Pluto at Last

After a 9½-year flight, NASA's New Horizons spacecraft is making a long-awaited visit to Pluto and its moons.

Emily Lakdawalla

Beyond any planet that's ever been explored before lies the frozen "Third Zone" of the solar system: the Kuiper Belt. It's dark, cold, and sluggish, a place so remote that its small, icy inhabitants take hundreds of years to complete a single orbit of the distant, dim Sun. We've only seen a handful of Kuiper Belt objects from Earth — and none of those as anything more than vague smudges. But after nearly a decade of interplanetary travel, NASA's New Horizons spacecraft is about to change the status quo. Now we're about to see, up close, the region's most famous member: Pluto.

New Horizons is not the first spacecraft to traverse this region of space, but it will be the first to study any of its denizens. The spacecraft follows a trail blazed by four others — twin pairs of Pioneers and Voyagers — that are well on their way to escaping our solar system entirely. Yet New Horizons is "less" in every way than its predecessors: a smaller vehicle, smaller data volume, smaller instrument package, and a price tag only 40% that of the Voyager mission.

NASA

FAST START Propelled by an Atlas V rocket, New Horizons left Earth on January 19, 2006, and attained 58,537 km (36,373 miles) per hour — so fast that the spacecraft reached the Moon's orbit only 9 hours after its launch.

Nor will it be the first craft to study a dwarf planet. That distinction goes to Dawn, which started orbiting asteroid 1 Ceres in March and has settled in for a year-long mission there (*S&T:* Apr. 2015, p. 20).

For New Horizons, orbiting Pluto will be impossible — like the Pioneers and Voyagers, New Horizons is a flyby mission. At 11:50 Universal Time on July 14, 2015, it will zip past Pluto at nearly 14 kilometers (8.6 miles) per second, never to return. And although it will gather observations throughout most of 2015, all of its highest-priority reconnaissance is squeezed into a 48-hour period around closest approach. How much can such a constrained spacecraft accomplish in only two days of work? Will it be worth the 9½-year wait?

A Challenging Assignment

The mission's highest-priority goals are to map the global geology of Pluto and its moon Charon, to determine their surface composition, and to study Pluto's wispy atmosphere. The target system's configuration presents several challenges that make New Horizons' task harder than it might otherwise be. For one thing, Pluto's spin axis is tilted sideways, much like that of Uranus. So, just as Voyager 2 saw only half of the planet

LONG TIME COMING No one knows what NASA's New Horizons spacecraft will find when it views Pluto and its moons up close for the first time, but the July 14th flyby is certain to be exciting.

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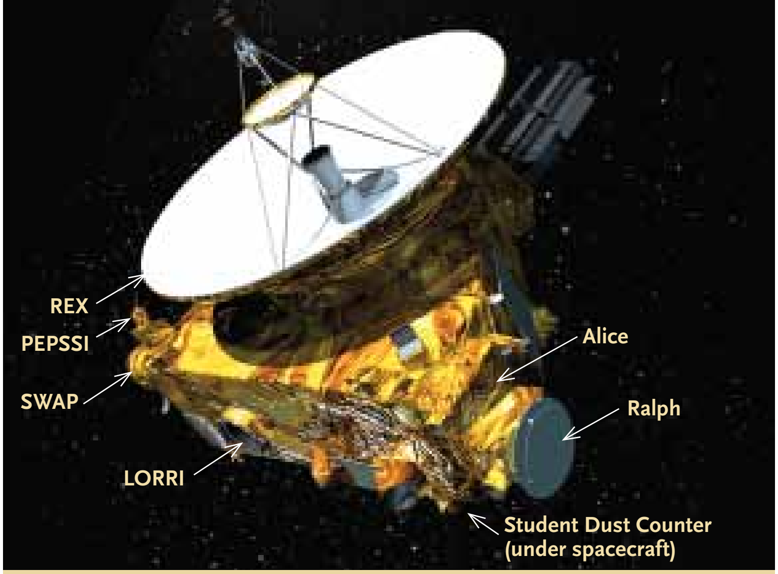
New Horizons' Instrument Payload



NASA / JHU-APL

Ralph MVIC (Multicolor Visible Imaging Camera): Combines medium-resolution panchromatic imager and moderate-resolution color imaging through blue, red, methane, and near-infrared filters.

Ralph LEISA (Linear Etalon Imaging Spectral Array): Near-infrared imaging and spectroscopy; will provide composition and thermal maps.

Alice: Ultraviolet imaging spectrometer; will analyze composition, structure, and escape rate of Pluto's atmosphere and will look for an atmosphere around Charon.

REX (Radio Science Experiment): Uses radio transmissions passing near limbs of Pluto and Charon to measure atmospheric pressure and temperature; also serves as a passive radiometer for studies of surface properties. Careful tracking of Doppler shifts during radio transmissions will refine the masses of Pluto and Charon.

LORRI (Long Range Reconnaissance Imager): Telescopic panchromatic camera with 2.63-m focal length; will obtain images at long distances, search for rings and moonlets, record Pluto's farside, and provide high-resolution geologic data on the hemisphere in sunlight.

SWAP (Solar Wind Around Pluto): Solar wind and plasma spectrometer; will measure the escape rate of atmospheric gases and observe Pluto's interaction with the solar wind.

PEPSSI (Pluto Energetic Particle Spectrometer Science Investigation): Hockey-puck-size time-of-flight mass spectrometer; will measure the composition and density of ions escaping from Pluto's atmosphere.

SDC (Venetia Burney Student Dust Counter): Built and operated by students at University of Colorado; measures interplanetary dust that strikes New Horizons during its long voyage.

during its 1986 flyby of Uranus, New Horizons will stare at one of Pluto's poles throughout approach, with only foreshortened views of the southern hemisphere. The south pole will be hidden in winter darkness.

Pluto and Charon are locked in a mutual spin-orbit resonance with each other and rotate very slowly, only once in 6.4 days. We'll only see one hemisphere of each world sunlit as the spacecraft races past them. The opposite hemispheres will be well lit 3.2 days earlier, when New Horizons is still millions of kilometers away and only barely able to discern detail on their surfaces.

Nor will the spacecraft get a chance to pass close by all of Pluto's other moons. When New Horizons was being designed and built, Pluto had only one known moon: Charon. Then, a year before launch, Hubble Space Telescope photos revealed two smaller siblings orbiting farther out: Nix and Hydra. The discovery of Kerberos (between Nix and Hydra) followed in 2011, and Styx (inside the orbit of Nix) in 2012. The science team has prioritized a single one, Nix, for detailed study; the rest will be relegated to distant views.

The smaller moons have presented a problem to mission planners since their discovery. All five moons experience micrometeoroid impacts relatively often, and the little ones lack sufficient gravity to hang on to the dust raised by each strike. This dust might form tenuous rings that share the little moons' orbits or, potentially, have spread beyond them. As the count of Pluto's companions swelled from one to five, mission planners confronted the terrifying possibility that New Horizons might smash into a sand-grain-size particle just as it crossed the moons' shared orbital plane — and be lost — before it had a chance to return its precious data.

Fortunately, careful analysis revealed that the location in the Pluto system most likely to be dust-free is along Charon's orbit — and this location in the moons' orbital plane is exactly the spot where New Horizons had already been targeted to traverse through the system. Charon probably sweeps that portion of space clean of dust with every revolution around Pluto.

Nonetheless, the spacecraft will conduct deep imaging surveys for dust rings as it approaches Pluto, just to be sure. If needed, the team could redirect New Horizons to an alternate trajectory that would be almost certainly safe, but the scientific cost of switching to a different flyby path would be high.

Approach Science

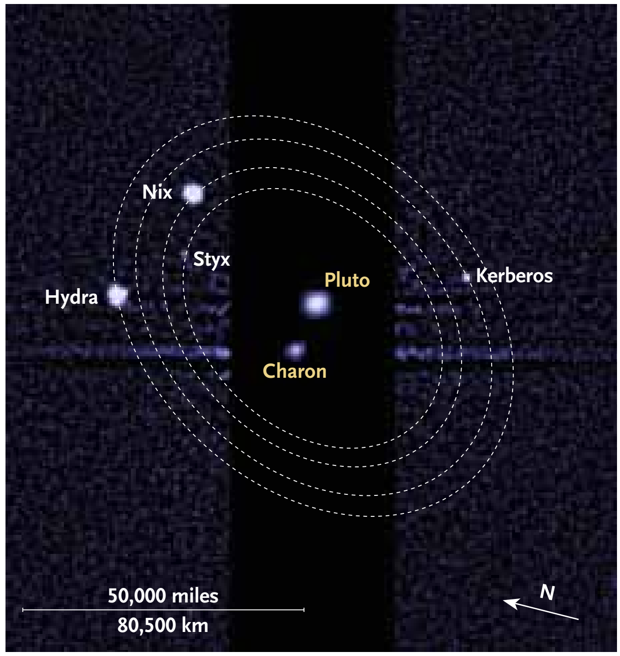
New Horizons has seven science instruments, which are described at left. PEPSSI (short for Pluto Energetic Particle Spectrometer Science Investigation) and SWAP (Solar Wind Around Pluto) are devices that measure energetic particles. Together with the Student Dust Counter (SDC), which — surprise! — counts hits from interplanetary dust particles, they have been gathering data throughout the cruise since leaving Earth. At Pluto, PEPSSI and SWAP will observe how the solar wind interacts with the molecules that stray off the top of Pluto's tenuous atmosphere.

Meanwhile, the Alice and Ralph spectrometers and Long Range Reconnaissance Imager (LORRI) camera will study Pluto's family from afar, even though they'll generate most of their high-priority data within the day before and after closest approach. Ralph is not a single instrument but instead a set of color and panchromatic cameras married with a near-infrared spectrometer, tasked with creating detailed surface-composition maps of Pluto and its moons. Alice will concentrate on analyzing Pluto's atmosphere. (You might recall that these were the names of main characters on *The Honeymooners* sitcom in the 1950s.) LORRI is the highest-resolution camera ever flown beyond Mars. Able to discern details just 1 arcsecond across, it spotted tiny Nix and Hydra circling Pluto from 200 million km away.

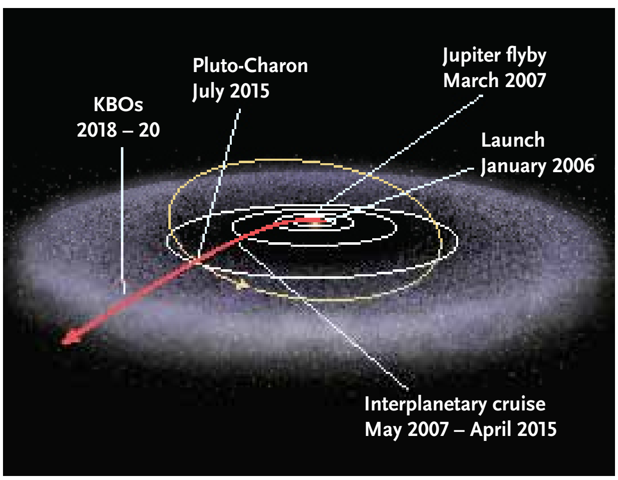
All of the mission's targets are very small compared to the worlds we've visited in the outer solar system before. For much of New Horizons' approach, LORRI recorded Pluto and its moons as little more than dancing dots, and it won't have improved upon Hubble's imaging until May. In fact, the entire Pluto system out to Hydra will fit comfortably within LORRI's field of view until June 25th, just three weeks before the flyby.

Throughout this period, New Horizons will send observations to Earth as rapidly as possible. But it's nearly 32 astronomical units (4.7 billion km) away, so these transmissions take about 4½ hours to get here. The long distance also attenuates the craft's radio signal, slowing the telemetry stream to 1 kilobit per second most of the time. At this rate, it takes about 50 minutes to transmit a single LORRI image to Earth.

Both the main antenna and the instruments are fixed to the spacecraft body, so New Horizons can't point at a target and transmit at the same time. (PEPSSI and SWAP are less sensitive to a given orientation, so they can continue gathering data while the spacecraft talks with Earth.) Throughout most of the approach, the mission plans call for alternating periods of remote-sensing observations and data transmission. This ensures that all the necessary optical navigational data reach Earth within a few days of acquisition.



FAMILY PORTRAIT A composite of images taken in 2012 by the Hubble Space Telescope shows Pluto's five known moons. Note how their highly inclined orbits create a "bull's eye" pattern as seen from the Earth-Sun perspective. (The brightness of Pluto and Charon has been reduced by a mask; faint horizontal stripes are imaging artifacts.)



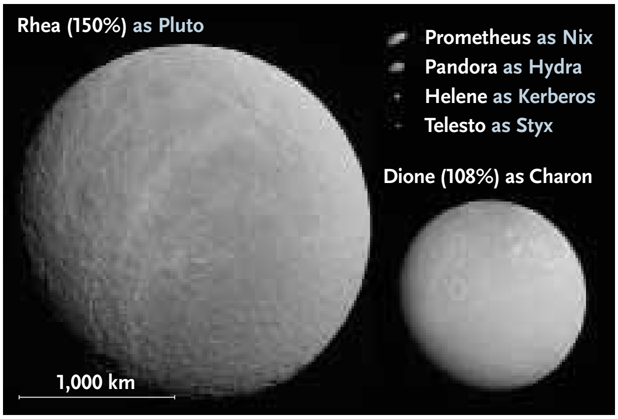
GETTING TO PLUTO New Horizons has traveled 4½ billion miles over 9½ years to reach the Pluto system. Along the way it got a speed boost from flying past Jupiter at close range.

New Horizons will empty its memory banks for the last time before the encounter in a two-week-long data dump from May 15th to 27th, during which no imaging will occur. Then new observations will be transmitted as they're obtained — even though the spacecraft will collect data faster than they can be relayed to Earth.

From Astronomy to Geology

The first set of images unambiguously better than Hubble's will not be taken until May 28th, when Pluto will span something more than eight LORRI pixels. Views of Pluto and Charon will continue to improve throughout June, though their surface features won't yet be readily discernible. We know Pluto is covered with patches of brighter and darker material; in June, we'll see those splotches rotate with Pluto's slow spin. Some of these might turn out to be clouds. Charon is comparatively gray and might appear featureless.

We recently saw, as Dawn approached Ceres, a dwarf planet morph from a smudgy disk into a world with rec-



DIVERSE TARGETS Assorted moons of Saturn serve as proxies to show the range of sizes of Pluto and its five moons. Nix is only about 100 km across, Styx no more than 25 km. Only Pluto, Charon, and Nix will be seen in detail during July's flyby.

ognizable geology. This transition happened once Dawn's camera recorded 200 pixels across Ceres's disk. For Pluto, this same threshold won't occur until July 12th, just two days before New Horizons' closest approach.

It's impossible to know when Pluto's true face will become evident. Its high-contrast surface should provide interesting views even from far away, but bright and dark patches could make it difficult to tell impact craters from surface coatings. At some point during the approach, Pluto will transition from a world seen only fuzzily to one that has mappable, nameable features.

Mission scientists hope this transition happens by July 7th, a week before the encounter. At that point the disk will only appear about 50 pixels across. Pluto's slow rotation means July 11th is the last day the spacecraft will see some regions in sunlight.

To mitigate the possible loss of New Horizons and all that high-priority science data, the last two days of the approach include four "fail-safe" radio transmissions. The spacecraft will sacrifice time that it might have used for observations close to Pluto in order to send home a tiny, carefully selected sampling of data from each of its science instruments. Back on Earth, anxious mission scientists will receive just a few images that resolve Pluto and its moons as geological worlds before the craft crosses the system's potentially hazardous orbital plane.

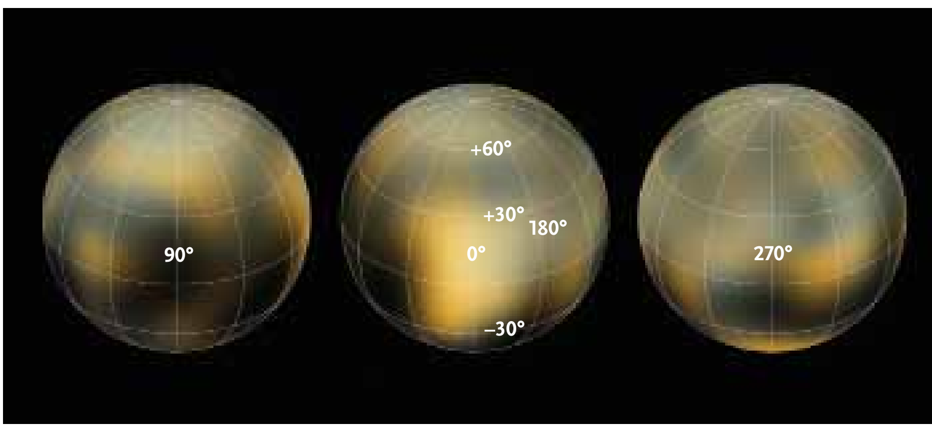
The Long Silence

The 48 hours around closest approach are so precious that the observing plan for that period has been set in stone since 2009. New Horizons has even rehearsed every turn and instrument operation of the sequence, gathering data on empty space in a dress rehearsal of July's command performance.

Any radio communications near this window would come at a cost of priceless time for science. Therefore, New Horizons will be mostly out of contact with Earth during the flyby's most critical period, called Near Encounter Phase. It begins with the spacecraft 1.2 million km from Pluto. Atmospheric scientists believe this is a bit beyond the maximum distance at which PEPSSI and SWAP might detect the shock front along which the solar wind collides with Pluto's escaping atmosphere. Once inside this boundary, PEPSSI and SWAP will directly sample gases and ions that originate from the dwarf planet's atmosphere.

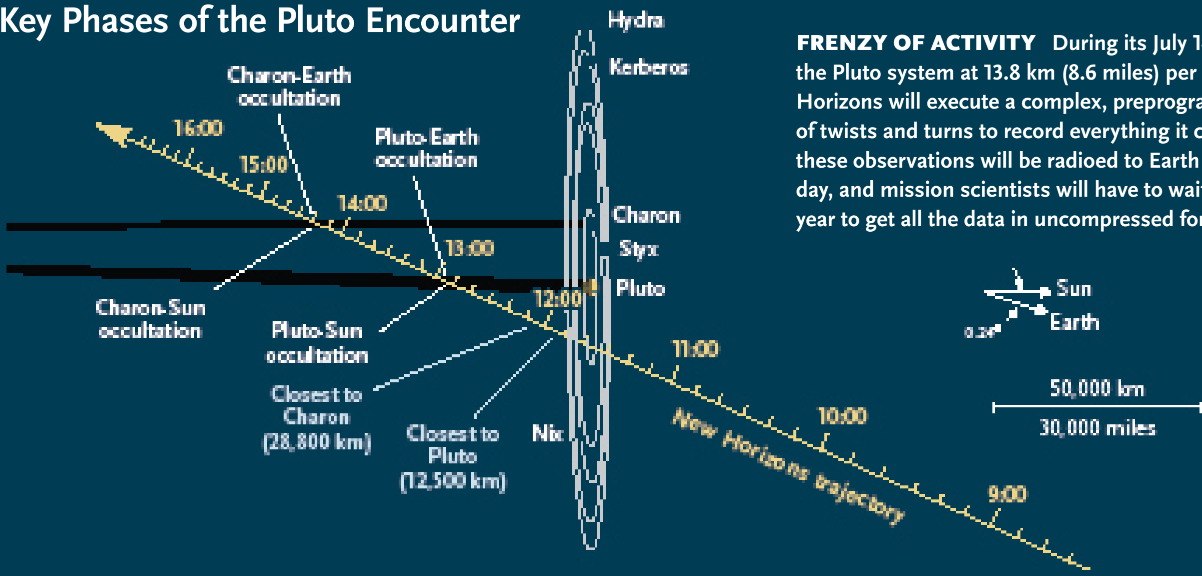
The spacecraft will twist and scan, pointing at Pluto, Charon, Nix, and Hydra in turn. It will map the reflected and thermal radiation coming from their surfaces while searching for undiscovered moonlets and rings. Its spectrometers and particle instruments will also sweep the space into which Pluto's atmosphere might be escaping. The plan is internally redundant so that, if any one instrument fails, New Horizons' highest-priority scientific goals can still be achieved with data from other instruments.

New Horizons will briefly turn toward Earth one last time before closest approach, transmitting a final image of Pluto, its globe still fitting easily inside LORRI's field of view. This transmission will end at 3:15 UT on Tuesday, July 14th. Then we'll have to endure 22 long hours of silence as the spacecraft gyrates through its busy obser-



PLUTO'S CHANGING FACE These maps, derived from sets of Hubble images, show that Pluto's surface is a mottled patchwork of white, dark-orange, and charcoal-black terrain. Researchers believe the coloration results from a combination of low-temperature ices and tar-like organic compounds created when solar ultraviolet light breaks up methane molecules.

Key Phases of the Pluto Encounter



FRENZY OF ACTIVITY During its July 14th pass through the Pluto system at 13.8 km (8.6 miles) per second, New Horizons will execute a complex, preprogramed sequence of twists and turns to record everything it can. None of these observations will be radioed to Earth until the next day, and mission scientists will have to wait more than a full year to get all the data in uncompressed form.

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Encounter phase	Dates	Starting range	LORRI's resolution	Major activities
Approach Phase 1	Jan. 6 – April 4	226×10^6 km	1,000 km/pixel	LORRI shoots images for optical navigation; SWAP, PEPSSI, and SDC measure environment unaffected by Pluto.
Approach Phase 2	April 4 - June 23	121×10^6 km	May 28: 281 km/px	Previous activities continue; Ralph (MVIC) and LORRI map Pluto to look for surface changes; LORRI searches for moonlets and rings.
Approach Phase 3	June 23 – July 13	26×10^6 km	July 1: 79 km/px July 12: 13 km/px	Previous activities continue; Ralph (LEISA) and Alice map atmosphere and look for variability; LORRI and Ralph (MVIC) map surface geology and search for hazes and clouds.
Near Encounter Phase	July 13–15	1.2×10^6 km	July 13: 4 km/px July 14: 0.4 km/px	High-resolution imaging; measurement of escaping atmosphere; REX and Alice record radio and solar occultations.
Departure Phase 1	July 15 – Aug. 4	1.2×10^6 km	July 15: 4 km/px	LORRI and Ralph (MVIC) image crescents and search for rings; SWAP and PEPSSI study magnetotail and pickup ions through one solar rotation; REX measures nightside temperatures.
Departure Phase 2	Aug. 4 – Oct. 22	24×10^6 km	(no imaging)	SWAP, PEPSSI, and SDC activities continue.
Departure Phase 3	Oct. 22 – Jan. 1, 2016	119×10^6 km	(no imaging)	SWAP, PEPSSI, and SDC activities continue.

vational schedule. As Pluto and Charon grow in apparent size, the spacecraft must begin shooting mosaics of overlapping images to cover their globes.

About 4 hours before closest approach, four of the Deep Space Network's giant radio dishes will begin to broadcast a pure, unmodulated signal toward Pluto that will race across space toward the retreating spacecraft. Closest approach happens at 11:50 UT, when New Horizons will pass 12,500 km from Pluto's surface. Fourteen minutes later the spacecraft comes its closest to Charon, which will be almost exactly opposite Pluto from New Horizons, 28,800 km away.

New Horizons will continue imaging as it begins to speed away from Pluto. LORRI will look toward its limb, potentially photographing haze layers floating high above Pluto's surface. By this time, the radio beam from Earth will have caught up with the spacecraft, which will record it as the signal strength begins to fade while passing through Pluto's atmosphere.

An hour after the flyby, the faint light of the Sun will briefly go out as New Horizons enters Pluto's shadow; a minute later, Pluto will block Earth as well. About 1½ hours later, New Horizons will experience a similar pair of occultations at Charon.

These radio occultations will enable scientists to sensitively probe the structure of Pluto's atmosphere and Charon's (if one exists). The Alice spectrometer will also watch the Sun wink out behind both bodies,

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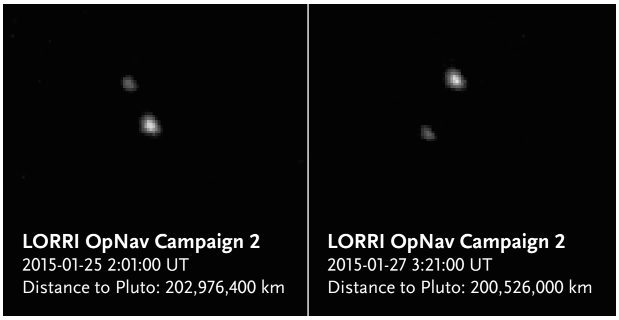

VIEW FROM AFAR New Horizons' LORRI telephoto camera recorded Pluto and dimmer Charon on January 25th and 27th from a distance of more than 200 million km. Flight planners use images like these to refine the objects' positions and to tweak the spacecraft's trajectory as needed.

measuring atmospheric composition from its effect on the solar spectrum. In between the Pluto and Charon occultations, the spacecraft will spin, allowing PEPSSI and SWAP to sensitively map the ions and neutral atoms streaming down Pluto's magnetotail (if it has one).

Nearly 9 hours after the flyby, New Horizons will take the briefest pause from its frenzied observations to radio a few precious packets of engineering data about its health. This "phone home" will take 4 hours 23 minutes to reach its apprehensive observers back on Earth, arriving — we hope! — at 1:09 UT on July 15th, confirming that the spacecraft survived the encounter and is continuing to operate normally.

But it'll be no time for New Horizons to rest. Following the flyby, as it rapidly recedes from Pluto, New Horizons will see Pluto and all its moons with the Sun positioned nearly behind them. This will yield pretty crescents in photos but also provide hints about the structure of the objects' surfaces from the way they scatter the high-angle light toward the spacecraft's cameras. New Horizons will also attempt an imaging feat: looking down on the nightside of Pluto, it will try to record regions not seen at high resolution in daylight, by using sunlight that has reflected first off Charon and then onto Pluto's darkened landscape.

The Near Encounter Phase ends a day after the flyby and transitions to the Departure Phase. New Horizons will use its cameras to study the system for only one full Pluto day (6.4 Earth days) following the close approach, seeing Pluto and all its moons as skinny crescents. Facing toward the Sun, New Horizons will continue its search for the dusty rings that might be generated from micrometeorite impacts onto the small moons. Meanwhile, PEPSSI, SWAP, and SDC will gather data for at least a month after the flyby, corresponding to one rotation of the distant Sun.

What Will We See — and When?

All these observations will fill the spacecraft's onboard memory to bursting. In all, it will take about 18 months to transmit the full, uncompressed data set back to Earth. Naturally, the mission scientists (and we!) want to get results as soon as possible. So through July 20th, New Horizons will return a carefully selected 1% of all the near-encounter science data, including 14 LORRI and two Ralph images of Pluto, Charon, Nix, and Hydra.

After that, the image pipeline will go dry for about two months. New Horizons will continue to transmit data in real time from PEPSSI, SWAP, and SDC. But before sending back any more images, the spacecraft will first transmit housekeeping data on all those frames, building a "library catalog" back on Earth that is

NASA / JPL / J. FOUST

The Long Road to Pluto

When New Horizons whizzes past Pluto this July, it will have been 9½ years since the spacecraft left Cape Canaveral, Florida. Yet that span pales in comparison to the 16 years it took to get a Pluto mission on the launch pad in the first place. Starting in 1990, five Pluto vehicles were proposed and cancelled before New Horizons got a green light from NASA in late 2001. Building a spacecraft is hard — but often the political hurdles are harder.

The first three Pluto proposals varied wildly in cost and complexity. "Pluto 350" was named after its mass in kilograms. That gave way to a two-ton behemoth based on the Saturn-bound Cassini spacecraft. The third concept, "Pluto Fast Flyby" (PFF), called for a pair of lightweight probes launched a year apart.

The Pluto Fast Flyby team poses with a mockup of their proposed spacecraft in 1992.

ready to receive the full-resolution pictures themselves.

On September 14th, New Horizons will begin transmitting the entire science data set, or at least the portion of it that can be digitally compressed. Only then will we really begin to unpack the visual riches from this historic encounter. Even with the use of strong compression algorithms to make the image files smaller, it will take two months to download every image. With that done, around November 16th, New Horizons will start again from the beginning, re-transmitting everything *without* compression. It will likely take another year, until November 2016, for the spacecraft to send all of its results across the 5 billion km separating it from Earth.

But waiting is nothing new for the New Horizons science team. It took decades to get a mission to Pluto approved and launched (as detailed below) and nearly another decade for the spacecraft to race outward from Earth to Pluto. A wait of another year for the full return of the science data is manageable. Besides, the lengthy data trickle will keep New Horizons in the news for years after the flyby, as we gain new insights on Pluto, Charon, Styx, Nix, Kerberos, and Hydra — and perhaps moons we haven't even discovered yet.

"We will be living in a year of discovery-suspense," comments deputy project scientist Kimberly Ennico (NASA Ames Research Center). "We are carrying modern instruments to 32 a.u. — megapixel cameras and thousand-pixel spectrometers. That means a lot of data, and also a lot of science and discovery."

Moreover, New Horizons' tour does not end at the Pluto system. Late in 2015, the spacecraft will fire its main engine to bend its path toward a newly discovered Kuiper Belt object, something much smaller than Pluto, setting up a flyby in late 2018 or early 2019. And, if we're lucky, continued ground-based searches will yield a second dim, distant object to explore beyond that. So New Horizons will give us our first views of at least seven worlds beyond Neptune, carrying on the tradition of discovery established by the Pioneers and the Voyagers. ✦

*An S&T contributing editor since 2010, Emily Lakdawalla blogs daily about solar-system science and space exploration for The Planetary Society (**planetary.org/blogs**). She thanks Kimberly Ennico for assistance with this article.*


NASA / JHU-APL

PLUTO-BOUND EXPERIMENT Technicians install the SWAP (Solar Wind Around Pluto) instrument, one of seven science packages carried by the New Horizons spacecraft.

More than half the cost of PFF was wrapped up in its beefy Titan launch vehicles. Alan Stern, who went on to lead the New Horizons effort, was so determined to get PFF off the ground and on to Pluto that he went shopping for cheaper rockets in Russia.

But the mission stalled following the loss of NASA's Mars Observer in 1993. In the meantime, astronomers were discovering additional icy worlds beyond Neptune's orbit, confirming the existence of the Kuiper Belt. Pluto, it seemed, was no longer a planetary outlier but instead just one example of an entirely new class of objects on the fringe of our planetary system.

This revelation led to a multiple-target concept called Pluto Express, which soon morphed into Pluto Kuiper Express. But when NASA canceled the mission in 2000, a groundswell of scientists, citizens, and advocacy groups pushed back. The space agency relented, accepting a new round of Pluto proposals in 2001 and selecting New Horizons later that year.

For behind-the-scenes views of preparations for New Horizons, visit http://is.gd/PlutoFlyby).

More funding skirmishes ensued — along with a frantic search for enough plutonium for the craft's fission-powered electrical generators. But when a comprehensive 2003 study by the National Academy of Sciences named Pluto a top priority for planetary exploration over the next 10 years, the future of New Horizons was secure. Humanity would finally get its first up-close look at Pluto.

For Alan Stern, the 26-year slog to get the first science results from Pluto is an important and cautionary tale for scientists with their own ambitious plans. "You have to really want it and be prepared to fight for it," he says. "There are many more good ideas than there is money to go around."

— Jason Davis

***Jason Davis** is a digital editor for The Planetary Society. He covers the society's science and technology projects.*