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Exploding bits of Bennu: Adventures in asteroid exploration

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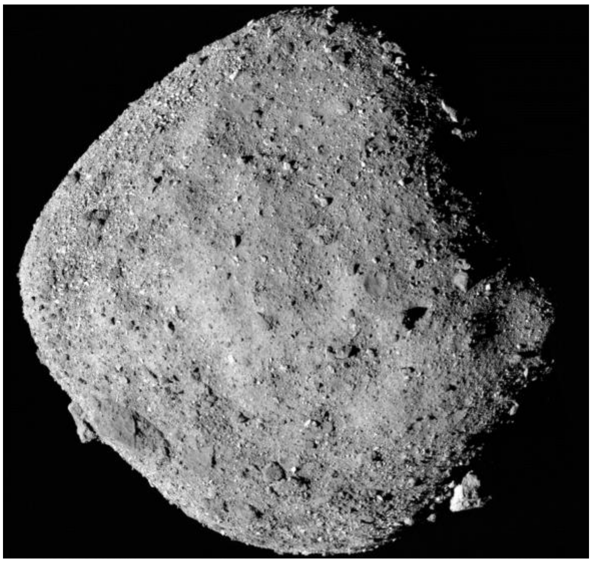
ABSTRACT

The NASA OSIRIS-REx spacecraft encountered many surprises while exploring asteroid Bennu. This asteroid is ejecting particles into space, leading to unexpected science results. With no risk to the satellite, the team is on track to collect and return a sample from this intriguing asteroid.



This mosaic image of asteroid Bennu is composed of 12 PolyCam images collected on Dec. 2 by the OSIRIS-REx spacecraft from a range of 15 miles (24 km). The image was obtained at a 50° phase angle between the spacecraft, asteroid and the Sun, and in it, Bennu spans approximately 1,500 pixels in the camera's field of view. Image credits: NASA/Goddard/University of Arizona ©

Asteroids are ancient remnants from the dawn of the solar system. Locked inside these comparatively small objects are clues to enduring questions about planet formation and the origins of life. Most asteroids orbit between Mars and Jupiter, in the main asteroid belt. Occasionally, an encounter with another object sends an asteroid into the inner solar system, where it becomes known as a near-Earth asteroid (NEA). Asteroids contain abundant natural resources in the form of metals, water, and organic compounds that could be exploited for future space exploration. NASA launched the OSIRIS-REx spacecraft to an NEA named Bennu, a water- and potentially organic-rich asteroid thought to contain primitive solar system material. The mission's primary objective is to return a sample of Bennu to Earth for laboratory investigation. As with all voyages of exploration, Bennu was full of surprises that challenged the team and provided unexpected scientific results.

The biggest surprise of the mission occurred on January 6, 2019, one week after the spacecraft entered orbit. The spacecraft routinely acquires images for optical navigation so that we can determine its position relative to the asteroid. We looked through these images for a public relations photo that included Earth, the Moon, and Bennu. To our astonishment, the images from that day showed Bennu spewing tiny pieces of rock into space.

Immediately, the team assessed whether these particles ejected from Bennu’s surface were hazardous. We found that even though some of them were bigger than a golf ball, they were, fortunately, moving too slowly to damage the spacecraft. Once we decided to continue with the mission, the team's attention shifted to understanding this fascinating phenomenon. Over the past year, we have observed particle ejection, placing Bennu in the rare class of "active asteroids," or rocky bodies that shed mass routinely.

Understanding the characteristics of the ejected particles required analyzing their brightness, position, and relative motion across a series of images. The mission’s flight dynamics and navigation experts were best situated to perform these analyses. This team routinely analyzes stars in the navigation images to determine the spacecraft’s location. They have all the tools to predict the spacecraft trajectory in the Bennu gravity field. The spacecraft's path is subject to some forces other than gravity, including solar radiation pressure, thermal emission, and spacecraft outgassing. So the team resourcefully applied their processes and knowledge from navigating the spacecraft to determine the ejection sites, trajectories, and fates of the particles.

The energies of the ejection events are small, about 100 millijoules or fewer per event. A small fraction of the particles is on escape trajectories. This means that they move fast enough to escape Bennu’s gravity (faster than ~20 cm/s) and leave the asteroid to become part of the interplanetary dust population. Many of the particles are on suborbital trajectories, leaving Bennu's surface at one location and impacting at another in a single arc. However, the most significant scientific payoff came from the particles in between: moving too slowly to escape Bennu and too quickly to impact the surface right away. These particles enter into orbit around Bennu, becoming a swarm of small moonlets. We can use the orbiting particles as individual gravity probes, mapping out the gravitational field of Bennu with a precision unobtainable from spacecraft tracking alone.

An outstanding question is what is causing the particle ejection events. The frequency and energy of the ejections make it possible to evaluate plausible mechanisms. In this study, we narrowed the list to three candidates: meteoroid impacts, the release of water vapor, and fracturing of rocks caused by thermally induced stress. All three of these mechanisms are consistent with the timing, energy, and particle sizes that we observed. In fact, they may all be playing a role. Thermal stresses caused by Bennu's rapid rotation may destabilize rock surfaces. Because Bennu contains abundant water-bearing clay minerals, these stresses may release water from the crystal structures. With the surface prepped in this manner, a meteoroid impact would readily disrupt the surface, sending hundreds of fragments into space.

The team is focused on preparing for the primary mission objective of collecting a sample. The sample collection is tentatively scheduled for August 25, 2020. Our sample collection device is capable of picking up rocks as large as 2 cm across. Some of the particles that were ejected and fell back to Bennu’s surface may be present in the material that is returned to Earth. Also, because Bennu is on an Earth-crossing orbit, ejected particles that escaped Bennu may be entering Earth's atmosphere as meteors every September. This discovery has opened up a new chapter in asteroid exploration. It demonstrates, once again, the value of exploring the unknown. Every time we visit a new destination in the solar system, the universe surprises us.