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The New Horizons Pluto Kuiper Belt Mission: An Overview with Historical Context

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Abstract NASA's New Horizons (NH) Pluto–Kuiper Belt (PKB) mission was selected for development on 29 November 2001 following a competitive selection resulting from a NASA mission Announcement of Opportunity. New Horizons is the first mission to the Pluto system and the Kuiper belt, and will complete the reconnaissance of the classical planets. New Horizons was launched on 19 January 2006 on a Jupiter Gravity Assist (JGA) trajectory toward the Pluto system, for a 14 July 2015 closest approach to Pluto; Jupiter closest approach occurred on 28 February 2007. The $\sim$400 kg spacecraft carries seven scientific instruments, including imagers, spectrometers, radio science, a plasma and particles suite, and a dust counter built by university students. NH will study the Pluto system over an 8-month period beginning in early 2015. Following its exploration of the Pluto system, NH will go on to reconnoiter one or two 30–50 kilometer diameter Kuiper Belt Objects (KBOs) if the spacecraft is in good health and NASA approves an extended mission. New Horizons has already demonstrated the ability of Principal Investigator (PI) 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 non-traditional entities, like the Johns Hopkins Applied Physics Laboratory (JHU/APL) and the Southwest Research Institute (SwRI) to explore the outer solar system, giving NASA new programmatic flexibility and enhancing the competitive options when selecting outer planet missions. If successful, NH will represent a watershed development in the scientific exploration of a new class of bodies in the solar system—dwarf planets, of worlds with exotic volatiles on their surfaces, of rapidly (possibly hydrodynamically) escaping atmospheres, and of giant impact derived satellite systems. It will also provide other valuable contributions to planetary science, including: the first dust density measurements beyond 18 AU, cratering records that shed light on both the ancient and present-day KBO impactor population down to tens of meters, and a key comparator to the puzzlingly active, former dwarf planet (now satellite of Neptune) called Triton which is in the same size class as the small planets Eris and Pluto.

Keywords Pluto · New Horizons · Mission · Kuiper belt

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1 Mission Overview

New Horizons is a flyby reconnaissance mission to provide the first in situ exploration of the Pluto system and KBOs. It is the first mission in NASA's New Frontiers series of medium-class, robotic planetary exploration missions. New Horizons is a Principal Investigator led mission; the author of this article is the mission PI.

The New Horizons flight system consists of a single, ∼400 kg spacecraft featuring redundant subsystems and seven scientific instruments. The spacecraft is powered by a Radioisotope Thermoelectric Generator (RTG).

The top level science goals of the New Horizons mission are, in priority order, to:

- Reconnoiter the Pluto system for the first time.
- Sample the diversity of KBOs by making one or more KBO flybys after the Pluto system flyby.
- Obtain Jupiter system science during the JGA; and
- Obtain cruise science along the route to Pluto and through the KB traverse.

The specific scientific measurement objectives of the mission were developed by NASA's Outer Planets Science Working Group (OPSWG; S.A. Stern chair) in 1992, and slightly refined and then re-ratified by the Pluto Kuiper Express (PKE) mission Science Definition Team (SDT) in 1996 (J.I. Lunine, chair; Lunine et al. 1996). These objectives were adopted by NASA for the mission Announcement of Opportunity (AO) that led to the selection of New Horizons (NASA 2001).

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 desirable. The Group 3 objectives add further depth and are termed desirable, but are of distinctly lower priority than the Group 2 objectives. These various objectives can be briefly summarized in Table 1.

Each of the Group 1 objectives was defined by the SDT in significantly more detail, giving measurement requirements that included resolutions, SNRs, dynamic ranges, etc., as appropriate. They will be described and discussed in the accompanying article by Young et al.

Since Pluto's small moons Nix and Hydra (Weaver et al. 2006) were not known in the 1990s when these objectives were constructed, they are not included. New Horizons, however, is in the enviable position of knowing about and being able to plan science observations for Nix and Hydra with almost 10 years advance notice from their discovery (itself motivated by New Horizons encounter planning) to arrival at the Pluto system. Therefore, the mission team is treating the compositional and geologic mapping of these bodies, along with other aspects of their study (orbit refinement, temperature measurements, etc.) as additional objectives. In addition to enhancing what we know about the Pluto system itself, the comparative study of Nix and Hydra to KBOs is expected to be particularly illuminating.

This article provides an overview of the mission, describing its history, its goals, its architecture and development, and its first two years of flight in summary form. Other articles in this Space Science Reviews volume provide more in-depth background regarding the mission, the mission science, and the spacecraft and its instrument payload. Other articles in this volume include a description of the mission's scientific objectives (Young et al. 2007), the instrument payload (Weaver et al. 2007), the spacecraft system (Fountain et al. 2007),

Table 1 New Horizons Pluto–Charon and KBO measurement objectives

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 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: Desirable
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

the mission design (Guo et al. 2007), the Ralph visible/infrared imager/imaging spectrometer instrument (Reuter et al. 2007), the Alice ultraviolet spectrometer instrument (Stern et al. 2007), the LORRI high resolution imager instrument (Cheng et al. 2007), the REX radio science instrument (Tyler et al. 2007), the SWAP plasma instrument (McComas et al. 2007), the PEPSSI high energy particle spectrometer instrument (McNutt et al. 2007), and the Venetia Burney Student Dust Counter instrument (Horanyi et al. 2007).

2 Pluto Mission Background Studies

In this section I briefly recapitulate the relevant history of Pluto mission studies. I begin with NASA's Voyager mission and work forward monotonically in time through the many studies of the 1990s; more details can be found in the book, *Pluto and Charon* (Stern and Mitton 2005). In Sect. 3, I will 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.

2.1 Voyager Pluto

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 at the time of Titan, 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.

2.2 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 (DPSWG) 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 (Farquhar and Stern 1990), was a 350-kg, RTG-powered vehicle with four instruments (imager, ultraviolet spectrometer, radio science, 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 so as to arrive at Pluto ca. 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 more costly, was perceived to have lower risk and a 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 mission to orbit Neptune was adopted as a high priority in the Solar System Exploration Subcommittee (SSES) 1990s planetary exploration plan derived in a "community roadmap shoot out" meeting held in February 1991. Following this, NASA's Solar System Exploration Division (then under the direction of W. Huntress) formed the Outer Planets Science Working Group (OPSWG; S.A. Stern, chair) 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 the Jet Propulsion Laboratory's (JPL's) R. Staehle 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 and carry only 7 kg of highly miniaturized (then non-existent) instruments, and fly two spacecraft to Pluto for <$500M, excluding launch costs. PFF caught the attention of then NASA Administrator D. Goldin, who directed all Pluto-350 and Mariner Mark II work to cease in favor of PFF. PFF would have launched its 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 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 of 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 \$800M, this pushed PFF to well over \$1B. 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 then NASA Administrator Goldin on PFF. Cost concerns subsequently caused PFF to be cut back to one spacecraft, but even this was too expensive for Administrator Goldin.

Following this, OPSWG chair Stern attempted to gain European and Russian collaboration in the mission to reduce cost so that a new start could be afforded. European interest was generally lukewarm. However, Russian interest was stronger. A concept emerged between Stern and Russia's director A. Galeev of the IKI space research center in Moscow that a Russian Proton launch vehicle would loft PFF, saving NASA the ∼\$400M 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 their first entrée to 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 Plank Institute for Planetary Physics offered to pursue German national funding for the Russian launch; the plan of the German scientists was to pay Russia for the Proton launch (∼\$30M at that time) in exchange for NASA accommodating a second probe on PFF which would impact Jupiter's moon Io during the JGA encounter.

Even with such innovative arrangements, however, PFF was never started into development owing to higher priorities within NASA for then Administrator Goldin. During 1994–1995, Mr. Goldin directed a series of studies to determine if PFF could fly without any foreign participation, 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 Mr. Goldin, who was perceived as not being able to cancel the Pluto effort but was unwilling to start it. Nonetheless, JPL carried the requested studies over a period of about a year; they concluded that although a slow (12–15 year) Delta II launched mission was feasible (something previously established for Pluto-350), non-nuclear 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. A Science Definition Team (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, however, 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 A. Stern, resulted from the PFF miniaturized instrument development program. These proposals were evaluated and ranked, but never selected. By September 2000, NASA cancelled PKE, still in Phase A, owing to mission cost increases which had once again pushed the projected mission cost well over the $1B mark.

3 The Birth of New Horizons

Following the cancellation of PKE, intense scientific and public pressure caused then NASA Associate Administrator for Space Science E. Weiler to solicit mission proposals for a "Pluto Kuiper Belt" (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 the following references are recommended: Stern (1993), Terrile et al. (1997), and Stern and Mitton (2005).

3.1 PKB Mission AO and Selection Process

The PKB AO was announced in a NASA Press Conference on 20 December 2000 and released on 19 January 2001. The AO (NASA 2001) mandated a two-step selection process with initial proposals due 20 March 2001 (later extended to 6 April 2001). Following a down-select to two teams, Phase A studies would be performed with due dates in the August-September timeframe. 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 U.S. Atlas V or Delta IV launch vehicle, and to do so within a complete mission cost cap of $506M FY2001 dollars. Launch vehicle selection between the Atlas V and Delta IV was planned for 2002. Two spare Cassini-Galileo RTGs were made available for use to proposal teams, with associated costs of $50M and $90M (the latter with higher power).

Shortly after the 19 January 2001 AO release, on 6 February 2001, the then-new Administration released its first budget, which cancelled PKB by not funding it in FY02 and future years. Within days, NASA announced the suspension of the PKB AO as well. However, intensive work on Capital Hill by the science community resulted in less than a week in a directive from the U.S. Senate 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 in order 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. I will now summarize the New Horizons mission as proposed.

The New Horizons team was formed by an agreement between PI Stern and APL Space Department Head Dr. Stamatios ("Tom") Krimigis that was made on 22 December 2000.

Fig. 1 New Horizons depicted over Pluto by planetary scientist and space artist Dan Durda

The science team was formed from Stern's PKE PERSI instrument proposal team and Dr. Lenard Tyler's PKE radio science proposal team, plus about five other scientists added 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 he 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 8 January 2001. Mission payload selection was largely complete by 22 January, just three 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 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 to 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) of the two RTGs that NASA offered in the AO.

In the proposal, strong emphasis was placed on reducing programmatic (i.e., cost and schedule) risk because (i) APL was viewed as a new entrant to outer planet missions and (ii) 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 in order 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; so we 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 5 February 2001, our PKB proposal was 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 provide 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 Fig. 1.

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

- PERSI, a PKE-proposed instrument package consisting of the Alice ultraviolet spectrometer and the Ralph multi-color imager/infrared imaging spectrometer.

Table 2 Proposed New Horizons payload

Instrument	Type	Sensor characteristics	Builders
PERSI	Remote sensing suite	MVIC (panchromatic and four-color CCD imager, 0.4–1.0 microns, 20 microradians/pixel), LEISA (near infrared imaging spectrometer, wedged filter, 1.25–2.5 μm, $R = 600$ for 2.1–2.25 microns and $R = 300$ otherwise, 62 microradians/pixel), and Alice (ultraviolet imaging spectrometer, 500–1850 Å, spectral resolution 3 Å, 5 milli-radians/pixel).	Ball, SwRI, NASA/Goddard Space Flight Center (GSFC)
REX	Uplink radio science, passive radiometry	Signal/noise power spectral density 55 db-Hz; ultrastable oscillator stability 1×10^{-13} in 1 second samples. Disk-averaged radiometry to ± 0.1 K.	Stanford, JHU/APL
PAM	Plasma and high energy particle spectrometers	SWAP (solar wind plasmas up to 6.5 keV, toroidal electrostatic analyzer and retarding potential analyzer), and PEPSSI (ions 1–5000 keV and electrons 20–700 keV, time-of-flight by energy to separate pickup ions).	SwRI, JHU/ APL
LORRI	High resolution imager	Panchromatic, narrow angle CCD imager, 0.30–0.95 microns, 5 microradians/pixel.	JHU/APL

- REX, an uplink radio science instrument with radiometer capabilities.
- LORRI, a long focal length panchromatic Charged Couple Device (CCD) camera to provide 4x higher resolution imaging than Ralph could accomplish.
- PAM, 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 Sensor Spectrometer Investigation (PEPSSI) energetic particle spectrometer adapted from the Energetic Plasma Sensor (EPS) sensor then in development for NASA's MESSENGER Mercury orbiter.

Table 2 provides some additional details on the payload as proposed. The article in this volume by Weaver et al. (2007) 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, to significantly exceed what PKE would have accomplished, but not to overburden the mission with a costly "Christmas tree" 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 sensor, a dust instrument for cruise science in the deep outer solar system and the Kuiper belt, bolometers, and a mass spectrometer.

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

I now return to the proposal process. Proposals were turned in on 6 April 2001. After a two month technical and programmatic review process, on 6 June 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 and was informed by a phone message to call home to "Dr. Yung" (meaning Co-Investigator Leslie Young), who relayed to him that NASA had called with the selection news somewhat earlier in the day. A kickoff meeting for the two Phase A studies was sponsored by NASA Headquarters on 18 June 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 18 September 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 11 September 2001 terrorist attacks on New York and Washington, D.C. interceded in the final days of proposal preparation. Owing to the nationwide stoppage of air transport (including overnight mail), a shut down of government activities in central Washington, D.C. for several days, and the general national paralysis that temporarily ensued, NASA extended the final proposal deadline to 25 September 2001.

Formal oral briefings on the proposals to a NASA Concept Study Evaluation Review Board were held for New Horizons and POSSE on 16 and 18 October, 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 and House-Senate conference agreement of a NASA FY2002 budget in early 2002 that included $30M 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 held up until 29 November. PI Stern was informed of the selection of New Horizons for Phase B development by a phone call from NASA's PKB Program Scientist, Dr. Denis Bogan, while he was at the annual AAS Division for Planetary Sciences meeting, which was held in New Orleans that year. A win party was held on Bourbon Street that night in the New Orleans French Quarter, but the details remain (perhaps understandably) fuzzy.

4 Mission Development Overview

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 ultrastable oscillator 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

Fig. 2 New Horizons spacecraft concept as originally proposed. Contrast to Fig. 1 with artwork by Dan Durda

System Requirements Review (SRR). 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 (2002) and Stern (2002) summarize the mission at this early development stage.

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 NRC Decadal Report in Planetary Sciences (Belton et al. 2002) 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.

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

May 2002:	Systems 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
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.

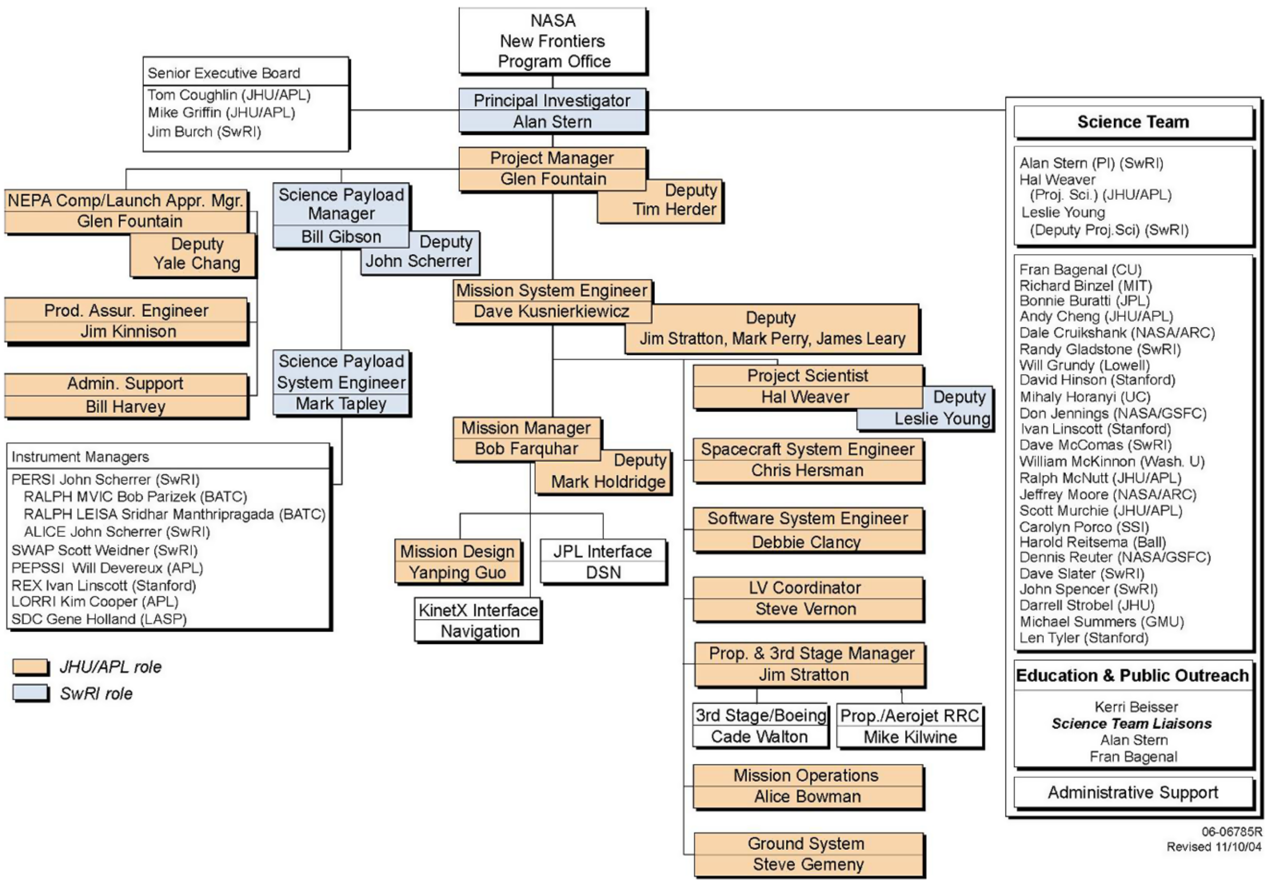

Fig. 3 New Horizons spacecraft-payload team project organization chart during spacecraft construction

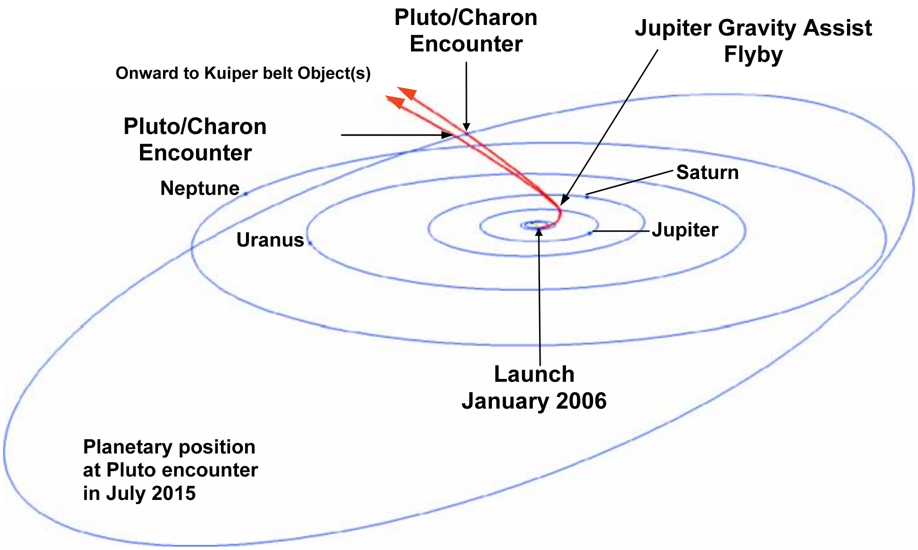

Fig. 4 New Horizons trajectory depiction. The two red trajectory lines show the range of possible encounter dates (2015–2020) that applied for all possible launch dates in the 35-day long 2006 launch window. Planetary positions are shown at the time of Pluto encounter in 2015

Fig. 5 The New Horizons spacecraft is shown here in a clean room, a few weeks before launch

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

- RTG fuel production difficulties that resulted in a 30 watt (15%) power decrease at Pluto.
- RTG mount and spacecraft balance issues that added over 50 kg in dry mass.
- Downsizing of the telecom high gain antenna from 3.0 to 2.1 m to save mass.
- A 25% increase in the power system capacitor bank capacity to source load transients up to 33 milli-farads.
- Removing corners on the triangular spacecraft structure to save mass.
- Increasing the onboard solid state memory to 64 Gigabits.
- Substituting heavier sun trackers when advanced development units stalled in production.

- Substituting traveling wave tubes for solid state power amplifiers in the telecom system.
- Changes in thruster positioning to accommodate plume impingement and fuel line routing concerns.
- Added telecom redundancy through cross strapping of the antenna and receiver/transmitter networks.

The most important instrument payload changes during development included:

- Addition of the Education and Public Outreach (EPO) Student Dust Counter to the payload.
- Separating the PERSI instrument into distinct Ralph (visible/infrared) and Alice (ultraviolet 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 KB and inner Oort Cloud by 2005.

The as-flown New Horizons payload is summarized in Table 3; many more details can be found in the accompanying article describing the New Horizons payload by Weaver et al. (2007).

During its development, over 2500 individuals worked directly on spacecraft, payload, ground system, RTG, and launch vehicle/upper stage development of New Horizons. Also during development, numerous personnel and programmatic changes also took place. The initial New Horizons project manager, Mr. Thomas Coughlin, retired. Tom was replaced by APL's highly qualified Mr. Glen Fountain at the start of 2004. The initial project scientist, Dr. Andrew Cheng stepped down during development and was replaced by Dr. Harold Weaver, in order to permit Dr. Cheng to place more emphasis on his critical role as the LORRI instrument PI. It is worth noting, to APL's credit, that in both of these cases, APL accepted the first choices of the PI for the replacement personnel. Since the project's inception, Dr. Leslie Young of SwRI served as the Deputy Project Scientist. The NASA Marshall Space Flight Center Discovery-New Frontiers Program office came into being in late 2004, following the dissolution of the JPL Discovery-New Frontiers Program office that operated from late 2003 to mid-2004.

These and other details of the development of New Horizons could easily fill an entire book; and indeed such a book might even be written some day. For now, the above listed summary will suffice as an introduction to the papers that follow in this volume of Space Science Reviews.

Table 3 New Horizons Payload

Instrument, PI	Measurement objectives	Characteristics
UV imaging spectrometer (Alice), S.A. Stern	• Upper atmospheric temperature and pressure profiles of Pluto • Temperature and vertical temperature gradient should be measured to ∼10% at a vertical resolution of ∼100 km for atmospheric densities greater than $\sim 10^9$ 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	Bandpass: 465–1881 Å; FOV: 4° × 0.1° plus 2° × 2°; Spectral resolution: 1.8 Å/spectral element, Spatial resolution: 5 mrad/pixel
Ralph/Multicolor Visible Imaging Camera (Ralph/MVIC), S.A. Stern	• Hemispheric panchromatic maps of Pluto and Charon at best resolution exceeding 0.5 km/pixel • Hemispheric 4-color maps of Pluto and Charon at best resolution exceeding 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 of Pluto and satellites • Panchromatic stereo images of Pluto and Charon, Nix, and Hydra • Orbital parameters, bulk parameters of Pluto and satellites • Search for rings • Search for additional satellites	Bandpasses: 400–975 nm (panchromatic), plus 4 color filters (Blue, Red, 890 nm Methane, Near-IR); FOV: 5.7° × 0.15° (stare, pan), or 5.7° × TBD (scan); IFOV: 20 μrad/pixel
Ralph/Linear Etalon Imaging Spectral Array (Ralph/LEISA), D. Jennings	• Hemispheric near-infrared spectral maps of Pluto and Charon at best resolution exceeding 10 km/pixel • Hemispheric distributions of N_2, CO, CH_4 on Pluto at a best resolution exceeding 10 km/pixel • Surface temperature mapping of Pluto and Charon • Phase-angle-dependent spectral maps of Pluto and Charon	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
Radio Science Experiment (REX), L. Tyler	• Temperature and pressure profiles of Pluto's atmosphere • Surface number density to ±1.5%, surface temperature to ±2.2 K and surface pressure to ±0.3 μbar • Surface brightness temperatures on Pluto and Charon • Masses and chords of Pluto and Charon; detect or constrain Pluto's J_2 • Detect, or place limits on, an ionosphere for Pluto	X-band (7.182 GHz uplink, 8.438 GHz downlink); Radiometry $T_{\mathrm{Noise}} < 150$ K; Ultra-Stable Oscillator (USO) frequency stability requirement: $\delta f/f = 3 \times 10^{-13}$ over 1 sec
Long Range Reconnaissance Imager (LORRI), A. Cheng	• Hemispheric panchromatic maps of Pluto and Charon at best resolution exceeding 0.5 km/pixel • Search for atmospheric haze at a vertical resolution <5 km • Panchromatic maps of the far-side hemisphere • High resolution panchromatic maps of the terminator region • Panchromatic, wide phase angle coverage of Pluto and satellites • Panchromatic stereo images of Pluto, Charon, Nix, and Hydra • Orbital parameters, bulk parameters of Pluto and satellites • Search for satellites and rings	Bandpass: 350–850 nm; FOV: 0.29° × 0.29°; IFOV: 5 μrad/pixel

Table 3 (*Continued*)

Instrument, PI	Measurement objectives	Characteristics
Solar Wind At Pluto (SWAP), D. McComas	• 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 with Pluto and Charon	FOV: 200° × 10° Energy range: 0.25–7.5 keV Energy resolution: RPA: 0.5 V (< 1.5 keV) ESA: 0.4 $\Delta E/E$ (>1.4 keV)
Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI), R. McNutt	• Composition and density of pick-up ions from Pluto, which indirectly addresses the atmospheric escape rate • Solar wind velocity and density, low energy plasma fluxes and angular distributions, and energetic particle fluxes in the Pluto system	Energy range: 1 keV–1 MeV FOV: 160° × 12° Resolution: 25° × 12°
Venetia Burney Student Dust Counter (SDC), M. Horanyi	• Trace the density of dust in the Solar System along the New Horizons trajectory from Earth to Pluto and beyond	12 PVF panels to detect dust impacts and 2 control panels shielded from impacts

5 Launch and Early Flight

On schedule as directed at selection in November 2001, New Horizons took flight in January 2006. Initial launch attempts on 17 and 18 January 2006 had been foiled by a weather front that adversely affected the launch site near Cape Canaveral, Florida on 17 January and the APL mission operations site in Columbia, Maryland on 18 January. On its third attempt, New Horizons launched, at 1900 UT on 19 January 2006. This date, coincidentally, was five years to the day since the PKB AO was released, 10 years to the week since the death of Pluto's discoverer, Clyde Tombaugh, and 76 years to the week since the discovery images of Pluto were obtained. It is worth noting that 19 January was the first date on which the Atlas V actually attempted to count to zero, and when it did, it launched.

At launch, New Horizons carried all of the instruments proposed for its scientific payload in 2001 as well as the Venetia Burney Student Dust Counter (SDC) added by PI Stern as an EPO enhancement in 2002; no payload descoping had occurred. When launched, New Horizons carried 78 kg of fuel and pressurant; virtually all of the 80 kg load it could possibly have carried in its fuel tank, a testament to the spacecraft and payload team's ability to control mass gain during development. At launch, the spacecraft also carried nine mementos to its target of the ninth planet. These were: two U.S. flags, the state quarters of Maryland and Florida, a small piece of the first private manned spacecraft, SpaceShip 1, a CDROM with over 100,000 names being sent to Pluto, another CDROM with numerous pictures of the spacecraft and spacecraft-mission development teams, a 1990 US postage stamp ("Pluto: Not Yet Explored"), and a small amount of the ashes of Pluto's discoverer, Clyde Tombaugh, whose remains have become, with the launch of New Horizons, the first of a human being launched beyond the solar system, to the stars.

The New Horizons Atlas V launch vehicle and STAR-48 upper stage both performed flawlessly, releasing the spacecraft on the proper trajectory some 50 minutes after launch. The spacecraft was contacted three minutes later and was found to be in good health. Subsequent tracking revealed the spacecraft to have received a highly accurate injection onto its

Jupiter course, with velocity errors of only about 18 meters/second. This was far less than the ∼100 meters/second fuel budget New Horizons carried for the purpose of post-launch trajectory correction. As a result, the spacecraft fuel supply available for mission science at Pluto and to explore KBOs is almost twice as large as nominal preflight predictions.

New Horizons was the fastest spacecraft ever launched. It crossed the orbit of the moon in ∼9 hours and reached Jupiter in record time—just 13 months. It will reach Pluto 9.5 years after launch and will then continue across the Kuiper belt on a hyperbolic trajectory that will escape to interstellar space.

During the first 10 weeks of flight, the spacecraft was spun down to its nominal cruise 5 RPM spin rate, and a thorough series of subsystem checkouts was conducted. These subsystem tests revealed very good performance in all subsystems. No significant hardware problems were revealed on the spacecraft. Also during this period a series of three trajectory correction maneuvers were carried out to refine the course to Jupiter; 20 meters/second of fuel were expended to carry out this sequence of maneuvers.

During the period from late March to late September 2006, all seven of the payload instruments were turned on, checked out, and calibrated. All of the instruments are working well. Six of the seven instrument door deployments were completed in this phase; the last, opening the Alice UVS solar occultation port to space, took place in July 2007 near 6.5 AU. No instrument problems were found to exist that will compromise their scientific capabilities at the Pluto system or KBOs, though minor issues—a PEPSSI mounting error on the spacecraft and a very small light leak with Ralph—have been documented.

Also during March–September 2006, several significant spacecraft software upgrades were performed. These added significant new capability to the onboard fault detection and correction ("autonomy") system, and corrected various software bugs and idiosyncrasies in both the Command and Data Handling (C&DH) and Guidance and Control (G&C) software package that had been detected after launch.

On 13 June 2006, New Horizons serendipitously flew past a small (∼4 km diameter), S-type asteroid called 2002 JF56 (later named "APL" by the IAU after nomination by PI Stern) at a fortuitously close range of just 104,000 kilometers. This "encounter," while distant from a scientifically important range, did result in some insights into this small body (Olkin et al. 2006). More importantly, however, the flyby was used to test instrument pointing and image motion compensation capabilities with a moving target. These tests were all successful.

New Horizons encountered Jupiter on 28 February 2007. Surrounding this event, from January to June 2007, New Horizons conducted an extensive series of over 700 Jupiter system observations. The Jupiter encounter was planned out to further calibrate instruments, test spacecraft and ground system procedures and capabilities as a risk reduction in advance of the Pluto encounter, and obtain new science to follow up on discoveries made by the most recent missions to Jupiter: Galileo and Cassini. More data was generated and downlinked from Jupiter than planned for Pluto, thanks to the higher New Horizons telemetry rates available at ∼5 AU than at 32 AU. The Jupiter encounter included a traverse far down Jupiter's magnetotail, which the spacecraft exited only after 2500 R_J; no previous spacecraft had ventured more than ∼100 R_J in this magnetotail.

During the latter half of 2007, New Horizons began its hibernation-wakeup checkout-hibernation cycling. A small (2.4 m/s) course correction was applied in September 2007, correcting aim point errors at Pluto from over 500,000 km to ∼50,000 km. Also in 2007, the science team reanalyzed the optimal arrival date and closest approach distance to Pluto, settling on 14 July 2015 and 12,500 km from Pluto's surface, respectively. Plans are in place for further flight software upgrades in 2008–2009 based on lessons learned at Jupiter.

New Horizons will require almost 8 years of cruise to fly from the end of its Jupiter encounter to the start of its Pluto encounter. During this time the spacecraft will spend about 10 months of each year in hibernation, preserving avionics lifetimes by shutting down much of its equipment and reducing costs by relaxing the need for constant monitoring and commanding. Once per week, the spacecraft operators will check a beacon tone indicating general health status from the spacecraft. Once each month, engineering telemetry will be collected to assess spacecraft health and subsystem trends in more detail. For two months each year, the spacecraft will be awakened for thorough check outs, instrument calibrations, cruise science, and trajectory corrections (if necessary). Cruise science includes interplanetary plasma and dust measurements, phase curve studies of Uranus, Neptune, Pluto, and bright KBOs, interplanetary Lyα measurements, and other studies. In 2010 and 2014, the spacecraft and ground team will additionally conduct full-scale Pluto encounter rehearsals in flight.

The Pluto system encounter will span $\sim$200 days beginning in early 2015 and lasting until about 30 days after Pluto closest approach. Complete data transmission, however, will require some 4 to 9 months after the encounter owing to the 1,000 bit/sec downlink rate at Pluto.

Near closest approach some 12,500 km over Pluto, Ralph will obtain maps of Pluto and Charon with kilometer-scale resolution; at closest approach, LORRI images at scales as high as 75 m/pixel may be achieved (depending on the final flyby distance selected). In addition, the Group 1 objectives call for mapping the surface composition and distributions of major volatile species, for which Ralph will obtain: (i) four-color global (dayside) maps at 1.6 km resolution, and (ii) diagnostic, hyper-spectral near-infrared maps at 7 km/pixel resolution globally (dayside), and at higher resolution for selected areas. Maps of surface-lying CH_4, N_2, CO, CO_2, and H_2O abundances will be obtained. Surface temperatures will be mapped by Ralph using temperature-sensitive infrared spectral features; these maps are expected to have resolutions as good as 2 deg K and 10 km; hemispheric-averaged surface brightness temperature will also be measured by the REX radiometer mode.

Characterization of Pluto's neutral atmosphere and its escape rate will be accomplished by: (i) Alice ultraviolet airglow and solar occultation spectra to determine the mole fractions of N_2, CH_4, CO and Ar to 1% in total mixing ratio and to determine the temperature structure in the upper atmosphere, (ii) REX radio occultations at both Pluto and Charon, measuring the density/temperature structure of Pluto's neutral atmosphere to the surface, (iii) SWAP and PEPSSI in situ determination of the atmospheric escape rate by measuring Pluto pickup ions, and (iv) Alice H Lyα mapping of Pluto and Charon in order to determine the rate of Roche-lobe flow of atmosphere from Pluto to Charon. Searches for atmospheres around Charon and KBOs will be made using Alice with both airglow and solar occultation techniques.

REX-derived Doppler tracking will also be used to measure the masses of Pluto and Charon, and to attempt J2 determinations; together with imagery-derived 3-D volumes, these data will be used to obtain improved densities. SDC will measure the density and masses of dust particles in the solar system from 1 AU to at least 40 AU, far surpassing the 18 AU boundary beyond which any dust detector has as yet penetrated.

Approximately three weeks after the Pluto closest approach, New Horizons will perform a trajectory correction maneuver to target its first KBO encounter. The target KBO will be selected after a deep search for candidates to be made in 2011–2013 after Pluto exits the dense background star fields of Sagittarius. Monte Carlo simulations indicate that 4 to perhaps 12 candidate KBOs may be detected within reach of the spacecraft's available fuel supply. These same simulations indicate a typical 2 to 3 year cruise time to reach the first KBO flyby. A second KBO flyby may also be possible given the available fuel. It is important to note, however, that any KBO encounter will require the approval of an extended mission budget from NASA.

6 Concluding Remarks

New Horizons is now safely in flight to make the first reconnaissance in 2015 of the fascinating Pluto-system: the farthest of the classical planets, the most accessible example of ice dwarf planets, and the most well known KBO.

If all goes well, New Horizons will then go on to make a flyby reconnaissance of a 30 kilometer to 50 kilometer diameter KBO some two to four years later. A second KBO encounter two to four years later still may even be possible, depending on spacecraft health, fuel status, our ability to detect sufficient KBOs within reach of the vehicle before it passes out of the classical KB at about 50 AU, and NASA funding.

Beyond completing the initial reconnaissance of the nine classical planets, New Horizons has already demonstrated the ability of PI-led missions to be mounted to the outer solar system, opening up a wide range of future possibilities. As well, the mission has proven the ability of non-traditional entities, like APL and SwRI to explore the outer solar system, giving NASA new programmatic flexibility and enhancing the competitive options available to NASA when selecting outer planet missions.

If New Horizons is successful, it will represent a watershed development in the scientific exploration of dwarf planets—an entirely new class of bodies in the solar system, of worlds with exotic volatiles on their surfaces, of rapidly (possibly hydrodynamically) escaping atmospheres, and of giant impact derived satellite systems. It will also provide the first dust density measurements beyond 18 AU, cratering records that shed light on both the ancient and present-day KB impactor population down to tens of meters, and a key comparator to the puzzlingly active, former dwarf planet (now satellite of Neptune) called Triton, which is as large as Eris and Pluto.

Following this article is a series of other articles describing in significantly more detail the mission trajectory, the mission science, the spacecraft, and the science payload and its individual instruments.

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