Part VIII

Space Missions to Icy Bodies: Past, Present and Future

Icy Bodies of the Solar System
Proceedings IAU Symposium No. 263, 2009
J.A. Fernández, D. Lazzaro, D. Prialnik & R. Schulz, eds.

doi:10.1017/S1743921310001985

New Horizons: Encountering Pluto and KBOs

Leslie A. Young[1] **and S. Alan Stern**[2]

[1]Southwest Research Institute,
1050 Walnut St., Suite 300,
Boulder CO 80302
email: layoung@boulder.swri.edu

[2]Southwest Research Institute,
1050 Walnut St., Suite 300,
Boulder CO 80302
email: alan@boulder.swri.edu

Abstract. New Horizons is a NASA mission to explore the Pluto system and the Kuiper Belt. The spacecraft was launched on 19 January 2006 and will begin its encounter studies of Pluto in early 2015, culminating on 14 July 2015 with a close approach just 12,500 km from Pluto. The spacecraft carries panchromatic and color images, IR and UV mapping spectrometers, a radio science package, two in situ plasma instruments, and a dust counter. We describe the capabilities of this instrument suite and the spacecraft, the observations planned for Pluto and its system of satellites, and our plans for KBO flybys to take place late in the 2010s.

Keywords. space vehicles, Pluto, Kuiper Belt

1. Introduction

New Horizons is a NASA mission to explore the Pluto system and the Kuiper Belt. Details of the New Horizons mission has recently been described in a series of papers in a special issue of Space Science Reviews (issue 140, 2008). This paper will recap the New Horizons mission, the mission design, its payload, and the planned observations, with a strong emphasis on the changes since the Space Science Review articles were resubmitted. This update is particularly timely for the planned observations, since the observation plans for the nine days around closest approach are well defined, with sequences built and tested on the spacecraft simulator.

2. Mission Overview

As described in Stern (2008) and Young *et al.* (2008), NASA defined three categories of science goals for a mission to Pluto: Group 1 (required), Group 2 (strongly desired), and Group 3 (desired). Young *et al.* (2008) presents the scientific motivation behind these goals, based on our knowledge of the Pluto system and its role in comparative planetology. Since the discovery of Pluto's moons Nix and Hydra in 2005, the New Horizons science team defined additional goals (Table 1). In general, Nix and Hydra goals paralleled the non-atmospheric goals for Pluto and Charon, but at one level lower in priority. We also took this opportunity to formalize additional science goals for Pluto and Charon that were not originally defined in the AO.

To address these goals, New Horizons carries four remote sensing and three in situ instruments, reviewed in Weaver *et al.* (2008). Alice (Stern *et al.* 2008), an ultraviolet spectrometer covering 465–1880 Å with a spatial resolution of 5 mrad/pixel, will

Table 1. Pluto-system Science Goals

Specified by NASA	Added by New Horizons Science Team
Group 1 Objectives: REQUIRED	
Global geology and morphology of Pluto & Charon Surface composition of Pluto & Charon Pluto's neutral atmosphere and its escape rate	None
Group 2 Objectives: STRONGLY DESIRED	
Time variability	Composition of dark surfaces on Pluto
Stereo of Pluto & Charon	Far-side imaging of Pluto & Charon
High resolution terminator images of Pluto & Charon	Far-side color/comp. of Pluto & Charon
High resolution surface composition of Pluto & Charon	High resolution imaging of Nix & Hydra
Pluto's ionosphere and solar wind interaction	Color & Composition of Nix & Hydra
Search for minor neutral species in Pluto's atmosphere	Shapes of Nix & Hydra
Search for an atmosphere around Charon	
Bolometric Bond albedos for Pluto & Charon	
Map the surface temperatures of Pluto and Charon	
Group 3 Objectives: DESIRED	
Energetic particle environment of Pluto & Charon	Surface microphysics of Pluto & Charon
Refine bulk parameters and orbits of Pluto & Charon	Measure temperatures of Nix & Hydra
Search for magnetic fields of Pluto & Charon	Measure the phase curve of Nix & Hydra
Search for additional satellites and rings	Image Nix and Hydra in stereo
	Education/Public Outreach

be primarily used for studying Pluto's atmosphere with airglow and UV occultations. The Ralph instrument (Reuter *et al.*, 2008) feeds two focal planes, the Multicolor Visible Imaging Camera (MVIC) and the Linear Etalon Imaging Spectral Array (LEISA). Ralph/MVIC, an imager with visible panchromatic arrays (400–975 nm) and color arrays (Blue, Red, methane, and near-IR) and a spatial resolution of 20 μrad/pixel, can observe large fields of view efficiently by scanning the spacecraft. Ralph/LEISA, an infrared imaging spectrometer spanning 1.25–2.5 μm at a resolution ($\lambda/\Delta\lambda$) of 240 to 550, is used to measure composition, temperatures, and mixing states of the surfaces in the Pluto system. The Long Range Reconnaissance Imager (LORRI, Cheng *et al.*, 2008) is a high-resolution (5 μrad/pixel) panchromatic imager (350–850 nm) that is used for our highest resolution images, as well as observations on approach and optical navigation. The Radio Experiment (REX, Tyler *et al.*, 2008) is used for an uplink occultation to probe Pluto's atmosphere and to provide radiometry at 4.2 cm. The Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI; McNutt *et al.*, 2008) is an energetic particle detector with 12 energy channels spanning 1–1000 keV, designed to study pickup ions from Pluto's escaping atmosphere. The Solar Wind at Pluto (SWAP, McComas *et al.*, 2008), a solar wind analyzer with a resolution $\Delta E/E < 0.4$ for energies between 25 eV and 7.5 keV, is used to measure the interaction of Pluto's atmosphere with the solar wind. The Venetia Burney Student Dust Counter (VB-SDC. Horányi *et al.*, 2008) measures the size distribution and density of particles with masses greater than $10^{-12}g$ during cruise.

The spacecraft was launched on January 19, 2006, used a Jupiter gravity assist with a closest approach on February 28, 2007, and will fly past Pluto on July 14, 2015. After

https://doi.org/10.1017/S1743921310001985 Published online by Cambridge University Press

Pluto, we expect to be able to encounter one or two Kuiper Belt Objects (KBOs) between 2016 and 2020. The mission design is described in Guo & Farquhar (2008). Updates to the trajectory presented in Guo & Farquhar (2008) were made by the science team in 2007, when they optimized the arrival date and distance. The encounter date in Guo & Farquhar (2008), chosen to allow solar and Earth occultations by both Pluto and Charon, was fortuitously the best for surface studies, giving good views of Pluto's bright terrain, dark terrain, the bright/dark transition, and the CO-rich longitudes. It was also near optimal for observing Nix and Hydra, and had Pluto/Charon separations that needed little slewing time. The flyby distance in Guo & Farquhar (2008) was acceptable for all Group 1 (required) goals, but allowed very little time for high-resolution observations at moderate or high-phase angles. The science team, recognizing the importance of getting a diversity of observations and a diversity of terrains for this first flyby of the Pluto system, chose a slightly more distant flyby, at the expense of slightly lower resolutions at closest approach. In the current trajectory, closest approach to Pluto is at 2015 July 14 11:50:00 UT, and New Horizons flies 13,695 km, 29,432 km, 22,012 km, and 77,572 km from the centers of Pluto, Charon, Nix, and Hydra.

3. Planned Observations at the Pluto System

Young *et al.* (2008) presents the strawman observing plan as formed pre-launch, between 2001 and 2005. These plans have been refined beginning in 2008. In particular, the time span covering seven days before to two days after closest approach have been completely defined by the science team and sequenced by the science operations team. At the time of writing, this nine-day sequence is being delivered by Science Operations to be run on our spacecraft simulator. Here, we describe updates to the planned observations at Pluto.

Approach Phase 1 runs from 180 to 100 days before closest approach (P-180 to P-100 days). During this time, the plasma instruments, SWAP and PEPSSI, will be measuring the ambient plasma to characterize the differences near Pluto. All four objects in the Pluto system (Pluto, Charon, Nix, and Hydra) are well separated from one another and detectable by LORRI, with Pluto being barely resolved (about 2.4–3 LORRI pixels in diameter). From 170 to 130 days before closest approach, LORRI will observe the system to improve the orbits of Pluto, Charon, Nix and Hydra, and look for variability in albedo patterns.

Approach Phase 2 runs from P-100 to P-21 days. Observations include the plasma, orbital, and panchromatic variability observations of Approach Phase 1. In addition, we begin looking for color variability, and search for satellites and rings. The start of this phase is chosen to roughly coincide with the time when LORRI resolution is better than that obtainable by HST.

Approach Phase 3 runs from P-21 to P-1 days, of which P-7 to P-1 days has been sequenced. Since Pluto rotates once every 6.4 days, this includes Pluto's best, second best, and third-best rotation before closest approach. We continue the observations from Approach Phase 2. During this period, PEPSSI and SWAP may detect pickup ions and the bow shock, contributing to the Group 1 goal of measuring atmospheric escape. In this period, Ralph/LEISA and Alice can begin looking for evidence of variability in the IR or UV. Near the end of this period, we can search for clouds or hazes, and track winds if discrete clouds exist. Several particularly photogenic shots for Education/Public Outreach happen in this phase, such as shots of the entire system just filling a LORRI field of view. Perhaps most importantly, this phase allows global maps of Pluto and Charon at longitudes other than those seen near closest approach.

Near Encounter Phase runs from P-1 to P+1 days, and has been entirely sequenced. The start of this phase continues the plasma, global mapping and cloud tracking observations from the end of Approach Phase 3. This phase also contains observations designed to study the shape and topography of Pluto and Charon (such as observations when the target fills a LORRI frame), UV observations for surface reflectance, high-resolution geologic, color, and compositional observations, and observations to measure temperatures with IR spectra and radiometry. This phase includes most of the Group 1 observations.

Departure Phase 1 runs from P+1 to P+21 days, of which P+1 to P+2 days has been sequenced. Plasma observations of pickup ions, the magnetotail (if present), and the ambient plasma environment, relating to the Group 1 goal of atmospheric escape, are taken throughout this phase. Remote sensing observations of Pluto and Charon are taken only during the best departure rotation, ending at P+6.4 days. These relate to the Group 1 goal of measuring Pluto's phase function. In this phase, we also measure nightside temperatures of Pluto with REX at two different longitudes, observe Nix and Hydra at high phase, and search for rings in forward scattering.

Departure Phase 2 runs from P+21 to P+100 days. Plans for Departure Phase 2 and 3 are less well developed than the other phases. SWAP and PEPSSI operate in this phase, as in all the phases. There will be a remote sensing campaign near P+30 days, including additional searches for rings or material in the Pluto-Charon L4/L5 points.

Departure Phase 3 runs from P+100 to P+180 days. The spacecraft is very quiet in this phase, with no remote sensing observations planned. SWAP and PEPSSI will continue to monitor the ambient plasma environment, and the VB-SDC will measure the dust environment near Pluto.

The plan described here differs from the pre-launch strawman timeline in Young *et al.* (2008) in five significant ways. First, the observations from P-7 to P+2 days have been sequenced, and include realistic overhead times (time to slew and settle, allocate the solid-state recorder, power cycle instruments, etc.), and realistic error ellipses (including time-of-flight knowledge and the uncertainty of the orbits of Nix and Hydra around the system barycenter). Second, it addresses the additional goals added by the Science Team (Table 1). Third, the encounter is much more robust. All Group 1 goals are addressed by one or more main observation, backup observations in case a single observation fails, and an observation with alternate instrument in case of a failure of a single instrument. For example, the Group 1 global maps of Pluto are taken with Ralph/MVIC in panchromatic at 0.46 km/pix, with Ralph/MVIC in color at 0.64 km/pix as a backup, and with LORRI at 0.85 km/pix as an alternate. Most Group 2 and 3 observations are similarly robust. Most goals are addressed with complementary measurement techniques, such as using both IR spectroscopy and 4.2-cm radiometry to measure surface temperatures. Fourth, all requested observations have been defined and ranked by the Pluto Encounter Planning team, a team that includes Leslie Young (Deputy Project Scientist and Pluto Encounter Planning lead), Alan Stern (New Horizons Principal Investigator), Jeff Moore (Geology, Geophysics, and Imaging lead), Will Grundy (Surface Composition lead), Randy Gladstone (Atmospheres lead) and Fran Bagenal (Plasma lead). This ranking has allowed the planning team to resolve all demands on resources (time, recorder volume, thruster usage) based on overall science return. Fifth, all observations from a May 4, 2009 version of the sequence have been audited by the Pluto Encounter Planning team for pointing, exposure time, roll angle, etc.; the October 2009 version of the sequence includes changes identified by the science team.

Nearly all the Group 1 observations are addressed in the period from 2.5 hours before to 1 hour after Pluto closest approach, from the 8.4 km/pixel Charon IR maps to the Pluto solar and Earth occultations (Table 2). This includes the Group 1 Pluto and Charon

Table 2. Observation plans near Closest Approach

Time[1]	Target	Instrument	Description	Resolution (km)	Solar phase angle (°)
−02:30	Charon	LEISA	C_LEISA_LORRI_1	8.4	27.2
		LORRI		0.68	
		Alice		238	
−02:15	Pluto	LEISA	P_LEISA_Alice_2a	6.7	22.2
		Alice		190	
−02:01	Pluto	LEISA	P_LEISA_Alice_2b	6.0	23.1
		Alice		169	
−01:45	Nix	LEISA	N_LEISA_LORRI_BEST	3.6	10.5
		LORRI		0.29	
−01:34	Pluto	LORRI	P_LORRI_STEREO_MOSAIC	0.37	25.4
		MVIC/Pan		1.56	
−01:14	Charon	LEISA	C_LEISA_HIRES	4.7	37.2
		LORRI		0.38	
		Alice		133	
−01:06	Charon	MVIC/Color	C_COLOR_2	1.4	39.4
−00:55	Pluto	LEISA	P_LEISA_HIRES	2.7	32.7
		LORRI		0.22	
		Alice		77	
−00:39	Pluto	MVIC/Color	P_COLOR_2	0.64	39.6
		Alice		56	
−00:32	Nix	MVIC/Pan	N_PAN_CA	0.46	92.2
−00:27	Pluto	MVIC/Pan	P_MPAN_1	0.46	49.8
		LORRI		0.11	
−00:23	Pluto	Alice	P_ALICE_AIRGLOW_HELD_1	121	55.2
−00:13	Pluto	MVIC/Pan	P_MVIC_LORRI_CA	0.29	75.8
		LORRI		0.07	
−00:07	Pluto	Alice	P_ALICE_AIRGLOW_HELD_2	78	91.8
−00:01	Charon	MVIC/Pan	C_MVIC_LORRI_CA	0.61	85.9
		LORRI		0.15	
+00:02	Pluto	MVIC/Pan	P_PHOTSCAN	0.26	121.4
+00:05	Pluto	REX	P_REX_THERMSCAN	250	132.4
+00:15	Pluto	MVIC/Pan	P_HIPHASE_HIRES	0.38	151.7
		LORRI		0.09	
+00:22	Pluto	MVIC/Pan	P_CHARONLIGHT	0.47	161.2
+01:02	Pluto/Sun	Alice	P_OCC	–	180.0
	Pluto/Earth	REX		–	

[1] Time from Pluto Closest Approach, 2015 July 15 11:50:00 UT, in hours:minutes

panchromatic maps (P_MPAN_1 and C_LEISA_LORRI_1), color maps (P_COLOR_2, C_COLOR_2), IR maps (P_LEISA_Alice_2a/2b, C_LEISA_LORRI_1), and the solar and Earth Pluto occultation (P_OCC).

Geology and panchromatic imaging. In addition to the Group 1 hemispheric observations of Pluto and Charon at 0.5 and 0.6 km/pixel, New Horizons will take higher resolution regional images. One pair – LORRI at 0.4 km/pix, 25° phase and Ralph/MVIC at 0.3 km/pix, 76° phase – will be used for stereo imaging on Pluto, to derive digital elevation models to 110 m accuracy over about a quarter of Pluto's visible disk. LORRI is used simultaneously with Ralph scans to observe three high-resolution stripes across Pluto's disk at 0.07, 0.11, and 0.22 km/pixel, and one across Charon at 0.15 km/pixel. The philosophy of the Pluto Encounter Planning team is to observe both Nix and Hydra well, but to emphasize Nix in order to well characterize one of Pluto's small moons. Therefore, we plan to observe Hydra at 1.14 km/pixel (40–146 pixels across Hydra's disk), and Nix

https://doi.org/10.1017/S1743921310001985 Published online by Cambridge University Press

at 0.46 km/pixel (87–307 pixels across Nix). A LORRI observation taken simultaeously with Ralph/LEISA has the potential for 0.29 km/pixel on Nix, depending where Nix falls in its error ellipse. Measuring the albedo of Pluto's dark pole will be important for constraining volatile transport models, and so we attempt this high-phase measurement twice, once with Ralph/MVIC just after closest approach (P_CHARONLIGHT), and once with LORRI 14 hours later. During Pluto's final approach rotation, we make global maps of the sunlit portions of Pluto and Charon at resolutions better than 30 km/pixel with LORRI, while on departure, observations taken every 3 to 6 hours allow us to build up maps of Pluto and Charon at high phase.

Color, composition, and temperature. The requirement for color images is 1.5–10 km/pix. New Horizons will exceed this, with Pluto and Charon color images at 0.7 km/pix and 1.4 km/pix, respectively. Nix and Hydra are also observed in color, at 2.0 and 4.6 km/pix respectively, with Ralph/MVIC. These color observations include a filter matched to methane's 890 nm absorption feature, so that, at least on Pluto, we will be able to derive crude compositional maps at geologic scales. For compositions, temperatures, and mixing states from infrared spectroscopy, we observe the entire hemispheres of Pluto, Charon, Nix, and Hydra at 6.0, 8.4, 3.6, and 14.6 km/pixel respectively with Ralph/LEISA. Hydra is expected to be barely resolved, but, as previously mentioned, the goal is to characterize Nix well. Regional IR maps of Pluto and Charon are at higher resolutions, 2.7 and 4.7 km/pixel, respectively. During Pluto's final approach rotation, we make global maps of the sunlit portions of Pluto and Charon at resolutions better than 120 km/pixel in color with Ralph/MVIC, and better than 370 km/pixel with Ralph/LEISA. On departure, observations are taken at specific longitudes to characterize the phase function and IR spectra of different types of terrain, and break some grain-size/temperature/mixing-ratio ambiguities. In addition to the disk-integrated brightness at 0.1 K sensitivity of the day and nightsides of Pluto and Charon, REX will observe Pluto with resolved thermal radiometry along two tracks at 0.3 K sensitivity per 325 km footprint, where one track crosses the specular point and the other crosses Pluto's nightside pole.

Atmosphere and Plasma. We observe both solar and Earth occultations of both Pluto (extending well above any expected ionoshere) and Charon (extending out to Charon's Hill sphere). In addition, we observe a stellar occultation by Pluto as a backup and to probe different areas of Pluto's atmosphere, and two Pluto appulses to further characterize Pluto's upper atmosphere. In the Near Encounter Phase, Alice observes 6.5 hours of airglow on approach and 3.6 hours on departure, with two opportunities near closest approach to resolve airglow at 78–121 km resolution (P_ALICE_AIRGLOW_HELD_1 and _2), and airglow of Charon and Nix to search for signs of an atmosphere. Images at high phase angle will be taken to look for hazes (P_HIPHASE_HIRES and others). Starting at P-1.5 days, we observe Pluto at a variety of time cadences to search for clouds, plumes, and wind motions. To search for a cloud of atomic H around Pluto, Alice will look for Lyman-α absorption near Pluto. The plasma instruments will be in nearly continuous operation in 2015, with continuous operation in the Near Encounter Phase. Regular rolls of the spacecraft will insure that the instruments will observe the planetary pickup ions.

4. Kuiper Belt Object flyby

Shortly after Pluto closest approach, we plan for New Horizons to execute a trajectory correction maneuver to direct the spacecraft to its next target, a Kuiper Belt Object (KBO), The KBO has not yet been identified or selected. Most likely, the encounter will be in 2018 or 2019, near 42 AU, due to the intrinsic peak in KBO distribution, the narrower cone of accessibility at smaller distances, and the faintness of more distant KBOs (Spencer *et al.* 2003).

The search area is in the Milky Way, making the search for faint KBOs (down to V = 27) difficult. The search area shrinks with time as it converges on the spacecraft trajectory, defined by KBO velocity dispersion, not available delta-V. We plan to select and fund KBO search teams in 2010 for searches in 2011 and 2012. Interested teams should contact Alan Stern (alan@boulder.swri.edu).

References

Cheng, A. F. *et al.* 2008, *Space Sci. Revs*, 140, 215
Guo, Y. & Farquhar, R. W. 2008, *Space Sci. Revs*, 140, 49
Horányi, M. *et al.* 2008, *Space Sci. Revs*, 140, 387
McComas, D. *et al.* 2008, *Space Sci. Revs*, 140, 261
McNutt, R. L. *et al.* 2008, *Space Sci. Revs*, 140, 315
Reuter, D. C. *et al.* 2008, *Space Sci. Revs*, 140, 129
Stern, S. A. 2008, *Space Sci. Revs*, 140, 3
Stern, S. A. *et al.* 2008, *Space Sci. Revs*, 140, 155
Spencer, J. S. *et al.* 2003, *Earth, Moon and Planets*, 92, 483
Tyler, G. L. *et al.* 2008, *Space Sci. Revs*, 140, 217
Weaver, H. A. 2008, *Space Sci. Revs*, 140, 75
Young, L. A. *et al.* 2008, *Space Sci. Revs*, 140, 93