Where rocks come alive: NASA's OSIRIS-REx observes an asteroid in action

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It's 5 o'clock somewhere—and while here on Earth, "happy hour" is commonly associated with winding down and the optional cold beverage, that's when things get going on Bennu, the destination asteroid of NASA's OSIRIS-REx mission.

In a special collection of research papers published Sep. 9 in the *Journal of Geophysical Research: Planets*, the OSIRIS-REx science team reports detailed observations that reveal Bennu is shedding material on a regular basis. The OSIRIS-REx spacecraft has provided planetary scientists with the opportunity to observe such activity at close range for the first time ever, and Bennu's active surface underscores an emerging picture in which asteroids are quite dynamic worlds. The fleeing particles are the beginning of many revelations—from its gravitational field, to its interior compostion, Bennu's charisma continues to unfold for the team.

The publications provide the first in-depth look at the nature of Bennu's particle ejection events, detail the methods used to study these phenomena, and discuss the likely mechanisms at work that cause the asteroid to release pieces of itself into space.

The first observation of particles popping off the asteroid's surface was made in January 2019, mere days after the spacecraft arrived at Bennu. This event may have gone completely unnoticed were it not for the keen eye of the mission's lead astronomer and University of Arizona's Lunar and Planetary Laboratory scientist, Carl Hergenrother, one of the lead authors of the collection.

Much like ocean-going explorers in centuries past, the space probe relies on stars to fix its position in space and remain on course during its years-long voyage across space. A specialized navigation camera onboard the spacecraft takes repeat images of background stars. By cross-referencing the constellations the spacecraft "sees" with programmed star charts, course corrections can be made as necessary.

Hergenrother was poring over these images that the spacecraft had beamed back to Earth when something caught his attention. The images showed the asteroid silhouetted against a black sky dotted with many stars—except there seemed to be too many.

"I was looking at the star patterns in these images and thought, 'huh, I don't remember that star cluster,'" Hergenrother said. "I only noticed it because there were 200 dots of light where there should be about 10 stars. Other than that, it looked to be just a dense part of the sky."

A closer inspection and an application of image-processing techniques unearthed the mystery: the "star cluster" was in fact a cloud of tiny particles that had been ejected from the asteroid's surface. Follow-up observations made by the spacecraft revealed the telltale streaks typical of objects moving across the frame, setting them apart from the background stars that appear stationary due to their enormous distances.

"We thought that Bennu's boulder-covered surface was the wild card discovery at the asteroid, but these particle events definitely surprised us," said Dante Lauretta, OSIRIS-REx principal investigator and professor at LPL. "We've spent the last year investigating Bennu's active surface, and it's provided us with a remarkable opportunity to expand our knowledge of how active asteroids behave."

Since arriving at the asteroid, the team has observed and tracked more than 300 particle ejection events on Bennu. According to the authors, some particles escape into space, others briefly orbit the asteroid, and most fall back onto its surface after being launched. Ejections most often occur during Bennu's local two-hour afternoon and evening timeframe.

The spacecraft is equipped with a sophisticated set of electronic eyes—the Touch-and-Go Camera Suite, or TAGCAMS. Although its primary purpose is to assist in spacecraft navigation, TAGCAMS has now been placed into active duty spotting any particles in the vicinity of the asteroid.

Using software algorithms developed at the Catalina Sky Survey, which specializes in discovering and tracking near-Earth asteroids by detecting their motion against background stars, the OSIRIS-REx team found the largest particles erupting from Bennu to be about 6 centimeters (2 inches) in diameter. Due to their small size and low velocities—this is like a shower of tiny pebbles in super-slo-mo—the mission team does not deem the particles a threat to the spacecraft.

"Space is so empty that even when the asteroid is throwing off hundreds of particles, as we have seen in some events, the chances of one of those hitting the spacecraft is extremely small," Hergenrother said, "and even if that were to happen, the vast majority of them are not fast or large enough to cause damage."

During a number of observation campaigns between January and September 2019 dedicated to detecting and tracking mass ejected from the asteroid, a total of 668 particles were studied, with the vast majority measuring between 0.5 and 1 centimeters (0.2-0.4 inches), and moving at about 20 centimeters (8 inches) per second, about as fast—or slow—as a beetle scurrying across the ground. In one instance, a speedy outlier was clocked at about 3 meters (9.8 feet) per second.

On average, the authors observed one to two particles kicked up per day, with much of the material falling back onto the asteroid. Add to that the small particle sizes, and the mass loss becomes minimal, Hergenrother explained.

"To give you an idea, all of those 200 particles we observed during the first event after arrival would fit on a 4-inch x 4-inch tile," he said. "The fact that we can even see them is a testament to the capabilities of our cameras."

The authors investigated various mechanisms that could cause these phenomena, including released water vapor, impacts by small space rocks known as meteoroids and rocks cracking from thermal stress. The two latter mechanisms were found to be the most likely driving forces, confirming predictions about Bennu's environment based on ground observations preceding the space mission.

As Bennu completes one rotation every 4.3 hours, boulders on its surface are exposed to a constant thermo-cycling as they heat during the day and cool during the night. Over time, the rocks crack and break down, and eventually particles may be thrown from the surface. The fact that particle ejections were observed with greater frequency during late afternoon, when the rocks heat up, suggests thermal cracking is a major driver. The timing of the events is also consistent with the timing of meteoroid impacts, indicating that these small impacts could be throwing material from the surface. Either, or both, of these processes could be driving the particle ejections, and because of the asteroid's microgravity environment, it doesn't take much energy to launch an object from Bennu's surface.

"The particles were an unexpected gift for gravity science at Bennu since they allowed us to see tiny variations in the asteroid's gravity field that we would not have known about otherwise," said Steve Chesley, lead author of one of the studies published in the collection and senior research scientist at NASA's Jet Propulsion Laboratory in Southern California. "The trajectories show that the interior of Bennu is not uniform. Instead, there are pockets of higher and lower density material inside the asteroid."

Of the particles the team observed, some had suborbital trajectories, keeping them aloft for a few hours before they settled back down, while others fly off the asteroid to go into their own orbits around the sun.

In one instance, the team tracked one particle as it circled the asteroid for almost a week. The spacecraft's cameras even witnessed a ricochet, according to Hergenrother.

"One particle came down, hit a boulder and went back into orbit," he said. "If Bennu has this kind of activity, then there is a good chance all asteroids do, and that is really exciting."

As Bennu continues to unveil itself, the OSIRIS-REx team continues to discover that this small world is glowingly complex. These findings could serve as a cornerstone for future planetary missions that seek to better characterize and understand how these small bodies behave and evolve.

More information: C. W. Hergenrother et al. Introduction to the Special Issue: Exploration of the Activity of Asteroid (101955) Bennu, *Journal of Geophysical Research: Planets* (2020). DOI: 10.1029/2020JE006549

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