Bridging the gap between the physical properties of asteroids inferred from remote sensing, surface interactions and samples retrieved

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Physical characteristics of asteroid drive our understanding of their evolution. In recent years, traditional and new remote sensing techniques have been used to quantify both the physical characteristics of an asteroid's surface and interior. These techniques consider gravity data and local slope across an asteroid, crater-derived seismicity and geological measurments. They also make use of a sound understanding of the cratering process and geo-technical approaches. All these methods give constraints on an asteroid interior and surface structure, cohesion and frictional properties. Additional insights are gained from discrete element models (DTMs) that explore how asteroids are modified by thermally driven spin-up processes. In many instances, all these techniques are successful when compared to assessments of surface interactions. The physical characteristics of samples are and will provide new constraints on how well these remote sensing techniques work. In this presentation, we review the range of remote sensing techniques that have been applied to understand the physical nature of asteroids. We show how well they compare with results from surface interactions, and we explore what can be learnt from current and future sample investigations.

Remote sensing data: Traditionally, broad physical attributes of an asteroid are obtained using mass estimates from gravity investigations using radio science data along with a shape model (e.g., S. Abe et al., 2006; Barnouin et al., 2024, 2019; Watanabe et al., 2019; Wilkison et al., 2002; Yeomans et al., 2000, 1997). Such investigations give key data on the bulk density of a body. To get at whether or not an asteroid is a rubble pile, spectral data (e.g., M. Abe et al., 2006; Clark et al., 2011; Murchie et al., 2002) typically constrains the properties of an analogue meteorite from which estimates of a bodies bulk and macro porosity can be made. When gravity assessments provide higher order terms, additional inferences on the internal structure are possible (e.g., Konopliv et al., 2014; Scheeres et al., 2020).

Considering seismicity resulting from cratering can provide further insights on the broad physical nature of an asteroid (Asphaug, 2008). Evidence of spatial variations in observed crater size-frequency distributions and any associated changes in crater depth-to-diameter have been used to understand an asteroid's seismic response to cratering (e.g., Richardson et al., 2020; Ballouz et al. 2024). Modeling of such spatial variations provide new constraints on the physical character of asteroids (Ballouz et al. 2024). Likewise, DTMs with broad asteroid shape attributes (e.g., flattened, longitudinal ridge), with other geological observations (asteroid-wide surface lineaments, scale of terraces, crater mounds and benches) give additional quantitative strength limits to an asteroid's interior (Barnouin et al., 2024; Zhang et al., 2022).

Separate approaches get at the physical characteristics of an asteroid regolith. These make use of the density and spin state of an asteroid to compute slope distributions and fairly simple Mohr-Coulomb stress-strain models. When combined with geological evidence for mass movements (e.g., Barnouin et al., 2022a; Jawin et al., 2020; Miyamoto et al., 2007; Tang et al., 2023) and reasonable assessments of the angular nature of the regolith (e.g., Barnouin et al., 2024; Robin et al., 2024) that provide friction angles, the cohesion of surface material can be predicted (Barnouin et al., 2024, 2022a, 2022b). These cohesion estimates are identical to strength assigned in crater scaling rules (Holsapple, 1993). Additional insights on the depth and strength of the regolith are provided by assessing topography near boulders (e.g., Daly et al., 2020; Jawin et al., 2020), and from the presence of crater ejecta (e.g., Perry et al., 2022) and mounds and benches (e.g., Daly et al., 2022). Boulder tracks are useful too (Bigot et al., 2024). To get at the strength of boulders, craters identified on boulders (Ballouz et al., 2020), as well as observed boulder camp-fires features provide limits.

Surface interactions: The Hayabusa 2 Small Carry-on Impact (SCI) experiment (Arakawa et al., 2020) and OSIRIS-REx's Touch-and-Go (TAG; Ballouz et al., 2021; Lauretta et al., 2022; Walsh et al., 2022) demonstrate that the analyses derived from remote sensing work. Both the remotes sensing assessments and the SCI and TAG findings show that the regolith of Bennu and Ryugu are effectively cohesionless. Similar findings were made at Dimorphos (Barnouin et al., 2024).

Samples: Sample density measurement further constrain the broad structure of asteroids. For instances, the samples returned from Ryugu push the estimates of macro-porosity to smaller values (in the 20-30% porosity range) than might not have been considered reasonable given the rubble pile appearance of the asteroid (e.g., Grott et al., 2020). Additional physical characterization (friction angle, angularity, porosity, and rock tensile and compressive strength) of samples will provide similar new perspectives on the nature of asteroid surface properties. These will lead to a greater understanding on how to explain the observed geology of these small bodies, and provide new constraints on the age and evolution of these asteroids.

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