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EXCLUSIVE INTERVIEWS

CHALLENGER'S LEGACY

The loss of invincibility, the cultural shakeout and the lessons that shaped today's NASA

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Orchestrating a cosmic dance

When the New Horizons probe flew by Pluto and its moon, Charon, last year, mission design leader Yanping Guo didn't have long to marvel at the achievement by her and colleagues at the Johns Hopkins University Applied Physics Laboratory. She got back to work planning a possible extended mission past a Kuiper Belt object in 2019. Aerospace America asked Guo to explain how her team managed to precisely direct a grand-piano-sized spacecraft past a dwarf planet 4.8 billion kilometers away.

A haze of hydrocarbon extends 130 kilometers above Pluto's surface in this image showing its atmosphere backlit by the sun during the New Horizons flyby.

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

When we began designing the New Horizons mission 15 years ago, scientists told us that we needed to fly by Pluto as early as possible before 2020. That's when Pluto, now known as a dwarf planet, would enter the part of its 240-year elliptical orbit that takes it farther from the sun. The atmosphere would cool and probably collapse, and it would be up to scientists two centuries from now to determine the composition of Pluto's atmosphere and whether its moon Charon has an atmosphere (scientists didn't know at that time that four additional moons would be discovered between 2005 and 2012). The atmospheric studies were among the key science objectives for the mission, along with studying the geology and surface composition of Pluto and Charon.

The New Horizons trajectory needed to be planned so that after passing Pluto, the sun would light up Pluto from behind as the spacecraft looked back with its ultraviolet spectrometer, called Alice. Pluto's surface would be shaded by this solar occultation, but sunlight passing through the atmosphere would reach Alice, which would measure the spectral absorption to determine the atmosphere's chemical constituents. Scientists planned to do the same when Charon passed in front of the sun in occultation to see if it has an atmosphere. Pluto also needed to be in front of Earth, so that scientists could focus on its lower neutral atmosphere and ionosphere. Radio waves transmitted through Pluto's atmosphere via the NASA Deep Space Network antennas in California and Australia would be collected by the spacecraft's Radio Science Experiment, called REX, which consists of circuitry in the New Horizons communications system. The same would be done when Charon was in front of Earth.

After we achieved that in July, I kept working on the post-Pluto trajectory, changing the trajectory toward 2014 MU69, a Kuiper Belt Object, for a close flyby estimated for January 1, 2019. We needed to make the necessary trajectory adjustment last year, even though NASA has not approved the extended mission operations yet, because doing them later would require expending more fuel. The initial KBO targeting maneuver required a delta-V of 57 meters per second and was divided into four shorter burns. On November 4 New Horizons completed the last of the four series of maneuvers that nudged it onto a path toward this ancient KBO.

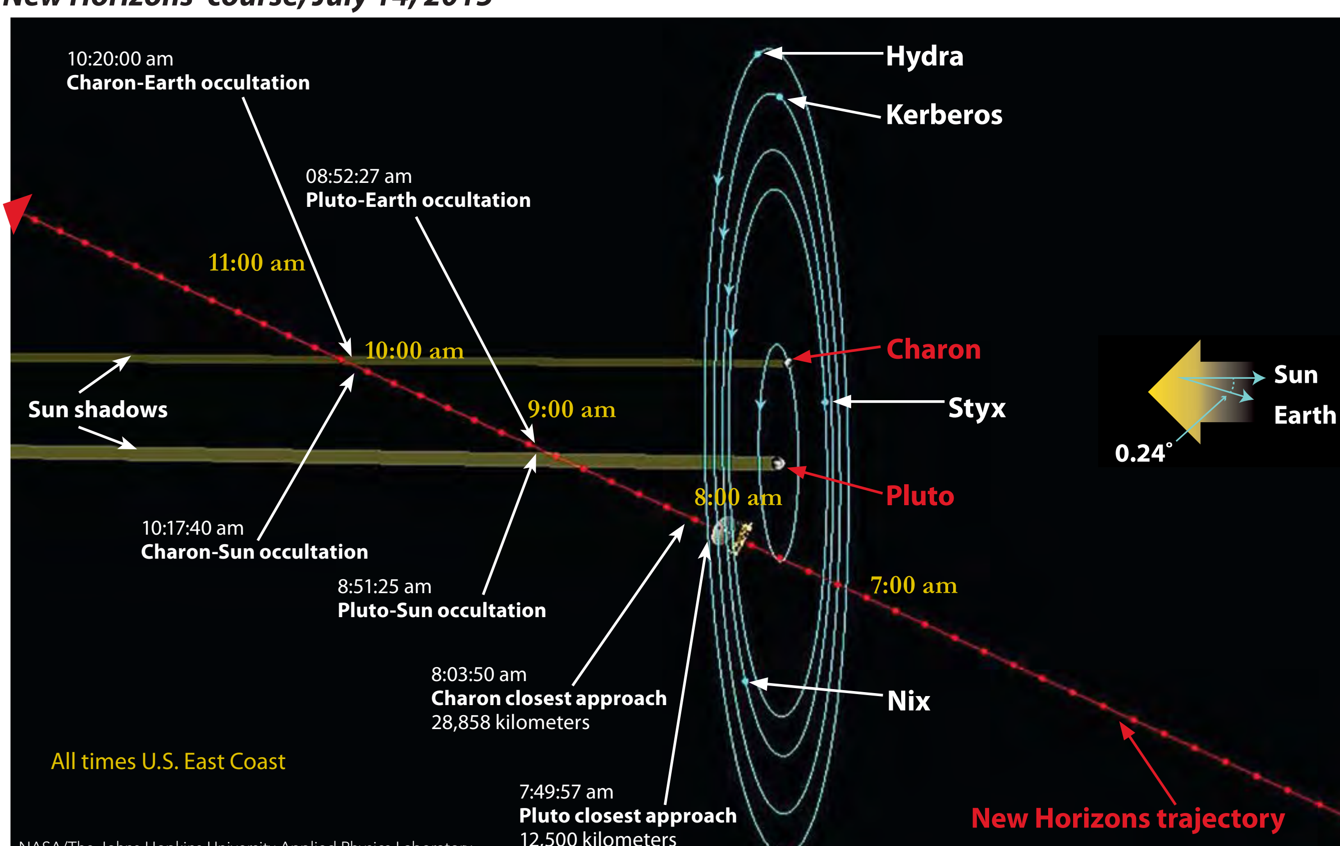
Producing the geometry for the Pluto flyby was complicated and challenging. We had to fly quickly to collect the science data before 2020, and we had to fly precisely to set up the necessary occultations. The movements of four bodies — Earth, Sun, Pluto and Charon — would have to be calculated relative to New Horizons. Because the mission was a flyby, we had only one chance to get it right.

I began the New Horizons mission design in 2000, calculating the mission trajectory based on the predicted coordinates of the celestial bodies that are stored in the Solar System Dynamics database maintained by NASA's Jet Propulsion Lab. Due to funding constraint, the original 2004 launch was later changed to 2006. We used a Jupiter gravity-assist flyby trajectory to shorten the flight time to get to Pluto in 2015. The Jupiter flyby would give New Horizons a crucial gravity assist and accelerate it by nearly 4 kilometers per second. We needed this assist, even though New Horizons was launched on the most powerful version of the Atlas rocket, the Atlas 5 551, and it got a kick 40 minutes after liftoff from a Boeing Star 48B solid rocket motor. It was the fastest spacecraft ever launched, speeding from Earth at approximately 36,000 mph.

The first order of business was to figure a basic geometry that would support the scientific observations. To achieve the Earth and solar occultations, we needed to have the Earth and sun pretty much in the same direction from Pluto during the flyby. That only happens twice a year from the vantage point of Pluto, once in January and once in July. The January occurrence is not a good geometry because Earth is behind the sun relative to Pluto, and you would have to send signals past the sun to reach the spacecraft, which

Feat of calculation

New Horizons' course, July 14, 2015



Six flyby events: The New Horizons path by Pluto and its moons had to be timed so that Pluto would cross in front of Earth from the vantage point of the spacecraft. New Horizons also needed a clear view of Pluto and its largest moon, Charon, and it had to pass through the sun shadows cast by these bodies. These occultations would reveal details that could not be detected any other way. During the Pluto-Earth occultation, for instance, radiowaves from NASA's Deep Space Network grazed Pluto's surface and were received by the spacecraft to measure any subtle bending caused by the dwarf planet's atmosphere.

The Pluto-bound New Horizons at Kennedy Space Center. The spacecraft flew by Pluto in 2015, but calculations for the mission trajectory began 15 years earlier.

would result in a lot of communications noise. We picked the July arrival, which offered the opposite geometry: The sun is behind Earth, so it would not block signals from Earth during the flyby. Once we settled on the July arrival, we had to pick the right Pluto flyby path to have the Earth and solar occultations by Pluto at the desired flyby distance for imaging. The specific Pluto arrival date in July was chosen to get Charon solar and Earth occultations that occur about 90 minutes after the Pluto occultations. The specific Pluto flyby time was selected to allow radio waves transmitting simultaneously from two different Deep Space Network stations during the Earth occultation.

Once all that was figured out, I began calculating the entire trajectory from launch to the Jupiter gravity assist to the Pluto flyby. This included establishing a 35-day launch window and the launch targets that the launch team would inject New Horizons to for the journey to Pluto. The spacecraft would be launched into a parking orbit coasting for about 19 minutes, and then at a precise moment the Atlas upper stage Centaur and Star 48B would inject New Horizons into this launch target.

The design work was done in stages. To figure out the launch window, I used approximate solutions for a quick and broad search of the trajectory space. A quick survey of the interplanetary transfer trajectory from Earth to Pluto via a Jupiter flyby on different launch and Pluto arrival dates was conducted using a commercial mission design software tool called MAnE, short for Mission Analysis Environment. With the launch window nailed down, I then computed integrated trajectories from launch to Pluto for each of the 35 launch dates using high-fidelity mission-specific models with another commercial tool, the STK Astrogator. In addition, I used my own tailor-made tool to verify the calculation results for a double check. We gave the launch team a different launch target for each date within the window.

In the early development phase, I had lots of interaction with Alan Stern, the mission's principal investigator, who was very engaged and wanted to know not just the high-level things but also the details.

The trajectory work did not end once New Horizons was launched. As we approached Pluto, I constantly assessed the trajectory against our science objectives. Long before that, we had developed, tested and re-tested software to calculate the necessary trajectory correction maneuvers or TCMs. The launch team delivered New Horizons to the designated launch target within the predicted accuracy, but it was not possible to perfectly predict all trajectory perturbations during the flight to Pluto. Those perturbations include solar radiation pressure on the spacecraft, the small but accumulating effect of the thermal radiation emitted by the New Horizons radioisotope thermal generator, and the unbalanced hydrazine thruster firings that controlled the pointing and orientation of the spacecraft. In addition to the trajectory perturbations, the predicted positions of Pluto based on the ground observations had large errors. From launch to flyby, we planned 25 TCMs but only nine were needed and executed. This included a final TCM on June 30 with a very small delta-V of 27 centimeters per second. This slightly adjusted the velocity so that the spacecraft would fly through the designated Pluto aim point at the selected time.

After a 9.5-year journey traveling 5.25 billion kilometers across the solar system, New Horizons flew by Pluto at a distance of 12,487 km from the surface, which was only 41.5 km off the designed aim point according to the reconstructed flyby trajectory by the Navigation team. The Pluto flyby time was 88 seconds earlier than the designed one. All four occultations were achieved as planned. Amazing images of Pluto and Charon were gathered during the flyby and continue to be downloaded, along with the atmospheric readings produced from the occultations.

Looking back on the last 15 years, it has been an incredible journey and I feel fortunate to have worked with such a talented team on this pioneering mission.

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