Proposing New Horizons

A post-doc's perspective

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Southwest Research Institute

for

University of Central Florida, Spring 2014, AST 6156

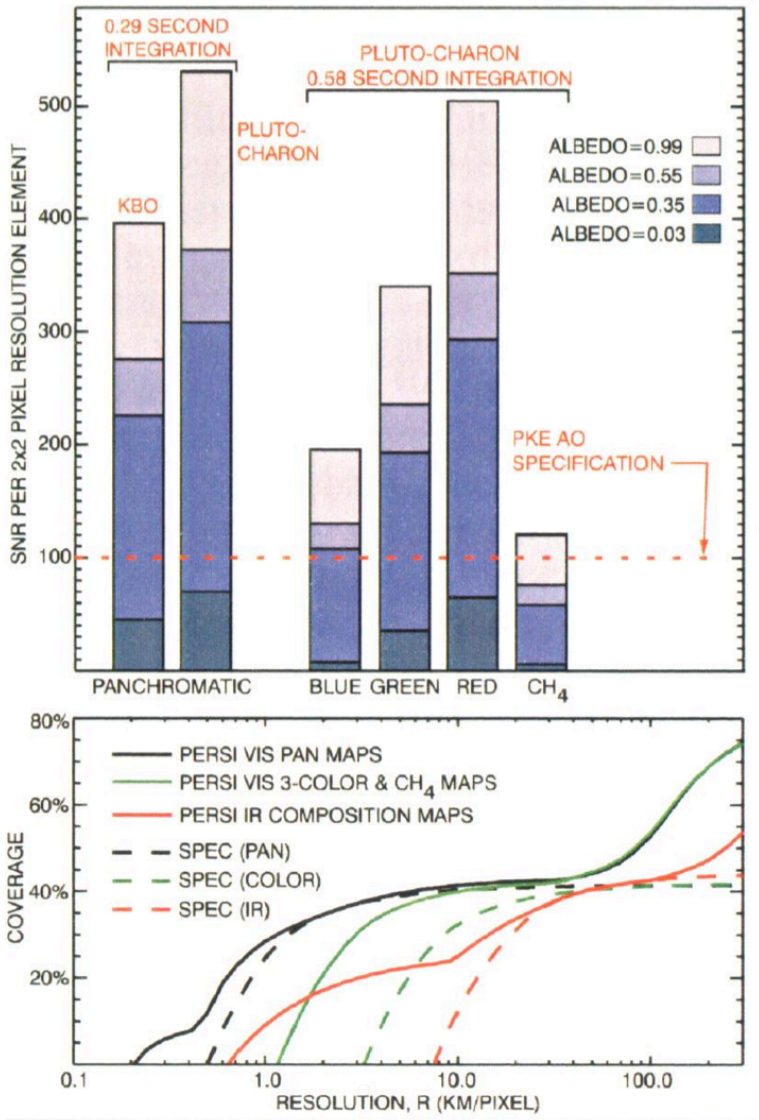
"New Horizons Approaches Pluto"

Coming into the Pluto Proposal Cold!

- Tons of Pluto Experience 1988-1999
  - Co-discovered Pluto's atmosphere by stellar occultation.
  - Co-discovered of N_2, CO on Pluto's surface.
  - Discovered CH_4 in Pluto's atmosphere, and placed upper limits on the CO.
  - Measured Pluto's mass from astrometry.
  - Understood instrument behavior, but not design.
- No Spacecraft experience (or politics, media...)
- Mixed proposal experience
  - Good record for telescope time.
  - Wrote some terrible funding proposals.

"Leslie, can you help me with this figure?"

- I arrived at SwRI Summer 1999
  - Post-doc for Alan Stern
- Pluto-Kuiper Express mission proposals due March 2000
  - We propose an integrated UV, Visible, IR instrument
  - Alan asked me to make figures showing Signal-to-Noise (SNR) compared with the Announcement of Opportunity (AO).
  - This required learning the details of the payload, the AO, and designing a flyby timeline!



Four Rules of Proposals
"Please, Fund Us Now"

- Be kind to the reviewers!

- Why is this important?
- Why is this easy?
- Why is this timely?

Four Rules of Proposals
"Please, Fund Us Now"

- Be kind to the reviewers! *PLEASE*

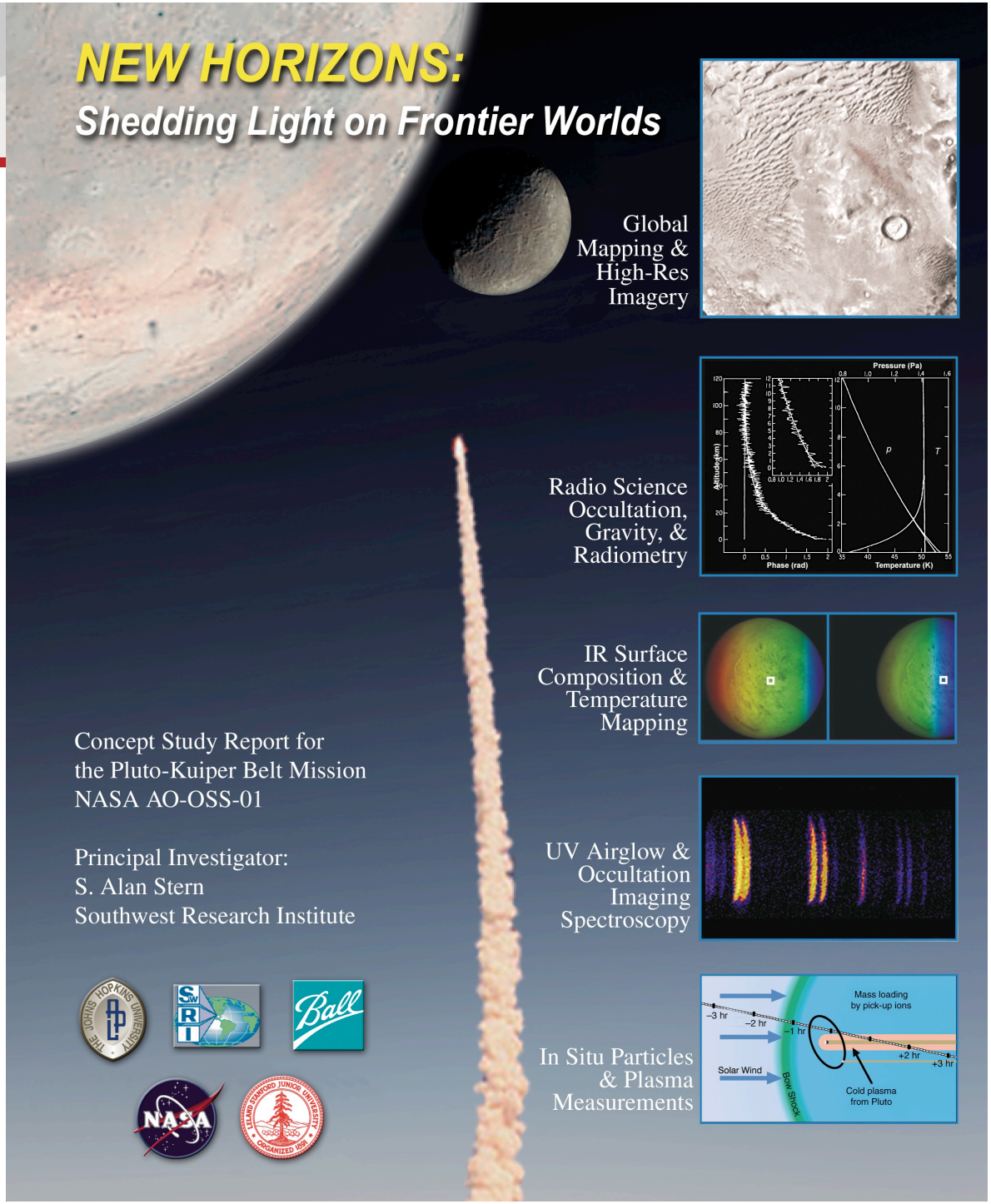
- Why is this important? *FUND*
- Why is this easy? *US*
- Why is this timely? *NOW*

542 pages of the New Horizons Concept Study Report

Section	Length
Front matter: Cover, 2-page Fact sheet, Executive Summary, Table of contents	31 pages
Science and Technical Sections	107 pages
Management, Public Impact, Development Plan	69 pages
Cost	56 pages
Other: Resumes, Planetary Protection, Data Management Plan, References, etc.	279 pages

Our Message in a One-Page Cover

- **Our team** (logos)
- **proposes** (see AO)
- **a mission of exploration** (title)
- **to send a spacecraft to distant Pluto-Charon** (subtitle, background)
- **to take pictures, vis/ IR spectra, and study the atmosphere and plasma** (diagrams).



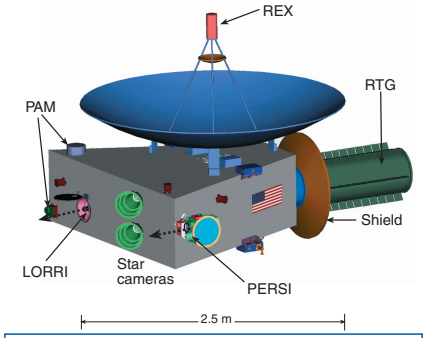
Feb 2013

Our Message in 2-Page Fact Sheet
Wondrous worlds, super science, plausible plan

NEW HORIZONS: Shedding Light on Frontier Worlds

Mission Overview. *New Horizons* is an exciting scientific investigation to obtain the first reconnaissance of Pluto-Charon, a binary planet, and one or more Kuiper Belt Objects. Understanding these worlds is fundamental to understanding the origin and evolution of the outer solar system.

New Horizons will seek to answer key scientific questions regarding the surfaces, atmospheres, interiors, and space environments of Pluto and Charon and Kuiper Belt Objects using imaging, visible and IR spectral mapping, UV spectroscopy, radio science, and in situ plasma sensors. *New Horizons* will fly through the Pluto-Charon system in 2014. Over a period of 150 days, it will conduct the first spacecraft reconnaissance of these worlds. The mission will continue on through the Kuiper Belt for further encounters.



Mission Management

Principal Investigator:	Dr. S. Alan Stern, SwRI
Project Manager:	Mr. Thomas Coughlin, JHU/APL
Payload Manager:	Mr. Bill Gibson, SwRI
Spacecraft:	JHU/APL

Mission Summary*

	Baseline	Backup
Launch date:	6–25 Dec 2004	9–25 Jan 2006
Launch vehicle:	Atlas V 541	Atlas V 541
C_3:	130 km²/s²	143 km²/s²
Post-launch ΔV:	290 m/s	290 m/s
Jupiter:	15 Apr 2006	29 Mar 2007
Pluto-Charon:	15 Jul 2014	17 Jul 2018
KBO(s):	2015–2019	2019–2026

*Delta IV 4050H options are also fully compatible, and costed. See §F and Foldout 4.

Mission Benefits

- Education/Public Outreach: Comprehensive formal and informal education programs at 2.1% of total budget minus ELV.
- Technology Transfer: Miniaturized digital solar attitude detector, low-power digital receiver.
- Small Disadvantaged Businesses: Proactive small and small disadvantaged business plan.

Science Payload

PERSI:	Visible mapping, IR spectroscopic mapping, and UV imaging spectroscopy (SwRI, Ball, NASA/GSFC)
REX:	Radio science and radiometry (Stanford, JHU/APL)
PAM:	Solar wind ion and energetic particle spectrometry (SwRI, JHU/APL)
LORRI:	Long-range and high-res visible mapping (JHU/APL)

Key Spacecraft Characteristics

Margins:	Power at Pluto 20%, Launch Dry Mass 22% (2006 mission, worst case ELV choice)
Power at Pluto:	F-5 RTG (181 W at 2014)
Wet mass at launch:	416 kg
Design heritage:	CONTOUR systems
Redundancy:	All major electronics Star cameras Data storage (2 × 16 Gb)
Propulsion:	Hydrazine monopropellant
Attitude control:	3-axis & spin-stabilized modes
Communications:	X-band, 2.5-m high gain antenna
Downlink from Pluto:	768 bps to 70-m DSN antenna
Beacon Cruise Mode:	Reduces risk

Baseline Mission Schedule and Cost Summary

	Phase A Concept Study	Phase B Formulation	Phase C/D Implementation	Phase E MO&DA	Phase F Extended Mission
Schedule	06/01–10/01	11/01–05/02	06/02–01/05	02/05–03/16	03/15–12/19
Cost w/ Reserve	$0.45 M FY01	$73.51 M FY01	$301.20 M FY01	$112.87 M FY01	$46.20 M FY01
Cost w/ Reserve	$0.45 M RY	$75.56 M RY	$321.02 M RY	$149.86 M RY	$73.00 M RY
Schedule Reserve*	None	4 Months Reserve		N/A	N/A

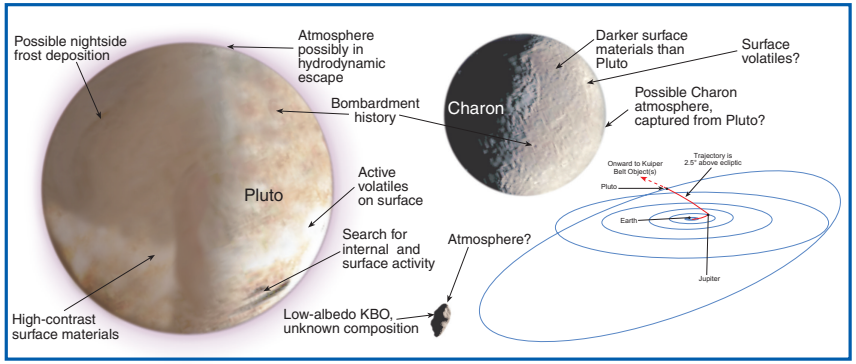
*Project reserves, except on RTG.

Total cost $488M ($FY01), 18% cost reserves except on launcher.

Feb 2013

New Horizons — *A mission to explore Pluto-Charon and Kuiper Belt Objects*

One of the best images of exotic Pluto and its icy moon Charon, as seen by the Hubble Space Telescope.



At Pluto-Charon, New Horizons will provide:

- *Images superior to those from the Hubble Space Telescope for 75 days before flyby (12 Pluto days)*
- *Global maps of both worlds at 40-km resolution and hemispheric maps at 1-km resolution*
- *IR spectral maps at up to 7-km resolution and visible 4-color maps at up to 3-km resolution*
- *High-resolution terminator images at 100-m resolution*
- *UV and radio occultations of both Pluto and Charon*
- *UV dayglow and nightglow spectra of Pluto's atmosphere*
- *In situ measurements of energetic particles and the solar wind*
- *Surface temperature maps at 50-km resolution*

Similar data will be obtained at one or more Kuiper Belt Objects.

Neptune's moon Triton is thought to be similar to Pluto. This Voyager 2 mosaic shows the fascinating complexity of this world and tantalizes us with the wonders that *New Horizons* will reveal at Pluto-Charon.

01-0634FS 9/10/2001

Our message in 5-page Executive Summary
Some excerpts, touting high return, low risk

All of these statements are backed up in the rest of the proposal

- The trans-Neptunian ... double planet Pluto-Charon ... remains unexplored.
- Sophisticated ... instrument, ... development heritage
- ... experienced spaceflight system and instrument providers.
- internationally respected Pluto-Charon and Kuiper Belt experts ... experienced instrument science leads
- Jupiter-system flyby to exercise our spacecraft &instruments, a bonus...
- fulfill *all* of the Group 1 and 2 (and most of the Group 3) measurement objectives
- within the PKB mission cost cap, and to do so with substantial cost reserves.

Getting into Detail (Backing up our Claims)
33-page Science & 76-page Technical

Science Section	**Pages**
Goals/motivation (Geology, Composition, Atmospheres, KBO)	4
Payload	16
Science Operations (encounter, downlink, AO specs, Cruise/Jupiter/KBOs)	10
Science Team	1
Data analysis and Archiving	2
Technical Section	**Pages**
Overview	1
Mission Design (trajectory, encounter date, etc.)	12
Spacecraft (antenna, thrusters, thermal, electrical, etc.)	28
Other (Integration & Test, Mission Ops, Facilities, Launch Vehicle, etc.)	33

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Goals/motivation
Example: Geology

- Widest context: comparison with Triton, etc.
- Thought-provoking science questions. For example:
  - Does Pluto display evidence of aeolian activity ?
  - Did cryo-volatiles ever erupt on the surfaces of Pluto or Charon?
- Observation goals:
  - (i) truly **global** maps of Pluto and Charon (including both approach farsides and winter-night terrains on Pluto) at characteristic resolutions of **50 km**, (ii) **hemi-spheric maps** of each body at resolutions down to **1 km**, and (iii) selected high-resolution **closeups** at resolutions as high as **100 m**.

Goals/motivation
Example: Geology traceability

New Horizons Pluto-Charon Science Traceability

(Blue = Main Measurement Technique; White = Supporting Observational Technique)

AO Goals (Numbered within AO Groups)	Summary of Pluto SDT Measurement Objective	*NHP* Measurement Technique(s)	*NHP* Instrument(s)	Text Reference	Notes
Group 1					
G1.1/Characterize geology and geomorphology	Map viewable disk: Pan-chromatic (1 km/lp) and in colors	Visible wavelength images	**PERSI/MVIC** Pan & 4-color,	§E.4.2.1	Will also include panchromatic 40 km/lp "far side" map with LORRI, and 50 km nightside map with MVIC
			LORRI, panchromatic		
G1.2/Surface composition mapping	Determine volatile distribution at 5-10 km/pxl	Surface IR mapping spectra	**PERSI/LEISA**	§E.4.2.2 §E.3.2.3	1.25-2.50 μm R = 300, 2.10-2.25 μm R = 600
		Visible color images	**PERSI/MVIC**	§E.4.2.2, §E.3.2.2	3 Vis-NIR colors
		8900 Å CH_4-band images	**PERSI/MVIC**	§E.4.2.2, §E.3.2.2	0.8 km/pixel hemispheric map

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G1.1/Characterize geology and geomorphology	Map viewable disk: Pan-chromatic (1 km/lp) and in colors	Visible wavelength images	**PERSI/MVIC** Pan & 4-color,
			LORRI, panchromatic

Science Goals in Announcement of Opportunity

Group 1 Objectives: REQUIRED
Specified by NASA
Characterize the global geology and morphology of Pluto and Charon
Map surface composition of Pluto and Charon
Characterize the neutral atmosphere of Pluto and its escape rate
Group 2 Objectives: STRONGLY DESIRED
Specified by NASA
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
Characterize Pluto's ionosphere and solar wind interaction
Search for neutral species including H, H2, HCN, and CxHy, 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 Objectives: DESIRED
Specified by NASA
Characterize the energetic particle environment of Pluto and Charon
Refine bulk parameters (radii, masses, densities) and orbits of Pluto & Charon
Search for magnetic fields of Pluto and Charon
Search for additional satellites and rings

Supplemental Science Goals Added by New Horizons Team

Group 1 Objectives: REQUIRED
Added and ranked by New Horizons Science Team
None
Group 2 Objectives: STRONGLY DESIRED
Added and ranked by New Horizons Science Team
Composition of dark surfaces on Pluto
"Far-side" imaging of Pluto and Charon
"Far-side" color and composition of Pluto and Charon
High resolution imaging of Nix and Hydra
Composition of Nix and Hydra
Shapes of Nix and Hydra
Group 3 Objectives: DESIRED
Added and ranked by New Horizons Science Team
Surface microphysics of Pluto and Charon
Measure the surface temperatures of Nix and Hydra
Measure the phase curve of Nix and Hydra
Image Nix and Hydra in stereo
Education/Public Outreach

Getting into Detail (Backing up our Claims)
33-page Science & 76-page Technical

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Payload Overview from Fact Sheet

- PERSI:

Visible mapping, IR spectroscopic mapping, and UV imaging spectroscopy

- REX:

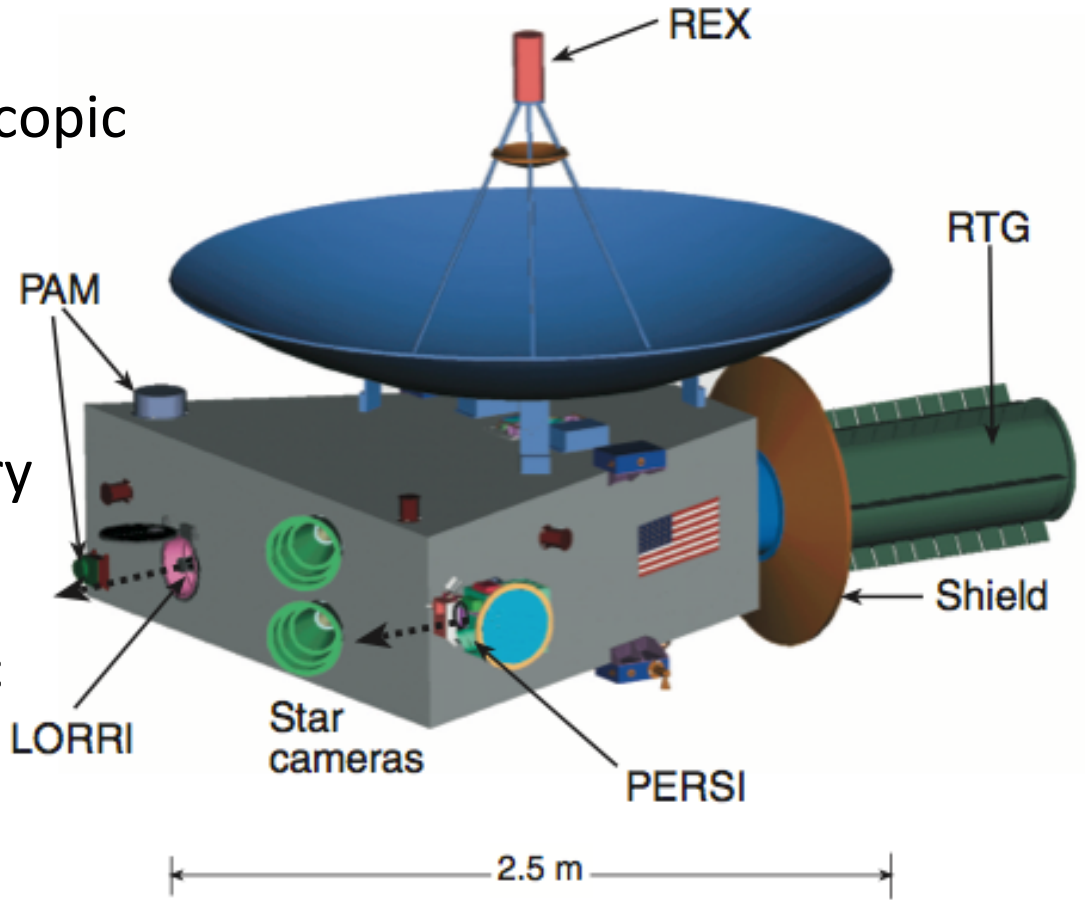
Radio science and radiometry

- PAM:

Solar wind ion and energetic particle spectrometry

- LORRI:

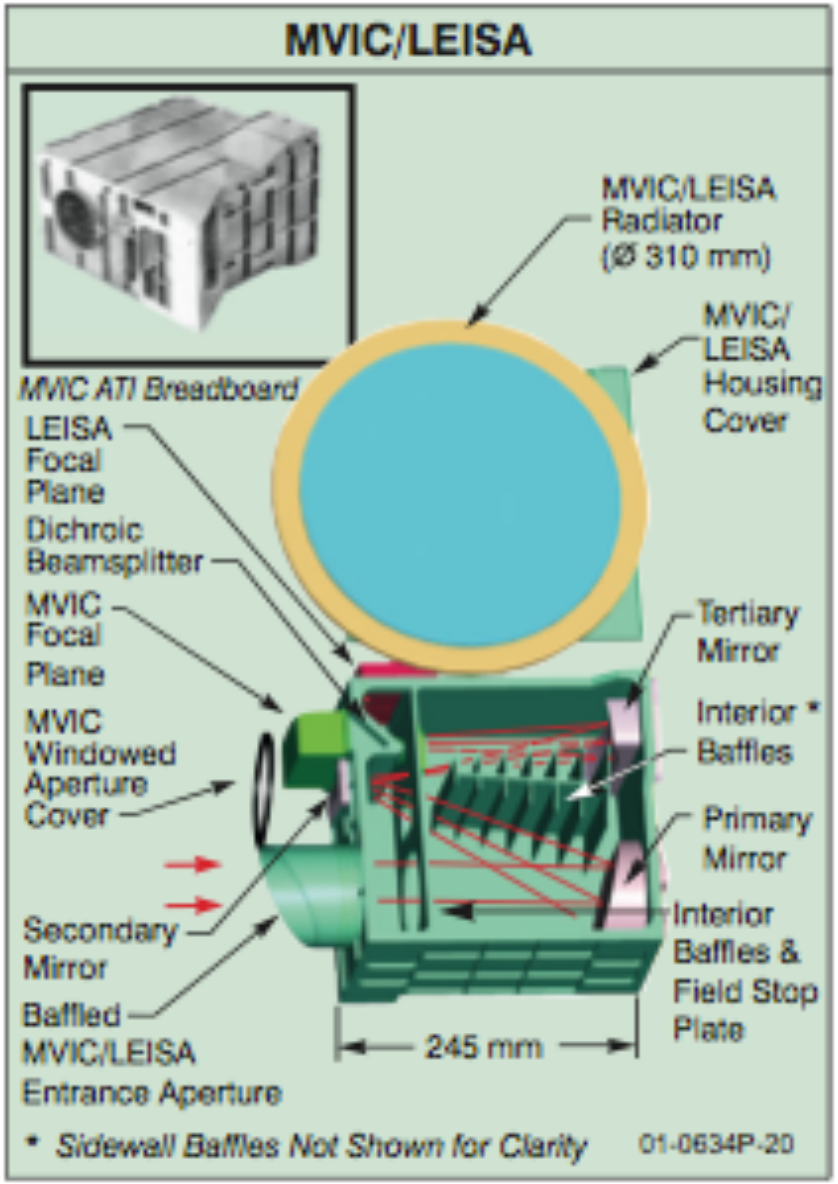
Long-range and high-res visible mapping

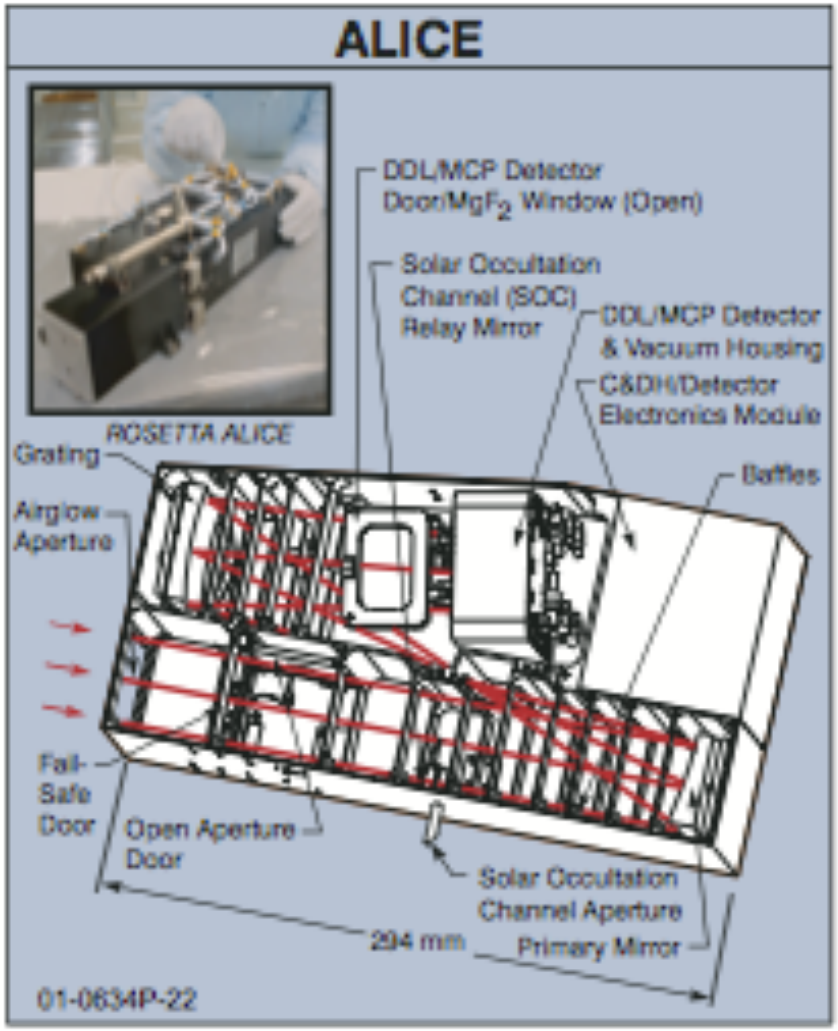


Pluto Exploration Remote Sensing Instrument (PERSI)

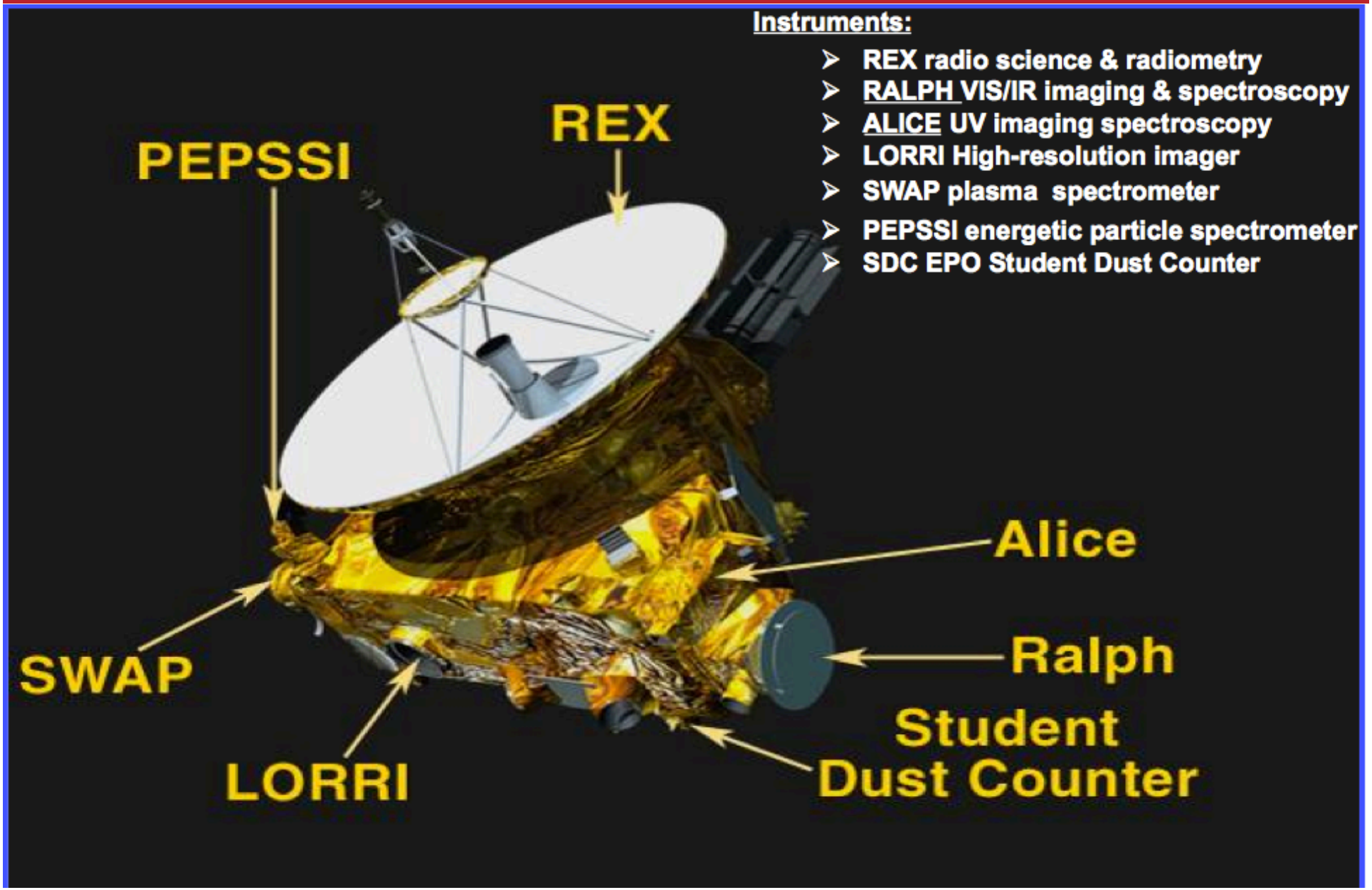
- "PERSI contains three sensors (Vis, IR, UV) sharing mechanical, thermal, electrical, and command/data handling resources; this integrated approach reduces cost and mass, and simplifies both spacecraft integration and encounter operations."

PERSI Sub-assemblies
Showing hardware reinforces the heritage





Payload: Changes since Proposal



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Strawman Encounter Plan
53 observations defined

Baseline Mission Strawman Timeline

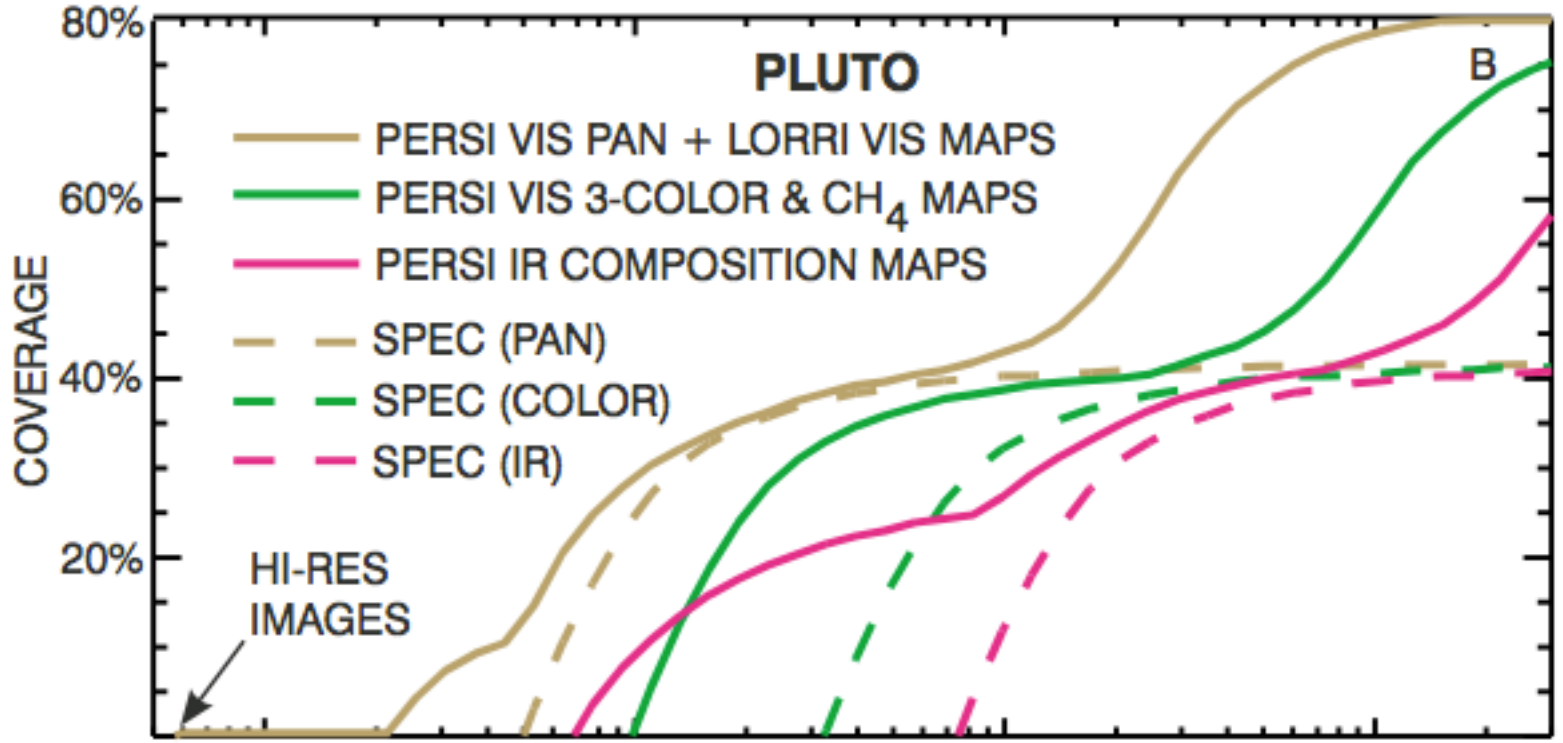
Obs #	Obs Prep Maneuver Time (min)	Obs Start (Time from C/A)	Range to Surface at Mid-Time (km)	Obs Duration	Sensor	Target	Measurement	Resolution (km/pixel)	Data Resident in Memory (Gb)*
Approach Observatory Phase (AOP)									
1	14	-3 months	1.14E+08	2 hours	ALL	Pluto	All-Instrument Survey		0.24
2	3	-3 months	1.14E+08	2 hours	ALL	Charon	All-Instrument Survey		0.47
3	14	-2 months	7.63E+07	2 hours	ALL	Pluto	All-Instrument Survey		0.24
4	3	-2 months	7.63E+07	2 hours	ALL	Charon	All-Instrument Survey		0.47
5	14	-45,-44...,-30d	4.76E+07	2 hours	ALL	Pluto	All-Instrument Survey		0.24
6	3	-45,-44...,-30d	4.76E+07	2 hours	ALL	Charon	All-Instrument Survey		0.47
7	14	-1 months	3.81E+07	1 hours	PERSI UV	Pluto	Example Stellar Occ	<25	0.29
8	14	-1 months	3.81E+07	1 hours	PERSI UV	Charon	Example Stellar Occ	<25	0.29
Approach Far Encounter Phase (AFEP)									
9	14	-11 to -4.5 d every 0.5d	1.25E+07	2 hours	ALL	Pluto	All-Instrument Survey		0.33
10	3	-11 to -4.5 d every 0.5d	1.25E+07	2 hours	ALL	Charon	All-Instrument Survey		1.73
Near Encounter Phase (NEP)									
11	14	-4 to -1d every 0.5d	3.08E+06	2 hours	ALL	Pluto	Best All-Instrument Survey		0.38
12	3	-4 to -1d every 0.5d	3.08E+06	2 hours	ALL	Charon	Best All-Instrument Survey		0.67
13	14	-867 min	7.02E+05	120 min	ALL	Pluto	Best All-Instrument Survey		0.39
14	14	-732 min	5.90E+05	120 min	ALL	Charon	Best All-Instrument Survey		0.69
15	14	-597 min	4.75E+05	100 min	PERSI UV	Both	Limb Deep Airglow (4 Sequential)	2,377	0.69
16	5	-491 min	3.83E+05	100 min	PERSI UV	Both		1,916	0.69
17	5	-385 min	2.91E+05	100 min	PERSI UV	Both		1,454	0.69
18	5	-279 min	1.99E+05	100 min	PERSI UV	Both		993	0.69
19	2	-176 min	1.48E+05	10 min	PERSI UV	Pluto	UV Pluto Surface Sampling	741	0.69
20	6	-159 min	1.38E+05	10 min	PERSI UV	Charon	UV Charon Surface Sampling	688	0.69
21	6	-142 min	1.20E+05	6 min	PERSI IR	Pluto	Surface Composition Map (2 Redundant)	7.5	1.15
22	3	-132 min	1.12E+05	6 min	PERSI IR	Pluto		6.9	1.62
23	6	-119 min	1.05E+05	6 min	PERSI IR	Charon	Surface Composition Map (2 Redundant)	6.5	1.97
24	3	-109 min	9.66E+04	6 min	PERSI IR	Charon		6.0	2.34
25	6	-96 min	8.78E+04	1 min	LORRI VIS	Charon	Pan Map	0.44	2.39
26	6	-88 min	7.67E+04	12 min	PERSI VIS	Charon	4 Color Map (2 Redundant & Stereo Pair)	1.5	2.59
27	6	-69 min	6.15E+04	12 min	PERSI VIS	Charon		1.2	2.84
28	6	-50 min	3.88E+04	12 min	PERSI VIS	Pluto	4 Color Map	0.78	3.58
29	3	-34 min	2.80E+04	6 min	PERSI VIS	Pluto	Panchromatic Map (2 Redundant & Stereo Pair)	0.56	3.83
30	3	-24 min	2.03E+04	6 min	PERSI VIS	Pluto		0.41	4.18
31	6	-11 min	1.35E+04	0.1 sec	LORRI VIS	Pluto	36-Frame Panchromatic High-Res Terminator Movie (2 Redundant & Stereo Pair)	0.07	4.68
32	2	-7 min	1.15E+04	36 x 0.1 sec	PERSI VIS LORRI VIS	Pluto		0.23 0.06	5.19
33	2	-3 min	1.02E+04	6 min	PERSI IR	Pluto	High Res. Surface Comp.	0.63	5.95
34	3	7 min	2.82E+04	18 x 0.1 sec	PERSI VIS LORRI VIS	Charon	18-Frame Panchromatic High-Res Movie (2 Redundant & Stereo Pair)	0.56 0.14	6.20
35	2	13 min	2.99E+04	18 x 0.1 sec	PERSI VIS LORRI VIS	Charon		0.60 0.15	6.45

Obs #	Obs Prep Maneuver Time (min)	Obs Start (Time from C/A)	Range to Surface at Mid-Time (km)	Obs Duration	Sensor	Target	Measurement	Resolution (km/pixel)	Data Resident in Memory (Gb)*
29	3	-34 min	2.80E+04	6 min	PERSI VIS	Pluto	Panchromatic Map	0.56	3.83
30	3	-24 min	2.03E+04	6 min	PERSI VIS	Pluto	(2 Redundant & Stereo Pair)	0.41	4.18

Departure Far Encounter Phase (DFEP)									
52	14	1 to 7 d every 0.5d	1.25E+06	2 hours	ALL	Pluto	Hi-Phase All-Instrument		4.53
53	3	1 to 7 d every 0.5d	1.25E+06	2 hours	ALL	Charon	Hi-Phase All-Instrument		4.80
Departure Observatory Phase (DOP)									
(Similar to Approach Observatory Phase, extending to TCA+60 d. Detail omitted)									4.37

Meeting and Exceeding AO Objectives at Pluto-Charon

- Use the strawman encounter plans and the payload capabilities to show New Horizons meets and exceeds the AO's science objectives.
- Show detailed calculations for for Group 1, shorter words for Group 2 & 3.



Science Traceability Matrix

	Science Requirements					
	Pluto-SDT	Expected Baseline Mission PKB Capability with *New Horizons*		Observation Number		MEETS/
	Measurement Requirement	Main	Supporting	Main	Supporting	EXCEEDS
GROUP 1 PLUTO	Pan Map, Viewable Disk, 1 km/lp @ SSP	**MVIC**: 2 Full Pan Maps: 1.1 & 0.8 km/lp	**MVIC & LORRI**: Rot. Resolved Pan Approach Maps; Nightside Map	29, 30	9,11,13,50,52	EXCEEDS
	2-5 Color Maps, Viewable Disk, 3-10 km/lp @ SSP	**MVIC**: 4 Full Color Maps: 1.6 km/lp	**MVIC**: Rotationally Resolved 4-Color Approach Maps	28	9,11,13,50,52	EXCEEDS
	Map to Specify Phase Integrals	**MVIC**: Maps at 6 phases, 0.4-1.0μm **LEISA**: Maps at 4 phases, 1.25-2.5μm	**MVIC, LORRI, & LEISA**: Rotationally Resolved Measurements, 11° & 169° Phase	13,21, 28 -32, 33 42,37, 46 ,50	9,11,13,50,52	EXCEEDS
	SNR ~100 Dynamic Range > 30	**MVIC**: SNR > 300 (Panchromatic) **MVIC**: SNR > 150 (Green, Red)	**MVIC**: SNR > 80 (Blue) **MVIC**: SNR > 50 (CH_4) **LORRI**: SNR > 160	All Sunlit Pluto **MVIC** Images	All Pluto **LORRI** Images	EXCEEDS

Measurement Requirement	Main	Main
Pan Map, Viewable Disk, 1 km/lp @ SSP	**MVIC**: 2 Full Pan Maps: 1.1 & 0.8 km/lp	29, 30

Here, this is just to show our layout: Letting the reviewer see the plan on one page

FOLDOUT 3: PLUTO-CHARON STRAWMAN ENCOUNTER PLAN

Science Requirements

	Pluto-SDT Measurement Requirement	Expected Baseline Mission PKB Capability with *New Horizons* Main	Supporting	Observation Number Main	Supporting	MEETS/ EXCEEDS
GROUP 1 PLUTO	Pan Map, Viewable Disk, 1 km/lp @ SSP	**MVIC**: 2 Full Pan Maps: 1.1 & 0.8 km/lp	**MVIC & LORRI**: Rot. Resolved Pan Approach Maps, Nightside Map	29, 30	9,11,13,50,52	EXCEEDS
	2-5 Color Maps, Viewable Disk, 3-10 km/lp @ SSP	**MVIC**: 4 Full Color Maps: 1.6 km/lp	**MVIC**: Rotationally Resolved 4-Color Approach Maps	28	9,11,13,50,52	EXCEEDS
	Map to Specify Phase Integrals	**MVIC**: Maps at 6 phases, 0.4-1.0μm **LEISA**: Maps at 4 phases, 1.25-2.5μm	**MVIC, LORRI, & LEISA**: Rotationally Resolved Measurements, 11° & 169° Phase	13,21, 28 -32, 33 42,37,46,50	9,11,13,50,52	EXCEEDS
	SNR ~100 Dynamic Range > 30	**MVIC**: SNR > 300 (Panchromatic) **MVIC**: SNR > 150 (Green, Red)	**MVIC**: SNR > 80 (Blue) **MVIC**: SNR > 50 (CH_4) **LORRI**: SNR > 160	All Sunlit Pluto **MVIC** Images	All Pluto **LORRI** Images	EXCEEDS
GROUP 1 CHARON	Pan Map, Viewable Disk, 1 km/lp @ SSP	**MVIC**: 2 Full Pan Maps: 1.2 km/lp Each	**MVIC & LORRI**: Rotationally Resolved Pan Approach Maps **LORRI**: Pan Map 0.8 km/lp	34,35	10,12,14,25, 51, 53	EXCEEDS
	2-5 Color Maps, Viewable Disk, 3-10 km/lp @ SSP	**MVIC**: 4 Full Color Maps (Twice!): 2.4 & 3.0 km/lp;	**MVIC**: Rotationally Resolved 4-Color Approach Maps	26, 27	10,12,14,51,53	EXCEEDS
	Map to Specify Phase Integrals	**MVIC**: Maps at 6 phases, 0.4-1.0μm **LEISA**: Maps at 4 phases, 1.25-2.5μm	**MVIC, LORRI, & LEISA**: Rotationally Resolved Measurements, 11° & 169° Phase	14,23,24, 26,27, 34,35,36 50	10,12,14,51,53	EXCEEDS
	SNR ~100 Dynamic Range > 30	**MVIC**: SNR > 240 (Panchromatic) **MVIC**: SNR > 110 (Green, Red)	**MVIC**: SNR > 60 (Blue) **MVIC**: SNR > 30 (CH_4) **LORRI**: SNR > 120	All Charon **MVIC** Images	All Charon **LORRI** Images	EXCEEDS
GRP 1 PLUTO	IR Spectral Maps, 1 Hemisphere, 10 km/px, Detect Δ Albedo = 0.02 N_2, CO, CH_4, ...Distribution at 5-10 km/pxl SSP Resolution	**LEISA**: 2 Full Maps: 7.0, 6.5 km/pxl	**LEISA**: Lower Resolution Farside Spectral Maps	21,22	11,13,46	EXCEEDS
		LEISA: 2 Full Maps: 7.0, 6.5 km/pxl	**MVIC**: CH_4 & Broadband Color Maps, 0.8 km/pixel	21,22	11,13,28	EXCEEDS
	λ/Δλ > 250 Over all or part of 1-5 μm	**LEISA**: λ/Δλ=300 over 1.25 -2.50 μm λ/Δλ=600 over 2.10 -2.25 μm	**MVIC**: CH_4 0.89 μm Maps **ALICE**: FUV Surface Spectra	All **LEISA** Obs	28 19	EXCEEDS
GRP 1 CHARON	IR Spectral Maps, 1 Hemisphere, 10 km/px, Detect Δ Albedo = 0.02 N_2, CO , CH_4 ...Distribution at 5-10 km/pxl SSP Resolution	**LEISA**: 2 Full Maps: 6.1, 5.6 km/px	**LEISA**: Lower Resolution Farside Spectral Maps	23,24	12,14,47	EXCEEDS
		LEISA: 2 Full Maps: 6.1, 5.6 km/pxl	**MVIC** CH_4 & Broadband Color Maps, 1.2 km/pixel	23,24	12,14, 26,27	EXCEEDS
	λ/Δλ > 250 Over all or part of 1-5 μm	**LEISA**: λ/Δλ=300 over 1.25 -2.50 μm λ/Δλ=600 over 2.10 -2.25 μm	**MVIC**: 0.89μm CH_4 Search Map **ALICE**: FUV Surface Spectra	All **LEISA** Obs	24,25 20	EXCEEDS
GROUP 1 PLUTO	Determine Mole Fractions of N_2, CO, CH_4, & Ar to 1% in Total Mixing Ratio	**ALICE**: Airglow, Solar Occultation, N_2, CO, CH_4, & Ar Mole Fracs to 1%	**LEISA**: Model Atm from Surface Composition & Temperature; **ALICE**: Stellar Occs	15-18,38	21,22,33 7,49	EXCEEDS
	Measure T, dT/dz at 100 km Vertical Resolution to 10% accuracy at $n > 10^7$ cm^{-3}	**ALICE**: Solar Occultation to 10% from $n=6x10^7$ to $6x10^8$ cm^{-3}	**ALICE**: 2 Stellar Occultations; **ALICE**: Solar Baseline Calibration	38	7, 49 48	EXCEEDS
	T and Distribution of Limb Hazes at Vertical Resolution < 5 km	**MVIC**: HI Phase Limb Map (2 km/lp); Coverage: $4x10^5$ km^2	**ALICE**: 1800-1850 Å Solar Occ **MVIC & LORRI**: All Maps	37	38 28-32	EXCEEDS
	Measure T, P at Atm. Base to ± 1 K and 0.1 μbar	**REX**: Radio Occultation	**ALICE**: Solar Occultation Modeling to Surface Possible?	39	38	EXCEEDS
	Determine the Atmospheric Escape Rate	**ALICE**: Solar Occultation Yield Esc Rate to 35%	**ALICE**: Lyα Maps Yield Hi-Specific Escape Rate **PAM**: Energetic Pickup Ions; Solar Wind Standoff Distance to 3000 km	38	15-18,40,41, 45 All **PAM** Obs	EXCEEDS
GROUP 2 PLUTO	Characterize Surface/Atm Variability	**ALL**: See Variability Sidebar		Numerous		Yes
	Image in Stereo	**MVIC**: 2/3 of C/A Hemisphere; 1 km/lp; 8° Stereo Angle	**MVIC**: Two 36-Frame Terminator Movies, $>3x10^3$ km^2 Coverage, 50% Overlap/Frame **LORRI**: $>5x10^3$ km^2 at 0.16 km/lp	29,30	31,32	Yes
	Map Terminator at High-Resolution	**MVIC**: Two 36-Frame Terminator Movies, $>10^3$ km^2 at up to 0.46 km/lp	**LORRI**: Two 36-frame Terminator Movies, $5x10^3$ km^2 at up to 0.1 km/lp	31,32	31,32	Yes
	Map Composition of Selected Areas at High-Resolution	**LEISA**: 360x500 km^2, 0.6 km/pixel	**MVIC**: Full Encounter Hemisphere, 2 km/lp CH_4 Maps	33	28	Yes
	Characterize Plus Ionosphere and Solar Wind Interaction	**REX**: Measure e^- Density to 10^3 cm^{-3} **PAM**: Energetic Pickup Ions; Solar Wind Standoff Distance to 3000 km	**ALICE**: Search/Map C, O, N^+; Map H Corona Against ISM Lyα	39 All **PAM** Obs	15-18,38,40, 41,45	Yes
	Search for Minor Pluto Atmospheric Neutrals (H, H_2,HCN,C,H_x,nitriles,...)	**ALICE**: Solar Occ (HCN, C_xH_y) Airglow (H_2,C,H,O,N,S,He,Ne, ...) Map H Corona Against ISM Lyα	**LEISA**: Constrain Atm from Surface Composition Maps	15-18,38,40, 41,45	21,22,46	Yes
	Determine Bond Albedos	**MVIC**: Phase-Dependent Maps, Pan plus 4 Colors	**LEISA**: Phase Dependent Spectral Maps	13,28-32,37,42, 50	13,21,22,33, 46,50	Yes
	Map Surface Temperature Fields	**LEISA**: λ/Δλ=600: Use N_2, H_2O, CH_4 Bands to Measure T vs. Location at 40-100 km Scale 2-6 K Resolution	**MVIC**: Model at few km scale from Albedo & Energy Balance. **ALICE** or **REX**: Model from Occ Near-Surf P,T, **REX** Radiometry	21,22,33	29,30 38,39	Yes
GROUP 2 CHARON	Characterize Surface/Atm Variability	**ALL**: See Variability Sidebar		Numerous		Yes
	Image in Stereo	**MVIC**: Encounter Hemisphere, 4 km/p,4 Colors, 6° Stereo Angle	**MVIC**: Terminator Stereo, 1.2 km/lp Panchromatic, $>2x10^3$ km^2 **LORRI**: $7x10^3$ km^2 at up to 0.3 km/lp	26,27	34,35	Yes
	Map Terminator at High Resolution	**MVIC**: 2 Overlapped Maps, $>6x10^3$ km^2 Overlapped	**LORRI**: Two 18-frame Movies, 2×10^3 km^2 at up to 0.3 km/lp	34,35		Yes
	Map Composition of Selected Areas at High Resolution	**LEISA**: Full C/A Hemisphere, 2.1 km/pixel	**MVIC**: Full Encounter Hemisphere, 3 km/lp CH_4 Maps	36	26,27	Yes
	Search for Charon Atmosphere	**ALICE**: Solar Occultation Search for N_2, CO, CH_4, Ar, C_xH_y etc.; Airglow Search for C,H,O,N,S, He, ions, etc. **REX**: Radio Occultation	**ALICE**: Stellar Occultation **LEISA**: Model/Constrain from Surface Comp Vapor Pressure **MVIC**: CH_4 Maps	15-18,43 44	8 23,24,36 26,27	Yes
	Determine Bond Albedos	**MVIC**: Phase-Dependent Maps, Panchromatic and 4 Colors	**LEISA**: Phase Dependent Spectral Maps	14,26, 27,34,35 51	14,23,24,36,51	Yes
	Map Surface Temperatures	**LEISA**: Use H_2O & CH_4 Band Positions	**MVIC**: Model Temp Fields from Albedo Energy Balance	23,24,36	26,27	Yes
GROUP 3 SYSTEM	Characterize Energetic Particles	**PAM**: Flux & Composition up to 5 MeV Particles		All **PAM** Obs		Yes
	Refine Bulk Parameters (Radii, Masses, Densities) & Orbits	**MVIC**: Measure Radii to <0.2%, Oblatenesses to <0.2%; Refine Helio & Charon Orbits (OpNav)	**REX**: with **MVIC** Determine Densities to 0.3%.	OpNav,1 -6,9 14, 28-32, 52,53	Radio Doppler Tracking	Yes
	Search for Magnetic Fields	None				No
	Search for Satellites & Rings	**MVIC**: Full Hill Sphere Search to 11 km Radius at Albedo=0.3; Hi-Phase Ring Search to $\tau \geq 10^{-3}$	**ALICE**: Solar Occ Ring Opacity Search to $\tau^3 10^{-3}$	1-6,9-14 37,42	38	Yes

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COLOR CODE

PEN COLORS: PURPLE = ALL NEW HORIZONS (MVIC, LEISA, ALICE, PAM, LORRI, COMBINED SEQUENTIAL OBSERVING SEQUENCE)
GREEN = MVIC OR LORRI VISIBLE IMAGERS | RED = LEISA IR SPECTROMETER | BLUE = ALICE UV SPECTROMETER
GOLD=REX RADIO SCIENCE | BLACK = PAM PLASMA | BACKGROUNDS: WHITE = PLUTO OR SYSTEM | GRAY = CHARON

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Baseline Mission Strawman Timeline

Obs #	Obs Prep Maneuver Time (min)	Obs Start (Time from C/A)	Range to Surface at Mid-Time (km)	Obs Duration	Sensor	Target	Measurement	Resolution (km/pixel)	Data Resident in Memory (Gb)*
Approach Observatory Phase (AOP)									
1	14	-3 months	1.14E+08	2 hours	ALL	Pluto	All-Instrument Survey		0.24
2	3	-3 months	1.14E+08	2 hours	ALL	Charon	All-Instrument Survey		0.47
3	14	-2 months	7.63E+07	2 hours	ALL	Pluto	All-Instrument Survey		0.24
4	3	-2 months	7.63E+07	2 hours	ALL	Charon	All-Instrument Survey		0.47
5	14	-45,-44 ...-30d	4.76E+07	2 hours	ALL	Pluto	All-Instrument Survey		0.24
6	3	-45,-44 ...-30d	4.76E+07	2 hours	ALL	Charon	All-Instrument Survey		0.47
7	14	-1 months	3.81E+07	1 hours	PERSI UV	Pluto	Example Stellar Occ	<25	0.29
8	14	-1 months	3.81E+07	1 hours	PERSI UV	Charon	Example Stellar Occ	<25	0.29
Approach Far Encounter Phase (AFEP)									
9	14	-11 to -4.5 d every 0.5d	1.25E+07	2 hours	ALL	Pluto	All-Instrument Survey		0.33
10	3	-11 to -4.5 d every 0.5d	1.25E+07	2 hours	ALL	Charon	All-Instrument Survey		1.73
Near Encounter Phase (NEP)									
11	14	-4 to -1d every 0.5d	3.08E+06	2 hours	ALL	Pluto	Best All-Instrument Survey		0.38
12	3	-4 to -1d every 0.5d	3.08E+06	2 hours	ALL	Charon	Best All-Instrument Survey		0.67
13	14	-867 min	7.02E+05	120 min	ALL	Pluto	Best All-Instrument Survey		0.39
14	14	-732 min	5.90E+05	120 min	ALL	Charon	Best All-Instrument Survey		0.69
15	14	-597 min	4.75E+05	100 min	PERSI UV	Both	Limb Deep Airglow (4 Sequential)	2,377	0.69
16	5	-491 min	3.83E+05	100 min	PERSI UV	Both		1,916	0.69
17	5	-385 min	2.91E+05	100 min	PERSI UV	Both		1,454	0.69
18	5	-279 min	1.99E+05	100 min	PERSI UV	Both		993	0.69
19	2	-176 min	1.48E+05	10 min	PERSI UV	Pluto	UV Pluto Surface Sampling	741	0.69
20	6	-159 min	1.38E+05	10 min	PERSI UV	Charon	UV Charon Surface Sampling	688	0.69
21	6	-142 min	1.20E+05	6 min	PERSI IR	Pluto	Surface Composition Map (2 Redundant)	7.5	1.15
22	3	-132 min	1.12E+05	6 min	PERSI IR	Pluto		6.9	1.82
23	6	-119 min	1.05E+05	6 min	PERSI IR	Charon	Surface Composition Map (2 Redundant)	6.5	1.97
24	3	-109 min	9.66E+04	6 min	PERSI IR	Charon		6.0	2.34
25	6	-96 min	8.78E+04	1 min	LORRI VIS	Charon	Pan Map	0.44	2.39
26	6	-88 min	7.67E+04	12 min	PERSI VIS	Charon	4 Color Map (2 Redundant & Stereo Pair)	1.5	2.59
27	6	-69 min	6.15E+04	12 min	PERSI VIS	Charon		1.2	2.84
28	6	-50 min	3.88E+04	12 min	PERSI VIS	Pluto	4 Color Map	0.78	3.58
29	3	-34 min	2.80E+04	6 min	PERSI VIS	Pluto	Panchromatic Map (2 Redundant & Stereo Pair)	0.56	3.83
30	3	-24 min	2.03E+04	6 min	PERSI VIS	Pluto		0.41	4.18
31	6	-11 min	1.35E+04	36 x 0.1 sec	PERSI VIS LORRI VIS	Pluto	36-Frame Panchromatic High-Res Terminator Movie (2 Redundant & Stereo Pair)	0.27 0.07	4.68
32	2	-7 min	1.15E+04	36 x 0.1 sec	PERSI VIS LORRI VIS	Pluto		0.23 0.06	5.19
33	2	-3 min	1.02E+04	6 min	PERSI IR	Pluto	High Res. Surface Comp.	0.63	5.95
34	3	7 min	2.82E+04	18 x 0.1 sec	PERSI VIS LORRI VIS	Charon	18-Frame Panchromatic High-Res Movie (2 Redundant & Stereo Pair)	0.56 0.14	6.20
35	2	13 min	2.99E+04	18 x 0.1 sec	PERSI VIS LORRI VIS	Charon		0.60 0.15	6.45
36	2	19 min	3.32E+04	6 min	PERSI IR	Charon	High Res. Surface Comp.	2.1	7.12
37	3	29 min	2.84E+04	5 min	PERSI VIS	Pluto	Haze Map (Pan)	0.57	7.37
38	14	49 min	5.92E+04	38 min	PERSI UV	Pluto	Pluto Solar Occ	9.8	7.64
39	00	49 min	5.92E+04	38 min	REX RADIO	Pluto	Radio Earth Occultation	<5	7.65
40	14	102 min	9.53E+04	16 min	PERSI UV	Pluto	Hi-Res. Nightglow E-W	476	7.65
41	6	125 min	1.15E+05	16 min	PERSI UV	Pluto	Hi-Res. Nightglow N-S	576	7.65
42	6	148 min	1.30E+05	5 min	PERSI VIS	Pluto	Ring Search & Nightside Image (Pan)	2.6	7.95
43	14	168 min	1.64E+05	35 min	PERSI UV	Charon	Charon Solar Occ	27.1	8.22
44	00	168 min	1.64E+05	35 min	REX RADIO	Charon	Radio Earth occultation	<5	8.23
45	14	218 min	2.15E+05	60 min	PERSI UV	Pluto	Deep Nightglow	1,075.7	8.23
46	3	282 min	2.47E+05	6 min	PERSI IR	Pluto	High Phase Surface Comp.	15.3	8.56
47	3	292 min	2.60E+05	6 min	PERSI IR	Charon	High Phase Surface Comp.	16.1	8.82
48	14	313 min	N/A	5 min	PERSI UV	Sun	Solar Calibration	NA	8.87
49	14	333 min	3.09E+05	45 min	PERSI UV	Pluto	Example Stellar Occ	<25	8.87
50	2	600 min	5.74E+05	2 hours	ALL	Pluto	Hi-Phase All-Instrument		9.20
51	3	724 min	6.88E+05	2 hours	ALL	Charon	Hi-Phase All-Instrument		10.15
Departure Far Encounter Phase (DFEP)									
52	14	1 to 7 d every 0.5d	1.25E+06	2 hours	ALL	Pluto	Hi-Phase All-Instrument		4.53
53	3	1 to 7 d every 0.5d	1.25E+06	2 hours	ALL	Charon	Hi-Phase All-Instrument		4.80
Departure Observatory Phase (DOP)									
(Similar to Approach Observatory Phase, extending to TCA+60 d. Detail omitted)									4.37

* Data from Approach Phases are losslessly compressed and downlinked prior to Near Encounter Phase. Data from the Near Encounter Phase are losslessly compressed at TCA – 1 day (Obs #11-12) and TCA + 1 day (Obs # 13-51). The data volumes shown in this foldout represent the total amount of on-board storage needed at the end of the specified observation. Data storage requirements increase when new data are taken and decrease as time and CPU cycles allow for lossless compression. Max data storage volume includes 664 Mb for distributed PAM observations, OpNav, retargetables, and Guest Observer (GI/PO) observations.

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Debrief Items 34 & 35

Data Storage High Water Mark*

Clarification

KEY ENCOUNTER ATTRIBUTES

- ✓ **Greatly exceeds baseline SDT science requirements.**
- ✓ **Added memory** enhances science return and data storage redundancy.
- ✓ **Long, 90-day timebase** of standardized pre-encounter observations significantly enhances science return.
- ✓ **Simple, "first target light" observations** test hardware and sequences, generate public excitement, & initiate data flow.
- ✓ **Sparse encounter timeline** except in the days around C/A allows single-shift (8hr/day) ops for most of each encounter.
- ✓ **Flexibility** for OpNav & TCM scheduling.
- ✓ **Maintains positive margins** for memory, power, and scheduling throughout.
- ✓ **"Bookend" calibrations** 4 months either side of each encounter.
- ✓ **Rapid (<30 day) data return** of high-priority/quick-look science protects against data loss, and ensures optimal scheduling of subsequent lossless data return.

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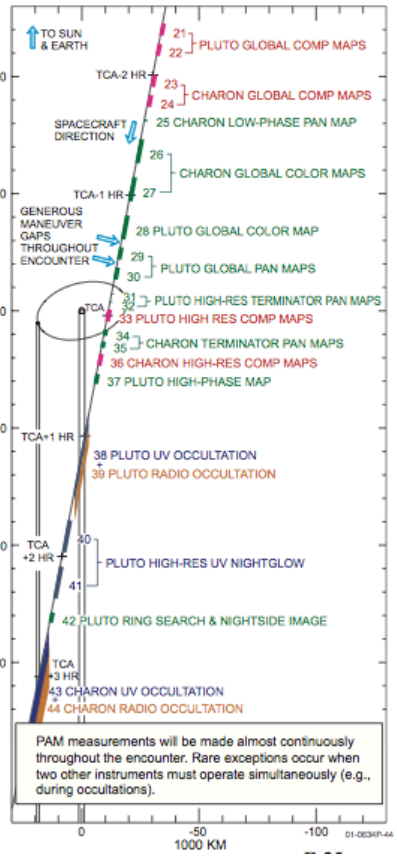

PAM measurements will be made almost continuously throughout the encounter. Rare exceptions occur when two other instruments must operate simultaneously (e.g., during occultations).

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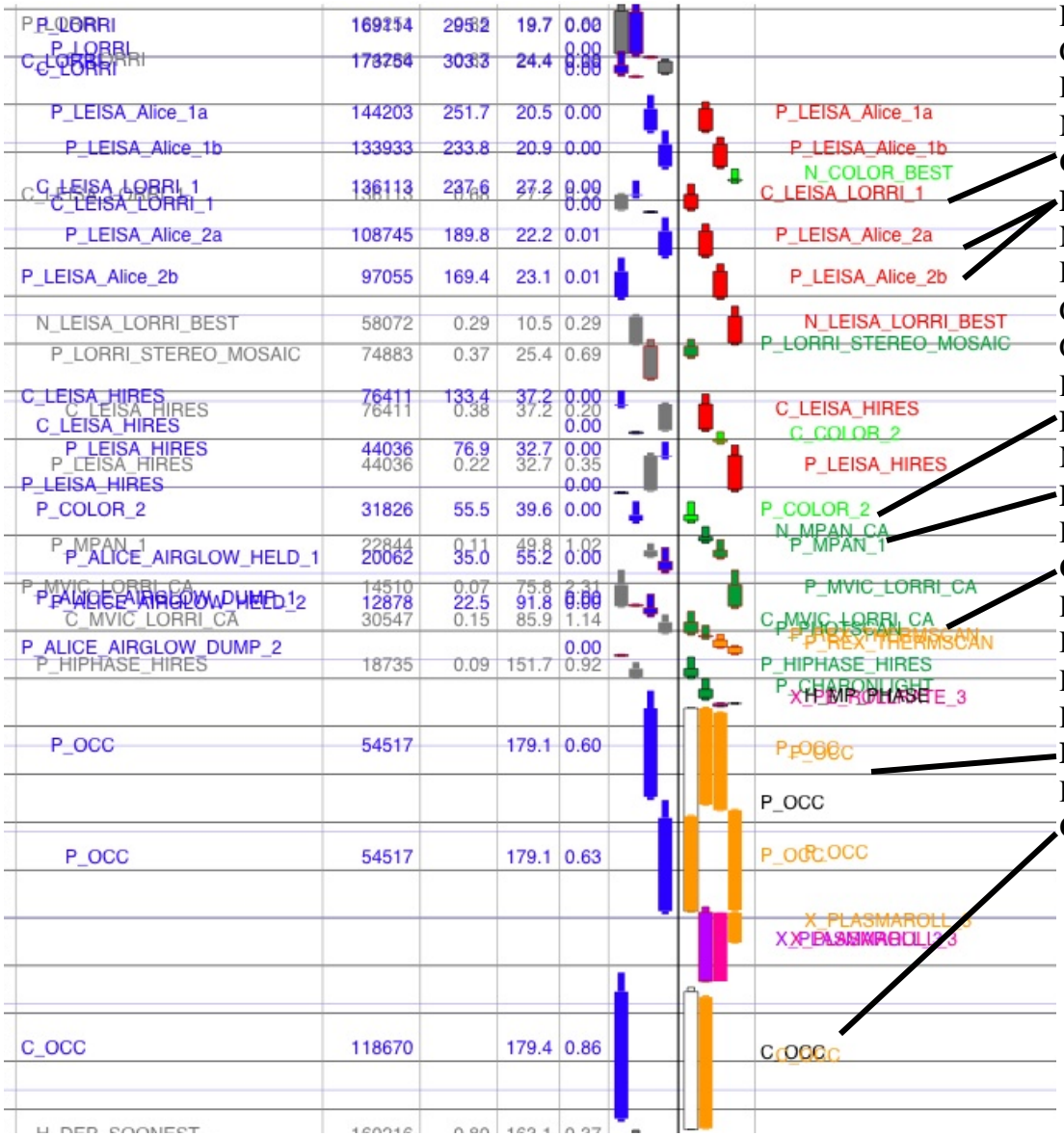
Encounter Plans: Changes since Proposal



Pluto global pan maps at 0.9 km/pix
Charon global pan maps at 0.9 km/pix
Pluto global IR at 9 km/pix
Nix global color maps at 2 km/pix
Charon global IR at 9 km/pix (+ pan at 0.6 km/pix)
Pluto global IR at 6 km/pix
Nix IR at 4 km/pix & pan at 0.3 km/pix
Pluto pan images at 0.4 km/pix
Charon IR at 5 km/pix (+ pan at 0.4 km/pix)
Charon global color at 1.4 km/pix
Pluto IR at 3 km/pix
Pluto global color at 0.7 km/pix
Nix pan at 0.5 km/pix
Pluto global pan at 0.5 km/pix, strip at 0.12 km/pix
Pluto pan at 0.3 km/pix, strip at 0.08 km/pix
Charon global pan at 0.6 km/pix, strip at 0.16 km/pix
Pluto (smeared) at 110 deg phase
Pluto radiometry at 230 km/pix
Pluto at 0.34 km/pix, 146 deg phase
Pluto in reflected Charonlight, 0.44 km/pix
Pluto solar and earth occultation
Plasma roll
Charon solar and earth occultation

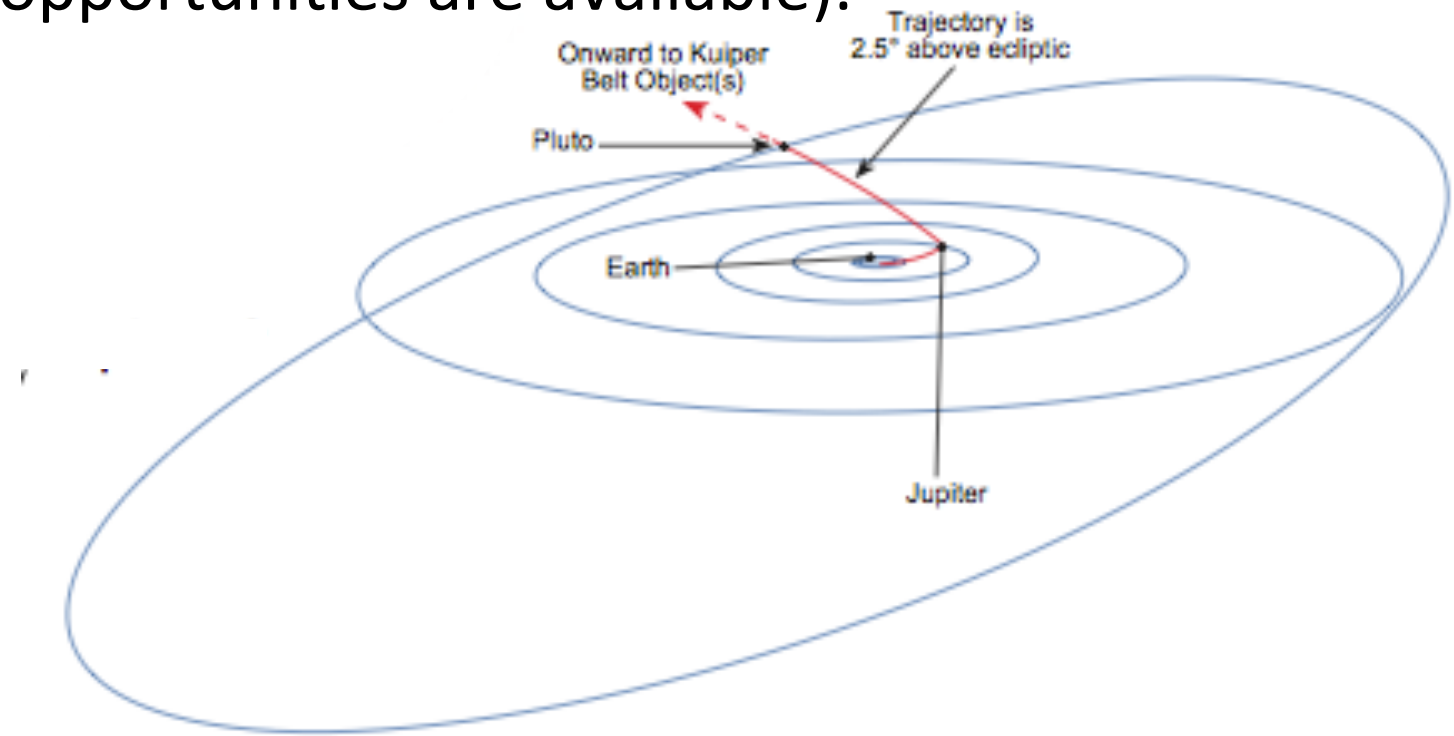
- Timeline addresses all group 1 (required) and 2 (strongly desired) goals, and all but one group 3 (desired) goal.
- All group 1, and most of group 2 and 3 are addressed redundantly
- P-7 days to P+2 days has already been sequenced and reviewed by the science team, with the final delivery due in November.

Getting into Detail (Backing up our Claims)
33-page Science & 76-page Technical

Science Section	**Pages**
Goals/motivation (Geology, Composition, Atmospheres, KBO)	4
Payload	16
Science Operations (encounter, downlink, AO specs, Cruise/Jupiter/KBOs)	10
Science Team	1
Data analysis and Archiving	2
Technical Section	**Pages**
Overview	1
Mission Design (trajectory, encounter date, etc.)	12
Spacecraft (antenna, thrusters, thermal, electrical, etc.)	28
Other (Integration & Test, Mission Ops, Facilities, Launch Vehicle, etc.)	33

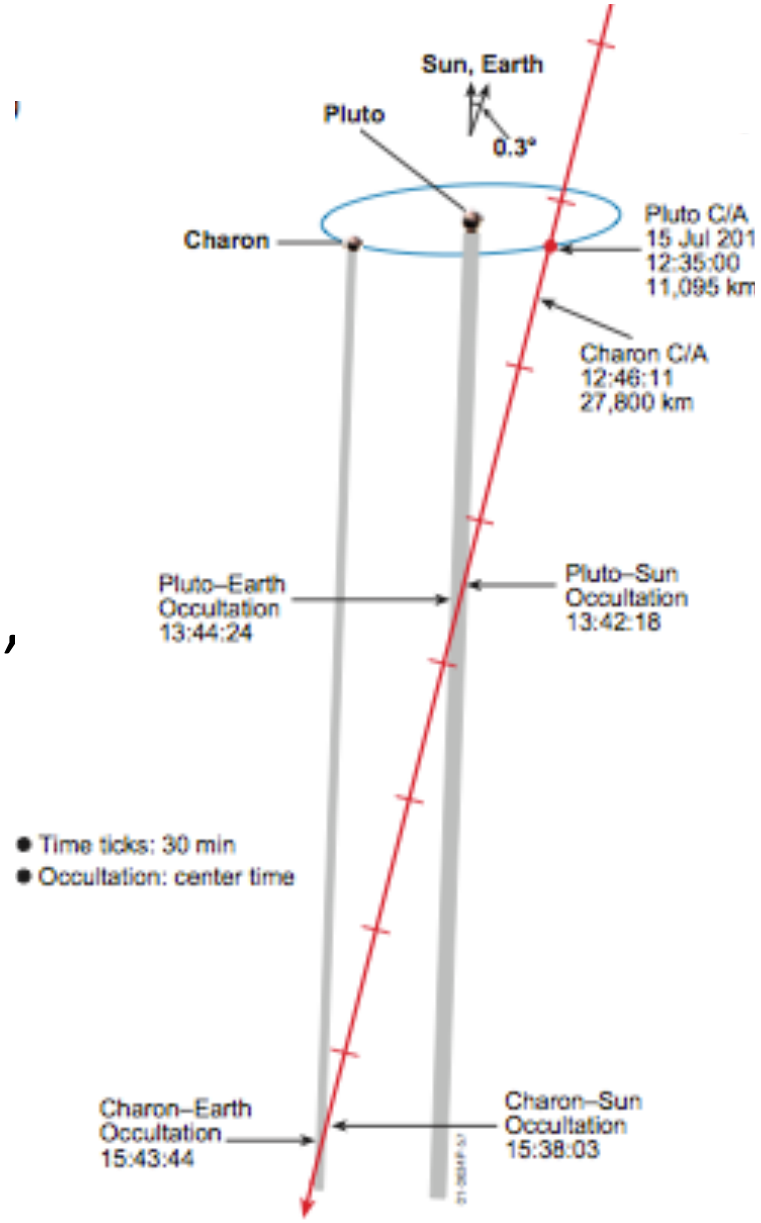
Mission Design: Getting to Pluto

- "The New Horizons mission design is simple and robust. ... No Earth or inner-planet gravity assists are required to reach Pluto- Charon; neither are any in-flight trajectory change maneuvers (though numerous mid-course correction opportunities are available)."



Geometry at Pluto: Timing and Closest Approach (C/A) Distance

- Timing allows Pluto and Charon occultations; 2 DSN uplink during Pluto occultation; encounter at opposition (less solar interference for radio occ).
- Distance allows good angles for approach imaging, high-resolution, and time between



Mission Design: Changes since Proposal

Mission Trajectory	**Proposal Baseline**	**Proposal Backup**	**Proposal Backup**	**As Flown**
Launch Date	6-24 Dec 2004	10-27 Jan 2006	9-25 Jan 2006	19 Jan 2006
Launch Vehicle	Delta IV 4050 H or Atlas V 541	Delta IV 4050 H	Atlas V 541	Atlas V 551
Jupiter Flyby	15-19 Apr 2006	10-14 Mar 2007	28 Mar-1 Apr 2007	28 Feb 2007
Pluto Flyby	15 July 2014	12 July 2016	10 July 2018	14 July 2015
Encounter Geometry	**Proposal Baseline**	**Proposal Backup**	**Proposal Backup**	**As Flown**
Optimum occ timing?	Yes	Yes	Yes	Yes
Optimum enc. longitude?	*Not studied*	*Not studied*	*Not studied*	Yes
Pluto C/A Dist	11,095 km (from PKE)	11,093 km	11,089 km	13,695 km Optimized by Science Team

Getting into Detail (Backing up our Claims)
33-page Science & 76-page Technical

Science Section	**Pages**
Goals/motivation (Geology, Composition, Atmospheres, KBO)	4
Payload	16
Science Operations (encounter, downlink, AO specs, Cruise/Jupiter/KBOs)	10
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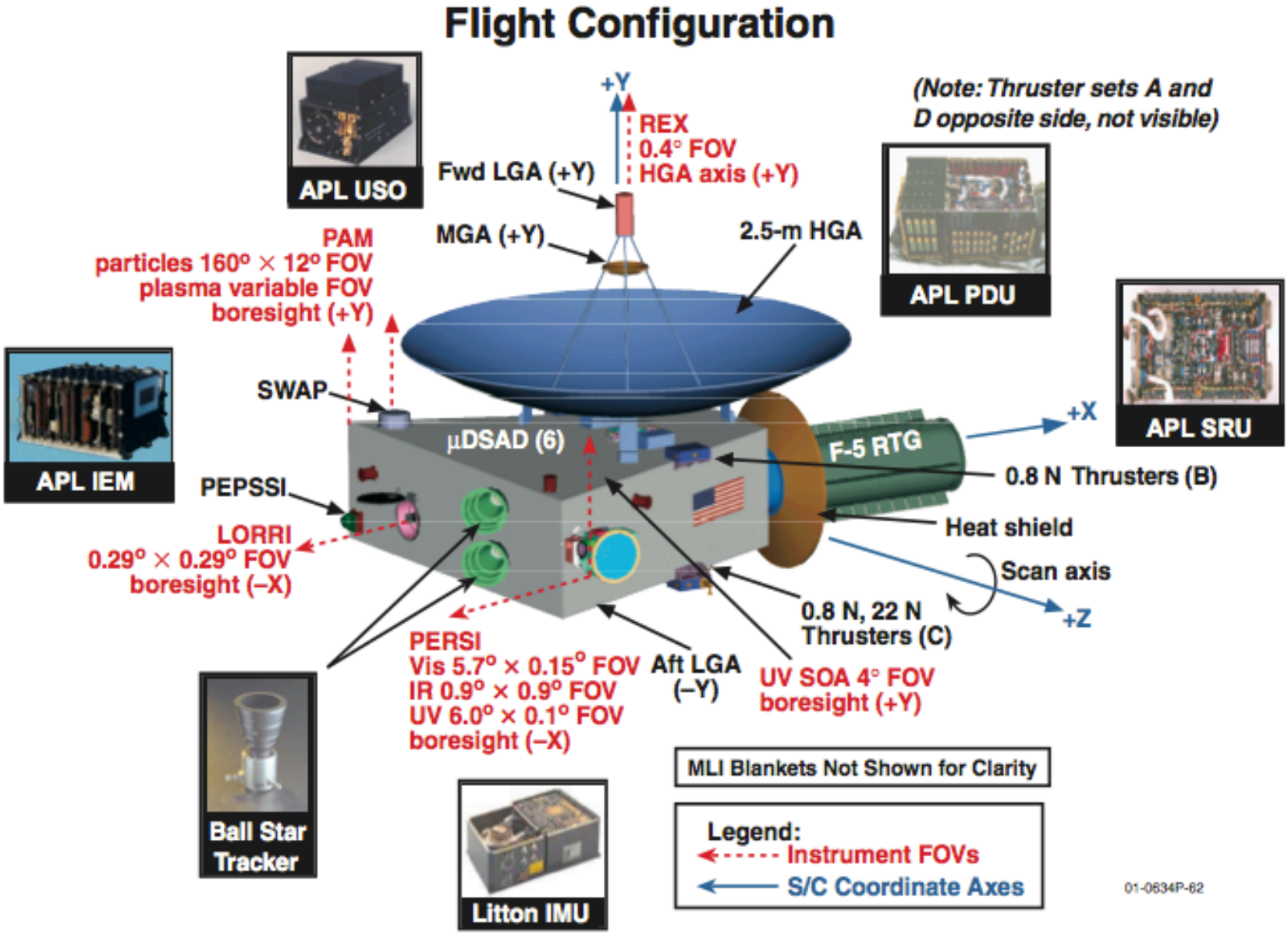
Other (Integration & Test, Mission Ops, Facilities, Launch Vehicle, etc.)	33

Spacecraft Diagram, with Photos of Heritage Hardware

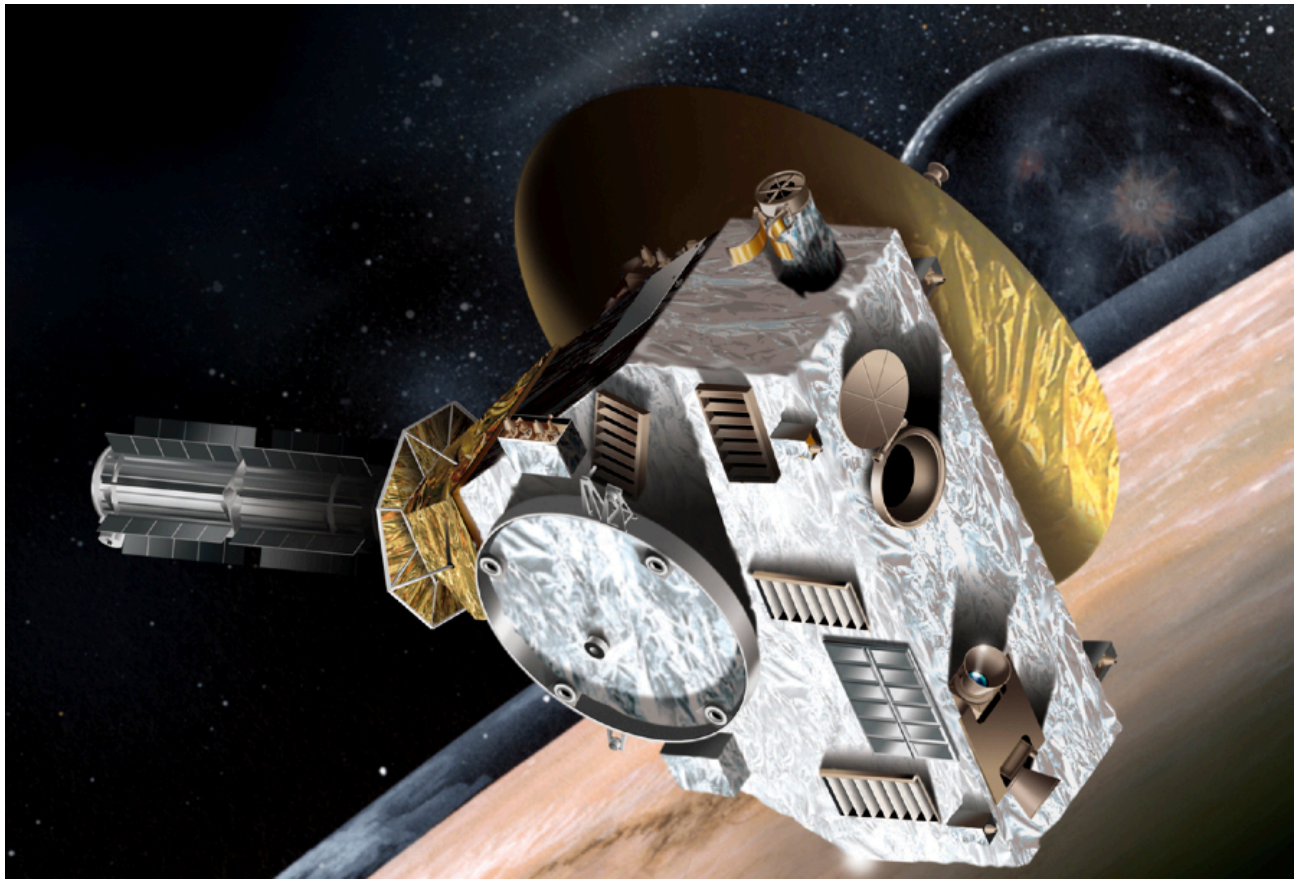


More on Low Risk! More! More!

- Most of the spacecraft systems are closely based on systems APL developed for NASA/CONTOUR, which is completing integration on schedule for launch on a 6+ year mission beginning next year. ... Further minimizing risk, our bus has no deployed or articulated mechanisms, and all instruments are body-mounted.
- Proposal includes a Component List table showing redundancy and design heritage, and a System Block Diagram showing Build-to-print vs. Modified Design vs. New Design vs. New Technology. This last is addressed in its own section (Incorporation of New Technology).

Spacecraft Design: Changes since Proposal

- Squared-off the triangle.
- Smaller antenna (2.1m).
- Repointed one star tracker.



New Horizons Team (2004)