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The Dynamics of Ejected Particles around Bennu

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Abstract

The OSIRIS-REx spacecraft has recently discovered small particles being ejected from the surface of the near-Earth asteroid Bennu[1]. Observations to date have shown that a number of particles have survived in orbit for multiple days after leaving the asteroid surface, while others escape or quickly return to the surface. This behavior is governed by the complex dynamical environment near the surface of small asteroids, as well as the constraints on the launching conditions provided by the spacecraft observations. This talk will explore the effects of the different forces that influence these trajectories, and will demonstrate the surprising variety of orbits that can be produced in this environment.

1. Introduction

Historically, studies of orbital dynamics around asteroids typically do not focus on low-altitude orbits as these are expected to generally be unstable due to the complicated gravity fields of small bodies and therefore are of little interest for spacecraft or long-term dynamical investigations[2]. Similarly, low-speed ejecta have not been significantly studied since cratering-level impacts should largely produce high-velocity ejecta. The ejected particles from Bennu, however, appear to fall in this gap of our previous experience–both existing at low-altitudes and having relatively low initial velocities.

Given these initial conditions, it is somewhat surprising to find that particles ejected from the surface do not all immediately return to the surface or escape. A considerable fraction of simulated particles have their periapse raised or moved by the combination of complicated gravitational effects and non-gravitational forces–which have significant effects on these high area-to-mass ratio particles–such that they do not crash on their subsequent periapse passages.

To understand this process in detail, we simulate many particle trajectories with varying initial conditions under the effect of the following dynamics: polyhedral gravity, solar radiation pressure (not necessarily cannonball and including eclipses from Bennu), thermal forces from Bennu, and third body gravity from Sun.

All particles simulated start from the surface of Bennu with initial velocities which are constrained by the observed particles around Bennu to date. The simulations were capped at 40 days of simulated time.

2. Initial Illustrative Results

A small subset of initial results are shown here to illustrate the complicated and surprising dynamical environment. Fig. 1 shows some examples of possible orbits from particles ejected off the surface of Bennu. This particular set have semimajor axes less than approximately 2 km and last the full 40 days of simulated time without either returning to Bennu's surface or escaping from the system. It is clear from the orbits shown that, while lasting a significant length of time, the orbits are highly dynamic.The classical orbit elements are changing rapidly throughout the simulation.

Fig. 2 shows statistics for one small set of simulated particles. In this case approximately 15% of orbits last for 1-5 days, while approximately 1% of the last the full 40 days simulated.

3. Summary and Conclusions

This talk will explain the effects of the various dynamics that control the orbits of Bennu's ejected particles. A variety of orbital evolutions are discussed, including an understanding of the initial conditions that lead to various families of orbits and particle end states. Besides the intrinsic value in understanding the dynamics

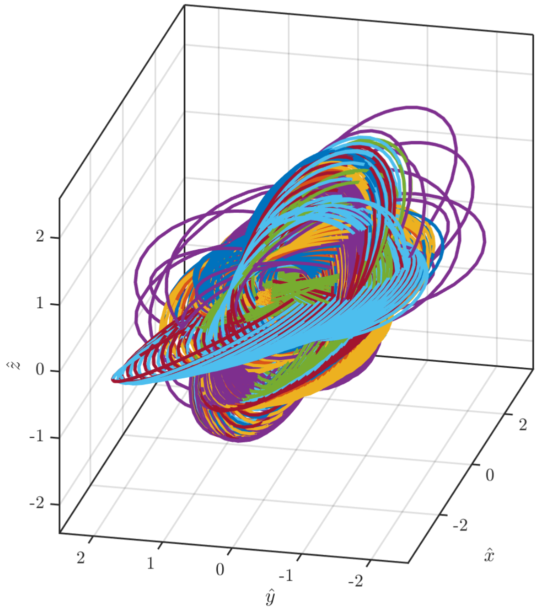

Figure 1: A set of example low-altitude trajectories which survive the full 40 days of simulated time. The frame is oriented such that $\hat{\mathbf{x}}$ is away from the sun along Bennu's orbital radius vector and $\hat{\mathbf{z}}$ is along Bennu's spin axis.

of this newly discovered natural phenomenon, there are a number of reasons why this knowledge is crucial for OSIRIS-REx moving forward. These include: understanding the dynamical environment in order to enable accurate gravity estimation from particle tracking; being able to map material transport across the surface of Bennu from ejection events; gaining insight into the amount and rate of material escape from the asteroid into interplanetary space; providing necessary statistics to de-bias observational data; and understanding the near-asteroid environment for operational safety and future mission planning.

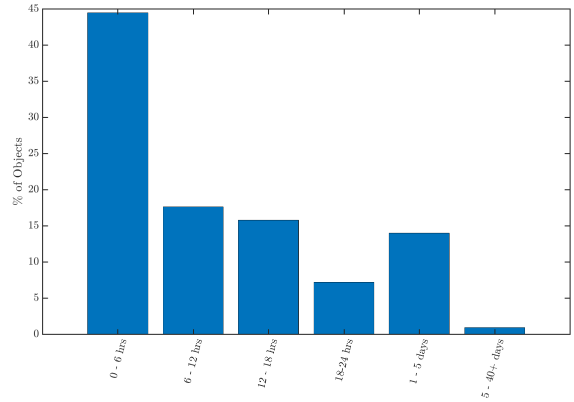

Figure 2: Lifetime statistics for one set of approximately 1500 simulated cases.

References

[1] Lauretta, D.S., DellaGiustina, D.N., et al.: "The unexpected surface of asteroid (101955) Bennu", Nature 568, 55-60, 2019.

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