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Trajectory Estimation and Physical Characterization of Particles in the Environment of (101955) Bennu

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Abstract

We report on the trajectory estimates of orbital and sub-orbital particles in the Bennu environment. We will describe the trajectories, including orbital characteristics and lifetimes. In addition, we will discuss the force model assumed, which is particularly challenging for these small particles, given the potential for stochastic accelerations related to possible fission or outgassing. A central objective of the effort is to estimate the ejection and impact locations of the particles. When eventually linked to high-resolution image analysis, we anticipate that the location information will provide constraints as to the nature of the particle ejection phenomenon and the mechanical properties of the surface materials.

1. Introduction

On Dec. 31, 2018, the OSIRIS-REx spacecraft entered orbit around its sample-return target, near-Earth asteroid (101955) Bennu. Optical navigation images taken less than a week after orbit insertion revealed that the asteroid was emitting centimeter- to decimeter-sized particles, many of which immediately escaped from Bennu. The mission team quickly began to tailor observations to better monitor the Bennu environment for additional ejection events and particle tracking. This monitoring effort revealed that, in addition to those ejected directly onto hyperbolic orbits, some ejected particles returned to the surface on sub-orbital trajectories, while others entered relatively long-lived orbits, up to five days and over a dozen revolutions.

2. Force Model

A preliminary step to trajectory estimation is deriving a dataset of astrometric detections that are associated to a single object and that can be fit to an orbit. Once a dataset is in hand, fitting orbits to Bennu's particles requires particular attention to the forces controlling the trajectory. Besides the point-mass gravitational acceleration from Bennu, the higher-order components of the gravity field and direct solar radiation pressure are predominant forces. Because these forces are important to the trajectory, one can estimate the coefficients of a spherical harmonic expansion and the area-to-mass ratio of the particles. The former can give deeper insight into the nature and geophysics of Bennu, while the latter constrains the physical properties of the particle. However, we have not ruled out the possibility of significant, unmodeled nongravitational accelerations (e.g., due to particle mass loss). Such forces could obscure the gravitational perturbations, increasing the challenge of estimating an accurate gravity field. On the other hand, the existence of such forces could illuminate the nature of the phenomenon that precipitated the ejection. Other important forces include radiation pressure due to reflected and emitted radiation from Bennu and from radiation reflected by the particle. Solar tides and the Poynting-Robertson effect are somewhat below the level of significance.

3. Objectives

The estimation and analysis of the particle trajectories can reveal important information about the principle cause of the particle ejection phenomenon, as well as the physical characteristics of both Bennu and the particles. The particles have the potential to reveal the gravity field of Bennu at much higher resolution than would have otherwise been possible by the OSIRIS-REx mission. A detailed gravity model can be used to constrain the density distribution and geophysical evolution of Bennu. Estimates of accelerations related to radiation pressure and mass loss will provide insight into the particle characteristics. Finally, a key objective of the trajectory estimation process is identification of ejection and impact locations. The distributions of the ejection events—spatially across the body, in terms of local solar time, or as a function of heliocentric distance—are key to understanding the underlying processes. Detailed analysis of high-resolution imagery of ejection sites can shed further light on the process at hand. Similar analysis of impact locations may provide insight as to the nature of the surface response to low-speed impacts.