TRAJECTORIES OF EJECTED PARTICLES IN BENNU'S ENVIRONMENT.

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Introduction: Observations by the OSIRIS-REx navigation camera NavCam 1 have revealed the presence of centimeter-scale, short-lived particles in the environment of Bennu [1]. In some cases these particles are clearly associated with large ejection events, with upwards of 100 detectable particles being released, while other ejection events appear to have only a few associated particles. In most cases the detections of a particle cannot be readily associated with a particular ejection event.

We are undertaking a major effort to fit trajectories to as many particles as possible. This effort is motivated by the goals of providing insight into the Bennu gravity field, the physical and dynamical properties of the particles, and the location of ejections and impacts.

Particle Trajectory Overview: Many observed particles are ejected directly onto hyperbolic escape orbits, while others return quickly to the surface on suborbital trajectories. A few particles persist in orbit about Bennu for a number of revolutions, in some cases upwards of a dozen revolutions.

The escape velocity from Bennu's surface is in the range of 10–20 cm/s, depending on location [2], and particles ejected in excess of the escape velocity will tend to hyperbolic escape. The fastest observed particles have velocities up to a few m/s; however, there are strong selection effects against detection of faster objects. This is because particles have so far been detected only in long exposure (~5 s) images separated by varying intervals of 7 minutes up to a few hours.

Particle Data: The particle trajectory estimation relies on NavCam [3] detections of particles. The particle positions are referenced to stars present in the image, leading to right ascension-declination (RA-DEC) measurements at the image mid-exposure time. Position uncertainties range from ~0.25–2.0 pixels.

Force Model: Fitting orbits to Bennu's particles requires particular attention to the forces governing the trajectory. The forces are dominated by the point-mass gravitational acceleration from Bennu, while the lower-order components of the gravity field and direct solar radiation pressure are also important. 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. 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.

Besides these known forces, which can be modeled with generally good fidelity, other forces appear to be acting on the particles, based on poor fits to the data. Estimating empirical accelerations allows us to ensure that the particle trajectories actually put the particle at the position at which it was detected. And the magnitude of these accelerations, which can be up to a few times 10^{-11} km/s^2, and their direction provide insight into their source. At this point we have not definitively identified the phenomenon responsible for these empirical forces. Current hypotheses include mismodeling of reflected radiation pressure or particle mass loss due to, e.g., particle outgassing or grain shedding. We do not suspect gas drag on the particles because the OSIRIS-REx spacecraft is in the same environment and it does not appear to be affected by such an acceleration. In any case, 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 particles and of the phenomenon that precipitated the ejection.

Objectives: The estimation and analysis of the particle trajectories can reveal important information about the principal 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.

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