ICE & STONE 2020

WEEK 49: NOV. 29-DEC. 5

Presented by The Earthrise Institute

#49

Authored by Alan Hale

THIS WEEK IN HISTORY

NOVEMBER **29** 30 1 2 3 4 5

NOVEMBER 29, 1996: A team of researchers led by Stewart Nozette publishes their paper describing the tentative detection of water ice at the moon's south pole in radar experiments conducted with the U.S. Defense Department's Clementine spacecraft. This detection has been confirmed by later spacecraft missions, and these efforts, and the overall significance of this discovery, are discussed in a previous "Special Topics" presentation.

NOVEMBER 29, 2012: Members of the MESSENGER science team announce that they have confirmed the presence of water ice in permanently shadowed craters near Mercury's north pole. The presence of this ice had been reported as far back as 1991, and the overall significance of this is discussed in a previous "Special Topics" presentation.

29 NOVEMBER **30** 1 2 3 4 5

NOVEMBER 30, 1609: The Italian astronomer Galileo Galilei observes the moon for the first time with his primitive telescope and sees that it is covered with craters. This was one of the first steps in the road to our understanding of the role that impacts have played in Earth's, and the solar system's, natural history, and this story is discussed more thoroughly in a previous "Special Topics" presentation.

NOVEMBER 30, 1954: A 4-kg meteorite crashes through the roof of a house near Sylacauga, Alabama and strikes Elizabeth Hodges, who was sleeping on the couch, in the leg. She received a severe bruise from the impact but was otherwise unharmed. This was the first confirmed case of a meteorite striking a human being, although since then earlier reports of apparent such incidents have been unearthed.

COVER IMAGE CREDIT:

Front and back cover: Astronaut Ron Garan, Expedition 28 flight engineer, tweeted this image from the International Space Station on Aug. 14 with the following caption: "What a 'Shooting Star' looks like from space, taken yesterday during Perseid Meteor Shower." The image was photographed from the orbiting complex on Aug. 13 when it was over an area of China approximately 400 kilometers to the northwest of Beijing. The rare photo opportunity came as no surprise since the Perseid Meteor Shower occurs every year in August.

Courtesy NASA/Ron Garan

29 30 DECEMBER 1 2 3 4 5

DECEMBER 1, 1963: Then-Yale University graduate student Brian Marsden publishes his paper analyzing the orbits of several "lost" periodic comets. Three of these comets, including two previous "Comets of the Week," were recovered as a direct result of Marsden's calculations. Another one of the comets Marsden examined is 3D/Biela, another previous "Comet of the Week," which has not been seen since the mid-19th Century and which almost certainly no longer exists.

DECEMBER 1, 1971: NASA's Mariner 9 mission, having recently arrived at Mars, takes the first close-up photographs of Mars' moon Phobos. Along with Deimos, which Mariner 9 photographed a few days earlier, these were the first close-up photographs ever taken of a solar system "small body." The small moons of the various planets are the subject of a previous "Special Topics" presentation.

DECEMBER 1, 2020: The very tiny "asteroid" 2020 SO, discovered this past September 17 by the Pan-STARRS survey, will pass 0.00034 AU (51,000 km, or 0.13 lunar distances) from Earth. This object appears to have been recently "captured" as a temporary "moon" of Earth – a phenomenon discussed in a previous "Special Topics" presentation – but unlike the objects described there, this appears to be of artificial origin and is likely the upper-stage booster rocket of the unsuccessful Surveyor 2 mission launched in September 1966.

DECEMBER 1, 2257: The large Kuiper Belt object, and "dwarf planet," (136199) Eris will pass through perihelion at a heliocentric distance of 38.09 AU. Eris and the other "dwarf planets" in the Kuiper Belt, together with the other objects in that part of the solar system, are the subject of a previous "Special Topics" presentation.

29 30 1 DECEMBER 2 3 4 5

DECEMBER 2, 1989: NASA's Solar Maximum Mission (SMM) satellite, launched in 1980 and repaired by Space Shuttle astronauts in 1984, re-enters Earth's atmosphere and disintegrates. Following the spacecraft's repair, SMM's coronagraph detected several near-sun comets, all of these being Kreutz sungrazers which are the subject of a previous "Special Topics" presentation.

DECEMBER 2, 1995: The joint NASA/ESA SOlar and Heliospheric Observatory (SOHO) spacecraft is launched from Cape Canaveral, Florida. SOHO was placed at the Earth-sun L1 Lagrangian point 1.6 million km directly sunward of Earth, and as of now two of its coronagraphs, along with the Solar Wind ANisotropies (SWAN) ultraviolet telescope, have discovered over 4000 comets, the large majority of these being Kreutz sungrazers. Two of SOHO's comets are, collectively, a previous "Comet of the Week," and Kreutz sungrazers as a whole are the subject of a previous "Special Topics" presentation.

DECEMBER 2, 2020: The only known "Earth Trojan" asteroid, 2010 TK7, will pass 0.217 AU from Earth. It is currently traveling eastward through the constellation of Hydra and is a dim object of 21st magnitude. Trojan asteroids, including 2010 TK7, are the subject of a previous "Special Topics" presentation.

DECEMBER 2, 2023: Predictions suggest that the Andromedid meteor shower may produce a strong display, possibly as many as 200 meteors per hour. The Andromedids are the debris from Comet 3D/Biela – a previous "Comet of the Week" – and are discussed in that presentation.

29 30 1 2 DECEMBER 3 4 5

DECEMBER 3, 1904: Charles Perrine at Lick Observatory in California discovers Jupiter's sixth known moon, since named Himalia. It was the first-discovered of Jupiter's outer moons, of which over 70 more have since been discovered; very recent survey results suggest that there could be several hundred additional small outer moons remaining to be discovered. The small moons of the various planets are the subject of a previous "Special Topics" presentation.

DECEMBER 3, 2014: JAXA's Hayabusa2 mission is launched from the Tanegashima Space Center in southern Japan. Hayabusa2's destination was the Apollo-type asteroid (162173) Ryugu, where it arrived in June 2018; since then it has deployed several landing rovers and collected soil samples. Hayabusa2 left Ryugu late last year and will be returning to Earth, with its collection of samples, next week. The Hayabusa2 mission is discussed in this week's "Special Topics" presentation.

DECEMBER 3, 2018: NASA's OSIRIS-REx mission arrives at the Apollo-type asteroid (101955) Bennu. After performing a detailed study of Bennu, OSIRIS-REx successfully retrieved samples from the surface this past October, and is expected to depart Bennu next March for a return to Earth, with its collection of samples, in September 2023. The OSIRIS-REx mission is discussed in this week's "Special Topics" presentation.

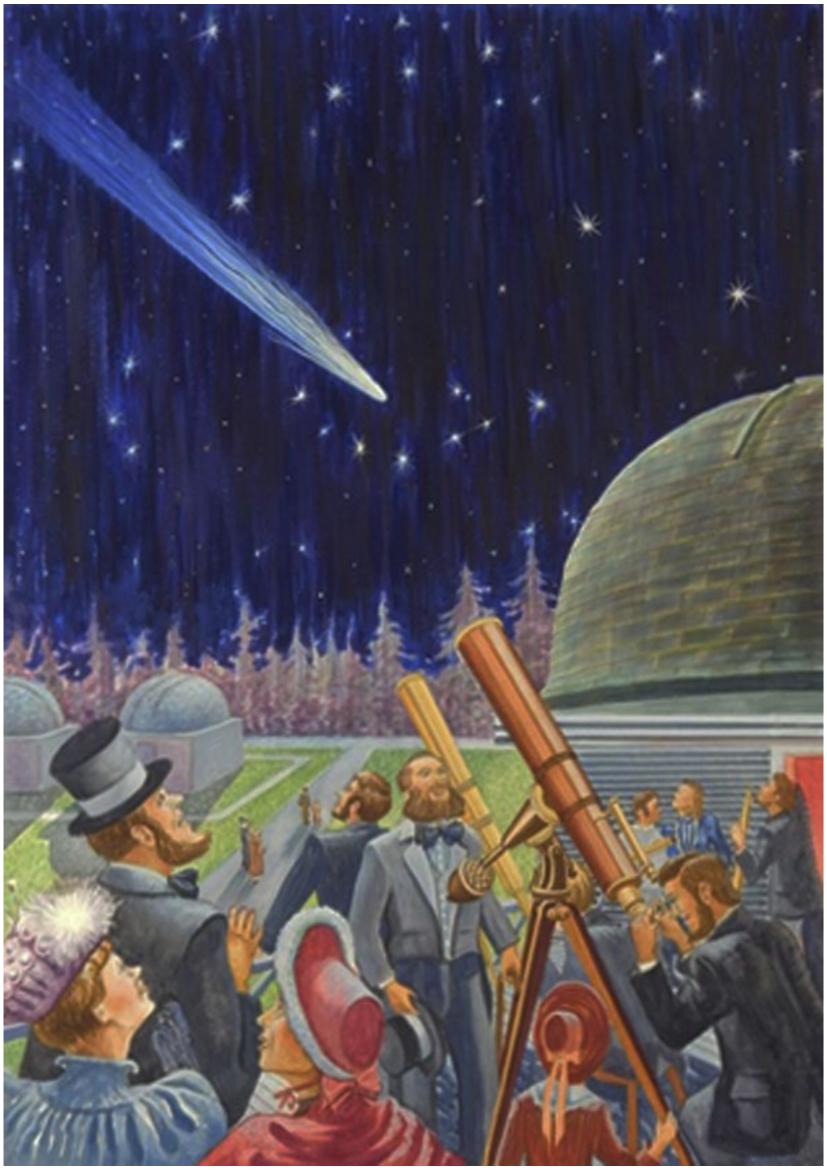
29 30 1 2 3 4 DECEMBER 5

DECEMBER 5, 2011: A moderately strong display of the Andromedid meteor shower – with a peak rate of close to 50 meteors per hour – is seen from Canada. There had not been any significant displays from the Andromedid shower in over a century, and thus this display was a complete surprise. The Andromedids are the debris from Comet 3D/Biela – a previous "Comet of the Week" – and are discussed in that presentation.

COMET OF THE WEEK: 109P/SWIFT-TUTTLE 1992t

Perihelion: 1992 December 12.32, q = 0.958 AU

One of the most prolific comet discoverers of the late 19th Century was the American amateur astronomer Lewis Swift, who did most of his observing from rural New York before relocating to southern California in the early 1890s. Swift discovered his first comet, a 7th-magnitude object, on July 15, 1862, which was then independently discovered three days later by Horace Tuttle at Harvard Observatory. The comet passed through perihelion during the latter part of August, and around that time was a moderately conspicuous naked-eye object of 2nd magnitude with a bright tail 25 to 30 degrees long. The astronomers of that era were able to determine that Comet Swift-Tuttle traveled in an elliptical orbit with an approximate orbital period of 120 years, and in 1867 the Italian astronomer Giovanni Schiaparelli announced that the comet's orbit coincided with that of the Perseid meteors, one of the strongest of the "annual" meteor showers and that peaks during the second week of August. This was the first conclusive evidence of the



Artist's conception of a public viewing of Comet 109P/Swift-Tuttle on the evening of August 30, 1862, from Harvard Observatory. The painting is by Howard J. Besnia.

Comet 109P/Swift-Tuttle on November 27, 1992. This was the approximate telescopic appearance around that time. Courtesy Chris Schur in Arizona.

now well-established link between comets and meteor showers, which was discussed in a previous "Special Topics" presentation.

One orbital period after 1862 brings us to the early 1980s, and in fact detailed calculations predicted a perihelion passage sometime around mid-1981. In the early 1970s, meanwhile, Brian Marsden – later the Director of the IAU's Minor Planet Center – took a different tack, and tried to identify previous returns of Comet Swift-Tuttle. One semi-promising candidate – which had initially been proposed by the British amateur astronomer William Lynn in 1902 – was a comet observed from China in July 1737 by the Jesuit missionary Ignatius Kegler. There were several problems with this possible identify, though, not the least of which was that it indicated an orbital period in excess of 130 years as opposed to the generally calculated period of 120 years. Nevertheless, Marsden calculated that, if the two comets were in fact identical, it would be returning to perihelion around late November 1992.

The early 1980s came and went without any sign of Comet Swift-Tuttle, and subsequently attention turned more strongly towards Marsden's prediction, especially after unusually strong bursts of the Perseids – to rates briefly as high as 450 meteors per hour – were observed during the 1991 and 1992 showers. Finally, on September 26, 1992, a Japanese amateur astronomer, Tsuruhiko Kiuchi, discovered a 10th-magnitude comet near the "bowl" of the Big Dipper which soon proved to be none other than the long-awaited Swift-Tuttle. This showed that Kegler's comet from 1737 was indeed Swift-Tuttle, and Marsden's prediction turned out to be only 17 days off.

The viewing geometry was not especially favorable in 1992, with the comet remaining relatively far from Earth: the minimum distance was 1.16 AU on November 8. It nevertheless reached a peak brightness of 5th magnitude during November and December and displayed a moderately bright tail a few degrees long during that time. After disappearing into evening twilight in late December it was picked up from the southern hemisphere as a 9th-magnitude object in late February 1993, and subsequently followed with large telescopes for the next two years as it receded from the inner solar system. There was a moderately strong display of Perseid meteors in 1993 and some enhanced activity in 1994, but ever since then the Perseids have returned to the strength that they've always regularly exhibited.

Comet 109P/Swift-Tuttle on December 15, 1992. Courtesy Michael Jaeger in Austria.

A Perseid meteor entering Earth's atmosphere over China, as seen from the International Space Station on August 13, 2011. Photograph by Ron Garan (ISS Expedition 28), courtesy NASA.

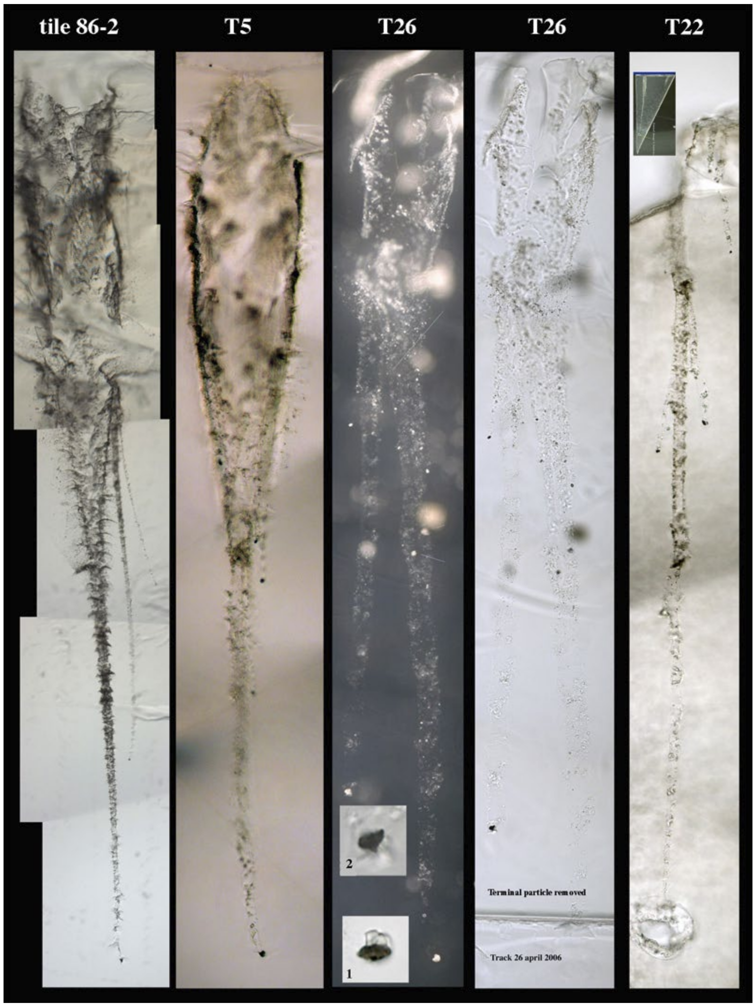
Comet Swift-Tuttle's orbit essentially intersects Earth's orbit – which is why we have the Perseid meteors in the first place – and with a retrograde orbit (inclination 113 degrees) the relative velocity is high, approximately 55 km/second. Furthermore, it appears to have a large nucleus, perhaps up to 30 km in diameter, so the catastrophic effects should it ever strike Earth would be devastating to Earth-based life. For a while there was concern that a possibility existed for an Earth impact at the comet's next return in 2126, however some detective work (by Marsden and, among others, American amateur astronomer Gary Kronk) showed that two comets in old Chinese records, specifically in 69 B.C. and in A.D. 188, were in fact earlier returns of Swift-Tuttle. With this information in hand it was now possible to establish that the "miss distance" in 2126 (on August 5) will be 0.153 AU. The comet will approach even slightly closer than that during the subsequent return in 2261 (0.147 AU, on August 24). It should become a spectacular object of magnitude 1 or 0 on both returns, but there is no danger of a collision.

A long-term study of Swift-Tuttle's motion by British astronomer John Chambers published in 1995 indicates that there will continue to be close approaches to Earth during subsequent millennia, until on September 14, 4479, Swift-Tuttle will pass so close to Earth that it is not possible to make accurate predictions of its future motion past that point; Chambers estimates the possibility of a collision as perhaps being one in a million. Even if there is no collision, the comet will continue making occasional close approaches to Earth, and this fact, together with its large size and the large relative velocity between it and Earth – which in turn would liberate an enormous amount of kinetic energy should an impact ever take place someday – means that Comet Swift-Tuttle can probably quite accurately be described, as one of the editors at Sky & Telescope magazine once put it, as "the single most dangerous object known to humankind."

SPECIAL TOPIC: SAMPLE RETRIEVAL MISSIONS

In most scientific disciplines, if we want to examine an object closely and in-depth, we can collect some kind of sample specimen of that object, take it to our laboratories, and perform any number of direct analysis examinations of that specimen. For the most part, in astronomy we can't do that; we are usually restricted to examining objects from far away, usually by examining the light we receive from them. The one exception to this comes from meteorites, where, in essence, the objects have come to us, and indeed, as covered in previous "Special Topics" presentations, we have learned quite a bit about various "small bodies" in our solar system, and even a little bit about the moon and Mars, as a result of laboratory analysis of meteorites that have been collected.

With meteorites, of course, we are restricted to whatever nature decides to send our way; if we want samples from anywhere else, we have to go out and collect them somehow. The one object where we have done so is the moon: the moon-landing Apollo missions in the late 1960s and early 1970s returned over 382 kg of lunar samples – most of which is still in storage and remaining to be examined – and three unmanned Luna probes (Luna 16, 20, and 24) from the then-Soviet Union during the early- to mid-1970s returned an additional 300 grams of lunar samples. Just last week China launched its Chang'e 5 mission for the collection of lunar samples and, if successful, it is expected to return those shortly after mid-December. Meanwhile, the Perseverance rover launched this past July is planned as the first step in a multi-mission joint NASA/ESA endeavor to collect Martian samples for return to Earth towards the end of this decade.



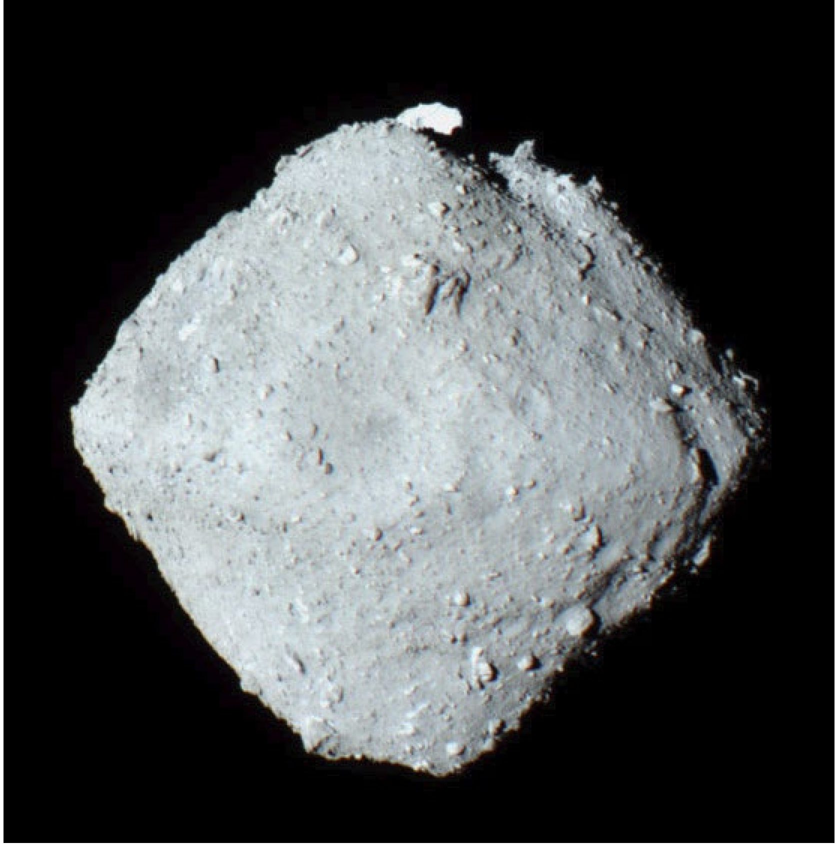
Particle tracks in aerogel collected during the Stardust mission's passage through the coma of Comet 81P/Wild 2 on January 2, 2004. Courtesy NASA.

As of now there have been four spacecraft missions that have been flown with the intent of collecting and returning samples from the solar system's "small bodies." The first of these was NASA's Stardust mission, which was launched on February 7, 1999, and which flew through the coma of Comet 81P/Wild 2 – the Week 1 "Comet of the Week" – on January 2, 2004. By means of an extremely lightweight and porous substance called "aerogel" Stardust collected over one million samples of dust particles from Comet 81P's coma, and then returned these to Earth on January 15, 2006. The Stardust mission as a whole is discussed in a previous "Special Topics" presentation, and specific results from the analyses of the returned samples are discussed in Comet 81P's "Comet of the Week" presentation.

The second mission was JAXA's Hayabusa mission, which was launched on May 9, 2003 and which arrived at the Apollo-type asteroid (25143) Itokawa in September 2005. Hayabusa was beset by various difficulties but during one of its brief landing attempts managed to collect approximately 1500 grains (with a total mass of slightly less than one gram) of surface material, which it eventually returned to Earth on June 13, 2010. The Hayabusa mission as a whole is discussed in a previous "Special Topics" presentation.

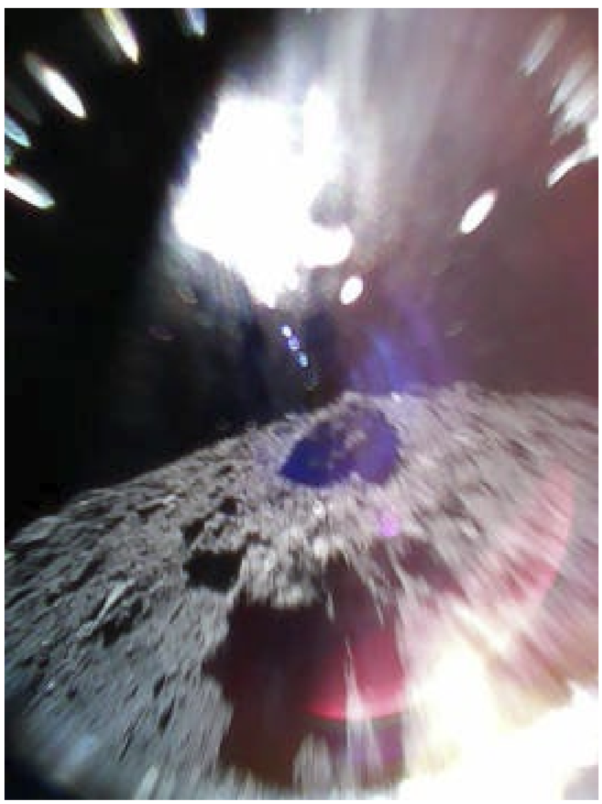
The remaining two sample-collection missions are going on at this time. The first of these is JAXA's Hayabusa2 mission, which was launched from the

Tanegashima Space Center in southern Japan on December 3, 2014. Hayabusa2's destination was the Apollo-type asteroid (162173) Ryugu, which was discovered on May 10, 1999 by the LINEAR program in New Mexico (and later named for the Dragon Palace from Japanese folk tales); it is a roughly spherical object approximately 1 km in diameter, and is a dark-colored primitive object somewhat similar to the carbonaceous chondrite meteorites (discussed in a previous "Special Topics" presentation). Hayabusa2 arrived at Ryugu on June 27, 2018 and went into orbit around it.



The asteroid (162173) Ryugu, imaged by the Hayabusa2 mission on July 12, 2018. Courtesy JAXA.

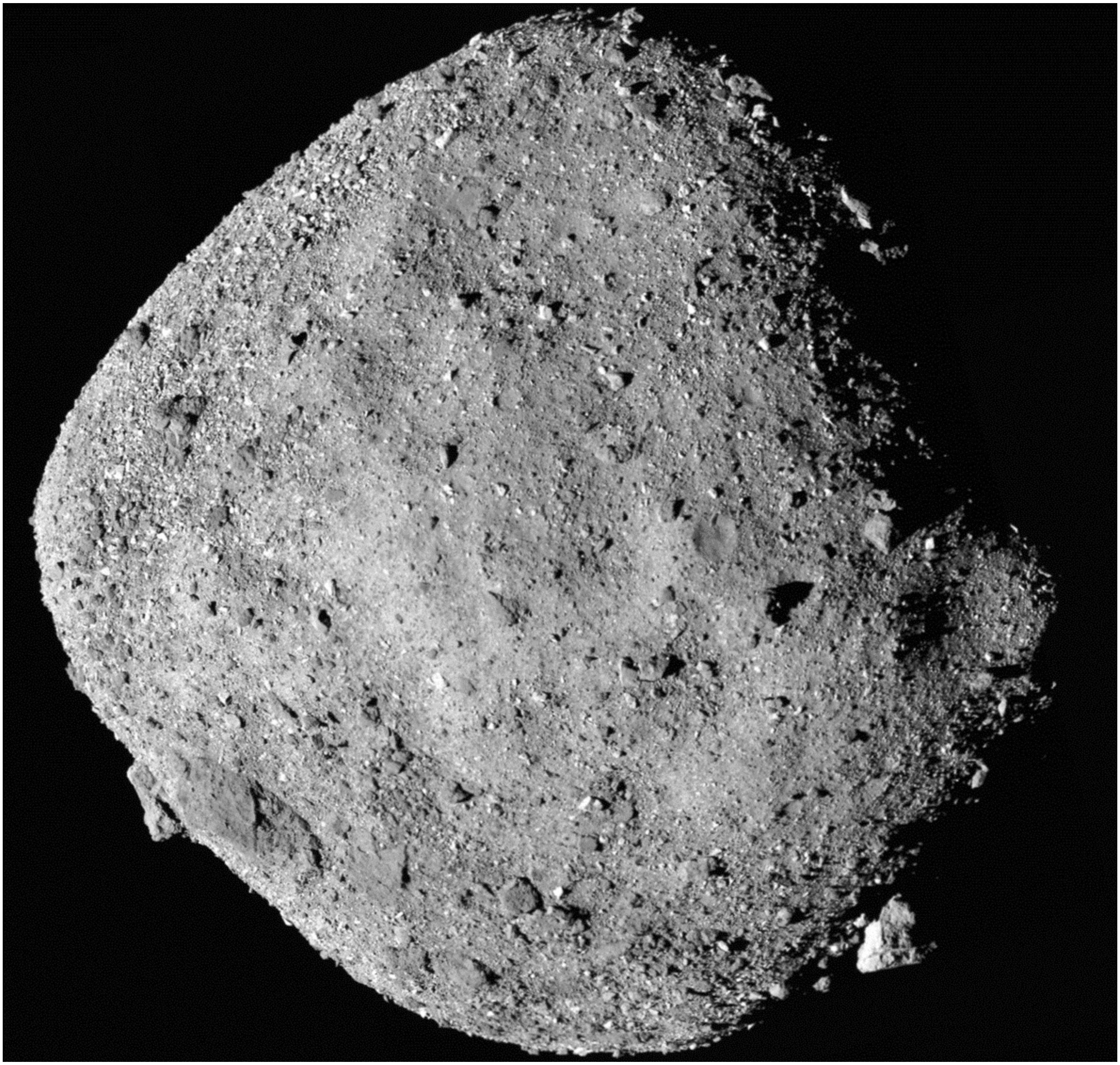
Although not every aspect of Hayabusa2's planned mission profile has gone as planned, overall it has been distinctly more successful than its predecessor. On September 21, 2018, Hayabusa2 successfully deployed two small MIcro-Nano Experimental Robot Vehicle for Asteroid (MINERVA) rovers onto Ryugu's surface, and two weeks later deployed the larger German-built Mobile Asteroid Surface Scout (MASCOT) rover as well. All three of these performed as expected, with several scientific instruments aboard MASCOT performing detailed scientific investigations. Meanwhile, Hayabusa2 itself briefly touched down twice onto Ryugu's surface, once on February 21, 2019 to collect surface samples, and again on July 11, 2019 to collect sub-surface material that had been exposed by a previously-deployed impactor. Both of these operations were successful and a third touchdown and sample collection maneuver was deemed not necessary and thus was cancelled.



A photograph taken from the surface of (162173) Ryugu by the MINERVA-II Rover IA on September 22, 2018. Courtesy JAXA/University of Aizu.

Hayabusa2, with its collected material samples, left Ryugu on November 13, 2019, and is due to arrive back at Earth next week on December 6. Upon doing so it is expected to release the capsule containing the sample materials, which will then land at the Woomera Test Range in South Australia where it can then be retrieved and the samples subsequently sent out for analysis. There is enough propellant left in the main spacecraft such that after it passes by Earth it will be sent towards a high-speed flyby of the Apollo-type asteroid (98943) 2001 CC21 in July 2026 and a rendezvous with another Apollo-type asteroid, 1998 KY26, in July 2031.

The other current mission is NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission, which was launched from Cape Canaveral, Florida on September 8, 2016. OSIRIS-REx's destination was the Apollo-type asteroid (101955) Bennu, which was discovered by LINEAR on September 11, 1999; following a worldwide naming contest, it received the name of the Egyptian bird-shaped deity that was suggested by a 9-year-old student from North Carolina, Michael Puzio. Like Ryugu, Bennu is also roughly spherical in shape, but is somewhat smaller, being approximately 500 meters



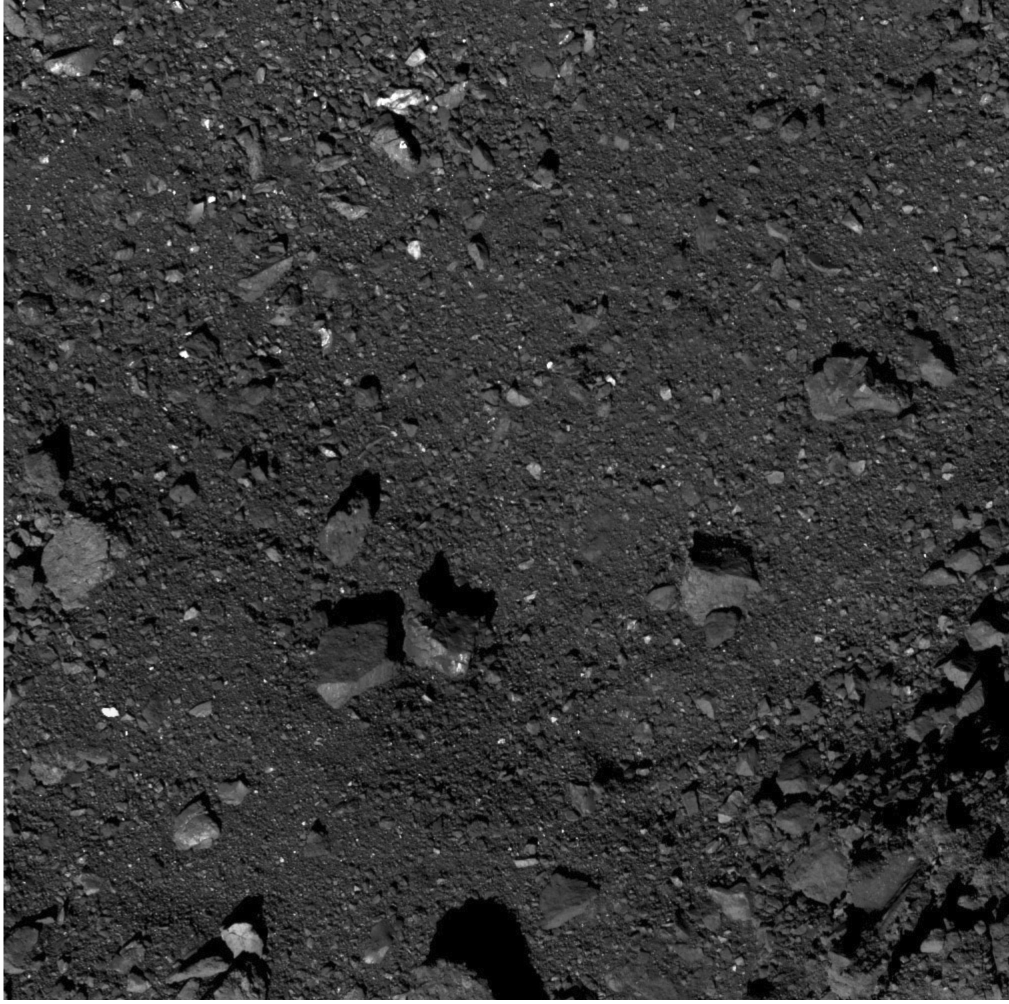
The asteroid (101955) Bennu, imaged by OSIRIS-REx on December 2, 2018. Courtesy NASA.

in diameter; it, too, is a dark-colored and primitive object.

OSIRIS-REx arrived at Bennu on December 3, 2018, although it did not go into orbit around it until the very end of that year. OSIRIS-REx contains a suite of scientific instruments that have been carrying out a wide range of investigations of Bennu, and among one of the earliest findings was the presence of water-related substances on Bennu's surface in the form of hydrated clays, a result consistent with the results of some recent ground-based studies. In early 2019, when Bennu was near perihelion, OSIRIS-REx detected several comet-like eruptions of dust grains and larger particles off Bennu's surface, indicating that Bennu can be considered one of the "active asteroids" that are the subject of next week's "Special Topics" presentation.

One of the primary elements of the OSIRIS-REx mission is the collection of samples from Bennu's surface, a task which turned out to be somewhat more difficult than expected due the fact that the surface contains a large number of boulders and not much in the way of "smooth" areas. Four potential sites were identified in August 2019, with the final selection of the site dubbed "Nightingale" being made in December. By means of a Touch-and-Go Sample Acquisition Mechanism (TAGSAM) device, wherein short bursts of nitrogen gas were fired at the surface, OSIRIS-REx successfully collected well over 200 grams of surface material this past October 20.

OSIRIS-REx is expected to remain in the vicinity of Bennu for a few more months, with a current planned departure date of March 3, 2021. Arrival at Earth is expected to occur on September 24, 2023, at which time the capsule containing the acquired samples will be deployed into the atmosphere, with touchdown expected at the Utah Test and Training Range west of Salt Lake City. From there, the retrieved samples will be disbursed to various laboratory facilities for analysis.



Close-up image of the "Nightingale" sample collection site on Bennu, taken on October 26, 2019 (slightly less than one year before the sample collection was performed). The field of view is approximately 14.4 meters across.

At this time there is one additional "small bodies" sample return mission in development, JAXA's Martian Moons Exploration (MMX) mission. As currently planned, MMX would be launching in September 2024, and after arrival at Mars orbit the following year would attempt one or two sample-collection landing maneuvers on Phobos, with the goal of collecting up to 10 grams of material. Afterwards, MMX would perform several flybys of Deimos before leaving Mars orbit in August 2028 for arrival back at Earth in July 2029.

Incidentally, (162173) Ryugu will be passing 0.061 AU from Earth this coming December 29, although it will remain a relatively faint object of 17th magnitude.

Meanwhile, (101955) Bennu, which passed 0.015 AU from Earth a week and a half after its discovery, has been identified as a Potentially Hazardous Asteroid (in the full sense of that term), and can make very close approaches to Earth on occasion, including one of 0.005 AU on September 23, 2060. The possibility of an Earth impact at some point in the future after that date remains a possibility, although numerical simulations indicate a more likely fate of impacting the sun someday. If an Earth impact does happen to become a realistic scenario someday, perhaps the information gleaned from OSIRIS-REx will help in determining the appropriate actions humanity will need to take.

Artist's conception of OSIRIS-REx approaching the "Nightingale" site on Bennu during the sample collection operation on October 20, 2020. Both images courtesy NASA/Goddard/ University of Arizona.

www.halebopp.org

www.iceandstone.space

PDF booklet prepared by RocketSTEM