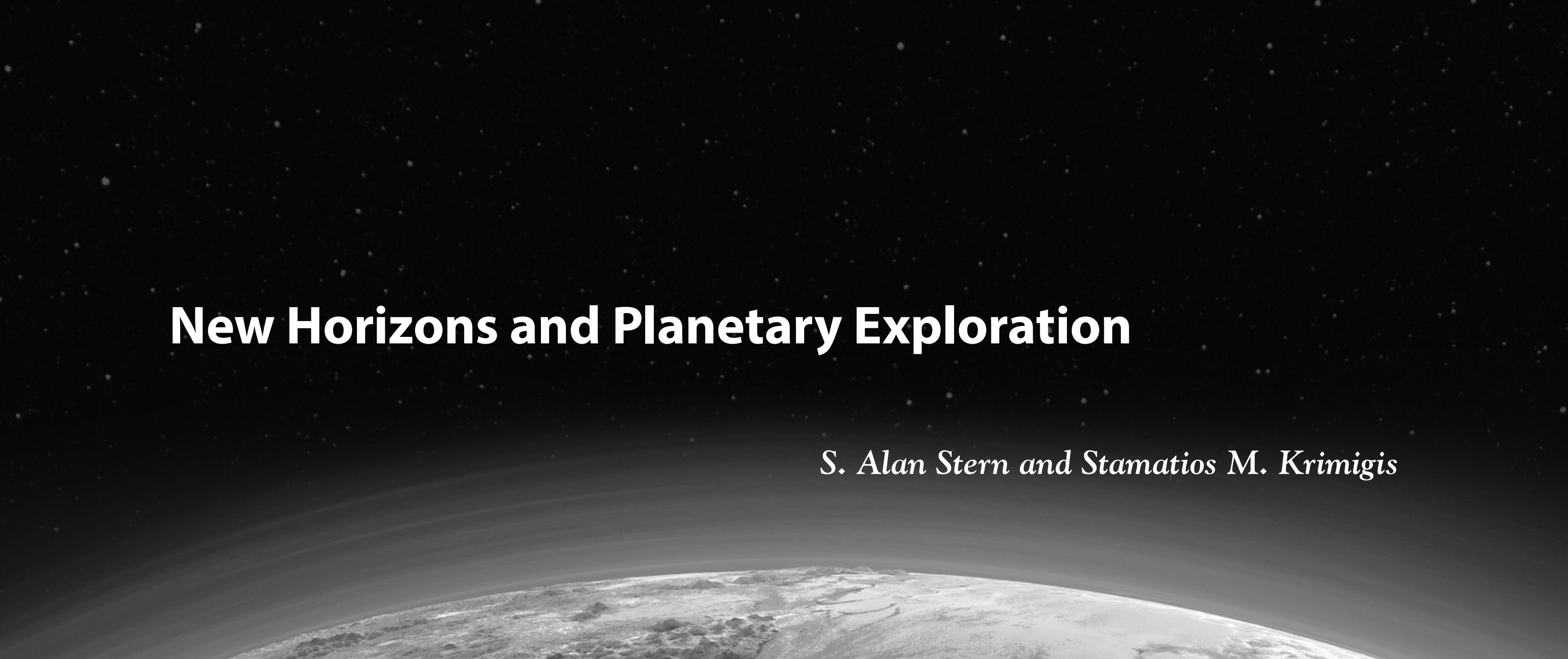

New Horizons and Planetary Exploration

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ABSTRACT

NASA's New Horizons Pluto–Kuiper Belt mission was selected for development on November 29, 2001, following a competitive selection resulting from a NASA mission announcement of opportunity. New Horizons undertook the first exploration of the Pluto system and the Kuiper Belt. It also represents a watershed development in the scientific exploration of a new class of bodies in the solar system—dwarf planets, worlds with exotic volatiles on their surfaces, rapidly (possibly hydrodynamically) escaping atmospheres, and giant impact-derived satellite systems. It also provided other valuable contributions to planetary science, including the first dust density measurements beyond 18 au (astronomical units), cratering records that shed light on both the ancient and present-day Kuiper Belt object (KBO) impactor population down to tens of meters, and a key comparator to the puzzlingly active former dwarf planet and Neptunian satellite, Triton, which is in the same size class as the small planets like Pluto and Eris. The ~475-kg spacecraft carries seven scientific instruments, including imagers, spectrometers, a radio science instrument, a plasma and particles suite, and a dust counter built by university students. New Horizons demonstrated the ability of principal investigator–led missions to use nuclear power sources and to be launched to the outer solar system. As well, the mission has demonstrated the ability of nontraditional entities, like the Johns Hopkins University Applied Physics Laboratory (APL) and the Southwest Research Institute (SwRI), to explore the outer solar system, giving NASA new programmatic flexibility and enhancing its competitive options when selecting outer planet missions. This article, which heavily adapts and borrows from a 2008 Space Science Reviews *article (vol. 140, pp. 3–21), is a historical overview of the origins of the New Horizons mission.*

CONTEXT: LOW-COST PLANETARY EXPLORATION

NASA's planetary program has managed to complete initial exploration of each of the nine classical planets in a period of just over 50 years, from Mariner 2 and 4 to Venus and Mars, respectively, in the 1960s to New Horizons to Pluto in 2015. It is a remarkable achievement indeed, but it was not

This article was heavily adapted and borrowed from a 2008 *Space Science Reviews* article by author Stern.[1]

without challenges, particularly during the 1960s. For example, two spacecraft were built for each first mission to Venus and Mars, with the expectation that only one was likely to survive, and indeed Mariner 1 and Mariner 3 suffered launch and spacecraft failures, respectively. Further, such early-era spacecraft were not expected to live more than a few months, making it problematic for them to achieve a planetary encounter before failing. Mariner 2, for example, lasted only 4 months and 7 days, just long enough to achieve a Venus encounter after 3 months and 17 days. So, the practice of dispatching two spacecraft per mission continued into the 1970s, especially to the outer planets, with Pioneer 10 and 11 to Jupiter and Voyager 1 and 2 to Jupiter and Saturn, respectively (the latter was initially named MJS-77 and planned to last for 4 years). It is truly astonishing that both Voyager spacecraft are presently in good health in their 46th year of operation. They are beyond the heliosphere in the very local interstellar medium (VLSIM), the farther being Voyager 1, which is currently near ~160 au (astronomical units; 1 au equals 150 million kilometers, the distance between Earth and the Sun).

The NASA planetary program in the early 1980s consisted of only the Galileo mission planned to orbit Jupiter and the Magellan mission to Venus. A plan to encounter Comet Halley in 1986 was abandoned; the repeated cost overruns of Galileo, together with the turmoil associated with the decision that all science mission launches should be on the Space Shuttle, contributed to this dearth of new starts. NASA even decided to withdraw from Ulysses, the joint mission with the European Space Agency (ESA) and the first out of the plane of the ecliptic by way of a Jupiter swing-by, a decision that severely strained the relationship between the two agencies for several years. By the early 1980s, however, a search was on to identify cost-effective planetary missions that could be implemented relatively rapidly.

In 1985, NASA proposed the Planetary Observer line of missions designed to explore the inner solar system, with Mars Observer (MO) as the first mission. Because of repeated cost overruns and delays, that spacecraft was not launched until September 1992, but communication with it was lost a few days before the planned Mars orbit insertion in August 1993. Congressionally imposed budget reductions in the fiscal year (FY) 1992–1993 budget cycle then forced NASA to cancel the Planetary Observer mission line. For exploration of the outer planets, NASA initiated the Mariner Mark II spacecraft bus development, designed to use Voyager and Galileo heritage plus selected new technologies to decrease costs and execute multiple missions using the same spacecraft design. The first of these was to be the CRAF (Comet Rendezvous and Asteroid Flyby) and Cassini Saturn orbiter missions, but when CRAF was cut from the program to decrease program costs, this effort, while ultimately successful with Cassini, failed to bring down costs.

The quest for low-cost planetary mission lines continued, however, with NASA's then Solar System Exploration Division (SSED) convening a workshop in 1989 that eventually proposed the Discovery line of low-cost planetary missions, with the Near Earth Asteroid Rendezvous (NEAR) as its first in the program.[2,3] NEAR met or exceeded all three principal goals for the Discovery Program: (1) cost of $150 million in FY1992 dollars (NEAR's cost was less than $112 million); (2) development time less than 36 months (NEAR's time from start of development to launch was 27 months); (3) launch vehicle to be a Delta II equivalent or less (NEAR was launched on a Delta II). NEAR achieved or exceeded all its science objectives and concluded the mission in 2001 by soft-landing on the asteroid 433 Eros, even though it was not designed to do so. In the process, NEAR established a new paradigm for low-cost planetary missions that continues to this day, with 13 Discovery missions launched to date and three more planned before the end of this decade.

The success of the Discovery line of missions led to the obvious question of whether this methodology would work for larger, non-flagship missions to the outer solar system. Ed Weiler, the NASA associate administrator for its Science Mission Directorate at the time, made an informal inquiry to APL—as the organization that designed, built, managed, and operated NEAR—for a quick study on the feasibility of such an approach. The study concluded that such an approach could be successful, even for missions larger than those in the Discovery line.[4] The NASA Solar System Exploration Subcommittee (SSES), in a letter to Weiler dated December 19, 2000, ranked as its first objective the exploration of Pluto and the Kuiper Belt. Later the National Academy of Sciences/National Research Council 2003 decadal survey, *New Frontiers in the Solar System: An Integrated Exploration Strategy*,[5] endorsed a Pluto–Kuiper Belt explorer as the highest-priority mission as well. NASA eventually proposed that Congress establish the New Frontiers line of missions for exploratory missions to the outer solar system in the FY2003 budget, although Congress had already funded the NASA-selected New Horizons, to be led by one of us, principal investigator (PI) S. A. Stern at the Southwest Research Institute (SwRI), for funding in FY2002 (more details to follow). Congress responded to NASA's request by approving the new mission line and directing that New Horizons be the first mission in its then new, New Frontiers series.

The legacy of the PI-led mission mode prescribed for the Discovery and New Frontiers lines goes back to NASA's Explorer program line managed by the Goddard Space Flight Center (GSFC) since the beginning of the space era. The first PI-led mission was Solar Mesosphere Explorer (SME), led by Charles Barth of the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado, built by Ball Aerospace, and launched in 1981. It was followed by AMPTE (Active Magnetospheric Particle Tracer Explorers), which consisted of three spacecraft: the US Charge Composition Explorer (CCE) led by PI S. Krimigis of APL, the German Ion Release Module (IRM) led by G. Haerendel of Max Planck Institute for Extraterrestrial Physics, and the UK subsatellite (UKS), a part of IRM, led by D. Bryant of Rutherford Appleton Laboratory. AMPTE was launched in 1984, within its original cost and schedule, and thus solidified the PI-led mission model as one of NASA's choices in managing science missions. The Advanced Composition Explorer (ACE), with PI Ed Stone of CalTech and built at APL, followed AMPTE and was again implemented within cost and schedule. It was the success of these missions that bolstered the argument for establishing a PI-led line of planetary science missions, which ultimately led to the Discovery line, with NEAR as the first mission.[2] Discovery's subsequent success was instrumental in the establishment of the PI-led New Frontiers line, with New Horizons as its first mission, as mentioned earlier.

Finally, it is of interest to examine the evolution of planetary mission developments from the Mariners of the 1960s to New Horizons some 40 years later. Mariner 2 did not carry a camera, but Mariner 4 flew the world's first digital camera, albeit primitive by today's standards. By the late 1970s, the Voyagers carried a rudimentary computer with dual 24-K memories and an instrument payload weighing a little over 100 kg in an 825-kg spacecraft. In contrast, New Horizons is ~475 kg with a payload of ~30 kg but vastly more capable in every respect.

To conclude this section, we note that, in the early 1980s, the NASA SSES developed an innovative classification of planetary missions including four stages: reconnaissance, exploration, intensive study, and understanding. The first stage consists of a planetary flyby, such as now exists only for Uranus (Voyager), Neptune (Voyager), and Pluto (New Horizons). *Exploration* means a more specialized mission with focused objectives based on a previous flyby, while *intensive study* calls for an orbiter mission, such as those that have been completed for Mercury, Venus, Mars, Jupiter, and Saturn. *Understanding* implies missions to answer specific questions, such as the Juno mission at Jupiter and the plethora of missions to Mars. It also means the development of extensive models that are able to simulate and interpret phenomena on each planet. It is quite clear that only the *reconnaissance* phase has been completed for Pluto and the Kuiper Belt by New Horizons, and that there is much more to be done in subsequent exploration phases.

NEW HORIZONS MISSION BACKGROUND AND OVERVIEW

The New Horizons flight system features redundant subsystems and seven scientific instruments. The spacecraft is powered by a radioisotope thermoelectric generator (RTG). (For more details on the instruments, refer to the article by Fountain et al., in this issue; for more on the spacecraft's performance, refer to the article by Hersman et al., in this issue.)

At its outset, the mission's top-level science goals were, in priority order, to:

- Reconnoiter the Pluto system for the first time
- Reconnoiter at least one Kuiper Belt object (KBO) after the Pluto system flyby
- Obtain Jupiter system science during its Jupiter gravity assist (JGA) maneuver
- Obtain various kinds of cruise science along the route to Pluto and through its Kuiper Belt traverse

The specific scientific measurement objectives of the mission were developed by NASA's Outer Planets Science Working Group (OPSWG; chaired by S. A. Stern) in 1992 and slightly refined and then re-ratified by the PKE (Pluto Kuiper Express) mission Science Definition Team (SDT) in 1996 (chaired by J. I. Lunine[6]). These objectives were adopted by NASA for the mission announcement of opportunity (AO)[7] that led to the selection of New Horizons.

The full suite of New Horizons mission science objectives described in that AO were ranked in three categories, called Group 1, Group 2, and Group 3. This categorization was first developed by OPSWG (then denoting the rank categories as Group IA, Group IB, and Group IC). Group 1 objectives represent an irreducible floor for the mission science requirements at the Pluto system. Group 2 goals add depth and breadth to the Group 1 objectives and are termed *highly desired*. The Group 3 objectives add further depth and are termed *desired*, but are of distinctly lower priority than the Group 2 objectives. These various objectives are briefly summarized here.

Group 1: Required

- Characterize the global geology and morphology of Pluto and Charon.
- Map the surface composition of Pluto and Charon.
- Characterize the neutral atmosphere of Pluto and its escape rate.

Group 2: Highly Desired

- Characterize the time variability of Pluto's surface and atmosphere.

- Image Pluto and Charon in stereo.
- Map the terminators of Pluto and Charon with high resolution.
- Map the surface composition of selected areas of Pluto and Charon at high resolution.
- Characterize Pluto's ionosphere and solar wind interaction.
- Search for neutral atmospheric species including H, H_2, HCN, and C_xH_y, and other hydrocarbons and nitriles in Pluto's upper atmosphere.
- Search for an atmosphere around Charon.
- Determine bolometric Bond albedos for Pluto and Charon.
- Map the surface temperatures of Pluto and Charon.

Group 3: Desired

- Characterize the energetic particle environment of Pluto and Charon.
- Refine bulk parameters (radii, masses, densities) and orbits of Pluto and Charon.
- Search for additional satellites and rings.

Each of the Group 1 objectives was defined by the SDT in significantly more detail, giving measurement requirements that included resolutions, signal-to-noise ratios, dynamic ranges, etc., as appropriate.

Since Pluto's small moons were not known in the 1990s when these objectives were constructed, detailed objectives for their exploration are not included above. Nonetheless, detailed reconnaissance objectives for all four of Pluto's small moons were added for that flyby. For the exploration of its first KBO, Arrokoth, a similar set of objectives to that listed above was constructed and executed.

EARLY PLUTO MISSION STUDIES

In this section we briefly recapitulate the relevant history of Pluto mission studies. We begin with NASA's Voyager mission and work forward in time through the many studies of the 1990s; more details can be found in the books *Pluto and Charon*[8] and *Chasing New Horizons*.[9] In the next main section, we describe the call for competed Pluto–Kuiper Belt (PKB) mission proposals in early 2001 and the selection of New Horizons at the end of that year.

NASA's Voyager 1 and 2 outer planets reconnaissance flyby missions included an option for Voyager 1 to fly from Saturn in 1980 to a late-1980s Pluto flyby. This option, however, was mutually exclusive with Voyager 1 making a close flyby of Saturn's large and complex atmosphere-laden moon Titan during its late-1980 exploration of the Saturn system. Owing in part to the lower risk of the Titan flyby than a long cruise to Pluto, and also the higher scientific priority of Titan at the time, the Pluto option was not exercised. Of course, at the time this decision was made, Pluto's atmosphere, its small satellites, its complex surface composition, and the entire Kuiper Belt all remained undiscovered, perhaps rationalizing the Titan choice from today's perspective. By the time of the 1989 Voyager 2 flyby of Pluto-analog Triton, however, Pluto's richness and context were beginning to be understood. That, combined with the fascinating results of Voyager 2's Triton flyby, including a pathologically young surface, active geysers, and an atmosphere, motivated interest, particularly in a handful of young planetary scientists, to successfully appeal to NASA in 1989 to begin Pluto mission studies.

Dedicated Pluto Mission Studies

Owing to the scientific interest and pressure resulting from Voyager's results at Triton and the burgeoning suspicion in the late 1980s that a Kuiper Belt existed beyond Neptune, NASA began studying dedicated Pluto flyby reconnaissance missions. The first such study (eventually dubbed Pluto-350) was undertaken as a part of the Discovery Program Science Working Group in 1989–1990. The study scientists for this effort were S. A. Stern and F. Bagenal; the study manager was R. Farquhar. The concept for this study was to send a "minimalist" scientific payload to Pluto–Charon for a bare-bones reconnaissance flyby; the Kuiper Belt was then undiscovered and not a part of the mission study. The resulting spacecraft[10] was a 350-kg RTG-powered vehicle with four instruments (an imager, an ultraviolet [UV] spectrometer, a radio science instrument, and a plasma package). Pluto-350 was to launch on a Delta II launch vehicle in 1999, perform several Earth and Venus gravity assists, and then use Jupiter for a final gravity assist in 2006 to arrive at Pluto around 2015. At the time of this study, a four-instrument spacecraft weighing half what Voyager did, and much lighter still than the Galileo, Magellan, and Cassini planetary spacecraft of the day, was considered controversial in terms of its small scope and its perceived high risk.

Shortly after the Pluto-350 study, NASA began studying flying a much larger Cassini-class Mariner Mark II mission to Pluto. This mission, though much costlier, was perceived to have lower risk and broader scientific potential. It would also provide a logical follow-on for the RTG-powered Mariner Mark II line that Cassini was then starting. Notably, this Pluto mission would have replaced the Cassini Huygens Titan entry probe with a short-lived, deployable second flyby spacecraft designed to fly over Pluto's far hemisphere some 3.2 days (one Pluto half-rotation) before or after the mother ship. This mission, along with a Mariner Mark II Neptune Orbiter, was adopted as a high priority in the SSES 1990s planetary exploration plan derived in a "community roadmap shoot-out" meeting held in February 1991. Following this, NASA's SSED (then under the direction of W. Huntress) formed the OPSWG (chaired by S. A. Stern) to shape the Pluto mission's scientific content, document its rationale, and prepare for an instrument selection process by the mid-1990s. By 1992, OPSWG had completed most of its assigned mission study support tasks. However, owing to tightening budgets at NASA, OPSWG also was asked to debate the large Mariner Mark II versus the much smaller Pluto-350 mission concepts. In early 1992, OPSWG selected Pluto-350 as the more pragmatic choice. It is worth noting that by this time, Mars Pathfinder and NEAR, also small spacecraft, were being started in NASA's Discovery Program, so smaller missions were becoming more accepted.

However, in early 1992, a new and radical mission concept called Pluto Fast Flyby (PFF) was introduced by R. Staehle (with the Jet Propulsion Laboratory, or JPL) as a "faster, better, cheaper" alternative to the Mariner Mark II and Pluto-350 Pluto mission concepts. As initially conceived, PFF was to weigh just 35–50 kg, carry only 7 kg of highly miniaturized (then nonexistent) instruments, and fly two spacecraft to Pluto for less than $500 million, excluding launch costs. PFF caught the attention of the NASA administrator at the time, D. Goldin, who directed all Pluto-350 and Mariner Mark II work to cease in favor of PFF. PFF would have launched two flyby spacecraft on Titan IV-Centaur launchers; these low-mass spacecraft would have shaved the Pluto-350 and Mariner Mark II flight times from 12–16 years down to as few as 7 or 8 years. Like Mariner Mark II and Pluto-350, PFF involved RTG power and JGAs. The heavier missions also involved Earth and Venus gravity assists on the way to Jupiter. All these mission concepts were developed by JPL mission study teams.

Shortly after PFF was introduced, however, it ran into problems. One was mass growth, which quickly escalated the flight system to the 140-kg class with no increase in mission payload mass. A second issue involved cost increases, largely due to a broad move within NASA to include launch vehicle costs in mission cost estimates. Because two Titan IV launchers alone cost over $800 million, this pushed PFF to well over $1 billion. A third issue was the turmoil introduced into NASA's planetary program by the loss of the Mars Observer in 1993. These various events began to sour Goldin on PFF. Cost concerns subsequently caused PFF to be cut back to one spacecraft, but even this was too expensive for Goldin.

OPSWG chair Stern attempted to gain European and Russian collaboration in the mission to reduce cost for an affordable new start. European interest was generally lukewarm. However, Russian interest was stronger. A concept emerged between Stern and A. Galeev, Russia's director of the IKI space research center in Moscow, that a Russian Proton launch vehicle would loft PFF, saving NASA the ~$400 million cost of the Titan IV launch. The incentive for Russia would be a probe, called a Drop Zond, which would enter Pluto's atmosphere to obtain mass spectroscopy and imagery before an impact on Pluto, as well as the country's first entrée into outer planets exploration. However, when Russia later asked in 1995 to be paid for this launch, rather than accepting the Drop Zond as a quid pro quo, W. Ip and I. Axford at Germany's Max Planck Institute for Planetary Physics offered to pursue German national funding for the Russian launch; the German scientists' plan was to pay Russia for the Proton launch (~$30 million at that time) in exchange for NASA accommodating a second probe on PFF that would impact Jupiter's moon Io during the JGA encounter.

Even with such innovative arrangements, however, PFF never progressed into development owing to higher NASA priorities for Administrator Goldin. During 1994–1995, Goldin directed a series of studies to determine whether PFF could fly without any foreign participation and without nuclear power (to Pluto!) and also whether it could be launched on a small launcher (i.e., a Delta II). These studies were widely considered in OPSWG to be diversionary tactics by Goldin, who was perceived as not being able to cancel the Pluto effort but was unwilling to start it. Nonetheless, JPL carried out the requested studies over a period of about a year, concluding that although a slow (12- to 15-year) Delta II-launched mission was feasible (something previously established for Pluto-350), nonnuclear Pluto missions were either too risky (e.g., using battery power alone) or beyond the cost or technological capability of the era. During this same period, however, PFF did solicit, select, and fund the breadboard/brassboard development of a breakthrough suite of competitively miniaturized imagers, spectrometers, and radio science and plasma instruments suitable for PFF.

Following on the rapidly expanding interest in the Kuiper Belt by the mid-1990s, NASA next directed JPL to reinvent PFF as Pluto Express (later named and more commonly known as Pluto Kuiper Express, or PKE). PKE was a single-spacecraft PFF mission with a 175-kg spacecraft, a 9-kg science payload, and a 2-Gbit solid-state memory. It would have launched in the 2001–2006 JGA launch window. An SDT chaired by J. I. Lunine was constituted in 1995 and delivered its report in 1996 for an anticipated instrument selection in 1996–1997. However, in late 1996, PKE mission studies were drastically cut back by Administrator Goldin, and no instrument selection was initiated.

By 1999, continued interest and pressure by the scientific community caused NASA to release a solicitation for PKE instruments; proposals were due in March 2000. Many of the proposals, including a radio science investigation led by L. Tyler, an energetic particle spectrometer led by R. McNutt, and a remote sensing investigations suite led by S. A. Stern, resulted from the PFF miniaturized instrument development program. These proposals were evaluated and ranked but never selected. By September 2000, NASA canceled PKE, still in Phase A, owing to mission cost increases that had once again pushed the projected mission cost well over the $1 billion mark.

NEW HORIZONS

After the cancellation of PKE, intense scientific and public pressure caused E. Weiler, who was then the NASA associate administrator for space science, to solicit mission proposals for a PKB flyby reconnaissance mission. That early 2001 solicitation and the resulting late 2001 selection of New Horizons are discussed in this section. For additional details about early Pluto mission studies, see Stern,[11] Terrile et al.,[12] Stern and Mitton,[8] and Stern and Grinspoon.[9]

PKB Mission AO and Selection Process

The fact of a PKB AO was first communicated in a NASA press conference on December 20, 2000, and the AO was released on January 19, 2001. The AO mandated a two-step selection process with initial proposals due March 20, 2001 (later extended to April 6, 2001). Following a down-selection to two teams, Phase A studies would be performed with due dates in the August–September time frame. Because no PI-led mission to the outer planets, nor any PI-led mission involving RTGs, had ever been selected, the AO was termed experimental by NASA, which made clear it was not obligated to select any proposals at all.

The PKB AO required responders to propose an entire PKB mission (i.e., not just the science payload or science investigation), to meet at least the detailed specifications of the Group 1 measurement objectives, to complete the Pluto flyby before the end of 2020, to launch aboard a US Atlas V or Delta IV launch vehicle, and to do so within a complete mission cost cap of $506 million FY2001 dollars. Launch vehicle selection between the Atlas V and Delta IV was planned for 2002. Two spare Cassini-Galileo RTGs were made available to proposal teams for use, with associated costs of $50 million and $90 million (the latter with higher power).

Shortly after the January 19, 2001, AO release, on February 6, 2001, the new administration released its first budget, which canceled PKB by not funding it in FY2002 and future years. Within days, NASA announced the suspension of the PKB AO as well. However, in less than a week, the science community's intensive work on Capitol Hill resulted in a US Senate directive to NASA to proceed with the AO so as not to limit congressional authority to override the PKB cancellation decision.

Five proposals were turned in to NASA. The contenders included two proposals from JPL (L. Soderblom and L. Esposito, PIs) and one from APL (S. A. Stern, PI). The Soderblom et al. proposal cleverly involved ion propulsion to remove the 2004–2006 JGA launch window constraint. The Esposito et al. and Stern et al. proposals both involved conventional JGA trajectories and no ion propulsion. We now summarize the New Horizons mission as proposed.

The New Horizons team was formed by an agreement between PI Stern and Stamatios ("Tom") Krimigis, who at the time was head of APL's Space Department, made on December 22, 2000. The science team was formed from Stern's PKE PERSI (Pluto Exploration Remote Sensing Investigation) instrument proposal team and Dr. Lenard Tyler's PKE radio science proposal team, plus about five other scientists from APL and other institutions to add scientific breadth for a full mission proposal. Dr. Andrew Cheng was named the New Horizons project scientist. The Tyler et al. radio science team had been the only radio science proposal for the 1999–2000 PKE AO, and Stern considered their participation to be a key strategic element of a winning PKB proposal.

The first face-to-face meeting of the New Horizons science and spacecraft teams took place at APL on January 8, 2001. Mission payload selection was largely complete by January 22, just 3 days after the PKB AO was released. The mission concept was to launch a small (400-kg class) flyby spacecraft based on heritage from APL's CONTOUR (Comet Nucleus Tour) multi-comet flyby mission, then in development for launch in 2002. The PKB spacecraft would be able to fly about 30 kg of instruments—far more than the 7–9 kg PKE would have been able to. It also would include substantial avionics and propulsion system redundancy for the long voyage, and it would use the lower-power (and lower-cost) RTG of the two that NASA offered in the AO.

In the proposal, strong emphasis was placed on reducing programmatic (i.e., cost and schedule) risk because (1) APL was viewed as a new entrant to outer planet missions, and (2) it was important to convincingly avoid the repeated cost escalations of the 1990s Pluto study and mission development attempts at JPL. A very large 48-Gbit solid-state memory was proposed for the mission to allow the spacecraft to take maximum advantage of its time in the Pluto system (by contrast, the PKE mission planned a 2-Gbit memory). Finally, every effort was made to propose the earliest feasible launch and arrival; the team proposed that launch would be in December 2004 toward a JGA, with a January 2006 backup JGA. The December 2004 launch would target a July 2012 arrival. After a long process of winnowing, on February 5, 2001, the SwRI–APL PKB proposal was

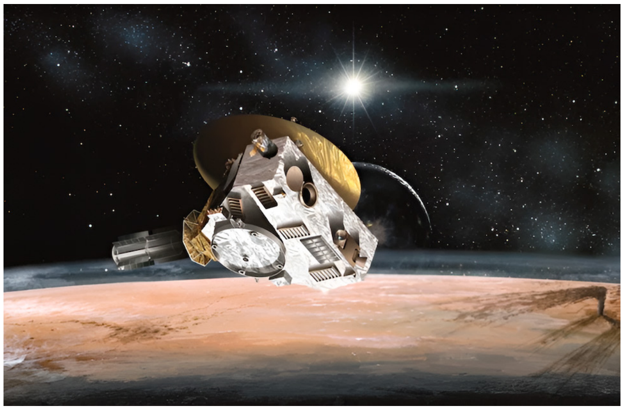

Figure 1. New Horizons over Pluto. Planetary scientist and artist D. Durda created a "2001-esque" Pluto flyby graphic. That image, with an as-launched New Horizons substituted for the 2001-era concept, is shown.

named New Horizons. The name was meant to symbolize both the new scientific horizons inherent in the exploration of the Pluto system and the Kuiper Belt, as well as the programmatic new horizons of PI-led outer planet missions. PI Stern commissioned planetary scientist and artist D. Durda to create a "2001-esque" Pluto flyby graphic that evoked a sense of new horizons. That image, with an as-launched New Horizons substituted for the 2001-era concept, is shown in Figure 1.

The proposed New Horizons payload consisted of the following four instrument packages:

1. **PERSI**, a PKE-proposed instrument package consisting of the Alice UV spectrometer and the Ralph multicolor imager/infrared (IR) imaging spectrometer
2. **REX**, short for Radio Science Experiment, an uplink radio science instrument with radiometer capabilities
3. **PAM (Particles and Atmospheres)**, a plasma package consisting of both the high-sensitivity Solar Wind Around Pluto (SWAP) solar wind monitor to address Pluto atmospheric escape objectives and the Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) adapted from the Energetic Plasma Sensor (EPS) sensor then in development for NASA's MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) Mercury orbiter
4. **LORRI**, short for Long Range Reconnaissance Imager, a long-focal-length panchromatic charge-coupled device (CCD) camera to provide imaging with four times higher resolution than Ralph could accomplish

Table 1 provides some additional details on the payload as proposed. The article by Fountain et al., in this issue, provides a more detailed overview of the as-launched scientific payload, which differs primarily in terminology (i.e., instrument names) and a few minor technical aspects from that described here. The objectives of this payload were to significantly exceed the minimum mission requirements laid out by the AO and to significantly exceed what PKE would have accomplished, but not to overburden the mission with a costly array of instruments incompatible with a highly cost-constrained outer planets mission. Other instruments considered but not included in this payload for various reasons were a magnetometer, a plasma wave senor, a dust instrument for cruise science in the deep outer solar system and the Kuiper Belt, bolometers, and a mass spectrometer. (A dust detector was subsequently added in Phase B as a student-built education and public outreach adjunct to the mission.)

PERSI and REX were termed the New Horizons "core payload," because they were sufficient to accomplish all

Table 1. Proposed New Horizons payload

Instrument	Type	Sensor Characteristics	Builders
PERSI	Remote sensing suite	• MVIC (Multispectral Visible Imaging Camera); panchromatic and four-color CCD imager, 0.4–1.0 μm, 20 μrad/pixel • LEISA (Linear Etalon Imaging Spectral Array); near-IR imaging spectrometer, wedged filter, 1.25–2.5 μm, R = 600 for 2.1–2.25 μm and R = 300 otherwise, 62 μrad/pixel • Alice (UV imaging spectrometer); 500–1,850 Å, spectral resolution 3 Å, 5 mrad/pixel	Ball, SwRI, GSFC
REX	Uplink radio science, passive radiometry	• Signal/noise power spectral density 55 dB-Hz • Ultra-stable oscillator (USO) stability 1×10^{-13} in 1-s samples • Disk-averaged radiometry to ±0.1 K	Stanford, APL
PAM	Plasma and high-energy particle spectrometers	• SWAP; solar wind plasmas up to 6.5 keV, toroidal electrostatic analyzer and retarding potential analyzer • PEPSSI; ions 1–5,000 keV and electrons 20–700 keV, time-of-flight by energy to separate pickup ions	SwRI, APL
LORRI	High-resolution imager	• Panchromatic, narrow-angle CCD imager, 0.30–0.95 μm, 5 μrad/pixel	APL

the Group 1 science that the PKB AO required proposers to meet. LORRI and PAM were termed the "supplementary payload" and were included to add depth and breadth to what the core instruments could do; however, the supplementary payload was clearly stated to be descopable should technical or programmatic considerations force cutbacks during development.

Proposals were turned in on April 6, 2001. After a 2-month technical and programmatic review process, on June 6, 2001, NASA announced the selection of JPL's POSSE (Pluto Outer Solar System Explorer; L. Esposito, PI) and APL's New Horizons for Phase A studies and further competition. PI Stern was at a Kuiper Belt meeting in Paris when he received a written phone message to call home to "Dr. Yung" (meaning, he concluded, co-investigator Dr. Leslie Young), who relayed to him that NASA had called with the selection news earlier in the day. A kickoff meeting for the two Phase A studies was sponsored by NASA Headquarters on June 18, 2001.

Both POSSE and New Horizons were funded by NASA at the $500,000 level for Phase A studies that were to be due on September 18, 2001. Both teams contributed substantial internal funds to supplement the NASA funding they received. The ground rules of the Phase A study were that the proposal teams could not augment their proposed science payloads or science teams, but were instead to provide additional engineering, cost, and schedule study to further flesh out their mission concepts. The September 11, 2001, terrorist attacks on New York and Washington, DC, interceded in the final days of proposal preparation. Owing to the nationwide stoppage of air transport (including overnight mail), a shutdown of government activities in central Washington, DC, for several days, and the general national paralysis that temporarily ensued, NASA extended the final proposal deadline to September 25, 2001.

Formal oral briefings on the proposals to a NASA concept study evaluation review board were held for New Horizons and POSSE on October 16 and 18, 2001, respectively.

In parallel with the Phase A and proposal activities described above, the scientific community and the New Horizons team also undertook a difficult effort to put funding in place in the NASA budget for FY2002's needed Phase B development. Had this not been done, any selection of a mission would have been moot, because no contract could be let to begin work, thereby ensuring that the 2004–2006 JGA launch window would not be met and no mission would be built (the next JGA window would not open until 2015). Ultimately, after much work and some intrigue, this effort succeeded with the Senate passage of, and House–Senate conference agreement on, a NASA FY2002 budget in early 2002 that included $30 million in supplementary funding for the PKB mission to initiate spacecraft and science instrument development as well as work toward launch vehicle procurement.

NASA selected New Horizons in mid-November. However, the formal announcement of this award was delayed until November 29. While he was at the annual American Astronomical Society Division for Planetary Sciences meeting in New Orleans, PI Stern was informed that New Horizons was selected for Phase B development in a phone call from NASA's PKB program scientist, Dr. Denis Bogan. A win party was held on Bourbon Street that night in the New Orleans French Quarter.

NEW HORIZONS MISSION DEVELOPMENT

Initiating the development of New Horizons was difficult for a variety of reasons. To begin, NASA's selection letter to PI Stern pointed out the numerous obstacles the mission faced before it could be confirmed. Among these were a lack of funding or a plan to fund after Phase B; the lack of a nuclear qualified launch vehicle; the short time to launch; and the lack of sufficient fuel to power a flight RTG. The award letter also postponed launch from December 2004 to January 2006, which implied a 5-year delay in arrival date from mid-2012 to mid-2017. NASA also soon insisted on New Horizons using the more expensive RTG of the two in inventory. Also complicating matters was the tragic loss of two key APL engineers responsible for REX USO development, who died in a small aircraft accident at the end of 2001.

The New Horizons team nonetheless began work in January 2002, initially focusing on the requirements development and documentation phase that would lead to a May 2002 System Requirements Review. PI Stern and the mission design team worked hard to shorten the flight time and move the arrival date earlier than 2017, ultimately achieving a mid-2015 arrival date. Stern and Cheng[13] and Stern[14] summarize the mission at this early development stage.

Figure 2. New Horizons spacecraft concept as originally proposed. Contrast this artwork, created by D. Durda, to the as-developed spacecraft shown in Figures 1 and 5.

The New Horizons science team, the larger planetary science community, APL, SwRI, and others worked to see funds included in the FY2003 budget for mission development after Phase B. A key aspect of this battle was meeting Space Science Associate Administrator E. Weiler's challenge that NASA and the administration would support New Horizons if the soon-to-be finalized National Research Council decadal survey in planetary sciences[5] ranked PKB as *the* highest-priority new start for solar system exploration. Owing to the scientific significance of the Kuiper Belt exploration in general, and Pluto system exploration in particular, this key milestone was accomplished in the summer of 2002, thereby largely ending funding battles over the mission (though severe cash flow difficulties persisted into FY2003).

Figure 2 depicts the spacecraft as designed. Figure 3 shows the project organization during spacecraft construction. Figure 4 depicts the mission trajectory. Figure 5 shows the assembled spacecraft during checkout at the launch site in Florida.

Major milestones in the development of New Horizons were as follows:

- May 2002: System Requirements Review
- October 2002: Mission Preliminary Design Review
- July 2002: Selection of the Boeing STAR-48 upper stage
- March 2003: Non-Advocate Review and Authorization for Phases C and D
- July 2003: Selection of the Atlas V 501 launch vehicle
- October 2003: Mission Critical Design Review

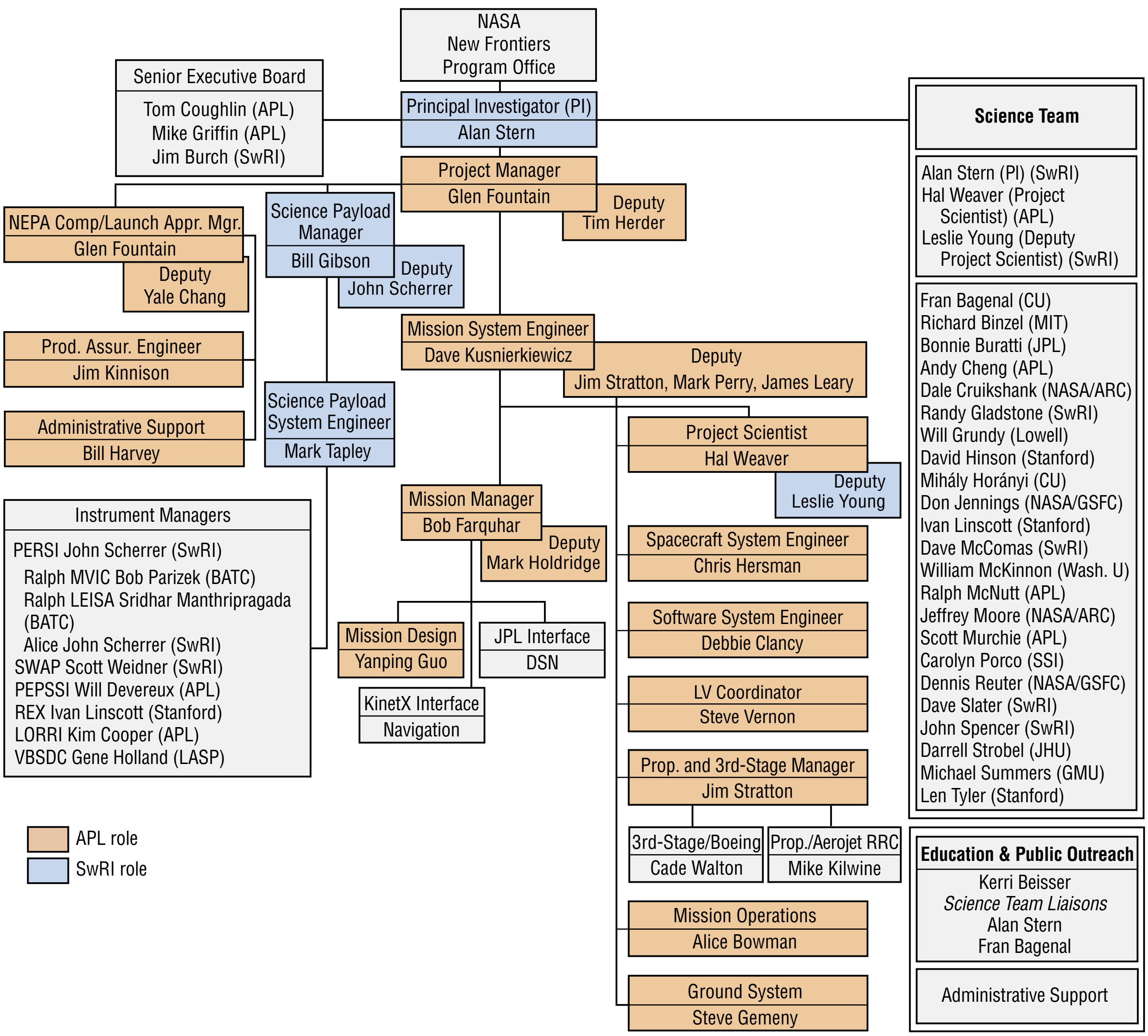

Figure 3. New Horizons spacecraft-payload team project organization chart during spacecraft construction.

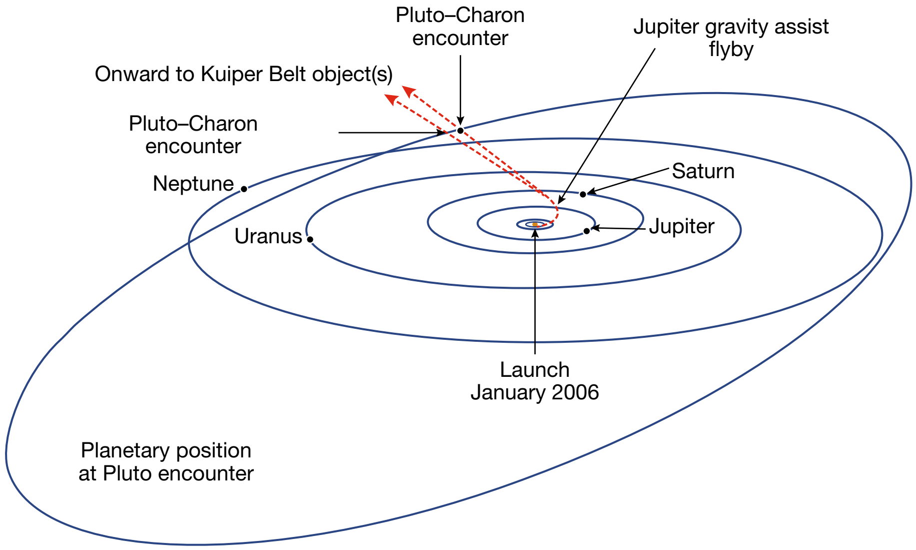

Figure 4. New Horizons trajectory depiction. The two red trajectory lines show the range of possible encounter dates (2015–2020) that applied for all possible launch dates in the 35-day 2006 launch window. Planetary positions are shown at the time of Pluto encounter in July 2015. The article by Holdridge et al., in this issue, provides details on trajectory and encounter planning.

- September 2004: First instrument payload delivery
- January 2005: Spacecraft structure complete
- March 2005: Final instrument payload delivery
- April 2005: Spacecraft integration complete
- May 2005: Beginning of spacecraft environmental testing
- September 2005: Spacecraft shipment to the launch site in Florida
- December 2005: Spacecraft mating with its launch vehicle
- January 2006: Launch

Figure 5. The New Horizons spacecraft. This photo was taken in a cleanroom at the NASA Kennedy Space Center a few weeks before launch.

During development, both the spacecraft and instrument payload designs evolved in many ways. The most important spacecraft changes during development included:

- Adapting to changes in the predicted RTG power at Pluto, resulting in 30 W (15%) less power than specified at the mission Critical Design Review, due to fuel production difficulties
- Adding over 50 kg in dry mass because of RTG mount and spacecraft balance issues
- Increasing the power system capacitor bank capacity by 25% to source load transients up to 33 mF
- Removing corners on the triangular spacecraft structure to save mass
- Increasing the onboard solid-state memory to 64 gigabits
- Substituting heavier star trackers when advanced development units stalled in production
- Substituting traveling wave tubes for solid-state power amplifiers in the telecommunications system to increase efficiency and save mass by reducing the high-gain antenna diameter from 2.5 m to 2.1 m
- Changing the thruster positioning to accommodate plume impingement and fuel line routing concerns
- Adding telecommunications redundancy through additional cross-strapping of the antenna and receiver/transmitter networks and USOs

- Replacing the internally redundant inertial reference unit with two miniature inertial measurement units, which increased mass but saved power
- Replacing the micro-digital solar attitude detector Sun sensor development with a commercial vendor's flight-qualified Sun sensor
- Adding redundancy into the spacecraft processor boot memory in the form of programmable read-only memory
- Adding cruise science during hibernation to the operations plan

The most important instrument payload changes during development included:

- Adding the education and public outreach Venetia Burney Student Dust Counter (VBSDC) to the payload
- Separating the PERSI instrument into distinct Ralph (visible/IR) and Alice (UV spectrometer) instruments
- Separating the PAM instrument into distinct SWAP (low-energy) and PEPSSI (high-energy) instruments
- Adding launch doors to PEPSSI, SWAP, and LORRI

Some notable scientific developments that occurred during mission development included the following:

- The discovery of Kuiper Belt satellites in 2001
- The discovery of factor-of-two increases in pressure and changes in the vertical structure of Pluto's atmosphere between 1988 and 2002
- The discovery of ammonium hydrates on Charon in 2004
- The discovery of high albedos and Pluto-like surface compositions on some KBOs by 2005
- The discovery of Pluto's satellites Nix and Hydra in 2005
- The discovery of objects roughly as large or larger than Pluto in the Kuiper Belt and inner Oort Cloud by 2005

The as-flown New Horizons payload is summarized in Table 2.

Over 2,500 individuals worked directly on spacecraft, payload, ground system, RTG, and launch vehicle/upper stage development for New Horizons. Also, numerous personnel and programmatic changes took place during development. The initial New Horizons project manager, Mr. Thomas Coughlin, retired and was replaced by APL's Mr. Glen Fountain at the start of 2004. Mr. Fountain stepped down as project manager in 2016 and was succeeded by Ms. Helene Winters. The initial project scientist, Dr. Andrew Cheng, stepped down during development and was replaced by Dr. Harold Weaver; Dr. Weaver stepped down in 2022 and was succeeded by Dr. Kelsi Singer.

NEW HORIZONS MISSION FIRSTS

A hallmark of the New Horizons mission is the large number of firsts it accomplished; these firsts are also discussed in the article by Buckley et al., in this issue. We now summarize some of the most notable firsts by New Horizons:

- Conducted the farthest exploration of worlds in history
- First APL mission to the outer planets
- First 21st-century mission to the outer solar system
- First mission to explore the Pluto system
- First mission to explore the Kuiper Belt and KBOs
- First mission to explore the deep magnetotail of Jupiter
- First PI-led mission to the outer solar system
- First PI-led $1 billion-class mission
- First PI-led nuclear-powered mission
- First mission in NASA's New Frontiers Program
- First planetary mission to carry a student-built instrument
- First mission to explore an object (Arrokoth) that was not known at the time of launch
- The fastest space mission ever launched
- First mission to employ spacecraft hibernation operationally
- First dust detector to operate beyond the orbit of Uranus
- First outer planets mission with a female project manager

In addition, New Horizons set two important development records. It was developed in just 4 years and 2 months from proposal acceptance to launch, less than half the time (and, in some cases, three to four times more quickly) than other 1980s and subsequent outer solar system missions. In addition, it was developed and flown at an inflation-adjusted cost of about one-fifth that of Voyager, demonstrating that it is indeed possible to explore outer solar system bodies at low cost when a project is sufficiently disciplined to accomplish it.

Table 2. The as-flown New Horizons payload

Instrument and Initial PI	Measurement Objectives[a]	Instrument Characteristics[b]
Alice UV imaging spectrometer, S. A. Stern (SwRI)	• **Upper atmospheric temperature and pressure profiles of Pluto** • **Temperature and vertical temperature gradient measured to ~10% at a vertical resolution of ~100 km for atmospheric densities >~10^9 cm^{-3}** • **Search for atmospheric haze at a vertical resolution <5 km** • **Mole fractions of N_2, CO, CH_4, and Ar in Pluto's upper atmosphere** • **Atmospheric escape rate from Pluto** • Minor atmospheric species at Pluto • Search for an atmosphere of Charon • Constrain escape rate from upper atmospheric structure	• UV spectral imaging • Bandpass: 465–1880 Å • 4.0 × 4.0 cm entrance aperture • Field of view (FOV): 4° × 0.1° plus 2° × 2° • Spectral resolution: 1.8 Å/spectral element • Spatial resolution: 5 mrad/pixel • Airglow and solar occultation channels
Ralph MVIC, S. A. Stern (SwRI)	• **Hemispheric panchromatic maps of Pluto and Charon at best resolution >0.5 km/pixel** • **Hemispheric four-color maps of Pluto and Charon at best resolution >5 km/pixel** • **Search for/map atmospheric hazes at a vertical resolution <5 km** • High-resolution panchromatic maps of the terminator region • Panchromatic wide-phase-angle coverage, panchromatic stereo images, orbital parameters, and bulk parameters of Pluto, Charon, Nix, and Hydra • Search for rings • Search for additional satellites	• Visible imaging • Bandpasses: 400–975 nm (panchromatic) plus four-color filters (blue, red, methane, near-IR) • 7.5-cm primary mirror • Focal length: 65.75 cm • FOV: 5.7° × 0.15° (stare, pan) or 5.7° × arbitrary (scan) • Instantaneous FOV (IFOV): 20 µrad/pixel
Ralph LEISA, D. Jennings (GSFC)	• **Hemispheric near-IR spectral maps of Pluto and Charon at best resolution >10 km/pixel** • **Hemispheric distributions of N_2, CO, CH_4 on Pluto at a best resolution >10 km/pixel** • Surface temperature mapping of Pluto and Charon • Phase-angle-dependent spectral maps of Pluto and Charon	• IR spectral imaging • 7.5-cm primary mirror • Focal length: 65.75 cm • Bandpass: 1.25–2.50 µm, $\lambda/\delta\lambda \approx 240$; 2.10–2.25 µm, $\lambda/\delta\lambda \approx 550$ • FOV: 0.9° × 0.9° • IFOV: 62 µrad/pixel
REX, L. Tyler (Stanford)	• **Temperature and pressure profiles of Pluto's atmosphere to the surface** • **Surface number density to ±1.5%, surface temperature to ±2.2 K, and surface pressure to ±0.3 mbar** • Surface brightness temperatures on Pluto and Charon • Masses and chords of Pluto and Charon; detect or constrain J2s • Detect, or place limits on, an ionosphere for Pluto	• X-band (7.182-GHz uplink, 8.438-GHz downlink) • Radiometry T_{Noise} < 150 K • USO frequency stability • $\delta f/f = 3 \times 10^{-13}$ over 1 s
LORRI, A. Cheng (APL)	• Hemispheric panchromatic maps of Pluto and Charon at best resolution >0.5 km/pixel • Search for atmospheric haze at a vertical resolution <5 km • Long time base of observations, extending over 10–12 Pluto rotations • Panchromatic maps of the far-side hemisphere • High-resolution panchromatic maps of the terminator region • Panchromatic wide-phase-angle coverage, panchromatic stereo images, orbital parameters, and bulk parameters of Pluto, Charon, Nix, and Hydra • Search for satellites and rings	• Visible panchromatic images • Bandpass: 350–850 nm • 20.8-cm primary mirror • Focal length: 262 cm • FOV: 0.29° × 0.29° • IFOV: 5 µrad/pixel • Framing camera with <0.3% geometrical distortion
SWAP, D. McComas (Princeton)	• **Atmospheric escape rate from Pluto** • Solar wind velocity and density, low-energy plasma fluxes and angular distributions, and energetic particle fluxes at Pluto–Charon • Solar wind interaction of Pluto and Charon	• Solar wind detector • FOV: 276° × 10° • Energy range – Electrostatic analyzer (ESA): 0.35–7.5 keV – Retarding potential analyzer (RPA): 0–2,000 V • Energy resolution – ESA: 0.085 ΔE/E – RPA: 0.5 V steps
PEPSSI, R. McNutt (APL)	• Composition and density of pickup ions from Pluto, which indirectly addresses the atmospheric escape rate • Energetic particle fluxes and angular distributions at the Pluto–Charon system • Solar wind interaction of Pluto and Charon	• Energetic particle detector • Energy range: 1 keV–1 MeV • FOV: 160° × 12° • Spatial resolution: 25° × 12° • Mass resolution: 2–15 amu
VBSDC, M. Horányi (University of Colorado Boulder)	• Trace the density of dust in the solar system along the New Horizons trajectory from Earth to Pluto and beyond	• 12 polyvinylidene fluoride (PVDF) panels to detect dust impacts and 2 control panels shielded from impacts • Panel area: 14.2 cm × 6.5 cm • Total area: 1,000 cm^2 • Detection limit: m > 10^{-12} g

Updated from Weaver et al. 2008.[15]
[a]Group 1 measurement objectives are bold. [b]Instrument characteristics are summary values.

CONCLUDING REMARKS

New Horizons successfully undertook the first exploration of both the Pluto system and a KBO, with flybys of each culminating on July 14, 2015, and January 1, 2019, respectively. Both flybys exceeded their scientific and technical requirements. New Horizons has subsequently continued in extended missions to explore the Kuiper Belt and outer heliosphere and to also undertake some astrophysical investigations that are enabled by its distant position beyond most of the solar system's dust and interplanetary hydrogen. As of this writing in 2023, the spacecraft and its payload remain in excellent health, with anticipated fuel, power, and communications capabilities needed to continue operations until ~2050, at which time the spacecraft is expected to be ~135 au in the interstellar medium. (Refer to the article by Hersman et al., in this issue, for more on New Horizons' past performance and future potential.) The search for a second KBO flyby target continues as well, though model predictions indicate that the available fuel is far short of what is required to ensure such a flyby.

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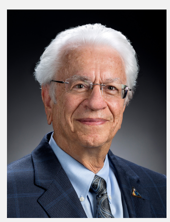

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