ICE & STONE 2020

WEEK 46: NOVEMBER 8-14

Presented by The Earthrise Institute

Authored by Alan Hale

THIS WEEK IN HISTORY

8 9 **NOVEMBER 10** 11 12 13 14

NOVEMBER 10, 2018: Astronomers Scott Sheppard, David Tholen, and Chad Trujillo discover the distant object 2018 VG18 – nicknamed "Farout" – located at a present heliocentric distance of 124 AU, at that time the most distantly observed object in the solar system. 2018 VG18 and other distant objects in the solar system are the subject of this week's "Special Topics" presentation.

8 9 10 **NOVEMBER 11** 12 13 14

NOVEMBER 11, 2028: NASA's Lucy mission is scheduled to fly by the Jupiter Trojan asteroid (21900) Orus. The Lucy mission and Trojan asteroids are discussed in previous "Special Topics" presentations.

8 9 10 11 **NOVEMBER 12** 13 14

NOVEMBER 12, 1799: Observers in Europe and in South America witness an extremely intense display of the Leonid meteor shower. The Leonid meteors are associated with Comet 55P/Tempel-Tuttle, and the relationship between comets and meteor showers is the subject of next week's "Special Topics" presentation.

NOVEMBER 12, 2013: German astronomer Ralf-Dieter Scholz announces the discovery of the star formally designated as WISE J072003.20-084651.2 but informally known as "Scholz's Star," a dim-low mass star in Monoceros located 22 light-years away. Studies of Scholz's Star indicate that it passed through the outer Oort Cloud 70,000 years ago, and may have sent a large number of comets into the inner solar system that may arrive within the next two million years. Scholz's Star is discussed in a previous "Special Topics" presentation.

NOVEMBER 12, 2014: The Philae lander, carried with ESA's Rosetta mission, attempts a soft-landing on the surface of Comet 67P/Churyumov-Gerasimenko, but bounces twice before coming to rest in a hole next to some high cliffs. Comet 67P is a previous "Comet of the Week," and Rosetta and Philae are discussed within that presentation.

8 | 9 | 10 | 11 | 12 | **NOVEMBER 13** | 14

NOVEMBER 13, 1577: Danish astronomer Tycho Brahe first sees the Great Comet of 1577, which has since been informally named for him. His scientific observations of the comet demonstrated that comets are astronomical, not atmospheric, phenomena. It is this week's "Comet of the Week."

NOVEMBER 13, 1833: Observers throughout the eastern U.S. witness an extremely intense display of the Leonid meteor shower; this is the famous night when "stars fell on Alabama." Meteor showers, and their relationship with comets, are the subject of next week's "Special Topics" presentation.

NOVEMBER 13, 2019: After orbiting the Apollo-type asteroid (162173) Ryugu for sixteen months, during which it deployed landing rovers and collected samples, JAXA's Hayabusa2 mission departs Ryugu for its return journey to Earth. The Hayabusa2 mission is discussed in a future "Special Topics" presentation.

8 | 9 | 10 | 11 | 12 | 13 | **NOVEMBER 14**

NOVEMBER 14, 1680: German astronomer Gottfried Kirch discovers what is now called the Great Comet of 1680; this was the first comet discovery to be made with a telescope. The Great Comet of 1680 is a future "Comet of the Week."

NOVEMBER 14, 1866: Observers in Europe witness a strong display of the Leonid meteor shower. The Leonids' parent comet, 55P/Tempel-Tuttle, had passed through perihelion earlier that year, and the relationship between that comet and the Leonids was demonstrated within a year. The overall relationship between comets and meteor showers is the subject of next week's "Special Topics" presentation.

NOVEMBER 14, 1971: NASA's Mariner 9 mission arrives at Mars and goes into orbit around it, becoming the first spacecraft to enter orbit successfully around another planet. Mariner 9 was also the first spacecraft to make close-up examinations of our solar system's "small bodies" when it observed the Martian moons Phobos and Deimos. The small moons of the solar system's planets are the subject of a previous "Special Topics" presentation.

NOVEMBER 14, 2003: Michael Brown, Chad Trujillo, and David Rabinowitz discover the distant object now known as (90377) Sedna. This was the first-known object that permanently inhabits the far outer solar system, and it along with more recently-discovered such objects are the subject of this week's "Special Topics" presentation.

NOVEMBER 14, 2018: Danish geologist Kurt Kjaer and his colleagues announce their discovery of a 31-km-wide impact crater underneath the ice of the Hiawatha Glacier in northwestern Greenland. The Hiawatha Crater has been proposed as possibly being associated with the meteorite fall of the Cape York meteorite – discussed in a previous "Special Topics" presentation – but this has not been conclusively demonstrated at this time.

COMET OF THE WEEK: "TYCHO BRAHE'S COMET" C/1577 V1

Perihelion: 1577 October 27.45, q = 0.178 AU

The Comet of 1577, as viewed from Prague on November 12, 1577. This is from an engraving made by Jiri Daschitzky.

In all of astronomical history, one of the names that stand out is that of the 16th Century Danish astronomer Tycho Brahe. Of noble birth, he showed an interest in astronomy at a young age, although his family tried to steer him into a career in statesmanship; however, with his observations and analyses of a brilliant supernova that appeared in Cassiopeia in 1572 – which even now is often informally referred to as "Tycho's Star"—he acquired an international reputation, and just a few years later King Frederick II of Denmark offered him exclusive usage of the island of Hven for the carrying out of astronomical observations. He was a meticulous observer of, among other things, the positions of the planets – all of this being carried out with his unaided eyes, since this pre-dated the invention of the telescope – however after the death of his patron two decades later Brahe had to relocate, eventually settling in Prague, where he remained until his death in 1601. While in Prague he worked with a younger protégé, Johannes Kepler, who after Brahe's death utilized his planetary measurements to derive empirically when we now call Kepler's Three Laws of Planetary Motion. There is a certain irony in this, in that it was Kepler's Laws that helped firmly establish the heliocentric model of the solar system that had been published in 1543 by the Polish astronomer Nicolaus Copernicus, which Brahe himself had never accepted.

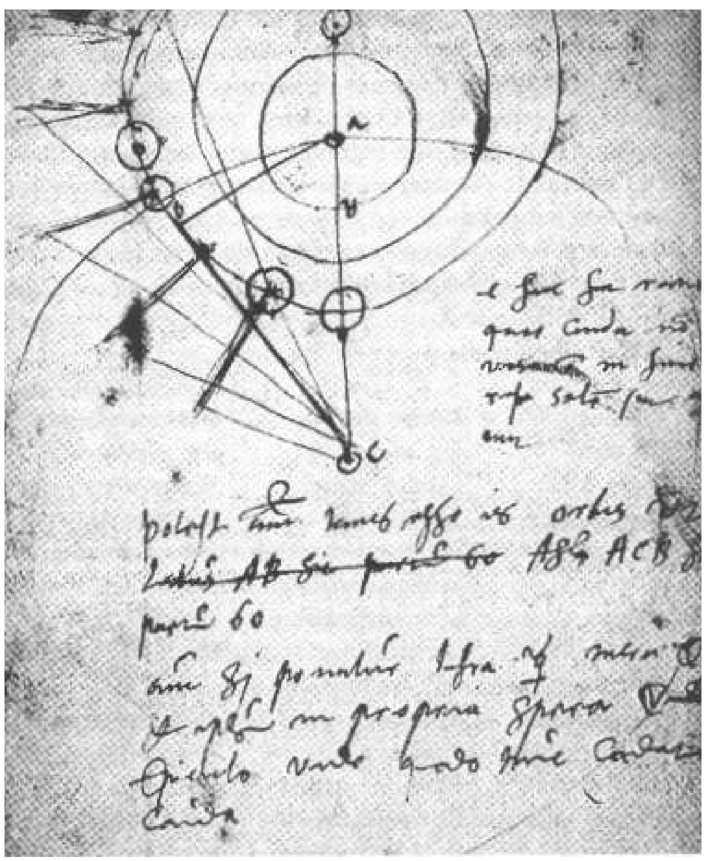
One of Brahe's most significant contributions to astronomy involved his observations of the brilliant comet that appeared in late 1577, and that is informally named for him, although he was not the first person to see it. It had approached the inner solar system from behind the sun, and after perihelion passage in late October it was first seen from Peru on November 1, where it was reported as being visible through clouds "like the moon" despite being at an elongation of only 11 degrees. A week later observers in Japan reported it as having a tail over 60 degrees long, with its being as bright as magnitude -3 or -4. Brahe himself first noticed it on the evening of November 13, when he was at one of the fishing ponds on Hven gathering fish for his evening meal and saw its reflection in the water.

The comet had been nearest to Earth (0.63 AU) on November 10, and it remained a brilliant

Woodcut made by Bartholomaus Kappeler, showing the Comet of 1577 over Augsburg, Bavaria, on November 12, 1577.

object for quite some time, apparently still being as bright as magnitude 0 in mid-December. It remained visible to the unaided eye until January 26, 1578, by which time its heliocentric distance had increased to 2.6 AU. Brahe was the last person to see it, and he was also the most meticulous observer of the comet, although numerous other observers throughout Europe and the Middle East, among other places, recorded detailed observations of it as well.

When Brahe compared his positional measurements of the comet with those made at the same times by other observers, most notably Thaddaeus Hagecius at Prague, he noticed that the comet did not exhibit any parallax when compared against the background stars. From this, he concluded that the comet must be at least six times farther away than the moon. Up until this time the prevailing thought about comets had been based upon ideas presented by the Greek philosopher Aristotle in the 4th Century B.C., wherein he considered comets as being "exhalations" in the upper atmosphere. The observations by Brahe and the other astronomers of his time demonstrated, on the other hand, that comets are located well beyond Earth and thus are true astronomical phenomena.

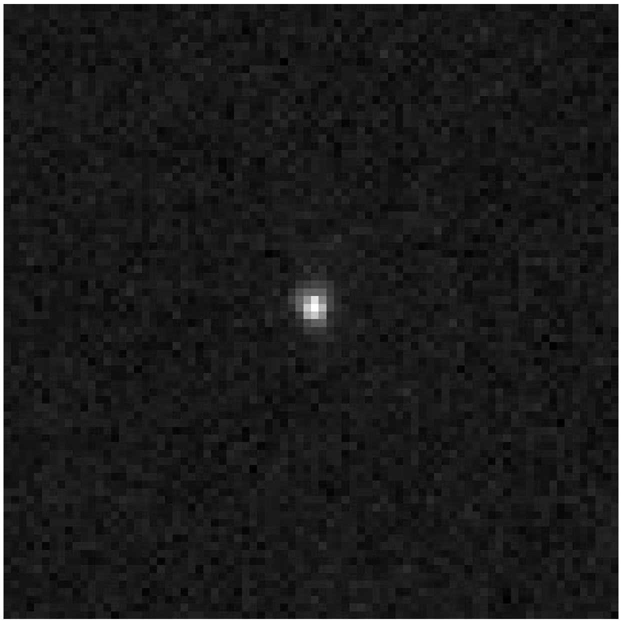


Tycho Brahe's notes concerning his observations of the Comet of 1577. The orbital diagrams are within the context of Brahe's views of a geocentric universe.

While perhaps not in as meticulous or detailed a fashion as Brahe, other astronomers observing the Comet of 1577 were able to reach similar conclusions. One of these, Michael Maestlin in Germany – at one time a pupil of Petrus Apianus (Peter Apian), who had first noticed with Comet 1P/Halley in 1531 that comets' tails are directed away from the sun – made a crude attempt to determine an orbit for the comet. While Maestlin made the prevailing, and erroneous, assumption that the comet's orbit was circular – and thus it cannot be considered as an actual reflection of reality – this exercise, along with the demonstrations that the 1577 comet, and thus presumably comets in general, was an astronomical phenomenon of the solar system and not an atmospheric phenomenon of Earth, makes the Comet of 1577 one of the most important scientific comets in history.

SPECIAL TOPIC: THE FAR OUTER SOLAR SYSTEM

It essentially goes without saying that our knowledge of all regions of the solar system has grown enormously during the past few decades. What we might call the "outer solar system," i.e., beyond Neptune, is a region where our knowledge has perhaps grown the most, since until quite recently we knew almost nothing about this part of our solar system. We knew that long-period comets pass through this region, fed in from the Oort Cloud at the extreme outer part of the solar system – and a population which has never been directly detected – and then there is the Kuiper Belt, something similar to which was first proposed in the mid-20th Century but, with the exception of Pluto, was not directly detected until the early 1990s. (The story of this was recounted in a previous "Special Topics" presentation.) As for what we might call the "far outer solar system," i.e., the region around a heliocentric distance of 100 AU and beyond, some of the "scattered disk" Kuiper Belt objects travel in this region for a significant part of their orbital journeys, but with the exception of them and the long-period comets passing through, this had essentially been a celestial "no man's land" as far as our knowledge was concerned.



(90377) Sedna as imaged with the Hubble Space Telescope on March 16, 2004. Courtesy NASA.

The first-known permanent resident of this part of the solar system was discovered on November 14, 2003, by Michael Brown, Chad Trujillo, and David Rabinowitz utilizing the 1.2-meter Schmidt telescope at Palomar Observatory in California. The object, near 21st magnitude at the time, has since been found to have been located at a heliocentric distance of 89.6 AU. Numerous astrometric measurements, including pre-discovery images dating to as early as 1990, have allowed a rather definitive orbit to be calculated: it is traveling in a very elongated comet-like orbit (eccentricity 0.84) with an approximate orbital period of 10,500 years; at perihelion, which it will reach in July 2076, its heliocentric distance will be at a still distant 76 AU, while at aphelion it travels out to an approximate heliocentric distance of 880 AU.

The object has since been assigned the asteroidal number (90377), and Brown and his team have named it Sedna, after the "Inuit goddess of the sea and the mother of all sea creatures." Because of its large distance it has not been easy to derive much in terms of Sedna's physical characteristics; the best data thus far suggest an approximate diameter of 1000 km, roughly 40% that of Pluto and slightly less than that of Pluto's large moon Charon. Despite some specific searches and some initial speculation, no moon has been detected around Sedna, thus it is currently not possible to derive an accurate value for its mass. It has a photometrically-determined rotation period of a little over 10 hours, and its surface appears to be quite red, suggesting the presence of organic substances called tholins (as is the case with several other objects in the outer solar system, and believed to be caused by bombardment from cosmic rays from the outside Galaxy). While this cannot be reliably determined at this time, Sedna is probably similar in structure to Pluto and other objects in the outer solar system.

From a dynamical perspective, Sedna's existence in its present orbit is difficult to explain. Gravitational perturbations by Jupiter and/or other planets in the inner solar system, even during the solar system's early days, are not sufficient for ejecting Sedna into its present orbit, and from various studies the sun's initial planet-forming disk is unlikely to have extended that far out. A gravitational capture from other stars that formed in the same initial star cluster as the sun would perhaps seem to be the most likely explanation, although there are difficulties with this type of scenario as well.

A question that remained was whether or not Sedna is unique, or if there are other, likely smaller, objects in this region of the solar system. Some of the "scattered disk" Kuiper Belt objects with very eccentric comet-like orbits have been detected in this part of the solar system, and indeed (136199) Eris, which was not too far away from aphelion at the time, was located at a heliocentric distance of 97.0 AU at the time of its discovery. These objects, unlike Sedna, do travel through the Kuiper Belt around the times of their

The discovery images of two additional objects in the far outer solar system. Left: 2012 VP113 on November 5, 2012, from Cerro Tololo Inter-American Observatory in Chile. This is a "stack" of three images, and 2012 VP113 is indicated by the three different-colored dots. Right: The object nicknamed "FarFarOut," taken in January 2018 with the 8.2-meter Subaru Telescope at Mauna Kea in Hawaii. Both images courtesy Scott Sheppard, David Tholen, and Chad Trujillo.

respective perihelion passages, and thus cannot really be considered as Sedna-like objects.

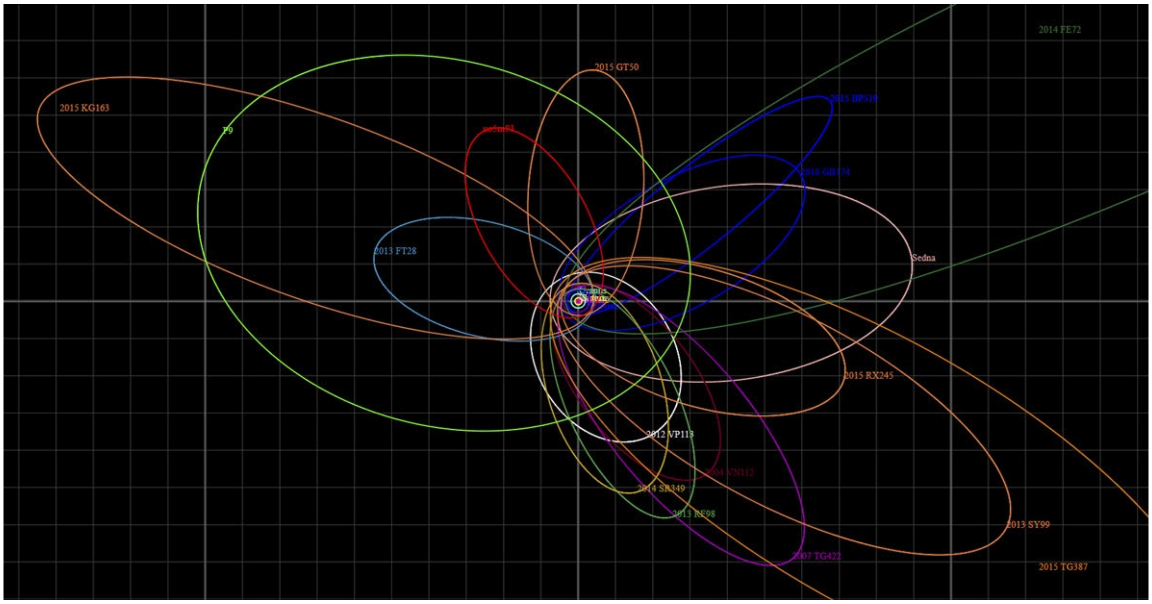
On November 5, 2012, Scott Sheppard and Chad Trujillo, observing from Cerro Tololo Inter-American Observatory in Chile, discovered a slow-moving 23rd-magnitude object since designated as 2012 VP113. After Sedna, this is the second-known permanent resident of the outer solar system, with a perihelion distance of 80.5 AU (and perihelion passage in 1979) and an orbital period of somewhat over 4100 years; because of a less elongated orbit (eccentricity 0.69) its aphelion distance (436 AU) is distinctly less than that of Sedna. For obvious reasons, physical data for 2012 VP113 is quite sparse, but it appears to have an approximate diameter of 600 km.

Three years later, on October 13, 2015, David Tholen and Chad Trujillo, at Mauna Kea Observatory in Hawaii, discovered a third such object, now designated and named as (541132) Leleakuhonua. This object has a perihelion distance of 65 AU (and will reach perihelion in 2078), and travels in a very elongated orbit (eccentricity 0.94) with an approximate orbital period of 33,000 years and an approximate aphelion distance of 2000 AU. It is a very dim object of 24th magnitude and appears to be about 350 km in diameter.

A handful of objects with elongated orbits like that of Sedna but with perihelion distances in the neighborhood of 50 AU have been discovered, although since 50 AU is near what is believed to be the outer boundary of the Kuiper Belt whether or not these can be considered Sedna-like objects or extreme "scattered disk" Kuiper Belt objects is perhaps a matter of definition. More recently, the team of Sheppard, Tholen, and Trujillo discovered 2018 VG18 in November 2018; its current heliocentric distance appears to be 124 AU (which led to the nickname "Farout"), but the best orbital calculations (based on an arc of three years), suggest that it is a typical (albeit somewhat large) "scattered disk" object well on the way towards aphelion. In early 2019 the same team announced the discovery of an apparently even more distant object (on images taken a year earlier), which does not have a formal designation but which is nicknamed "FarFarOut;" it is at an estimated heliocentric distance of 140 AU – the farthest distance at which a solar system object has thus far been observed – but with observations on only two nights it is not possible for any kind of valid orbit to be computed at this time.

While it does not seem to be as populated as the Kuiper Belt, this region of the solar system clearly possesses a population of objects, and their extreme distance only allows for the larger objects to be detected at this time. Even many of these can only be detected when in the general vicinity of perihelion passage, although they would spend most of their orbital journey much farther from the sun. Sheppard and his colleagues have concluded that there may be as many as two million objects in this region larger than 40 km in diameter, with a total combined mass about 80% that of Pluto.

Although the total known number of Sedna-like



The orbits of known objects in the far outer solar system, including the Sedna-like objects and extreme "scattered disk" Kuiper Belt objects. A potential orbit for "Planet Nine" is also indicated (as "P9") in green. Copyright Tom Ruen, licensed via Creative Commons.

objects and extreme "scattered disk" objects is still relatively small, astronomers have noticed that they share some similar orbital characteristics. Their respective perihelion points all lie near the plane of the ecliptic and they all share the same basic orbital orientation which, even with the rather small number of objects involved, appears to be too similar to be due to coincidence or to observational bias. Even if, for some unknown reason, they had all started out in such a configuration, over the lifetime of the solar system gravitational influences from the planets and from the overall Galaxy would have spread the orbits out into a more random distribution. It might appear that some unseen factor was maintaining this overall configuration.

In early 2016 Michael Brown and Konstantin Batygin – both at CalTech – examined this phenomenon, and concluded that a massive object in the outer solar system was the most likely culprit. This so-called "Planet Nine," as this object has come to be called, would have five to ten times the mass of Earth and would orbit the sun at an average heliocentric distance of perhaps 400 to 700 AU, corresponding to an orbital period of 8000 to 18,000 years. Its orbit would be mildly eccentric (eccentricity 0.2 to 0.6) and moderately inclined (inclination 20 to 30 degrees).

Even though this putative "Planet Nine" does answer some questions, acceptance of this idea is by no means universal among astronomers. At least some astronomers have pointed out that other mechanisms, for example, the combined gravitational pulls over time of the objects within the main Kuiper Belt, could have boosted objects like Sedna into the more distant solar system, although this doesn't quite explain the apparent non-random distribution of their orbital orientations. There is also the issue of how "Planet Nine" would have gotten out to where it supposedly is in the first place; such an object almost certainly would not have formed there. Brown and Batygin have proposed that gravitational perturbations by Jupiter and other inner solar system planets might have kicked it out there during the early days of the solar system. Other explanations, for example, a capture of an escaped object from one of the stars that formed with the sun, are also potentially conceivable.

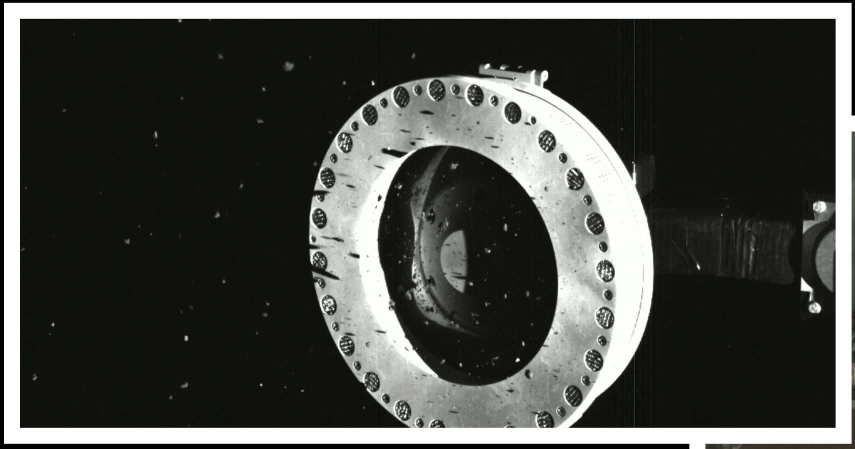
"Planet Nine" should, in theory, be detectable with the equipment we have available nowadays, although since it has not been detected by the various surveys nor in deliberate searches through infrared data obtained by NASA's Wide-field Infrared Survey Explorer (WISE) mission, it must currently be fainter than about 21st magnitude. To be sure, there is a very large amount of sky where it could be located, although some attempts have been made, based upon the locations of the currently-known very distant objects, to predict an approximate location. Some of these predicted locations are in or around the constellation Cetus, while others suggest it may be near Orion or Taurus – and thus would be buried within a rich Milky Way star field background. If it is closer to aphelion than it is to perihelion, it may well be fainter than expected, perhaps 23rd or 24th magnitude, or fainter.

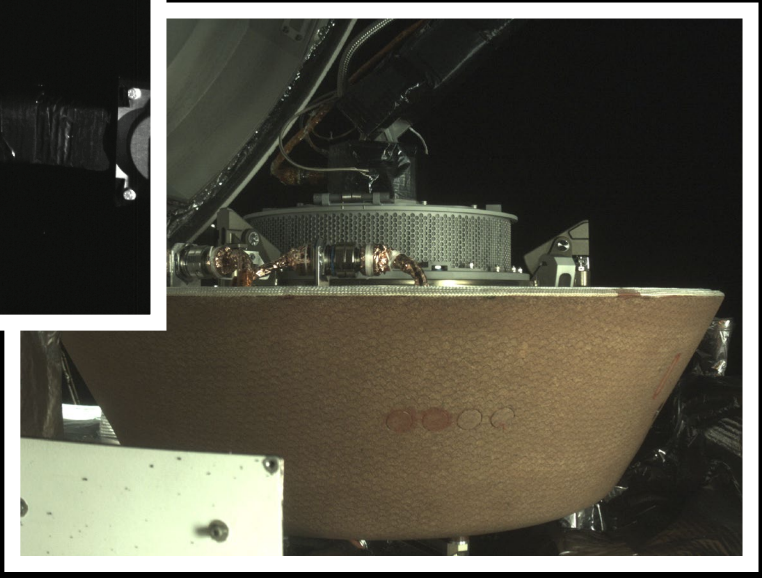
Some deliberate searches for "Planet Nine" have been conducted within the recent past, and are ongoing or are planned at this time. When the Vera Rubin Observatory (VRO) becomes operational within the next couple of years it should be regularly surveying the entire sky down to 24th magnitude, and thus may very well pick up "Planet Nine" – if it actually exists. At the very least, the VRO should be discovering additional objects in this largely unknown part of the solar system, and thus at some point begin to shed significant light on just what is, and what is not, out there.

OSIRIS-REX SAMPLES ASTEROID BENNU

NASA's OSIRIS-REx mission achieved its main objective when the spacecraft successfully touched down on the asteroid briefly and collected samples) right photo) of it while the asteroid was more than 200 million miles from Earth. The six-second touch and go exceeded its goal of collecting at least 2 ounces (60 grams) of surface material. The sample collector head was stowed earlier than planned into its Sample Return Capsule (bottom right) to prevent loss of any more of the significant amount of rocks and dust from the TAGSAM head (bottom left).

Images courtesy NASA/ Goddard/University of Arizona/ Lockheed Martin.





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