HIGHER-ORDER GRAVITY AND GLOBAL GEOPHYSICAL PROPERTIES OF (101955) BENNU. D. J. Scheeres[1], J.W. McMahon[1], A.S. French[1], A.B. Davis[1], D.N. Brack[1], S. Chesley[2], D. Farnocchia[2], Y. Takahashi[2], R.S. Park[2], J. Leonard[3], P. Antreasian[3], K. Getzandanner[4], A. Liounis[4], D.E. Highsmith[4], D. Rowlands[4], E. Mazarico[4], M. Moreau[4], P. Tricarico[5], O.S. Barnouin[6], M.G. Daly[7], R.W. Gaskell[5], E.E. Palmer[5], J. Weirich[5], C.L. Johnson[5,8], M.M. Al Asad[8], J.A. Seabrook[7], J. Roberts[7], C.W. Hergenrother[9], M.C. Nolan[9], and D. S. Lauretta[9]. [1]Smead Department of Aerospace Engineering Sciences, University of Colorado, Boulder, CO, USA (scheeres@colorado.edu), [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [3]KinetX, Simi Valley, CA, USA, [4]Goddard Space Flight Center, Greenbelt, MD, USA, [5]Planetary Science Institute, Tucson, AZ, USA, [6]JHU Applied Physics Laboratory, Laurel, MD, USA, [7]York University, Toronto, Canada, [8]Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, Canada, [9]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA.

Introduction: The current best estimates of asteroid (101955) Bennu's gravity field will be presented, based on a series of independent solutions from different teams involved on the OSIRIS-REx mission. In addition to classical radio science techniques for estimating a body's gravity field coefficients, the discovery of ejected particles about Bennu that remain in orbit for several days or more provides a unique opportunity to probe the gravity field to higher degree and order than possible by using conventional spacecraft tracking [1]. However, the non-gravitational forces acting on these particles must also be characterized, and their impact on solution accuracy must be assessed, requiring the different gravity field estimates to be compared and reconciled.

Given the measured gravity field of Bennu, rigorous constraints on its internal density heterogeneity can be found by comparing the measured field with the constant density field computed from the asteroid shape. These results in turn provide unique insight and constraints on the global geophysical processes that drive the external and internal morphology of small rubble pile asteroids such as Bennu.

Finally, definitive results on the surface and close-proximity force environment of Bennu can be derived and updated from the initial analysis based on the total mass and constant density shape. Several aspects of the environment are highly sensitive to the gravity field, and are expected to change from earlier results.

Our presentation will summarize the current gravity field solutions and uncertainties, update the surface and proximity environment models, and provide the geophysical implications and interpretations of these measurements.

Gravity Field Estimates: Current estimates of the Bennu gravity field coefficients will be presented, based on spacecraft tracking data and the tracking of the orbits of particle ejected from the asteroid surface. The teams producing independent assessments of the gravity field are from the University of Colorado, which leads the Radio Science Working Group, the Jet Propulsion Laboratory, KinetX Aerospace, and NASA's Goddard Space Flight Center. These different teams are applying different methodologies to fit and model the relevant spacecraft dynamics and ejected particle trajectories. We will present a synthesis and comparison of these results, which will allow for a more precise characterization of the uncertainties in the higher degree and order gravity field coefficients.

The data types to be used in these determinations will vary between the objects being tracked. For the spacecraft-based estimates, they will include Doppler and range data, optical navigation images of Bennu, and potentially lidar measurements from the OLA instrument. For the particle-based estimates, they will include images of the particles taken from the OSIRIS-REx spacecraft.

Updated Environment Models: Previously published results for the Bennu environment were based on an assumed constant density gravity field and earlier version of the asteroid shape model [2]. Some of the determined quantities are very sensitive to the mass distribution and asteroid shape, and thus must be updated and their implications reevaluated. For example, the stability of the Bennu-synchronous orbits (i.e., equilibrium points) was previously found to be highly sensitive to small variations in the asteroid shape, even with a constant density gravity field. The location and energy level of these equilibria directly control the rotational Roche lobe of the body and its intersection with the surface. Earlier results showed a clear transition of surface slopes at the lobe intersection with Bennu. Thus, a key result will be the presentation of these results with improved model accuracy. Other quantities of interest across the surface will also be updated.

Density Inhomogeneities: Based on the arrival observations of Bennu, the displacement of the center of mass and the rotation axis from the measured shape model indicated a level of gross density inhomogeneity within the asteroid [2,3]. The current presentation will update these density offsets for the most recent shape model, incorporating optical and lidar measurements.

In addition to these updates, the higher-degree and order gravity field coefficients will be used to test different density distribution models. The hypotheses we plan to use for this phase of the analysis will include inclusion of an inhomogeneity at the core of the body and symmetric inhomogeneities at the equator and mid-latitudes. Future analyses will investigate the density inhomogeneities using all degrees and orders of the estimated field, utilizing techniques described in [4].

Geophysical Models: Using the determined density inhomogeneity patterns we will investigate specific geophysical aspects of Bennu. It should be noted that current estimates show the measured J_2 and J_4 gravity coefficients to be larger than the constant density values. If these trends stay consistent with the final gravity field estimates, it points to a combination of an over-dense equator and under-dense center. The evaluation of the other gravity field coefficients will be able to constrain the degree to which the interior density is inhomogeneous, applying the simple theory outlined in [5].

An over-dense equator is consistent with transport of material to the equator at a lower porosity. This would match with the lower slope region being within the rotational Roche lobe. If this is paired with a lower-density interior, then it could be consistent with a period of past rapid spin and failure of the interior of the body along with preferential transport of material to the equator.

An alternate hypothesis holds that the asteroid took on its shape when it was initially formed and has not shifted since that epoch [6]. This would be consistent with a stronger rubble pile that has not changed its shape or rearranged material over many YORP cycles. Tests of this hypothesis are not as clear, and require additional simulations of how rubble pile asteroids coalesce after the catastrophic disruption of their parent body.

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