# New missions mine **asteroid secrets**

When Rosetta landed on a comet, the world held its breath. Now, scientists are about to attempt an even more ambitious mission — twice.

**by Elizabeth Tasker**

**ON** Friday, February 15, 2013, everybody was staring up at the sky. They were waiting for the record-breaking close approach of asteroid 367943 Duende. This 100-foot-wide (30 meters) space rock was due to pass our planet at a distance of only 17,000 miles (28,000 kilometers), sweeping inside the ring of geostationary weather and communications satellites that keep pace above the equator. Then, while the world stared in one direction, a second asteroid shot in from behind and exploded above Chelyabinsk, Russia.

Pieces of the surprise asteroid fell to Earth to become meteorites. It was a sizable 65 feet (20m) in diameter, and its fireball explosion lit up the morning sky brighter than the Sun. Buildings in six neighboring cities were damaged and about 1,500 people sustained injuries needing hospital treatment. The shock left everyone asking one question: How could scientists know about Duende but have missed the approach of the Chelyabinsk asteroid?

**Elizabeth Tasker** *is an astronomer at Hokkaido University in Japan, building stars and planets in her computer. She is on Twitter: @girlandkat.*

## Two missions, one goal

The answer goes far beyond one rogue asteroid, demanding that we understand intimately the composition and movement of distant, dark, orbiting rocks. Two space agencies are setting out to tackle the problem. This September, NASA will launch its Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) spacecraft to the asteroids. It is a journey that runs hot on the heels of the Japanese Aerospace Exploration Agency's (JAXA) asteroid mission, Hayabusa2. Both spacecraft are due to intercept their targets in 2018, with plans to touch down and gather rocks from the asteroid surfaces. These handfuls of pebbles will be incredibly precious because humans have retrieved pristine samples from only two surfaces beyond our planet: the Moon, using the full power of the Apollo program, and asteroid 25143 Itokawa, in a daring mission by Hayabusa2's predecessor. And it is these pebbles that should shed light on the difficult problem of tracking asteroids.

OSIRIS-REx and Hayabusa2 are heading for asteroids that orbit the Sun close to Earth. This classifies the two mission targets as near-Earth objects (NEOs). Hayabusa2 is heading for an asteroid named 162173 Ryugu, a rock a little over half a mile (1km) across whose orbit does not pose any threat to our planet. The target for OSIRIS-REx is the asteroid 101955 Bennu, about half Ryugu's size but with a more risky future.

Most asteroids reside in the asteroid belt, a band of rocks that orbits the Sun between Mars and Jupiter. Asteroids may leave this desirably distant location to approach Earth after collisions that scatter the rocks into different orbits. Their new routes through the solar system depend on gravitational tugs from the Sun and planets and the mysteriously tricky effect of sunlight.

When sunlight strikes an asteroid, its surface absorbs the Sun's energy and re-emits it as heat. There is a delay between these two events while the rock warms, during which time the asteroid rotates. This motion causes it to emit the heat in a different direction than when it absorbed the energy. The result is like catching a ball and throwing it to a person standing to your right. The small recoil from catching and throwing push in different directions, and you feel a force. For light particles called photons, this is called the Yarkovsky effect.

While the Yarkovsky effect also pushes on Earth, the force is too tiny to make any difference to our motion. Even on an asteroid the effect is not large, but over time it can change the asteroid's trajectory enough to make it a real problem.

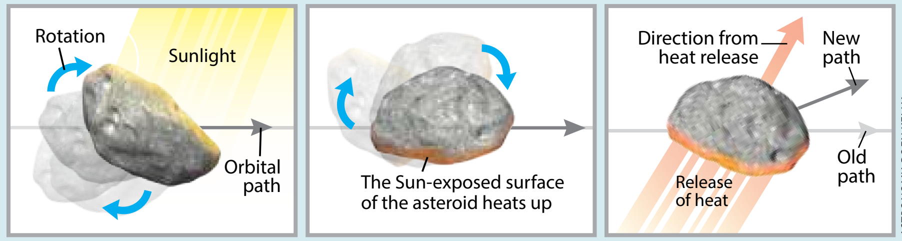
The direction and strength of the Yarkovsky sunlight push depend on the type of rock and its shape. Different materials have different heating and cooling rates, and surface topography may place part of an asteroid permanently in shadow. This is the crux of why asteroid motion is so hard to predict: Scientists do not know enough about asteroid composition to accurately calculate the Yarkovsky force.

Bennu is currently orbiting the Sun between Venus and Mars on a path that brings it close to Earth every six years.

**Two spacecraft from two nations — Hayabusa2 from Japan (left) and OSIRIS-REx from the United States (below) — will make their way to small, dark, moving asteroid targets. But the most audacious part of the missions comes when they attempt to return bits of their asteroids home to Earth.**

ILLUSTRATION BY ASTRONOMY: RON MILLER, AFTER NASA (OSIRIS-REX), AKIHIRO IKESHITA (HAYABUSA2)

## Asteroid motion is tough to predict




**The Yarkovsky effect describes how light can change an object's path by pushing it in one direction when the object absorbs light, and in another when the object later emits the energy as heat.**

While the asteroid is not in immediate danger of hitting our planet, there is a 1 in 2,500 chance that it will strike Earth in the late 22nd century. This is one of the highest probabilities of any known asteroid.

Scientists cannot be more precise about Bennu's fate without knowing more about the force from the Yarkovsky effect. It is one thing to predict Bennu's motion a few years out, but decades of cumulative Yarkovsky effects will make its position less certain 200 years in the future. A major goal for OSIRIS-REx is to record Bennu's motion accurately enough to measure sunlight's push. This will both constrain Bennu's future path and make vital improvements to the predictions for other NEOs.

### The beginnings of life

Yet the threat of an Armageddon impact from an unknown asteroid is only half of the reason for these twin missions. Examinations of meteorites have revealed that many once contained water, leaving them packed with organic molecules. These finds open the door to the intriguing possibility that life on Earth may have come from space.

Exactly how life began on Earth remains unknown. In most formation theories for our solar system, Earth's building blocks were dry grains too warm to contain the amounts of water the planet boasts today. The young desert Earth then gained its oceans from the arrival of ice-laden meteoroids. It is possible that this water delivery also contained the first organic molecules. To prove this theory, scientists need to find a similar icy rock while it is still in space, uncontaminated by the now-biologically active Earth.

There are two main reservoirs for meteoroids that are siblings to the ones that hit early Earth. The first are the comets that originate from beyond Neptune. Consisting mainly of ice, comets grow their distinctive tail as they travel toward the heat of the Sun. But measurements of the vapor surrounding comet nuclei suggest they were not our water delivery service.

Most cometary water contains too much deuterium, a heavy version (with a neutron) of the hydrogen atom (no neutron) that bonds with oxygen to make a water molecule. In December 2014, based on its studies of Comet 67P/Churyumov-Gerasimenko, the European Space Agency's Rosetta team concluded it was unlikely our oceans came from the comet population.

The second option is asteroids. Ground-based observations of Ryugu suggested the asteroid might contain water-rich minerals that must have formed in wet conditions. While Ryugu is too small to support liquid water, water in its parent asteroid may have left it full of organic molecules.

The same may also be true of Bennu. Both asteroids are carbonaceous chondrites, a class that formed in the early days of the solar system and has remained nearly unchanged during the past 4.5 billion years. This makes them kin to the meteorites that struck early Earth. It is therefore a good bet that any molecule found on these bodies would have also been delivered to our planet in its past.

### Touching the asteroids

OSIRIS-REx and Hayabusa2 will arrive at their respective targets in 2018. Then they will begin intensive 1.5-year analyses of their asteroids, exploring their structure from the largest scales down to surface grains smaller than a millimeter. Yet the most daring moments will be when the two spacecraft touch down on the asteroid surfaces.

When Rosetta visited Comet 67P, it dispatched the Philae lander to the surface to make a one-way trip, which went awry when the probe bounced repeatedly, landing on its side in a dark shadow. But in order to return asteroid samples to

**Japanese Aerospace Exploration Agency scientists successfully test Hayabusa2's Small Carry-on Impactor. They plan to use it to blow a 33-foot (10 meters) crater in asteroid Ryugu to collect samples from its interior.** JAXA/NIHONKOHI

Earth, OSIRIS-REx and Hayabusa2 must land the main spacecraft to gather material and then safely take off back into space. The small surface area of the asteroids, their weak gravity, and the unknown surface composition make this a dangerous endeavor, and failure could cost a mission its whole spacecraft. However, this mammoth task has been undertaken successfully once before.

As its name implies, Hayabusa2 has a predecessor. The first Hayabusa spacecraft returned to Earth in June 2010, bringing with it samples from asteroid Itokawa.

Like the Rosetta mission, Hayabusa did not have an easy time landing in the low-gravity environment of such a small rock. The spacecraft was designed to make only a brief touchdown on the asteroid's surface, but a malfunction caused it to bounce just as Philae did a decade later. When Hayabusa fell back to the asteroid's surface, it stayed there for half an hour, exposing itself to temperatures far beyond its design specification.

Despite this, Hayabusa survived to make a second successful landing attempt. It returned to Earth to bring back the first grains from an asteroid. Unlike Ryugu and Bennu, Itokawa has changed greatly since its formation and contains no signs of water or organic molecules. What it did provide was a resource on how sunlight can weather an asteroid's surface — information that will be key to understanding the observations from OSIRIS-REx and Hayabusa2. Its return also highlighted the importance of such sample retrieval missions.

"The images of these tiny grains appeared and were instantly recognizable to petrologists," says Harold Connolly, the mission sample scientist for OSIRIS-REx, as he describes the presentation of the results from Hayabusa. "It was a fixed moment in time for me."

It was a discovery that never would have been as obvious from an analysis performed remotely in space. Connolly realized that to understand our planet's past and future, he had to return to the asteroids.

The mechanism for collecting these vital grains is different between the two current missions. OSIRIS-REx will touch down at the end of its mission in 2019. When it lowers onto Bennu's surface, an extended mechanical arm will release a strong jet of nitrogen gas. As the jet hits the surface, loose rocks and grains will be stirred up and collected in the sample chamber at the end of the arm. "Our collector is a lot like a vacuum cleaner or Hoover," explains Connolly. "It will sweep up rock particles on the surface of Bennu using an inert gas." This inert gas will not contaminate or change the samples scientists need for their studies.

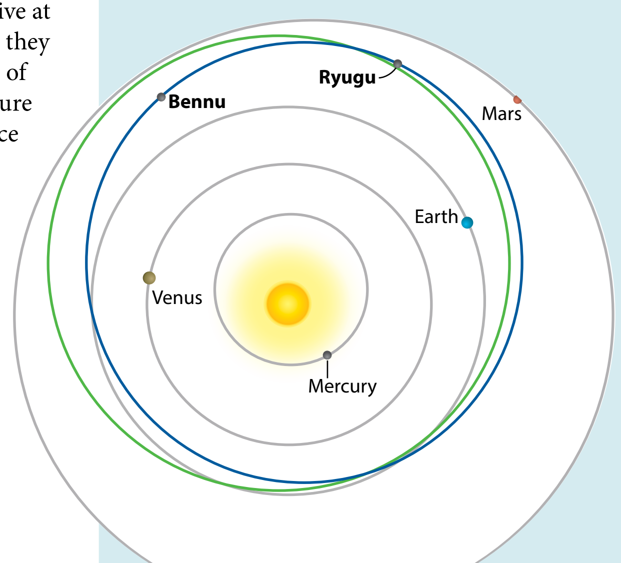
To check that this system will work in the vicinity of the asteroid, NASA scientists tested the equipment back on Earth in the so-called "vomit comet." Named for its effect on the stomach of human passengers, the airplane mimics the low-gravity environment of space through regular dips in its flight.

The cleaning job will yield a sizable haul of rocks for OSIRIS-REx — between 2 ounces and 4 pounds (60 grams to 2 kilograms) of differently sized particles. The plan is to perform this challenging landing only once, but OSIRIS-REx is equipped to try three times if there are any problems.

Hayabusa2 has a different game plan. The spacecraft intends to land not just once, but three times on Ryugu. By gathering material at different sites, Hayabusa2 will sample any variation in the asteroid's composition. It is a schedule that increases the risk to the spacecraft, but then, Japan has done this before.

## Crossing paths

**Ryugu and Bennu have Earth-crossing orbits, but Bennu's has a much higher chance of impacting Earth in a few centuries.** *ASTRONOMY*: ROEN KELLY




**Scientists work on the nearly complete Hayabusa2 spacecraft prior to its launch.** JAXA

**Hayabusa2 launched December 3, 2014, and is already well on its way toward asteroid Ryugu and set to arrive in 2018.** JAXA

**OSIRIS-REx displays its high-gain antenna and solar arrays before engineers move it from construction to environmental testing in October 2015.** LOCKHEED MARTIN CORP.

**Hayabusa2 will shoot an explosive charge into asteroid Ryugu and then flee to the space rock's far side to avoid damage when it blows. The spacecraft will return to sweep up the pulverized material churned up from deep inside the asteroid's bulk.** AKIHIRO IKESHITA

## WHAT'S IN A NAME?

**Bennu**
In 2013, the Planetary Society held a naming contest for the asteroid 1999 $RQ_{36}$. The winner was 9-year-old Mike Puzio, who submitted the name Bennu, an Egyptian deity depicted as a heron in mythology and associated with the god Osiris. In addition to the mythological pairing, Puzio also thought the spacecraft resembled a bird in flight, and the asteroid itself an egg.

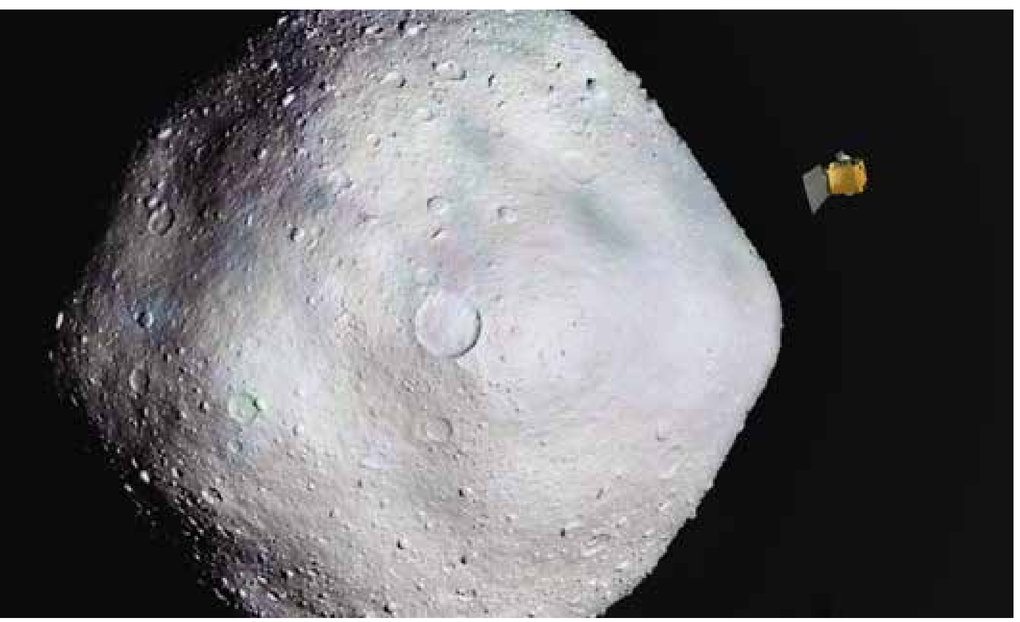
**Ryugu**
The Japanese space agency renamed its target from 1999 $JU_3$ to Ryugu in 2015, also based on public submissions. In Japanese folklore, the hero Taro Urashima retrieves a treasure chest from a dragon-guarded castle named Ryugu at the bottom of the sea. Likewise, astronomers count on Hayabusa2 to bring back treasures that will inform them about Earth's oceans. — **Korey Haynes**

To stir up the surface material for collection, Hayabusa2 will fire a bullet into the asteroid as it touches down for its first two landings. At least one of these locations will be at the site of the observed water-rich minerals, while the second will be selected after Hayabusa2 has scouted the asteroid from above.

On the third landing, the spacecraft plans to gather material from deeper inside Ryugu's belly. For that, a larger explosion is needed. Hayabusa2 is carrying a "Small Carry-on Impactor" containing 10 pounds (4.5kg) of explosives. When it hits the asteroid, the resulting blast will carve a crater up to 33 feet (10m) across. To protect itself from the explosion, Hayabusa2 will duck behind the asteroid, dispatching a camera to monitor the result in its stead. Then the spacecraft will make its final collection from the freshly exposed rock.

While Hayabusa2 cannot linger on the surface, it will leave behind a lander packed with three rovers. These robotic explorers will examine Ryugu's surface in greater detail and test the challenges of motion in a low-gravity environment.

Hayabusa2 is aiming for a smaller sample yield than OSIRIS-REx, with a minimum weight of 100 milligrams. Small though this sounds, the first Hayabusa mission revealed an enormous amount of information about the asteroid, Itokawa, with roughly 10,000 times less material. A tenth of a gram is sufficient for all the analysis the mission needs to complete, although the team's best-case scenario will see several grams returned to Earth.



**NASA scientists overlaid simulated craters and topography on real radar images of asteroid Bennu, with an artist's depiction of OSIRIS-REx in flight next to it. Genuine high-resolution images will not arrive until shortly before the spacecraft itself does in 2018.** NASA/JPL/GOLDSTONE/GSFC/UA/MIKE NOLAN (ARECIBO OBSERVATORY)/BOB GASKELL (PLANETARY SCIENCE INSTITUTE)

Samples from the three sites will be stored separately inside Hayabusa2's container, which will be completely sealed to prevent contamination from terrestrial molecules upon return to Earth. Hayabusa2 is due to land in the Australian outback at the end of 2020, while OSIRIS-REx will land in the Utah desert in 2023. When the containers are cracked open, the science teams will be looking into time capsules from the earliest days of our solar system.

## Teamwork

Having independent data from two asteroids greatly reduces the possibility that the collected sample is not typical of the objects. This allows for scientists to draw much bigger deductions from the data. "Samples from two asteroids more than doubles their worth," states Connolly.

Because of this, NASA and JAXA officially joined the OSIRIS-REx and Hayabusa2 missions with a "Memorandum of Understanding." The two teams will share expertise and exchange a fraction of the samples from each mission. JAXA will send 10 percent of the Hayabusa2 samples from Ryugu to NASA, which in turn will send half a percent of the OSIRIS-REx Bennu sample to JAXA. The difference in the figures reflects OSIRIS-REx's larger sample size, and the fact that JAXA will make use of NASA's Deep Space Network of communication antennas to track Hayabusa2 on its journey.

Hayabusa2's first landing on Ryugu will come a year before OSIRIS-REx touches down on Bennu. Both teams will be glued to the data so that they can prepare for any surprises in their future landings. In return, the OSIRIS-REx team is sharing its software to construct three-dimensional models of asteroids to assist Hayabusa2 in its navigation.

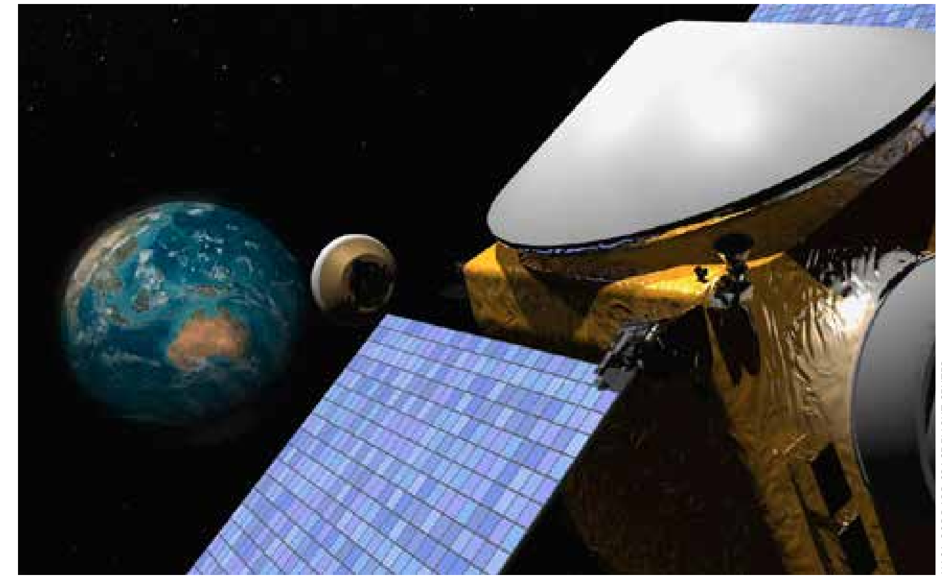
Both agencies strongly support this collaboration, as revealed in a meeting between the director general of the Institute of Space and Astronautical Sciences at JAXA, Saku Tsuneta, and OSIRIS-REx's principal investigator, Dante Lauretta, in October 2014. "For a center director to reach out and discuss a particular science expedition is unprecedented," says Connolly, who was also at the meeting.

Connolly has been working extensively with his sample collection counterpart on the Hayabusa2 mission, Shogo Tachibana. The two agree that the collaboration is rewarding but not always easy.

The differences in size between the two space agencies has raised questions about the balance of power. Japan initially voiced concerns that a collaboration with NASA would result in the larger agency dominating both asteroid missions. But Japan's expertise in asteroid missions and meteorite science balances the scale. "In asteroid research, we can make this an even collaboration between us," Tachibana states.

But JAXA's smaller size contributes other more subtle factors to the work culture as well. "Japan is used to working alone," explains Tachibana. "We operate more as a family than a corporate business, where everyone's role is implicitly understood. But a company the size of NASA requires detailed contracts for all aspects of the research."

Such cultural differences don't exist only within the mission teams. Connolly describes his experience during a visit to Japan when a bartender found out that Tachibana was a member of the Hayabusa2 mission. "This guy went down on one knee to shake Shogo's hand," he says. "That would never happen in America! There is a huge difference in perception."



**An artist envisions OSIRIS-REx releasing its Sample Return Capsule when it returns to Earth. It should land in the Utah desert in 2023.** NASA GODDARD SPACE FLIGHT CENTER

Yet despite these mismatches in size and recognition, NASA and JAXA are taking similar steps to reach beyond the scientific community. Both organizations held public naming competitions for their asteroid targets. Additionally, the OSIRIS-REx team is organizing a citizen science project to help identify NEOs. Project "Target Asteroids!" asks amateur astronomers to send in images of asteroids to increase researchers' knowledge of these poorly understood objects. The two missions keep their websites busy with animated videos, interviews with project scientists, and mission updates. Much of JAXA's outreach takes place in Japanese, of course, but they also run an English Twitter feed and share news on the mission website in both languages.

**Hayabusa2 will return its samples in 2020, when they plummet to the Australian outback.** AKIHIRO IKESHITA

Even with all the differences international collaborations can bring, there is no doubt in the minds of the OSIRIS-REx and Hayabusa2 teams of the worth of this partnership. The samples OSIRIS-REx and Hayabusa2 will bring home contain the history not of a single country, but of all life on Earth, and keys to its future as well. Both groups want to ensure the best expertise is waiting to receive it. ◑

**OSIRIS-REx will reach out its sample collector like a vacuum cleaner extension (inset) to gather samples from asteroid Bennu's surface, possibly retrieving up to a few pounds.** NASA GODDARD SPACE FLIGHT CENTER

**Exactly a year after its launch on December 3, 2014, Hayabusa2 performed an Earth flyby on its way to asteroid Ryugu, capturing this image at a distance of 340,000 kilometers (211,000 miles).** JAXA