New Horizons:
To Pluto and Beyond

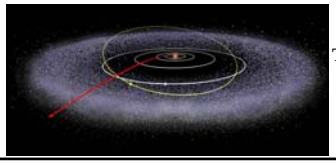
John Spencer
New Horizons Science Team
SwRI Boulder

Astr 4800: "Space Science: Practice and Policy"
October 31st 2007

Why Explore Pluto-Charon
Why Explore the Kuiper Belt?

PLUTO AND CHARON

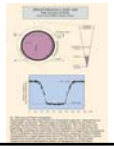
PARAMETER	PLUTO	CHARON
ROTATION PERIOD	6.3872 days	6.3872 days
RADIUS	1150 - 1215 km	600 - 640 km
DENSITY	about 2 g/cm^3	1 - 2 g/cm^3
BRIGHTNESS	13.6 magnitude	15.5 mag
GEOMETRIC ALBEDO	0.55, variable	0.32
COLOR (V-I)	0.93 magnitude	0.83 mag
KNOWN SURFACE ICES	CH_4, N_2, CO, ?	H_2O, ?
ATMOSPHERE	CONFIRMED	DOUBTFUL



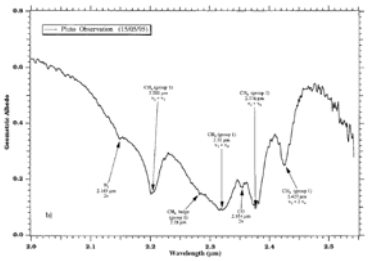
The Kuiper Belt

Pluto-Charon is Scientifically Exciting and Truly Unique

- **Pluto is neither a terrestrial nor a gas giant planet: It is a wholly new type: an ice dwarf, common to the deep outer solar system.**
- **Pluto-Charon is the solar system's only known binary planet, with implications for atmospheric transfer and for better understanding the formation of the Earth-Moon system.**
- **Pluto's atmosphere is a transitional case between a cometary and a classical planetary atmosphere, and is the only expected site of planetary hydrodynamic escape.**
- **Pluto's surface consists of a complex mélange of volatile ices (N2, CO, CH4,…) and organics.**
- **Pluto's surface is among the most variegated and contrasty in the solar system.**

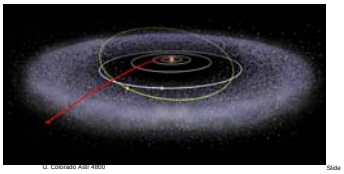


Pluto's Complex Near-IR Spectrum



Pluto-Charon & Kuiper Belt Are A Scientific Treasure-Trove

- **Pluto-Charon's surfaces record the details of outer solar system bombardment. Comparison of Pluto's cratering record with Charon's should yield a direct comparison of present-day to the time-integrated KB impactor flux, down to impactor scales of tens of meters.**
- **The Kuiper Belt is the best "archeological site" to explore mid-stage accretion in the outer solar system.**



Prehistory

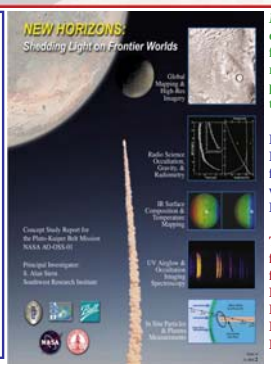
- NASA and the planetary science community began studying Pluto missions in the late 1980's
- Discovery of the Kuiper Belt in 1992 added impetus
- An AO for instrument proposals for a JPL-led mission was announced, then cancelled, in 2000
- Pressure from the community and the public resulted in re-instatement in early 2001, with a request for proposals for a PI-led mission

Rob Staehle, leader of the JPL Pluto mission planning team, with Patsy and Clyde Tombaugh, ~1996

New Horizons: Overview

Science Team:

Fran Bagenal
Rick Binzel
Bonnie Buratti
Andy Cheng
Dale Cruikshank
Randy Gladstone
Will Grundy
Dave Hinson
Mihaly Horanyi
Don Jennings
Ivan Linscott
Jeff Moore
Dave McComas
Bill McKinnon
Ralph McNutt
Scott Murchie
Carolyn Porco
Harold Reitsema
Dennis Reuter
Dave Slater
John Spencer
Darrel Strobel
Mike Summers
Alan Stern
Len Tyler
Leslie Young



New Horizons was one of the consortia proposals submitted for AO-OSS-01, NASA's request for flyby mission proposals to Pluto-Charon and the Kuiper Belt.

New Horizons was selected by NASA on 29 Nov 2001, and funded at $30M for FY2002, we are now completing Phase B.

The 107th Senate and House funded New Horizons to enter full-scale development in their FY03 NASA markups. President Bush signed this NASA FY03 funding bill on 20 Feb 2003.

2001: Proposal Site Visit

New Horizons Selected!

Date: Thu, 29 Nov 2001 14:26:27 -0700 (MST)
From: Alan Stern-- SwRI/Boulder <alan@boulder.swri.edu>
X-X-Sender: <alan@clavius>
To: PKB Management -- alan stern <astern@boulder.swri.edu>,
Subject: We WON!!!!

EVERYONE-- LESS THAN AN HOUR AGO NASA HEADQUARTERS CALLED TO SAY WE WON THE PLUTO COMPETITION, AND WILL BE FUNDED TO PROCEED!!

WE DID IT!

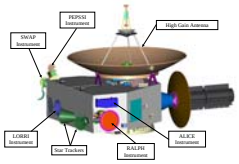
MORE SOON,
ALAN

Full Project Team

- SwRI and APL Teamed to Lead the Project:
  - SwRI to lead science team and payload, serve as PI institution
  - APL to lead mission development & operations
- With Five Major Team Partners:
  - Ball for RALPH instrument
  - NASA/GSFC for the LEISA IR focal plane
  - Stanford for the REX radio science investigation
  - JPL for DSN, Navigation, Col support
  - Boeing as third stage supplier
- And a World Class Pluto-Kuiper Belt Science Team:
  - 25 members, various institutions

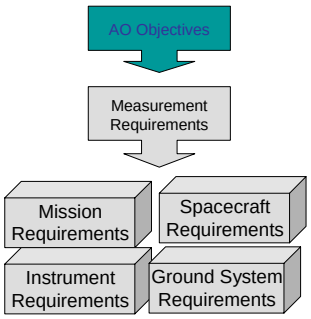
New Horizons Overview

- Spacecraft: A heritage-base, highly-redundant systems, and carrying a 300 m/s ΔV budget. Mass: 415 kg.
- Encounters: A five-month Pluto-Charon encounter; then on to explore one or more KBOs.
- Payload: 6 distinct instruments, plus EPO Student Dust Counter.
- Science Performance: Exceeds the AO specs for all Group 1 objectives; meets or exceeds the all Group 2, and 3 of the 4 Group 3 objectives.
- Cost: ~$150M below the New Frontiers cap (through Phase E).



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)

Requirements Flowdown

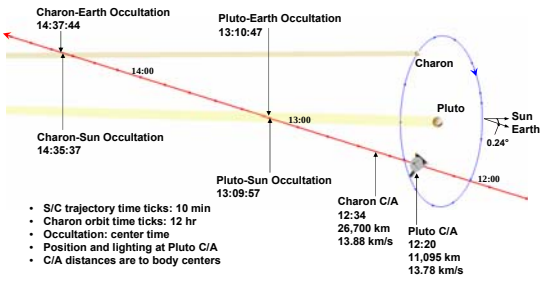


Measurement Objectives
(PKB Science Definition Team)

Group 1 Objectives:
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:
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 composition of selected areas of Pluto & Charon at high resolution
Characterize Pluto's ionosphere and solar wind interaction
Search for neutral species including H, H_2, HCN, and C_xH_y, and other hydrocarbons and nitriles in Pluto's upper atmosphere
Search for an atmosphere around Charon
Determine bolometric Bond albedos for Pluto and Charon
Map the surface temperatures of Pluto and Charon
Group 3 Objectives:
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

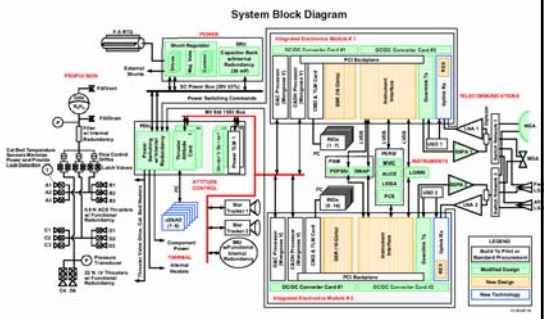
2006 Baseline Mission Design

Pluto-Charon Encounter Geometry – Delta Launch 14 July 2015



- S/C trajectory time ticks: 10 min
- Charon orbit time ticks: 12 hr
- Occultation: center time
- Position and lighting at Pluto C/A
- C/A distances are to body centers

Spacecraft System Redundancy



Payload Overview

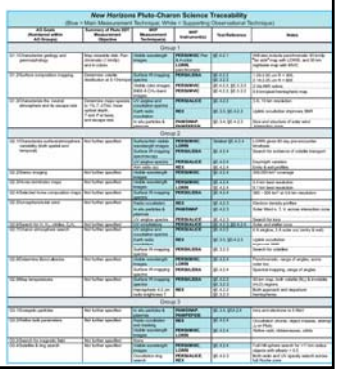
- ***Ralph*** VIS/IR imaging & spectroscopy remote sensing
- ***Alice*** UV spectrometer
- ***REX*** uplink radio science & passive radiometry.
- ***LORRI*** high-resolution (long focal length) imager.
- ***SWAP & PEPSSI*** particles & plasmas suite.
- ***Venetia*** Student Dust Counter

Science Fulfillment

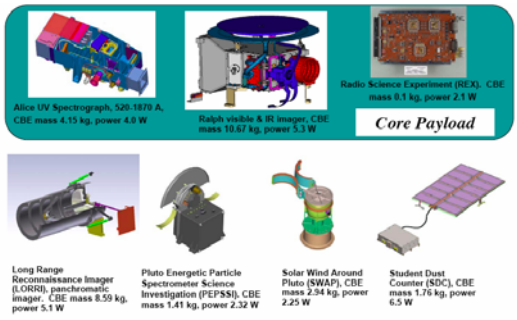
Traceability:

Science objectives trace into measurement techniques & instruments.

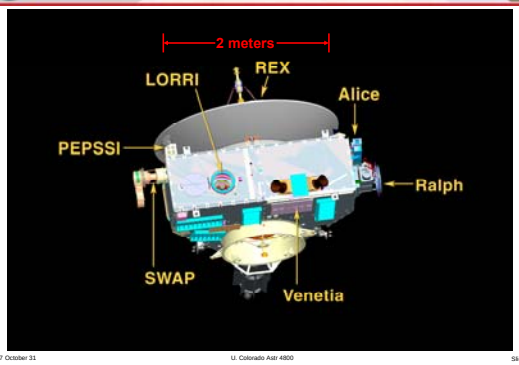
New Horizons meets or exceeds all PKB Group 1 & Group 2, and 3 of the 4 PKB Group 3 measurement objectives.



New Horizons Instruments

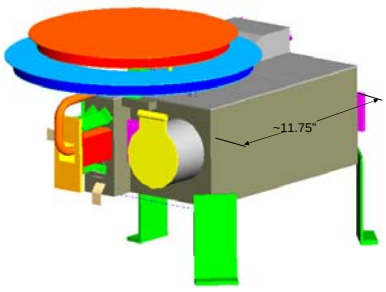


New Horizons Spacecraft

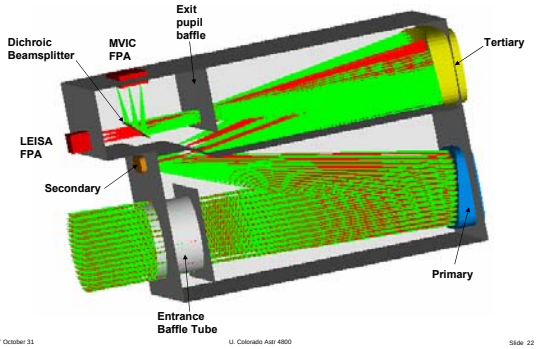


Ralph

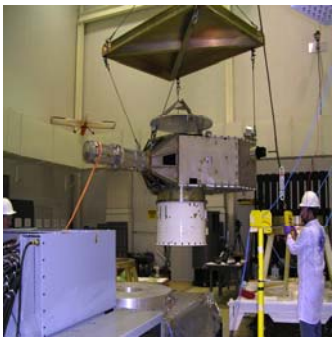
(not to scale)



Ralph Internal Features



2004: Building



2005: Completing

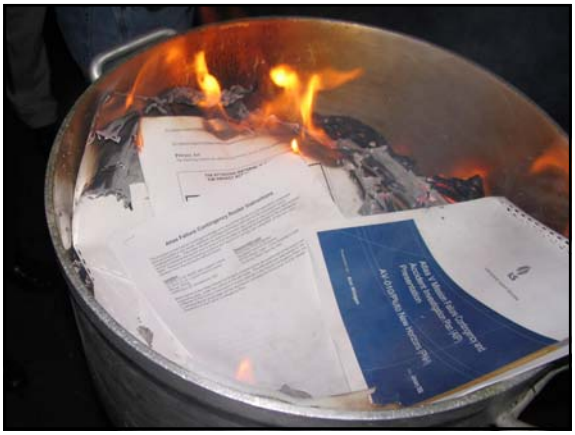
2005: Testing

Late 2005: At the Cape

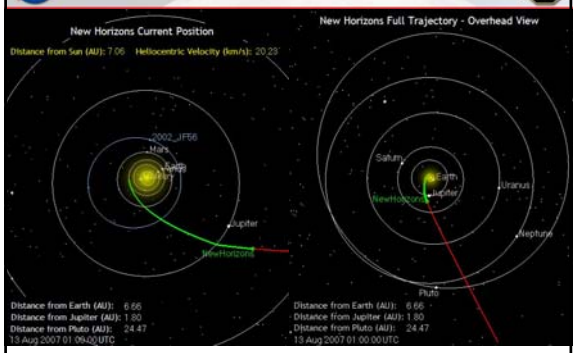
- December 11th 2005

Launch 2006 January 19 14:00 EST

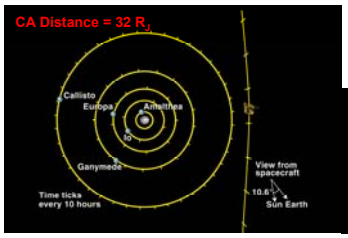
- Nearly perfect trajectory
- Fastest Earth departure ever (36,000 miles per hour)
- Passed Moon's orbit in 9 hours
- Pass orbits of:
  - Mars on 4/7/2006
  - Jupiter on 2/28/2007
  - Saturn on 6/8/2008
  - Uranus on 3/18/2011
  - Neptune on 8/24/2014
- Pluto system encounter on 7/14/2015



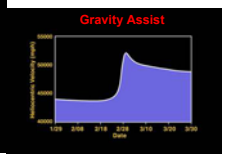
New Horizons Trajectory



New Horizons Jupiter Encounter

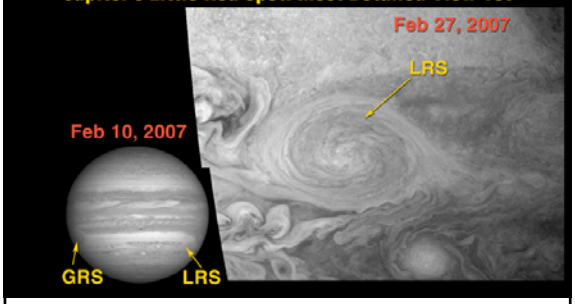


Encounter Closest Approach at: 2007 Feb 28 05:43:40 UTC



- **NH Jupiter encounter objectives**
  1. **Gravity Assist**
  2. **Stress test for Ops Team**
  3. **Calibration Observations**
  4. **Jovian system science**
- **International Observing Campaign**
  - **Hubble, Chandra, XMM**
  - **Rosetta, MRO (HIRISE)**
  - **IRTF, Gemini, Subaru, KPNO, VLT, AAT**
  - **Amateurs**

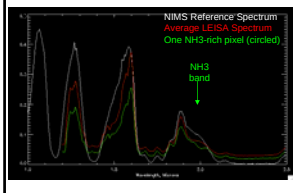
Jupiter's Little Red Spot: Most Detailed View Yet

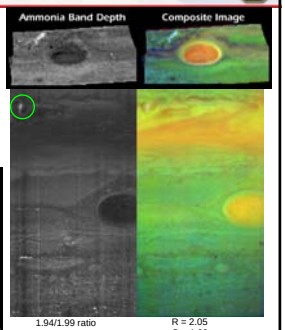


- Images at 10 hour and 15 minute intervals, to track large-scale and small-scale motions
- Cheng et al. 2007, Science, in press

Mapping NH_3 Clouds with LEISA

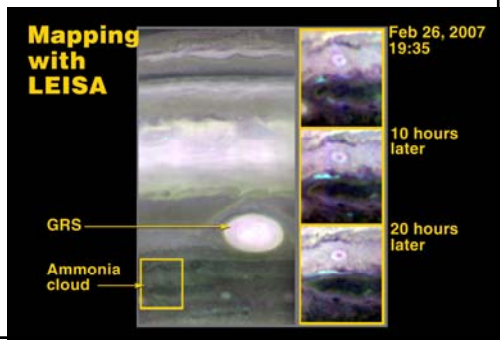
- Multiple image cubes of GRS region with LEISA
  - 3-D cloud movies
  - Follow up on Galileo discovery of NH_3 ice clouds NW of GRS
- This region was unusually tranquil, but there were other turbulent regions where NH3 upwelling observed





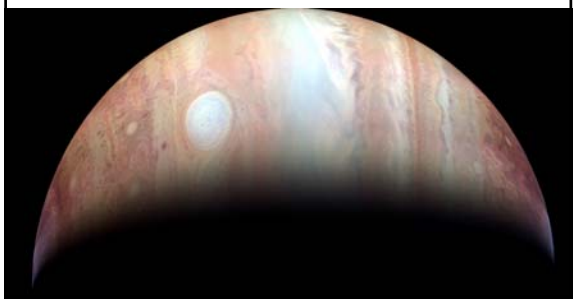
NH3 Cloud Evolution

- Reuter et al. 2007, Science

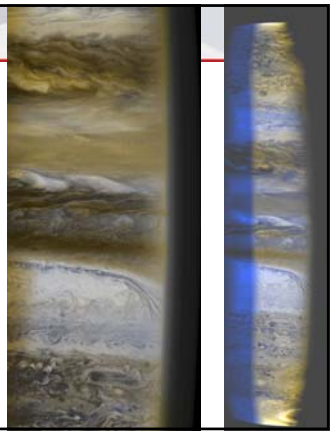


Global Jupiter LEISA Map

- Color: Red = 1.59 microns, Green = 1.94 microns, Blue=1.84 microns
- Cloud altitude: cooler colors = higher

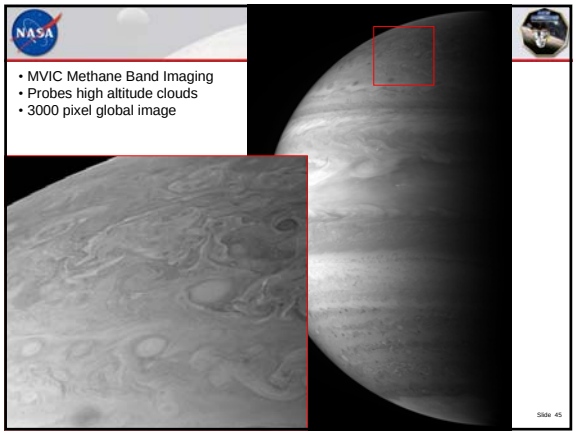


- MVIC Color Imaging
- Use multiple filters to probe 3-D atmospheric structure
- Only unsaturated near the terminator (except in CH4 band)
- Cloud topography seen near terminator



2007 October 31

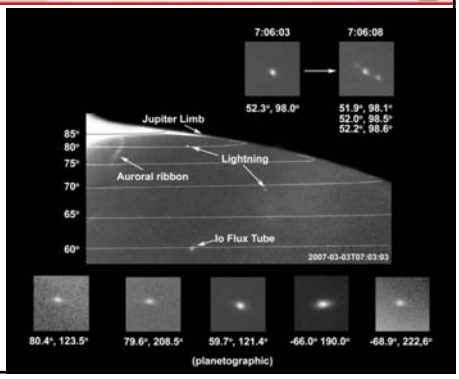
- MVIC Methane Band Imaging
- Probes high altitude clouds
- 3000 pixel global image



Slide 45

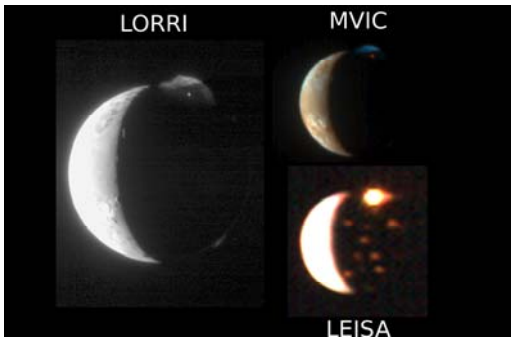
Jupiter Lightning with LORRI

- Baines et al 2007, Science
- First high-latitude lightning observations



2007 October 31

Io: Coordinated Observations with Each Remote Sensing Instrument

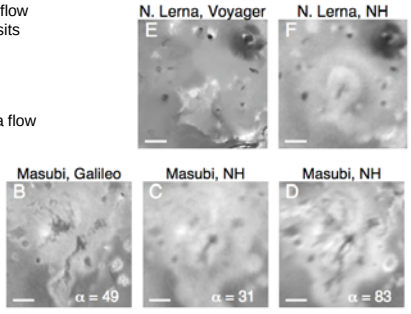


2007 October 31 U. Colorado Astr 4800 Slide 47

Changes at Lerna and Masubi

Lerna: New lava flow and plume deposits

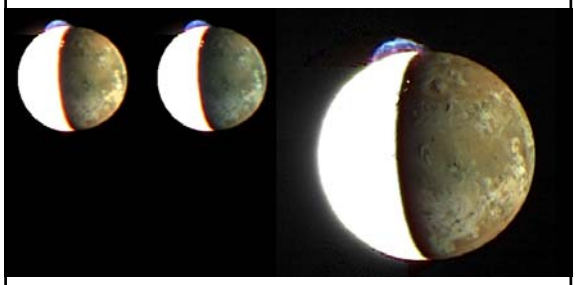
Masubi: new lava flow and plume deposits: thin coating on old flows



2007 October 31 U. Colorado Astr 4800 Slide 48

Nightside Color Imaging

- Combined LORRI and MVIC



Plume Potpourri

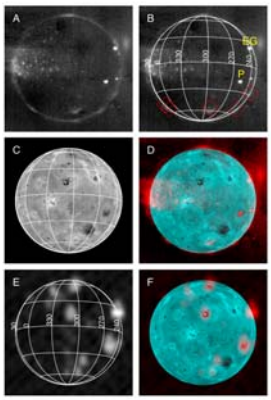
North Lerna, Marduk, Kurdalagon

Prometheus plume on the limb

Tvashtar illuminating the surface, Zal in Jupiter shine, Masubi in Jupiter shine at 176° phase

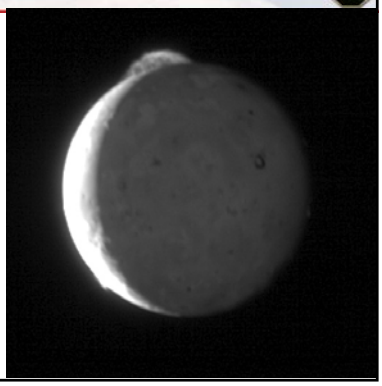
Eclipse Images

- Glowing plumes
- Visible-wavelength bright spots near sub-Jupiter point (seen previously by Galileo)
- Correlated with dark volcanic centers seen in sunlit images
- Not correlated with near-IR thermal emission seen by LEISA
  - Probably non-thermal



Tvashtar Movie

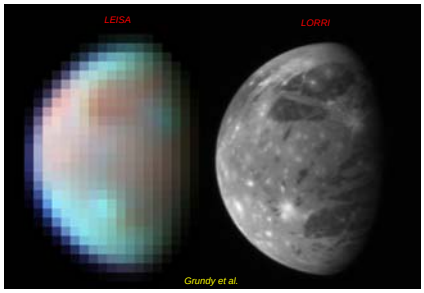
- 5 frames
- 8 minutes



Io & Europa : LORRI + MVIC

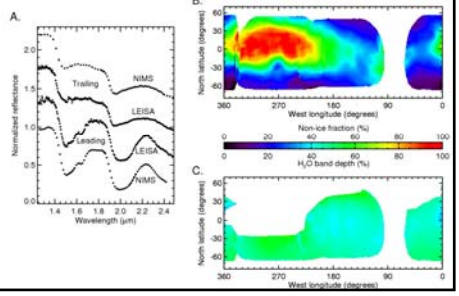
LEISA Mapping of Galilean Satellite Near-IR Spectra

- Grundy et al. 2007, Science



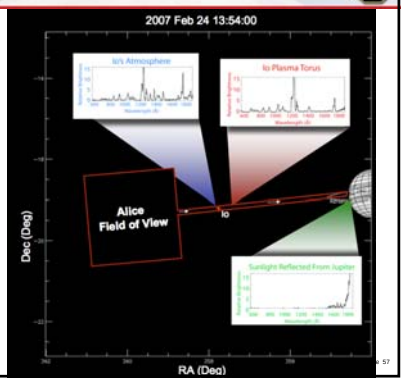
LEISA Europa

- Improved mapping of distribution of non-ice component from band shape
  - Very symmetrical about antapex except for icy impact ejecta from Pwyll
- Water ice band depth
  - Notably constant across the surface



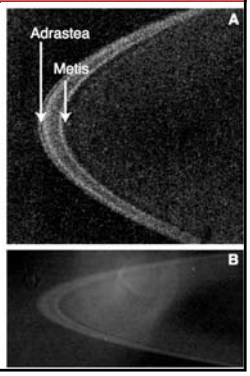
UV Spectroscopy with Alice

- **Spatially-resolved UV spectroscopy of Jovian system**
- **Io plasma torus**
- **Auroral emissions from Jupiter and satellites**
- **UV continuum from Jupiter + satellites**
- **Stellar occultations of Jupiter and satellite atmospheres**



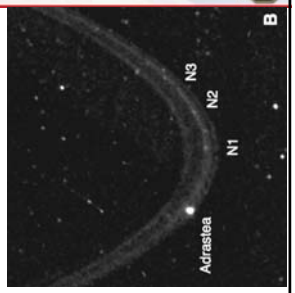
Rings

- Showalter et al. 2007 Science, submitted
- Best-ever low-phase images of the Jovian ring: distribution of large particles controlled by Adrastea and Metis

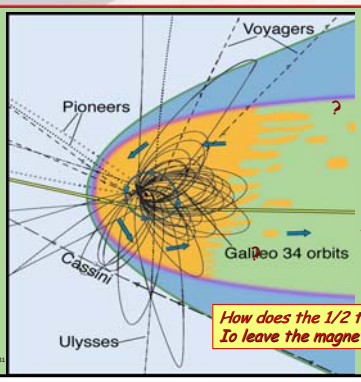


Ring Clumps

- Extensive satellite searches found no satellites down to ~1 km size.
- But found clumps instead!
  - Two sets, both in central arc
- One set near Adrastea but not associated with it
- Recent collisional remnants?
  - Maybe not: not much fine dust seen at high phase
- Resonant confinement by Metis?

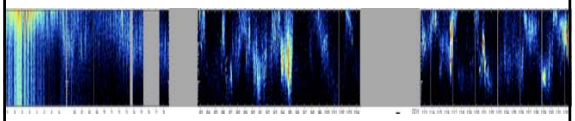


Magnetotail

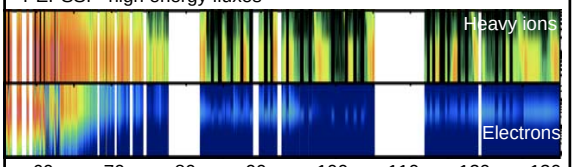


New Horizons Data

SWAP - low energy ion fluxes

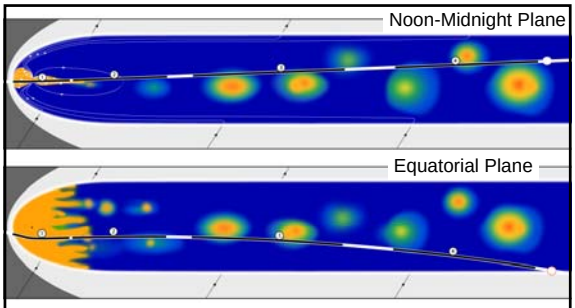


PEPSSI - high energy fluxes



60 70 80 90 100 110 120 130

Day of Year

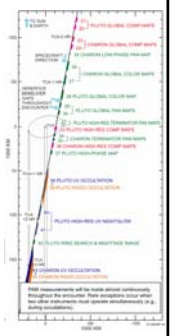


What we found …

- BIG, BLOBS of HEAVY IONS
- Slow flow down magnetotail
- Fine structure, variability
  - minutes to days

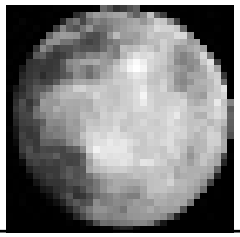
Pluto Encounter Highlights

- **Six months of encounter science.**
- **Exceed HST resolution for 150 days(!)**
- **Map Pluto's "far-side" 3.2 days out at 40 km res.**
- **Map Pluto night-side frost deposition in Charon light.**
- **Obtain global composition maps of Pluto & Charon.**
- **Obtain radio and UV occultations of both Pluto & Charon.**
- **Map surface temperatures at high resolution.**
- **Directly measure Pluto's escape rate.**



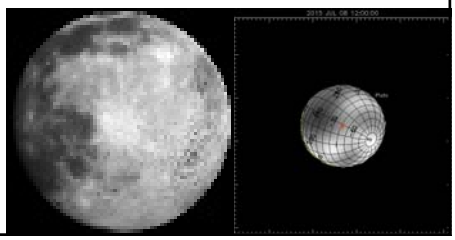
Pluto Approach: -12 days

- CML 259 degrees
- Range 14,292,000 km
- Angular diam 0.167 mrad



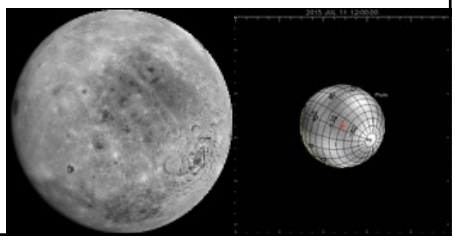
Pluto Approach: -6 days

- CML 237 degrees
- Range 7,135,000 km
- Angular diam 0.335 mrad



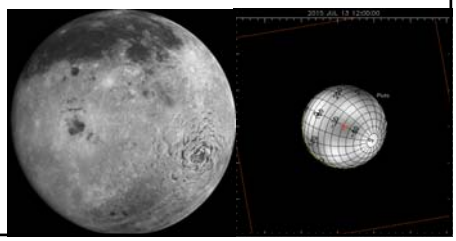
Pluto Approach: -3 days

- CML 46 degrees
- Range 3,564,000 km
- Angular diam 0.671 mrad
- Best view of the "opposite" side



Pluto Approach: -1 day

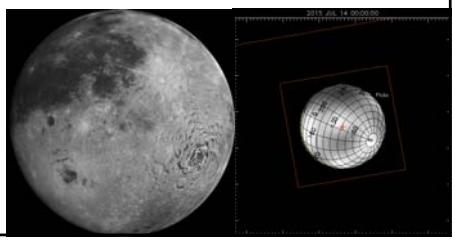
- CML 158 degrees
- Range 1,180,000 km
- Angular diam 2.02 mrad



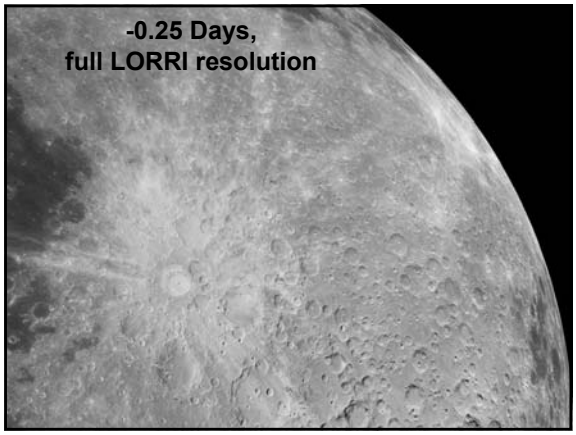
2007 October 31

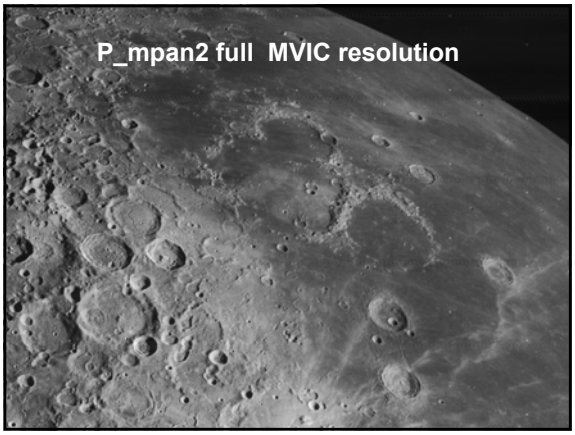
Pluto Approach: -0.5 day

- CML 186 degrees
- Range 584,000 km
- Angular diam 4.09 mrad



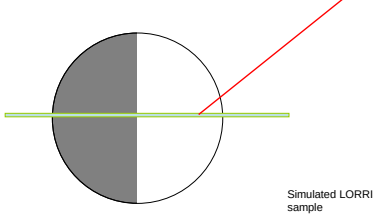
2007 October 31





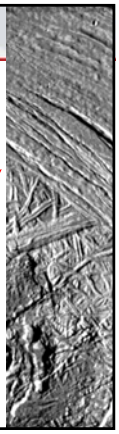
Close-Approach Observations

- LORRI slewing mosaic?
  - 300 overlapping images, taken every 2 seconds
  - Contiguous limb to terminator "noodle", 1024 x 23,400 pixels (equivalent to 23 edge-to-edge pointed LORRI frames)

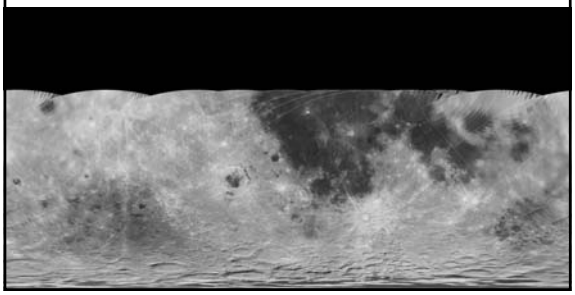


Simulated LORRI sample

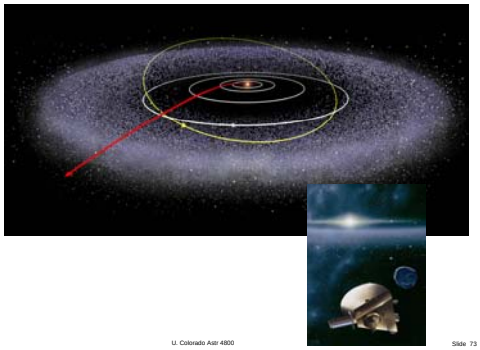
2007 October 31



Final Composite "Pluto" Map

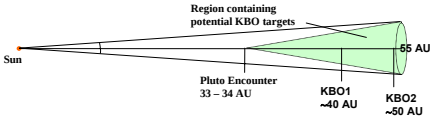


On To the Kuiper Belt



New Horizons Mission To Kuiper Belt Objects

- **Ground-based campaign to locate candidate KBOs along the spacecraft nominal trajectory up to 55 AU from Sun.**
- **On-board ΔV is capable of reaching multiple KBOs with size > 50 km.**



- **Select first KBO target before Pluto encounter.**
- **Execute a TCM at P+14d to alter trajectory towards first KBO.**
- **Obtain OpNav image of targeted KBO as early as 3-5 weeks out.**
- **Refine KBO encounter accuracy with a trim TCM incorporating OpNav data.**
- **KBO flyby velocities ~ 8-14 km/s.**