OSIRIS-REx Gravity Field Estimates for Bennu using Spacecraft and Natural Particle Tracking Data

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Abstract

The current best estimates of Bennu's gravity field will be presented, based on the independent solutions from four different teams involved on the OSIRIS-REx mission. The discovery of ejected particles about Bennu that may remain in orbit for several days or more provide a unique opportunity to probe the gravity field to higher degree and order than possible by using conventional spacecraft tracking. However, the non-gravitational forces acting on these particles must also be characterized, and their impact on solution accuracy must be assessed. This talk will present the latest results from the mission, incorporating spacecraft tracking from the lowest orbit in which the satellite will be during the mission.

1. Introduction

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. This talk summarizes the estimates from four teams on the OSIRIS-REx mission that are independently processing these results, using unique combinations of data and models. The gravity field information is key for understanding and constraining the interior mass distribution of the asteroid. Based on the Approach data published in [1] it is already evident that density inhomogeneities exist within Bennu. Thus, it is expected that the analysis of higher degree and order gravity field coefficients will provide additional insight into the interior structure of the body [2].

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 and possibly lidar measurements.

2. Expected Results

Due to the particle ejection events encountered at Bennu, with multiple particles being lofted into low-radius trajectories that may persist over several orbits, there is a possibility for insight into gravity field components at much higher degree and order than was nominally planned for. However, the uncertainty in these higher order gravity coefficients may be large, because they are based on tracking natural particles with unknown properties and mass loss characteristics.

At the time of the meeting, the OSIRIS-REx spacecraft will have completed its Orbital B phase, which is an extended period of time when the spacecraft will be in a Sun-terminator orbit with a radius less than 1 km. During this orbit phase, the spacecraft is in its closest sustained orbit about Bennu, and hence experiences the strongest perturbations from the nonuniform mass distribution within Bennu. Prior to the observed particle ejection events, this orbit period was thought to be the best opportunity to gain insight into the gravity field coefficients of this body, with expectations being that the spacecraft would experience sensitivity to select gravity coefficients up to degree and order 4 [3]. The gravity field coefficients estimated during this time are still of high importance, as they will serve as a ground-truth for comparisons with gravity coefficients inferred by tracking the ejected particles.

The natural particles are highly sensitive to the Bennu gravity field, as they emanate from the surface and can have repeated close approaches to the surface. Initial analysis shows that the particle trajectories can be sensitive to gravity coefficients up to degree and order 8 or 9. Estimation of coefficients up to this order would provide unprecedented insight into the interior of a rubble-pile asteroid. However, the motion of these particles are affected by significant non-gravitational forces, due to solar radiation pressure and thermal emission from the asteroid surface. Further complicating the situation is possible mass loss from the ejected particles, which would corrupt the information on these gravity terms. If the particle trajectories can be accurately fit, however, they will allow for considerable leverage in understanding density inhomogeneities.

3. Analysis of Uncertainties

A key component of this work is the identification of systematic modeling and measurement uncertainties in the estimated gravity field. This will be done using several different approaches. First, a classical covariance analysis of the expected uncertainties in the determined gravity field coefficients will be carried out. A key element of this analysis will be to characterize the effect of unmodeled non-gravitational forces on the ejected particles. The non-gravitational forces acting on the ejected particles will likely not be well modeled and could lead to systematic errors and uncertainties in the determined gravity field coefficients. These objects may have complex shapes and be tumbling due to torques imparted on the particles during ejection from the surface. This will lead to non-constant solar radiation pressure forces acting on these particles over time. As the shapes of the ejected particles cannot be observed, it is not possible to uniquely account for these effects. Even more dramatic, the particles may be outgassing once separated from the asteroid surface environment. Should this occur the particles will also be subject to "jetting" that would mask or alter the estimated effect of gravity coefficients. A covariance analysis is able to estimate the induced uncertainties in the estimated gravity field coefficients accounting for these effects, and thus provide estimates of confidence in these solutions.

Another approach to assess the systematic uncertainties in these gravity coefficients is to directly compare independent estimates, and estimates generated using different combinations of data. In this area it will be crucial to compare the gravity field coefficients that can be estimated using the spacecraft tracking data with the coefficients estimated from the ejected particles. The spacecraft-based gravity field estimates are expected to have very low levels of uncertainty in non-gravitational perturbations, and thus can serve as a "truth" estimate, even though the statistically significant estimates will not extend to high degree and order. Where they overlap with the particle-based estimates will be important, however, as ideally they should have the same value. The talk will present current progress on these activities as well.

4. Summary and Conclusions

The possibility of combining tracking data from the spacecraft and from natural particle trajectories can yield unprecedented insight into the gravity field coefficients of the asteroid Bennu. This talk will present current estimates of Bennu's gravity field following the lowest orbit period planned during the mission.

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References

[1] D.J. Scheeres, et al. : "The dynamic geophysical environment of (101955) Bennu based on OSIRIS-REx measurements," *Nature Astronomy* 3, 352-361, 2019.

[2] Tricarico, P. et al.: Interior structure of Bennu from OSIRIS-REx data, EPSC-DPS, 15–20 September 2019, Geneva, Switzerland, 2019.

[3] J.W. McMahon, et al. : "The OSIRIS-REx Radio Science Experiment at Bennu," *Space Science Reviews* 214, 43, 2018.