insect damage than when the volatiles were applied to a plant of the other chemotype—a hint of a kin effect.

The mustard *Arabidopsis thaliana* has provided another clue. About 8 years ago, Jorge Casal, a plant biologist at the University of Buenos Aires, noticed that *Arabidopsis* plants growing next to relatives shift the arrangement of their leaves to reduce shading of their neighbors, but don't do that when the neighbors are unrelated. How they sense the presence of relatives was a mystery, however.

The plants do have light sensors, and in 2015, Casal's team discovered that the strength of reflected light striking nearby leaves signaled relatedness and triggered the rearrangements. Relatives tend to sprout leaves at the same height, bouncing more light onto each other's leaves. By shifting leaves to reduce how much they shade each other, the relatives cumulatively grow more vigorously and produce more seeds, his team found. "There is no other case of kin recognition in plants where the cue, the receptors, and the fitness consequences have been established," Casal says.

Since then, he has shown that when sunflower kin are planted close together, they, too, arrange themselves to stay out of one another's way. The sunflowers incline their shoots alternately toward one side of the row or the other, Casal and his colleagues reported in 2017 in the *Proceedings of the National Academy of Sciences*. Taking advantage of the effect, they planted 10 to 14 related plants per square meter—an unheard of density for commercial growers—and got up to 47% more oil from plants that were allowed to lean away from each other than plants forced to grow straight up.

Chui-Hua Kong, a chemical ecologist at the China Agricultural University in Beijing, is exploiting a similar effect to boost rice yields. His lab studies rice varieties that give off weed-killing chemicals in their roots. Right now, they don't have high enough yields to replace commonly grown varieties that require herbicides. But in 3-year-long field tests, kin-recognizing versions of these self-protective rice varieties produced a 5% increase in yield when grown with kin, rather than unrelated plants, Kong and colleagues reported in late September 2018 in *New Phytologist*. To test the approach on a larger scale, he and his colleagues are planting "kin" seedlings of the weed-killing strain together in paddy fields in South China.

Brian Pickles, an ecologist at the University of Reading in the United Kingdom, proposes that kin recognition could even help forests regenerate. By tracing flows of nutrients and chemical signals between trees connected by underground fungi, he showed that the firs preferentially feed their kin and warn them about insect attacks. The finding suggested a family of firs would grow faster than unrelated trees.

To some biologists, the emerging picture of communicating, cooperating plants is still based on thin evidence. Laurent Keller, an evolutionary biologist at the University of Lausanne who has shown that some apparent signs of kin recognition in *Arabidopsis* can instead stem from innate differences among the plants, calls for more rigor in studies. "People have started to realize that it is important to think carefully about the design of the experiment to rule out other potential explanations," he says.

Keller is keeping an open mind and predicts stronger evidence of plant kin recognition will emerge. Karban is already convinced. "We are learning that plants are capable of so much more sophisticated behavior than we had thought," he says. "It's really cool stuff." ■

Initially disbelieved, Susan Dudley's work on plant kin recognition is winning over more biologists.

PHOTO: TASMIN CHU

PLANETARY SCIENCE

Asteroid mission faces 'breathtaking' touchdown

As first data roll in from Hayabusa2, engineers plan descent to rocky surface

By **Dennis Normile***, in Yonago, Japan*

Japan's Hayabusa mission made history in 2010 for bringing back to Earth the first samples ever collected on an asteroid. But the 7-year, 4-billion-kilometer odyssey was marked by degraded solar panels, innumerable mechanical failures, and a fuel explosion that knocked the spacecraft into a tumble and cut communications with ground control for 2 months. When planning its encore, Hayabusa2, Japan's scientists and engineers were determined to avoid such drama. They made components more robust, enhanced communications capabilities, and thoroughly tested new technologies.

But the target asteroid, Ryugu, had fresh surprises in store. "By looking at the details of every asteroid ever studied, we had expected to find at least some wide flat area suitable for a landing," says Yuichi Tsuda, Hayabusa2's project manager at the Japan Aerospace Exploration Agency's Institute of Space and Astronautical Science (ISAS), which is headquartered in Sagamihara. Instead, when the spacecraft reached Ryugu in June 2018—at 290 million kilometers from Earth—it found a cragged, cratered, boulder-strewn surface that makes landing a daunting challenge. The first sampling touchdown, scheduled for October, was postponed until at least the end of this month, and at a symposium here on 21 and 22 December, ISAS engineers presented an audacious new plan to make a pinpoint landing between closely spaced boulders. "It's breathtaking," says Bruce Damer, an origins of life researcher at the University of California, Santa Cruz.

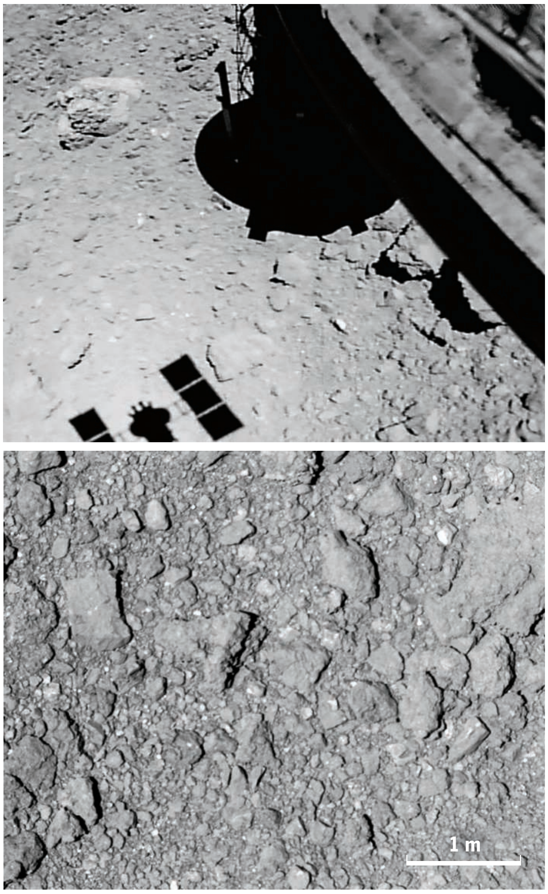
Yet most everything else has gone according to plan since Hayabusa2 was launched in December 2014. Its cameras and detectors have already provided clues to the asteroid's mass, density, and mineral and elemental composition, and three rovers dropped on the asteroid have examined the surface. At the symposium, ISAS researchers presented early results, including evidence of an abundance of organic material and hints that the asteroid's parent body once held water. Those findings "add to the evidence that asteroids rather than comets brought water and organic materials to Earth," says project scientist Seiichiro Watanabe of Nagoya University in Japan.

Ryugu is 1 kilometer across and 900 meters top to bottom, with a notable bulge around the equator, like a diamond. Visible light observations and computer modeling suggest it's a porous pile of rubble that likely agglomerated dust, rocks, and boulders after another asteroid or planetesimal slammed into its parent body during the early days of the solar system. Ryugu spins around its own axis once every 7.6 hours, but simulations suggest that during the early phase of its formation, it had a rotation period of only 3.5 hours. That probably produced the bulge, by causing surface landslides or pushing material outward from the core, Watanabe says. Analyzing surface material from the equator in an Earth-based laboratory could offer support for one of those scenarios, he adds. If the sample has been exposed to space weathering for a long time, it was likely moved there by landslides; if it is relatively fresh, it probably migrated from the asteroid's interior.

So far, Hayabusa2 has not detected water on or near Ryugu's surface. But its infrared spectrometer has found signs of hydroxide-bearing minerals that suggest water once existed either on the parent body or on the asteroid, says Mutsumi Komatsu, a planetary materials scientist at the Graduate University for Advanced Studies in Hayama, Japan. The asteroid's high porosity also suggests it once harbored significant amounts of water or ice and other volatile compounds that later escaped, Watanabe says. Asteroids such as Ryugu are rich in carbon as well, and they may have been responsible for bringing both water and carbon, life's key building block, to a rocky Earth early in its history. (Comets, by contrast, are just 3% to 5% carbon.)

Support for that theory, known as the late heavy bombardment, comes from another asteroid sample return mission now in progress. Early last month, NASA's OSIRIS-REx reached asteroid Bennu, which is shaped like a spinning top as well and, the U.S. space agency has reported, has water trapped in the soil. "We're lucky to be able to conduct comparative studies of these two asteroid brothers," Watanabe says.

Geologist Stephen Mojzsis of the University of Colorado in Boulder is not convinced such asteroids will prove to be the source of Earth's water; there are other theories, he says, including the possibility that a giant Jupiter-like gaseous planet migrated from the outer to the inner solar system, bringing water and other molecules with it around the time Earth was formed. Still, findings on Ryugu's shape and composition "scientifically, could be very important," he says.



Hayabusa2 imaged its shadow during a rehearsal descent (top). A close-up shows a surface strewn with boulders (bottom).

Some new details come from up-close looks at the asteroid's surface. On 21 September, Hayabusa2 dropped a pair of rovers the size of a birthday cake, named Minerva-II1A and -II1B, on Ryugu's northern hemisphere. Taking advantage of its low gravity to hop autonomously, they take pictures that have revealed "microscopic features of the surface," Tsuda says. And on 5 October, Hayabusa2 released a rover developed by the German and French space agencies that analyzed soil samples in situ and returned additional pictures.

The ultimate objective, to bring asteroid samples back to Earth, will allow lab studies that can reveal much more about the asteroid's age and content. ISAS engineers programmed the craft to perform autonomous landings, anticipating safe touchdown zones at least 100 meters in diameter. Instead, the biggest safe area within the first landing zone turned out to be just 12 meters wide.

That will complicate what was already a nail-biting operation. Prior to each landing, Hayabusa2 planned to drop a small sphere sheathed in a highly reflective material to be used as a target, to ensure the craft is moving in sync with the asteroid's rotation. Gravity then pulls the craft down gently until a collection horn extending from its underside makes contact with the asteroid; after a bulletlike projectile is fired into the surface, soil and rock fragments hopefully ricochet into a catcher within the horn. For safety, the craft has to steer clear of rocks larger than 70 centimeters.

During a rehearsal in late October, Hayabusa2 released a target marker above the 12-meter safe circle; unfortunately, it came to rest more than 10 meters outside the zone. But it is just 2.9 meters away from the edge of a second possible landing site that's 6 meters in diameter. Engineers now plan to have the craft first hover above the target marker and then move laterally to be above the center of one of the two sites. Because the navigation camera points straight down, the target marker will be outside the camera's field of view as Hayabusa2 descends, leaving the craft to navigate on its own.

"We are now in the process of selecting which landing site" to aim for, says Fuyuto Terui, who is in charge of mission guidance, navigation, and control. Aiming at the smaller zone means Hayabusa2 can keep the target marker in sight until the craft is close to the surface; the bigger zone gives more leeway for error, but the craft will lose its view of the marker earlier in the descent.

Assuming the craft survives the first landing, plans call for Hayabusa2 to blast a 2-meter-deep crater into Ryugu's surface at another site a few months later, by hitting it with a 2-kilogram, copper projectile. This is expected to expose subsurface material for observations by the craft's cameras and sensors; the spacecraft may collect some material from the crater as well, using the same horn device. There could be a third touchdown, elsewhere on the asteroid. If all goes well, Hayabusa2 will make it back to Earth with its treasures in 2020. ■

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