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News & Highlights

Asteroid Missions Begin to Pay Off

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Space missions targeting asteroids, loosely bound clumps of rock, ice, and metals, some of which are thought to pre-date the sun, are on a roll. In December 2020, the Japan Aerospace Exploration Agency (JAXA) completed a mission to scoop up a small amount of material from the asteroid Ryugu and deliver it back to Earth [1]. Earlier, in October 2020, the US National Aeronautics and Space Administration (NASA) acquired a sample, which will begin its return to Earth in March 2021, from the asteroid Bennu [2]. Meanwhile, the China National Space Administration (CNSA) has proposed a similar mission to retrieve a sample from the near-Earth asteroid Kamo'oalewa [3], and a joint NASA–European Space Agency (ESA) effort is preparing a mission to demonstrate the feasibility of nudging an asteroid away from a collision course with Earth [4].

The sample-retrieval missions to Ryugu, Bennu, and Kamo'oalewa will not be the first time that scientists have had access to materials from asteroids.

"When you see a shooting star, that is actually a small piece of a comet or asteroid that intersected the Earth. So, in a way, we have been getting samples without ever having to send missions," said Chris Lewicki, founder of Interplanetary Enterprises in Seattle, WA, USA. "But now, being able to definitively say, 'This material came from this spot, it has this orbit around the sun, and its parent body has these characteristics,' that really tells us an incredible amount about the billions of years of chemistry that got us to where we are today," said Lewicki, a former senior flight systems engineer and flight director on multiple missions at the NASA Jet Propulsion Laboratory in Pasadena, CA, USA.

The first attempt to acquire a sample from an asteroid was Hayabusa, a JAXA spacecraft launched in 2003. Beset by numerous hardware failures, Hayabusa returned to Earth a scant millionth of a gram of material from the asteroid Itokawa in 2010 [5].

Undeterred by the disappointing returns of Hayabusa, JAXA began building Hayabusa's successor in early 2011. Launched in 2014, this spacecraft, Hayabusa2 (Fig. 1), travelled 290 million km to reach the asteroid Ryugu in July 2018. Once there, it studied the 900 m wide asteroid from orbit using a suite of observation instruments, including optical cameras, infrared cameras, and light detection and ranging (LIDAR). It also delivered three small rovers to Ryugu to study its surface at close range [5].

In February 2019, Hayabusa2 itself landed on Ryugu's surface, fired two small projectiles into the asteroid, and collected a sample of the resulting debris cloud. The spacecraft fired a larger projectile two months later to gather even more material [5]. After several more months of observations, the spacecraft began its return journey back to Earth in November 2019, releasing its sample return capsule into Earth's atmosphere in December 2020. The capsule parachuted down near Woomera in South Australia, containing an estimated payload of several grams (Fig. 2) [1].

"This was an incredibly complex mission, and it all went off beautifully—they have opened the first sample container, and it

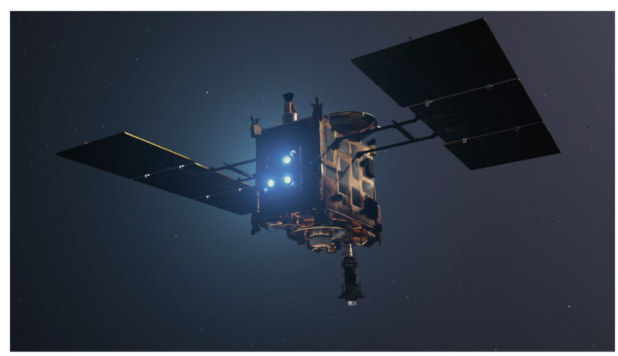

Fig. 1. Artistic rendition of Hayabusa2 firing its ion thrusters in space. Credit: German Aerospace Center (public domain).

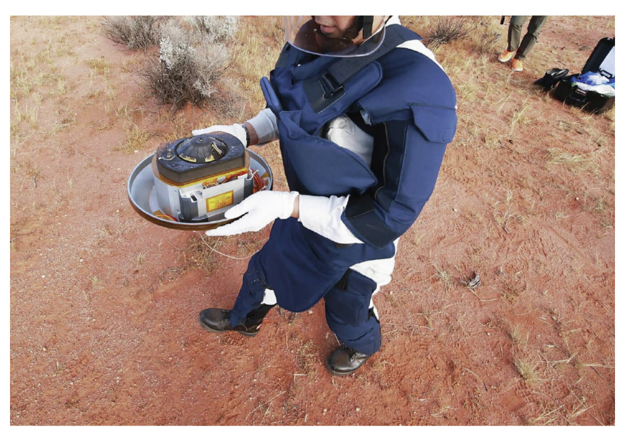

Fig. 2. A JAXA scientist retrieves the capsule containing a sample of the asteroid Ryugu dropped by Hayabusa2 near the South Australia town of Woomera. Credit: JAXA (public domain).

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seems like it has exactly what they needed in it," said Jonathan McDowell, an astrophysicist at the Harvard–Smithsonian Center for Astrophysics in Cambridge, MA, USA.

Hayabusa2 is now flying another mission, using two flybys of Earth to slingshot itself toward asteroid 1998 KY26 for observations projected to begin in July 2031 [5]. JAXA will leverage what it learned from the first two Hayabusa missions for a new mission called Martian Moons eXploration (MMX), with the goal of bringing back samples from Phobos, the largest moon of Mars [1].

NASA launched its asteroid sample-retrieval mission Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) in September 2016. The spacecraft arrived at the asteroid Bennu, about 3.22×10^8 km from Earth, in December 2018 (Fig. 3) [2]. Once there, mission controllers discovered that Bennu's surface was much rockier than expected. "They had to redesign their sampling approach after they arrived at the asteroid," said McDowell. "But they figured out how to make it work with the spacecraft they had."

After two rehearsals, OSIRIS-REx successfully executed a touch-and-go sample collection on 20 October 2020. For this maneuver, the craft descended close to the surface and extended a 3.4 m long sampling arm about 5 cm into the loose dust (Fig. 4). It then fired nitrogen gas from a high-pressure bottle into the surface to force material from Bennu into a circular collection chamber attached to the arm. The chamber filled with so much material—estimated at about 400 g—that NASA canceled a planned second collection [6]. The overflowing material initially prevented the mylar flaps meant to seal the chamber from closing, allowing some of the material to float away. But the chamber is now secured within OSIRIS-REx's sample return capsule [7].

Scheduled to depart from Bennu in March 2021, OSIRIS-REx is expected to deliver its sample capsule back to Earth in September 2023. Like Hayabusa2, it will then change course and head back into the solar system for additional missions.

Unlike Ryugu and Bennu, the asteroid Kamo'oalewa—the target of CNSA's proposed asteroid sample-collection mission, called ZhengHe—is relatively close to Earth, and is the nearest of Earth's quasi-satellites. While orbiting the sun, Kamo'oalewa constantly loops around the Earth along a highly eccentric path, but never wanders more than 3.8×10^7 km away [3]. ZhengHe's mission plan calls for launch in 2022 [8]. After returning samples of Kamo'oalewa to Earth, the Chinese craft would then journey to the solar system's asteroid belt to study the comet 133P/Elst–Pizarro.

Fig. 3. NASA's OSIRIS-REx has been studying the 510 m wide asteroid Bennu up close since 2018. In October 2020, the spacecraft got even closer to collect a surface sample expected to reach the Earth in September 2023. Credit: NASA/Goddard/University of Arizona (public domain).

Fig. 4. OSIRIS-REx's 3.4 m long sampling arm extended a dinner-plate-size sampling chamber 5 cm into the loose dust on Bennu, collecting about 400 g of material from the asteroid's surface. Credit: NASA (public domain).

While it may take years for researchers to draw scientific conclusions based on analysis of the samples collected by Hayabusa2, OSIRIS-REx, and ZhengHe, some entrepreneurs hope one day to exploit the abundant resources expected to exist within asteroids. "All the same knowledge gained about operating a craft near an asteroid and extracting material off its surface is going to be critical for asteroid mining," said Lewicki.

But asteroids also have the potential to wreak havoc. Astronomers have identified about 16 000 asteroids sized between 140 and 1000 m in diameter in our solar system, with more thought yet to be discovered [4]. If an object near the top of this size range happened to collide with Earth (an event similar to the one thought to have caused the extinction of dinosaurs), the impact and its fallout would likely destroy civilization. NASA's Double Asteroid Redirection Test (DART) mission will test impact-mitigation strategies that could avert disaster by shoving such cosmic menaces out of Earth's way [4].

DART, a white cube the size of a small cargo van (Fig. 5), is scheduled to launch in summer 2021. Its target is Dimorphos, a 160 m secondary body (or "moonlet") orbiting the 780 m asteroid Didymos. The spacecraft will deliberately crash itself into the moonlet at a speed of $6.6 \text{ km}\cdot\text{s}^{-1}$, imparting a collision energy equivalent to an explosion of several tons of trinitrotoluene. The impact, scheduled for October 2022, is expected to change the speed of Dimorphos in its orbit around Didymos by a fraction of one percent. If all goes as planned, this will alter the moonlet's orbital period by several minutes, enough to be observed and measured using telescopes on Earth. "A very small change in the orbital period of this tiny moonlet is much easier to measure than a very small change in the position of the asteroid would be," said McDowell. "It is really a super-clever idea."

In the second part of this collaborative mission, the European Space Agency's Hera spacecraft will travel to Didymos four years after DART makes impact. Once there, Hera will image the crater that DART made to assess the damage and add to the understanding of what an actual asteroid deflection mission might entail [9].

"It is tricky, because you actually want to deflect it rather than blow it to pieces, which could create buckshot that slams into Earth. You want it to lodge inside the asteroid and nudge it a bit," said Robert Jedicke, a research specialist at the Institute for Astronomy at the University of Hawaii at Manoa. "All these missions

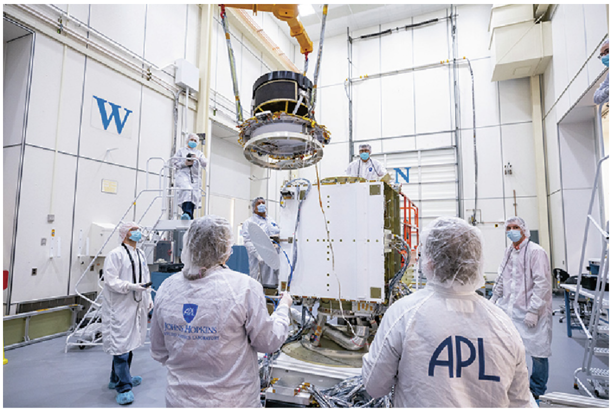

Fig. 5. Engineers position the DART's thruster assembly atop the spacecraft. Credit: NASA/Johns Hopkins Applied Physics Laboratory/Ed Whitman (public domain).

examining asteroid composition and structure are giving us the confidence we will be able to pull it off."

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