GRAVITY SCIENCE IN THE YEAR 2050. J. T. Keane[1], [1]University of Arizona, Tucson, AZ, USA (jkeane@lpl.arizona.edu)

Introduction: Measurements of moments of inertia, gravity, and topography are some of the most powerful probes for investigating the interior structure of solar system objects. Remote measurements of these geophysical quantities have revolutionized our understanding of the formation and evolution of almost every object in the solar system. In this abstract, I summarize the present state of gravity science in the solar system, and current gaps in our knowledge that could be addressed by robotic missions in the coming decades.

The Current State of Planetary Gravity Science: Fig. 1 summarizes the resolution of published gravity fields for all solid solar system objects for which a gravity field has been measured. Here, I focus only on objects for which higher-order gravity fields have been measured (spherical harmonic degree l=2 and above).

The Moon is a clear example where our understanding of the object has been substantially shaped by gravity science. The earliest gravity field measurements from the Apollo spacecraft, subsatellites, and Lunar Orbiters, revealed a gravity field vastly different than the Earth's. The Moon's gravity field was lumpy, with several large mass concentrations ("mascons") significantly perturbing the orbits of spacecraft [1]. When spacecraft returned to lunar orbit in the 1990s and 2000s, gravity and topography enabled the first detailed studies of the gigantic South Pole-Aitken impact basin on the lunar farside (the largest confirmed impact basin in the inner solar system) [2]. After Clementine, Lunar Prospector, and Kaguya, the gravity field of the Moon was known to l~150 (resolution ~ 100 km). This all changed in 2012 with the successful Gravity Recovery and Interior Laboratory (GRAIL) mission [3]. The dual

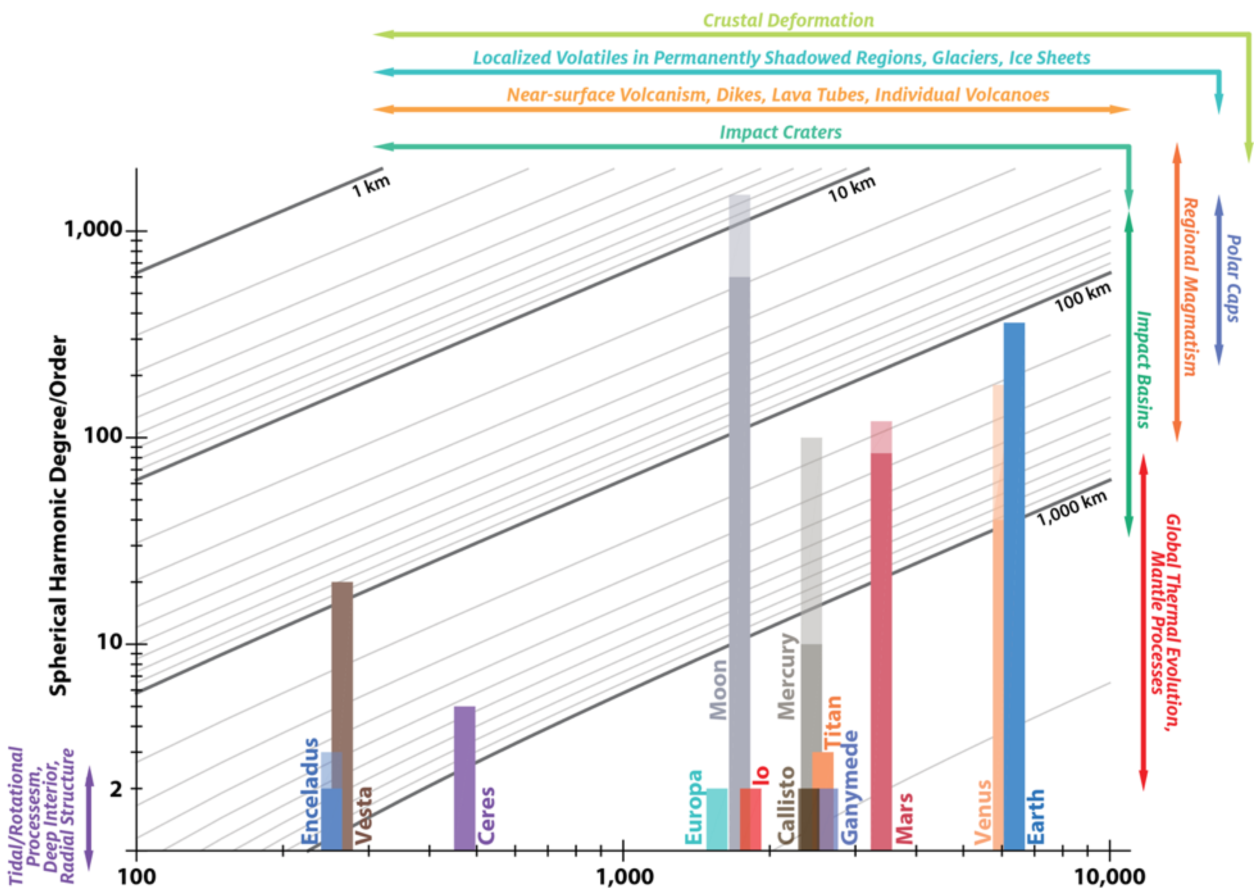

Figure 1. *The resolution of all published gravity datasets for solar system objects. Colored arrows on the margins of the plot indicate what geologice features can be probed as a function of spatial/spectral resolution.*

spacecraft GRAIL mission used spacecraft-to-spacecraft ranging, and a low orbital altitude (at times <10 km) to provide unprecedented high quality, global gravity measurements. In fact, the Moon now has the most well characterized gravity field of any object in the solar system (*l*=1500, resolution ~ 10 km; Fig. 2). Coupled with comparably high resolution topography data (from LRO/LOLA), GRAIL has provided insight into a variety of geologic processes—from the formation of impact basins [4-5], the early thermal evolution of the Moon [6], volcanic processes [7], and the presence of a liquid outer core [8].

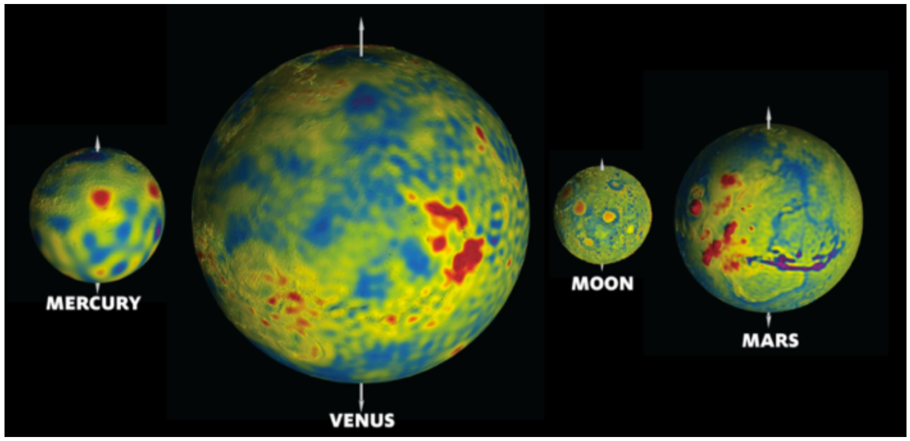

***Figure 2**. The gravity fields of Mercury, Venus, the Moon, and Mars. The differences between the gravity fields of each world is due both to differences in geology (e.g. volcanism on Venus verse impacts on the Moon), and resolution of the gravity field. In this visualization, Mercury's gravity field is expanded to l=10; Venus to l=80; the Moon to l=600; and Mars to l=100.*

Our present-day knowledge of the gravity fields of the Earth, Venus, and Mars (Fig. 2) are comparable to our mid-1990's understanding of the Moon's gravity field. While future missions (or renewed analyses of exisitng spacecraft data) may further improve the resolution of the gravity fields of these planets, they will almost certainly never reach the caliber of the GRAIL gravity field—simply because the presence of an atmosphere prohibits a low-altitude gravity science campaign. Nonetheless, gravity-focused missions to Venus in particular may be able to monitor atmospheric dynamics in a way similar to what has been done for the Earth with the Gravity Recovery and Climate Experiment (GRACE) and Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) [9].

Mercury (Fig. 2), Vesta, and Ceres, all have similarly low resolution gravity fields, comparable to the state of knowledge of the Moon in the 1960's, and thus only provide insight into the longest-wavelength structures on these worlds.

The quality of measured gravity fields drops off precipitously in the outer solar system. Degree-2 gravity fields have been measured for only a handful of moons of Jupiter and Saturn, and even then often rely on significant assumptions; for example, assuming a fixed ratio between degree-2 spherical harmonics [10]. If we continue our analogy with lunar gravity science, the current state of knowledge of the gravity fields of icy satellites are comparable to the Moon circa the year 1800! (The Moon's degree-2 gravity field was inferred by eye and telescopic observations of the Moon's libration and orbital motion.)

A Vision for Planetary Geophysics in the Year 2050: The icy satellites are the single largest gap in our current understanding of planetary gravity fields. A dedicated geophysics mission (consisting perhaps of a gravity science package and laser altimeter or stereo camera) would revolutionize our understanding of icy worlds. Furthermore, a high resolution gravity field of an icy satellite would provide a unique counterpoint to the high resolution gravity field of the Moon, and enable a variety of comparative planetology studies. For example, we only recently believe we understand how multi-ring basins form on the Moon [5, 11], and plausibly the other terrestrial planets by extension. Perhaps the best test for the numerical modelers would be to predict how such impact basins would form on icy worlds, where the rheology is substantially different. Like GRAIL, an icy world geophysics mission would perhaps be best suited for a low-cost (Discovery class) mission, in tandem, or subsequent to a more traditional remote sensing spacecraft.

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