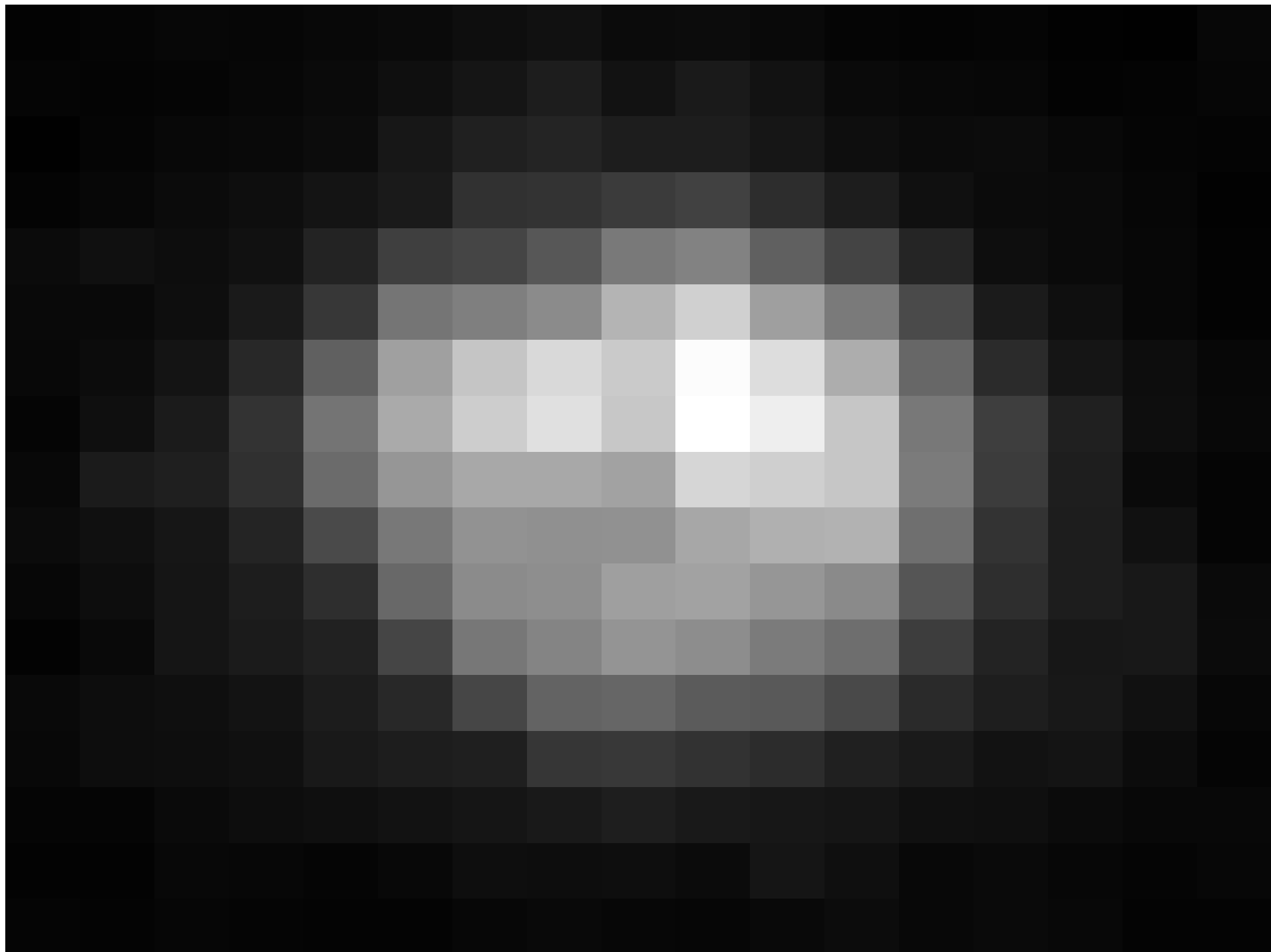


# The Exploration of Pluto By New Horizons

Alan Stern/SwRI

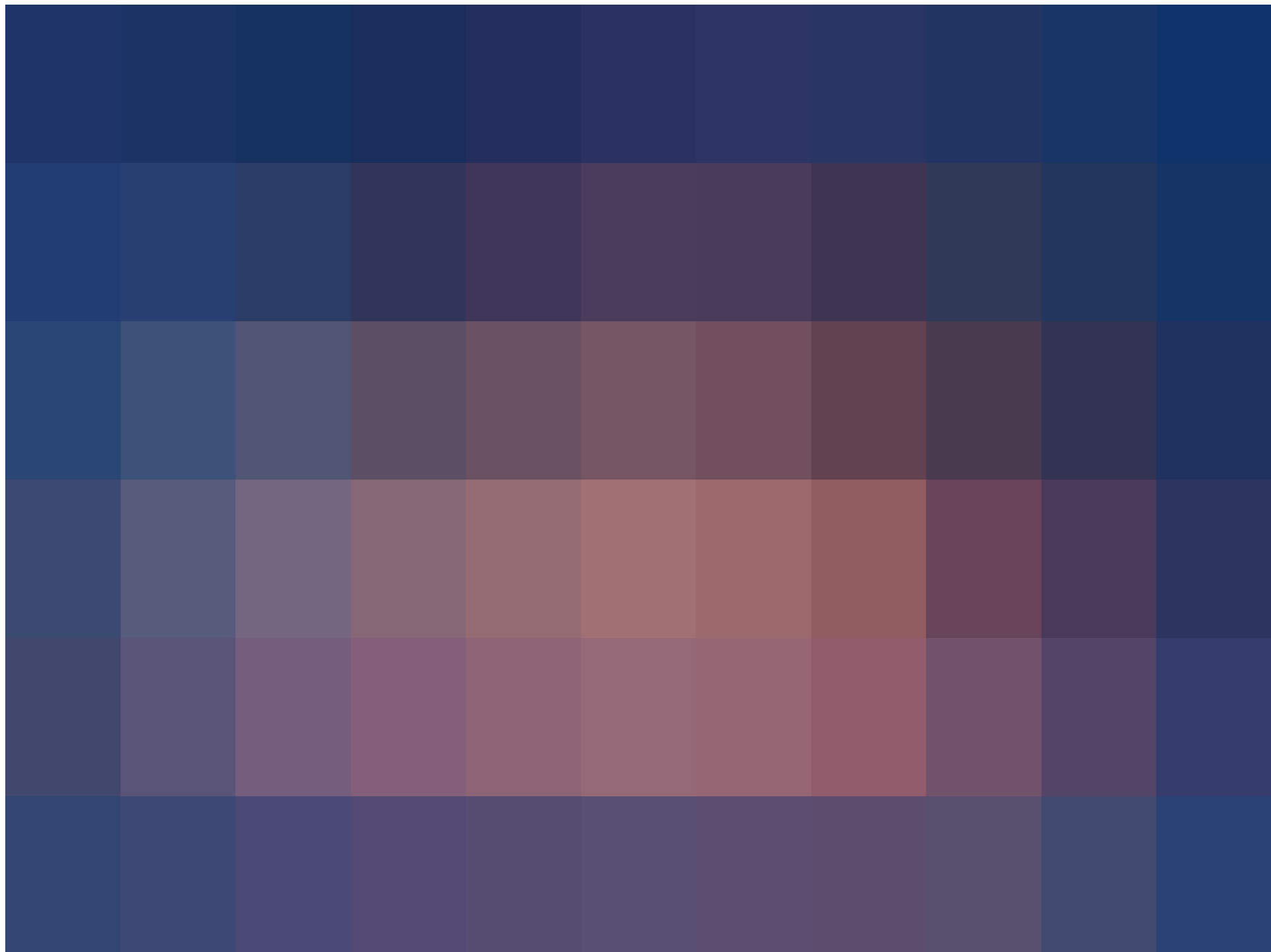






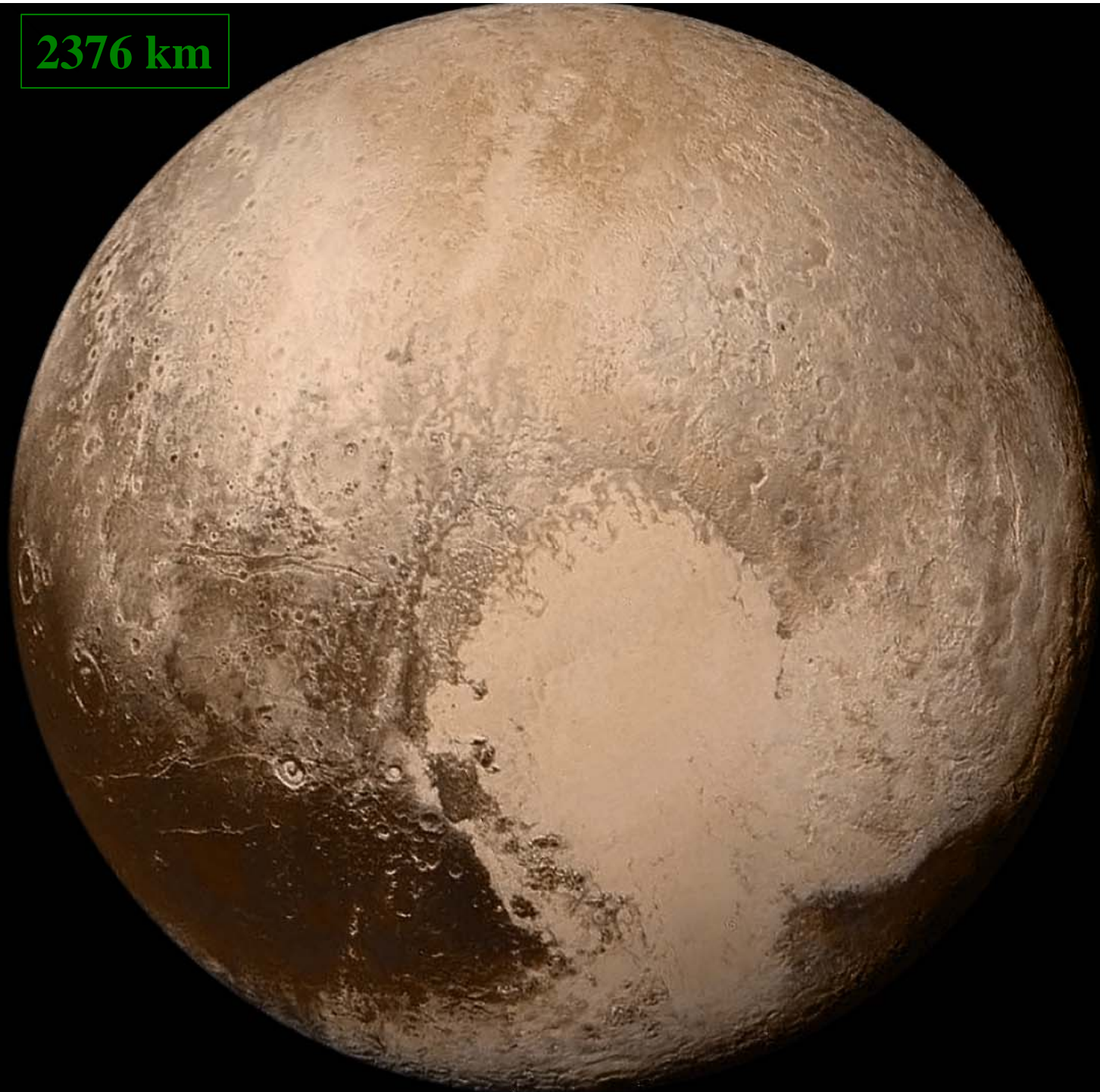




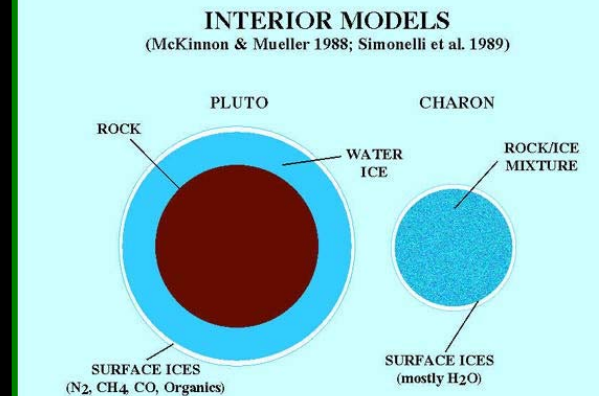
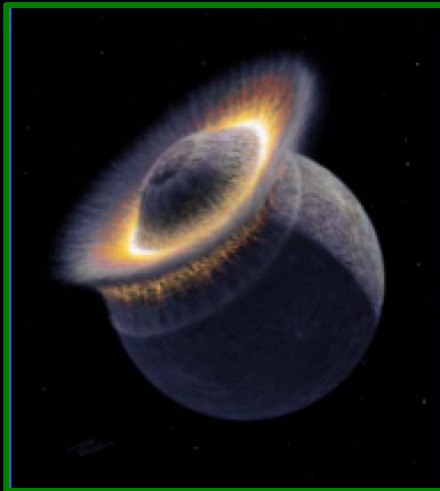
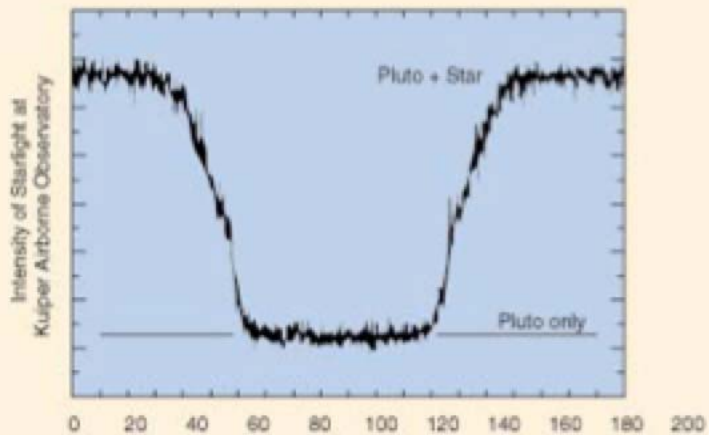
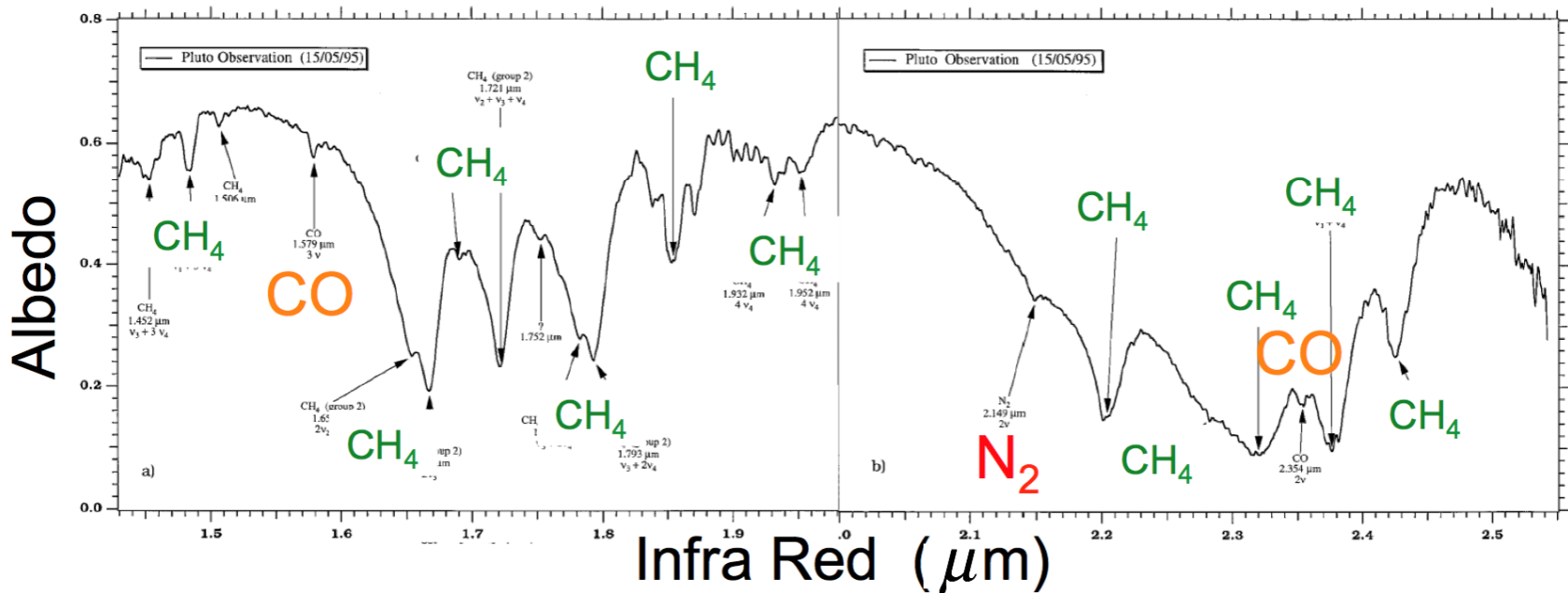




2376 km

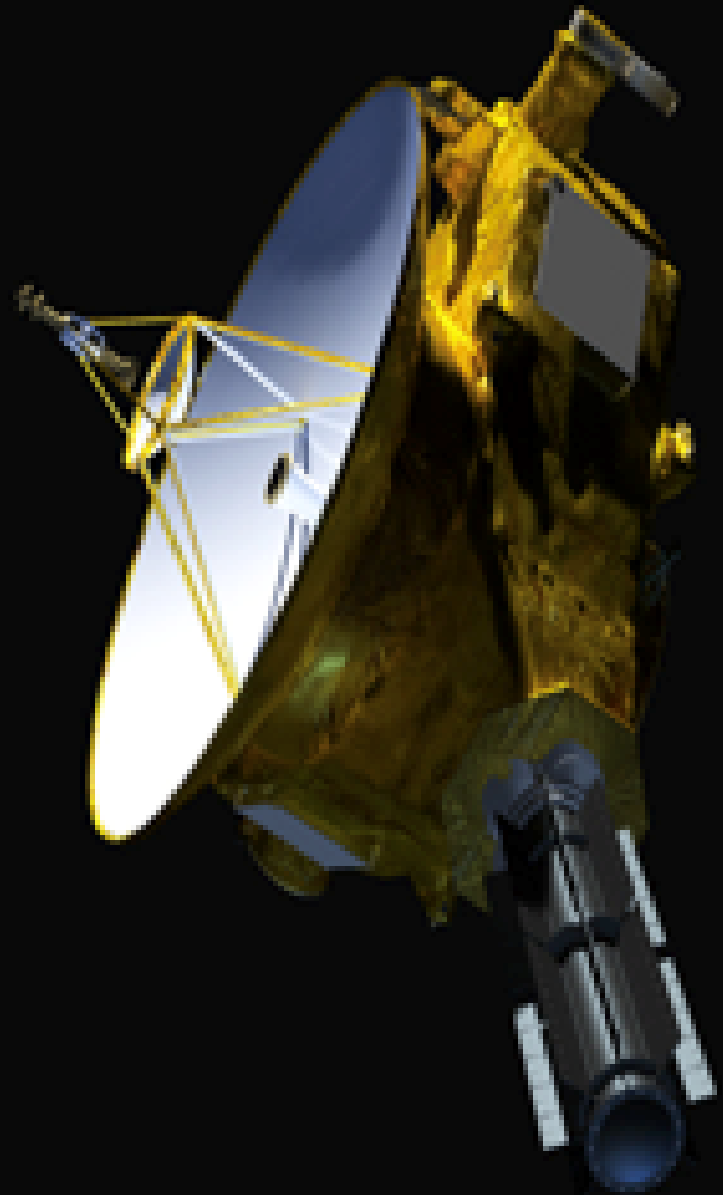


# Pluto's Surface Composition Is Complex

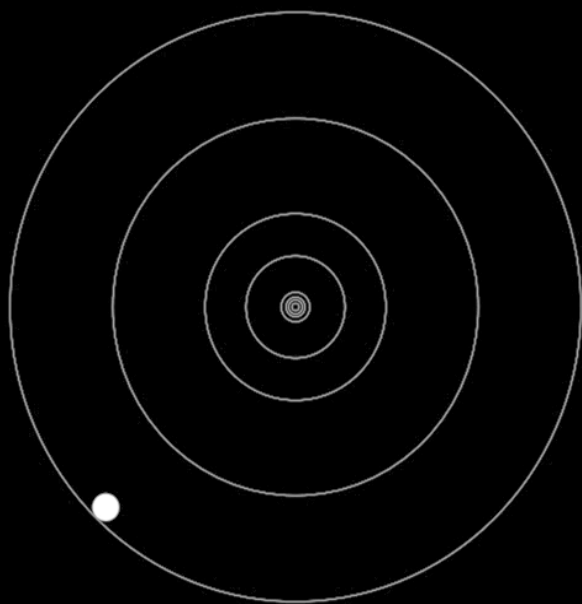


# Mission History

- 1990: Pluto 350
- 1991: Pluto Mariner Mark II
- 1992: Pluto Fast Flyby
- 1994: Pluto Express
- 1997: Pluto Kuiper Express
- 2001: New Horizons







# New View of the Solar System

- Third class of planetary body
- Dwarf planets most common type

## Kuiper Belt



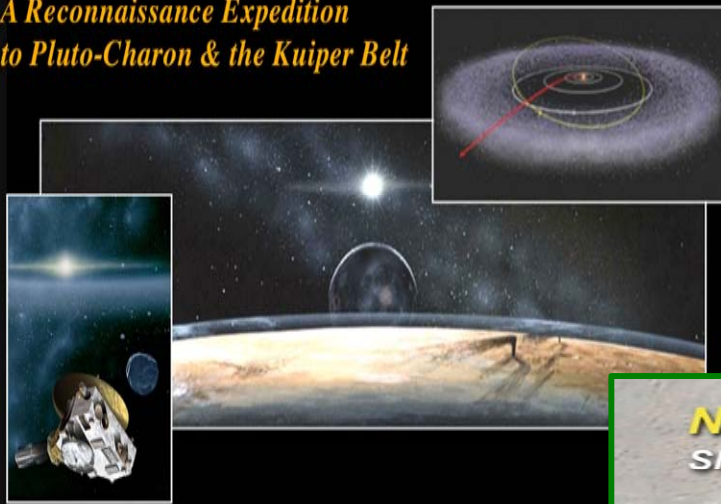
## Asteroid Belt

Scale  
1000 km



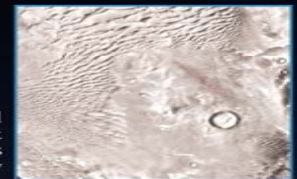
Highest Funding Priority Medium-Scale Mission  
 New Start of the 2003 Planetary Decadal Survey:

*A Reconnaissance Expedition  
 to Pluto-Charon & the Kuiper Belt*

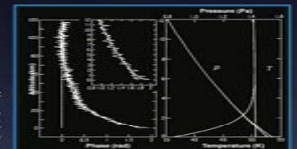


**NEW HORIZONS:**  
 Shedding Light on Frontier Worlds

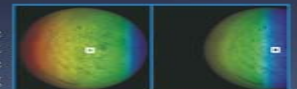
Global Mapping & High-Res Imagery



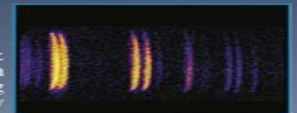
Radio Science Occultation, Gravity, & Radiometry



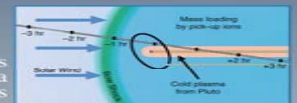
IR Surface Composition & Temperature Mapping



UV Airglow & Occultation Imaging Spectroscopy



In Situ Particles & Plasma Measurements



Concept Study Report for  
 the Pluto-Kuiper Belt Mission  
 NASA AO OSS-01

Principal Investigator:  
 S. Alan Stern  
 Southwest Research Institute







# 2002-2005: DESIGN, BUILD, TEST

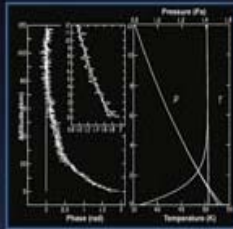


## NEW HORIZONS: Shedding Light on Frontier Worlds

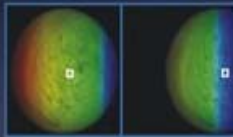
Global Mapping & High-Res Imagery



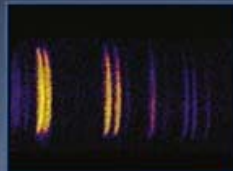
Radio Science Occultation, Gravity, & Radiometry



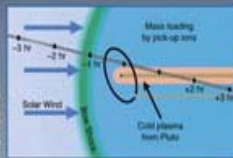
IR Surface Composition & Temperature Mapping



UV Airglow & Occultation Imaging Spectroscopy

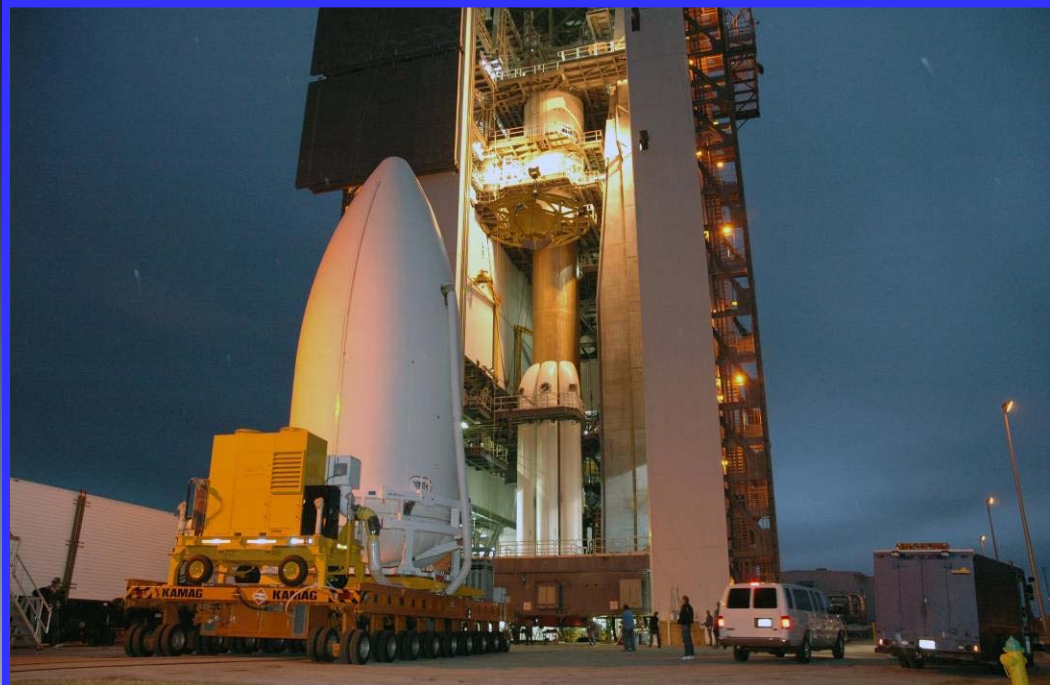
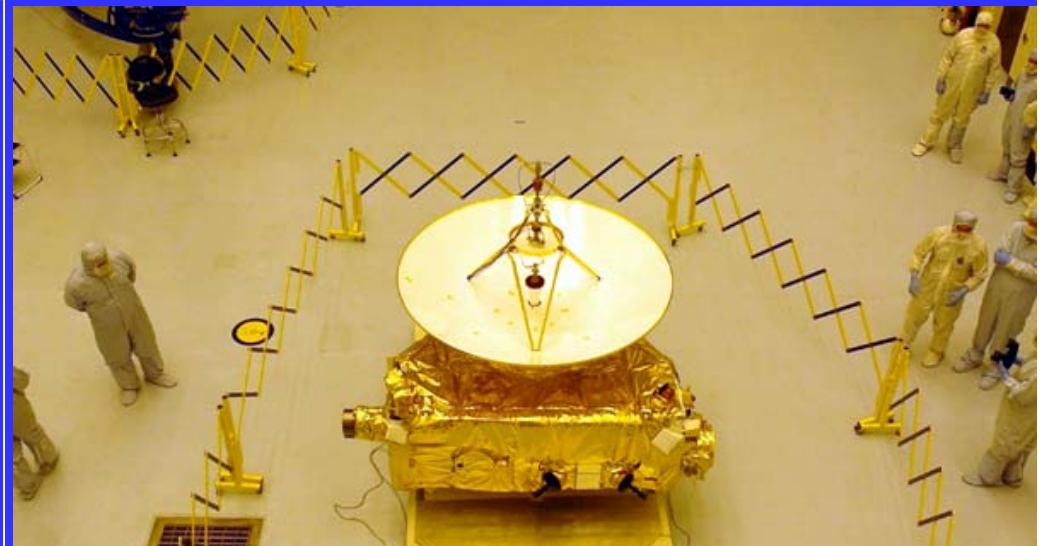


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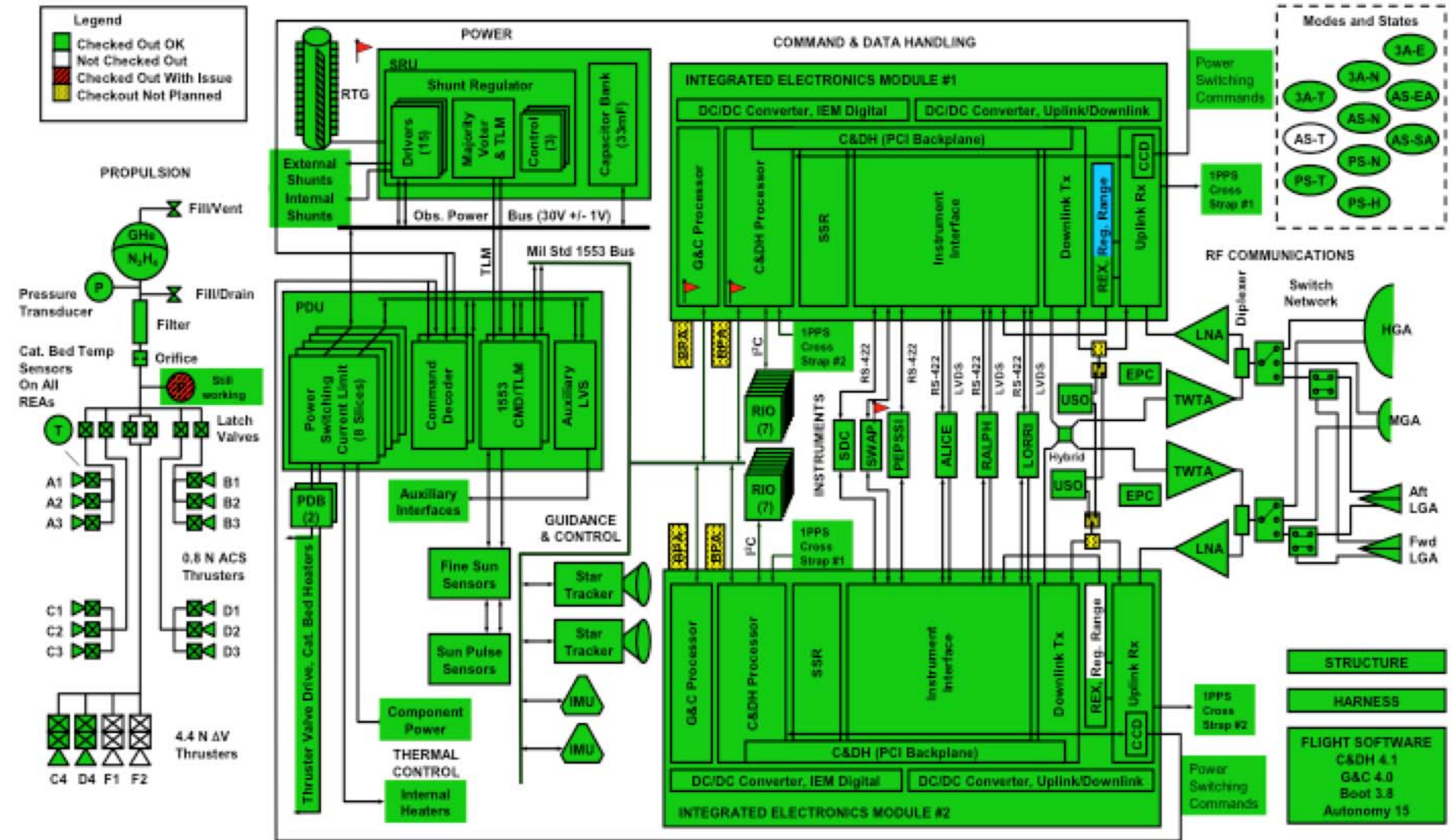
# AT THE CAPE: NOV 2005







# INSIDE NEW HORIZONS



As of 9/28/07

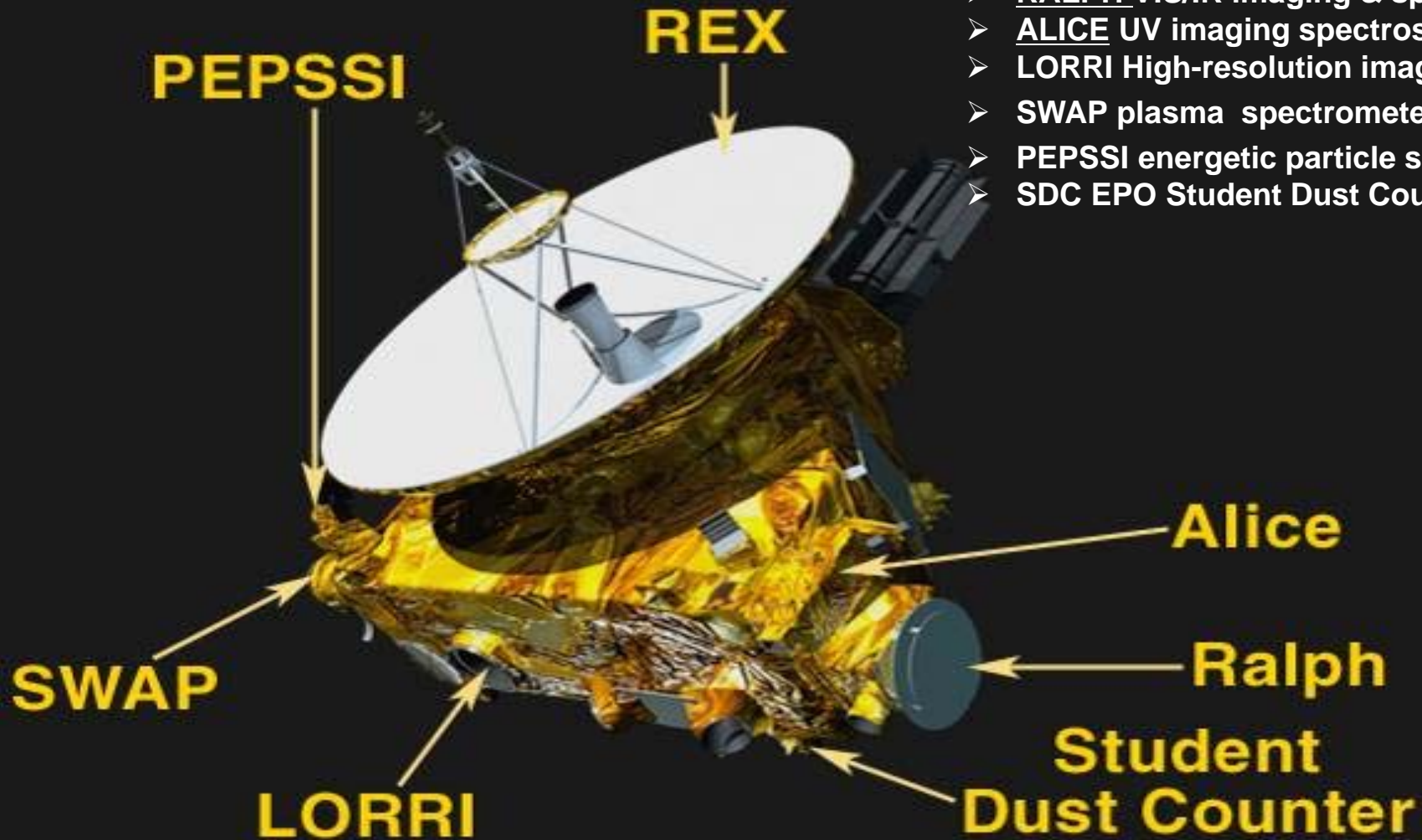


# THE SCIENTIFIC PAYLOAD



## Instruments:

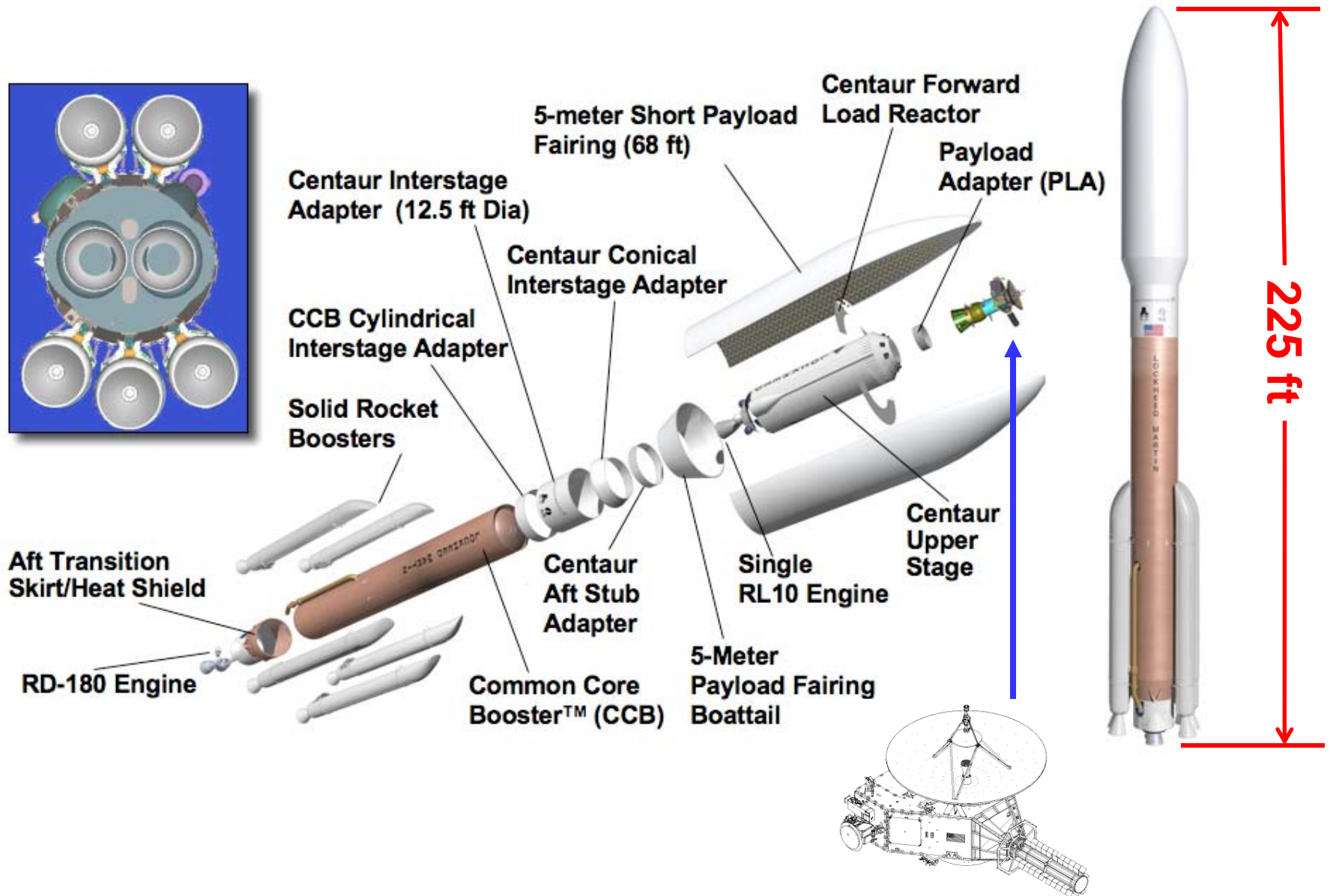
- REX radio science & radiometry
- RALPH VIS/IR imaging & spectroscopy
- ALICE UV imaging spectroscopy
- LORRI High-resolution imager
- SWAP plasma spectrometer
- PEPSSI energetic particle spectrometer
- SDC EPO Student Dust Counter





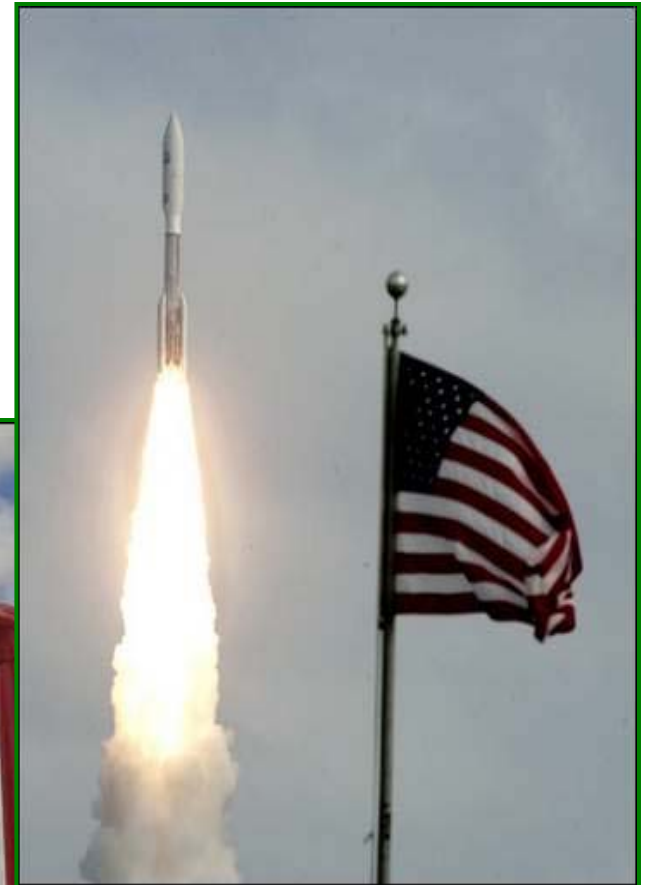


# LAUNCH VEHICLE





# LAUNCH 19 JANUARY 2006

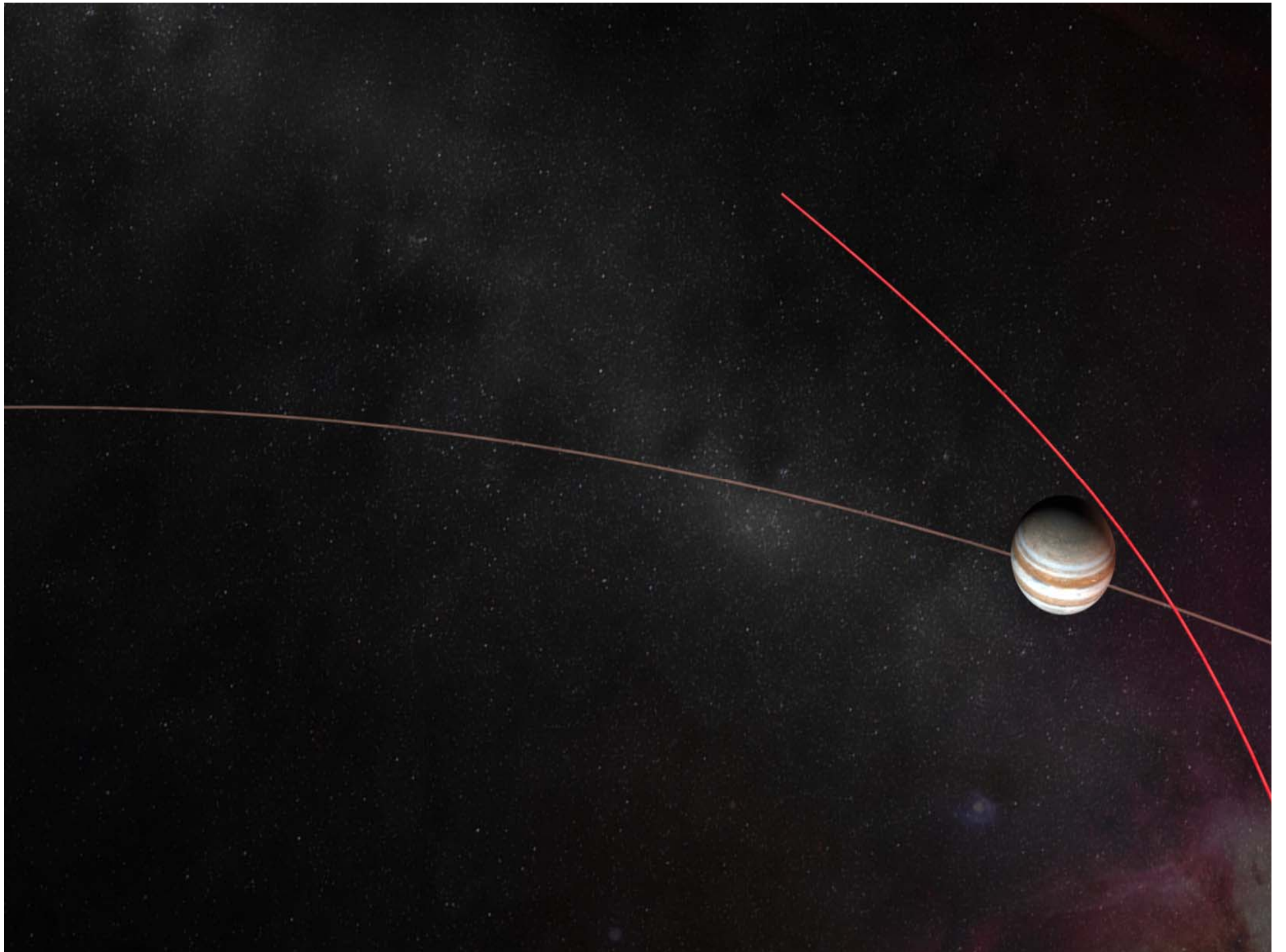


# Science



NEW HORIZONS  
at Jupiter







# WELCOME TO ENCOUNTER!

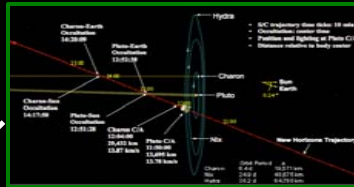
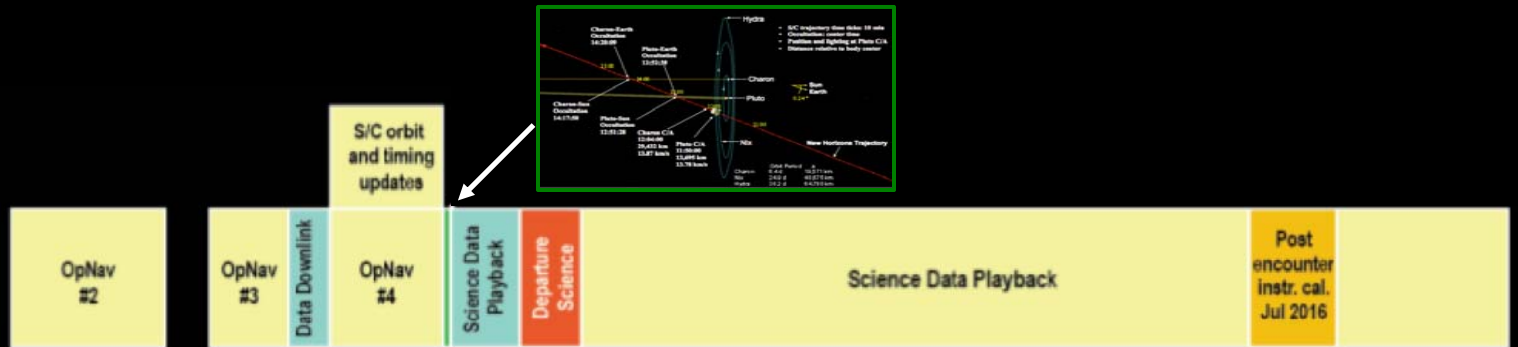


# ENCOUNTER OVERVIEW

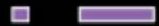
## TIMELINE



## PRIMARY OPERATIONS



## HAZARD SEARCH

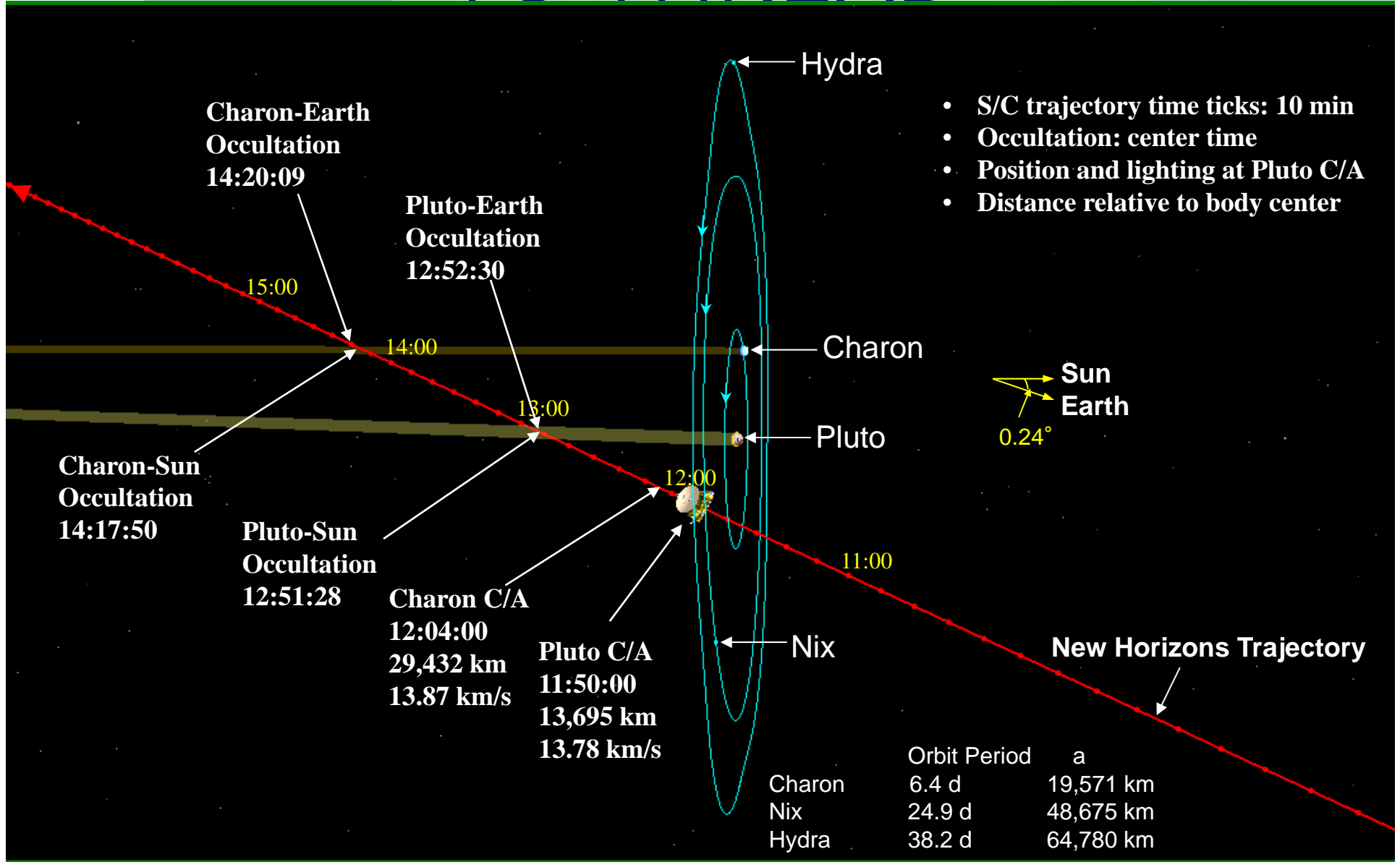


## MANEUVERS





# AND NEEDLES TO THREAD



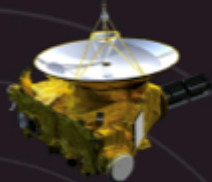


# A PEEK INSIDE THE PLUTO PUBLIC RELATIONS MACHINE

News Media Reports

2,800

on New Horizons' Pluto Flyby



450

Number of newspapers around the world that featured the Pluto image on the front page (7/15).

783K

Number of web stream plays on NASA TV. The normal average is 10K plays per day.

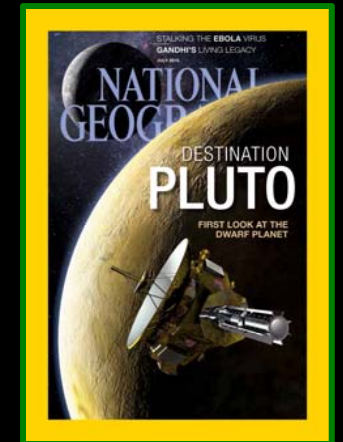
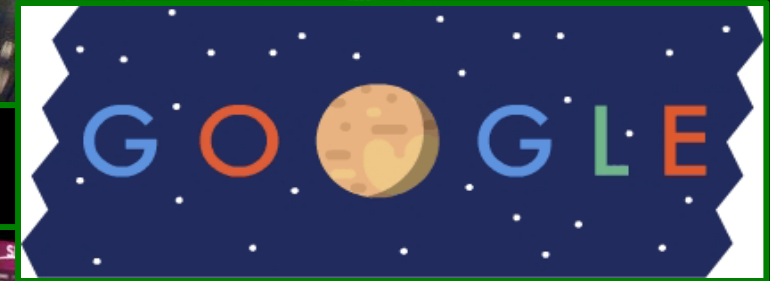
42%

Percentage of web traffic to all U.S. Govt. sites that was going to NASA.gov an hour prior to the flyby.

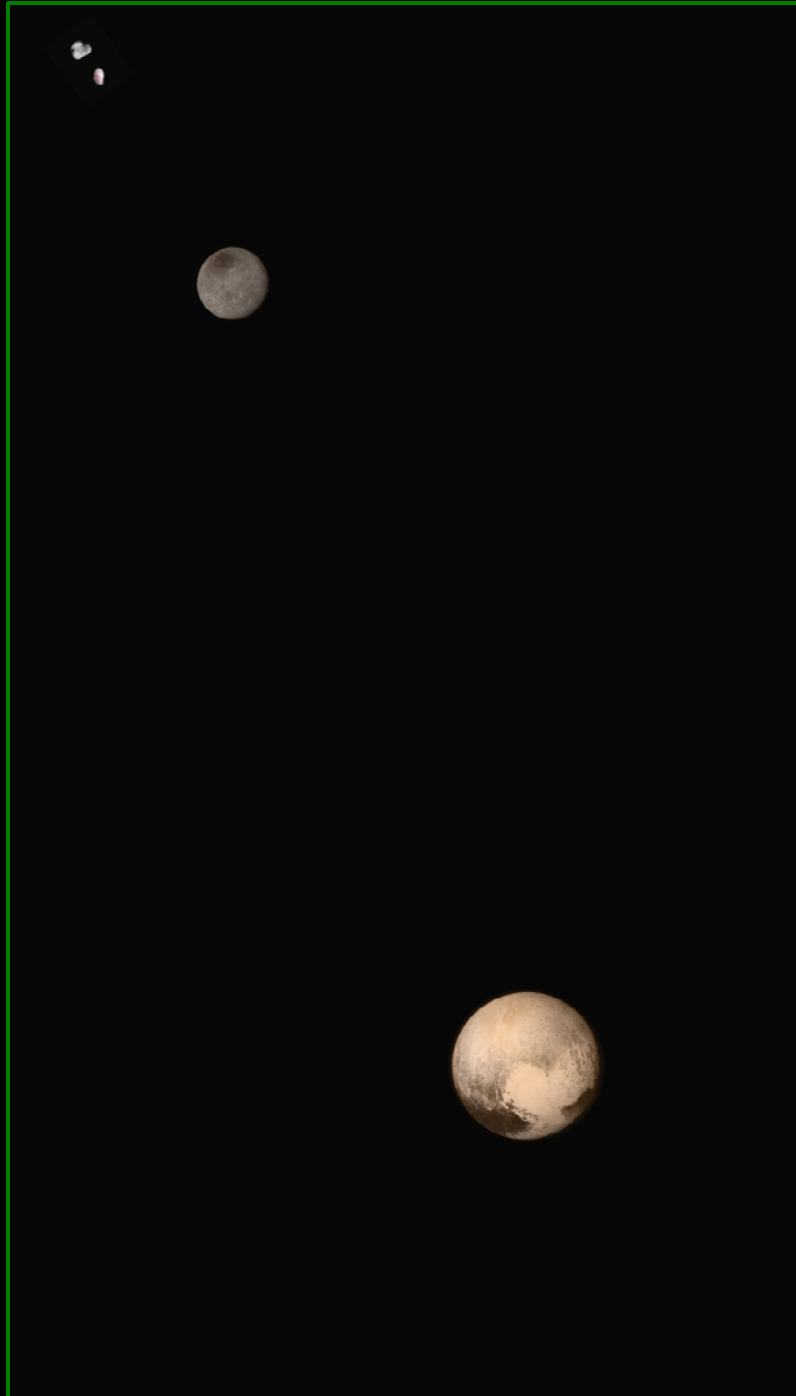
9.9M

Number of page views on NASA.gov resulting from 4.1 million sessions and 3.4 million users.

© Don Davis







**All surface  
feature names  
in this talk  
are informal.**

40 km

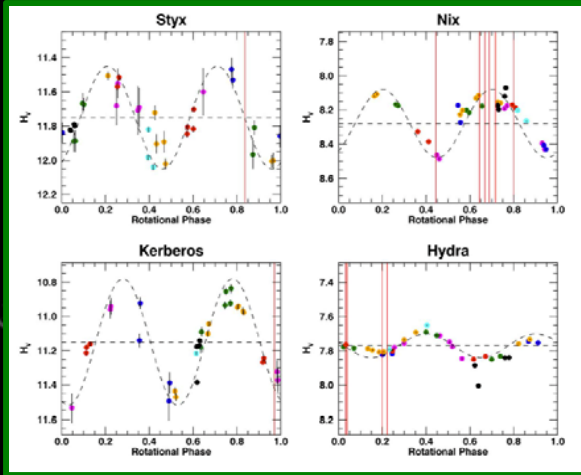
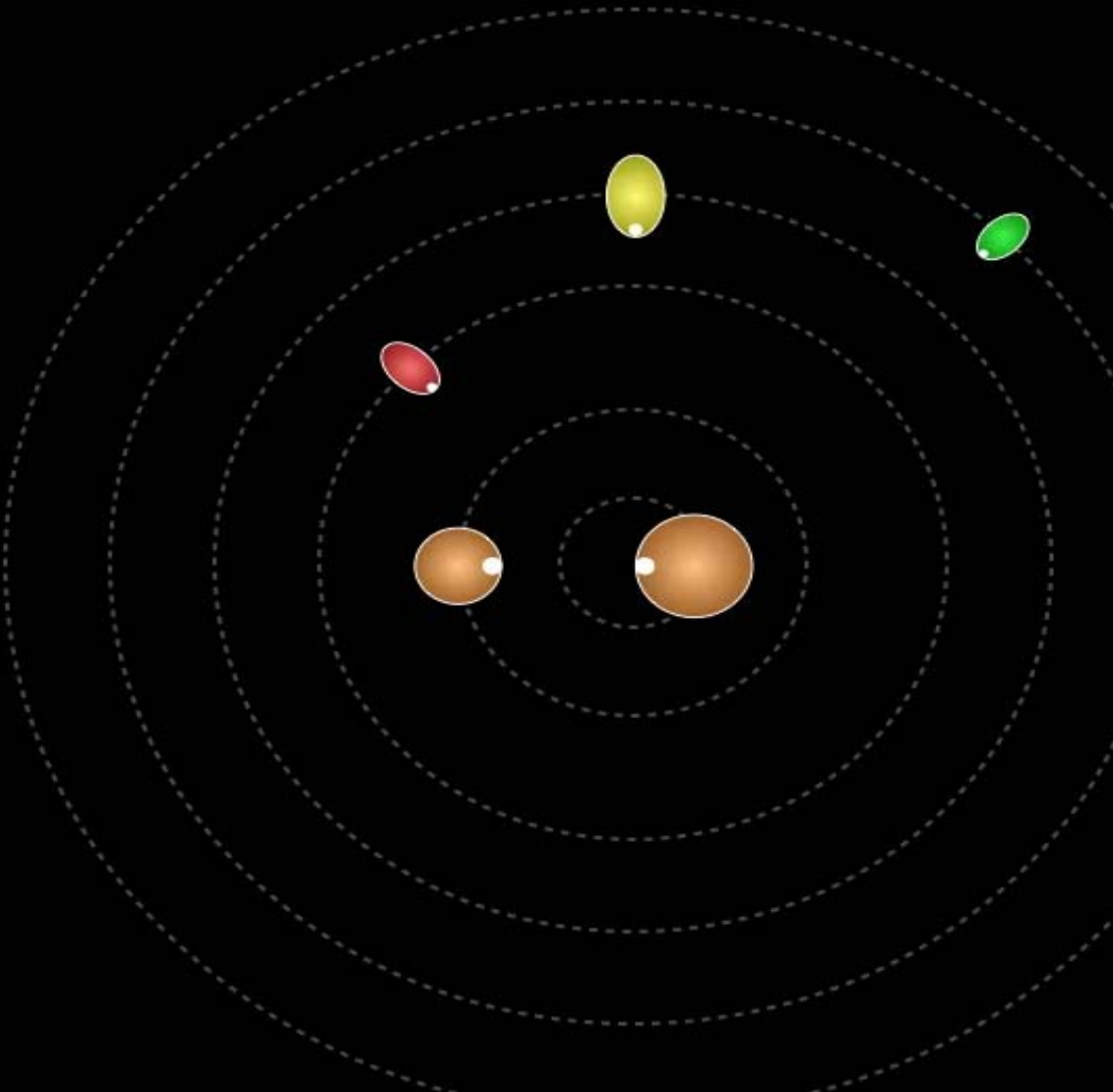
Styx

Nix

Kerberos

Hydra

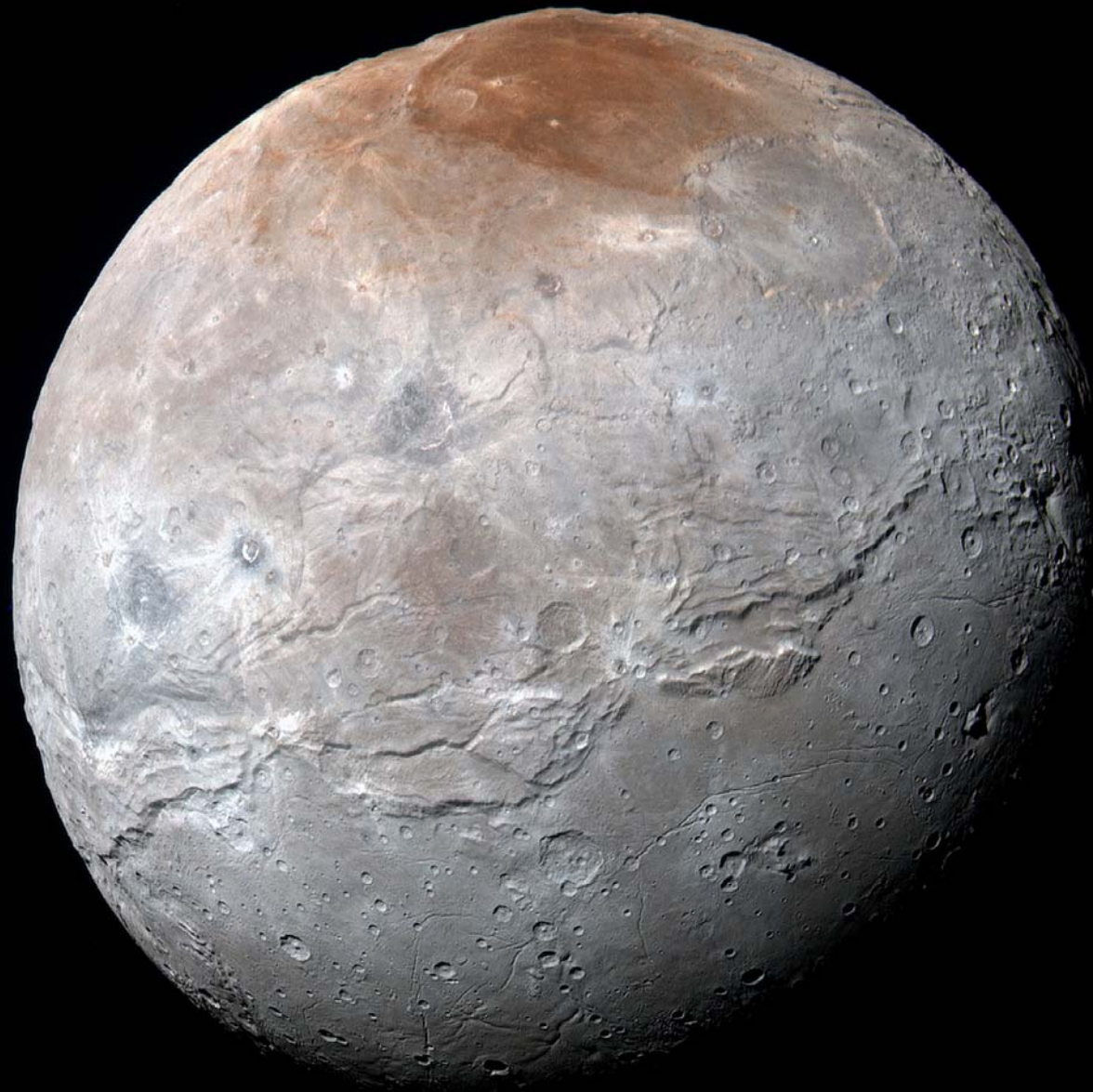




Body	Spin Period	
	Days	Orbits
Pluto	6.387	1
Charon	6.387	1
Styx	3.239	6.22
Nix	1.829	13.6
Kerberos	5.33	6.04
Hydra	0.4295	88.9

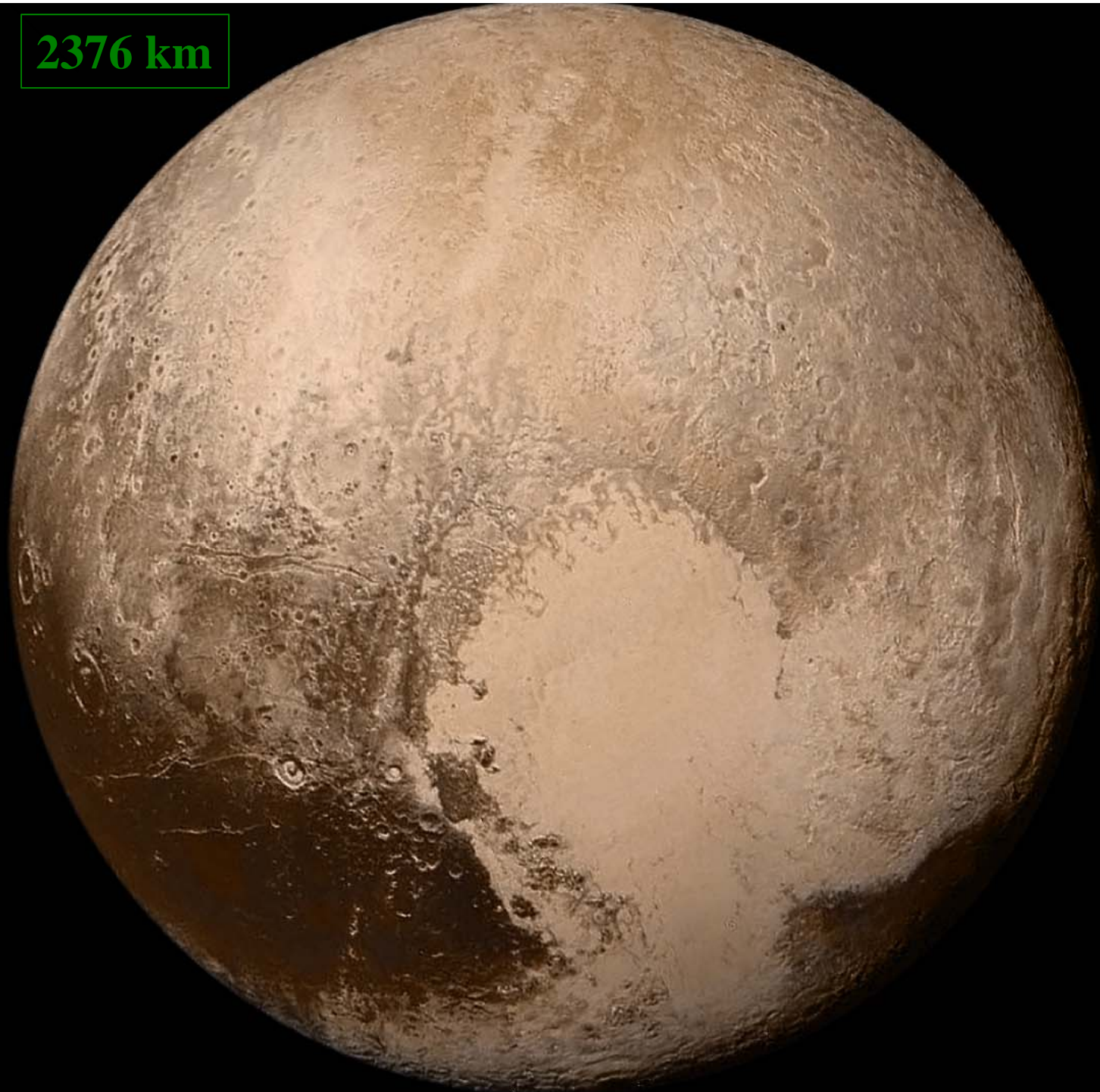
PLUTO'S SMALL SATELLITES  
ARE ALL NON-SYNCHRONOUS ROTATORS



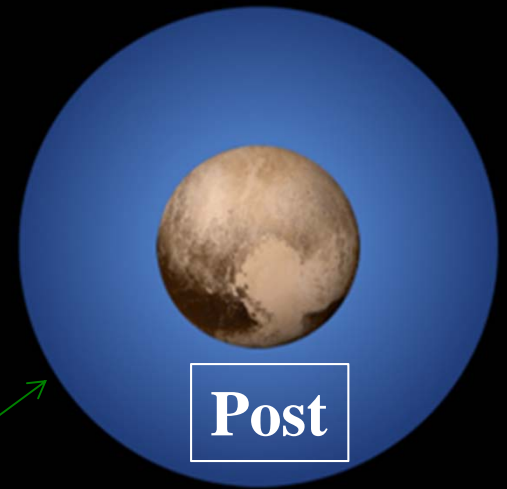




2376 km

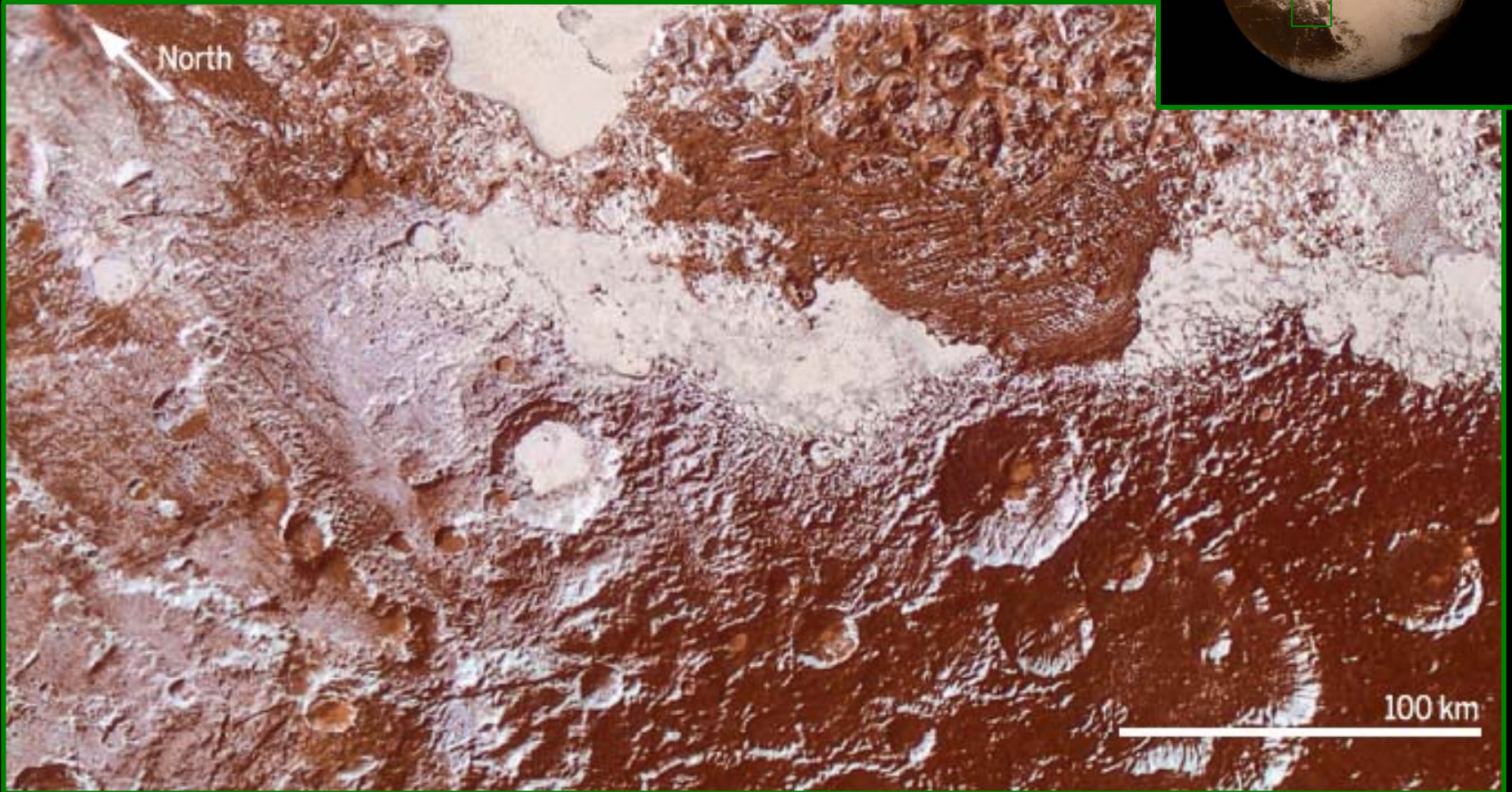
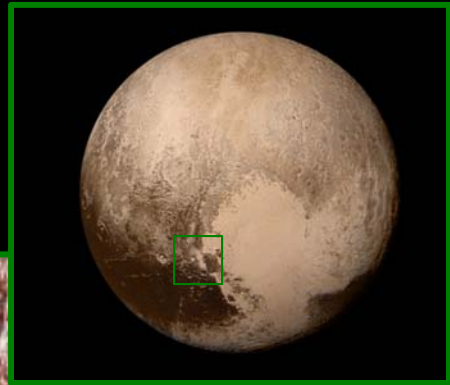




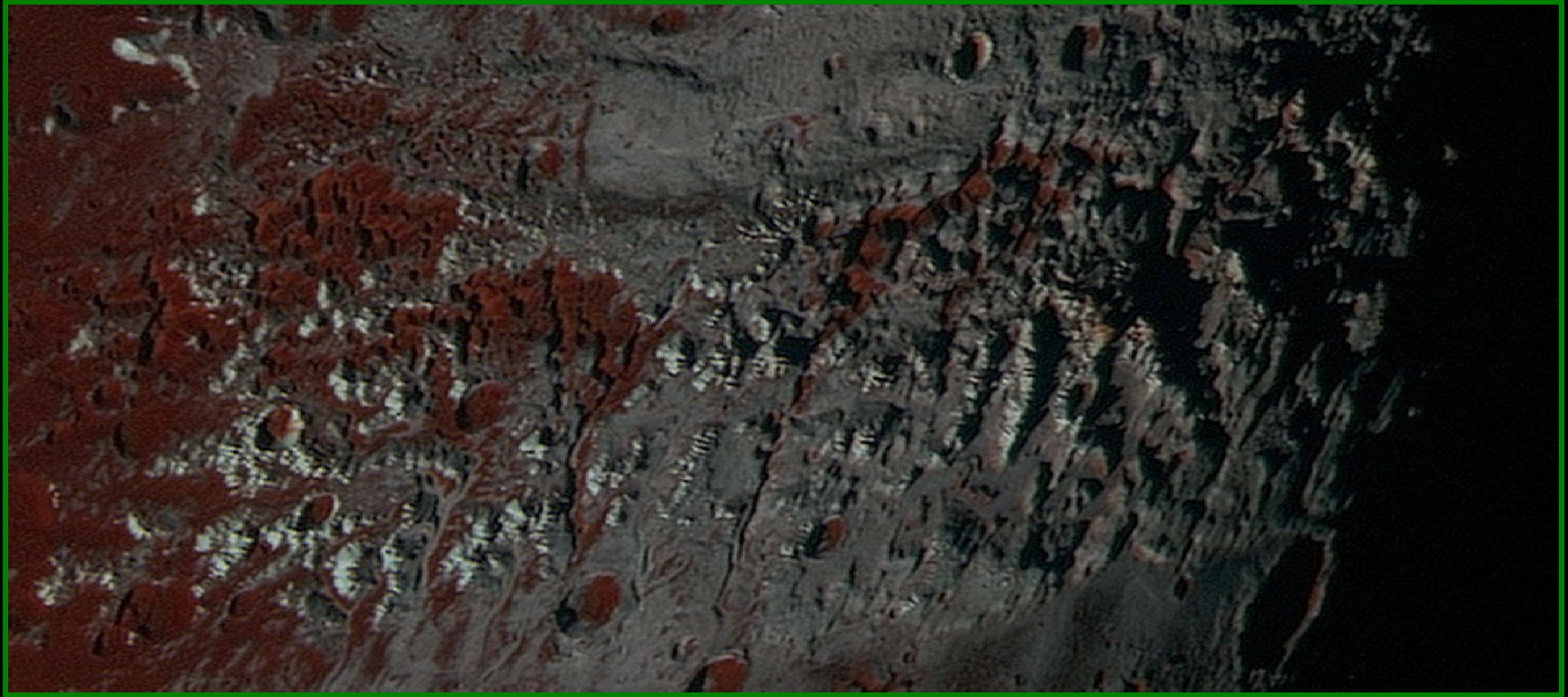


**The EUV/FUV solar  
occultation revealed colder  
atmospheric temperatures,  
which in turn reduced both  
scale heights & escape rates,  
and showed the escape  
mode to be Jeans, not  
hydrodynamic.**

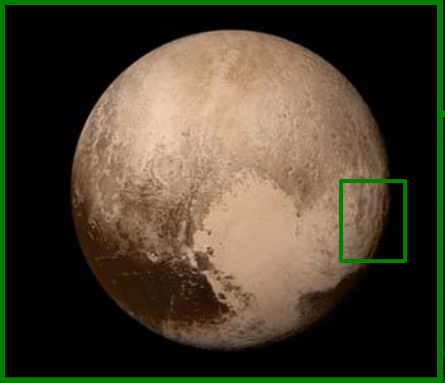
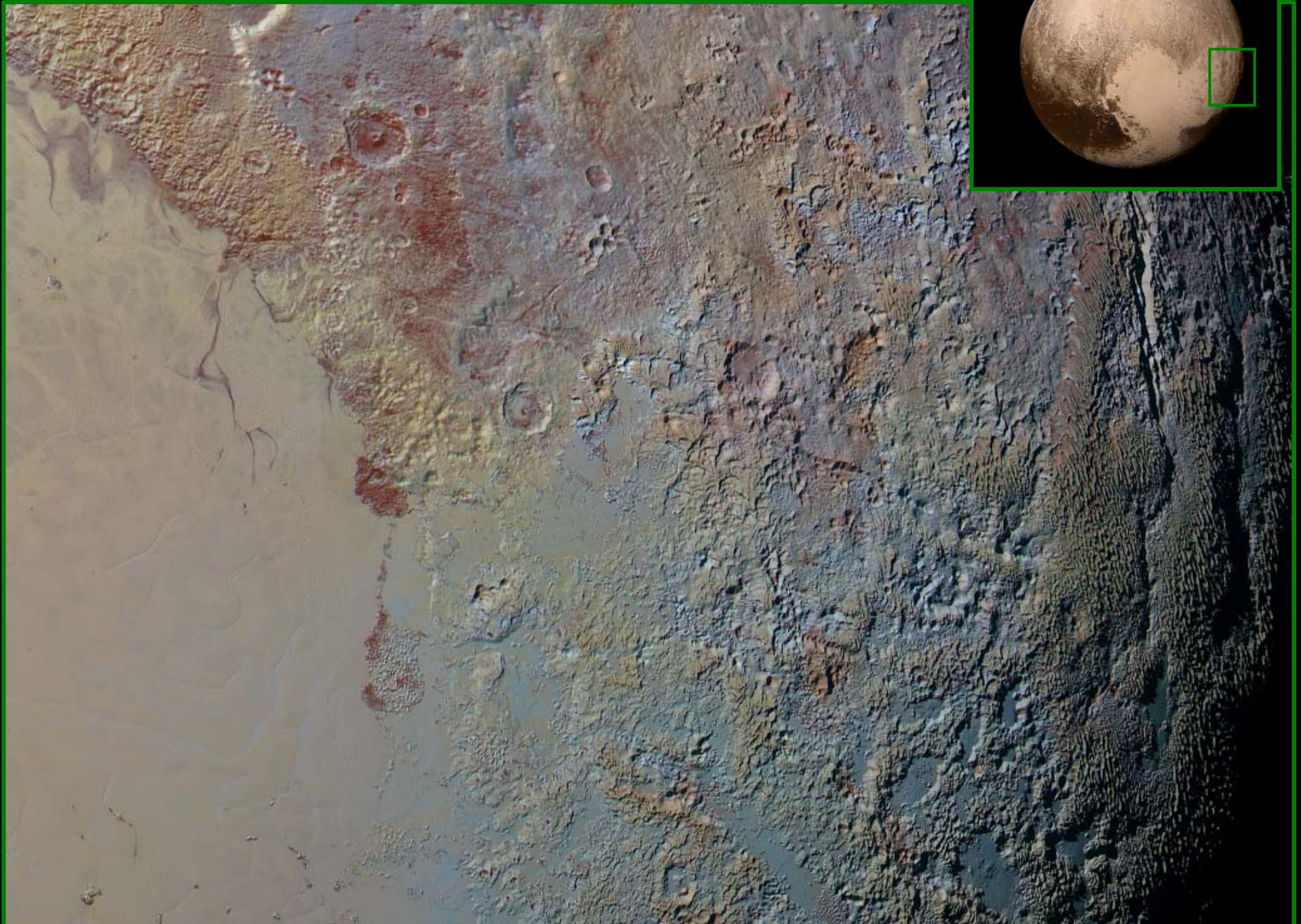




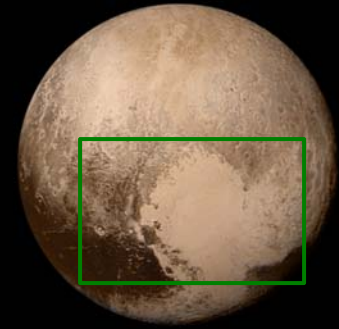
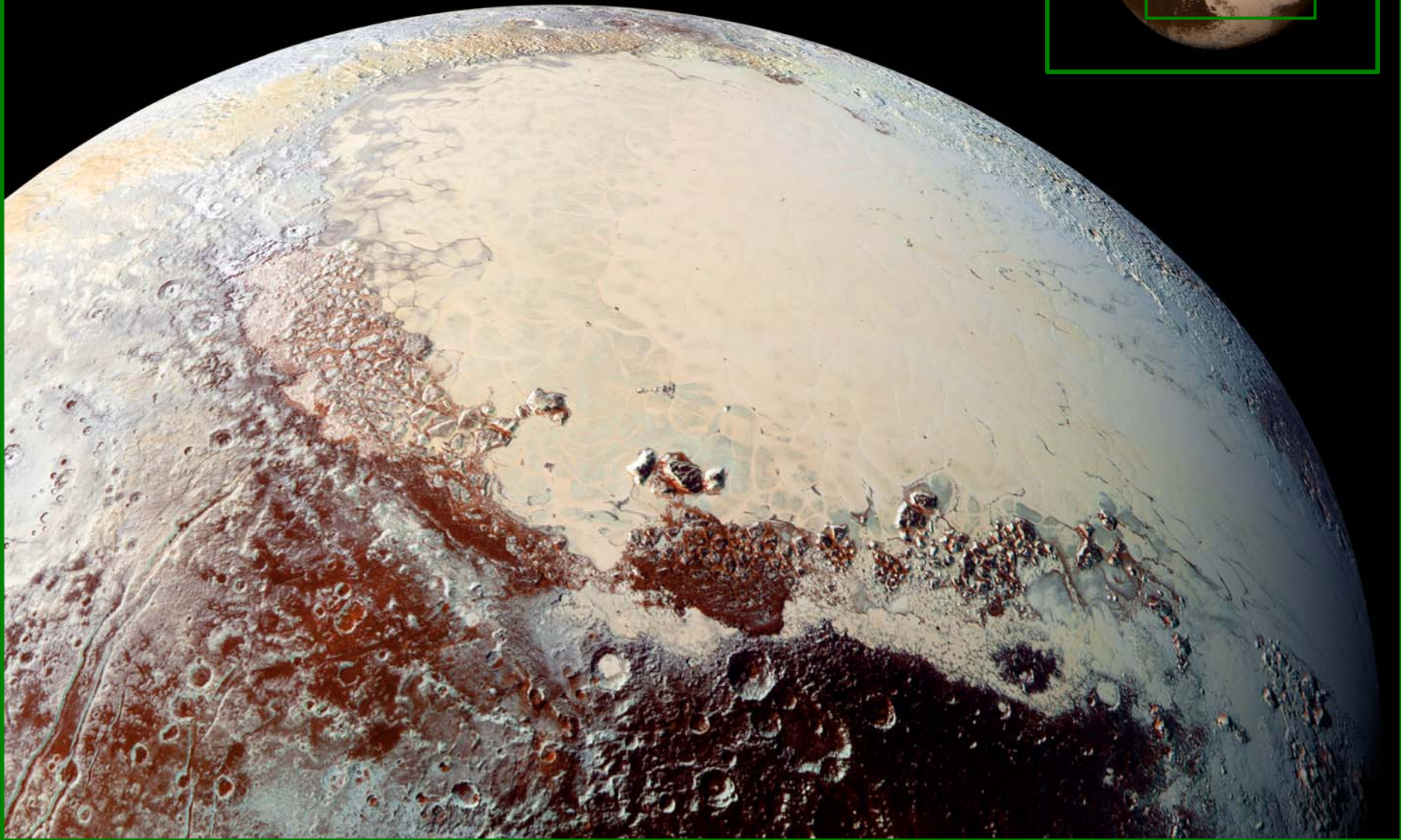




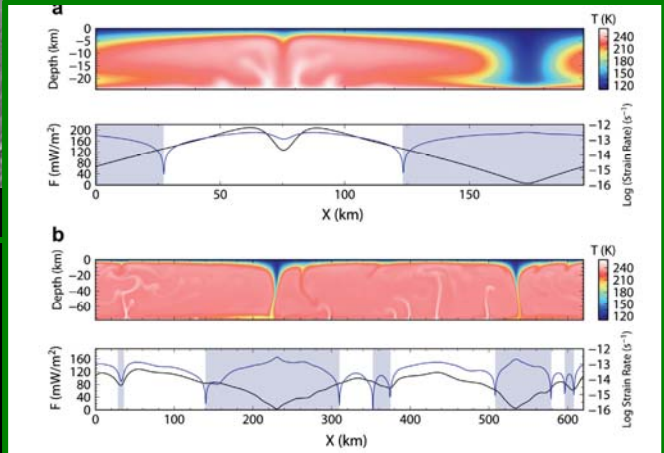
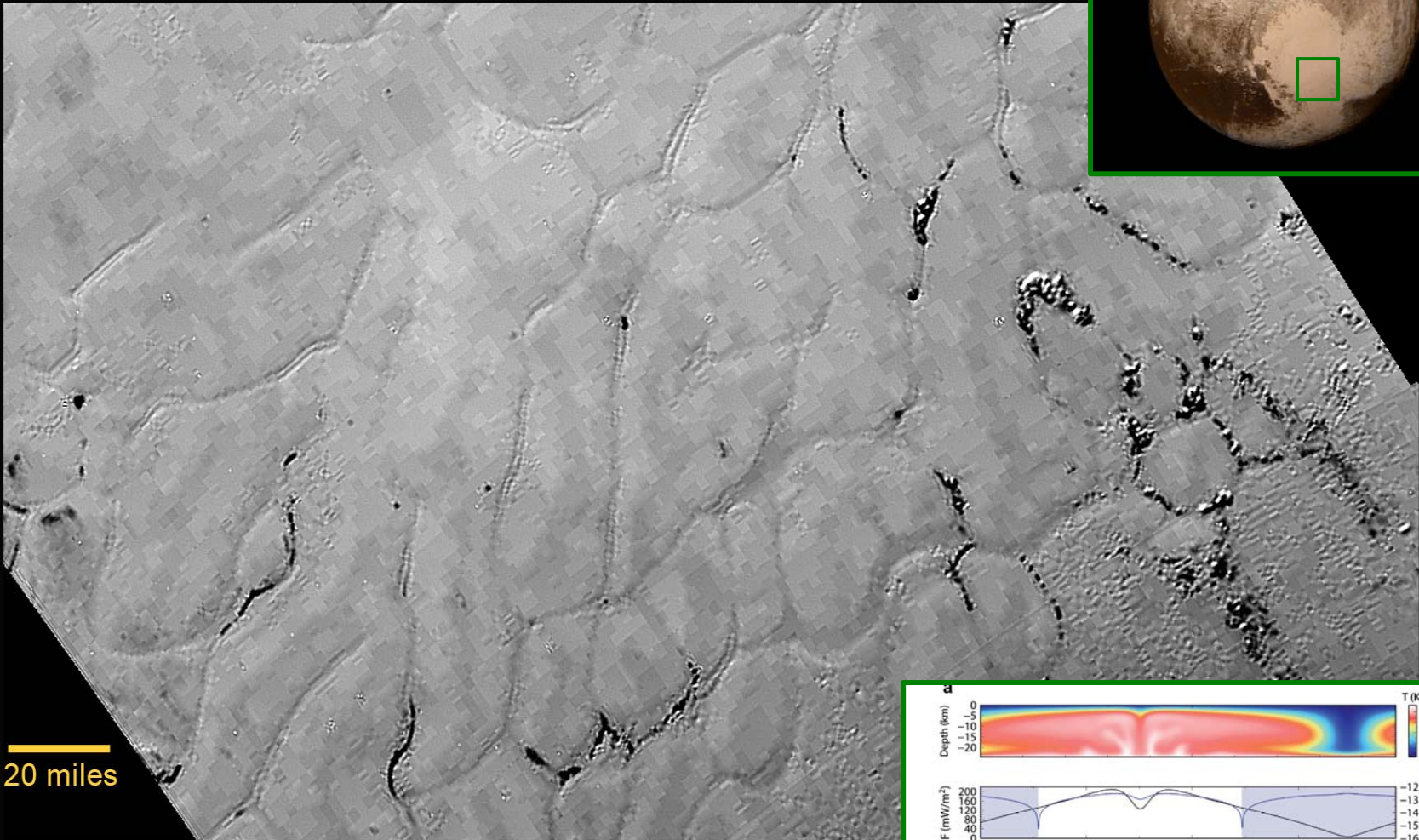
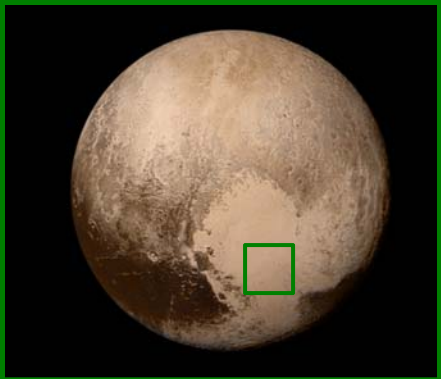


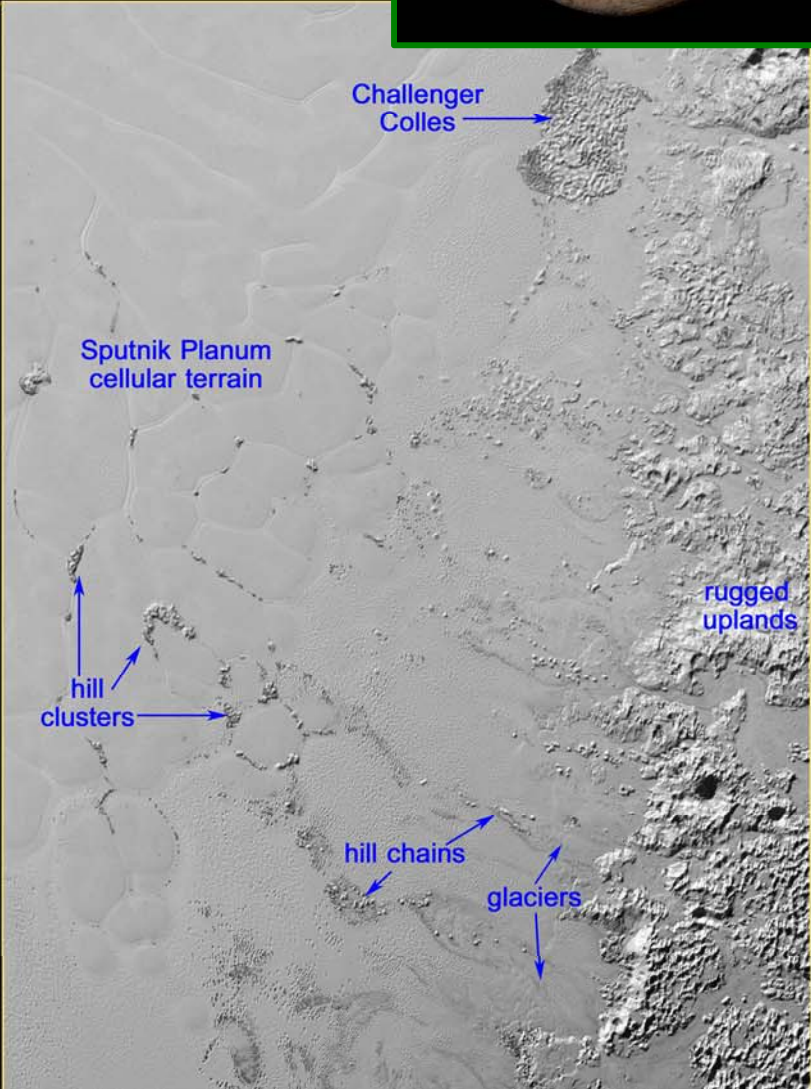
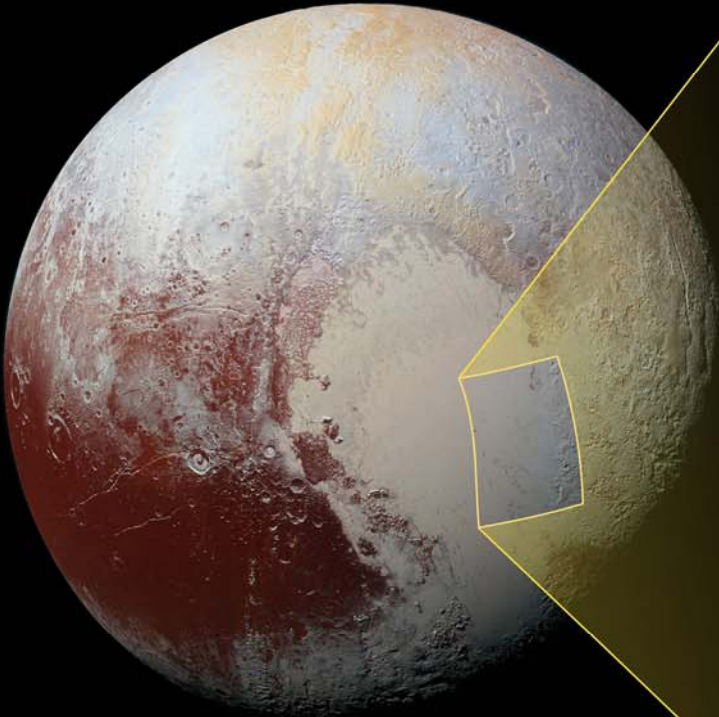
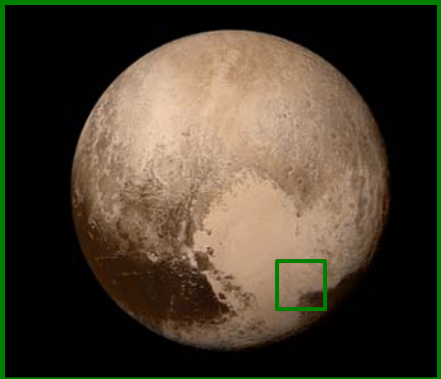






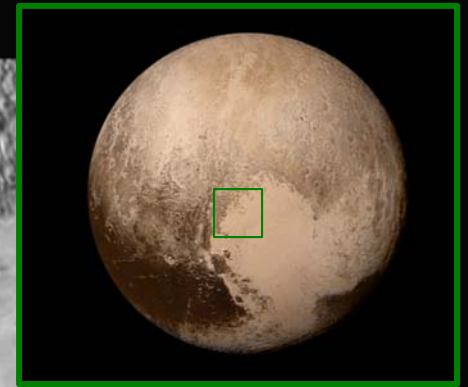
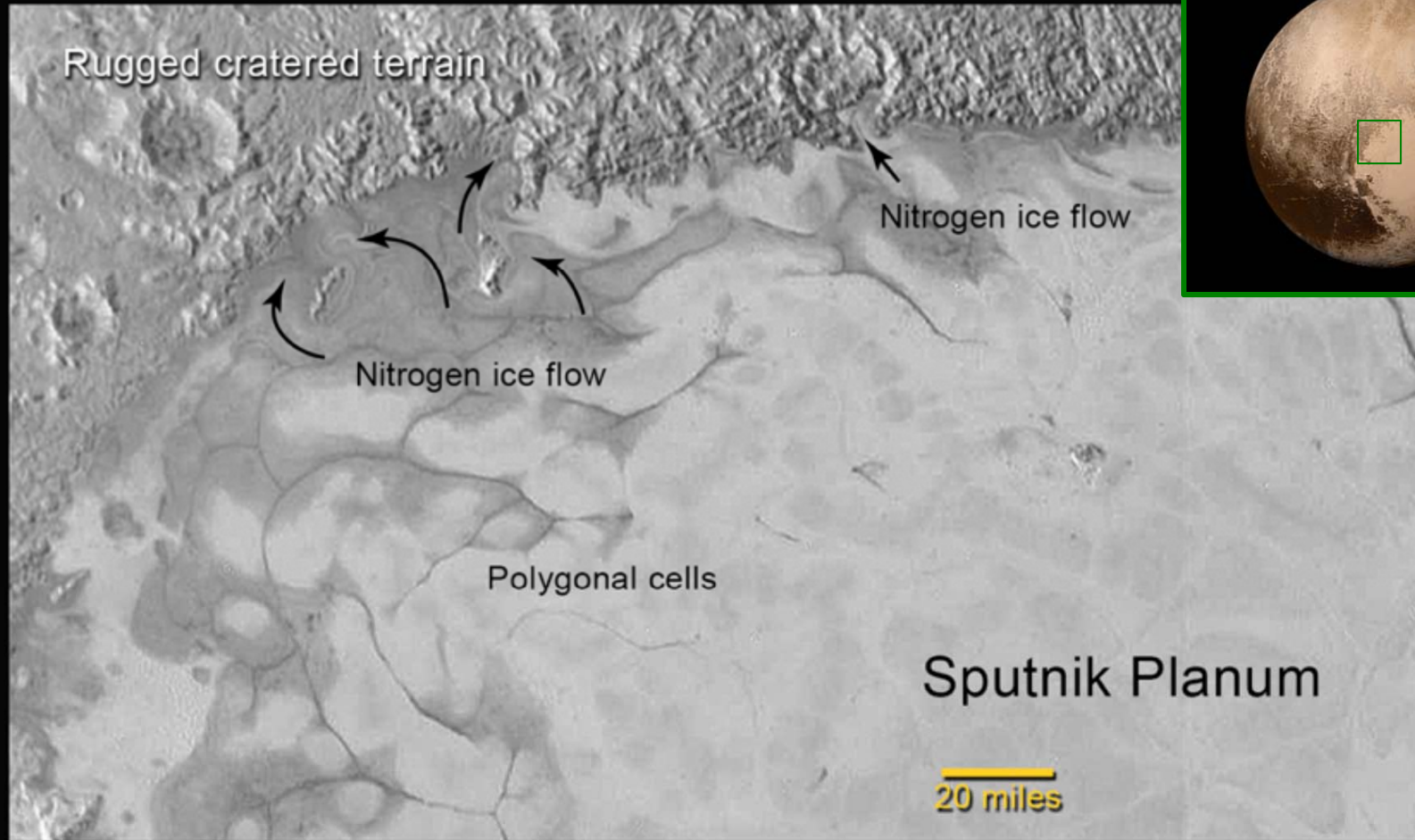




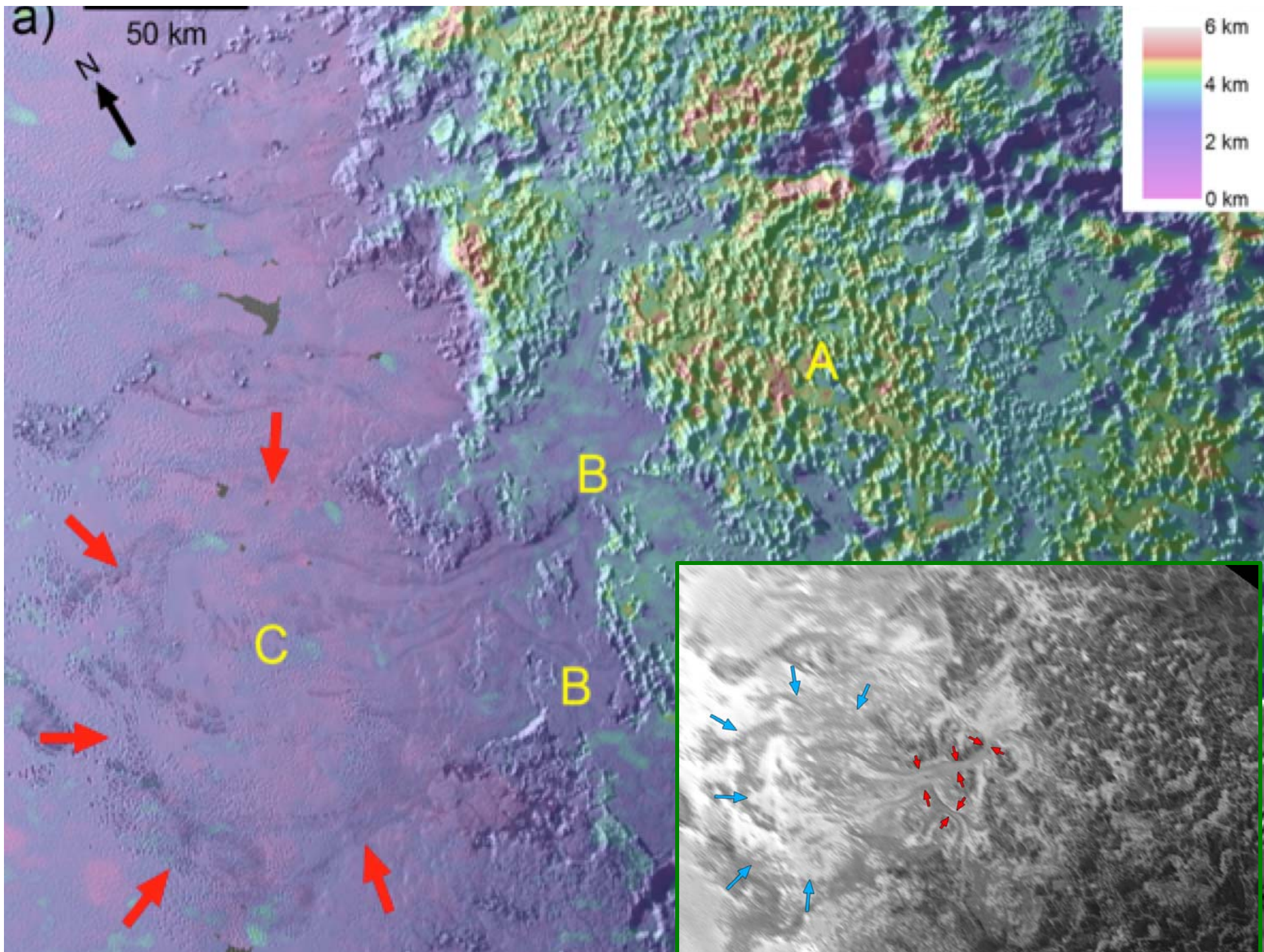




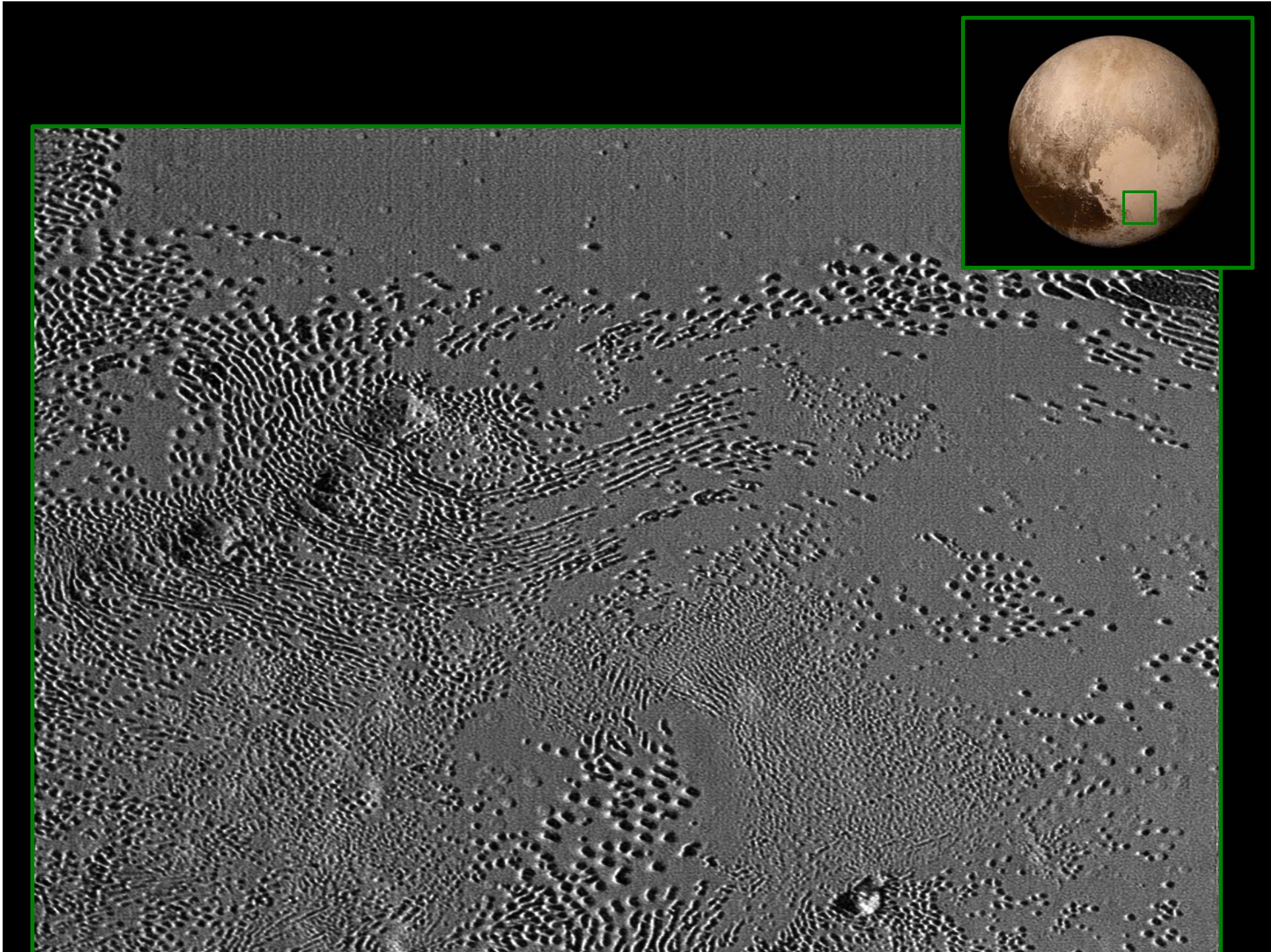
# NEW HORIZONS: GLACIAL FLOW ON PLUTO



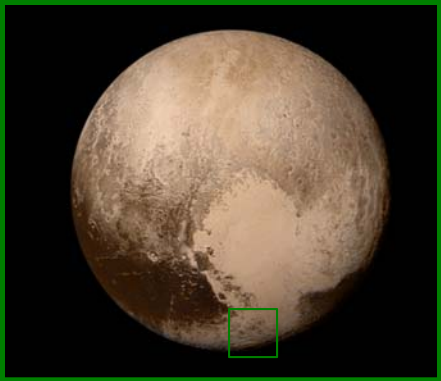
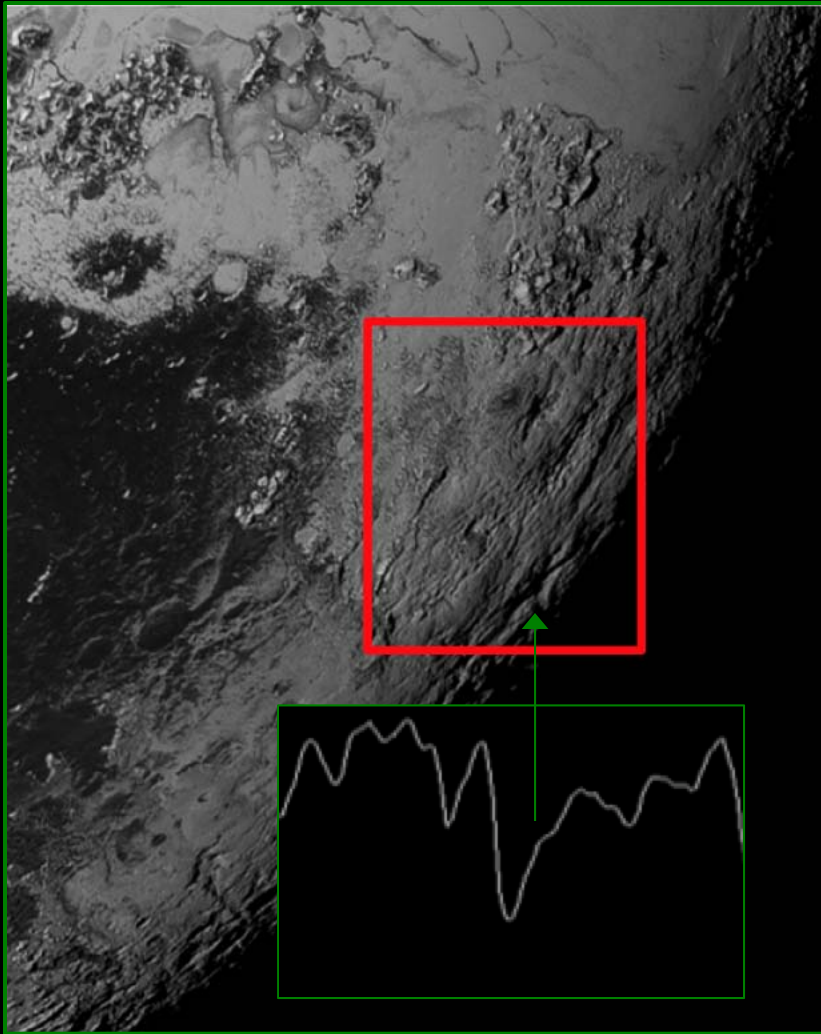








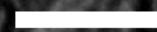




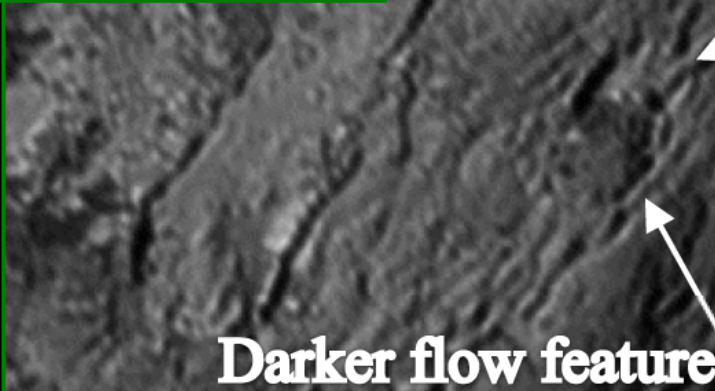
**Morgoth Macula**

**Quidlivun Cavus**

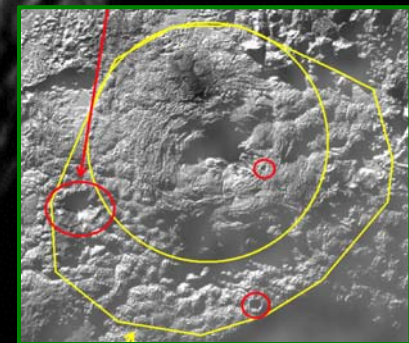
**~50 km**

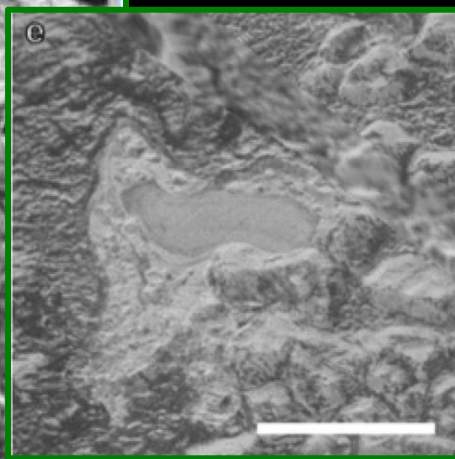
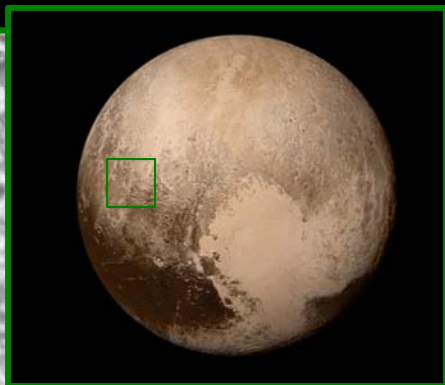
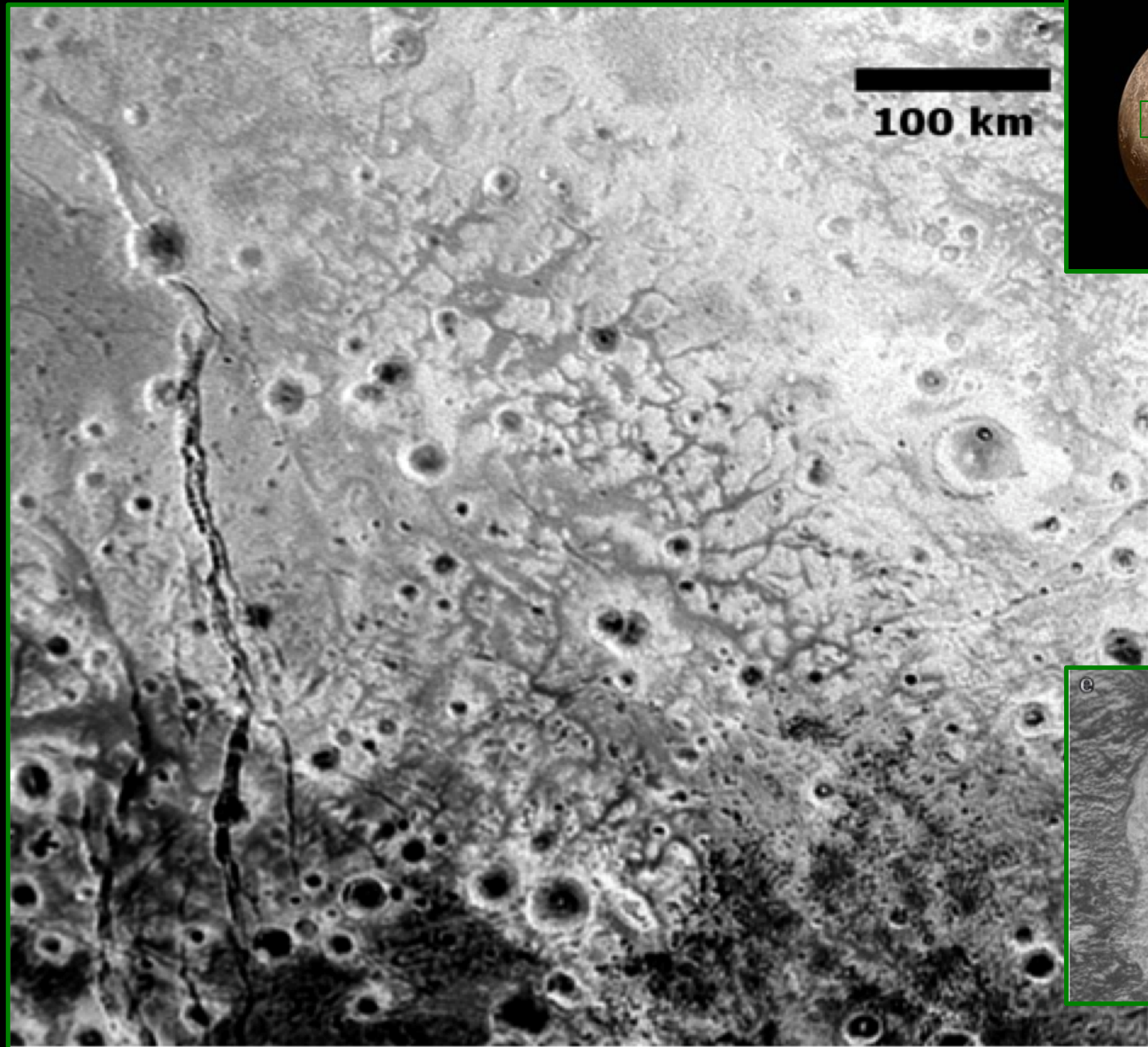


**Smaller cousin?**

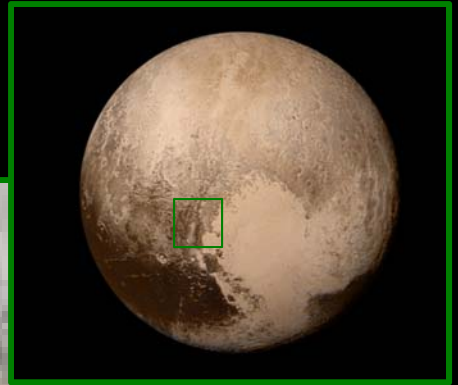
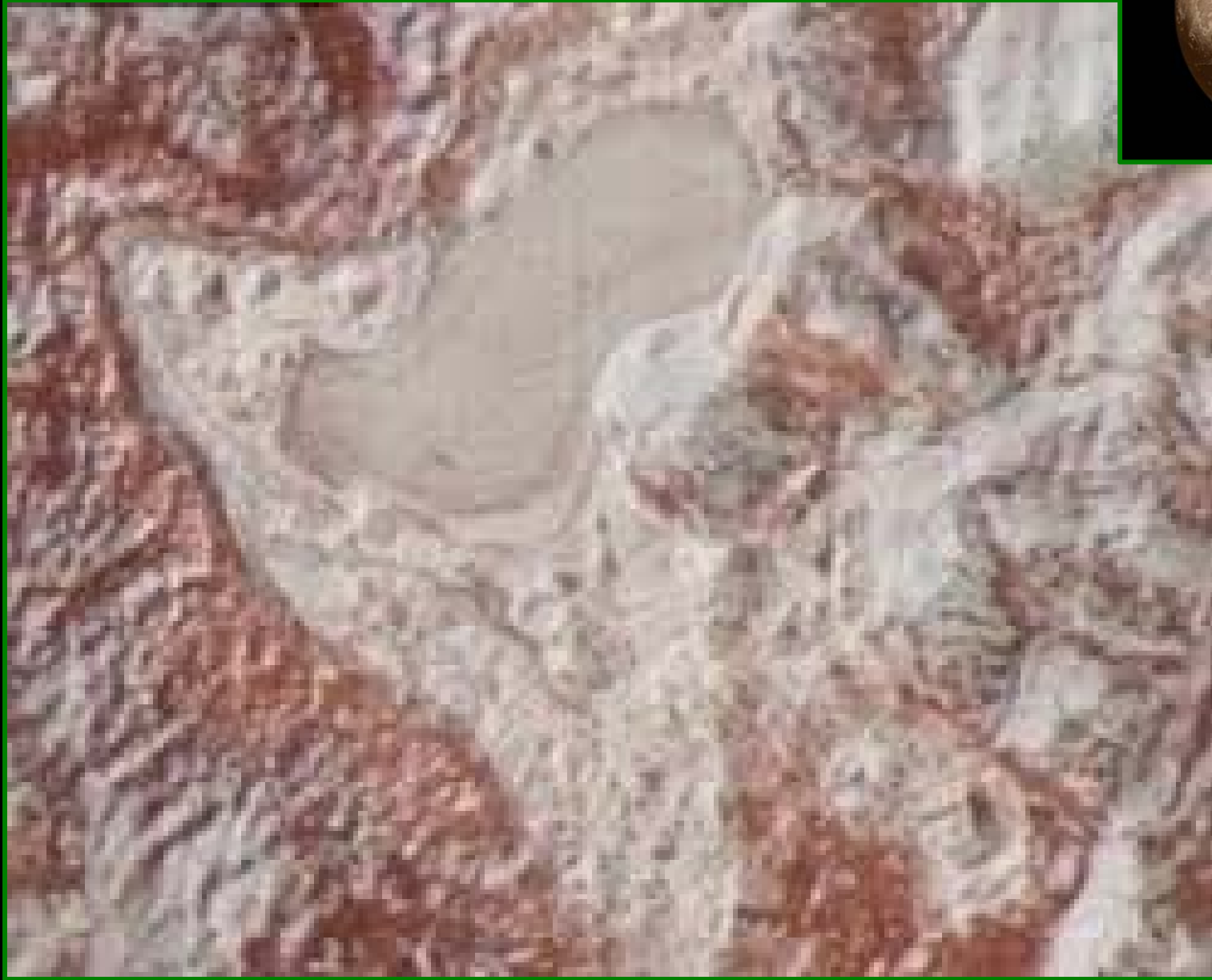


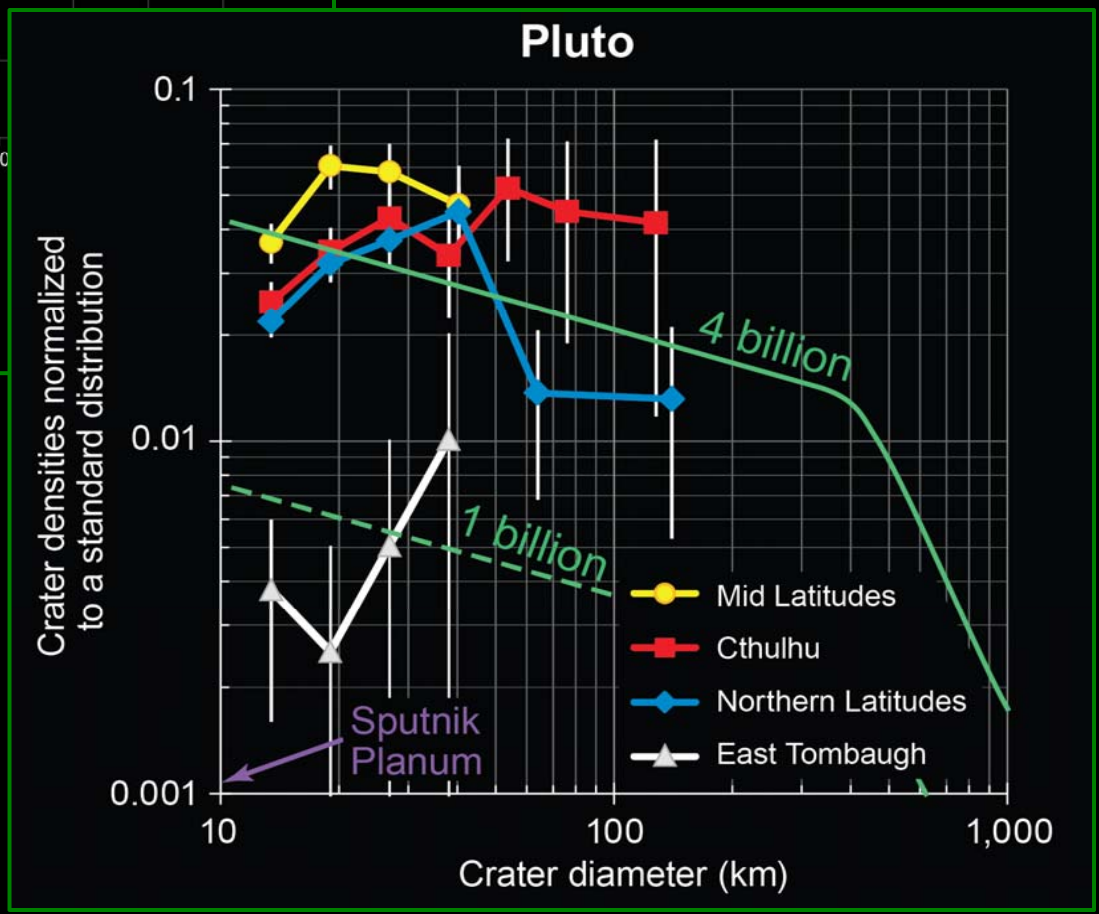
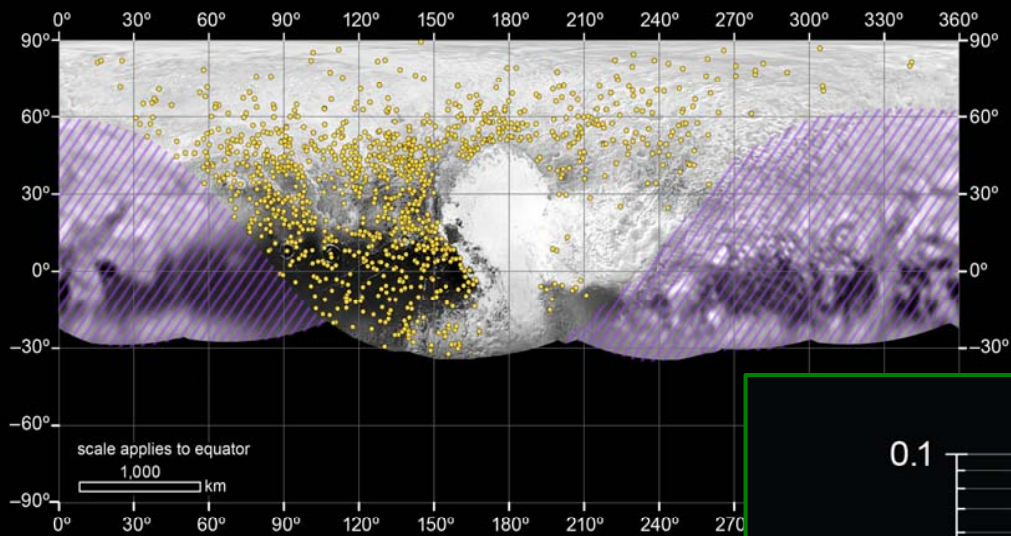
**Darker flow feature**













Ultimate bodybuilding: The quest for exoskeletons p. 270

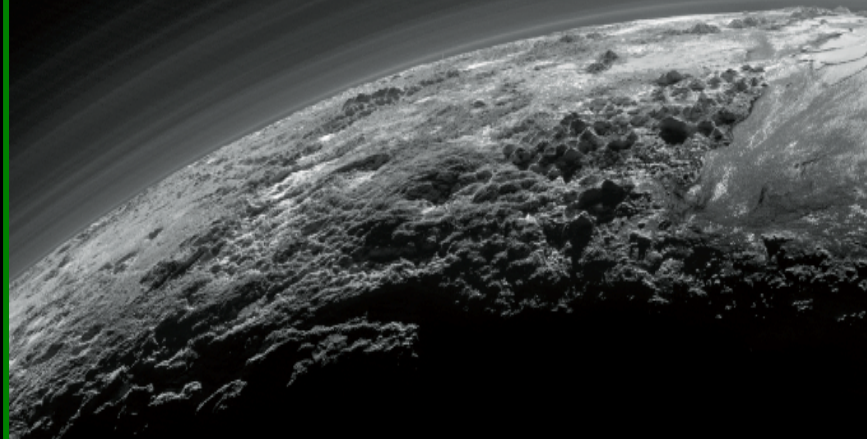
Giving a boost to quantum electronics pp. 280 & 307

Engineering remote-controlled T cells p. 293

# Science

\$10  
16 OCTOBER 2015  
sciencemag.org

AAAS



## *Flying past Pluto*

New Horizons finds surprises at Pluto and Charon pp. 260 & 292

# Science

\$15  
18 MARCH 2016  
sciencemag.org

AAAS

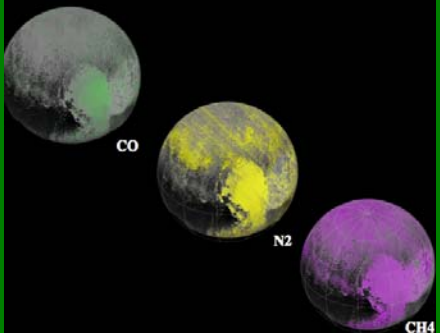
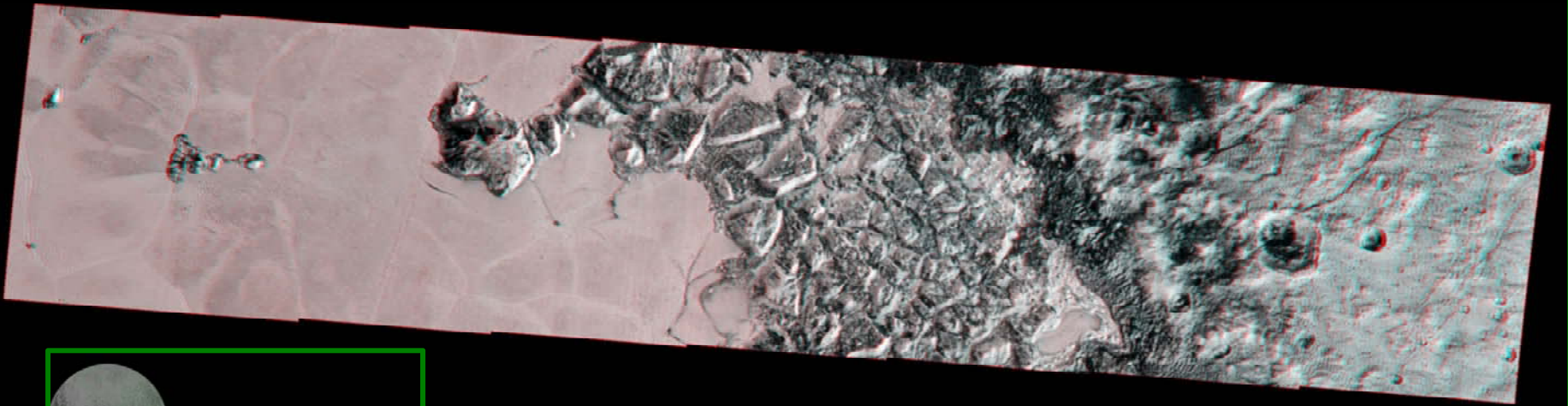
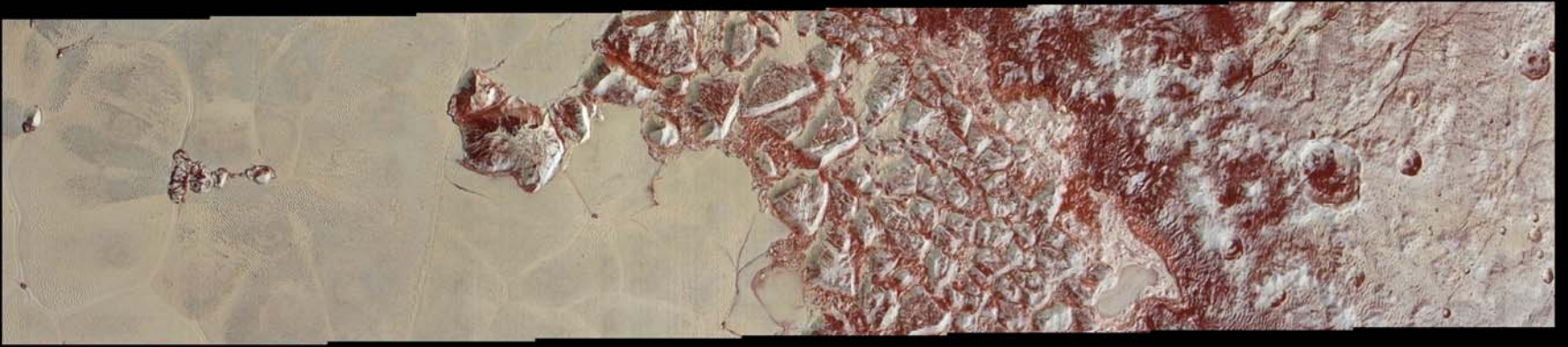
## *A new horizon*

The Pluto system seen up close

pp. 1280–1293

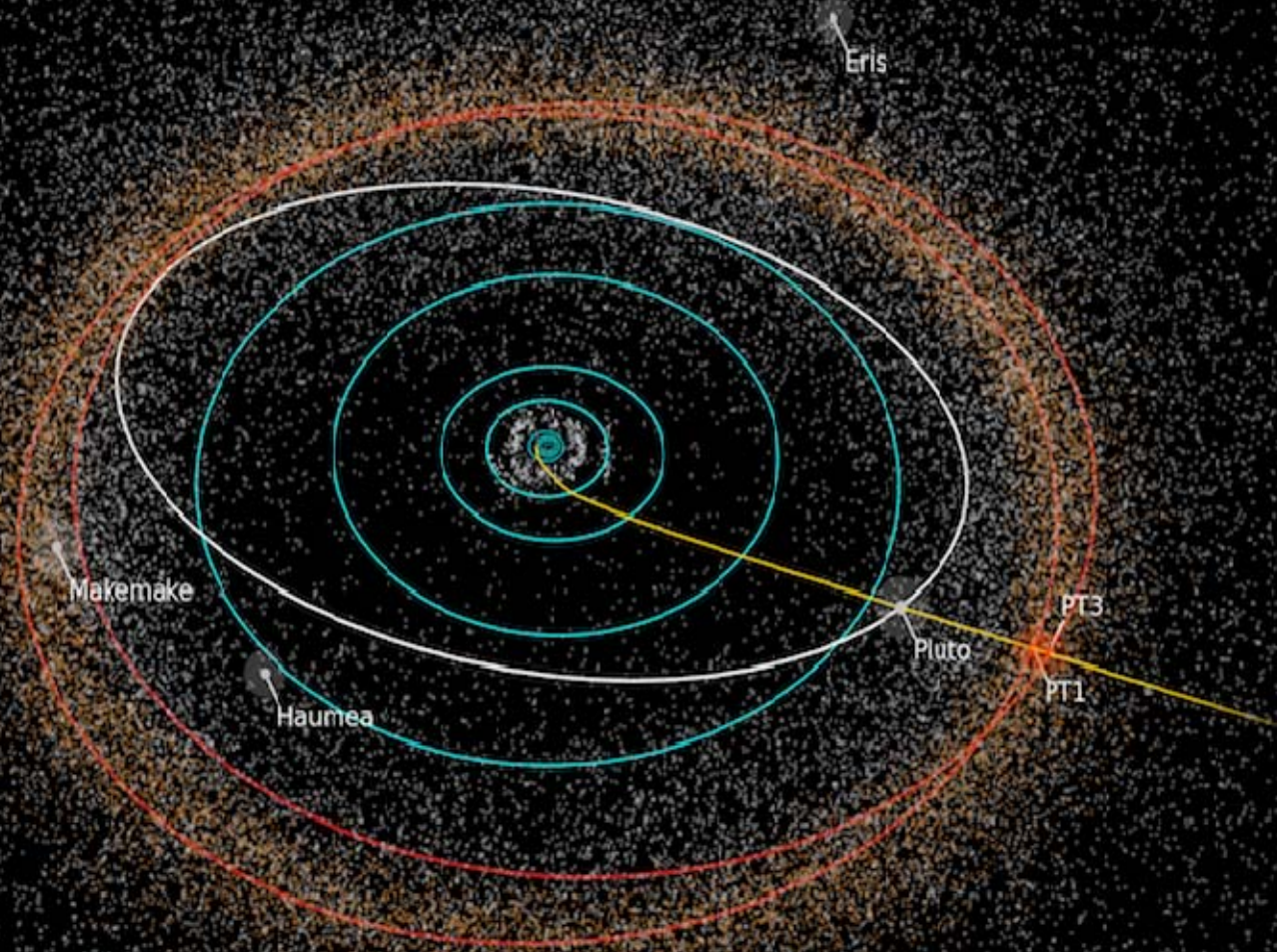








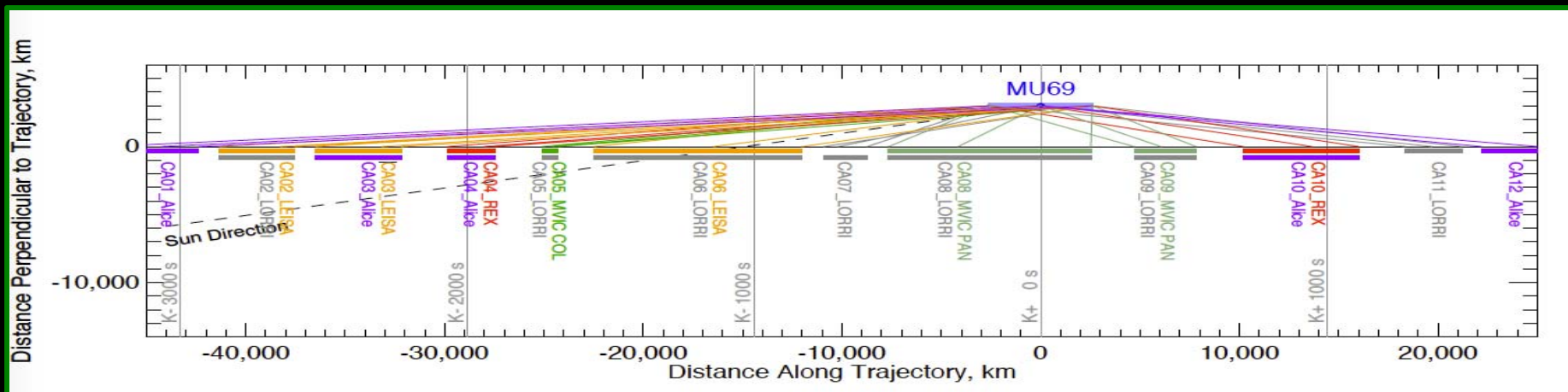
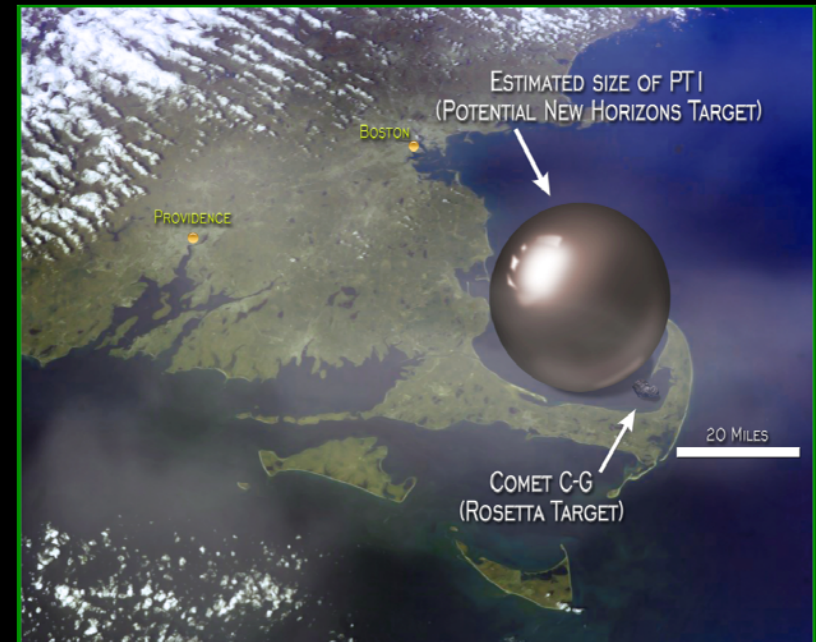
# EXTENDED MISSION: 2016-2021





# KBO CLOSE (3,000 KM) FLYBY

	PT1
<b>MPC Designator</b>	<b>2014 MU69</b>
<b>Diameter Range</b>	<b>21-40 km</b>
<b>Orbital Semi-major Axis</b>	<b>44.2 AU</b>
<b>Orbital Eccentricity</b>	<b>0.036</b>
<b>Orbital Inclination</b>	<b>1.9 deg</b>
<b>KBO Type</b>	<b>Cold Classical</b>
<b>Encounter Date</b>	<b>1 Jan 2019</b>



# KBO EXTENDED MISSION SCIENCE OBJECTIVES

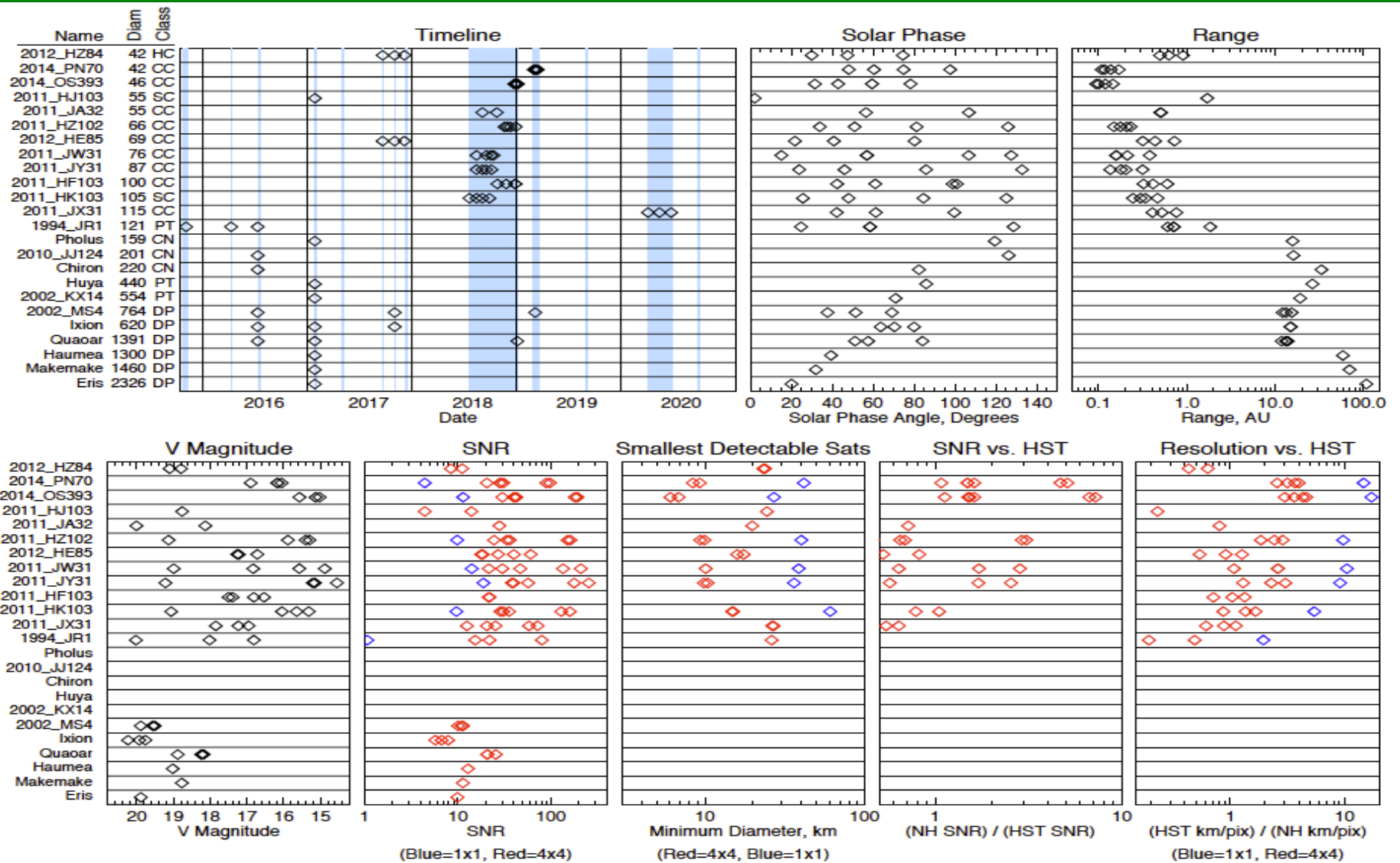
- **Close flyby of a primordial KBO planetesimal: 2019.**
- **Distant flyby observations of ~20 other KBOs: 2016-2020.**
- **Search for Centaur and KBO Rings: 2016-2020.**
- **Heliospheric transect of the Kuiper Belt—plasma, dust, and neutral gas observations: 2016-2021.**
- **Potentially conduct astrophysical cruise science: 2020-2021.**

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# KBO EXTENDED MISSION KBO SURVEY SCIENCE











# Backups

# Is It Really So Hard?

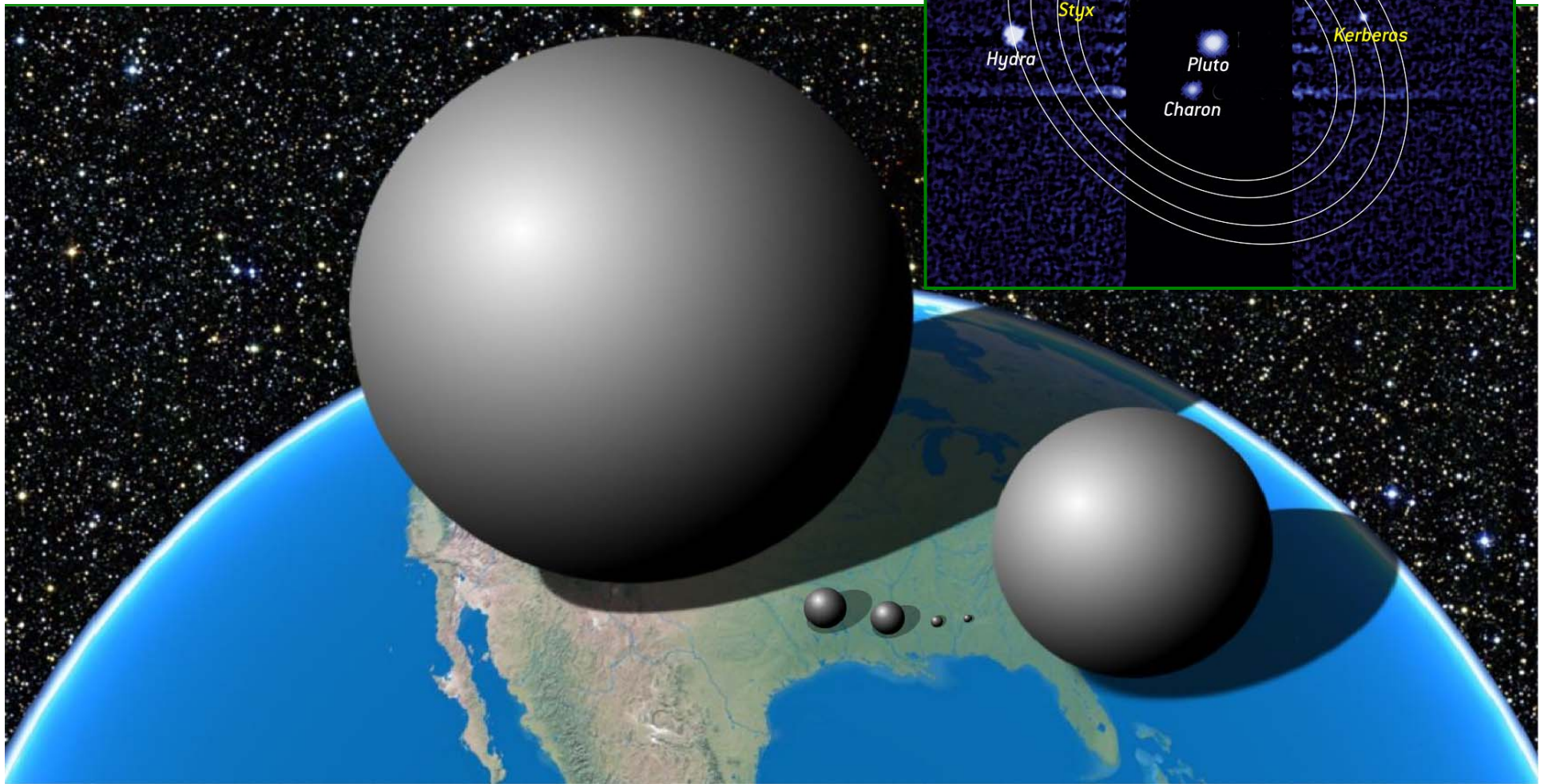


????????????????????????????????





# WITH SIX BODIES TO STUDY





**Stephen Hawking**

April 30 at 8:00am · 🌐

The New Horizons pioneering, decade-long mission is to travel to the outer reaches of our solar system, in order that we can discover more about our most distant planet, Pluto, and the Kuiper belt in which it is located. This July, **NASA - National Aeronautics and Space Administration's** New Horizons probe will fly by Pluto at 14km/s, using instruments to examine its atmosphere and surface and then transmit this information back 3 billion miles by X band for us to interpret and view. This would have been the subject of science fiction when I was at school, but is now science fact. I feel proud and honoured for such a momentous scientific mission to be completed within my lifetime, and plan to celebrate in my own way, with a Pluto party in July. My congratulations to everyone on the New Horizons team. With imagination and determination, it is humbling to see what we are capable of. -SH



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👍 Cindy Conrad, Carole Jones Stern, Joel Parker and 5,606 others like this.

Most Relevant ▾

↪ 571 shares



# 2005: TESTING



**June 2005 – GSFC Spin Balance**

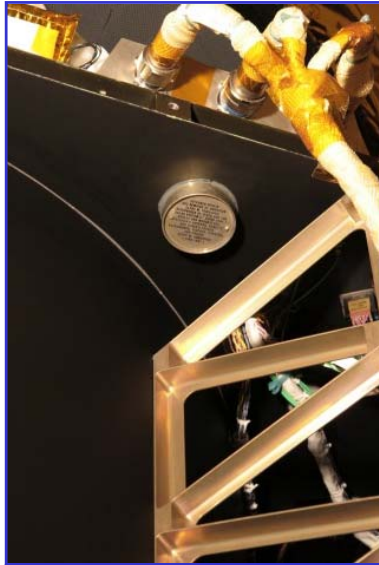




# MOMENTOS



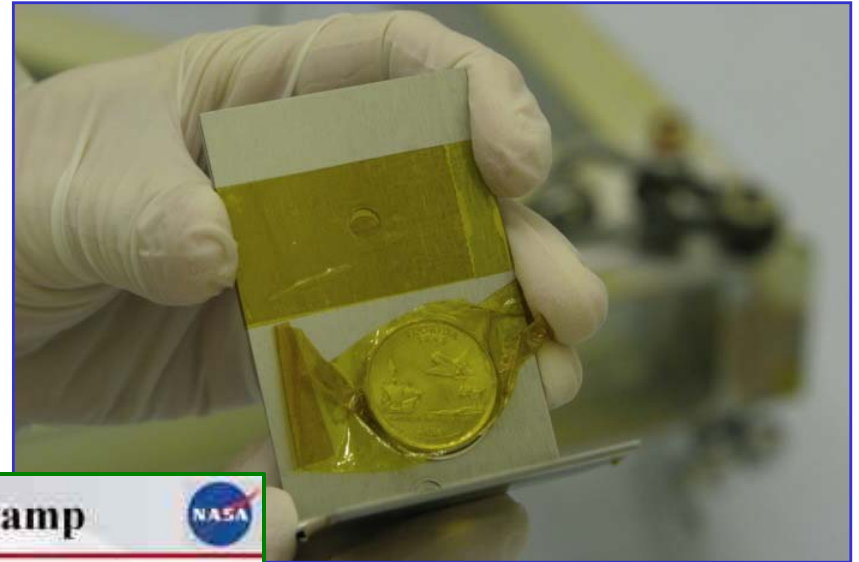
## Clyde Tombaugh's Remains



Interred herein are remains of American Clyde W. Tombaugh, discoverer of Pluto and the solar system's "third zone." Adelle and Muron's boy, Patricia's husband, Annette and Alden's father, astronomer, teacher, punster, and friend:  
Clyde W. Tombaugh (1906-1997).



## Florida & Maryland Quarters

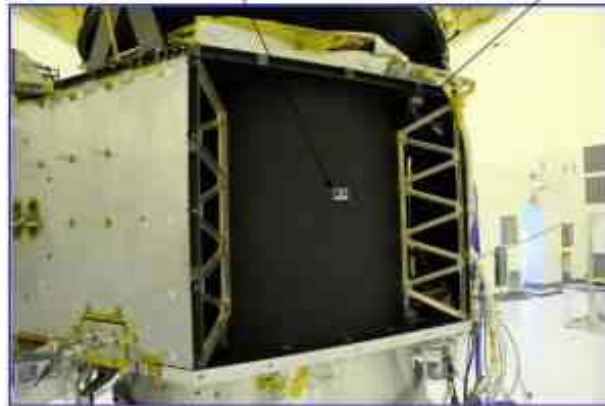


## Clyde and the Stamp



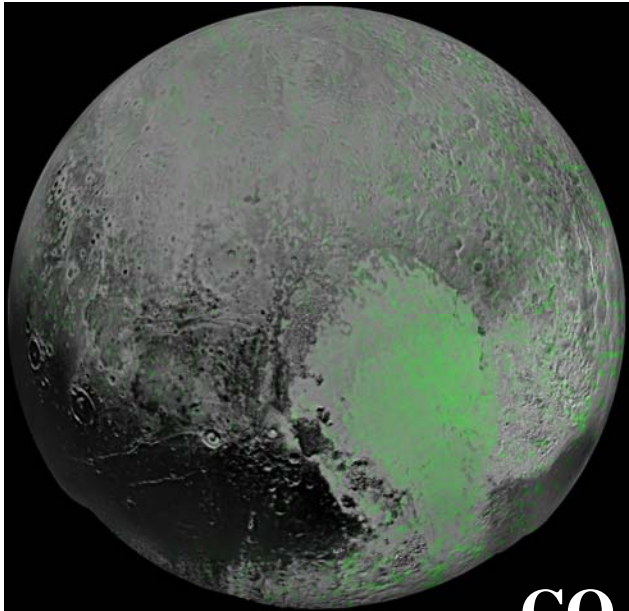
Stamp

Clyde

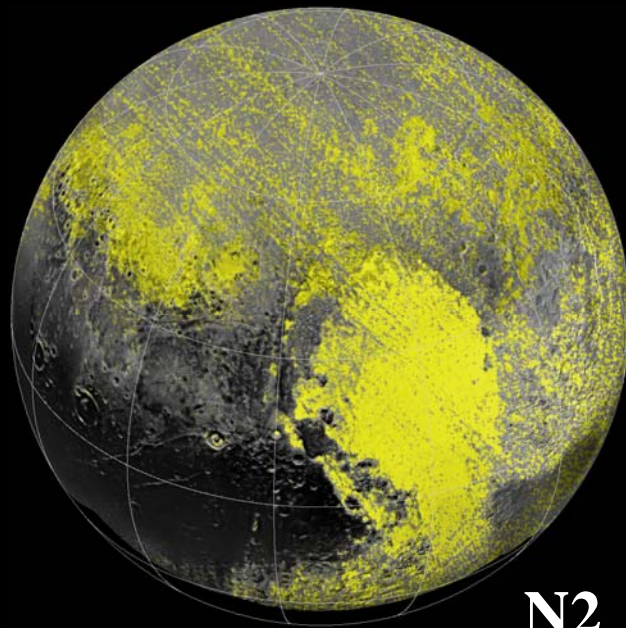


Jan 2016

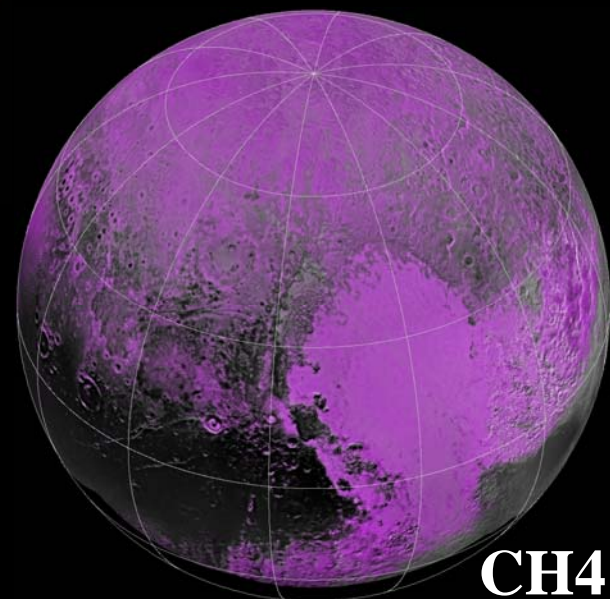
4.2016



**CO**



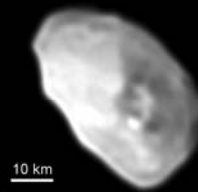
**N2**



**CH4**



Pluto's moon Nix  
as seen by *New Horizons*



10 km

LORRI  
Panchromatic



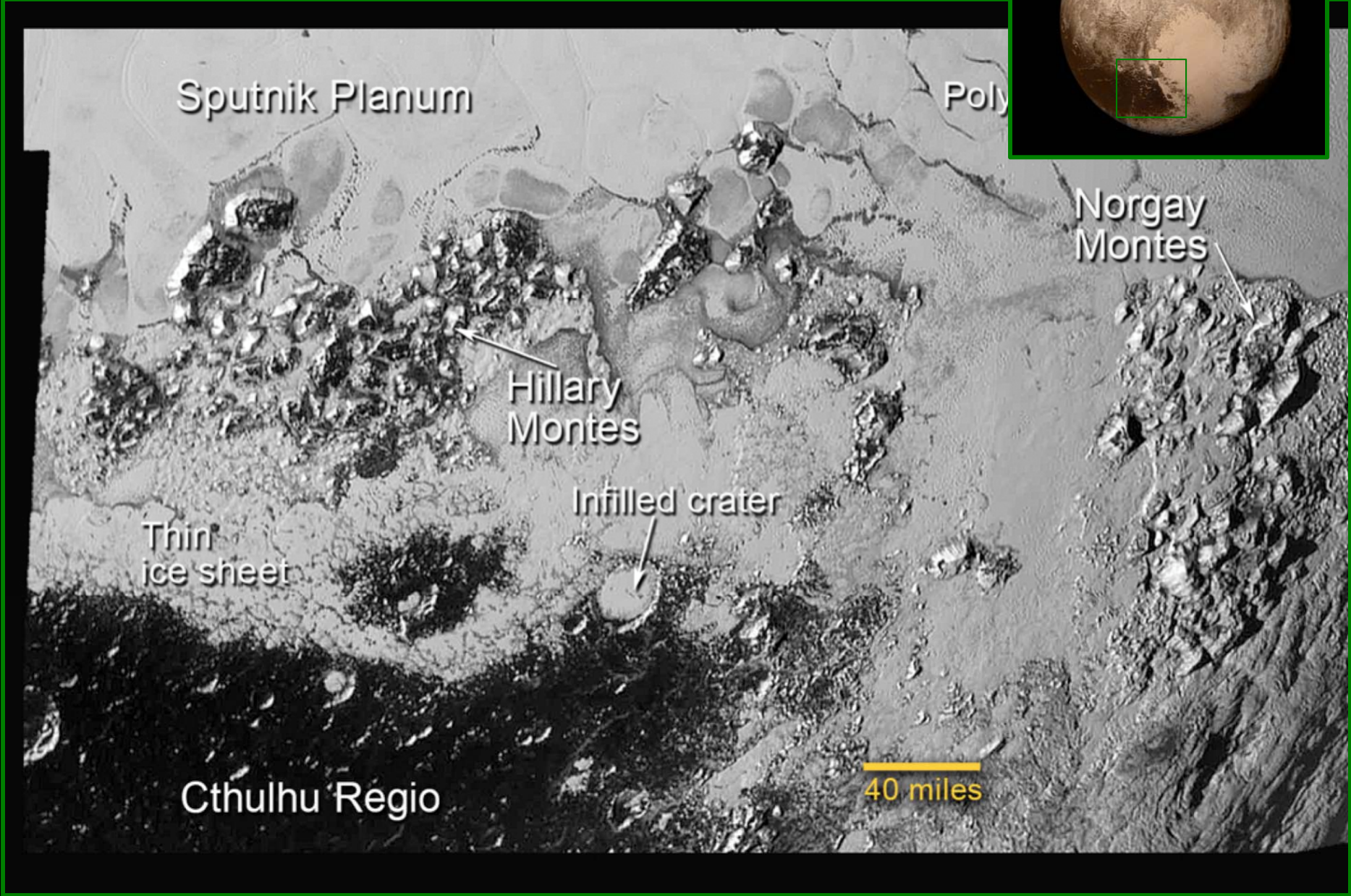
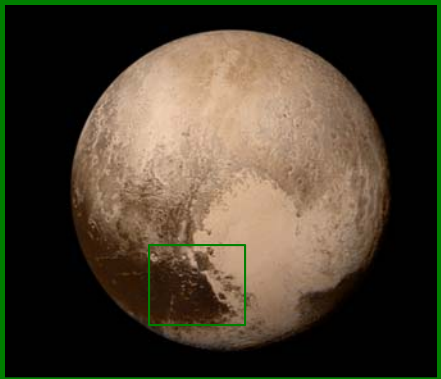
MVIC  
Enhanced Color



LORRI/MVIC  
Composite







Sputnik Planum

Poly

Norgay  
Montes

Hillary  
Montes

Infilled crater

Thin  
ice sheet

Cthulhu Regio

40 miles





I



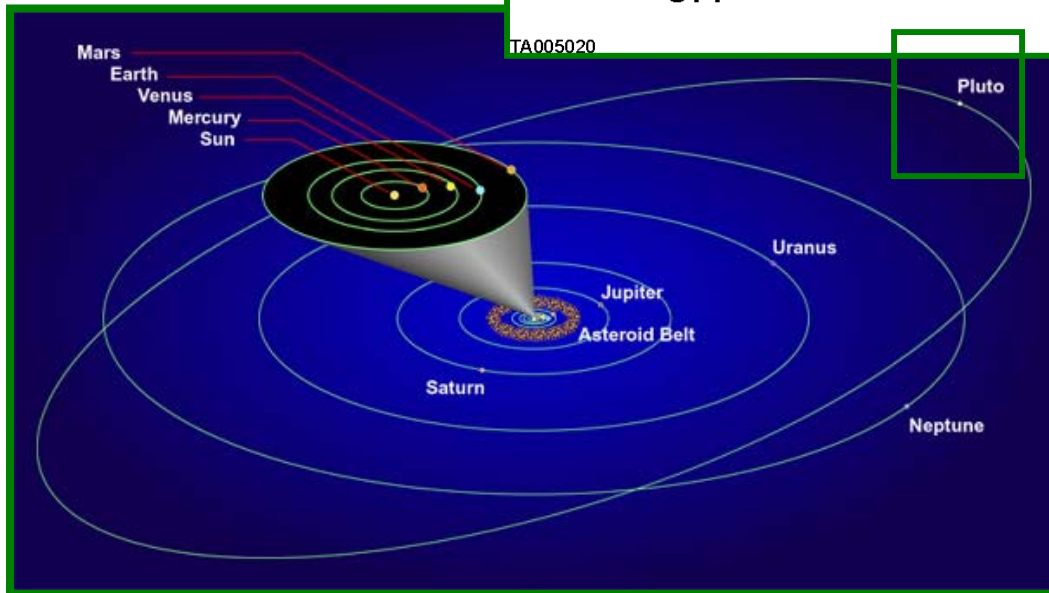
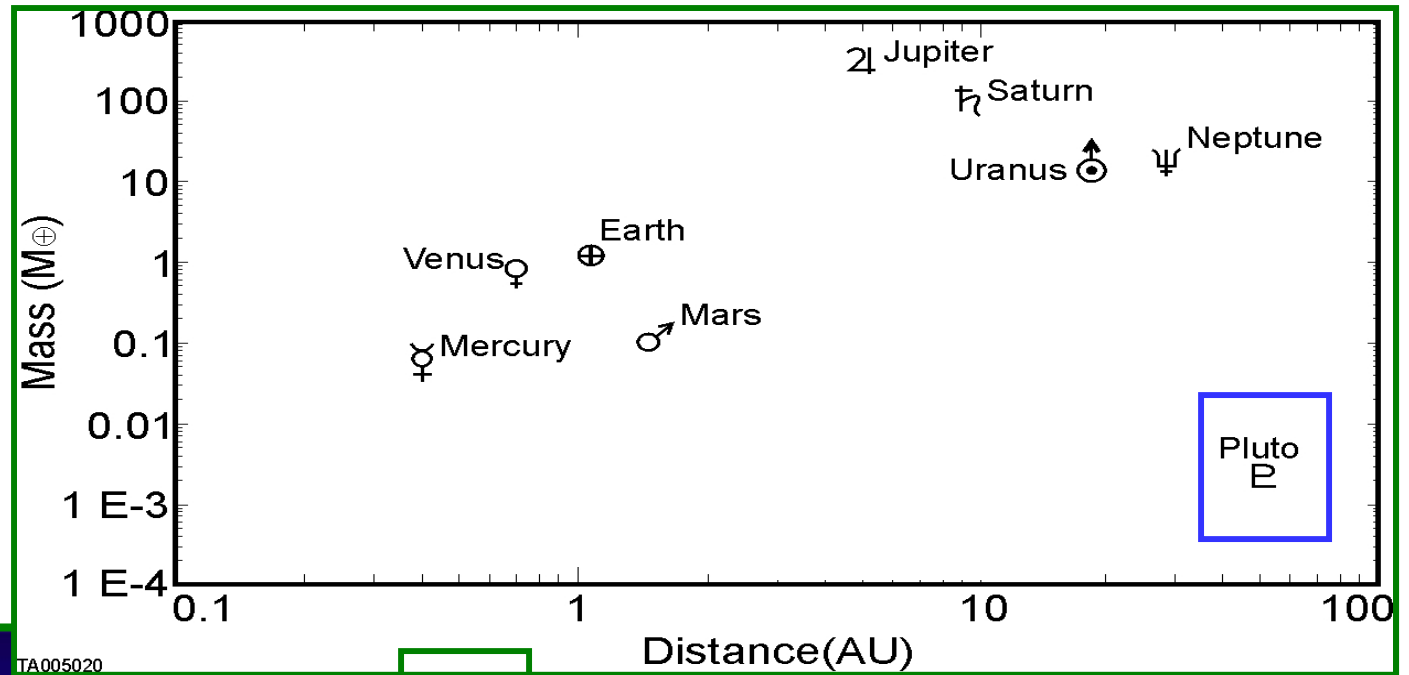
PLUTO

July 14, 2015: NASA's New Horizons #PlutoFlyby





# LONE MISFIT?



The Old View:  
4 Terrestrial Planets  
4 Giant Planets  
1 Misfit Pluto



# PLUTO SYSTEM MEASUREMENT OBJECTIVES



## **Group 1 Objectives: Required**

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: Important**

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<sub>2</sub>, HCN, and C<sub>x</sub>H<sub>y</sub>, 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**

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



# PAYLOAD DETAILS



<b>Alice</b>	<b>UV Spectrometer</b>	<ul style="list-style-type: none"> <li>➤ 46.5-188.0 nm, 0.3 nm resolution</li> <li>➤ FOV 4° x 0.1° "slot" and 2° x 2° "box", 5 mrad/pixel</li> <li>➤ Airglow &amp; occultation capabilities</li> </ul>
<b>Ralph/ MVIC</b>	<b>Multispectral Visible Imaging Camera (Pan/Color Imager)</b>	<ul style="list-style-type: none"> <li>➤ Panchromatic (350-850 nm) &amp; 4-color (Blue, Red, CH<sub>4</sub>, Near-IR)</li> <li>➤ FOV 5.7° x 0.15° or 5.7° x scan length, 20 microrad resolution</li> </ul>
<b>Ralph/ LEISA</b>	<b>Linear Etalon Imaging Spectral Array (IR Imaging spectrometer)</b>	<ul style="list-style-type: none"> <li>➤ 1.25-2.50 micron at R=240 and 2.10-2.25 micron at R = 550</li> <li>➤ FOV 0.9° x 0.9° (scanned), 62 microrad/pixel</li> </ul>
<b>LORRI</b>	<b>LONg-Range Reconnaissance Imager (High-Resolution Imager)</b>	<ul style="list-style-type: none"> <li>➤ Panchromatic (350-850 nm)</li> <li>➤ FOV 0.29° x 0.29° , 5 microrad/pixel</li> </ul>
<b>REX</b>	<b>Radio Experiment (Uplink, Radiometry)</b>	<ul style="list-style-type: none"> <li>➤ Part of telecommunications systems, with 2.1 m antenna</li> <li>➤ X-band (7.182 GHz uplink, 8.438 GHz downlink)</li> </ul>
<b>SWAP</b>	<b>Solar Wind at Pluto (Solar Wind Detector)</b>	<ul style="list-style-type: none"> <li>➤ 0.25-7.5 KeV. RPA: 0.5V (&lt;1.5 keV), ESA: ΔE/E=0.4 (&gt;1.4 keV)</li> <li>➤ FOV 200° x 10°</li> </ul>
<b>PEPSSI</b>	<b>Pluto Energetic Particle Spectrometer Science Investigation (Particle Detector)</b>	<ul style="list-style-type: none"> <li>➤ e<sup>-</sup>: 25-500 KeV, Protons: 40-500 KeV, CNO: 150-1000 KeV</li> <li>➤ FOV 160° x 12° , 25° x 12° resolution</li> </ul>
<b>SDC</b>	<b>Situ Dust Counter</b>	<ul style="list-style-type: none"> <li>➤ 0.10 m<sup>2</sup> active area,</li> <li>➤ Threshold Mass ~10<sup>-12</sup> gram (~1 micron)</li> </ul>





# HIGH PAYLOAD FUNCTIONAL REDUNDANCY



AO Objective	Primary Sensor(s)	Fallback	Supporting	Fidelity of Fallback + Supporting	
<b>Group 1</b>					
Geology/ Geophysics	pan	MVIC pan	LORRI, MVIC color	LEISA	High
	color	MVIC 4-color	MVIC 2-color	LEISA	High
Surface composition	LEISA 4 quadrants	LEISA 2 of 4 quadrants	MVIC CH4 mapping	High	
Neutral atmosphere	Both ALICE and REX	Either ALICE or REX	SWAP, PEPSSI, MVIC	Medium	
<b>Group 2</b>					
Surface and atmospheric variability	MVIC, LORRI, LEISA, ALICE, REX	Any of MVIC, LORRI, LEISA, ALICE, or REX	SWAP, PEPSSI	High	
Stereo	MVIC pan	MVIC color, LORRI		High	
Hi-res terminator maps	MVIC pan	MVIC color, LORRI		High	
Hi-res composition maps	LEISA 4 quadrants	LEISA 2 of 4 quadrants	MVIC CH4 mapping	High	
Ionosphere/solar wind	Both REX and SWAP	Either REX or SWAP	ALICE	High	
Other atmospheric species	ALICE		SWAP, PEPSSI, [LEISA]	Low	
Charon atmosphere	ALICE		REX, LEISA	High	
Bond albedos	MVIC pan	MVIC color	LORRI, LEISA	Medium	
Surface temperatures	REX and LEISA 4 quadrants	LEISA 2 of 4 quadrants or REX		High	
<b>Group 3</b>					
Energetic particles	PEPSSI		SWAP	Low	
Bulk parameters	MVIC, LORRI, LEISA, REX	Any of MVIC, LORRI, LEISA, or REX		High	
Satellite and ring search	MVIC pan	MVIC color, LORRI	ALICE, REX	High	

[ ] implies indirect measurement requiring modeling



# ENCOUNTER GOALS



- **MEET/EXCEED ALL PROPOSED SCIENCE**
- **INCLUDE SMALL SATELLITE OBSERVATIONS**
- **INCLUDE PAYLOAD CAL CAMPAIGN**
- **BE ROBUST TO ANOMALIES**
- **INCLUDE “PROGRESS” DOWNLINKS FOR HEALTH & SAFETY, EPO, SCIENCE, FAIL SAFE**
- **LEAVE >40% OF LAUNCH LOAD PROPELLANTS FOR KBO EXTENDED MISSION**



# ENCOUNTER DESIGN SCORECARD



## ENCOUNTER FULLFILLMENT



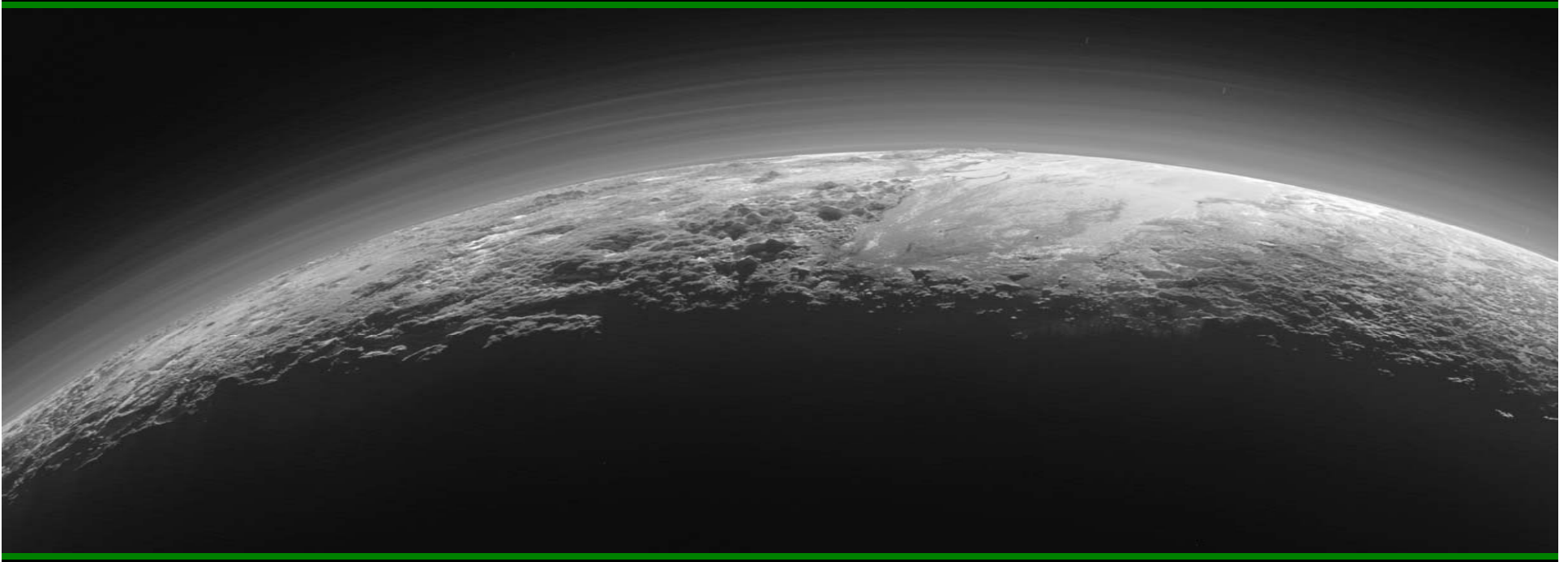
Group 1 Objectives: REQUIRED		Pluto	Charon			
PROP	Characterize the global geology and morphology of Pluto and Charon	Exceed	Exceed			
	Map surface composition of Pluto and Charon	Meet	Meet			
	Characterize the neutral atmosphere of Pluto and its escape rate	Exceed	n/a			
Group 2 Objectives: STRONGLY DESIRED		Pluto	Charon	Nix	Hydra	P4 etc.
PROPOSED	Characterize the time variability of Pluto's surface and atmosphere	Meet	n/a	n/a	n/a	n/a
	Image Pluto and Charon in Stereo	Meet	Meet			
	Map the terminators of Pluto and Charon with high resolution	Meet	Meet	n/a	n/a	n/a
	Map the surface composition of Pluto and Charon with high resolution	Meet	Meet	n/a	n/a	n/a
	Characterize Pluto's ionosphere and solar wind interaction	Meet	n/a	n/a	n/a	n/a
	Search for neutral species in Pluto's upper atmosphere	Meet	n/a	n/a	n/a	n/a
	Search for an atmosphere around Charon	n/a	Meet	n/a	n/a	n/a
	Determine bolometric Bond albedos for Pluto and Charon	Meet	Meet	n/a	n/a	n/a
Map the surface temperatures of Pluto and Charon	Meet	Meet	n/a	n/a	n/a	
NEW	Composition of dark surfaces on Pluto	Exceed	n/a	n/a	n/a	n/a
	"Far-side" imaging of Pluto and Charon	Exceed	Exceed	n/a	n/a	n/a
	"Far-side" color and composition of Pluto and Charon	Exceed	Exceed	n/a	n/a	n/a
	High resolution imaging of Nix and Hydra	n/a	n/a	Exceed	Exceed	Exceed
	Composition of Nix and Hydra	n/a	n/a	Exceed	Exceed	Exceed
Shapes of Nix and Hydra	n/a	n/a	Exceed	Exceed	Exceed	
Group 3 Objectives: DESIRED		Pluto	Charon	Nix	Hydra	P4 etc.
PROP	Characterize the energetic particle environment of Pluto and Charon	Meet	Meet	n/a	n/a	n/a
	Refine bulk parameters (radii, masses, densities) and orbits of Pluto & Charon	Meet	Meet	n/a	n/a	n/a
	Search for magnetic fields of Pluto and Charon	Indirect	Indirect	n/a	n/a	n/a
	Search for additional satellites and rings	Meet	Meet	n/a	n/a	n/a
NEW	Surface microphysics of Pluto and Charon	Exceed	Exceed	n/a	n/a	n/a
	Measure the surface temperatures of Nix and Hydra	n/a	n/a	Exceed	Exceed	Exceed
	Measure the phase curve of Nix and Hydra	n/a	n/a	Exceed	Exceed	Exceed
	Image Nix and Hydra in stereo	n/a	n/a	Exceed	Exceed	Exceed
	Education/Public Outreach	Exceed	Exceed	Exceed	Exceed	Exceed





# PLUTO SYSTEM FLYBY RECAP

- **All flyby objectives met or exceeded.**
- **PDS Archiving Begins April 2016, Complete October 2017.**
- **ROSES NF-DAP Call This Year.**
- **Over 25 Publications Will Have Been Submitted by Next Month.**



Ultimate bodybuilding: The quest for exoskeletons p. 270

Giving a boost to quantum electronics pp. 280 & 307

Engineering remote-controlled T cells p. 293

# Science

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**Flying past Pluto**  
New Horizons finds surprises at Pluto and Charon pp. 260 & 292

RESEARCH

## RESEARCH ARTICLE SUMMARY

PLANETARY SCIENCE

### The Pluto system: Initial results from its exploration by New Horizons

S. A. Stern,\* F. Bagenal, K. Emico, G. R. Gladstone, W. M. Grundy, W. B. McKinnon, J. M. Moore, C. B. Olkin, J. R. Spencer, H. A. Weaver, L. A. Young, T. Andert, J. Andrews, M. Banks, B. Bauer, J. Bauman, O. S. Barnouin, P. Bedini, K. Beisser, R. A. Beyer, S. Bhaskaran, R. P. Binzel, E. Blum, M. Bird, D. J. Boggs, A. Bowman, V. J. Bray, M. Brownie, C. Brown, M. R. Buckley, M. W. Buie, R. J. Buratti, S. S. Bushman, A. Calloway, B. Carcich, A. F. Cheng, S. Conrad, C. A. Conrad, J. C. Cook, D. P. Cruikshank, O. S. Custodio, C. M. Dalle Ore, C. Debevoise, Z. J. B. Dischner, P. Dumont, A. M. Earle, H. A. Elliott, J. Erod, C. M. Ernst, T. Finley, S. H. Flanigan, G. Fountain, M. J. Freeze, T. Greshouse, J. L. Green, Y. Guo, M. Hahn, D. P. Hamilton, S. A. Hamilton, J. Hanley, A. Harch, H. M. Hart, C. B. Hestman, A. Hill, M. E. Hill, D. P. Hinson, M. E. Holdridge, M. Horányi, A. D. Howard, C. J. A. Howett, C. Jaclaman, R. A. Jacobson, D. E. Jennings, J. A. Kammer, H. K. Kang, D. E. Kaufmann, P. Kollmann, S. M. Krimigis, D. Kussleridzevich, T. R. Lauer, J. E. Lee, K. L. Lindstrom, L. R. Lincott, C. M. Lisse, A. W. Lumsford, V. A. Malder, N. Martin, D. J. McComas, R. L. McNutt Jr., D. Meade, T. Mehall, E. D. Medina, M. Mitchell, D. Nelson, F. Nimmo, J. I. Nunez, A. Osampo, W. M. Owen, M. Pastozold, B. Page, A. H. Parker, J. W. Parker, F. Pelletier, J. Peterson, N. Pineda, M. Piquette, S. B. Porter, S. Prokopa, J. Redfern, H. J. Reitsema, D. C. Reuter, J. H. Roberts, S. J. Robbins, G. Rogers, D. Rose, K. Runyon, K. D. Retherford, M. G. Ryschewitsch, P. Schenk, E. Schindhelm, B. Sepan, M. R. Showalter, K. N. Singer, M. Solari, D. Stanbridge, A. J. Steff, D. F. Strobel, T. Stryk, M. E. Summers, J. R. Szalay, M. Tapley, A. Taylor, H. Taylor, H. B. Throop, C. C. C. Tsang, G. L. Tyler, O. M. Unruh, A. J. Verisicer, M. H. Vestergaard, M. Vincent, R. Weibert, S. Weidner, G. E. Weigelt II, O. L. White, K. Whittenburg, B. G. Williams, K. Williams, S. Williams, W. W. Woods, A. M. Zangari, E. Zirnstein

**INTRODUCTION:** Pluto was discovered in 1930 and was long thought to be a misfit or anomaly in the solar system. However, the 1992 discovery of the Kuiper Belt—a torus-shaped region beyond Neptune's orbit, and the largest structure in our three-zoned planetary system—provided new context, showing Pluto to be the largest of a new class of small planets formed in the outer solar system during the ancient era of planetary accretion ~4.5 billion years ago. NASA's New Horizons spacecraft made the first exploration of Pluto, culminating on 14 July 2015; it collected numerous remote sensing and in situ measurements of Pluto and its system of five moons. We report the first scientific results and interpretations of that flyby.

**RATIONALE:** The New Horizons spacecraft completed a close approach to the Pluto system at a distance of 13,000 km from Pluto's center. The spacecraft carries a sophisticated suite of scientific instruments, including the Ralph multicolor/panchromatic mapper and mapping infrared composition spectrometer; the LORRI longfocal-

length panchromatic visible imager; the Alice extreme/ultraviolet mapping spectrograph; twin REX radio science experiments; the



**Pluto mosaic made from New Horizons LORRI images taken 14 July 2015 from a distance of 80,000 km.** This view is projected from a point 1800 km above Pluto's equator, looking northeast over the dark, cratered, informally named Cthulhu Regio toward the bright, smooth expanse of icy plains informally called Sputnik Planum. Pluto's north pole is off the image to the left. This image mosaic was produced with panchromatic images from the New Horizons LORRI camera, with color overlaid from the Ralph color mapper onboard New Horizons.

SWAP solar wind detector; the PEPSI high-energy charged particle spectrometer; and VESDA, a dust impact detector. Together these instruments collected more than 50 gigabits of data on the Pluto system near the time of the spacecraft's closest approach.

**RESULTS:** We found that Pluto's surface displays a wide variety of landforms and terrain ages, as well as substantial albedo, color, and compositional variation. Evidence was also found for a water ice-rich crust, geologically young surface units, tectonic extension, surface volatile convection, possible wind streaks, volatile transport, and glacial flow. Pluto's atmosphere is highly extended, with trace hydrocarbons, a global haze layer, and a surface pressure near 10 micrometers. The bulk densities of Pluto and Charon were found to differ by less than 10%, which is consistent with bulk rock contents for the two bodies that are likewise similar. This could imply that both precursor bodies were undifferentiated (or only modestly differentiated) prior to their collision—which would have profound implications for the timing, the duration, and even the mechanism of accretion in the central Kuiper Belt.

Pluto's large moon Charon displays extensional tectonics and extensive resurfacing, as well as possible evidence for a heterogeneous crustal composition; its north pole displays puzzling dark terrain. The sizes of Pluto's small satellites Nix and Hydra were measured for the first time, as were their surface reflectivities, which are puzzlingly higher than Charon's. No new satellites were detected.

**CONCLUSION:** The New Horizons encounter revealed that Pluto displays a surprisingly wide variety of geological landforms, including those resulting from glaciological and surface-atmosphere interactions as well as impact, tectonic, possible cryovolcanic, and mass-wasting processes. This suggests that other small planets of the Kuiper Belt, such as Eris, Makemake, and Haumea, could express similarly complex histories that rival those of terrestrial planets. Pluto's diverse surface geology and long-term activity also raise fundamental questions about how it has remained active many billions of years after its formation. ■

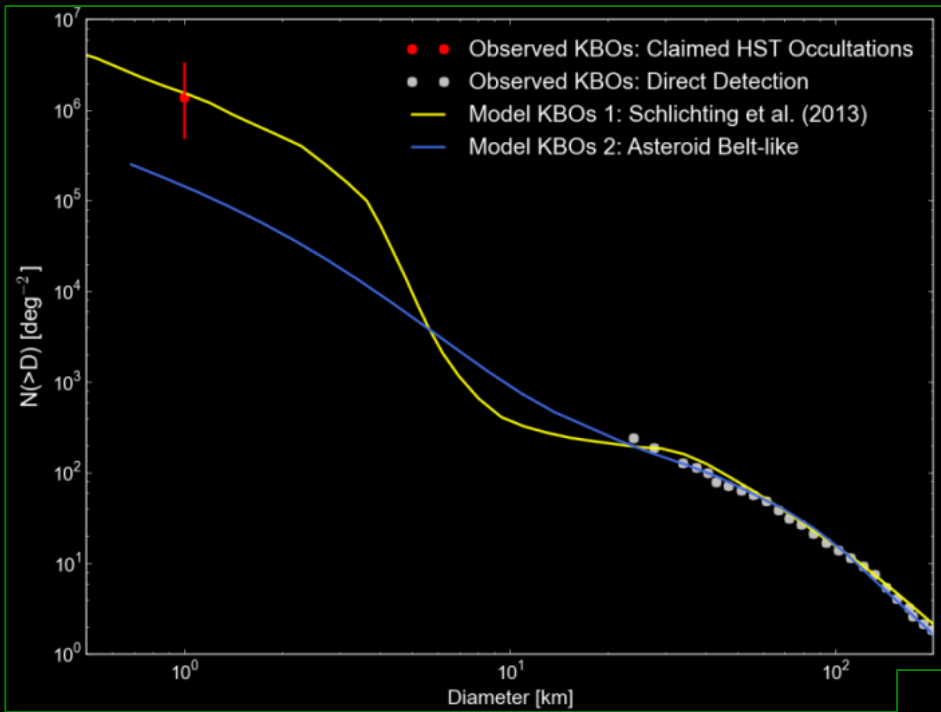
\*List of affiliations is available in the full article online.  
\*Corresponding author. E-mail: stern@stern.nyu.edu  
Cite this article as: Stern et al., Science 350, 260-292 (2015). DOI: 10.1126/science.1261835

292 16 OCTOBER 2015 • VOL. 350 ISSUE 408A

sciencemag.org SCIENCE

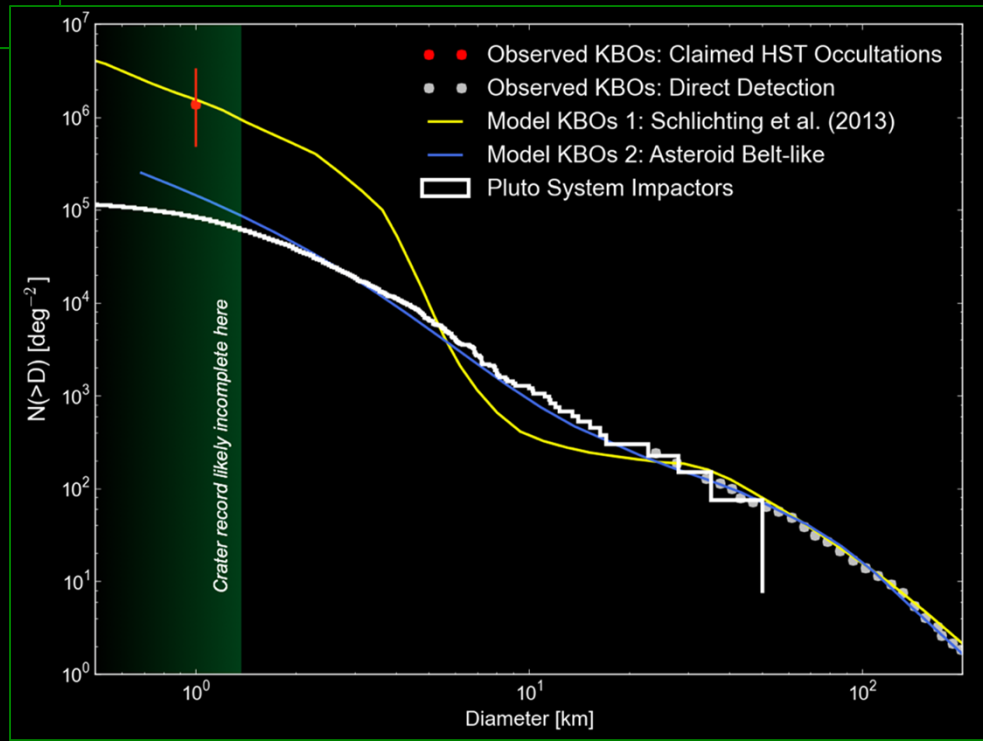


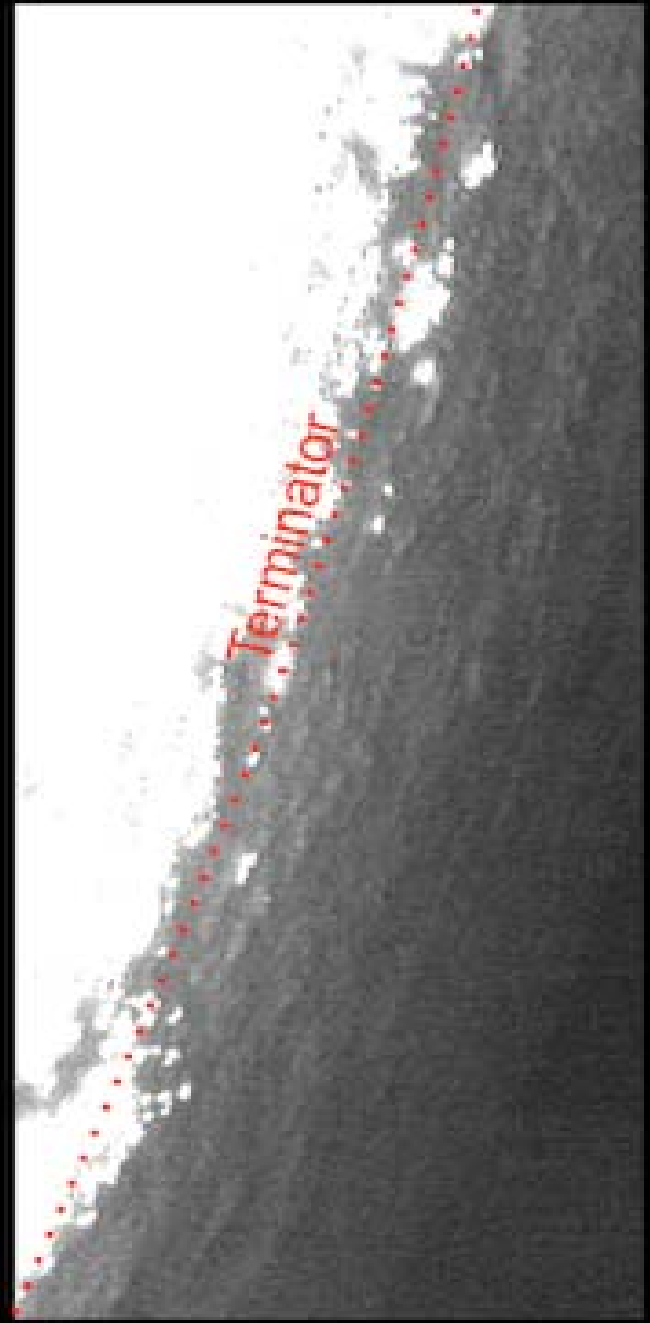
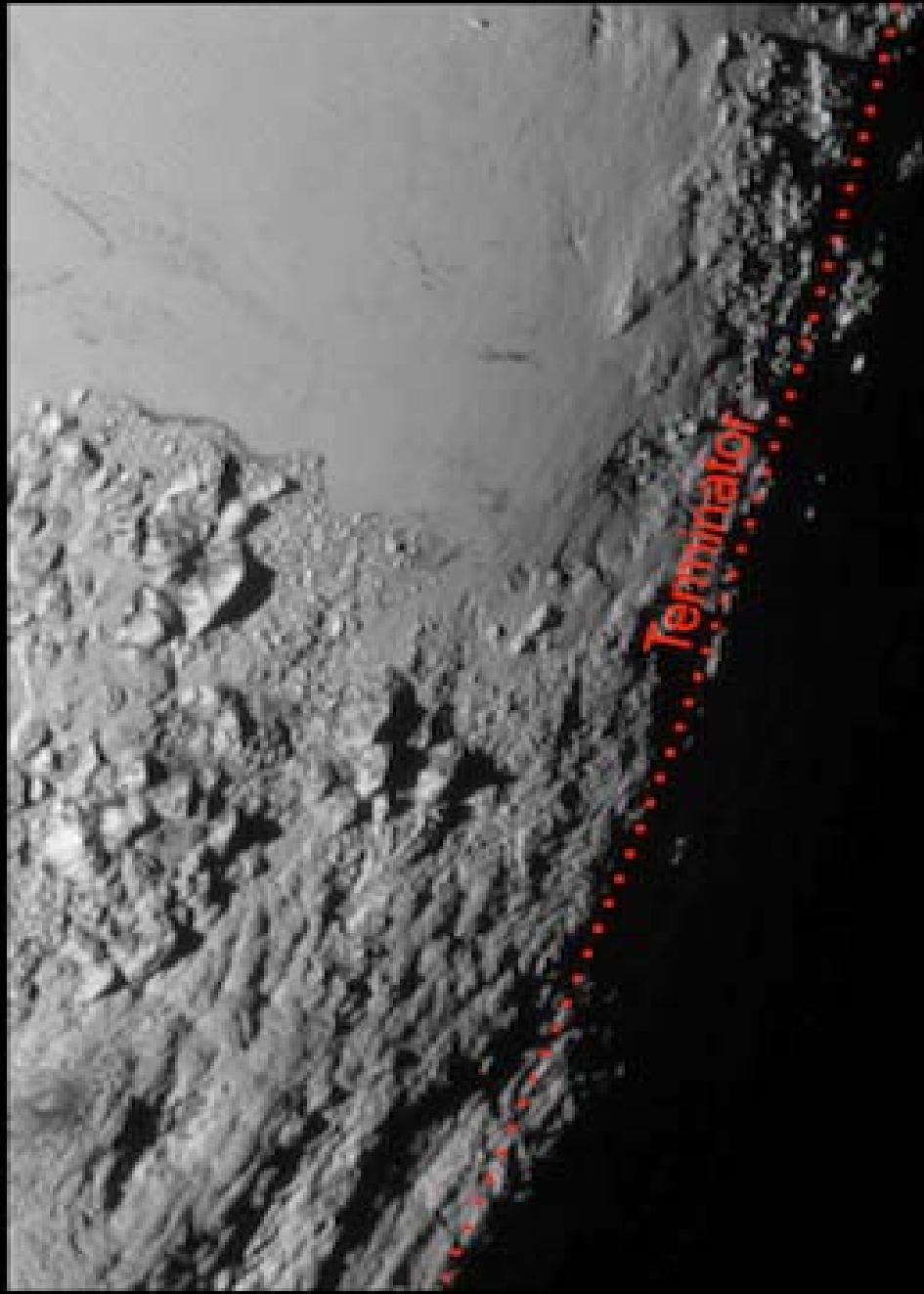
# Probing the Kuiper Belt Population Structure



Before NH

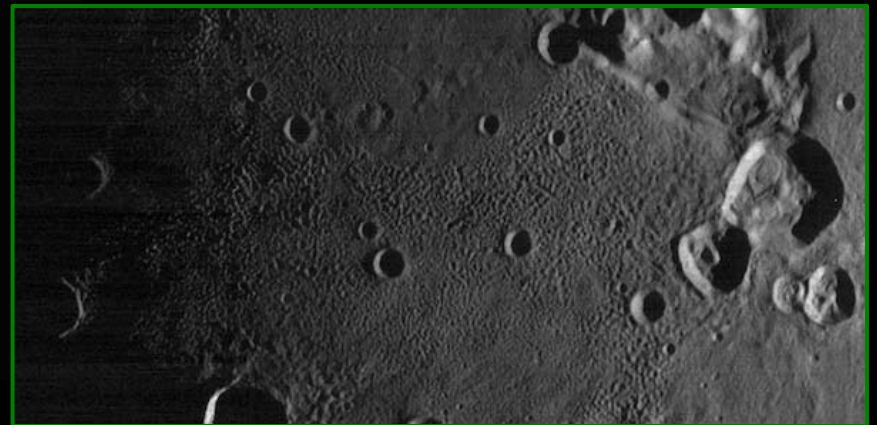
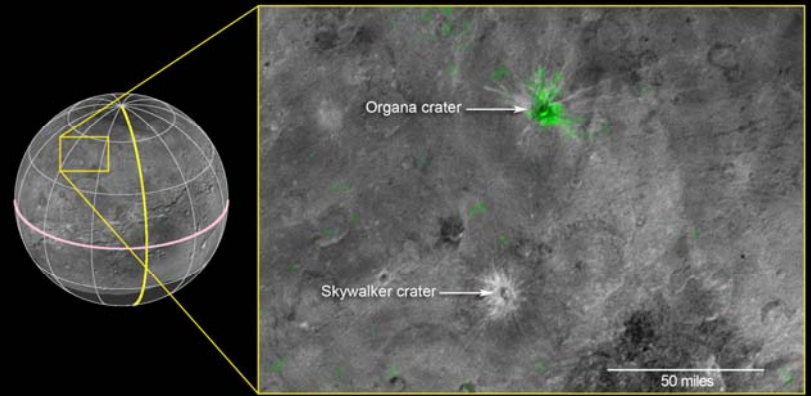
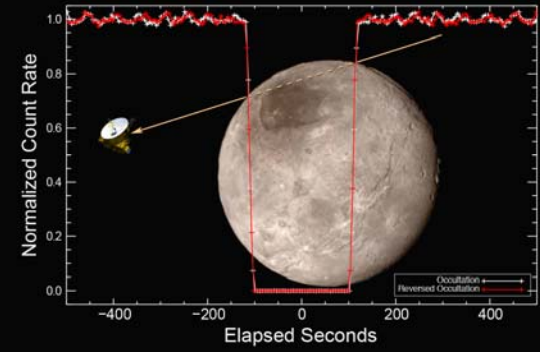
After NH



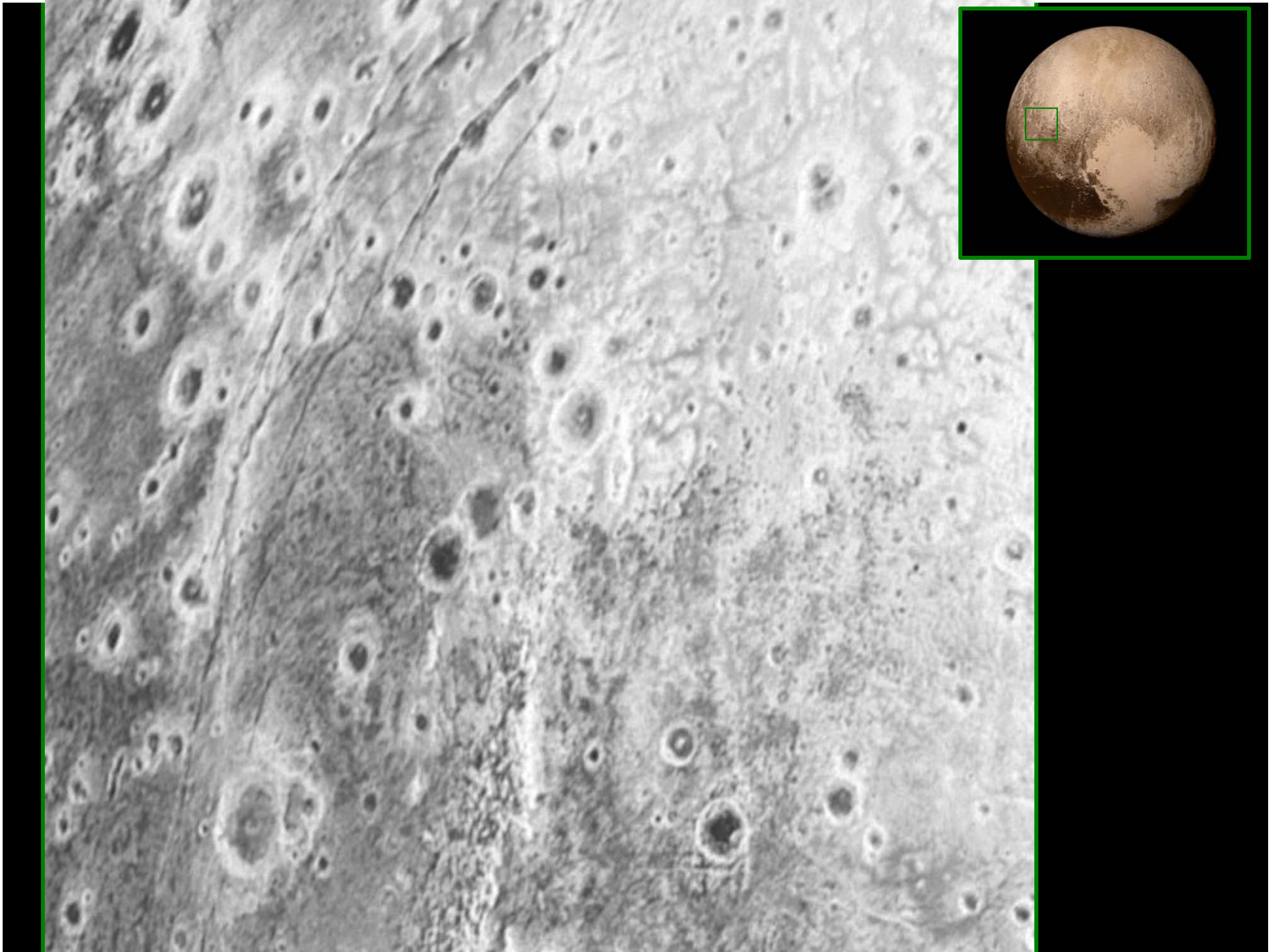




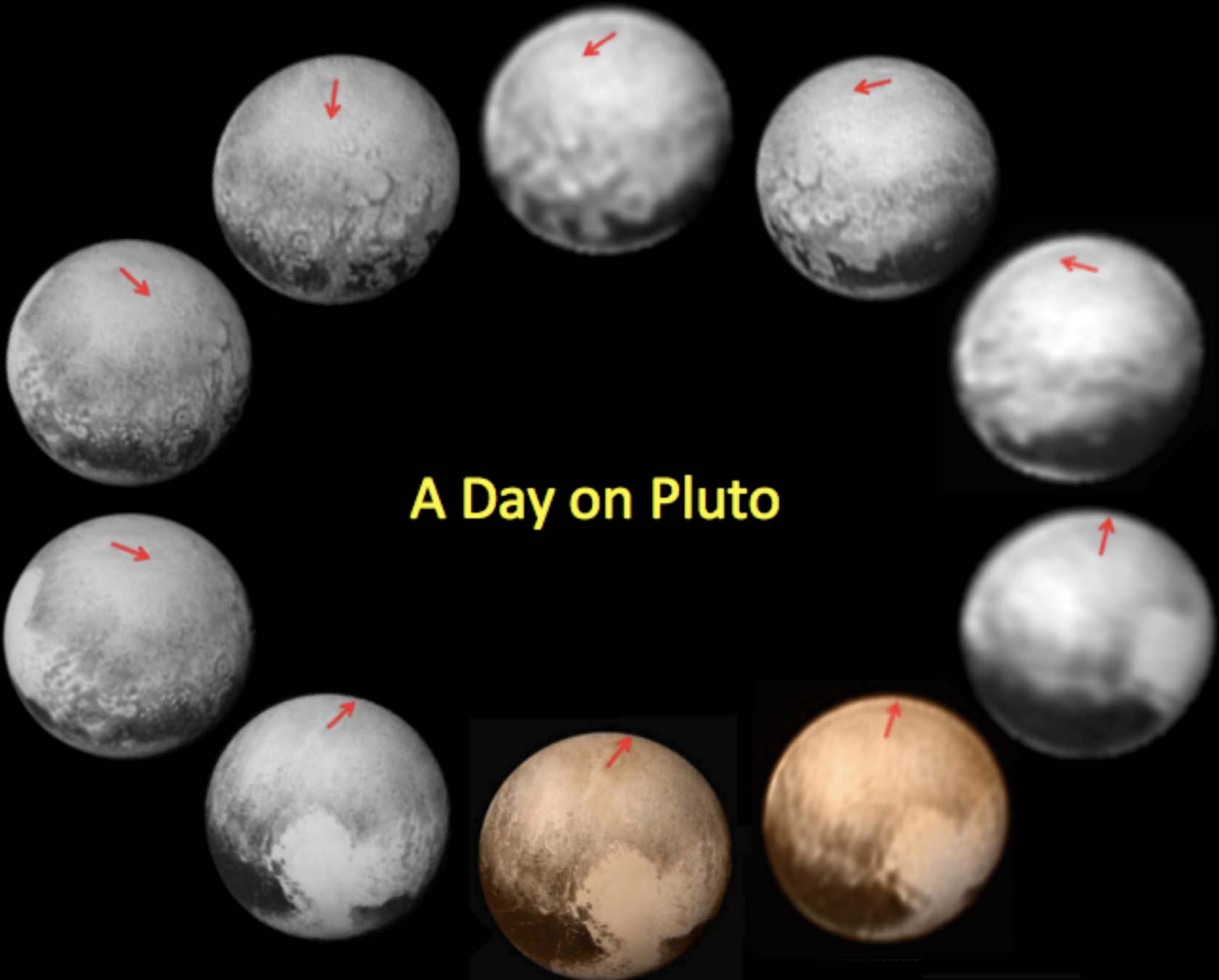
### Alice Solar Occultation of Charon



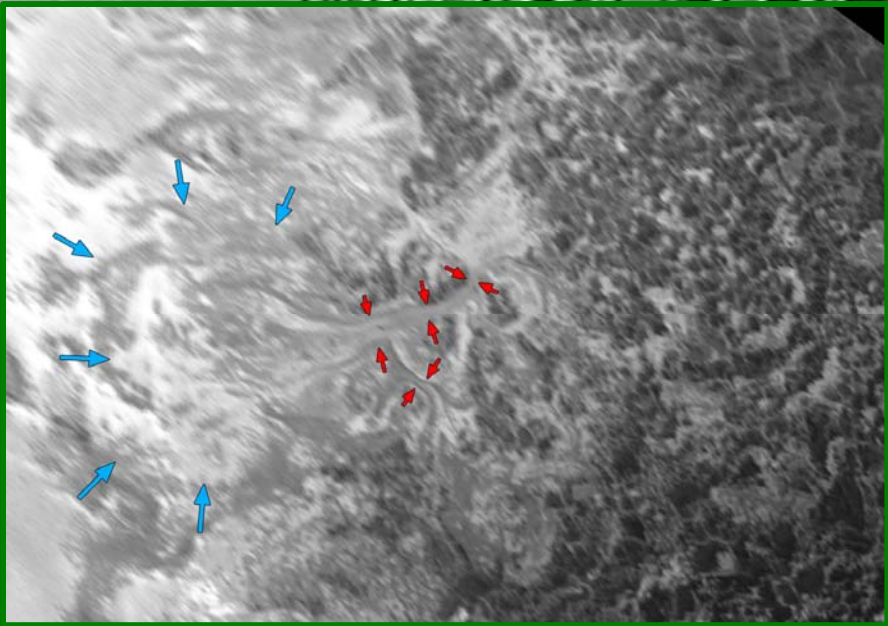
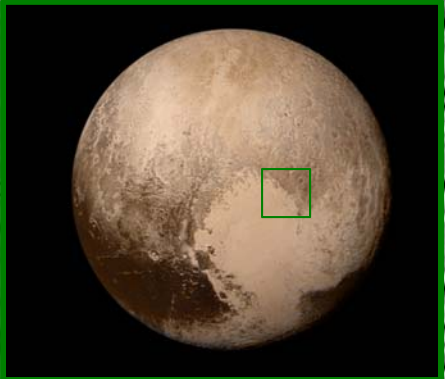
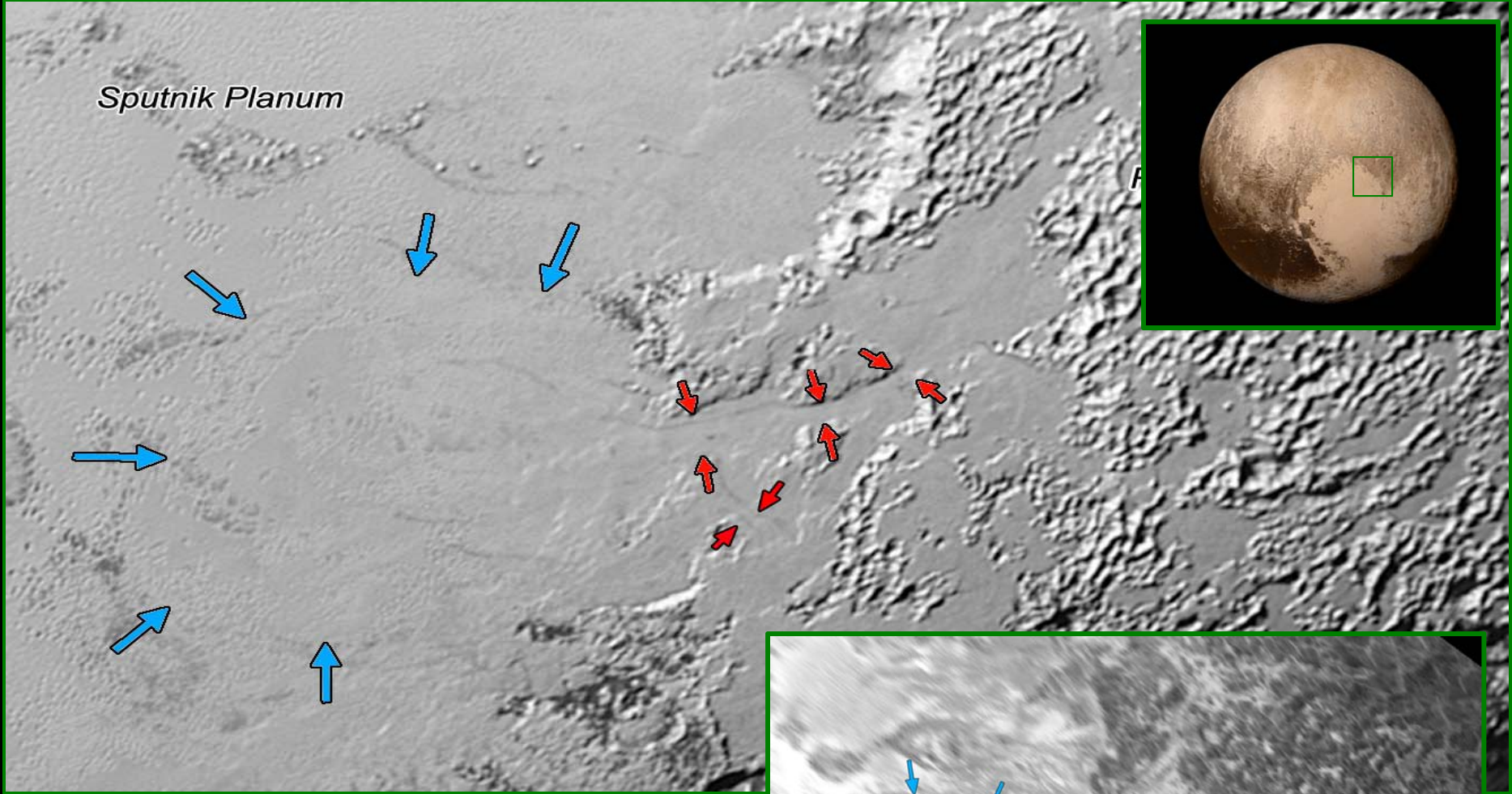




# A Day on Pluto



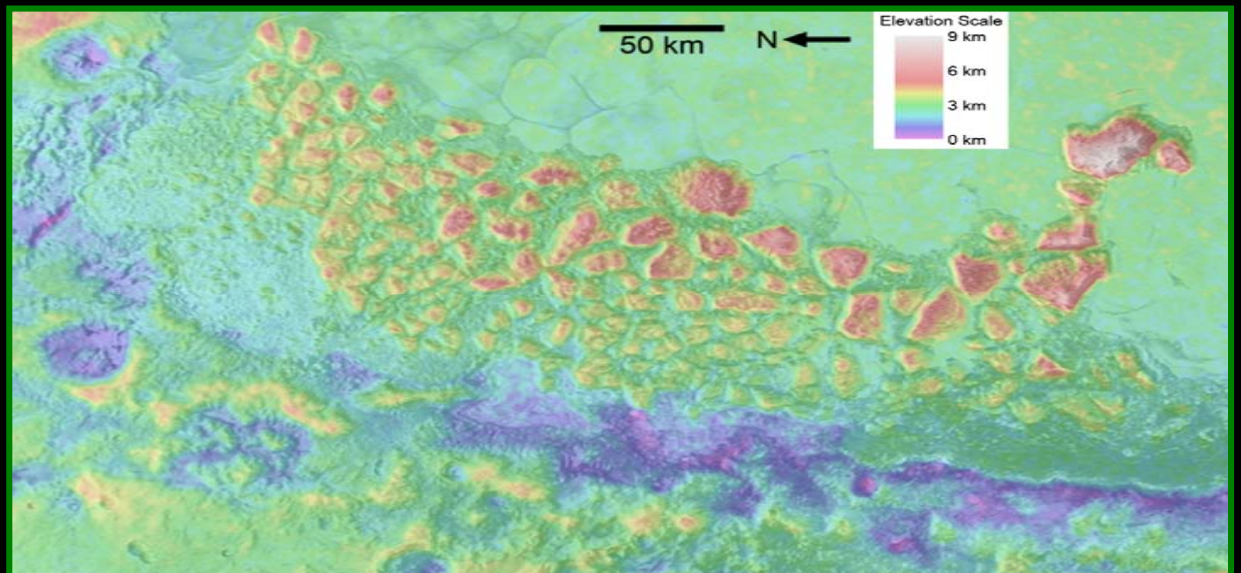
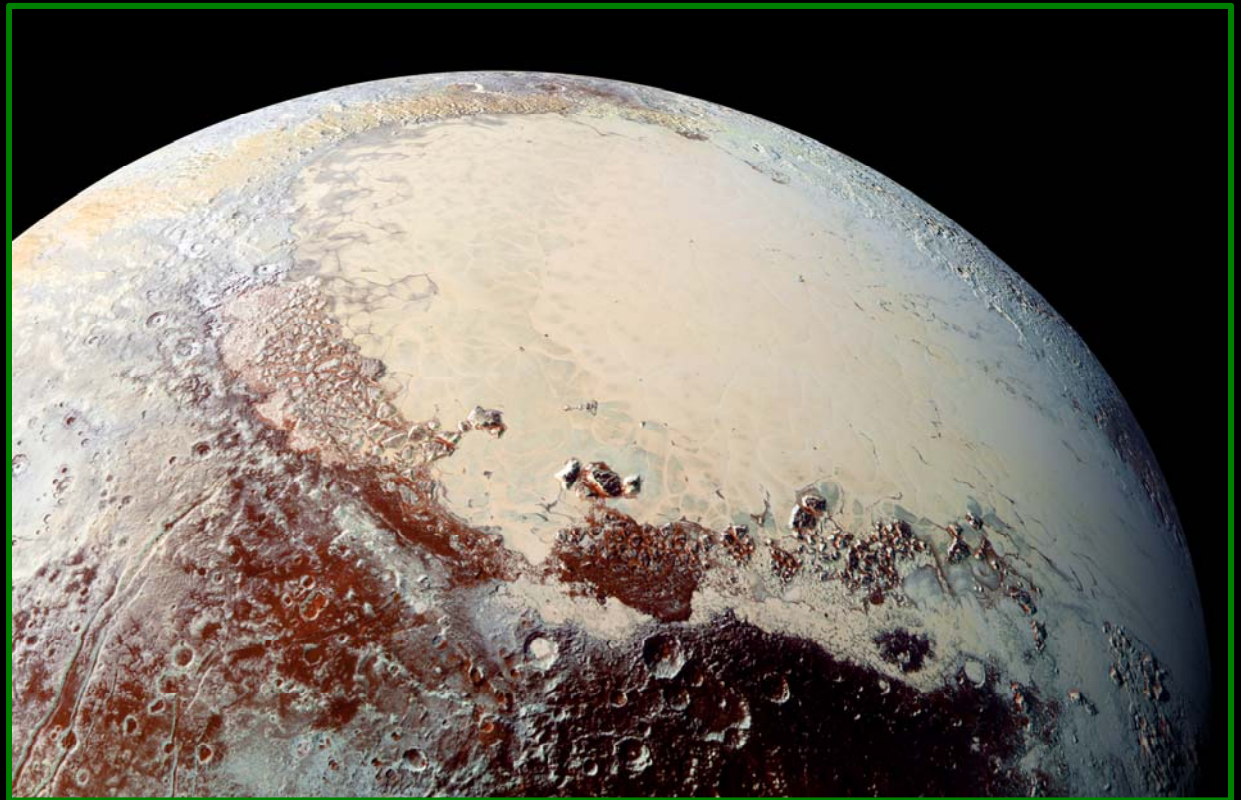






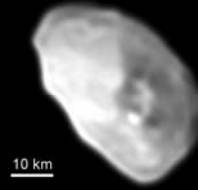
**Water ice is buoyant in either  $N_2$  or  $CO$  ice, so blocks of water ice embedded or buried in solid  $N_2/CO$  will seek to rise isostatically.**

**Numerous mountains on Pluto appear to be floating.**





Pluto's moon Nix  
as seen by *New Horizons*



10 km

LORRI  
Panchromatic



MVIC  
Enhanced Color



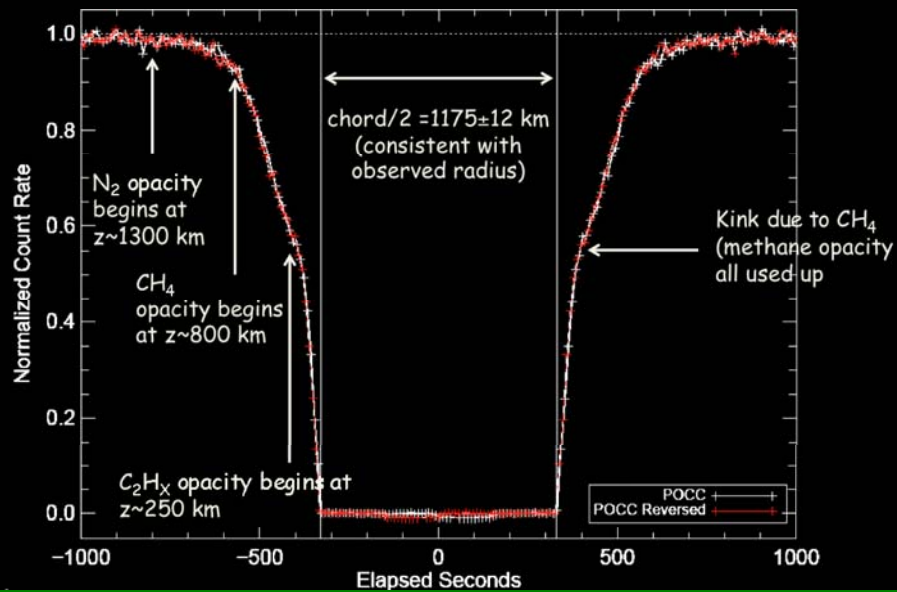
LORRI/MVIC  
Composite



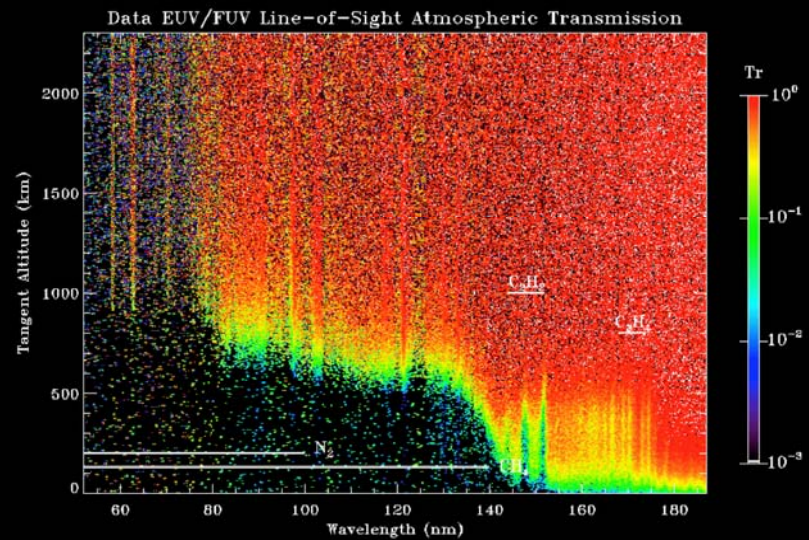
L



# Alice Pocc Total Count Rates

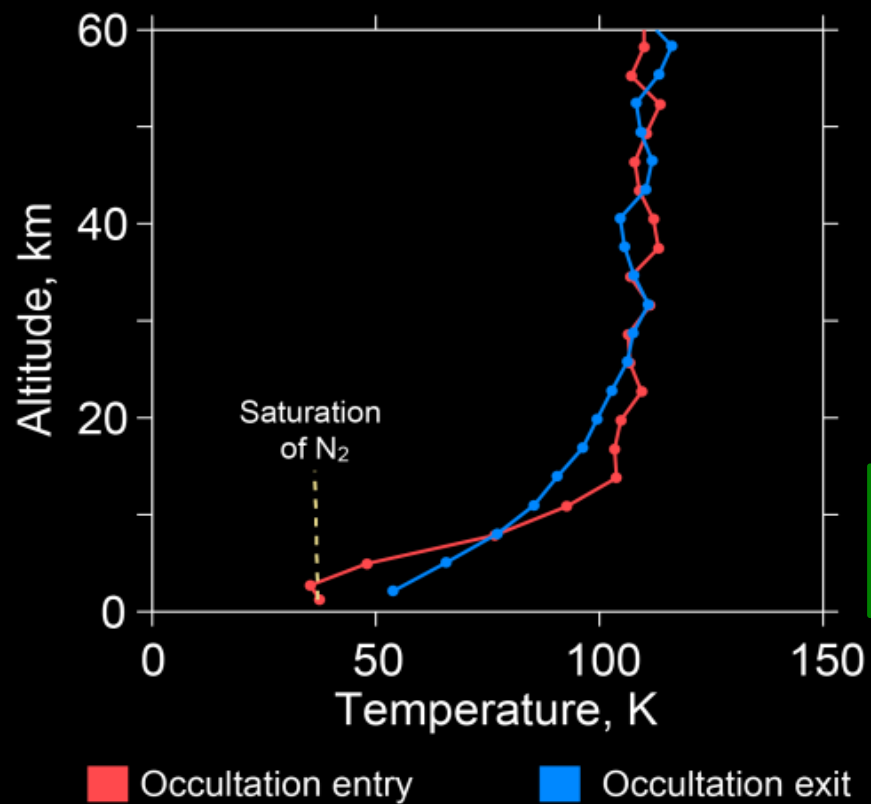
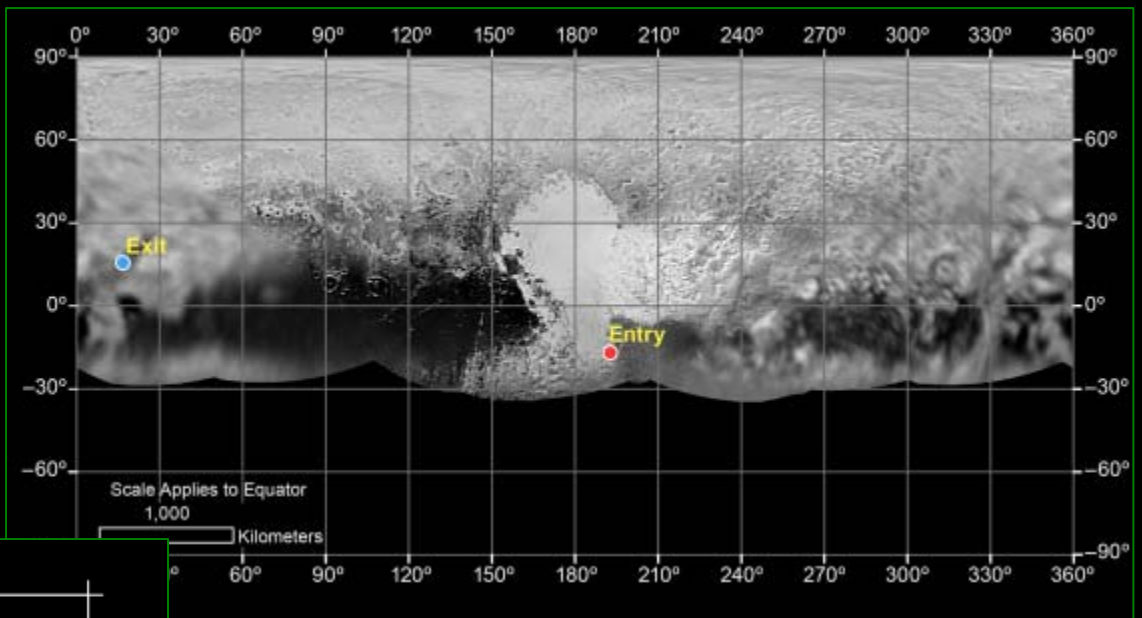


# Pluto's FUV Opacity

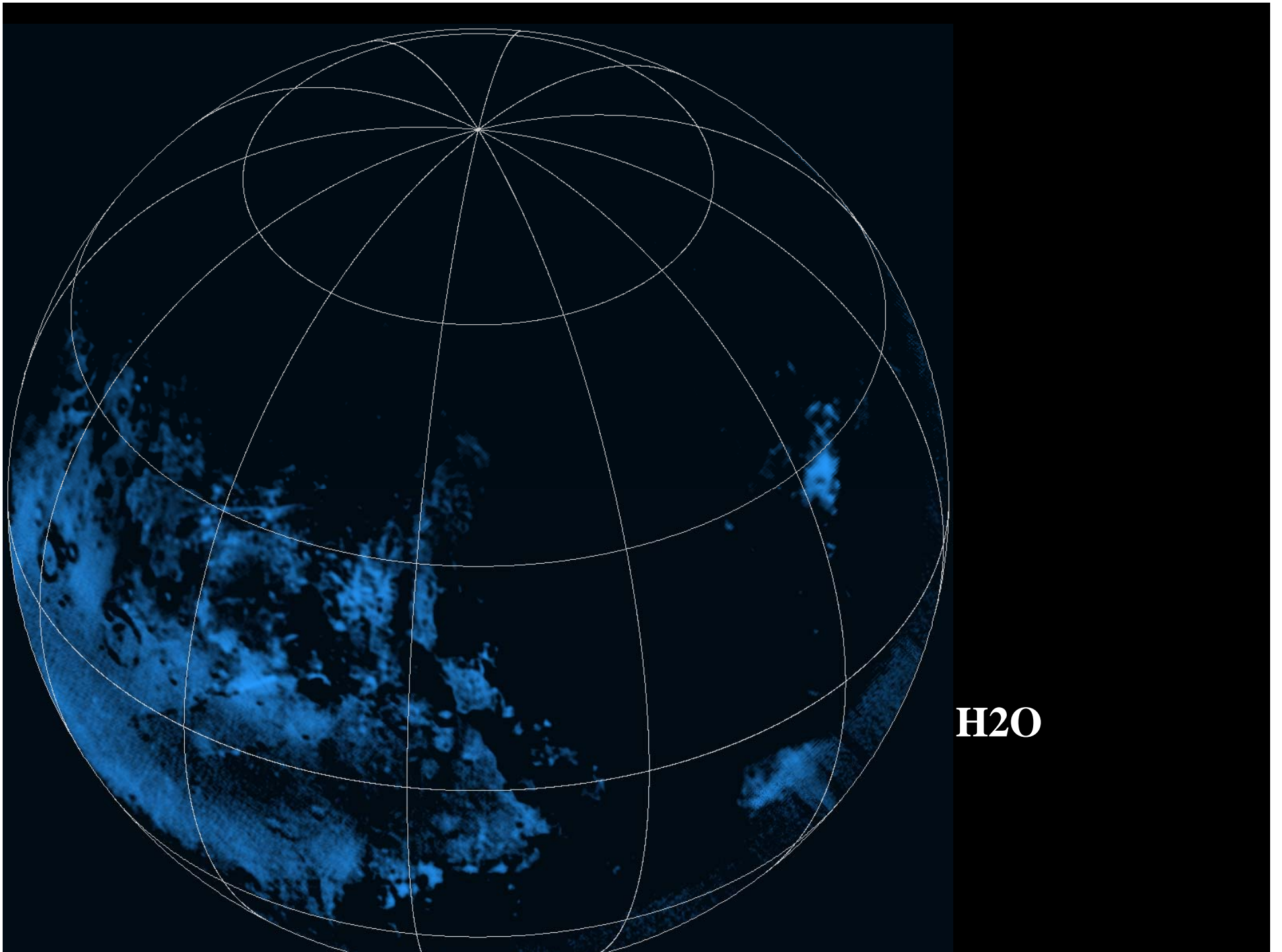




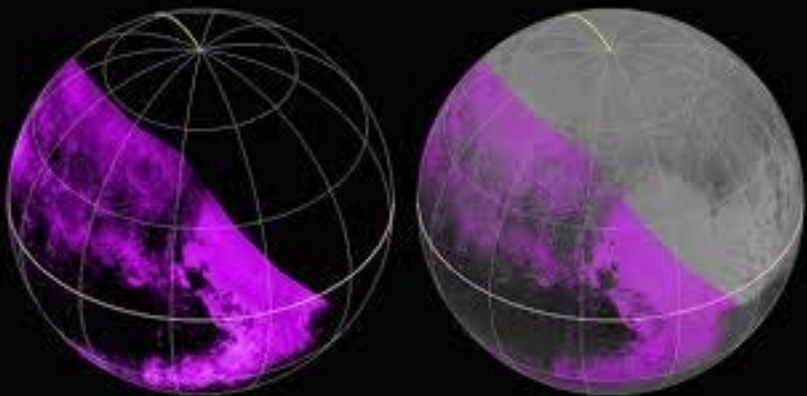
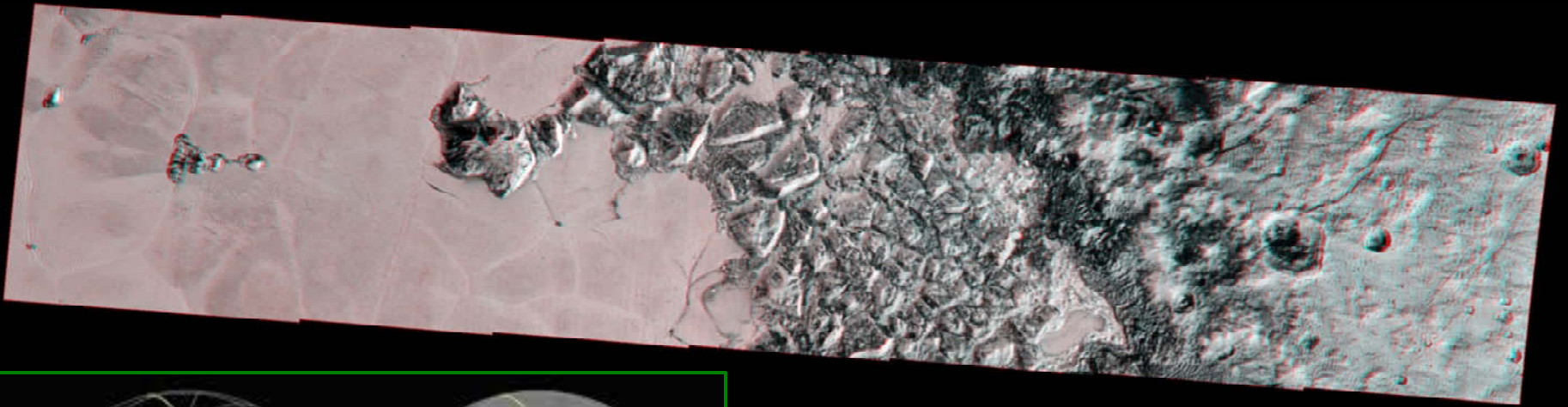
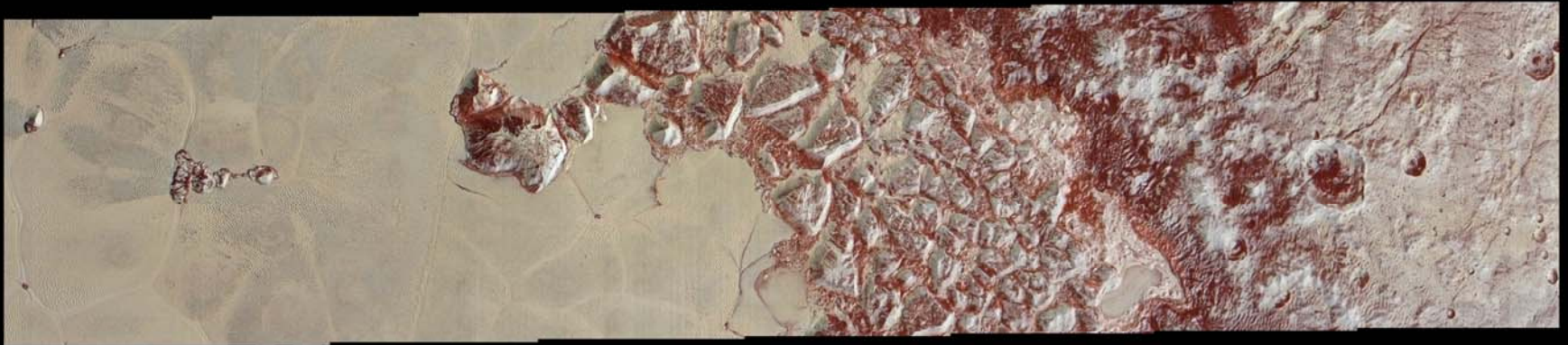
# Selected REX Radio Occultation Results



Note differencing temperatures at entry and exit occultations.



**H2O**

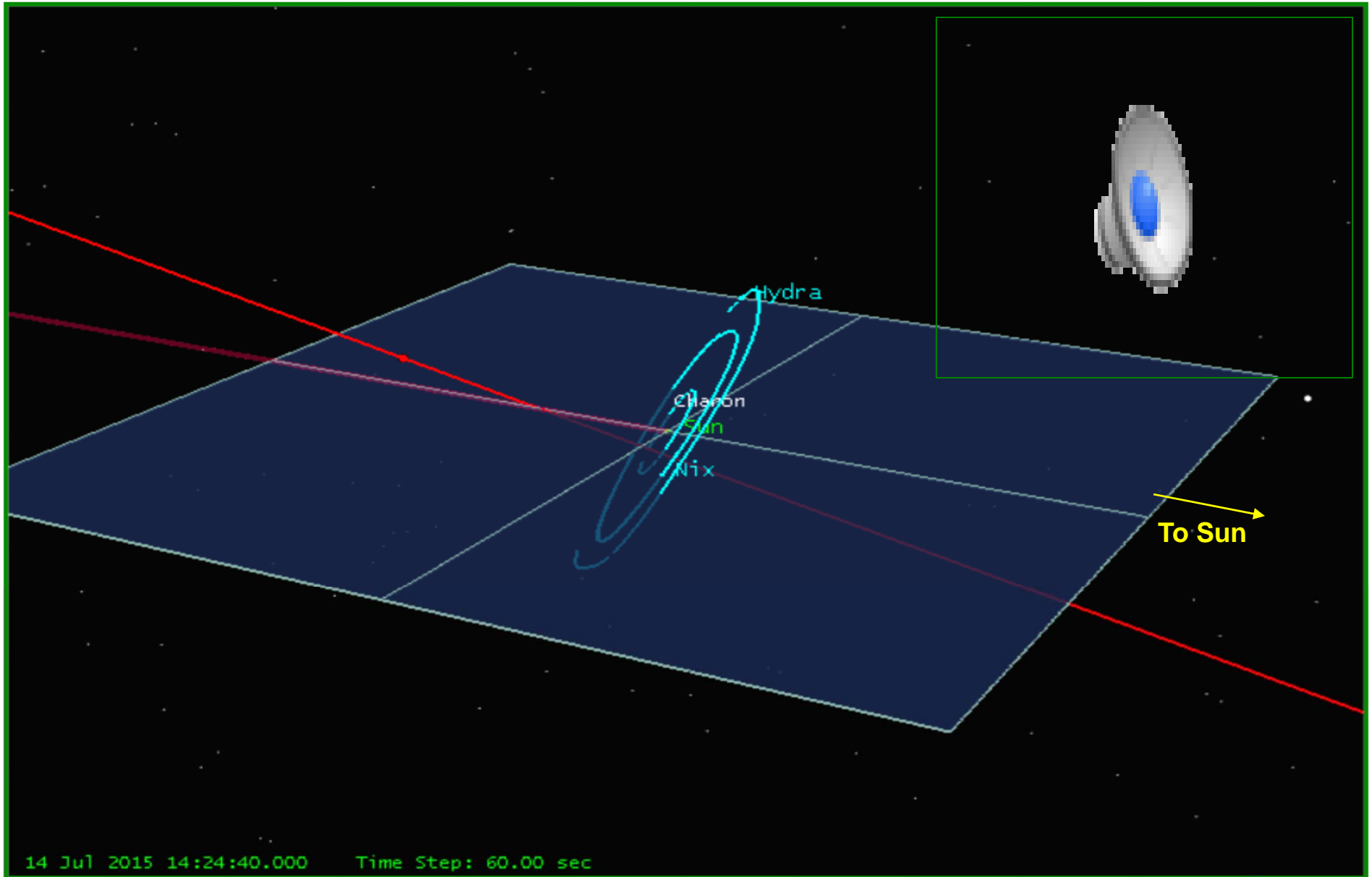


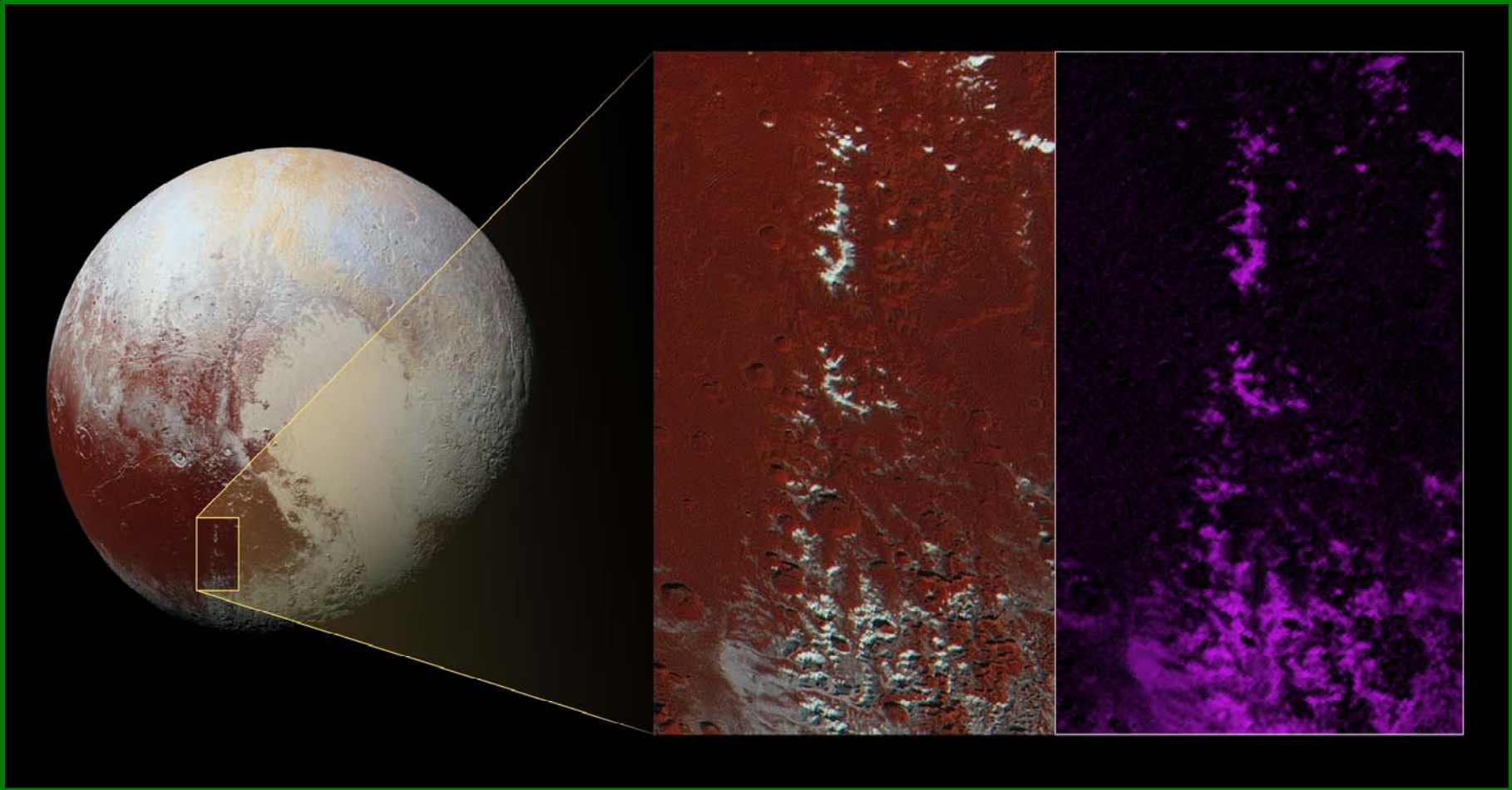




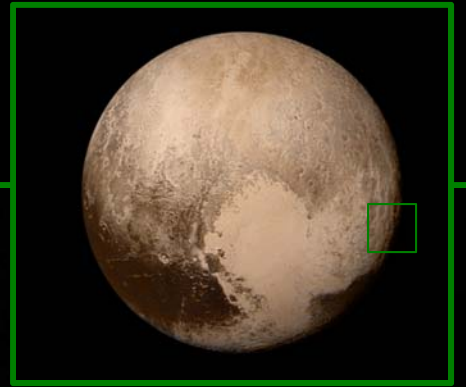
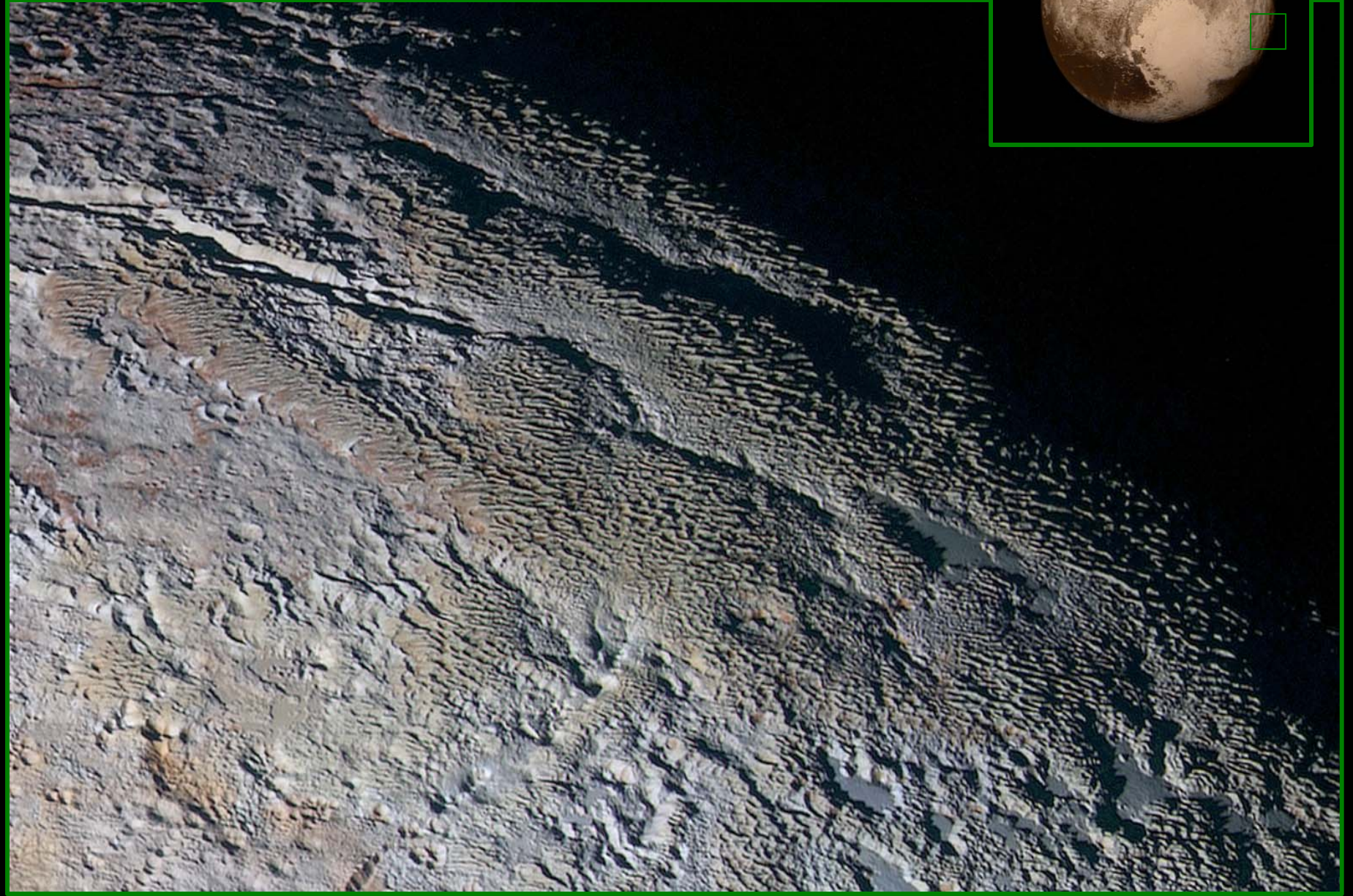


# A SPECIAL ENCOUNTER GEOMETRY













"All the News That's Fit to Print"

# The New York Times

Late Edition

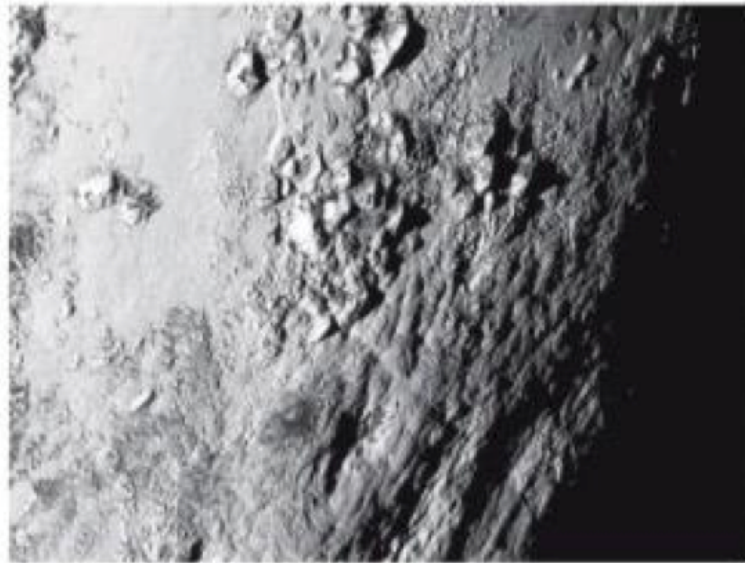
Today, every news, event, and issue is reported, every news, event, and issue is reported, every news, event, and issue is reported.

Vol. CLXXV No. 54,929

New York, Thursday, July 15, 1965

NEW YORK, THURSDAY, JULY 15, 1965

12-50



Pluto's Portrait: Ice Mountains, No Craters and, for Scientists, a 'Toy Store'

**WASHINGTON** — The first photograph of Pluto has revealed a landscape of ice mountains and an absence of craters — a discovery that, to some scientists, suggests a young planet and provides preliminary support for a theory that a half-point in the reading.

Just 12 years after the Wright brothers would hardly dare to get their wings off the ground, a satellite from Earth has scanned the solar system to a point, its reports show today before stars. The light on Thursday, when New Horizons passed within 31 miles of the distant dwarf planet, came 48 years to the day after William Herschel's spectral search a century and a half ago.

Pluto was a low-velocity target for the mission. Within the past couple of days, it has been discovered that a dwarf world made up of ice and rock is the primary of an icy body with an atmosphere of methane. All of this was discovered only because there is now enough light and energy to be captured by the flying probe of the planet.

"Scientists say now it is clear that Pluto is a very young planet, and that it is still in the process of forming," said Alan Stern, the mission's principal investigator, and acting chief scientist at Johns Hopkins.

Without directly an atmospheric reading to confirm the methane composition of Pluto, Stern said: "This is what we wanted."

"This is what we've seen," he added, looking at the image that shows a landscape of ice mountains, but no craters.

Earlier in the day, Stern's team had also taken the first hints of a possible ocean of liquid water in the atmosphere of Pluto. On days past the planet where there are thin bits of water, the probe may "be seeing clouds in the atmosphere."

Stern said the team did not see any signs of the ice that he found in the past, but he said the team would not see any other signs of the ice.

It is believed that Pluto had a contracting stage of the first 100 million years of its life, followed by a long (but short) stage of contraction. The probe is expected to see a dark, reddish-brown surface, with a layer of ice on top. The probe will also see a layer of ice on top.

The first image was the largest ever of a dwarf planet, and it is the first image of a dwarf planet. The probe is expected to see a dark, reddish-brown surface, with a layer of ice on top.



An image of Pluto showed mountains about as high as the Rockies.

## YEARS OF TRADING AND COMPROMISE SEALED IRAN DEAL

ASSIST FROM A SUITAN

Concluding That Halting Bank Development Exposed All Else

**By DAVID S. REYNOLDS and MICHAEL S. CHAMBERLAIN**

**WASHINGTON** — The 10-year search for a nuclear accord between Iran and the United States has been a long and painful one. It has been a process of trading and compromise, with each side making concessions to reach an agreement.

The American negotiators, led by Secretary of State John Kerry, insisted on excluding the Iranian Revolutionary Guard Corps, the Islamic Revolutionary Guards Corps, the Iranian intelligence services and the country's oil ministry, which was opposed to halting the flow of oil to the United States.

In a compromise, the United States agreed to allow the Revolutionary Guards to continue to exist, but to limit their activities to those that are not related to the nuclear program.

The deal is a landmark in the history of international relations, and it is expected to have a major impact on the global oil market.

## Senate Approves Housing Measure With Rent Subsidy

Administration Forces Bill to Kill 'Socialists'

SENATE APPROVES HOUSING MEASURE WITH RENT SUBSIDY

**WASHINGTON, July 15** — The Senate on Thursday approved a bill to provide rent subsidies for low-income families, but the measure was amended to include provisions that would limit the number of tenants in a building.

The bill was passed by a vote of 75 to 20. It provides for a maximum of \$150 million in rent subsidies over the next five years. The bill also provides for a maximum of 10 tenants in a building.

The bill was amended to include provisions that would limit the number of tenants in a building. This was done to address concerns from some members of the Senate that the bill would be too costly.

# New York Times

LATE CITY EDITION  
12-4  
New York Times, Inc.  
Times Square, New York, N.Y.

NEW YORK, FRIDAY, JULY 16, 1965

TEN CENTS

## First Mars Photo Is Transmitted; Mariner Signals Indicate Planet Lacks a Liquid Core Like Earth's

Administration Forces Bill to Kill 'Socialists'

SENATE APPROVES HOUSING MEASURE WITH RENT SUBSIDY

**WASHINGTON, July 15** — The first photograph of Mars was transmitted to Earth by the Mariner 4 spacecraft on Thursday. The image showed a rocky, cratered surface, similar to the moon.

The photograph was taken from a distance of 14,000 miles. It shows a dark, reddish-brown surface with numerous craters of various sizes. The atmosphere is very thin.

The image is the first ever taken of Mars. It is expected to provide valuable information about the planet's geology and atmosphere.

## Other Data Sent

SENSORS FIND SCANT RADIATION BELT AND THIN ATMOSPHERE



FIRST CLEAR-UP OF MARS: Photograph was by Mariner 4 of the planet and sent back to earth. The area covered along edge of planet is about 200 miles. What was taken is about 10,000 miles. It is expected to add greatly to scientists' knowledge of Mars.



**Spyder Webb** @Spyder\_Webb · 4h

Front page of The New York Times as it appeared on 16 July 2015 and 16 July 1965 #PlutoFlyBy

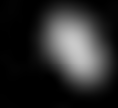
#NewHorizons #Mariner

You, Pluto, NASA New Horizons and 7 others

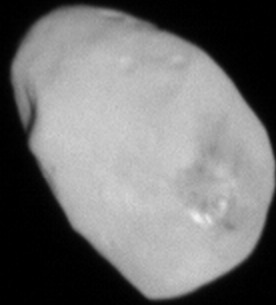
← ↻ 3 ☆ 3 ...



**At least two and possibly all four moons are the result of mergers between smaller bodies. Pluto may have had many more moons in the past.**



Styx



Nix



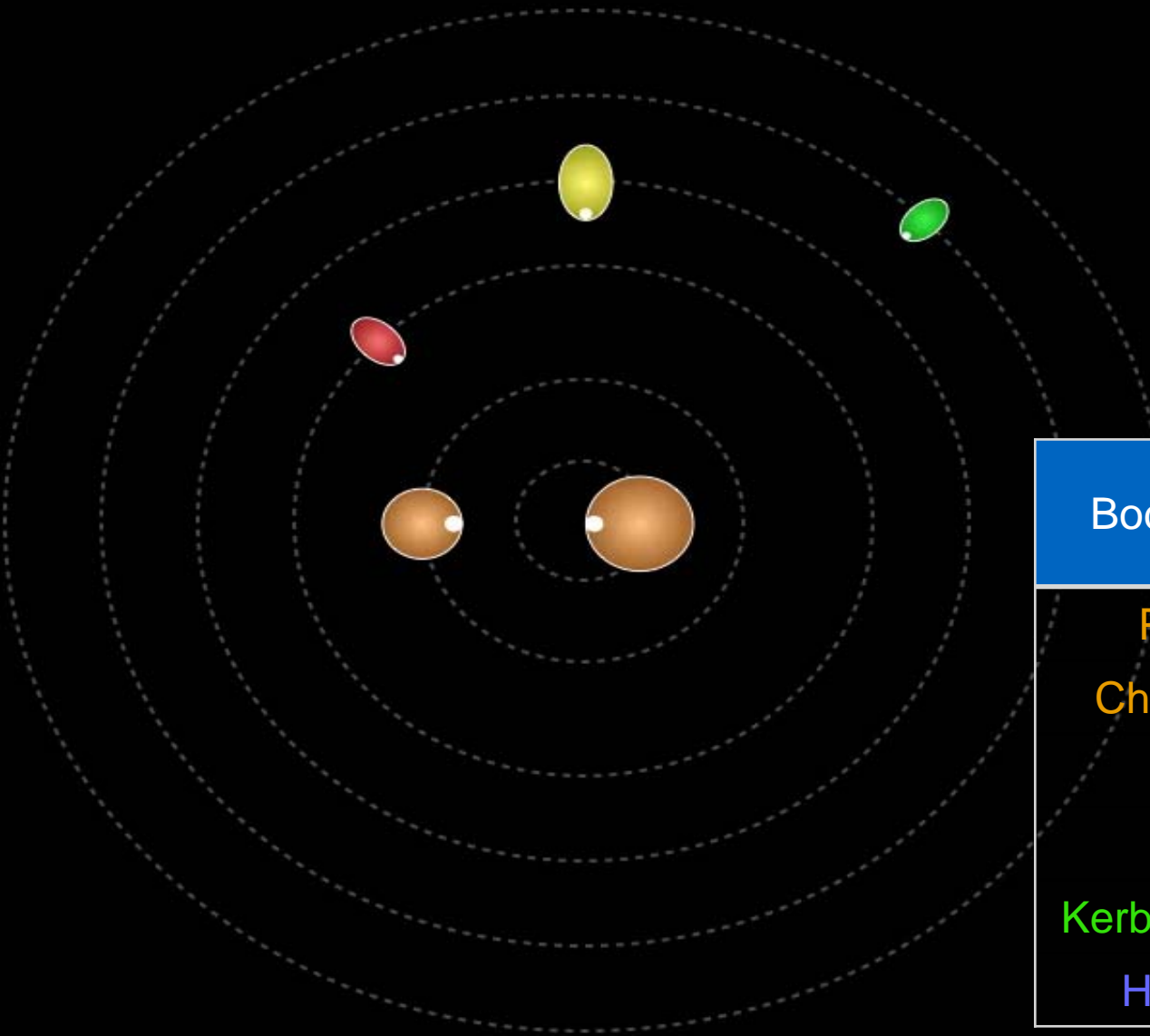
Kerberos



Hydra

...NOT  
synchronous!

Body	Spin Period	
	Days	Orbits
Pluto	6.387	1
Charon	6.387	1
Styx	3.239	6.22
Nix	1.829	13.6
Kerberos	5.33	6.04
Hydra	0.4295	88.9

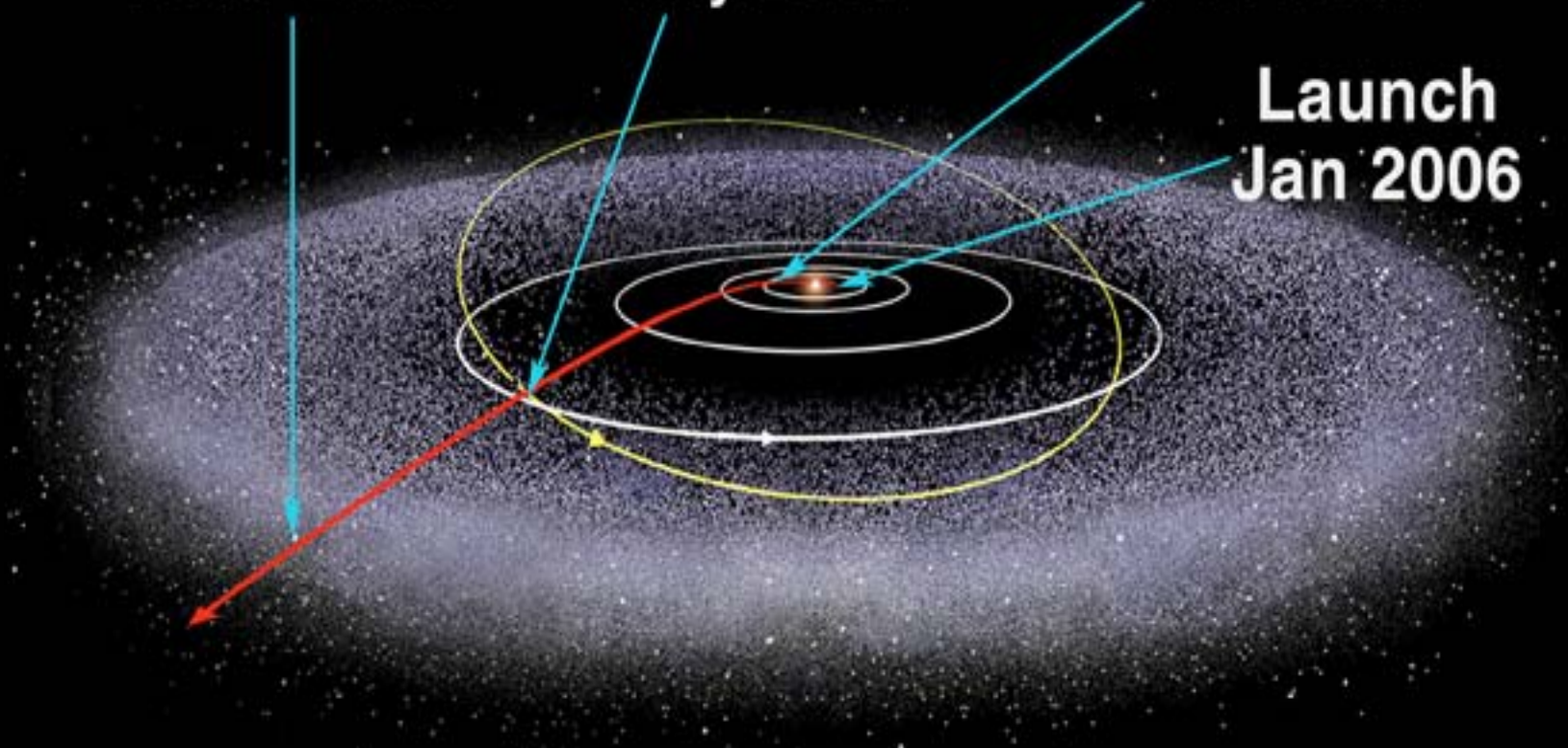


**KBOs**  
**2016–2020**

**Pluto System**  
**July 2015**

**Jupiter System**  
**Feb 2007**

**Launch**  
**Jan 2006**







# JUPITER OBJECTIVES



## **Objectives Met**

- 1. Flew through Pluto aim point**
- 2. Served as flyby/encounter pathfinder**
- 3. Collected diverse scientific data**

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# Newsweek

U.S. WORLD BUSINESS TECH & SCIENCE

TECH & SCIENCE

## NASA Begins Countdown to Pluto Flyby

BY STAV ZIV 11/15/15 AT 4:59 PM



SPACE.COM

TECH SPACEFLIGHT SCIENCE & ASTRONOMY

TRENDING: Skywatching Guide # Space Webcasts # Mars Rover Curiosity # Solar Flares # Space Photos

## NASA's New Horizons Spacecraft Wakes Up for Pluto Encounter in 2015

by Caita Cofield, Space.com Staff Writer | December 07, 2014 09:12am ET

1692  
134  
7627  
102



# LA Los Angeles Times

## NASA's New Horizons spacecraft is awake and cruising toward Pluto





# The New York Times

## NASA Spacecraft Closing In on Dwarf Planets Pluto and Ceres

By KENNETH CHANG, JUN 18, 2015

It is small. It is round. It was once a planet, but is now cast off as too diminutive. In March, a NASA spacecraft will arrive there to begin the first close-up examination of a dwarf planet. It is not Pluto. It is instead Ceres, 600 miles wide, the largest of the asteroids between Mars and Jupiter. "We're going to reveal the fascinating details of a giant world of rock and ice," said Marc Rayman, the chief engineer for NASA's Dawn spacecraft. "It's not like we're just going out to visit a chunk of rock the size of one of those mountains," he said, pointing to the San Gabriel Mountains outside the windows at NASA's Jet Propulsion Laboratory in Pasadena, Calif. "Ceres has 38 percent of the area of the continental United States. It's actually the largest body between the sun and Pluto that a spacecraft has not yet visited."

## SEVEN WONDERS OF THE MILKY WAY

# Astronomy

The world's best-selling astronomy magazine

## NASA SETS ITS SIGHTS ON PLUTO

New Horizons spacecraft begins its approach


How astronomers hear stellar heartbeats

The telescope at the end of the world

Discover Orion's deep-sky gems

Deep-sky imaging from England

Bob Berman on the universe's shadows




# NBC NEWS

## New Horizons Probe to Snap Pictures of Pluto

The high-resolution camera on NASA's New Horizons spacecraft has begun capturing images of Pluto in preparation for its flyby less than six months from now... but it will take a few more days to process the image data, the mission's principal investigator said.

"We got telemetry indicating the Sunday imaging went well and that the images have 'normal engineering parameters,'" Alan Stern, a planetary scientist from the Southwest Research Institute who heads the mission team, told NBC News in an email Monday. "The images themselves won't be on the ground for a day or two... We're off to the races!"

This race is a marathon rather than a sprint: The New Horizons probe was launched nine years ago, and it's now more than 3 billion miles (4.8 billion kilometers) from Earth. At that distance, it takes 4.5 hours for signals from the spacecraft to arrive. The probe's 2nd probe is still 125 million miles (200 million kilometers) from Pluto, and that means the dwarf planet will look like little more than a bright dot in this week's pictures from New Horizons' Long Range Reconnaissance Imager, or LORRI. However, even that dot can serve to guide the spacecraft toward its close encounter with Pluto on July 14... and the view will improve dramatically in the months ahead.



TOM COSTELLO  
NBC NEWS

# TIME

## NASA Spacecraft Wakes Up as It Approaches Pluto

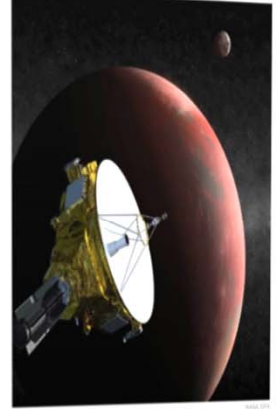
Justin Worland | Space.com | Dec 8, 2014

New Horizons will come closest to the dwarf planet on July 14

A NASA spacecraft has emerged from hibernation in preparation for completing its nine-year, 2.9-billion-mile journey to observe Pluto from up close, the space agency said.

Sending its signal at the speed of light, the New Horizons ship beamed a report down to Earth that it was back in active mode as of Dec. 6.

"Technically, this was routine, since the wake-up was a procedure that we'd done many times before," said Glen Fountain, the mission's project manager. "Symbolically, however, this is a big deal. It means the start of our pre-encounter operations."



An undated artist's concept shows the New Horizons spacecraft as it approaches Pluto and its largest moon, Charon.