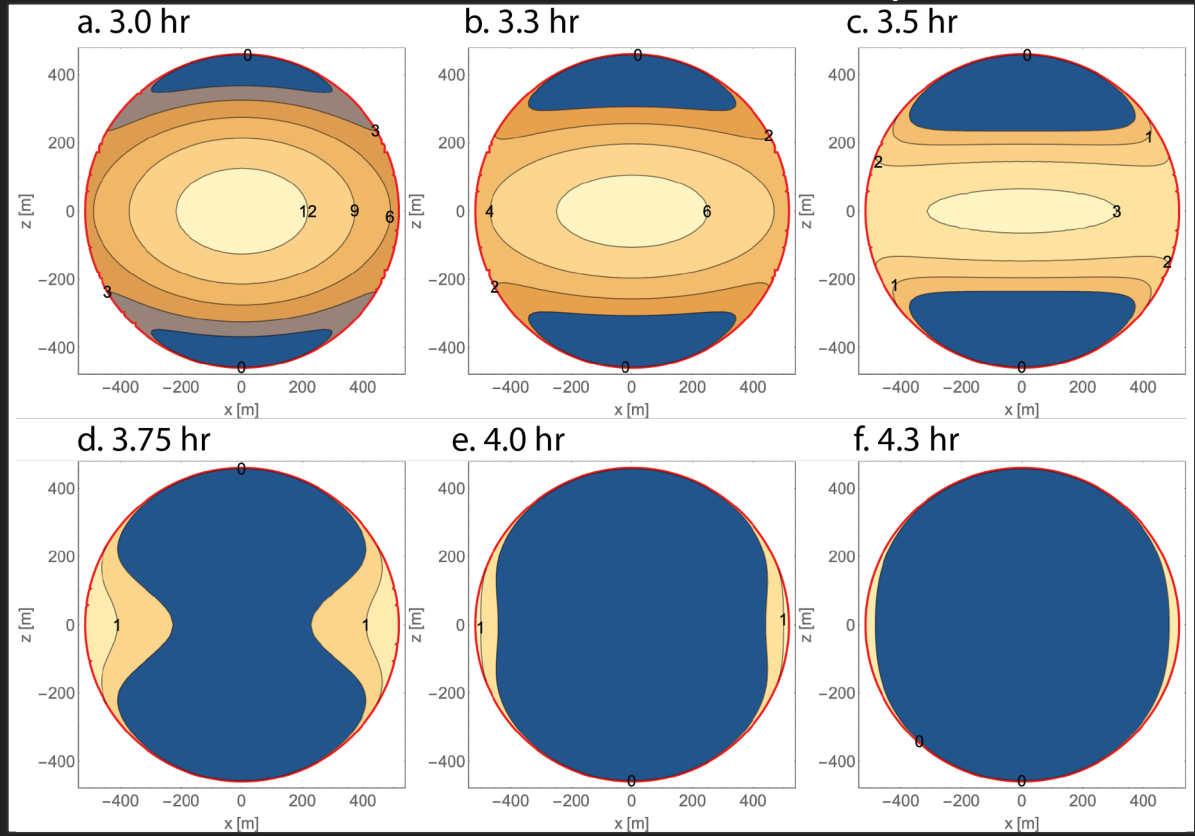
Cheng et al. (2021)



Stress distribution changes with a spin period, meaning that the strength distribution varies by rotation.

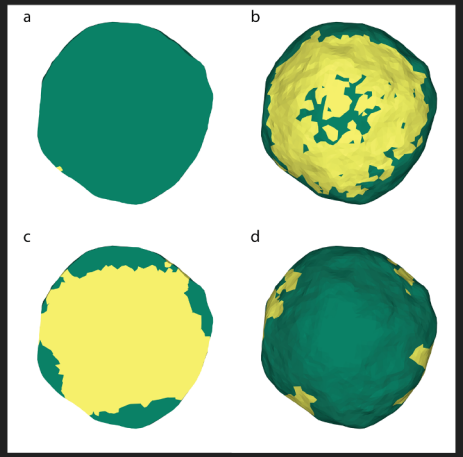
Hirabayashi et al. (2020)

- The interior experiences the highest stress at a short spin period while the surface becomes sensitive to a long spin period.
- If inelastic deformation occurs, this changes the density distribution (i.e., porosity).

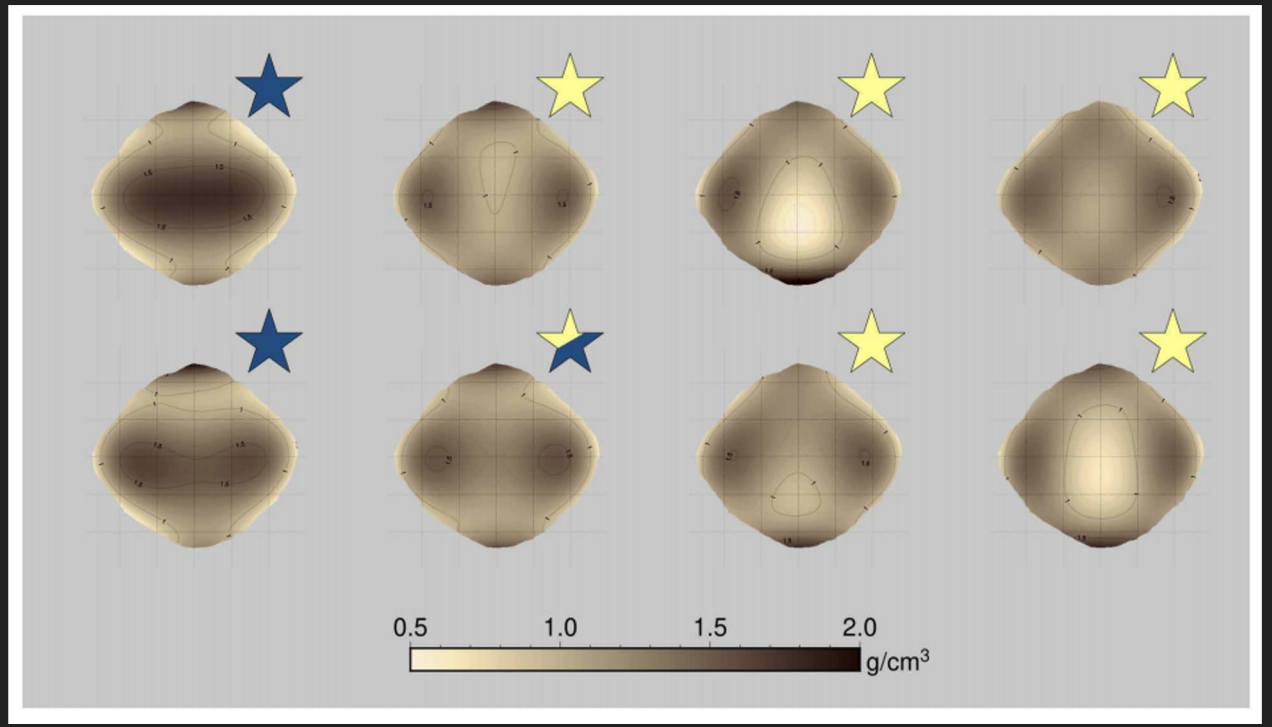


OSIRIS-REx measured the gravity field to constrain the internal structure of Bennu.

- Bennu's possible internal structure includes a less dense core and a less dense surface.

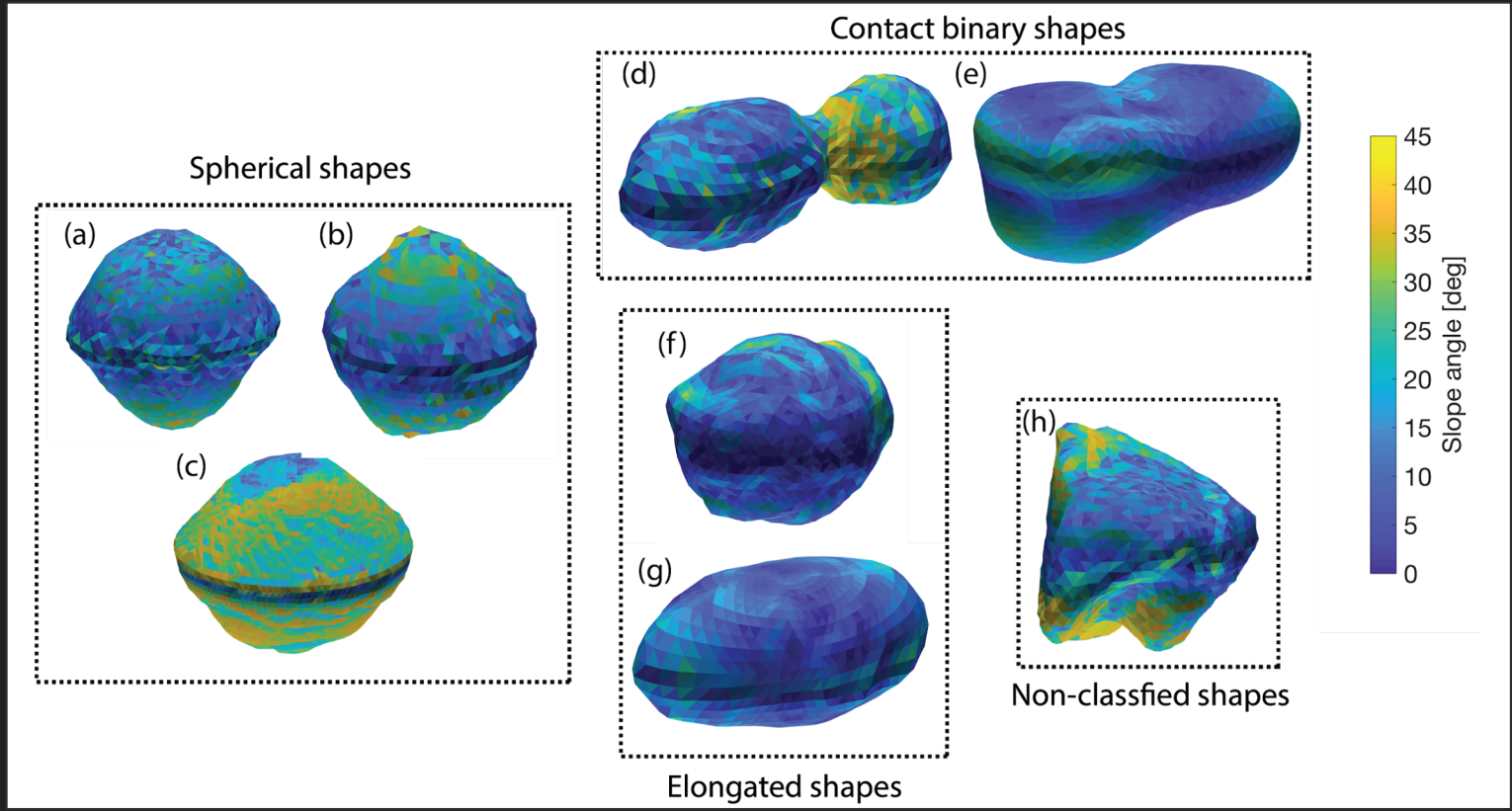


Hirabayashi et al. (2020)



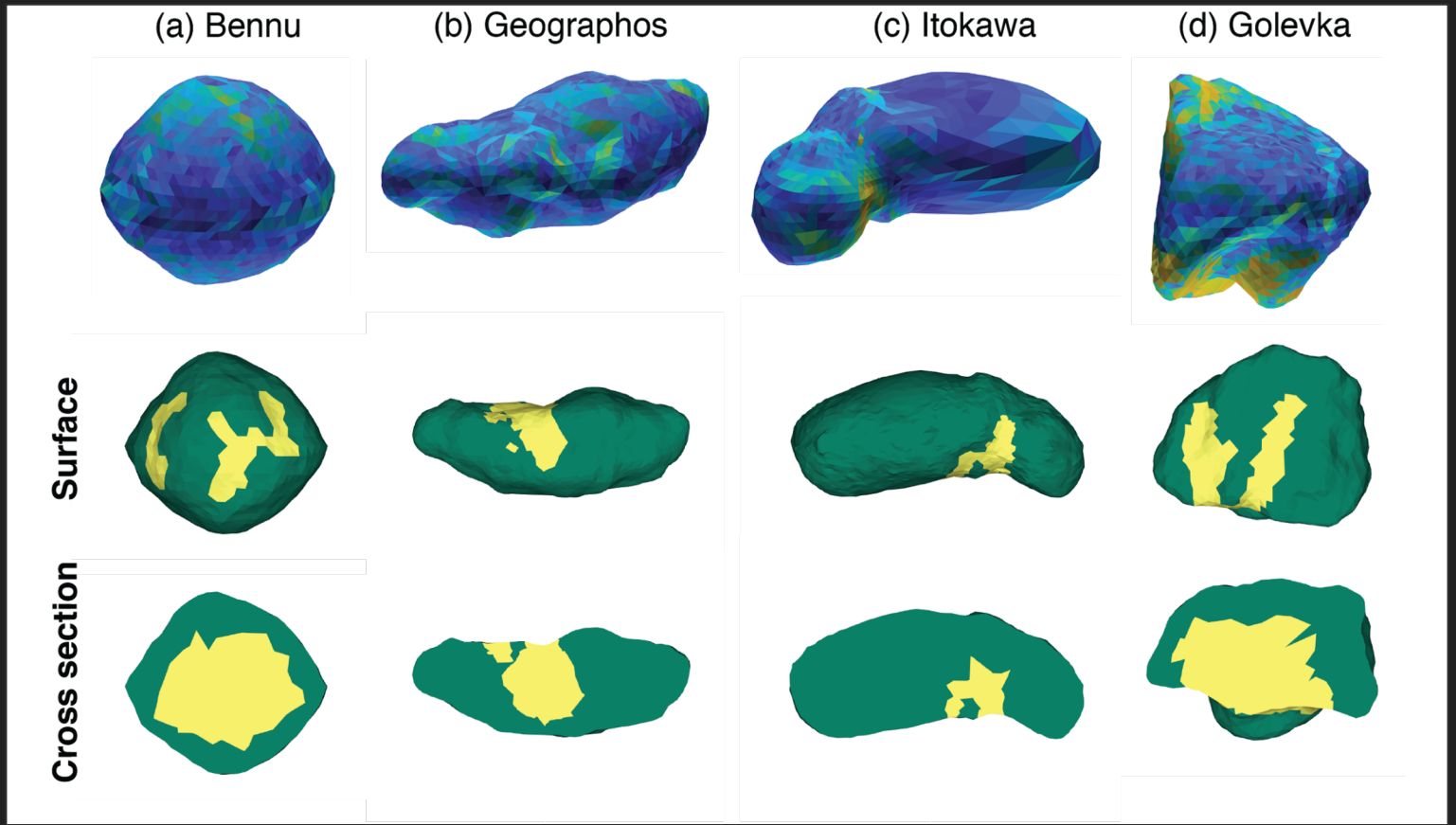
Scheeres et al. (2020)

Small bodies have irregular shapes.



The shapes may give some information about small bodies' structure.

Hirabayashi et al. (2019)



Findings for small body interiors

- Cohesion is a key parameter controlling the internal strength of small bodies.
- YORP (and BYORP)-induced torques have changed small bodies' spin (and mutual orbit) states, changing their internal conditions over a long period.
- Inelastic deformation changes the spatial porosity distribution, causing the density distribution, which induces structural heterogeneity.
- Shape irregularities contribute to the internal conditions because of different inelastic deformation processes in each body.
- Depending on the internal structure, the reshaping behavior is different, leading to a different evolution process that happens to each body. Elongated bodies are more sensitive to their reshaping processes.

Open questions for small body interiors

Scientific questions

- (Look inside) What does the small body interior look? Not yet fully observed uniquely. Shattered? Rubble pile?
- (Cohesion) How does cohesion play roles in holding the shape and reshaping modes?
- (Granular mechanics) How do granular flows behave in microgravity environments? Overcome simulation and experimental challenges?
- (Formation and evolution) What is the connection between the formation and evolution processes and the currently observed configurations?
- (Evolution) What does the spin state distribution tell about the interior? Was it driven by YORP or impact processes?

Planetary defense

- (Influence) What does the internal structure (as well as asymmetric shapes) control impact cratering processes?
- (Monitoring) How can we apply our understandings to existing small bodies broadly?
- (Interaction with the public) How can we use our knowledge to communicate with the public for this issue?