National Aeronautics and Space Administration

NEW HORIZONS
Beyond Pluto

The Ultima Thule Flyby
January 1, 2019

Kuiper Belt Extended Mission
Ultima Thule Flyby Press Kit
December 2018

www.nasa.gov/newhorizons
www.pluto.jhuapl.edu

Cover Image Credit: NASA

Table of Contents

Media Contacts

Policy/Program Management

NASA Headquarters
Dwayne Brown
(202) 358-1726
dwayne.c.brown@nasa.gov

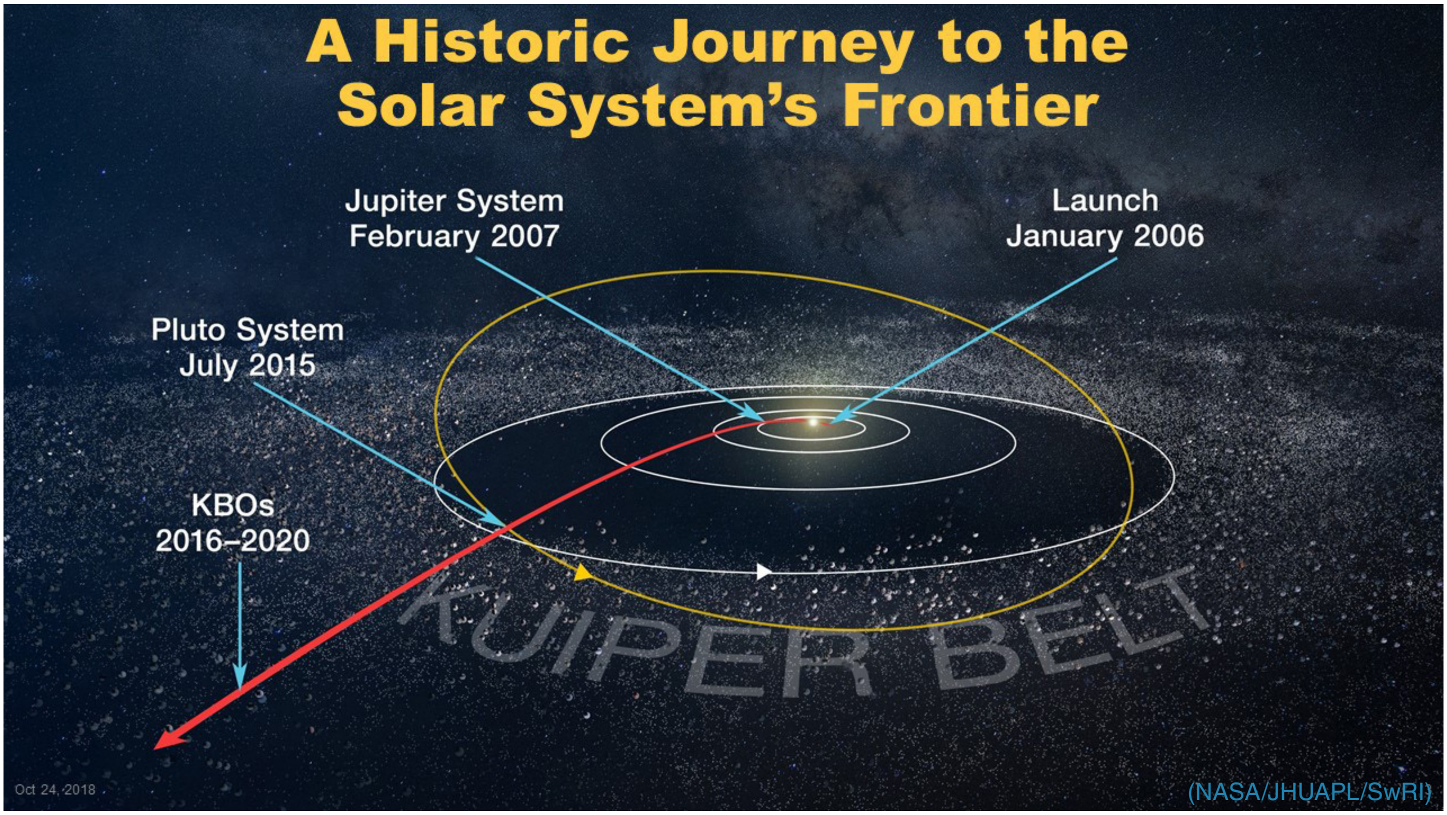
JoAnna Wendel
(202) 358-1003
joanna.r.wendel@nasa.gov

Mission Management
Spacecraft Operations

Johns Hopkins University Applied Physics Laboratory
Michael Buckley
(240) 228-7536
michael.buckley@jhuapl.edu

Principal Investigator Institution
Science and Science Operations

Southwest Research Institute
Maria Stothoff
(210) 522-3305
maria.stothoff@swri.org



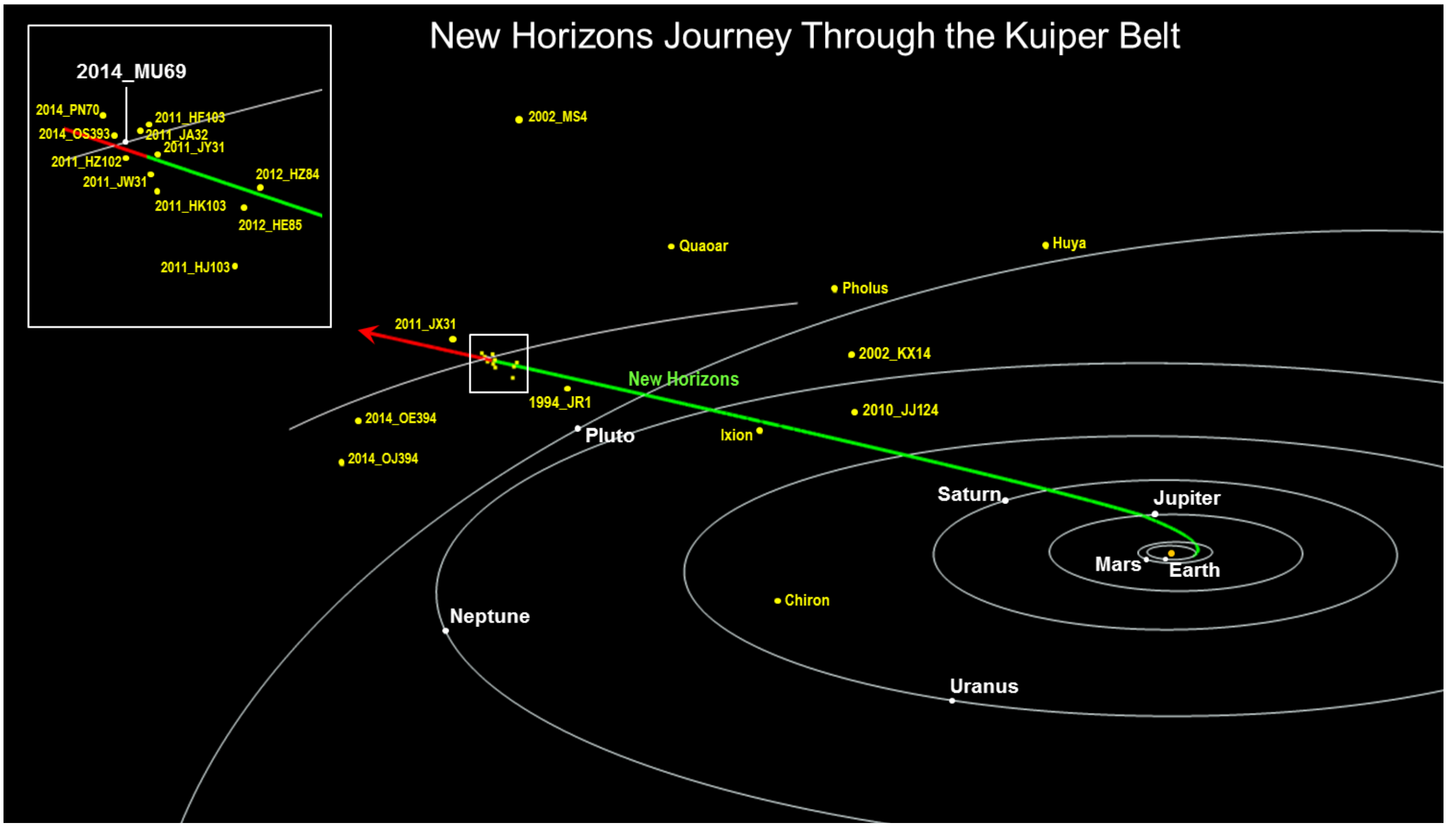
NASA's New Horizons: The Kuiper Belt Extended Mission

NASA's New Horizons is the first mission to explore Pluto and the Kuiper Belt, the region of ancient, icy, rocky bodies beyond the orbit of Neptune. The mission was authorized after being ranked at the top of the 2003 National Academies planetary decadal survey queue for medium-scale missions.

The New Horizons spacecraft was launched on Jan. 19, 2006, passed Jupiter for a gravity boost and a successful test of the science payload in February 2007, and made a historic flight through the Pluto system on July 14, 2015 – returning data that is still transforming our view of these intriguing worlds on the planetary frontier.

With Pluto and its moons in the rearview mirror, New Horizons is speeding deeper into the Kuiper Belt, conducting a wide variety of observations of Kuiper Belt objects (KBOs), Centaurs and the heliosphere, and heading toward a flyby of 2014 MU69 (nicknamed "Ultima Thule"; pronounced "Ultima too-lee"), an ancient KBO and a building block of the solar system, on Jan. 1, 2019.

The Kuiper Belt Extended Mission (KEM) takes New Horizons 1 billion miles (1.6 billion kilometers) beyond Pluto for its rendezvous with Ultima Thule, which was discovered in 2014 using the powerful Hubble Space Telescope. The extended mission before and after the Ultima flyby also includes New Horizons team studies of distant KBOs, and heliospheric dust and plasma science as far out as 50 astronomical units from the Sun in 2021. For reference, 1 astronomical unit (or AU) is the average distance from the Sun to Earth.



New Horizons' path through the solar system. The green segment shows where New Horizons has traveled since launch; the red indicates the spacecraft's future path. The yellow names denote the Kuiper Belt objects New Horizons has observed or will observe from a long distance. (NASA/JHUAPL/SwRI)

New Horizons opens the door to our solar system's next frontier – the Kuiper Belt, an ancient and well-preserved realm of small worlds and other bodies we're just beginning to understand. We once thought that Pluto marked the "end" of the planetary system; in fact, Pluto is only the beginning – a harbinger of a new zone of small icy worlds and dwarf planets that outnumber the larger planets of the solar system. KBOs likely hold keys to understanding fundamental aspects of planet formation, the origin of our solar system's architecture and even some aspects of terrestrial evolution – such as its bombardment by impactors.

The New Horizons close flyby of Ultima Thule – which will be the farthest encounter of a planetary object in history – adds another chapter to the mission's remarkable story. The KEM has two primary objectives:

> **Conduct a close flyby of at least one KBO.** New Horizons will fly about three times closer to Ultima Thule than it did to Pluto. Using all seven onboard science instruments, New Horizons will obtain extensive geological, geophysical, compositional and plasma/energetic particle data on Ultima; it also will search for and study any satellites, rings and atmosphere around Ultima. The mission team estimates it will take about 20 months to downlink the stored encounter data through NASA's Deep Space Network – finishing around September 2020 – followed by a year of data analysis and archiving.

New Horizons is a principal investigator (PI)-led mission; the Southwest Research Institute (SwRI) of San Antonio is the PI institution, and Alan Stern, of SwRI's office in Boulder, Colorado, leads the mission as PI. The Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland, manages the mission for NASA's Science Mission Directorate. APL built and operates the New Horizons spacecraft; SwRI led development of the New Horizons science payload. SwRI also leads science operations and data processing, which take place at the Tombaugh Science Operations Center at SwRI in Boulder.

Survey the Kuiper Belt. From its unique vantage point in the Kuiper Belt, New Horizons is making observations that can't be made from Earth or by any other spacecraft. New Horizons will train its cameras on at least 25 KBOs, taking long-distance images to estimate each object's shape and surface properties, and to search for rings and moons. The spacecraft also will measure Kuiper Belt dust production and distribution, map the density of neutral gas in the heliosphere, measure plasma and energetic particles to better understand the heliosphere and how space weather affects KBOs, and search for dust around assorted KBOs and Centaurs to determine the frequency of their ring systems.

New Horizons is the first mission under NASA's New Frontiers Program, managed by NASA Marshall Space Flight Center in Huntsville, Alabama.

New Horizons Online

www.nasa.gov/newhorizons

www.pluto.jhuapl.edu

www.twitter.com/NASANewHorizons

www.twitter.com/NewHorizons2015

www.facebook.com/newhorizons1

https://seeultimathulenow.com/

Media Services Information

***Note:** Should a federal government shutdown continue through New Horizons' Ultima Thule flyby – and NASA TV, nasa.gov and other agency digital and social channels remain offline – check the New Horizons project website at http://pluto.juapl.edu for the latest coverage plans.*

News and Status Reports

NASA and the New Horizons team will issue periodic status reports on mission activities and make them available online at www.nasa.gov/newhorizons and http://pluto.jhuapl.edu. The websites also include information on press accreditation, media briefings, special press opportunities and on-site logistics at APL during the Ultima Thule flyby.

On-Site Media Logistics

News media representatives covering the Ultima Thule flyby in person must be accredited through NASA and APL. The New Horizons media center at APL will operate from Dec. 30, 2018, through Jan. 3, 2019, to accommodate mission activities and daily news/science briefings. Journalists may call (240) 228-7536 for more information.

New Horizons on the Web

New Horizons information – including an electronic copy of this press kit, press releases, fact sheets, mission details and background, status reports and images – is available on the web at http://pluto.jhuapl.edu and www.nasa.gov/newhorizons. Mission updates are also available on Twitter (@NASANewHorizons) and Facebook (www.facebook.com/newhorizons1).

NASA Television

NASA TV channels are digital C-band signals carried by QPSK/DVB-S modulation on satellite Galaxy-13, transponder 11, at 127 degrees west longitude, with a downlink frequency of 3920 MHz, vertical polarization, data rate of 38.80 MHz, symbol rate of 28.0681 Mbps and 3/4 FEC. A Digital Video Broadcast-compliant Integrated Receiver Decoder is needed for reception. A full schedule of New Horizons broadcasts, including commentary and clean feed channels, will be available on the NASA TV schedule at https://www.nasa.gov/multimedia/nasatv/index.html#public.

Eyes on Ultima

Through NASA's Eyes on the Solar System program, the public can follow the path of New Horizons as it speeds through the outer reaches of the solar system toward Ultima Thule and "watch" a simulation of the Ultima flyby in real time over New Year's 2019. "Eyes" is available on the web at http://eyes.nasa.gov.

Flyby Media Events Schedule

Saturday, December 29

8 a.m. – 1 p.m.

Tours of the mission operations and science operations centers at APL. This will be an opportunity to gather b-roll footage and images of these critical working areas, which will be closed to media and the public during flyby week. Media will meet at the Kossiakoff Center and travel (by shuttle bus) to the operations areas. Please bring a photo ID to obtain an APL visitor badge; non-U.S. citizens must show a passport.

Sunday, December 30

11 a.m. – 6 p.m.

Media center opens; interview opportunities with New Horizons team members.

Monday, December 31

Noon – 2 p.m.

Media Center opens; team member overview talks on mission science.

2 – 3 p.m.

Media briefing on mission status, flyby preview and latest approach images.

7 p.m. – midnight

Team member/guest talks and panel discussions on mission status, NASA exploration, New Horizons and the Kuiper Belt.

Midnight – 1 a.m. (Jan. 1)

Countdown celebration to Ultima closest approach (12:33 a.m.), with real-time simulations of New Horizons spacecraft activity. (Note that New Horizons is ***not*** in contact with Earth during closest approach.)

1 a.m.

Media center closes.

Tuesday, January 1

9 a.m.

Media center opens.

10 – 11 a.m.

Live coverage of New Horizons mission operations, receipt of signal from the spacecraft confirming a successful flyby.

11 a.m. – 12:30 p.m.

Team recognition; media briefing covering spacecraft health, mission status, (possibly) latest images downlinked before the flyby.

2 p.m.

Media center closes.

Wednesday, January 2

2 p.m.

Media briefing covering flyby images and science data, mission status.

Thursday, January 3

2 p.m.

Media briefing covering flyby images and science data, mission status.

Quick Facts

Mission

Launch: Jan. 19, 2006, from Launch Complex 41 at Cape Canaveral Air Force Station, Florida.

Launch vehicle: Lockheed Martin Atlas V-551 (core Atlas booster [with five solid rocket boosters attached] with a Centaur upper stage) and a Boeing STAR-48B solid-propellant rocket third stage.

Launch vehicle height (with payload): 196 feet (59.7 meters).

Launch vehicle weight (fully fueled): Approximately 1.26 million pounds (575,000 kilograms).

Jupiter gravity assist: Feb. 28, 2007.

Jupiter closest approach distance and speed: About 1.4 million miles (2.3 million kilometers) at 47,000 miles per hour (21 kilometers per second).

Planetary orbit crossings: Moon (9 hours after launch); Mars (April 7, 2006); Asteroid APL (June 13, 2006); Jupiter (Feb. 28, 2007); Saturn (June 8, 2008); Uranus (March 18, 2011); Neptune (Aug. 25, 2014).

Pluto flyby: July 14, 2015.

Pluto closest approach distance and speed: About 7,750 miles (12,500 kilometers) at approximately 31,000 miles per hour (14 kilometers per second).

Charon closest approach and speed: About 18,000 miles (29,000 kilometers) at same approximate Pluto flyby speed.

Pluto distance from Earth in July 2015: Approximately 2.96 million miles (4.77 billion kilometers).

Planned Ultima Thule closest approach and speed: About 2,200 miles (3,500 kilometers) at approximately 32,000 miles per hour (14 kilometers per second).

Ultima Thule distance from Earth in January 2019: 4.1 billion miles (6.6 billion kilometers).

Spacecraft

Size: The primary structure is about the size of a baby grand piano; 27 inches (0.7 meters) tall, 83 inches (2.1 meters) long and 108 inches (2.7 meters) at its widest. An 83-inch (2.1-meter) diameter antenna dish is attached to the top deck; the spacecraft measures 87 inches (2.2 meters) tall from the payload attachment fitting on the bottom deck to the top of the dish antenna stack.

Launch weight: 1,054 pounds (478 kilograms); included 170 pounds (77 kilograms) of hydrazine propellant and a 66-pound (30-kilogram) science instrument payload.

Power: Total power available for the Ultima Thule encounter is 190 watts from a single radioisotope thermoelectric generator.

Propulsion: 16 hydrazine-fueled thrusters, used for trajectory adjustments and attitude control.

Science instruments: The New Horizons science payload is the most capable suite of instruments ever launched on a first reconnaissance mission to an unexplored planet. It includes the Alice ultraviolet imaging spectrometer to probe atmospheric composition and surface structure; the Ralph visible and infrared camera/spectrometer to obtain high-resolution color maps and surface composition maps; the LORRI long-range telescopic camera for high-resolution surface images; the SWAP and PEPSSI particle spectrometers to measure solar wind charged particles in and around a planet's atmosphere; the student-built SDC detector to measure masses of space-dust particles; and two copies of the REX radio science experiment to examine atmospheric structure, surface temperatures and a radar reflectivity.

Program

First mission in NASA's New Frontiers Program, a class of principal investigator (PI)-led projects larger than Discovery missions.

Cost: Approximately $720 million (including spacecraft and instrument development, launch vehicle, mission operations, data analysis and education/public outreach) covering the primary mission from 2001 through 2017. Approximately $81 million (covering operations, data analyses, data archiving and engagement/communications) for the Kuiper Belt Extended Mission through 2021.

A Mission of Firsts

New Horizons is the first…

- Mission to study the Pluto system.
- Mission to study Kuiper Belt objects.
- Mission to explore a world that hadn't been discovered when it launched.
- PI-led outer planets mission.
- Planetary mission to carry a student-built instrument.
- Spacecraft to carry a working dust detector beyond the orbit of Uranus.
- Outer planets mission led by the Johns Hopkins University Applied Physics Laboratory and Southwest Research Institute.
- NASA New Frontiers mission.

New Horizons is also the fastest spacecraft ever launched, has traveled the farthest distance to reach its primary science target, holds the record for most distant exploration of worlds, and completed the first reconnaissance of our solar system's classical planets.

The Kuiper Belt

New Horizons is the first mission to explore the Kuiper Belt, the “third zone” of our solar system, a region beyond the rocky inner planets and the outer giant gas planets.

In 1992, Dave Jewitt and Jane Luu at the University of Hawaii discovered a small object, designated 1992QB1, orbiting the Sun beyond Neptune at a distance of about 40 astronomical units (AU) – 40 times the distance between the Sun and Earth. Since then, more than 2,100 similar objects with orbits beyond Neptune have been discovered, and scientists estimate there are several hundred thousand objects bigger than 20 miles across waiting to be discovered in that vast region of the solar system. About a dozen objects in the Kuiper Belt are larger than 600 miles (1,000 kilometers) across, of which Pluto, near 1,500 miles (2,400 kilometers) in diameter, is the largest.

We call this assemblage of bodies the Kuiper Belt, in honor of Dutch-American astronomer Gerard Kuiper (1905–1973), who predicted about the existence of small bodies beyond Neptune in the 1950s. Some call this the Edgeworth/Kuiper Belt, sharing the honor with Irish scientist Kenneth Edgeworth, who published a similar idea in the 1940s. The inhabitants of this realm are called Kuiper Belt objects (KBOs), Edgeworth/Kuiper Belt objects, or simply trans-Neptunian objects (TNOs). Most of the short-period comets we see in the inner solar system likely come from the Kuiper Belt, being held there in cold storage until random gravitational tugs from Neptune nudge them inward.

10 Things: The Kuiper Belt

It’s vast and mysterious, cold and dark. It’s a place we’ve only just begun to explore, but it holds important clues to the origins of our solar system. Visit NASA’s Solar System website at https://solarsystem.nasa.gov/ for 10 things to know about the Kuiper Belt.

Classifying Kuiper Belt Objects

We classify objects found in the Kuiper Belt based on their orbits. The main categories are:

“Cold Classical” KBOs: “Cold” here refers not to temperature but to the circular, uninclined orbits of these objects. Cold Classical KBOs occupy a narrow region about 6 AU wide, between 42 and 48 AU from the Sun, and about 3 AU thick. There aren’t any large (500 miles across or larger) KBOs in this group and they tend to be redder than other KBOs, so they might have a different origin. These objects are called “classical” KBOs since they are on the sorts of orbits that Kuiper talked about and they represent a “bedrock sample” of the primordial Kuiper Belt. ***Ultima Thule is a member of the Cold Classical category.*** The Cold Classicals appear to be the gravitationally unperturbed and original material of the Kuiper Belt.

“Hot Classical” KBOs: Here, “Hot” refers to the eccentric and inclined orbits of these objects. Though they have a similar average distance from the Sun as Cold Classical KBOs, their eccentric and inclined orbits cause them to stray much farther from that average position.

Resonant KBOs are locked in an orbital dance with Neptune – that is, they orbit in resonance with that planet. The 3:2 resonant objects, which include Pluto, make two orbits around the Sun for every three of Neptune’s orbits. These are sometimes called “Plutinos” or “little Plutos.” The 2:1 objects are farther from the Sun and orbit once for every two orbits of Neptune.

Scattered KBOs have probably wandered too close to Neptune in the past, and Neptune’s gravity has knocked them onto unstable orbits, sometimes taking them hundreds of AU from the Sun at their most distant point and bringing them closer to the Sun than Neptune at their closest.

The last category, sometimes called the Extreme TNOs, is so new that so far it has only a few known members, such as Sedna and 2012 VP113. These objects may end up not being considered part of the Kuiper Belt at all. Sedna never gets closer than 76 AU and reaches 1,000 AU at the most distant point of its 12,000-year orbit. Sedna is at least half the size of Pluto and is probably one of the largest members of a huge population of undiscovered objects in this distant region of the solar system.

Read more about the Kuiper Belt at http://pluto.jhuapl.edu/Ultima/About-the-Kuiper-Belt.php. (NASA/JHUAPL/SwRI)

Discovering Kuiper Belt Objects

Because they are small and far away, KBOs look like faint stars even through the world's largest telescopes. Modern astronomers use extremely sensitive digital cameras – highly specialized versions of the digital cameras now in wide use by shutterbugs around the world – to discover KBOs. Digital cameras used by astronomers are so sensitive that they must be operated at extremely cold temperatures, around –58 to –148 degrees Fahrenheit (–50 to –100 degrees Celsius) to minimize detector noise and maximize sensitivity.

Sizes and Colors

The largest two Kuiper Belt objects are Pluto and Eris, with Pluto being slightly larger at a diameter of 1,477 miles (2,377 kilometers). There are 10 other known KBOs with diameters that are approximately 600–900 miles (950–1,500 kilometers), including Pluto's largest moon, Charon. Most KBOs are much smaller.

Mission Overview: Path to Ultima

Primary Mission Target: Pluto

A direct airplane flight might be the quickest way across the country, but the fastest spacecraft route to Pluto requires a trip past Jupiter. The giant planet's gravity can actually "slingshot" a spacecraft toward the outer solar system.

There are two reasons why the New Horizons science team wanted to reach Pluto as soon as possible. The first had to do with Pluto's atmosphere: Since 1989, Pluto has been moving farther from the Sun, getting less heat every year. As Pluto got colder scientists expected its atmosphere would "freeze out," so the team wanted to arrive while there was a chance to study a thicker atmosphere.

The second reason was to map as much of Pluto and its largest moon, Charon, as possible. On Earth, the North Pole and other areas above the Arctic Circle have half a year of night and half a year of daylight. In the same way, parts of Pluto or Charon never see the Sun for decades at a time. The longer the wait, more of Pluto and Charon would have been shadowed in a long "arctic night," impeding the spacecraft's ability to take pictures of the surface in reflected sunlight.

3 … 2 … 1 … Pluto! Team members, family, friends and fans gathered at the Johns Hopkins University Applied Physics Laboratory to mark the moment of New Horizons' closest approach to Pluto on July 14, 2015. (NASA/JHUAPL/SwRI)

A Prime Opportunity

By launching in January 2006, New Horizons could take advantage of a gravity assist from Jupiter. In February 2007, New Horizons passed through the Jupiter system at more than 50,000 miles per hour (80,500 kilometers per hour), ending up on a path that got it to Pluto on July 14, 2015.

During the 8-plus-year cruise from Jupiter to Pluto, the mission team monitored the health of the spacecraft while planning and practicing for the encounter with Pluto and Charon. At the same time, observers used telescopes on and above Earth to find and study Kuiper Belt objects that the spacecraft could fly by after Pluto (as part of a possible extended mission). The "KBOs" are ancient, icy bodies – unexplored building blocks of the solar system – that orbit beyond Neptune.

The Voyage

The first 13 months included spacecraft and instrument checkouts, instrument calibrations, small trajectory correction maneuvers and rehearsals for the Jupiter encounter. New Horizons began passing planetary orbits at record speed, reaching the orbit of Mars on April 7, 2006. It also tracked a small asteroid, later named "APL," in June 2006.

Jupiter closest approach occurred Feb. 28, 2007. Moving about 51,000 miles per hour (about 23 kilometers per second), New Horizons flew about three to four times closer to Jupiter than the Cassini spacecraft, coming within 1.4 million miles (2.3 million kilometers) of the large planet. Science at Jupiter included meteorology, aurora studies, magnetospheric sampling, dust sampling and surface mapping, compositional mapping and atmospheric studies of Jupiter's large moons.

Activities during the approximately 8-year cruise to Pluto included annual spacecraft and instrument checkouts, course corrections, instrument calibrations and Pluto encounter rehearsals. The spacecraft also collected valuable data on the solar wind, cosmic rays and dust distribution across the giant planet region. During the cruise, New Horizons also crossed – in record time – the orbits of Saturn (June 8, 2008), Uranus (March 18, 2011) and Neptune (Aug. 25, 2014).

Closing in on Pluto

The cameras on New Horizons began taking data on Pluto and its five moons several months before the spacecraft arrived. Pluto and Charon first appeared as unresolved bright dots, but the dwarf planet and its moons appeared larger as the encounter date approached. Three months from the closest approach – when Pluto was about 65 million miles (105 million kilometers) away – the cameras on the spacecraft could make the first maps. For those 3 months, the mission team routinely took better and better pictures and spectra.

The Pluto System Encounter

At closest approach, the spacecraft came about 7,750 miles (12,500 kilometers) from Pluto and about 17,900 miles (28,800 kilometers) from Charon. On the way in, the spacecraft looked for ultraviolet emissions from Pluto's atmosphere and made global maps of Pluto and Charon in green, blue, red and a special wavelength that is sensitive to methane frost on the surface. It also took spectral maps in the near infrared, telling the science team about Pluto's and Charon's surface compositions and locations of these materials.

During the half hour when the spacecraft was closest to Pluto or its largest moon, it took close-up pictures in both visible and near-infrared wavelengths. The best pictures of Pluto depicted surface features as small as 230 feet (about 70 meters) across.

Even after the spacecraft passed Pluto and its moons, its work was far from done. Looking back at the mostly dark night-time side of Pluto or Charon was the best way to spot haze in the atmosphere, to look for rings, and to figure out whether their surfaces are smooth or rough. As the spacecraft flew through the shadows cast by Pluto and Charon, it looked back toward the Sun and Earth, watching the light from the Sun and radio waves from transmitters on Earth – measuring the atmosphere as the spacecraft "watched" the Sun and Earth set behind Pluto and its largest moon.

Pluto Revealed: A World with a Heart

The flyby of Pluto on July 14, 2015, was the culmination of a decades-long quest to see and understand the classical solar system's most distant planet.

Pluto in true color. (NASA/JHUAPL/SwRI)

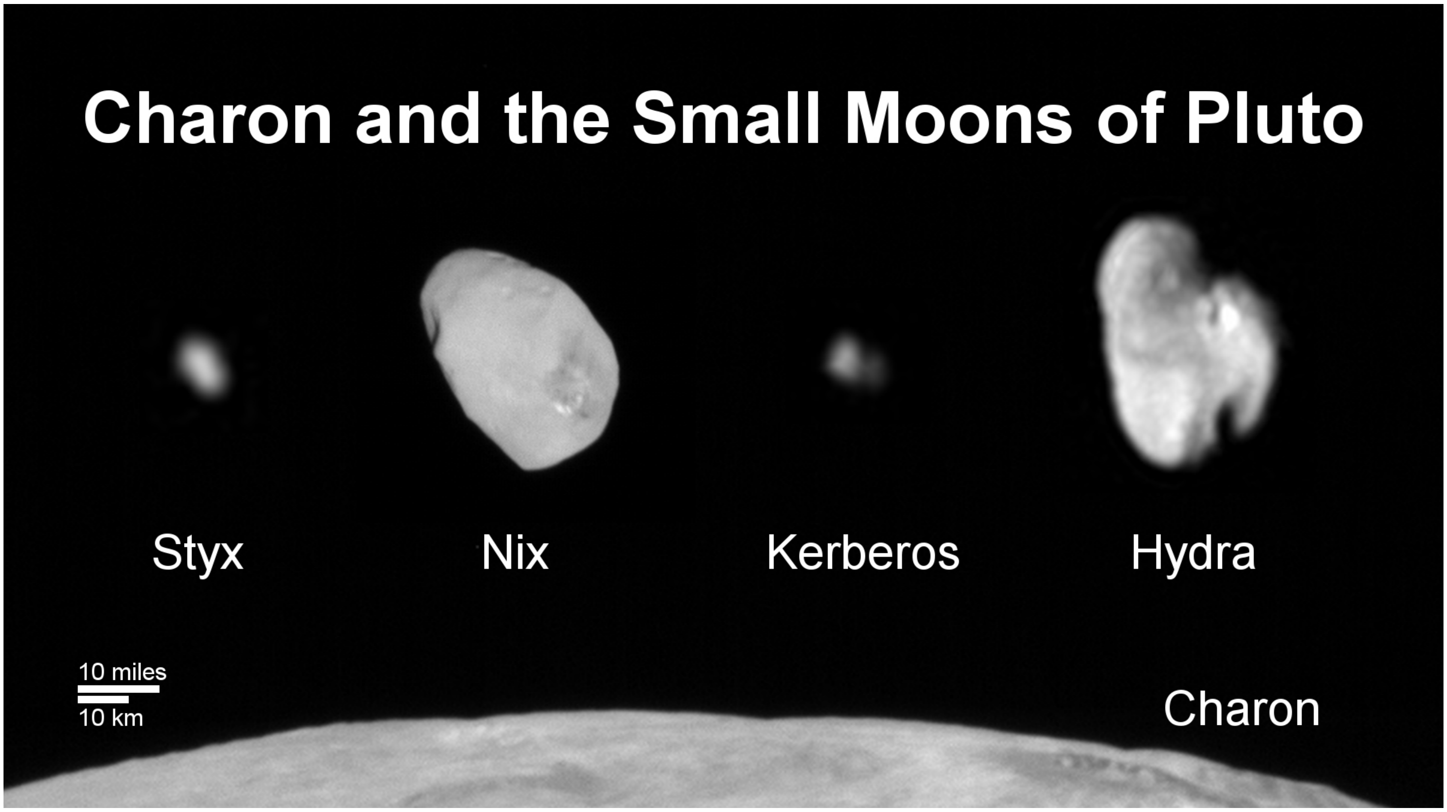
It also turned out to be a new beginning, revealing for the first time the potential complexity of small (or dwarf) planet systems in the Kuiper Belt. New Horizons' seven instruments took over 50 gigabits of data at Pluto – on approach, passing through the system, and on departure.

Pluto was revealed to be a geologically and meteorologically active world. Its size and density were accurately determined; the former turned out to be at the upper range of estimates made from Earth-based observations. Pluto remains, for now, the largest known world in the Kuiper Belt. Made largely of rock – about two-thirds, by mass – but with substantial ice and carbonaceous (organic) material, Pluto possesses a rock core and predominantly water-ice mantle. Surface layers and deposits of volatile ices such as nitrogen (N_2), methane (CH_4) and carbon monoxide (CO), along with dark, reddish, organic matter often referred to as tholins, complete the picture.

Pluto's volatile ices can sublimate and condense under the influence of even the feeble sunlight at Pluto's distance, and nitrogen ice in particular is soft enough to flow across Pluto's incredibly cold surface (about 40 Kelvin – or –387 degrees Fahrenheit – as measured by New Horizons). And flow it does, from high-standing water-ice-rich terrains, through gaps in the mountains, and down to a vast, frozen nitrogen-ice sea called Sputnik Planitia – one half of a stunning heart-shaped feature named Tombaugh Regio. This icy plain is actually a giant ice sheet, filling several kilometers deep a great impact basin more than 600 miles (1,000 kilometers) across, itself the product of the collision between a large (roughly 120-mile/200-kilometer wide) Kuiper Belt object (KBO) and Pluto over 4 billion years ago.

Pluto's topography is rugged, with some water-ice mountain blocks reaching heights of 3 miles (5 kilometers). The density of impact craters on Pluto varies widely, from heavily cratered terrains in Cthulhu Regio that must date back to the early days of the solar system, to Sputnik Planitia itself, which shows no impact craters at all in New Horizons' highest-resolution images (about 230 feet, or 70 meters, per pixel). The solid nitrogen ice in Sputnik Planitia is organized into giant convection cells, slowly churning over hundreds of thousands of years, transporting Pluto's modest interior heat outward.

The position of Sputnik Planitia on Pluto's tidal axis (the imaginary line that runs through the centers of Pluto and Charon) could be evidence of a slip, or polar wander, of Pluto's surface to a preferred orientation. Such a slip is circumstantial evidence that under Pluto's water-ice mantle, perhaps at a depth of close to about 90 miles (150 kilometers), lies an inner ocean of water.



(NASA/JHUAPL/SwRI)

Farewell Pluto: Blue skies and a complex, layered atmosphere are stunningly visible in this image taken by New Horizons as it sped away from the Pluto system on July 14, 2015. (NASA/JHUAPL/SwRI)

Pluto's atmosphere was measured by New Horizons ultraviolet solar and radio occultations. It's quite thin, about 11.5 чbar at the surface, and dominated by nitrogen gas in vapor-pressure equilibrium with surface nitrogen ice. Methane is the next most abundant gas and several simple hydrocarbons were discovered as well. The temperature in the atmosphere rises over the first 25 kilometers (about 15 miles) or so, peaking at around 115 Kelvin (–252 degrees Fahrenheit), and gradually falling with increasing altitude. The temperature at Pluto's exobase, hundreds of kilometers above the surface, was much lower than previously thought, which means that Pluto's atmosphere is not escaping as fast as previously believed. Even more interesting, the dominant gas escaping is the lighter component, methane, not nitrogen. As thin as Pluto's atmosphere is, it can transport sublimed ices from one part of Pluto's surface to another, and downslope wind speeds are great enough to form methane-particle "sand dunes" at the edge of Sputnik Planitia.

But the best surprise was saved for last. Turning New Horizons' imaging telescopes to look back at Pluto on departure, numerous, nearly concentric haze layers were discovered surrounding the planet, extending several hundred kilometers/miles above the surface and creating a blue hue in Pluto's atmosphere.

Moons

Pluto's satellites also did not disappoint. Charon, the large moon, has a surface dominated by water ice and no atmosphere. New Horizons' Linear Etalon Imaging Spectral Array (LEISA) spectrometer confirmed the presence of ammonia ice across much of the surface, along with concentrations associated with specific impact craters. Charon's poles are stained red from cold-trapped, radiation-processed methane that escaped from Pluto. Charon is not currently

Pluto's largest moon, Charon, in true color. (NASA/JHUAPL/SwRI)

geologically active, and impact cratering on its surface led New Horizons science team members to estimate its overall surface age at approaching 4 billion years.

But its geological past was spectacular. Much of Charon's northern hemisphere visible to New Horizons at closest approach is broken into great crustal blocks and canyons many miles deep. In contrast, the plains of the southern hemisphere, named Vulcan Planitia, appear to have been resurfaced by thick, icy – or cryovolcanic – flows. The totality of Charon's geological history suggests that it too is differentiated and possessed an internal ocean, but owing to the moon's smaller size relative to Pluto, it cooled and its ocean froze, causing its surface to expand and rupture, which in turn facilitated the cryovolcanic eruptions we see in Vulcan.

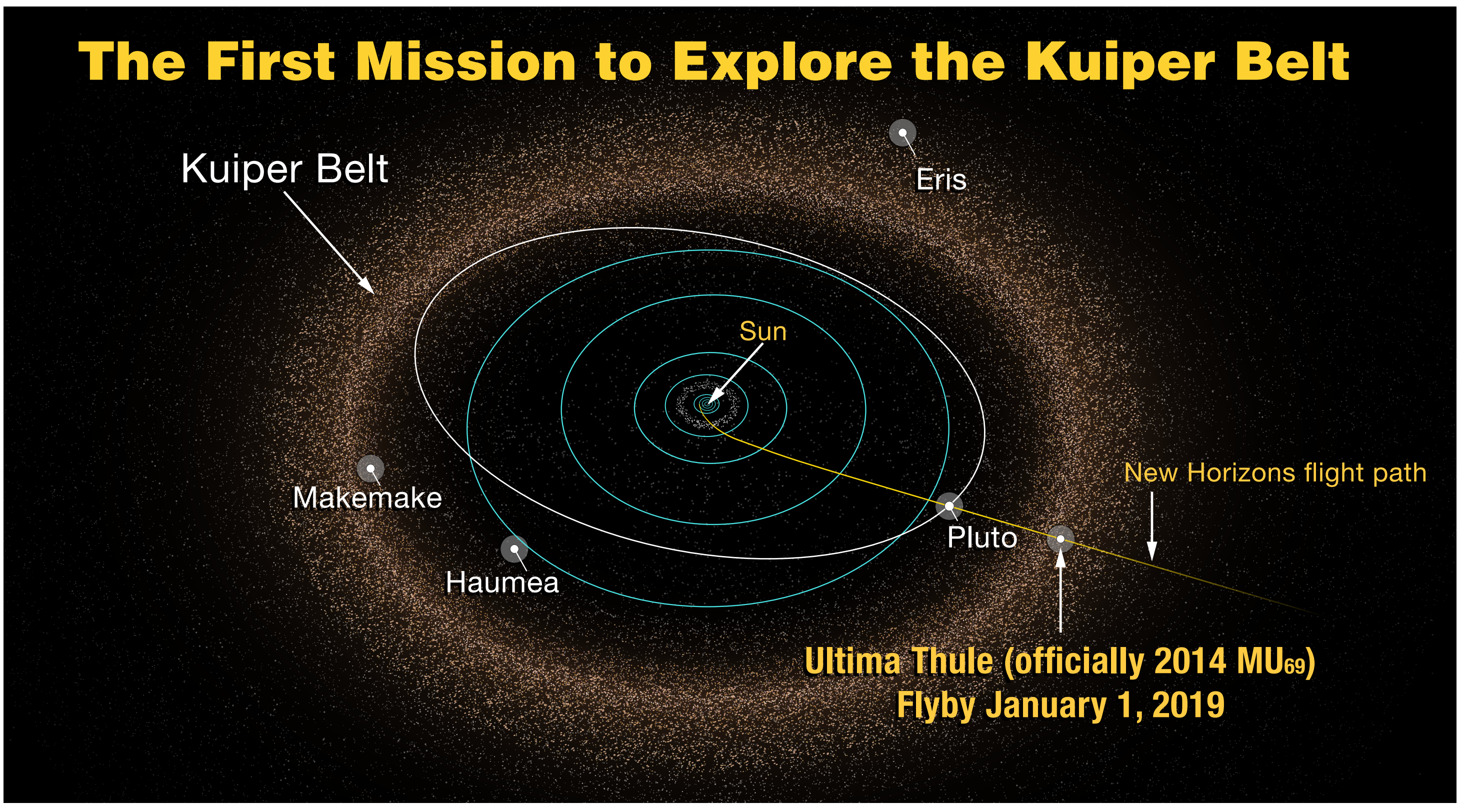
Pluto's smaller moons – Styx, Nix, Kerberos and Hydra, all discovered by New Horizons team members with the Hubble Space telescope after the mission began – were imaged on a best-effort basis. They are irregular, on the order of 6 to 30 miles (10 to 50 kilometers) across, and highly reflective. Infrared spectra indicate surfaces of almost pure water ice. These moons orbit in the same plane as Pluto and Charon but at great distances – far enough that tides have not slowed any of the small moons to the synchronous spin state common among regular satellites elsewhere in the solar system. In fact, some of the spin states are bizarre: all four highly elongated objects rotate much faster than synchronous, with their rotational poles highly inclined relative to those of Pluto and Charon (which are aligned). The relativities and surface compositions of Pluto's small moons are quite different from most similarly sized KBOs, which are much darker, often redder, and spectrally featureless, but are consistent with being debris from the giant impact that created the Pluto-Charon binary at the beginning of solar system.

Exploring the Kuiper Belt

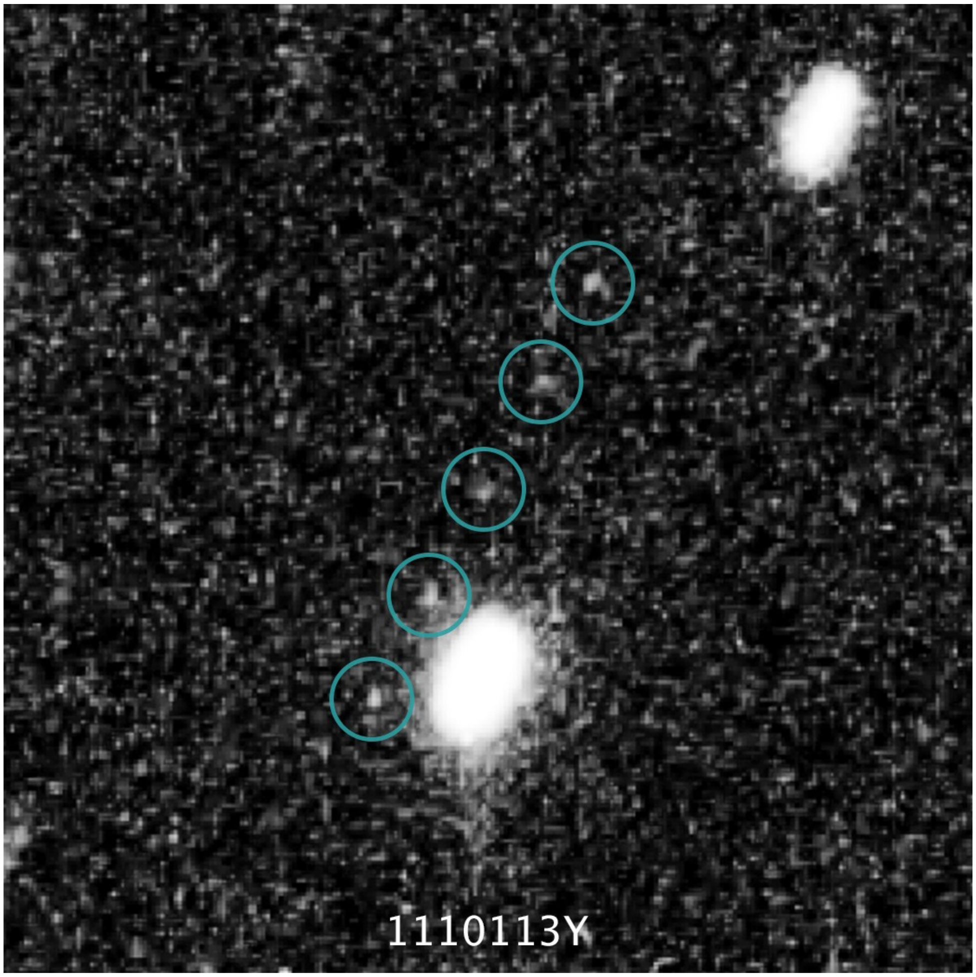
With Pluto behind it, New Horizons headed deeper into the Kuiper Belt to explore other smaller and more primitive KBOs. An extensive search with ground-based telescopes and the Hubble Space Telescope resulted in the discovery, in summer 2014, of two KBOs that were close enough to the spacecraft's trajectory that the spacecraft could be diverted to perform a close flyby of one of them.

Shortly after the Pluto flyby, in August 2015, the team chose one of these, 2014 MU69 (now nicknamed Ultima Thule) as the flyby target. In early November 2015, New Horizons fired its thrusters to alter the direction of its trajectory by 3 million miles (5 million kilometers), to intercept Ultima on Jan. 1, 2019.

The spacecraft's path to Ultima takes it through the densest part of the Kuiper Belt, passing within 1 astronomical unit (the distance between Earth and the Sun, which is about 93 million miles or 150 million kilometers) of about two other known KBOs. Though none of these objects will appear as more than a point of light in New Horizons' cameras, the spacecraft has or will still observe each from unique angles not possible from Earth to learn about their surface properties, and it will search for moons and rings with greater sensitivity than the most powerful telescopes on or near Earth. New Horizons is also taking pictures of several larger but more distant KBOs, including dwarf planets, to measure their brightness from its unique perspective.



(NASA/JHUAPL/SwRI)



The June 2014 Hubble Space Telescope discovery image of the object the team first tagged “PT1,” for “Potential Target 1.” Its official designation became 2014 MU69, before the team, with public input, nicknamed it Ultima Thule.
(NASA/ESA/SwRI/JHUAPL/New Horizons KBO Search Team)

Meet Ultima Thule

No other mission has ever targeted to and explored an object that wasn’t even ***discovered*** when it launched.

The New Horizons team enlisted the Hubble Space Telescope to search for a Kuiper Belt object (KBO) to fly by after Pluto. Using observations made with Hubble on June 26, 2014, the science team discovered an object that New Horizons could reach with its available fuel. The object was subsequently designated 2014 MU69 and given the minor planet number 485968. In March 2018, based on significant public input, the team announced the nickname “Ultima Thule” (pronounced “Ultima too-lee”) – which means “beyond the known world” – for its target object.

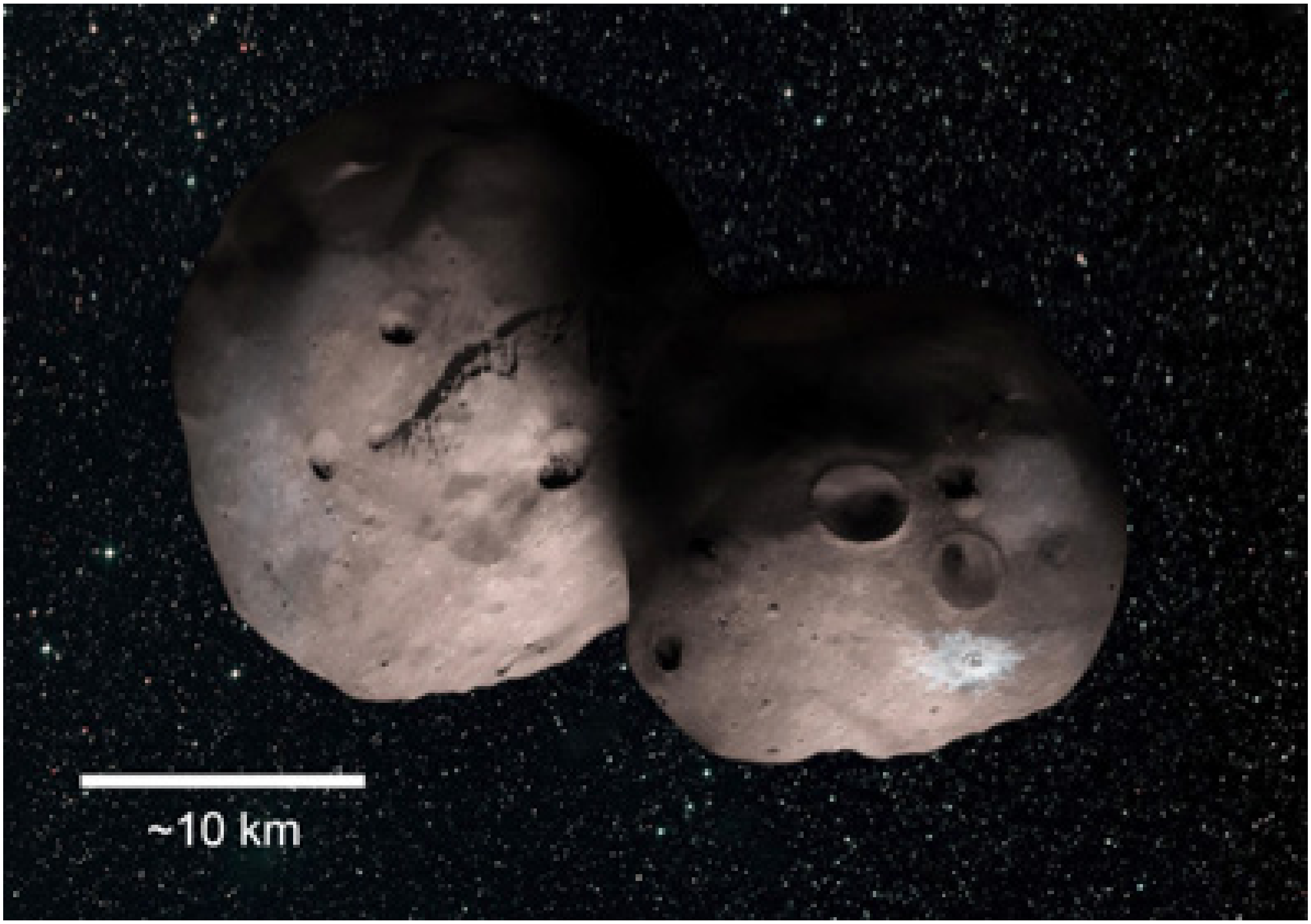
Ultima Thule is located in the heart of the Kuiper Belt, in the outermost regions of the solar system, beyond the orbit of Neptune. At 12:33 ET on Jan. 1, 2019, the New Horizons spacecraft will fly by Ultima Thule at a distance of 2,200 miles (3,500 kilometers). At the time, Ultima Thule will be almost 4 billion miles (6.5 billion kilometers) from the Sun, making the flyby the most distant ever attempted, and the first time that a KBO has been seen close-up.

In July 2017, New Horizons team members and collaborators working in Argentina watched Ultima Thule pass in front of a star – observing what's known as a stellar occultation – learning much about the KBO's size and shape. Read and watch the stories behind these critical international observations at http://pluto.jhuapl.edu/Ultima/Exploring-the-Kuiper-Belt.php.
(Alistair Daynes/ReWildTV, for GHSPi)

In the meantime, the New Horizons team has pieced together a profile of Ultima that will help it to plan accurate observations. In June and July 2017, Ultima Thule passed in front of a star as seen from Earth (known as a stellar occultation).

Using those occultation observations, team members figured that Ultima could be an "extreme prolate spheroid" – think of a skinny football – or even a binary pair. The odd shape has scientists thinking two bodies may be orbiting very close together or even touching – what's known as a close or contact binary. The data also allowed observers to estimate Ultima's size at no more than 20 miles (30 kilometers) long, or, if a binary, each at about 9–12 miles (15–20 kilometers) in diameter. Using the Hubble Space Telescope, the team determined that Ultima is redder than Pluto, though not as red as Mars.

We will only know what Ultima Thule's surface looks like once New Horizons has sent back the first pictures after it has flown by, although based on observations of solar system objects, it will almost certainly display impact craters.



Artist's impression of Ultima Thule as a contact binary. (NASA/JHUAPL/SwRI/Alex Parker)

The lighting at Ultima's surface is very dim, as it receives only about 0.05% of the light from the Sun that Earth does. From Hubble observations we know Ultima Thule has a reddish color, probably caused by exposure of hydrocarbons to sunlight over billions of years. The flyby will also reveal whether it has any moons or rings.

We do know this: Ultima Thule will be the most primitive object yet explored, and it will reveal to us what conditions were like in this distant part of the solar system as it condensed from the solar nebula.

Making History

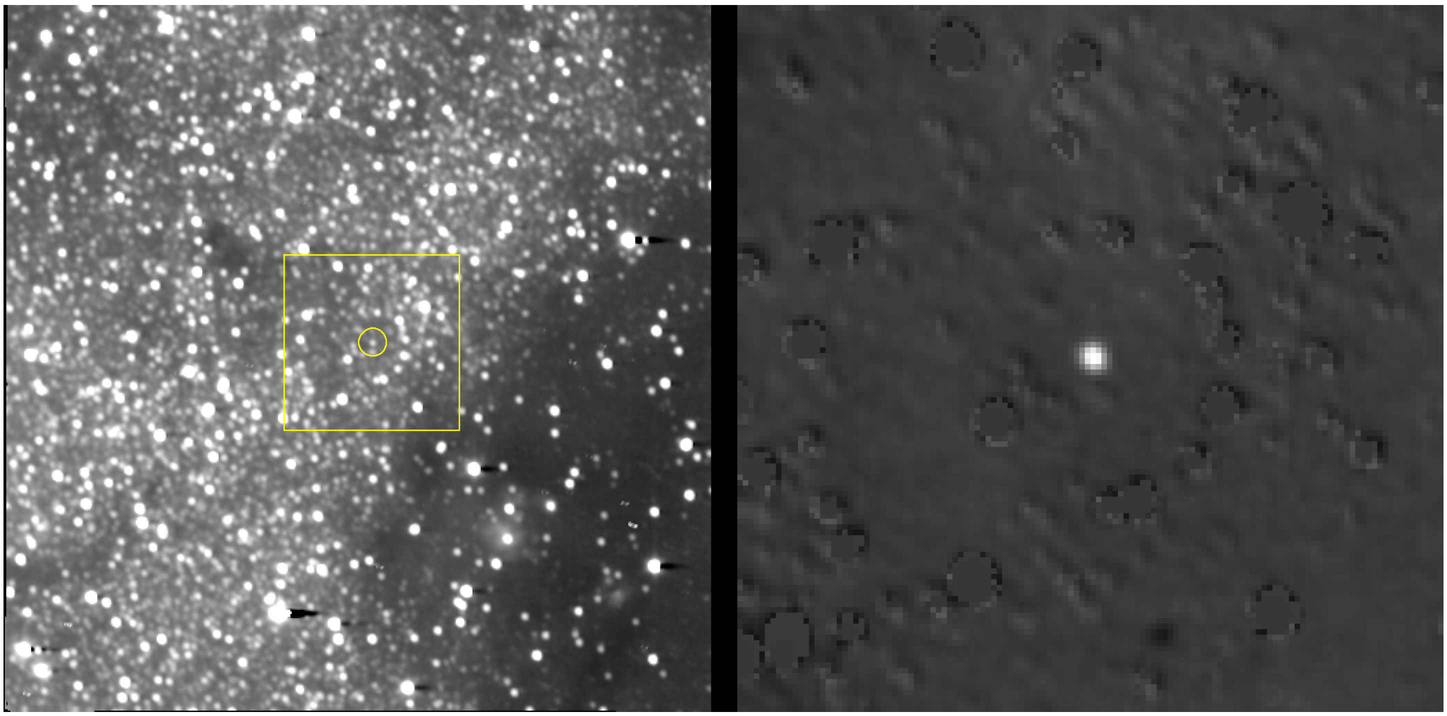
The flyby of Ultima will be…

- The farthest exploration of any worlds in space (by far).
- The first-ever exploration of small KBOs.
- A look at the most well preserved sample of solar system formation conditions to date.

Approach to Ultima

New Horizons' approach to Ultima began in August 2018, when the spacecraft took its first pictures of its target, which appeared as a faint dot barely visible against a crowded field of stars. The spacecraft continues to take regular images of Ultima as it gets closer and brighter, using them to check that it is on the right course, and firing its thrusters to make course corrections as necessary.

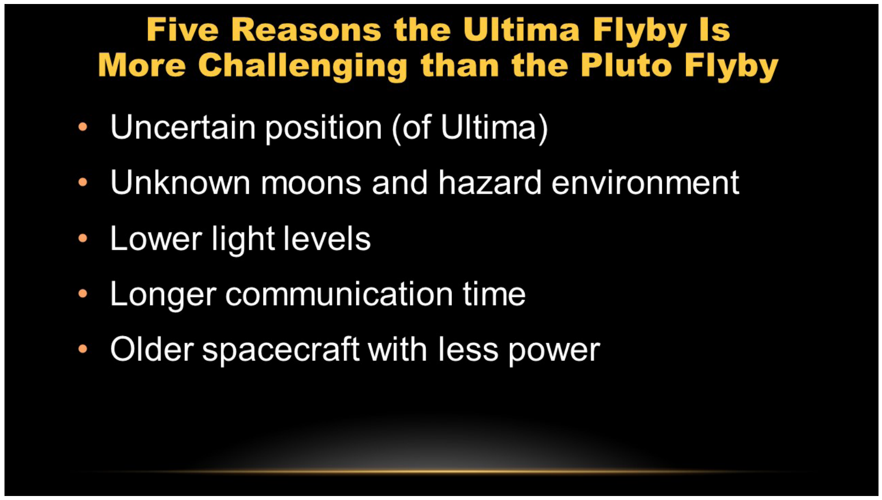
In early December, the mission team performed an intensive campaign of imaging to look for any rings or moons around Ultima. Finding no danger, the team opted for the planned trajectory, designed for a closest approach distance of 2,175 miles (3,500 kilometers). (Backup plans would have diverted New Horizons to a more distant alternate trajectory, with a close approach distance of 6,214 miles or 10,000 kilometers.)



Composite image of Ultima Thule taken Dec. 1, 2018. At left is the full Long Range Reconnaissance Imager (LORRI) image with a yellow circle centered on the location of Ultima Thule; at right, the region within the yellow box has been expanded, with stars subtracted to better see Ultima. The Kuiper Belt object was 4.01 billion miles (6.47 billion kilometers) from the Sun and 24 million miles (38.7 million kilometers) from New Horizons when the images were taken. Images like these are critical for navigating the spacecraft toward its target. (NASA/JHUAPL/SwRI)

In the last few days of the approach, the navigation team will analyze the latest images of Ultima taken by New Horizons to refine estimates of the Kuiper Belt object's position relative to the spacecraft. If necessary the team will uplink the updated information to New Horizons, so that the spacecraft can more accurately time its observations and point its cameras.

Intensive science observations begin 24 hours before the flyby. The spacecraft will take frequent grayscale, color, near-infrared and ultraviolet observations of Ultima as it rotates, to investigate its shape, composition and any possible gas release. Long-exposure imaging of the space surrounding Ultima will search for rings or moons and determine their orbits.



Observations at closest approach – set for 12:33 a.m. EST on Jan. 1, 2019 – need to account for the fact that Ultima's exact position is uncertain. That's why these observations consist of long scans to obtain color and grayscale images, and infrared spectra, of all the possible locations where Ultima ***might*** appear to be from the spacecraft's moving vantage point.

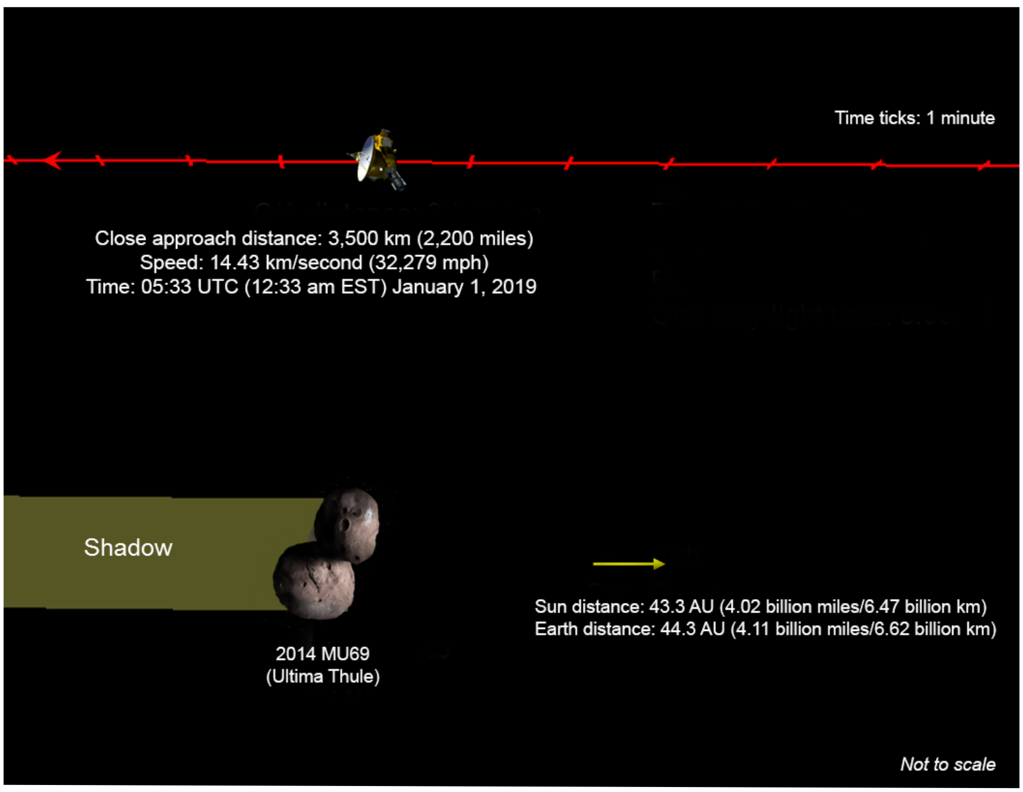
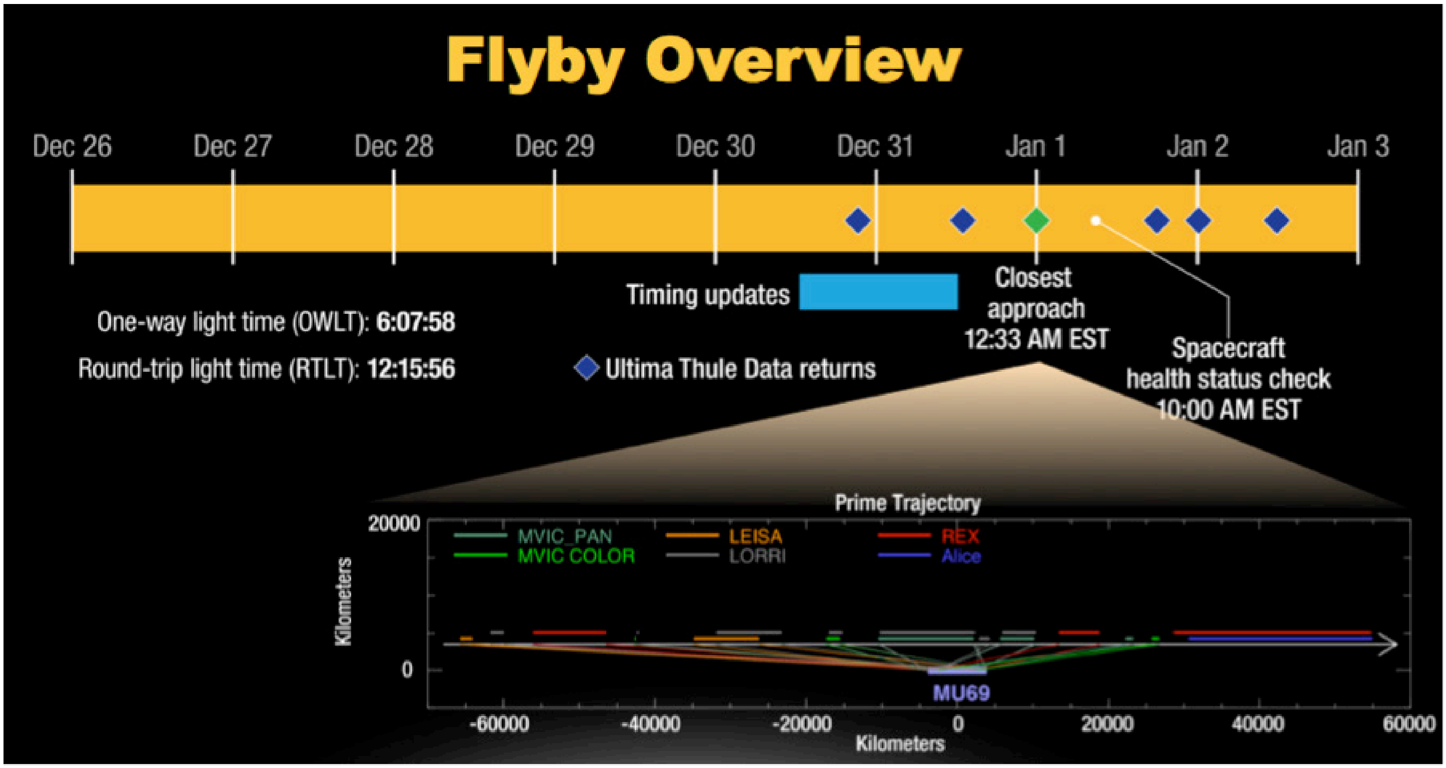


Diagram of New Horizons' path "over" Ultima Thule. (NASA/JHUAPL/SwRI)

The pixel sizes of the best expected color and grayscale images and infrared spectra will be 330 meters, 140 meters and 1.8 kilometers, respectively. There is a chance of higher-resolution grayscale images, with 33-meter pixels, if the high-resolution Long Range Reconnaissance Imager (LORRI) is able to point accurately at Ultima – but the necessary accuracy isn't guaranteed. The team will also attempt to detect both the daytime and nighttime heat radiation from Ultima and its radar reflectivity, using the radio instrument.

After closest approach, New Horizons will point its ultraviolet instrument at the Sun to look for absorption of ultraviolet light by any gases being released by Ultima (though detection of such outgassing is unlikely). It will also make additional searches for rings around Ultima. Four hours after the flyby, the spacecraft will turn briefly to Earth to report that the flyby was successful. A few hours after that, it will begin the roughly 2-year process of downlinking the approximately 7 gigabytes of data acquired during the flyby.



New Horizons' cameras, imaging spectrometers and radio science experiment are the busiest members of the payload during close-approach operations. New Horizons will send high-priority images and data back to Earth in the days surrounding closest approach; placed among the data returns is a status check – a "phone home signal" from the spacecraft, about 10 hours after the flyby, indicating its condition. That signal will need just over 6 hours, traveling at light speed, to reach Earth. (NASA/JHUAPL/SwRI)

Science Objectives at Ultima Thule

Group 1 objectives (highest priority):

- Characterize the global geology and morphology
- Map surface composition
- Search for satellites and rings

Group 2 objectives (medium priority):

- Constrain composition/magnitude of any volatile/dust escape
- Determine physical and photometric properties of the surface
- Determine crater size/frequency distributions
- Characterize any satellites and rings

Group 3 objectives (lowest priority):

- Constrain bulk parameters (mass, density)
- Characterize scattering properties of any satellites and rings
- Perform supplementary compositional studies
- Determine/constrain microwave scattering properties

After Ultima

Following the flyby of Ultima Thule, New Horizons will continue studying the Kuiper Belt through at least April 2021, the end of its currently funded extended mission operations.

It will take about 20 months, through September 2020, to return all the Ultima Thule flyby data to Earth. But even while doing that, the spacecraft will observe more Kuiper Belt objects (KBOs) with its telescopic, onboard LORRI. These images will be used to study the rotation rates and surface properties of these KBOs, and to search for satellite systems around them. New Horizons will also continue to use its space plasma and dust sensors to map the charged-particle radiation and dust environment in the Kuiper Belt, out to a distance 50 times as far from the Sun as the Earth is, just past the outer limits of Pluto's orbit. At the same time, New Horizons will map the interplanetary hydrogen gas, from the solar wind, that fills the Kuiper Belt. These studies will improve on what the legendary Voyager spacecraft could do when they traversed this region, because the sensors on New Horizons are much more advanced than the 1970s-era Voyager technology.

The spacecraft is healthy and has power and fuel to operate until sometime in the 2030s. New Horizons will be in the Kuiper Belt until the late 2020s. In 2020, the New Horizons team will propose a second Kuiper Belt extended mission to NASA.

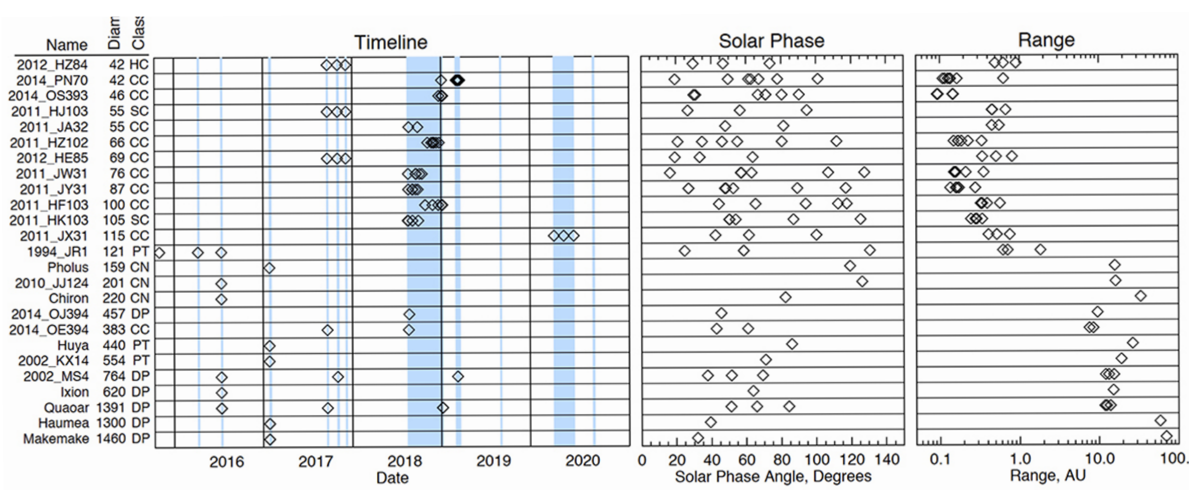
Other KEM Science: A Unique Perspective

New Horizons is not just a mission to Pluto and Ultima Thule. As NASA's only observatory in the Kuiper Belt, New Horizons is making observations of "distant" Kuiper Belt objects (KBOs) at viewing geometries inaccessible from Earth.

Why is this important? One of the ways that scientists learn about the small-scale physical characteristics of planetary surfaces comes from looking at them at different viewing angles. Astronomers refer to the angle between the Sun, the target (the KBO) and the telescope (LORRI) as the "solar phase angle." Being able to measure reflected sunlight from a KBO's surface, from "full moon" to "thin crescent," is the best way to determine properties such as surface roughness, porosity and particle transparency.

KBOs are so far away (almost 45 times farther from the Sun than Earth is) that the phase angle never exceeds 2 degrees when viewed from Earth. But New Horizons can observe a much larger range of phase angles and therefore characterize surface properties in the outer solar system like no other observatory can.

New Horizons will also continue to observe distant KBOs at regular intervals, enabling measurement of their rotation periods by determining how often their reflectance changes in repeatable ways, as different surface areas are illuminated. Like Ultima Thule, many distant KBOs observed by New Horizons are likely irregularly shaped and not spherical.



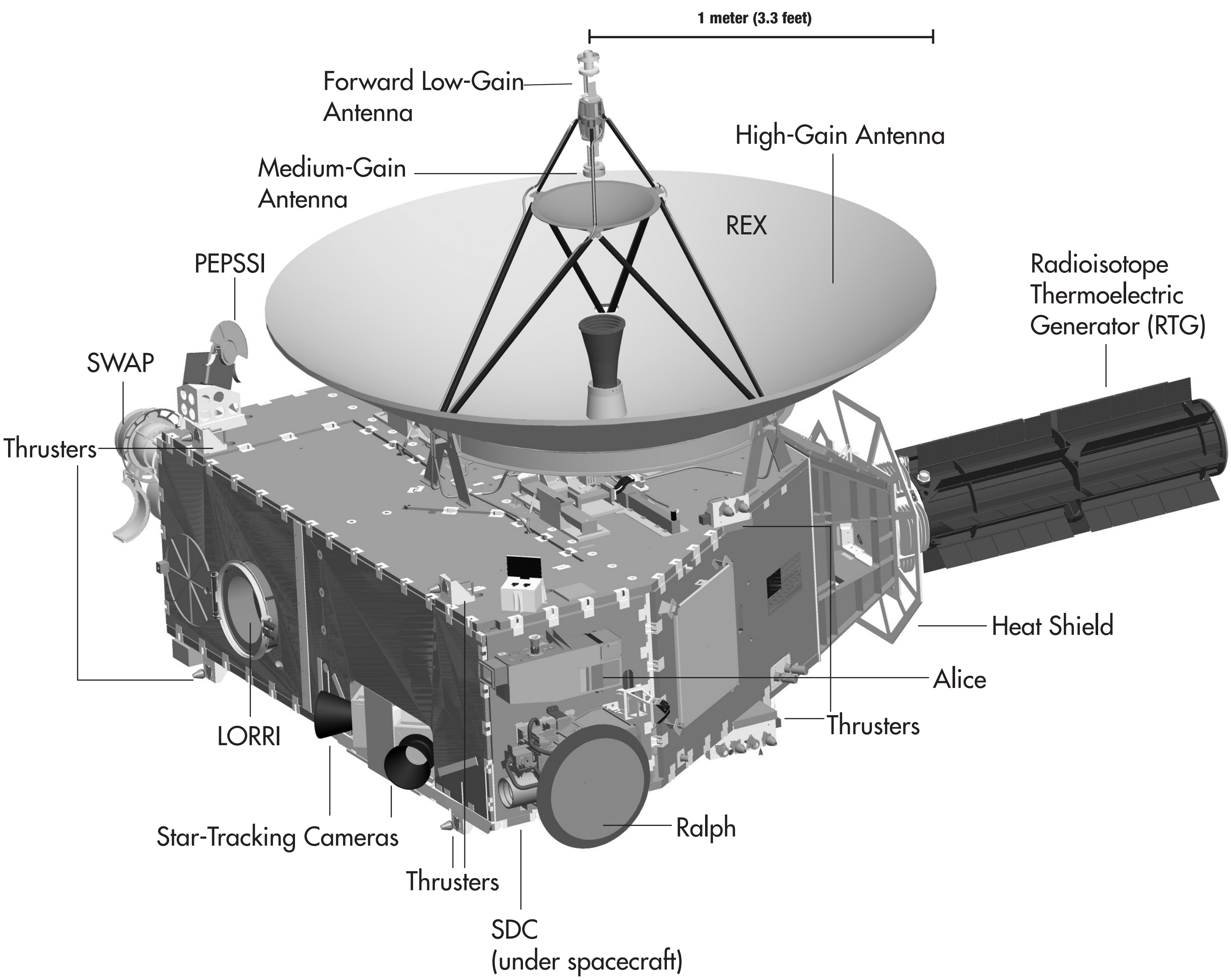
This figure summarizes the extended mission plan to observe distant KBOs. At left are the names and class of the KBOs on the New Horizons observing schedule (HC = Hot Classical, CC = Cold Classical, SC = Scattered, PT = Plutino, CN = Centaur, DP = Dwarf Planet). The diamonds on the timeline indicate planned observation dates, which must occur when the spacecraft is in three-axis/guidance and control mode (shaded blue regions). Panels to the right show the solar phase angle – the angle between the Sun, the observation target and the spacecraft – and the KBO's range from New Horizons in astronomical units (AUs). (Note that 1 AU is the average distance between Earth and the Sun, 93 million miles or 149 million kilometers.)

The New Horizons Spacecraft

Designed and integrated at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland – with contributions from companies and institutions in the United States and abroad – the New Horizons spacecraft is a robust, lightweight observatory that has withstood the long, difficult journey from the launch pad on Earth to the solar system's coldest, darkest frontiers.

The New Horizons science payload was developed under direction of the Southwest Research Institute (SwRI), with instrument contributions from SwRI, APL, NASA's Goddard Space Flight Center, the University of Colorado, Stanford University and Ball Aerospace Corporation. Fully fueled, the agile, piano-sized probe weighed 1,054 pounds (478 kilograms) at launch. Designed to operate on a limited power source – a single radioisotope thermoelectric generator (RTG) – New Horizons needs less power than two 100-watt light bulbs to perform its Kuiper Belt Extended Mission (KEM).

On average, each of the seven science instruments uses between 2 and 10 watts – about the power of a night light – when turned on. The instruments send data to the two onboard solid-state memory banks, where data are recorded before later playback to Earth. During normal operations, the spacecraft communicates with Earth through its 83-inch (2.1-meter)-wide high-gain antenna. Smaller antennas provide backup communications. When the spacecraft was in hibernation through long stretches of its voyage, its computer was programmed to monitor its systems and report its status back to Earth with a specially coded, low-energy beacon signal.



New Horizons' "thermos bottle" design retains heat and keeps the spacecraft operating at room temperature without large heaters. Aside from protective covers on five instruments that were opened shortly after launch, and one small protective cover opened after the Jupiter encounter, New Horizons uses no deployable mechanisms or scanning platforms. It does have backup devices for all major electronics, its star-tracking navigation cameras and data recorders.

New Horizons has operated mostly in a spin-stabilized mode while cruising between planets, and also in a three-axis "pointing" mode that allows for pointing or scanning instruments during calibrations and planetary encounters (like the Jupiter flyby and, of course, at Pluto). Small thrusters in the propulsion system handle pointing, spinning and course corrections. The spacecraft navigates using onboard gyros, star trackers and Sun sensors. The spacecraft's high-gain antenna dish is linked to advanced electronics and shaped to receive even the faintest radio signals from home – a necessity when the primary mission's main target was more than 3 billion miles (4.83 kilometers) from Earth and light itself took more than 4.5 hours to go from Earth to the spacecraft.

Structure

New Horizons' primary structure includes an aluminum central cylinder that supports the spacecraft body panels, supports the interface between the spacecraft and its RTG power source, and houses the propellant tank. It also served as the payload adapter fitting that connected the spacecraft to the launch vehicle.

Keeping mass down, the panels surrounding the central cylinder feature an aluminum honeycomb core with ultra-thin aluminum face sheets (about as thick as two pieces of paper). To keep it perfectly balanced for spinning operations, the spacecraft was weighed and then balanced with additional weights just before mounting on the launch vehicle.

Command and Data Handling

The Command and Data Handling system – a radiation-hardened 12-megahertz Mongoose V processor guided by intricate flight software – is the spacecraft's "brain." The processor distributes operating commands to each subsystem, collects and processes instrument data, and sequences information sent back to Earth. It also runs the advanced "autonomy" algorithms that allow the spacecraft to check the status of each system and, if necessary, correct any problems, switch to backup systems or contact operators on Earth for help.

For data storage, New Horizons carries two low-power solid-state recorders (one backup) that can hold up to 8 gigabytes each. The main processor collects, compresses, reformats, sorts and stores science and housekeeping (telemetry) data on the recorder – similar to a flash memory card for a digital camera – for transmission to Earth through the telecommunications subsystem.

The Command and Data Handling system is housed in an Integrated Electronics Module that also contains a vital guidance computer, the communication system and part of the Radio Science Experiment (REX) instrument.

Thermal Control

New Horizons is designed to retain heat like a thermos bottle. The spacecraft is covered in lightweight, gold-colored, multilayered thermal insulation – like a survival camping blanket – which holds in heat from operating electronics to keep the spacecraft warm. Heat from the electronics has kept the spacecraft operating at between about 50–85 degrees Fahrenheit (about 10–30 degrees Celsius) throughout the journey.

New Horizons' sophisticated, automated heating system monitors power levels inside the craft to make sure the electronics are running at enough wattage to maintain safe temperatures. Any drop below that operating level (about 150 watts) and it will activate small heaters around the craft to make up the difference. When the spacecraft was closer to Earth and the Sun, louvers (essentially heat vents) on the craft opened when internal temperatures were too high.

The thermal blanketing – 18 layers of Dacron mesh cloth sandwiched between aluminized Mylar and Kapton film – also helps to protect the craft from micrometeorites.

Propulsion

The propulsion system on New Horizons is used for course corrections and for pointing the spacecraft. It is not needed to speed the spacecraft along its trajectory to Ultima Thule and beyond; that was done by the launch vehicle, with a boost from Jupiter's gravity. But it does make small corrections to the flight path and tiny changes to the speed to ensure that New Horizons arrives when and where it can make the best observations. For example, after the Pluto encounter, it changed the trajectory very slightly to go to Ultima Thule.

The New Horizons propulsion system includes 16 small hydrazine-propellant thrusters mounted across the spacecraft in eight locations, a fuel tank and associated distribution plumbing. Four of these thrusters, each of which provides 1 pound (4.4 Newtons) of force are used for course corrections. Operators also employ 12 smaller thrusters – each providing about 3 ounces (0.8 Newtons) of thrust – to point, spin up and spin down the spacecraft. Eight of the 16 thrusters aboard New Horizons are considered the primary set; the other eight comprise the backup (redundant) set.

At launch, the spacecraft carried 170 pounds (77 kilograms) of hydrazine, stored in a lightweight titanium tank. Helium gas pushes fuel through the system to the thrusters. The Jupiter gravity assist, and the mission design calling for flybys at Pluto and Ultima Thule (instead of entries into orbit), reduced the amount of propellant needed for the mission. At the end of the KEM, New Horizons is expected to have about 24 pounds (11 kilograms) of fuel remaining—this is about equivalent to the amount of fuel it took to target the Ultima Thule flyby.

Guidance and Control

New Horizons must be oriented precisely to collect data with its scientific instruments, communicate with Earth, or maneuver through space.

Attitude determination – knowing which direction New Horizons is facing – is performed using star-tracking cameras, Inertial Measurement Units (IMUs) (containing sophisticated gyroscopes and accelerometers that measure rotation and horizontal/vertical motion) and digital Sun sensors. Attitude control for the spacecraft – whether in a steady, three-axis pointing mode or in a spin-stabilized mode – is accomplished by using thrusters.

The IMUs and star trackers provide constant positional information to the spacecraft's Guidance and Control processor, which like the Command and Data Handling processor is a 12-megahertz Mongoose V. New Horizons carries two copies of each of these units for redundancy. The star-tracking cameras store a map of about 3,000 stars; 10 times per second one of the cameras snaps a wide-angle picture of space, compares the locations of the stars to its onboard map, and calculates the spacecraft's orientation. The IMU measures spacecraft angular rates 100 times a second. If data shows New Horizons is outside a predetermined position, small hydrazine thrusters will fire to reorient the spacecraft. The Sun sensors back up the star trackers; they would find and point New Horizons toward the Sun (with Earth nearby) if the other sensors couldn't find home in an emergency.

Operators use thrusters to maneuver the spacecraft, which has no internal reaction wheels. Its smaller thrusters are used for fine pointing; thrusters that are approximately five times more powerful are used during the trajectory course maneuvers that guide New Horizons toward its targets. New Horizons spins – typically at 5 revolutions per minute – during trajectory-correction maneuvers and long radio contacts with Earth, and while it "hibernates" during long cruise periods. Operators steady and point the spacecraft during science observations and instrument-system checkouts.

Communications

New Horizons' X-band communications system is the spacecraft's link to Earth, returning science data, exchanging commands and status information, and allowing for precise radiometric tracking through NASA's Deep Space Network of antenna stations.

The system includes two broad-beam, low-gain antennas on opposite sides of the spacecraft, which were used early in the mission for near-Earth communications, as well as a 12-inch (30-centimeter) diameter medium-gain dish antenna and a large, 83-inch (2.1-meter) diameter high-gain dish antenna. The antenna assembly on the spacecraft's top deck consists of the high, medium, and forward low-gain antennas; this stacked design provides a clear field of view for the low-gain antenna and structural support for the high and medium-gain dishes. Operators aim the antennas by turning the spacecraft toward Earth. The high-gain beam is only 0.3 degrees wide, so it must point directly at Earth. The wider medium-gain beam (4 degrees) is used in conditions when the pointing might not be as accurate. All antennas have right-hand circular and left-hand circular polarization feeds.

Data rates depend on spacecraft distance, the power used to send the data and the size of the antenna on the ground. For most of the mission, New Horizons has used its high-gain antenna to exchange data with the Deep Space Network's largest antennas, 230 feet (70 meters) across. Even at Ultima, because New Horizons will be more than 4 billion miles (6.4 billion kilometers) from Earth and radio signals will take more than 6 hours to reach the spacecraft, it can send information at about 1,000 bits per second. It will take 20 months to send the full set of Ultima flyby science data back to Earth.

New Horizons is flying the most advanced digital receiver ever used for deep-space communications. Advances include regenerative ranging and low power – the receiver consumes 66 percent less power than earlier deep-space receivers. The REX that examined Pluto’s atmosphere is also integrated into the communications subsystem.

The entire telecom system on New Horizons is redundant, with two of everything except the high-gain antenna structure itself.

Accurate Ranging

New Horizons is the first mission to use onboard regenerative ranging to track the distance between the spacecraft and Earth. When a spacecraft is far from home, the ranging tone sent from the ground to measure distance is weak (or “noisy”) by the time it reaches the spacecraft’s communications system. In normal ranging, the spacecraft simply amplifies and sends the noisy tone back to Earth, which adds errors to the range measurement. In regenerative ranging, the spacecraft’s advanced electronics track and “regenerate” the tone without the noise. The ground station on Earth receives a much clearer signal – giving navigators and operators a more accurate lock on the spacecraft’s distance, and improving their ability to guide New Horizons through the solar system.

Power

New Horizons’ electrical power comes from a single RTG. The RTG provides power through the natural radioactive decay of plutonium dioxide fuel, which creates a huge amount of heat. Unlike a normal reactor, the plutonium-238 used in the RTG cannot undergo a chain reaction. But, its normal decay rate is high enough (that is, its half-life is short enough) that it always releases heat at a high rate. That heat is converted directly to electrical power by thermocouples.

The New Horizons RTG, provided by the U.S. Department of Energy, carries approximately 24 pounds (11 kilograms) of plutonium dioxide. Onboard systems manage the spacecraft’s power consumption so it doesn’t exceed the steady output from the RTG, which has decreased by about 3.5 watts per year since launch.

Typical of RTG-based systems, as on past outer-planet missions, New Horizons does not have a battery for storing power.

At the start of the mission, the RTG supplied approximately 245 watts (at 30 volts, direct current) – the spacecraft’s shunt regulator unit maintains a steady input from the RTG and dissipates power the spacecraft cannot use at a given time. By January 2019 (when New Horizons flies past Ultima Thule) that supply will have decreased to about 190 watts at the same voltage, so New Horizons will ease the strain on its limited power source by cycling science instruments during the encounter.

The spacecraft’s fully redundant Power Distribution Unit (PDU) – with 96 connectors and more than 3,200 wires – efficiently moves power through the spacecraft’s vital systems and science instruments.

The New Horizons Mission Operations Center at the Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland. (NASA/JHUAPL/SwRI)

Sending Commands to the Spacecraft

All commands sent to New Horizons must pass a rigorous development and review process to ensure the safety of the spacecraft. The mission operations team works closely with the instrument, science and spacecraft teams to develop the commands that perform New Horizons' activities. After the command sequences are tested on a New Horizons simulator, the New Horizons Mission Operations Center at the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland, sends them to the Deep Space Network (DSN), which is operated and managed by the Jet Propulsion Laboratory in Pasadena, California.

Ground Stations

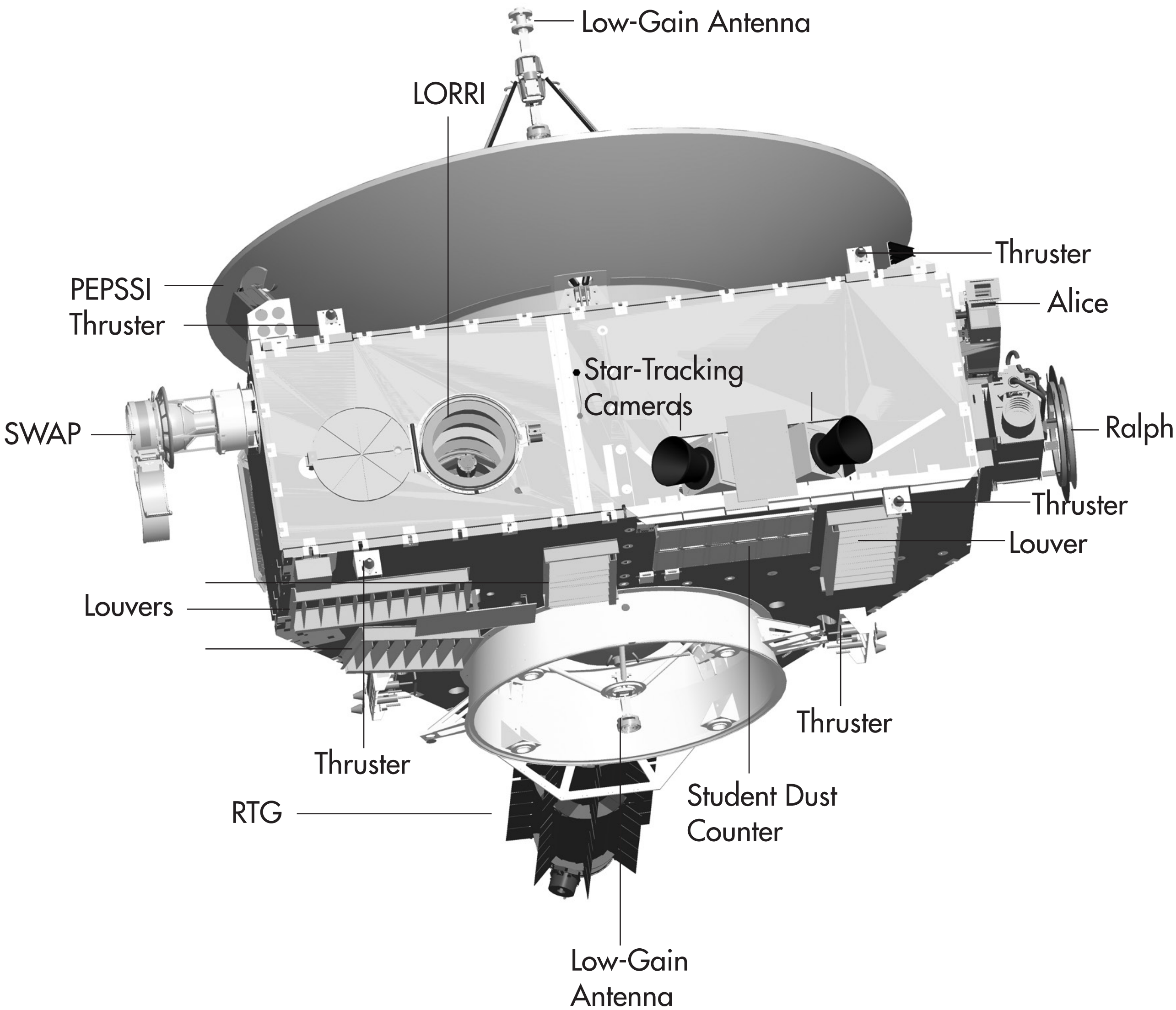
You need pretty large antennas to send data over billions of miles – and fortunately, NASA has them. The New Horizons mission operations team communicates with the spacecraft through NASA's DSN antenna stations. The DSN consists of facilities in California's Mojave Desert (pictured here); near Madrid, Spain; and near Canberra, Australia. These stations are separated in longitude by about 120 degrees, assuring that any spacecraft can be observed without interruption as Earth rotates.

Deep Space Network (DSN) antennas at NASA's Goldstone DSN complex in California. (NASA)

Science Instruments

The New Horizons science payload consists of seven instruments – three optical instruments, two plasma instruments, a dust sensor and a radio science receiver/radiometer. This payload was designed to investigate the global geology; the surface composition and temperature; and the atmospheric pressure, temperature and escape rate of Pluto and its moons. The payload is now being used to explore the Kuiper Belt object (KBO) Ultima Thule, the most distant object ever targeted for a flyby.

The payload is incredibly power efficient – with the instruments collectively drawing less than 28 watts – and represents a degree of miniaturization that is unprecedented in planetary exploration. The instruments were designed specifically to handle the cold conditions and low light levels in the Kuiper Belt.



Alice

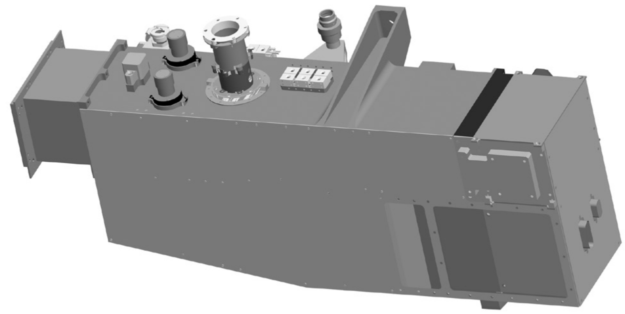
MASS: 9.9 pounds (4.5 kilograms)

AVERAGE POWER: 4.4 watts

DEVELOPMENT: Southwest Research Institute (SwRI)

PRINCIPAL INVESTIGATOR: Alan Stern, SwRI

PURPOSE: Study atmospheric composition and structure



Alice is a sensitive ultraviolet imaging spectrometer designed to probe the composition and structure of Pluto's dynamic atmosphere. Where a spectrometer separates light into its constituent wavelengths (like a prism), an "imaging spectrometer" both separates the different wavelengths of light and produces an image of the target at each wavelength. Alice's spectroscopic range extends across both extreme and far-ultraviolet wavelengths from approximately 500 to 1,800 angstroms. The instrument detected a variety of gases in Pluto's atmosphere and determined their relative abundances, giving scientists the first complete picture of Pluto's atmospheric composition. Alice set tight upper limits on the maximum density of any ionosphere around Pluto and on that of any atmosphere around Pluto's largest moon, Charon. It will now search for any atmosphere or exosphere around Ultima Thule.

Alice consists of a compact telescope, a spectrograph and a sensitive electronic detector with 1,024 spectral channels at each of 32 separate spatial locations in its long, rectangular field of view. Alice has two modes of operation: an "airglow" mode that measures ultraviolet emissions from atmospheric constituents and an "occultation" mode, where it views the Sun or a bright star through an atmosphere and detects atmospheric constituents by the amount of sunlight they absorb. Absorption of sunlight by the atmosphere at Pluto (or Ultima Thule, if it has one) showed up as characteristic "dips" and "edges" in the ultraviolet part of the spectrum of light that Alice measured. This technique is a powerful method for measuring even traces of atmospheric gas.

A first-generation version of New Horizons' Alice (smaller and a bit less sophisticated) flew aboard the European Space Agency's Rosetta spacecraft, used to explore the escaping atmosphere and complex surface of a comet. Later versions are flying or scheduled to fly aboard LRO, Juno, JUICE and Europa Clipper.

Ralph

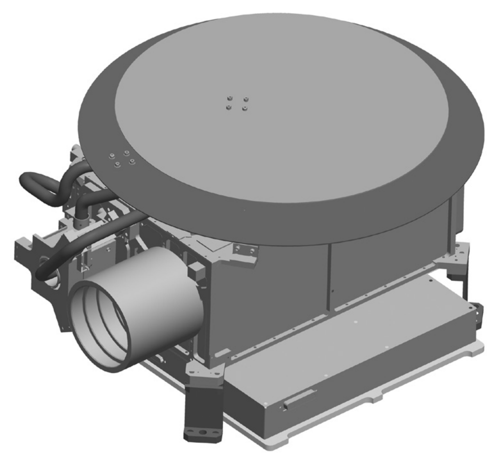
MASS: 22.7 pounds (10.3 kilograms)

AVERAGE POWER: 6.3 watts

DEVELOPMENT: Ball Aerospace Corporation, NASA Goddard Space Flight Center, Southwest Research Institute (SwRI)

PRINCIPAL INVESTIGATOR: Cathy Olkin, SwRI

PURPOSE: Study surface geology and morphology; obtain surface composition and surface temperature maps



Ralph, the main "eyes" of New Horizons, is charged with making the maps that show what Pluto, its moons and other KBOs look like. (The instrument is so named because it's coupled with the Alice ultraviolet spectrometer in the New Horizons remote-sensing package – a reference familiar to fans of "The Honeymooners" TV show.)

Ralph consists of three panchromatic (black-and-white) and four color imagers inside its Multispectral Visible Imaging Camera (MVIC), as well as an infrared compositional mapping spectrometer called the Linear Etalon Imaging Spectral Array (LEISA). LEISA is an advanced, miniaturized short-wavelength infrared (1.25–2.50 micron) spectrometer provided by scientists from NASA's Goddard Space Flight Center. MVIC operates over the bandpass from 0.4 to 0.95 microns. Ralph's suite of eight detectors – seven charge-coupled devices like those found in a digital camera, and a single infrared array detector – are fed by a single, sensitive magnifying telescope with a resolution more than 10 times better than the human eye can see. The entire package operates on less than half the wattage of an appliance light bulb.

Ralph took images at increasing frequency as New Horizons approached, flew past, and then looked back at the Pluto system. The MVIC images helped scientists to map landforms in black-and-white and color with a best resolution of about 820 feet (250 meters) per pixel, create stereo images to determine surface topography, and refine the radii and orbits of Pluto and its moons. It found clouds and hazes in Pluto's atmosphere, and searched for rings and additional satellites around Pluto. It also obtained images of Pluto's night side, illuminated by "Charon-light." At the same time, LEISA mapped the amounts of nitrogen, methane, carbon monoxide, and frozen water and other materials, including organic compounds, across the sunlit surfaces of Pluto and its moons.

It also let scientists map surface temperatures across Pluto and Charon by sensing the spectral features of frozen nitrogen, water ice and carbon monoxide. At Ultima, Ralph will map the surface in color, map the surface composition, and search for moons and rings.

Radio Science Experiment (REX)

MASS: 3.5 ounces (100 grams)

AVERAGE POWER: 2.1 watts

DEVELOPMENT: Johns Hopkins University Applied Physics Laboratory, Stanford University

PRINCIPAL INVESTIGATORS: Ivan Linscott, retired from Stanford University

PURPOSE: Measure atmospheric temperature and pressure (down to the surface); measure density of the ionosphere; search for atmospheres around Charon and other KBOs

REX consists only of a small printed circuit board containing sophisticated signal-processing electronics integrated into the New Horizons telecommunications system. Because the telecom system is redundant within New Horizons, the spacecraft carries two copies of REX. Both can be used simultaneously to improve the data return from the radio science experiment.

REX used an occultation technique to probe Pluto's atmosphere and to search for an atmosphere around Charon. After New Horizons flew by Pluto, its 83-inch (2.1-meter) dish antenna pointed back at Earth. On Earth, powerful transmitters in NASA's largest Deep Space Network antennas beamed radio signals to the spacecraft as it passed behind Pluto. The radio waves bent according to the average molecular weight of gas in the atmosphere and the atmospheric temperature.

Space missions typically conduct this type of experiment by sending a signal from the spacecraft through a planet's atmosphere and back to Earth. (This is called a "downlink" radio experiment.) New Horizons was the first to use a signal from Earth – the spacecraft was so far from home and moving so quickly past Pluto and Charon that only a large, ground-based antenna could provide a strong enough signal. This new technique, called an "uplink" radio experiment, is an important advance beyond previous outer planet missions.

At Ultima, scientists will use REX data to derive accurate globally averaged dayside and nightside temperature measurements, measure Ultima's mass, and attempt to measure its radar reflectivity.

Long Range Reconnaissance Imager (LORRI)

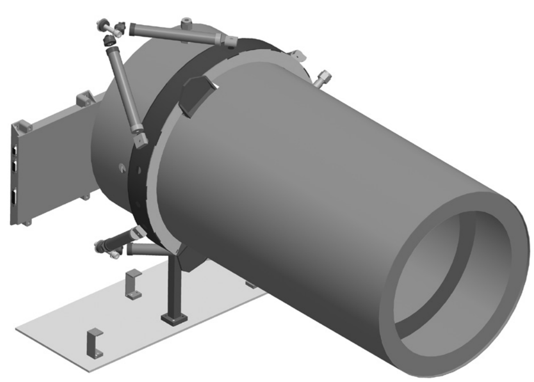
MASS: 19.4 pounds (8.8 kilograms)

AVERAGE POWER: 5.8 watts

DEVELOPMENT: Johns Hopkins University Applied Physics Laboratory (APL)

PRINCIPAL INVESTIGATOR: Hal Weaver, APL

PURPOSE: Study geology; provide high-resolution approach and highest-resolution encounter images



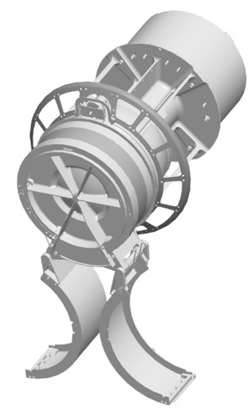
LORRI, the "eagle eyes" of New Horizons, is a panchromatic high-magnification imager, consisting of a telescope with an 8.2-inch (20.8-centimeter) aperture that focuses visible light onto a charge-coupled device. It's essentially a digital camera with a large telephoto telescope – only fortified to operate in the cold, hostile environs near Pluto and beyond.

LORRI has no color filters or moving parts – operators take images by pointing the LORRI side of the spacecraft directly at their target. The instrument's innovative silicon carbide construction keeps it focused through the extreme temperature dips New Horizons has experienced on the way to and through the Kuiper Belt.

LORRI images were New Horizons' first of the Pluto system, starting about 180 days before closest approach, when Pluto and its moons still resembled little more than bright dots. Approximately 100 days before closest approach – in April 2015 – LORRI images began to surpass Hubble-quality resolution, providing never-before-seen details each day. At closest approach, LORRI imaged select sections of Pluto's sunlit surface at football-field-size resolution, resolving features at about 164 feet (50 meters) across.

This range of images gave scientists an unprecedented look at the geology on Pluto and its moons – including the number and size of craters on each surface, revealing the history of impacting objects in that distant region. LORRI also yielded important information on the history of Pluto's surface, searched for activity such as geysers on that surface, and looked for hazes in Pluto's atmosphere. LORRI is also providing the highest resolution and sensitivity images of many KBOs as New Horizons passes them in the extended mission. At Ultima, LORRI will be used to map the KBO in greatest detail, and to research for moons and rings.

Solar Wind Around Pluto (SWAP)



MASS: 7.3 pounds (3.3 kilograms)

AVERAGE POWER: 2.3 watts

DEVELOPMENT: Southwest Research Institute

PRINCIPAL INVESTIGATOR: David McComas, Princeton University

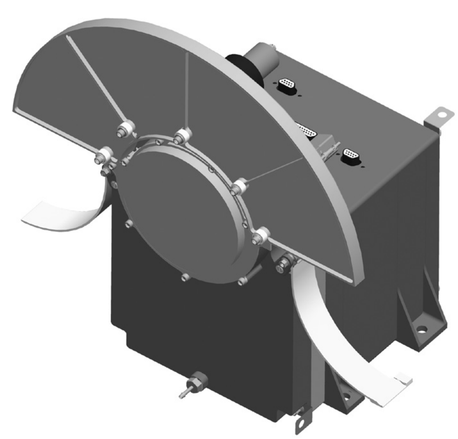
PURPOSE: Study solar wind interactions and atmospheric escape

The SWAP instrument measured interactions of Pluto with the solar wind – the stream of fast charged particles flowing from the Sun. The incredible distance of Pluto from the Sun required the SWAP team to build the largest-aperture instrument ever used to measure the solar wind.

The atmospheric gases that escape Pluto's weak gravity leave the planet as neutral atoms and molecules. These atoms and molecules are ionized by ultraviolet sunlight (similar to Earth's upper atmosphere and ionosphere). Once they become electrically charged, the ions and electrons are "picked up" and carried away by the solar wind. In the process, these pickup ions gain substantial energy (thousands of electron-volts). This energy comes from the solar wind, which is correspondingly slowed down and diverted around Pluto. SWAP measures low-energy interactions, such as those caused by the solar wind. By measuring how the solar wind is perturbed by the interaction with Pluto's escaping atmosphere, SWAP helped to determine the escape rate of atmospheric material from Pluto.

At the top of its energy range SWAP can detect some pickup ions (up to 6.5 kiloelectron volts, or keV). SWAP combines a retarding potential analyzer (RPA) with an electrostatic analyzer (ESA) to enable extremely fine, accurate energy measurements of the solar wind, allowing New Horizons to measure minute changes in solar wind speed. The amount of Pluto's atmosphere that escapes into space provides critical insights into the structure and destiny of the atmosphere itself. SWAP will perform similar science at Ultima.

Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI)



MASS: 3.3 pounds (1.5 kilograms)

AVERAGE POWER: 2.5 watts

DEVELOPMENT: Johns Hopkins University Applied Physics Laboratory (APL)

PRINCIPAL INVESTIGATOR: Ralph McNutt Jr., APL

PURPOSE: Study the density, composition, and nature of energetic particles and plasmas resulting from the escape of Pluto's atmosphere

PEPSSI, the most compact, lowest-power directional energetic particle spectrometer flown on a space mission, searched for neutral atoms that escape Pluto's atmosphere and become charged by their interaction with the solar wind. It detected the material that escapes from Pluto's atmosphere (such as molecular nitrogen, carbon monoxide and methane), which breaks up into ions and electrons after absorbing the Sun's ultraviolet light, and streams away from Pluto as "pickup" ions carried by the solar wind.

PEPSSI is a classic "time-of-flight" particle instrument: particles enter the detector and knock other particles (electrons) from a thin foil; they zip toward another foil before hitting a solid-state detector. The instrument clocks the time between the foil collisions to tell the particle's speed (measuring its mass) and figures its total energy when it collides with the solid-state detector. From this, scientists can determine the composition of each particle. PEPSSI can measure energetic particles up to 1,000 kiloelectron volts (keV), many times more energetic than what SWAP can measure. Together the two instruments made a powerful combination for studying the Pluto system.

By using PEPSSI data to count particles, and knowing how far New Horizons was from Pluto at a given time, scientists were able to tell how quickly the planet's atmosphere is escaping and gain new information about what the atmosphere is made of.

PEPSSI will perform similar science at Ultima.

Venetia Burney Student Dust Counter (SDC)

MASS: 4.2 pounds (1.9 kilograms)

AVERAGE POWER: 5 watts

DEVELOPMENT: Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder

PRINCIPAL INVESTIGATOR: Mihaly Horanyi, University of Colorado at Boulder

PURPOSE: Measure concentration of dust particles in outer solar system

Designed and built by students at the University of Colorado at Boulder, the SDC detects microscopic dust grains produced by collisions among asteroids, comets and even KBOs during New Horizons' long journey. Officially a New Horizons Education and Public Outreach project, SDC is the first science instrument on a NASA planetary mission to be designed, built and "flown" by students. The SDC counts and measures the sizes of dust particles, producing information on the collision rates of such bodies in the outer solar system. At Pluto, SDC was also used to search for dust that might be generated by collisions of tiny "impactors" on Pluto's small moons.

The instrument includes two major pieces: an 18-by-12-inch detector assembly, which is mounted on the outside of the spacecraft and exposed to the dust particles; and an electronics box inside the spacecraft that, when a hit occurs on the detector, deciphers the data and determines the mass and speed of the particle. Because no dust detector has ever operated beyond 18 astronomical units from the Sun (nearly 1.7 billion miles, or 2.7 billion kilometers, about the distance from Uranus to the Sun), SDC data is giving scientists an unprecedented look at the sources and transport of dust in the solar system.

With faculty support, University of Colorado students have been distributing and archiving data from the instrument, and they lead a comprehensive education and outreach effort to bring their results and experiences to classrooms of all grades.

In June 2006, the instrument was named for Venetia Burney, who at age 11 offered the name "Pluto" for the newly discovered ninth planet in 1930.

At Ultima, SDC will search for orbiting dust associated with the KBO.

New Horizons Mission Management

As principal investigator (PI), Alan Stern, of the Southwest Research Institute's (SwRI) Boulder, Colorado, operation, leads the New Horizons mission. The Johns Hopkins University Applied Physics Laboratory (APL), Laurel, Maryland, manages the New Horizons mission for the Science Mission Directorate, NASA Headquarters, Washington, D.C.

At NASA Headquarters, Thomas Zurbuchen is the associate administrator for the Science Mission Directorate, and Lori Glaze is the acting director of the Planetary Science Division. Curt Niebur is the New Horizons program scientist, and Adriana Ocampo is the New Horizons program executive. At NASA's Marshall Space Flight Center, Huntsville, Alabama, R. Brian Key is acting Planetary Missions program manager, and James Lee is New Horizons mission manager.

At APL, Helene Winters is the New Horizons project manager, Carl Engelbrecht is deputy project manager, and Harold Weaver is New Horizons project scientist. Mark Holdridge is encounter mission manager, Alice Bowman is mission operations manager, Chris Hersman is mission systems engineer, Yanping Guo is mission design team lead, and Kerri Beisser is education and communications manager. Michael Ryschkewitsch is the head of the APL Space Exploration Sector, and Ralph Semmel is the director of APL.

At SwRI in Boulder, Cathy Olkin and John Spencer are New Horizons deputy project scientists, and Cindy Conrad directs the office of the PI. At SwRI in San Antonio, John Andrews is New Horizons SwRI project manager, and John Scherrer is deputy project manager. Jim Burch is vice president of the Space Science and Engineering Division, and Adam Hamilton is the president and CEO of SwRI.

Fred Pelletier leads the project navigation team at KinetX Inc., Simi Valley, California.

New Horizons science team members get their first close-up look at Pluto on the early morning of July 14, 2015 – and immediately begin their analyses. (Michael Soluri)

The New Horizons Science Team

Principal Investigator
Alan Stern
Southwest Research Institute

Project Scientist
Hal Weaver
Johns Hopkins University Applied Physics Laboratory

Deputy Project Scientists
Cathy Olkin, Southwest Research Institute
John Spencer, Southwest Research Institute

Assistant Project Scientists
Joel Parker, Southwest Research Institute
Anne Verbiscer, University of Virginia

Co-Investigators
Rick Binzel
Massachusetts Institute of Technology

Daniel Britt
University of Central Florida

Marc Buie
Southwest Research Institute

Bonnie Buratti
NASA Jet Propulsion Laboratory

Andy Cheng
Johns Hopkins University Applied Physics Laboratory

Dale Cruikshank
NASA Ames Research Center

Heather Elliott
Southwest Research Institute

Randy Gladstone
Southwest Research Institute

Will Grundy
Lowell Observatory

Matt Hill
Johns Hopkins University Applied Physics Laboratory

Mihaly Horanyi
University of Colorado

Don Jennings
NASA Goddard Space Flight Center

Ivan Linscott
Stanford University (retired)

Jeff Moore
NASA Ames Research Center

Dave McComas
Southwest Research Institute

JJ Kavelaars
University of Victoria, Canada

William McKinnon
Washington University in St. Louis

Ralph McNutt
Johns Hopkins University Applied Physics Laboratory

Cathy Olkin
Southwest Research Institute

Alex Parker
Southwest Research Institute

Joel Parker
Southwest Research Institute

Simon Porter
Southwest Research Institute

Silvia Protopapa
Southwest Research Institute

Dennis Reuter
NASA Goddard Space Flight Center

Paul Schenk
Lunar and Planetary Institute

Kelsi Singer
Southwest Research Institute

John Spencer
Southwest Research Institute

Mark Showalter
SETI Institute

Anne Verbiscer
University of Virginia

Hal Weaver
Johns Hopkins University Applied Physics Laboratory

Leslie Young
Southwest Research Institute

Amanda Zangari
Southwest Research Institute

Theme Team Leads

Geology & Geophysics Investigation
Jeff Moore
Deputies: John Spencer, William McKinnon

Composition
Will Grundy
Deputy: Dale Cruikshank

Particles & Atmospheres
Randy Gladstone
Deputies: Leslie Young, Heather Elliot

Kuiper Extended Mission Planning
John Spencer
Deputy: Anne Verbiscer

A New Year
New Worlds
New Horizons