

# Exploring a new world at the Edge of the Solar System

*The Ultima Thule Flyby*

**JJ Kavelaars**

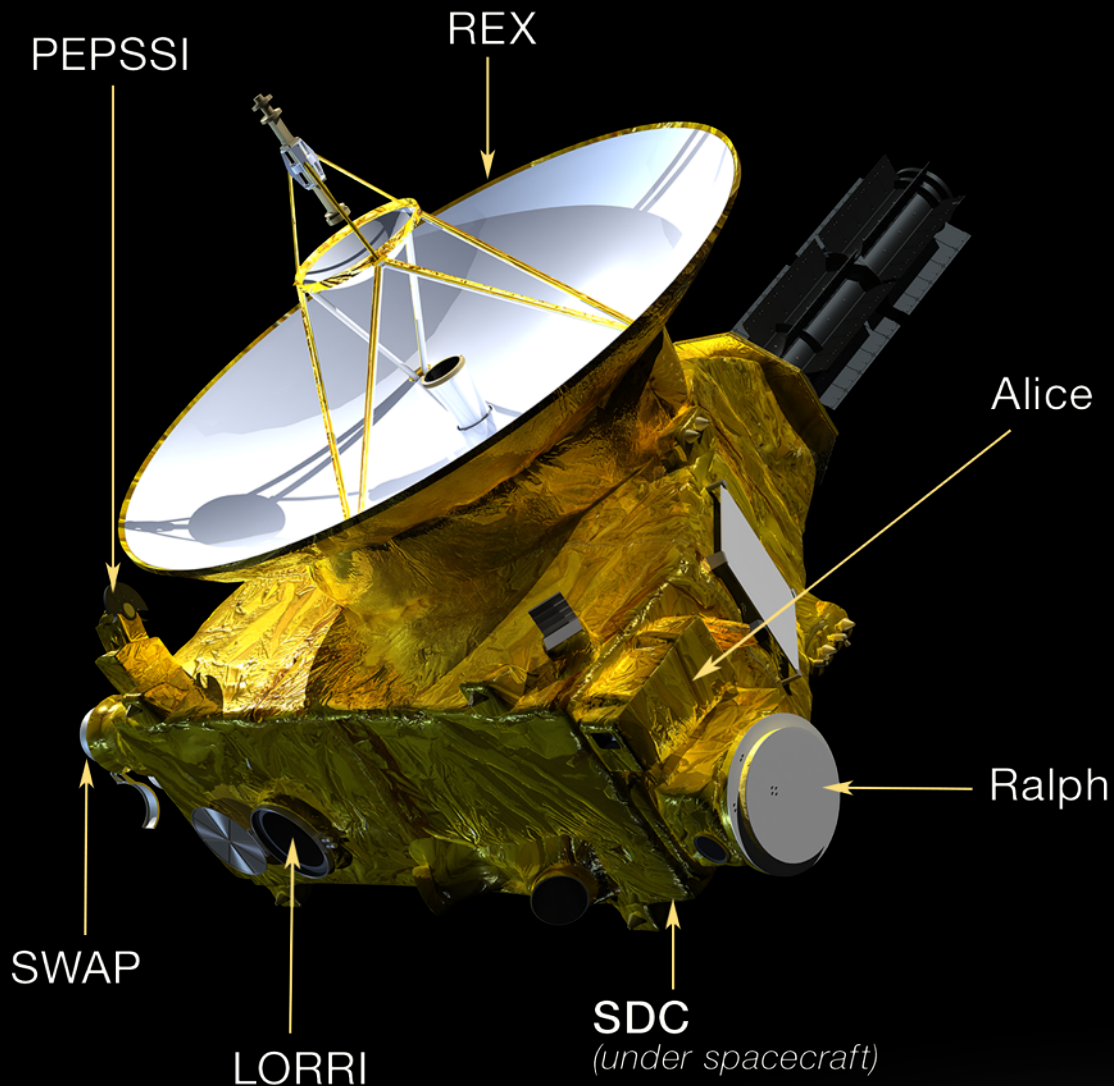
*New Horizons Co-Investigator*

*National Research Council of Canada*



# **The Journey Begins: 19 January 2006**

# New Horizons Instruments



**LORRI:** High-Resolution Panchromatic Imager: Geology, Navigation, Searches for Moons and Rings

**Ralph:** Color Imager and Infrared Composition Mapper

**Alice:** Ultraviolet Spectral Imager: Atmospheric Searches

**REX:** Radio Science Experiment: Surface Temperature and Radar Reflectivity

**SWAP:** Low-Energy Charged Particle Detector: Solar Wind Interaction with Ultima

**PEPSSI:** High-Energy Charged Particle Detector: Search for Emitted Ions

**SDC:** Dust Impact Detector

# The Pluto System through the Eyes of New Horizons

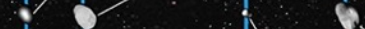


Pluto

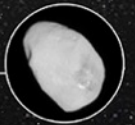
sized to approximate scale



Charon



Styx



Nix



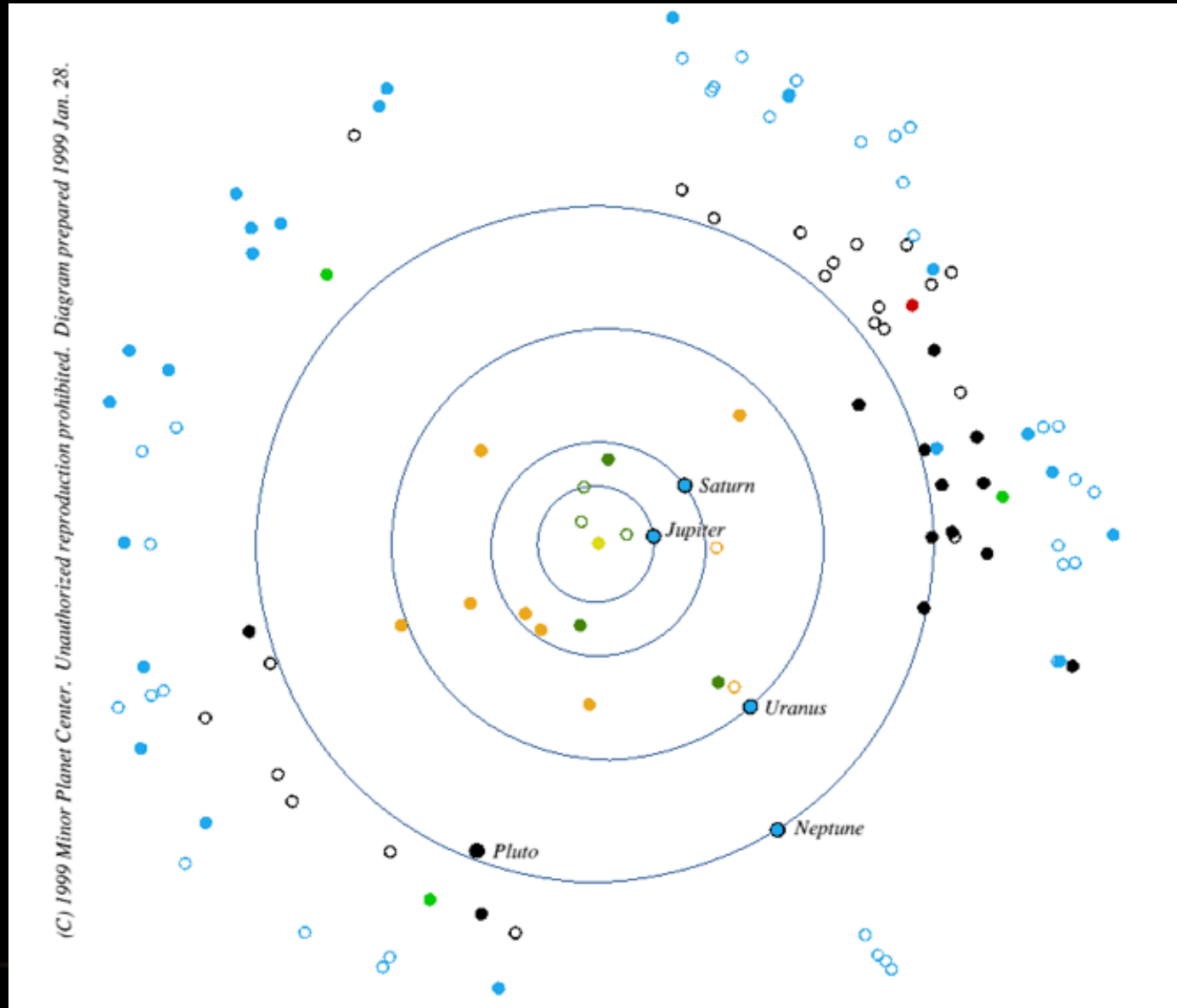
Hydra



Kerberos

# Pluto's Amazing Terrain Diversity

# Planning knowledge of Kuiper belt.

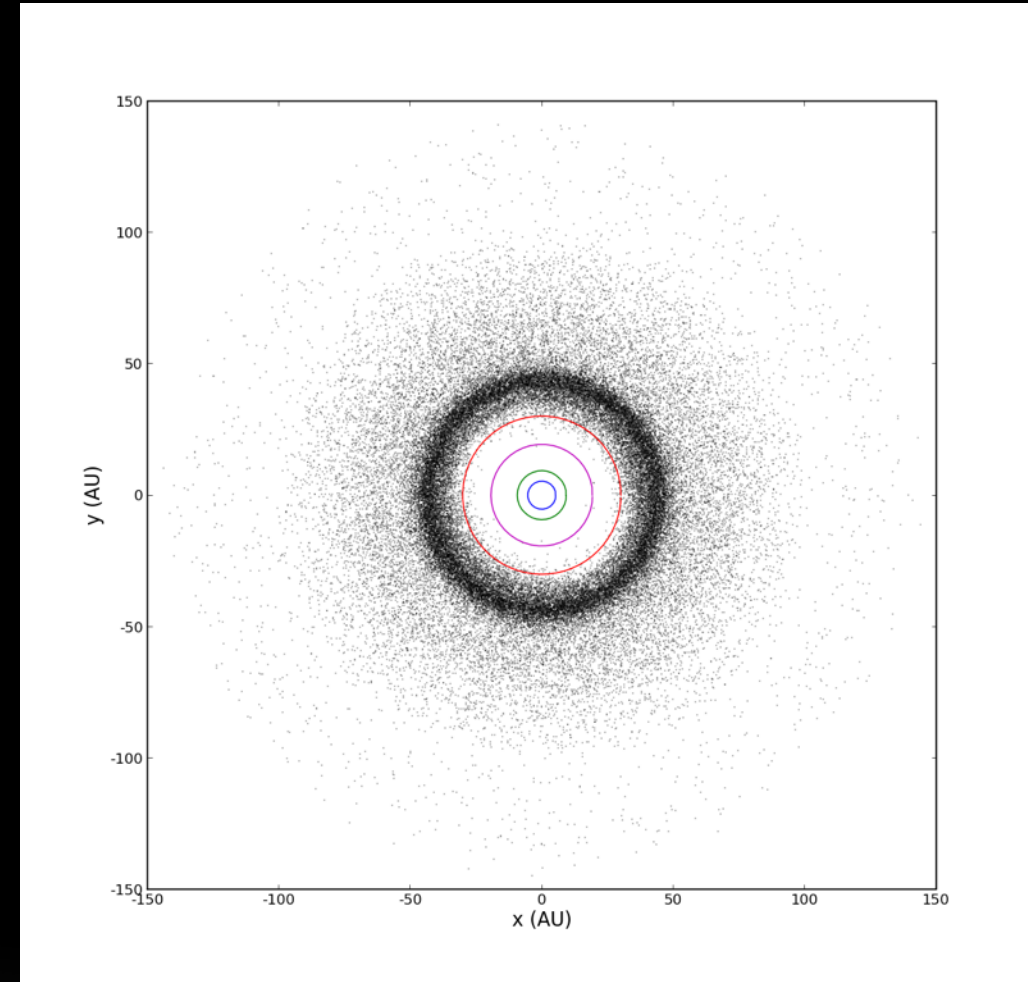


# Hindsight is 20/20

## Canada France Ecliptic Plane Survey (CFEPS)

Full data release in 2011

- 183 Kuiper belt objects
- Known detection biases
- Reveals the 'Kernel' of the Kuiper belt
- More exactly defines the location of the orbit plane
- Combined with associated deep surveys indicates required change in the size-distribution
- Allows a synthetic model to be used for detailed model analysis



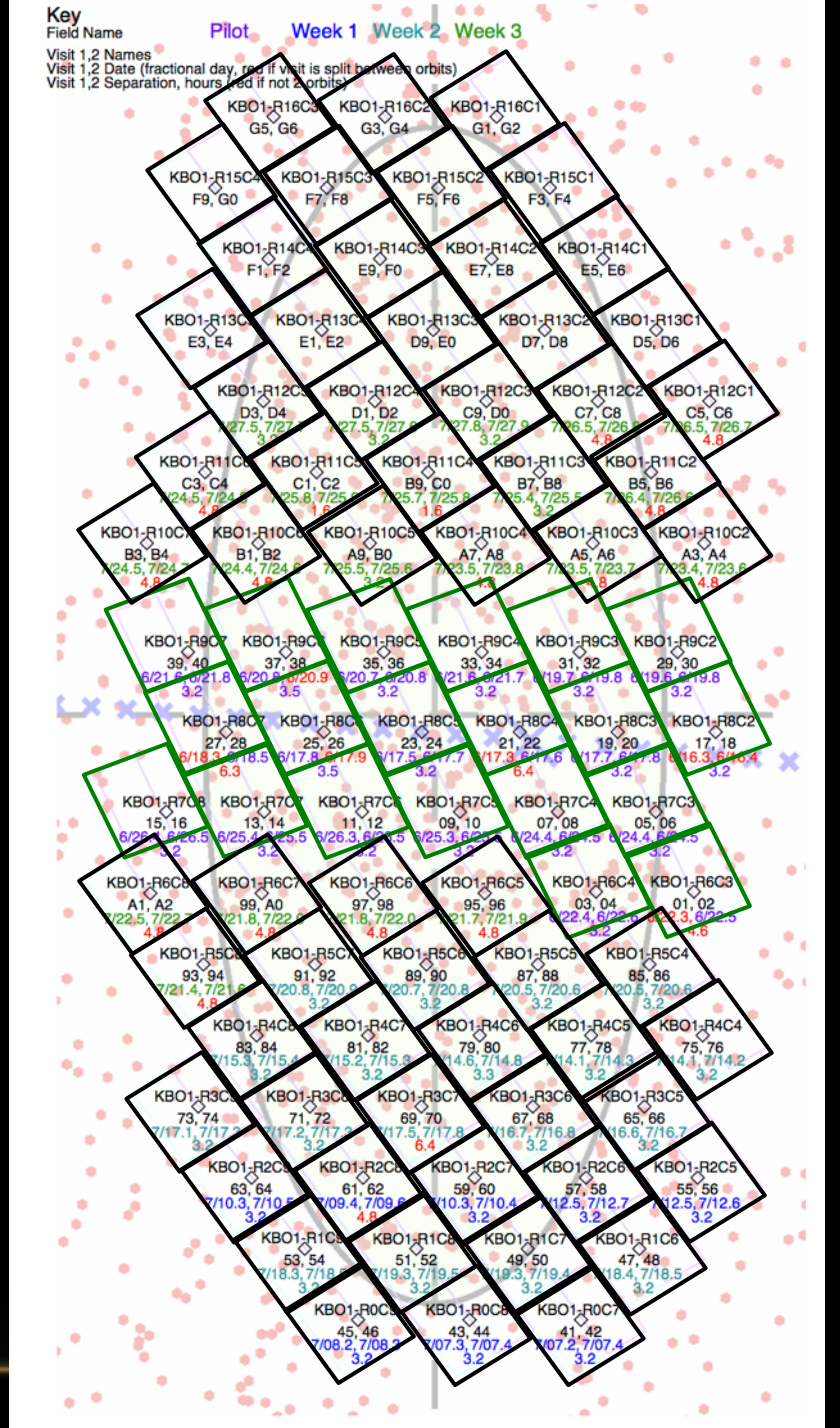
# Hubble to the Rescue

- 166 orbits, 830 images, 83 fields
- Images processed with 1-2 days of receipt to reveal moving objects
- Reach magnitude 27.5



Red dots are 100 x CFEPS model of encounterable objects

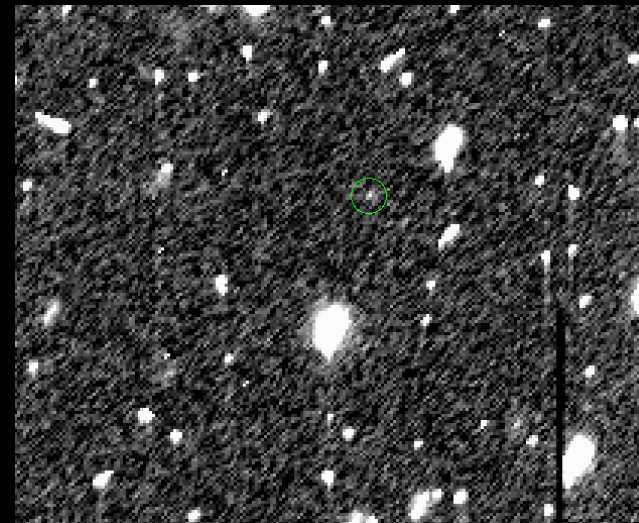
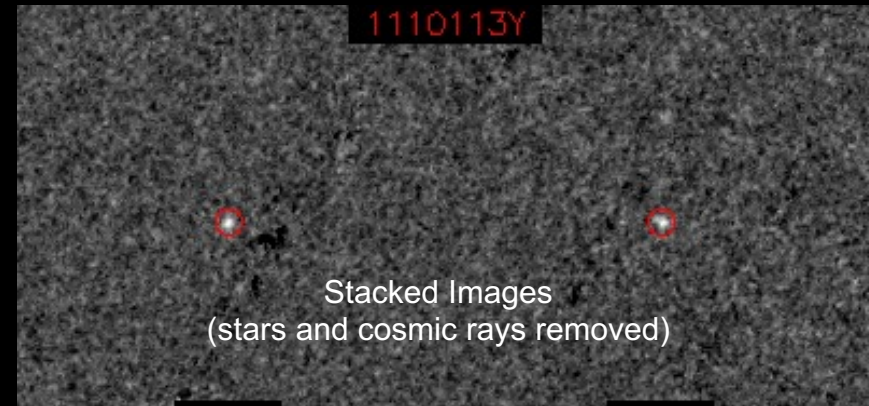
5 images star-subtracted, robustly stacked at KBO





# SUCCESS!

3 'encounterable'  
KBOs found





# The Reward



- Around 2019: Our first view of a new kind of world...

*Final slide of July 2014 presentation announcing we had found a potential target.*



Simulated view of KBO, showing expected image quality

# Pluto's Blue Sky!



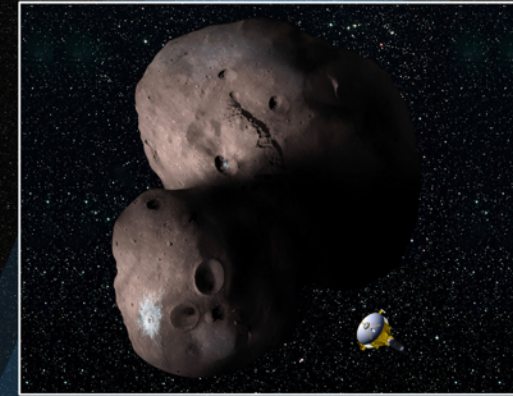
# Explore Deeper in the KB

Flyby of *Ultima Thule* on New Year's Day 2019  
Flyby distance = 3500 km (2170 miles)

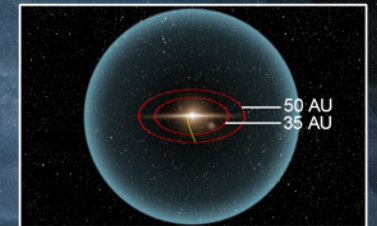
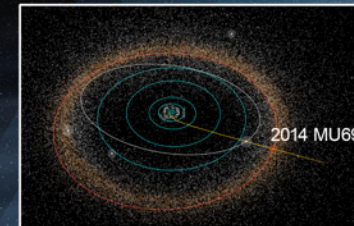


# NEW HORIZONS KUIPER BELT EXTENDED MISSION

First Mission to Explore Primitive KBOs and the Kuiper Belt



Close Flyby of a KBO: 2019



Surveying KBOs and the Kuiper Belt Environment to 50 AU

Measuring the Surface Properties, Satellite/Ring Systems, and Shapes of Many More KBOs

Measuring Kuiper Belt/Heliospheric Dust, Gas, Solar Wind, and Energetic Particles

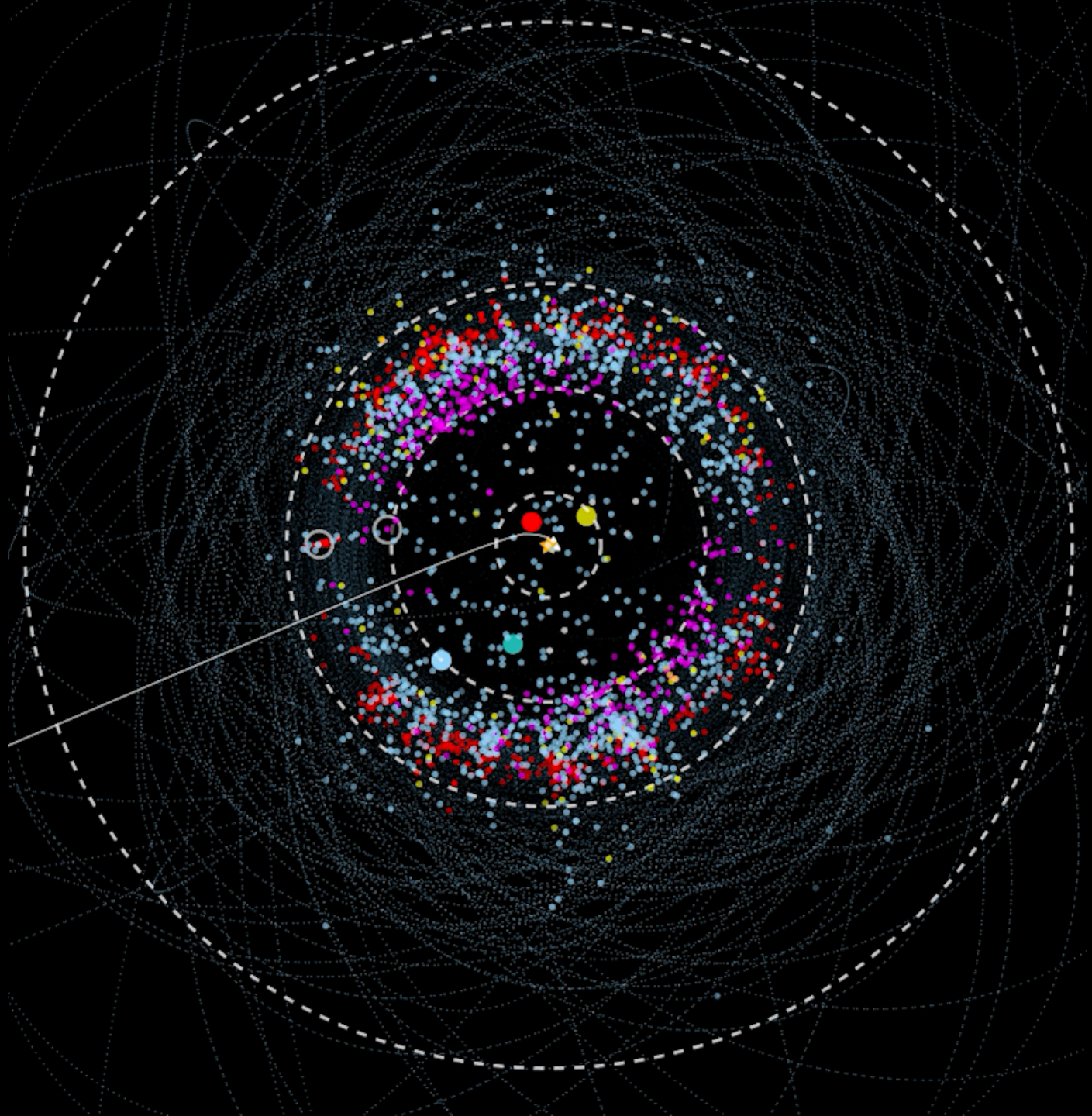
Proposed by:  
Southwest Research  
Institute

Dr. S. Alan Stern  
Principal Investigator

15 April 2016



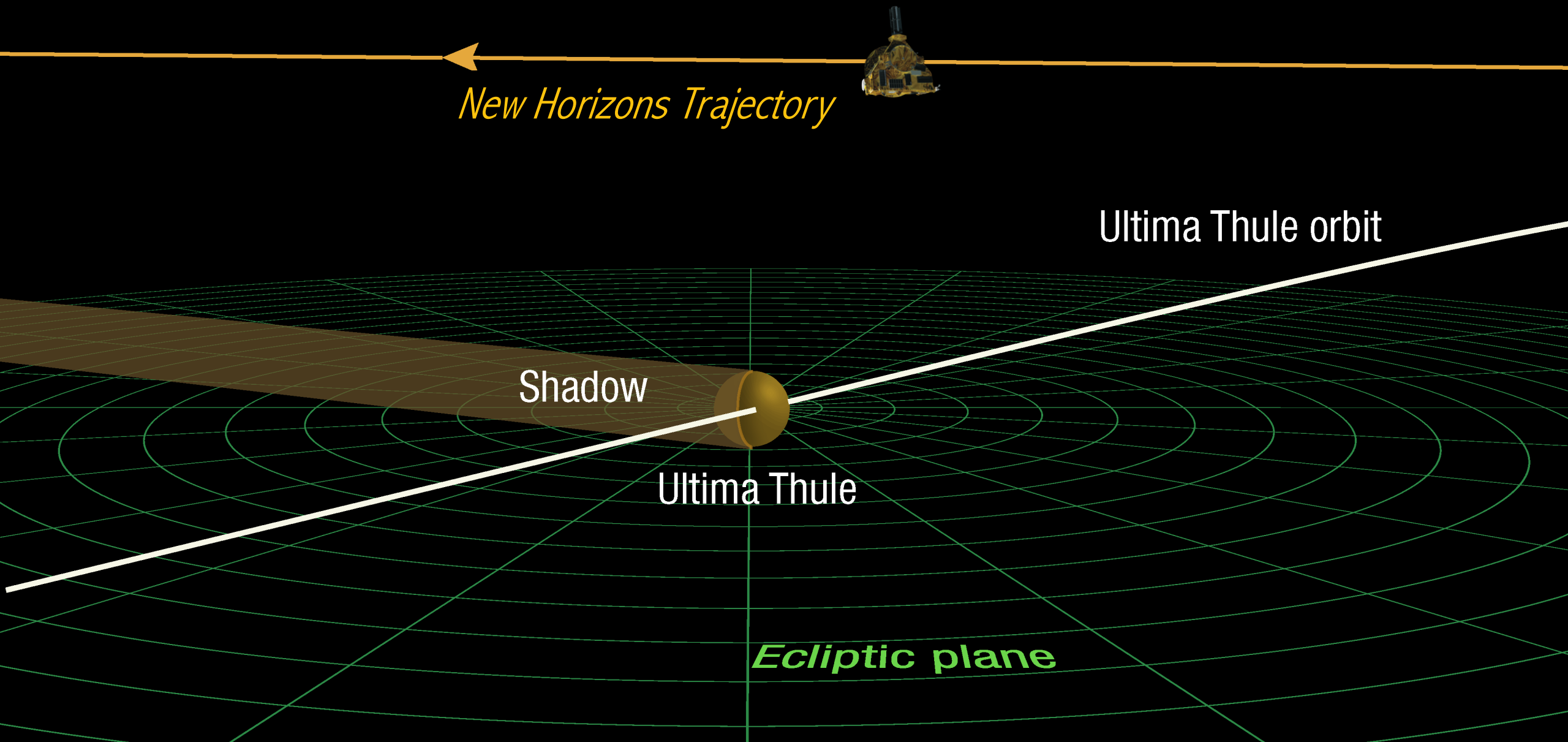
# Historic Journey to the Solar System's Frontier



# Ultima Thule: A More Challenging Flyby

- Target is 80× smaller in diameter than Pluto
- ~4× closer flyby, requiring more navigational precision
- Uncertain target location (discovered 2014, P=293 yr)
- Unknown environment
- ~4× darker target, lower light levels
- Reduced spacecraft power
- 12.25 hour round-trip light time

# January 1<sup>st</sup> Closest Approach



*New Horizons Trajectory*

Ultima Thule orbit

Shadow

Ultima Thule

*Ecliptic plane*

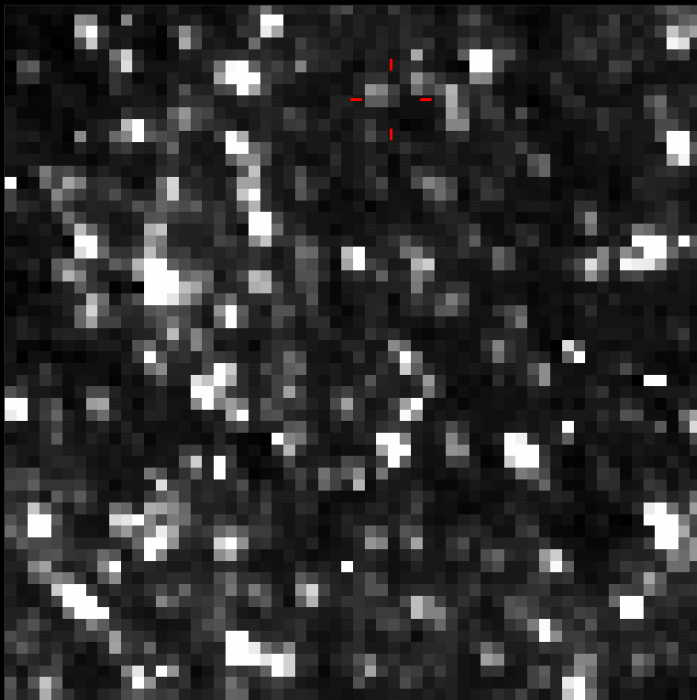
# Navigating to Ultima Thule

- Spacecraft tracked by Deep Space Network
- Ultima tracked by Hubble, then New Horizons
- Differences in Ultima's position compared to nominal resulted in course corrections up to Dec 18
- On Dec 30, we transmitted pointing and timing corrections to New Horizons

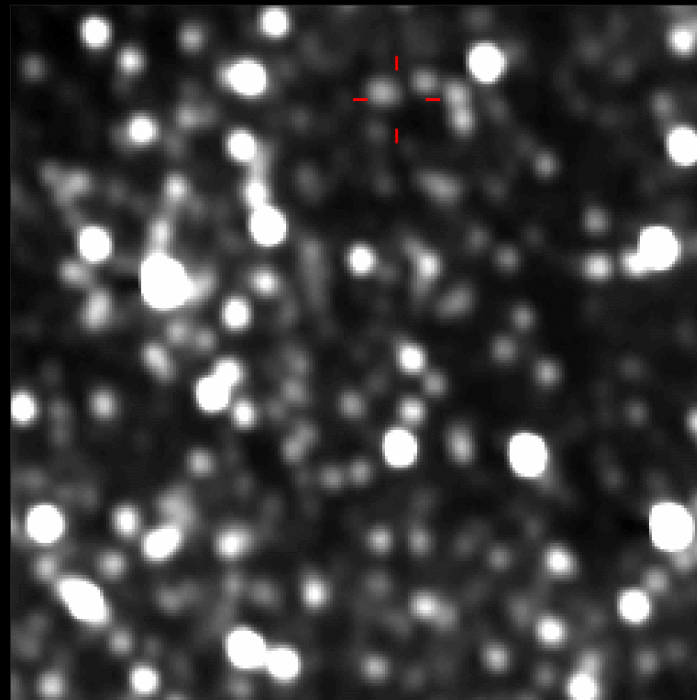


# Optical Navigation

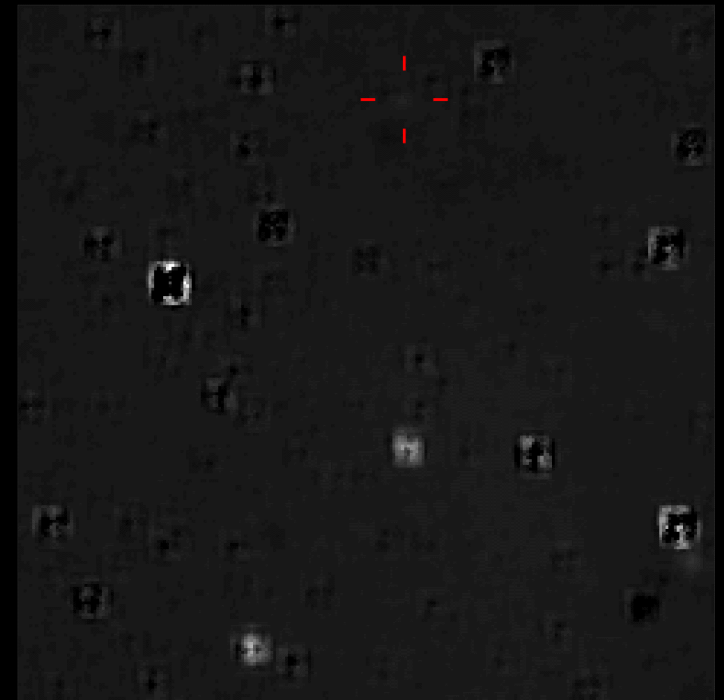
Raw Image



Processed



Stars Subtracted



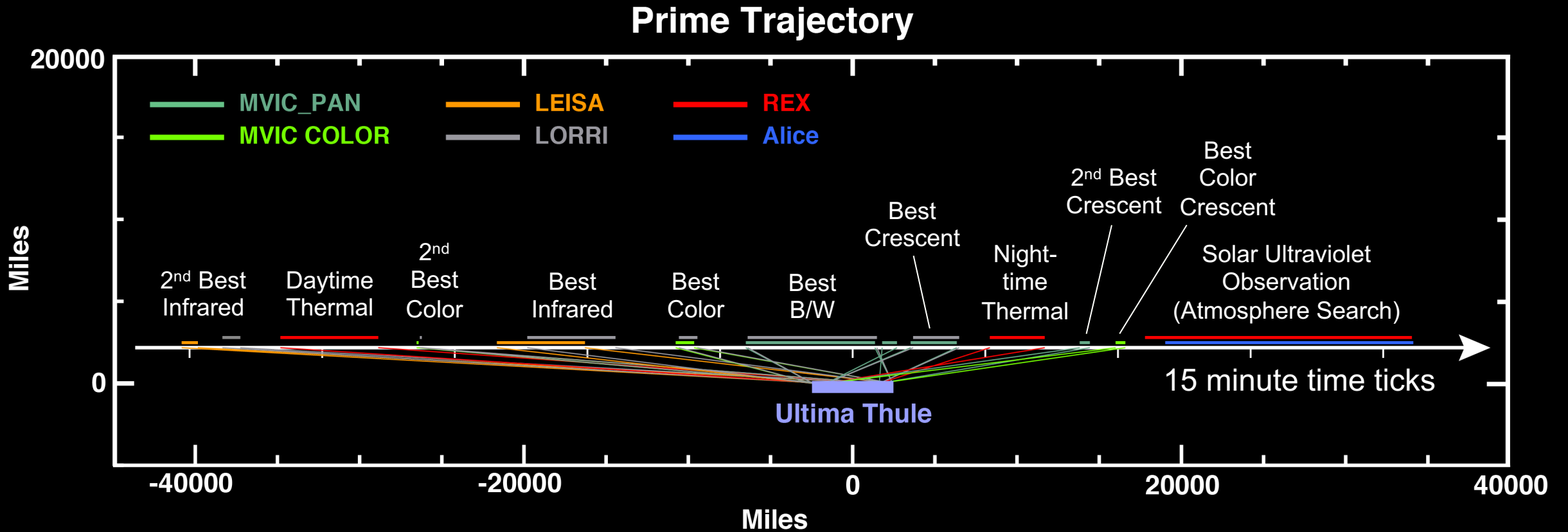
AUGUST 16, 2018



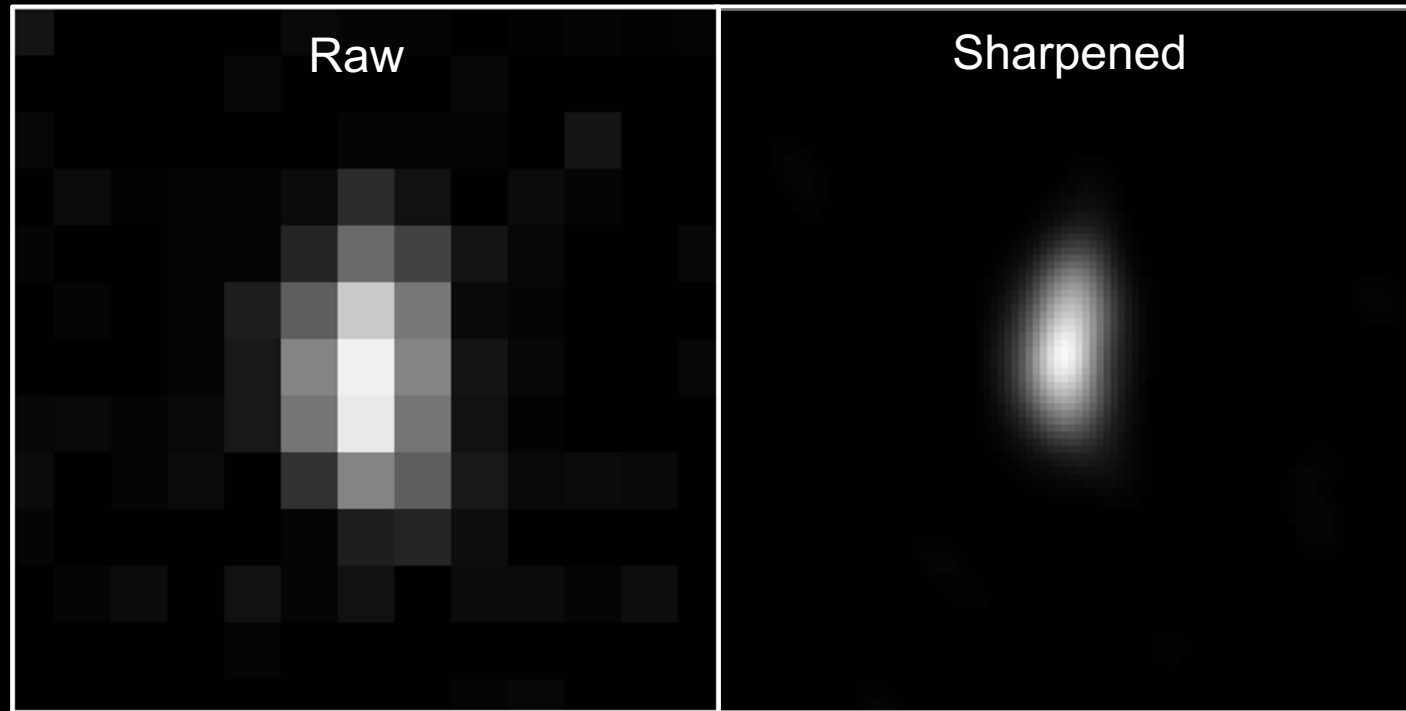
# Ultima Thule Science Objectives

- Map geology and morphology
  - Craters, fractures, topography
- Map surface color and composition
  - Search for ices: ammonia, carbon monoxide, methane, water ice
  - What makes Ultima Thule dark and red?

# The Flyby Sequence



# First Images of Ultima Thule's Shape



- Images taken at 16:56 UT (11:56 am EST) December 30, 2018
  - 37 hours before Closest Approach (CA)
- Range to Ultima: 1.2 million miles (1.9 million kilometers)
- Original pixel size: 5.8 miles (9.4 kilometer)

Jet Propulsion Laboratory | California Institute of Technology


**DEEP SPACE NETWORK NOW** [DSN home](#) [i](#)

LAST UPDATED: DEC 31 11:32 PM (UTC)

Location	TESS	MMS2	ORX	NHPC
<b>MADRID</b> JAN 1 12:32 AM				
	63	65	54	55
<b>GOLDSTONE</b> DEC 31 3:32 PM				
	14	24	25	26
<b>CANBERRA</b> JAN 1 10:32 AM				
	43	34	35	36

**TARGET**

## NEW HORIZONS [i](#)



[VIEW ANTENNA](#)
[VIEW SPACECRAFT](#)
[VIEW WORLD MAP](#)

[NHPC](#)

**SPACECRAFT**

**NAME**  
New Horizons

**RANGE**  
6.62 billion km

**ROUND-TRIP LIGHT TIME**  
12.27 hours

**ANTENNA**

[+ more detail](#) [credits](#) [contact us](#)

# The Reveal



# What A Difference a Day Makes

Jan 1, 2019



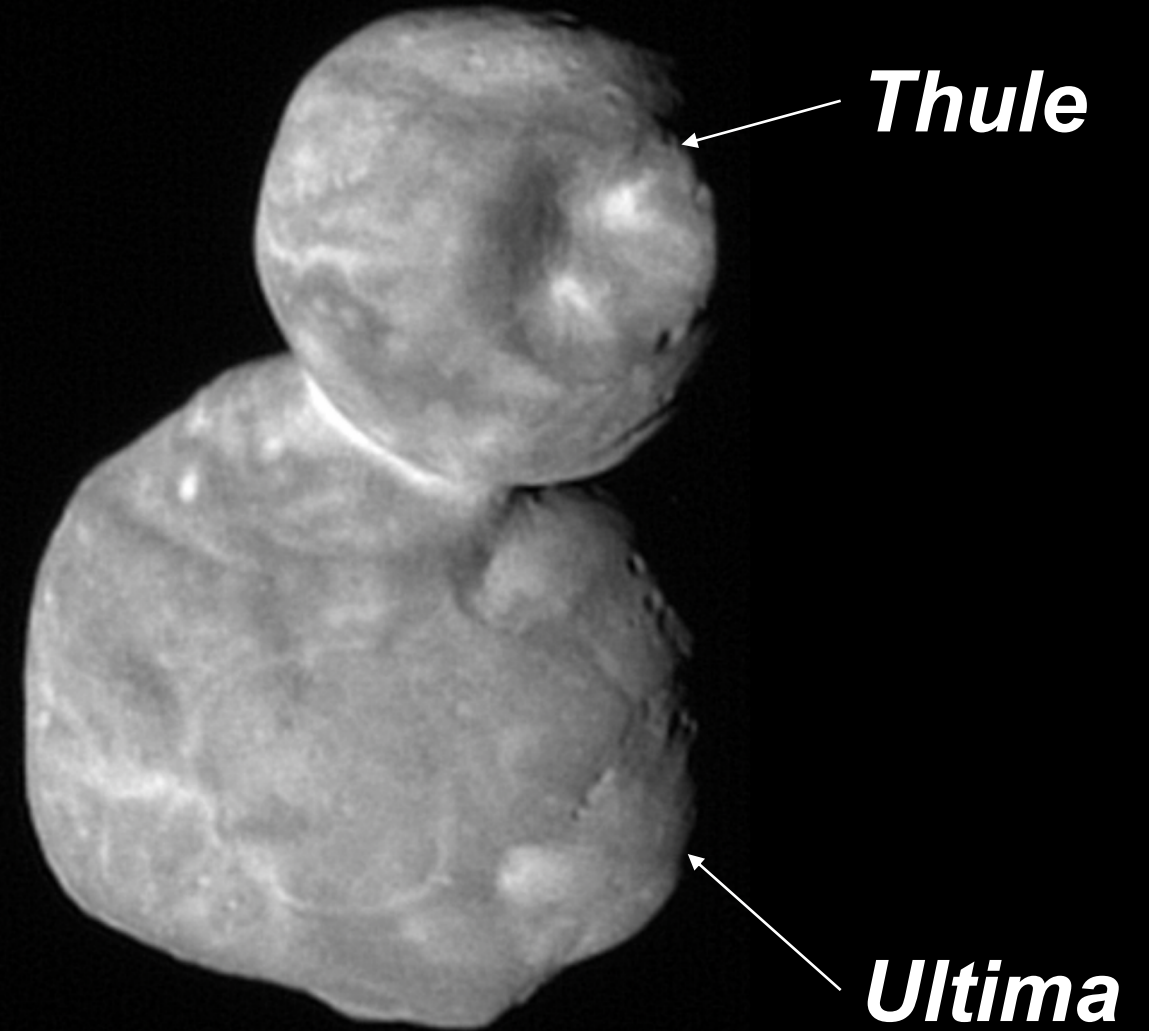
30 km

# Highest Resolution MVIC Image

Best View of Ultima  
Thule

Closest Approach  
Optical and Colour

Merger of Two  
Planetesimals?





“Maryland”  
~7–7.5 km

Smaller Depressions <1 km

Pit Chain  
or Impact  
Craters?

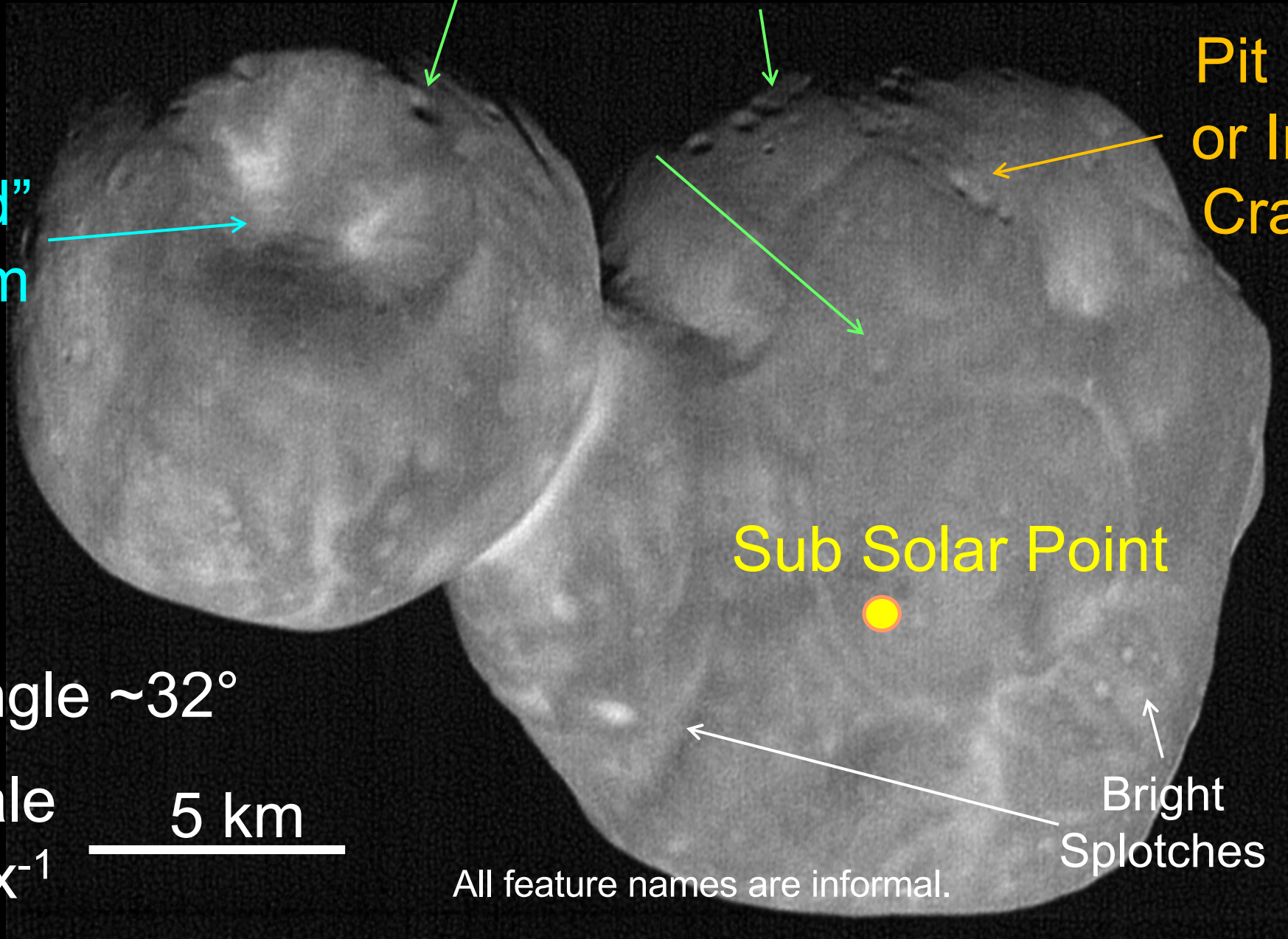
Sub Solar Point

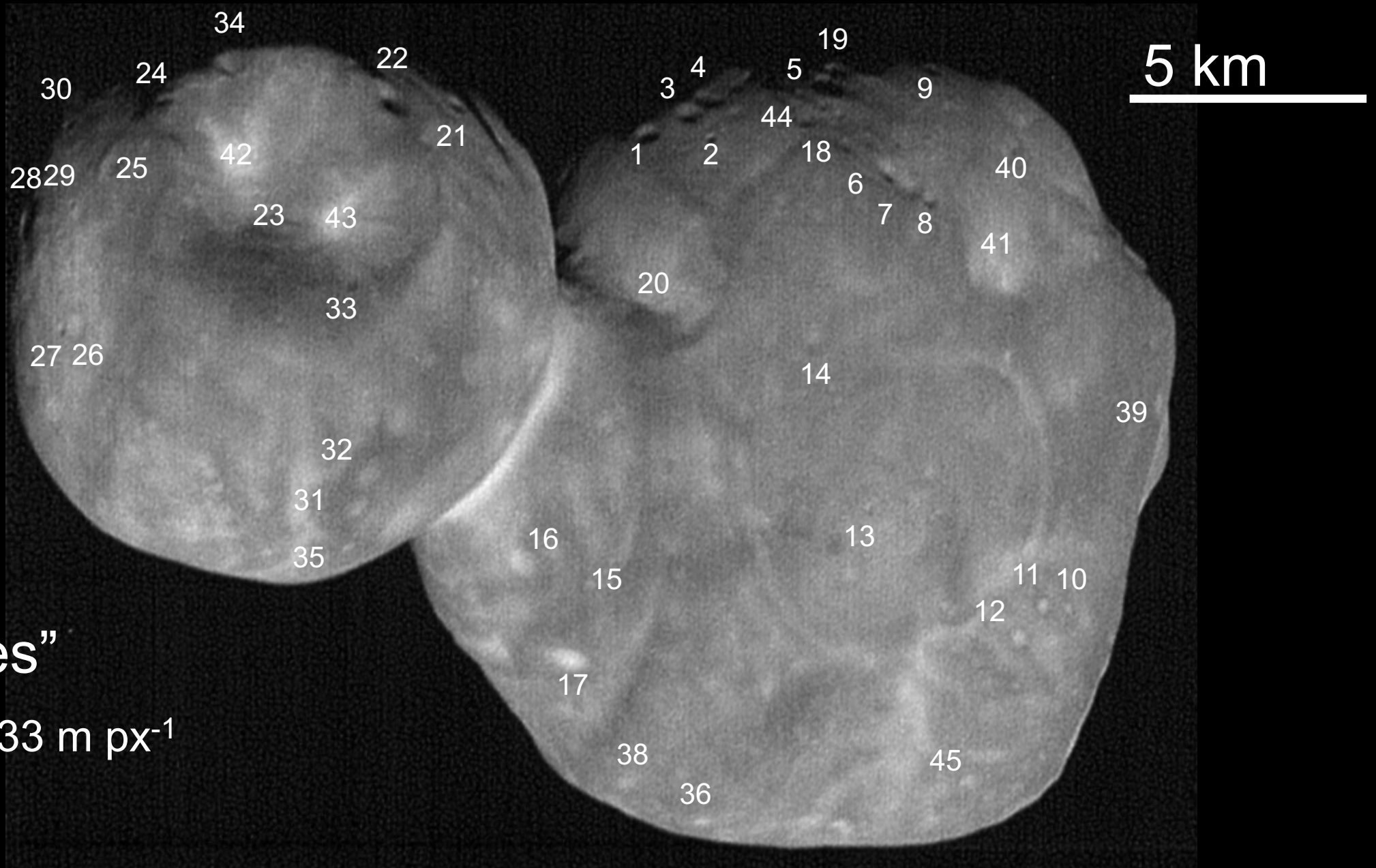
Phase angle  $\sim 32^\circ$

Pixel scale  $\sim 33 \text{ m px}^{-1}$   
5 km

Bright  
Splotches

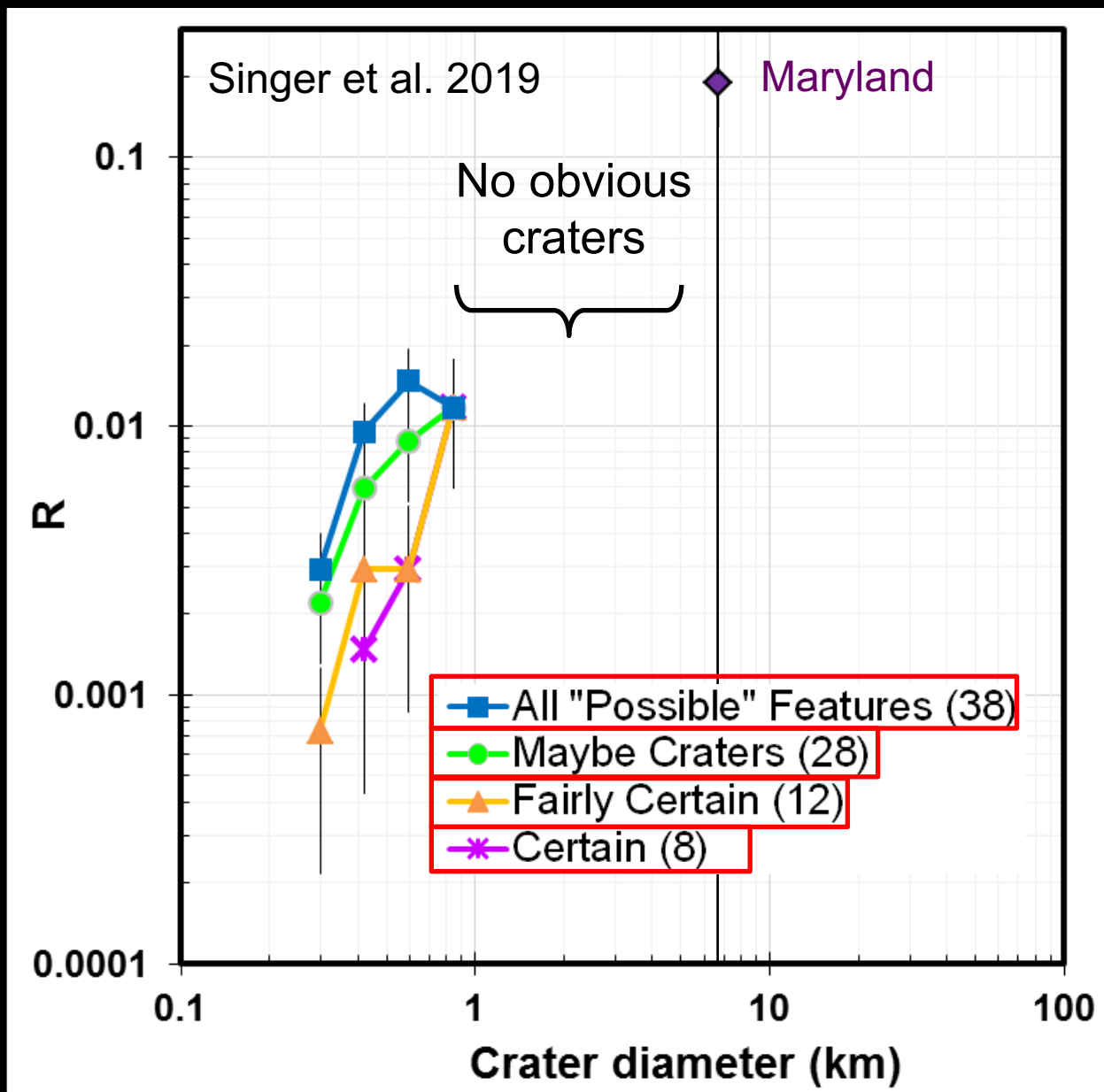
All feature names are informal.





45 “features”

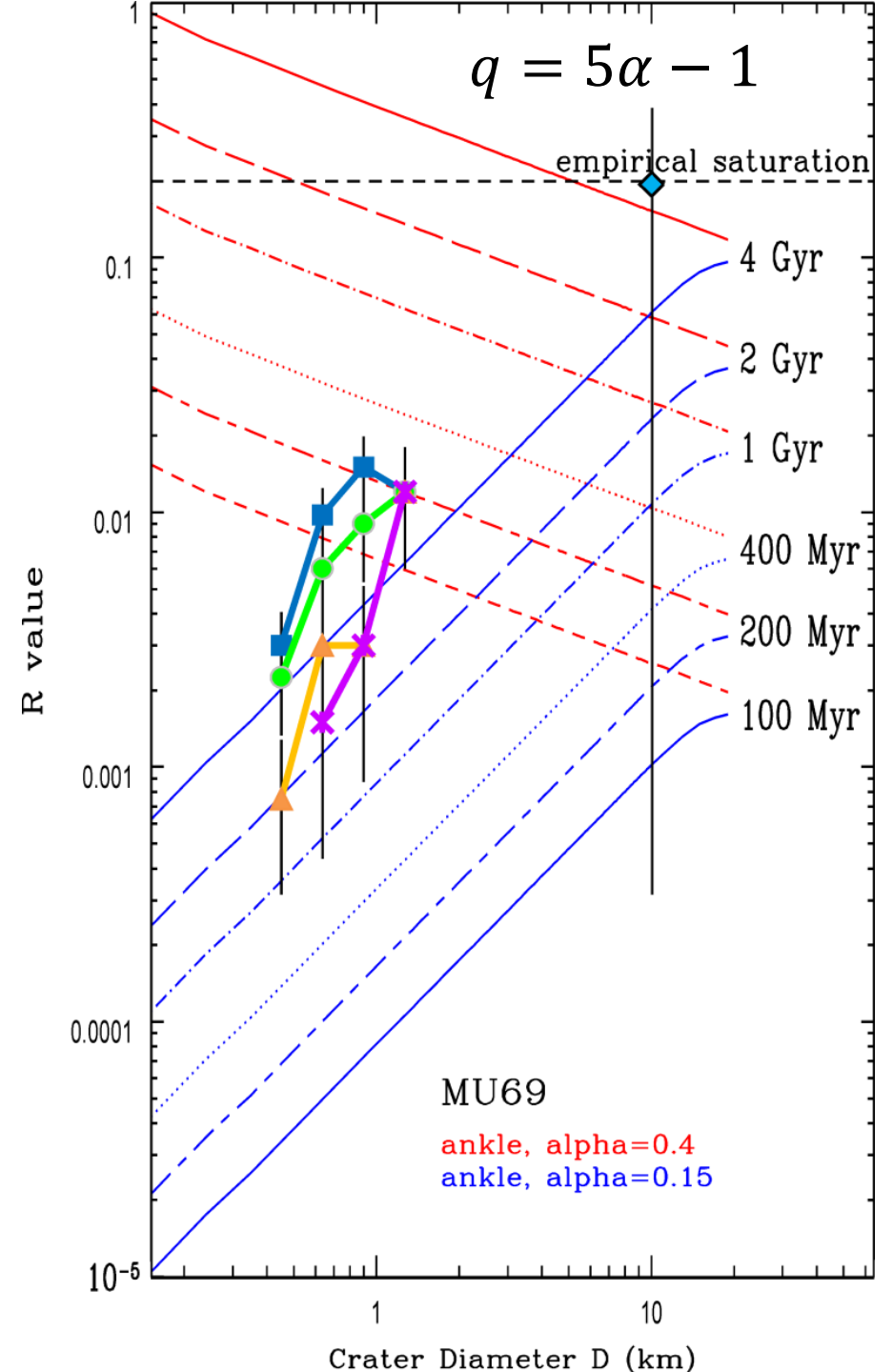
Pixel scale  $\sim 33 \text{ m px}^{-1}$



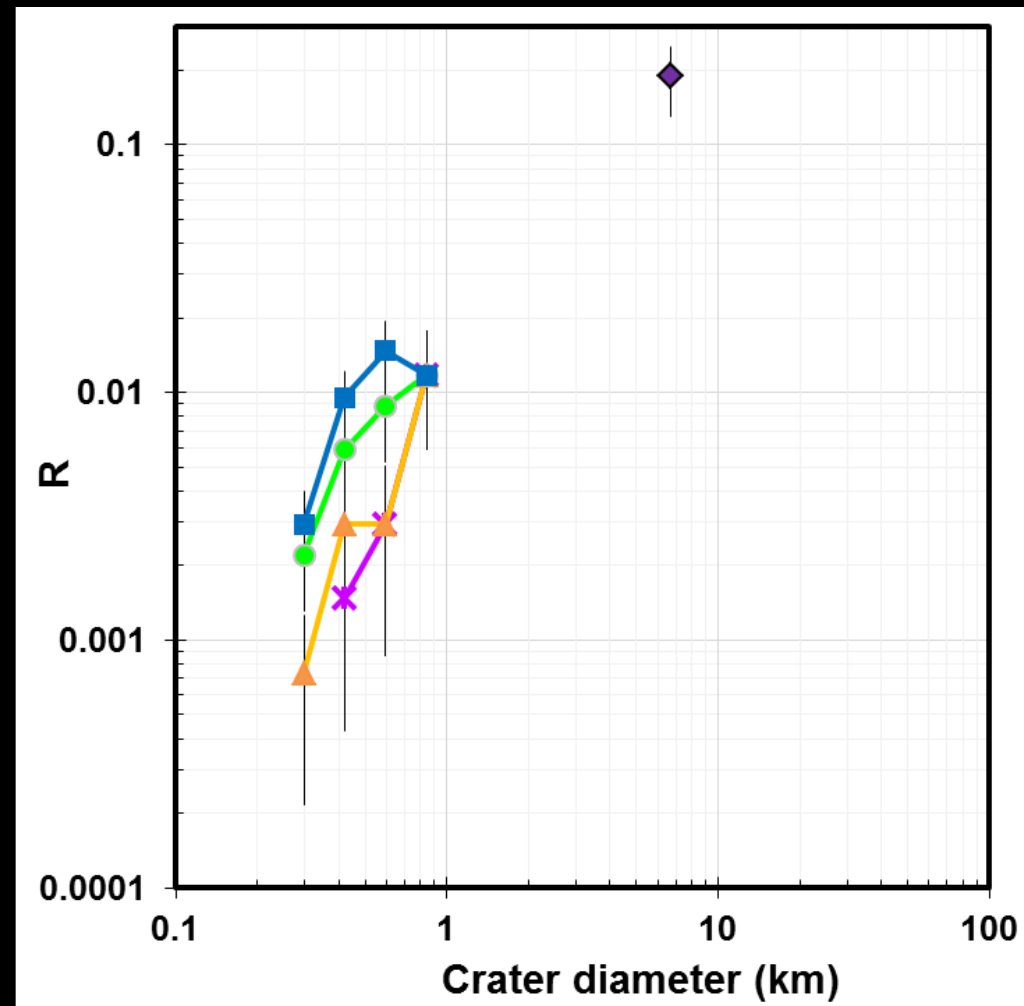
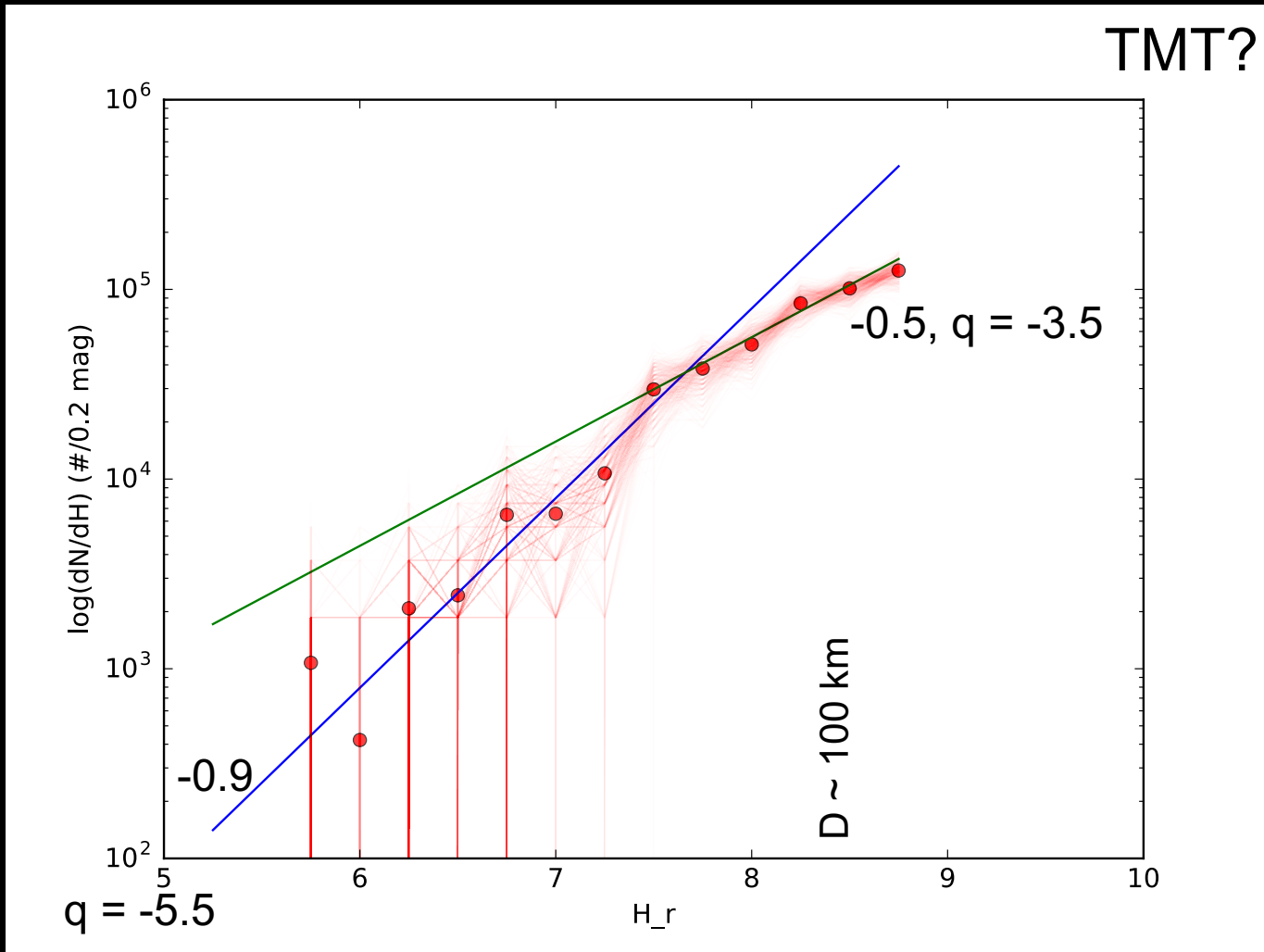
Impactor  $d$

~100 m

~1.5 km

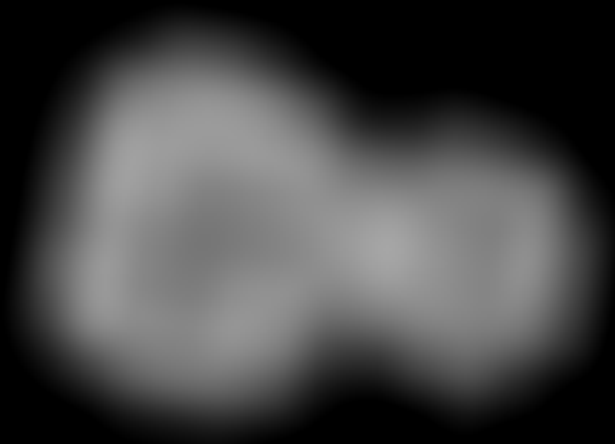


# OSSOS TNO Luminosity Function



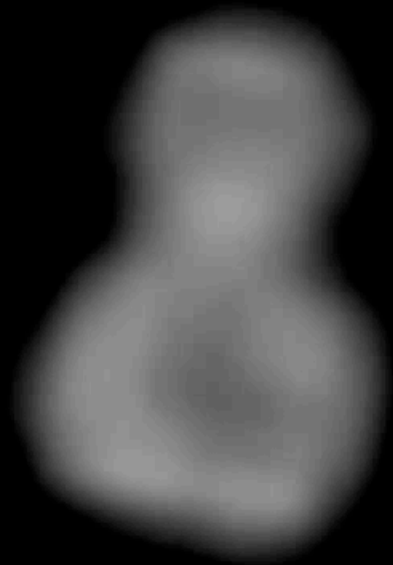
Impactor  $d$  ————+—————+—————  
 ~100 m                      ~1.5 km

# Ultima Thule Has 16 hr Rotation



2018-12-31 20:00

# Ultima Thule Has 16 hr Rotation



De-rotated and resized

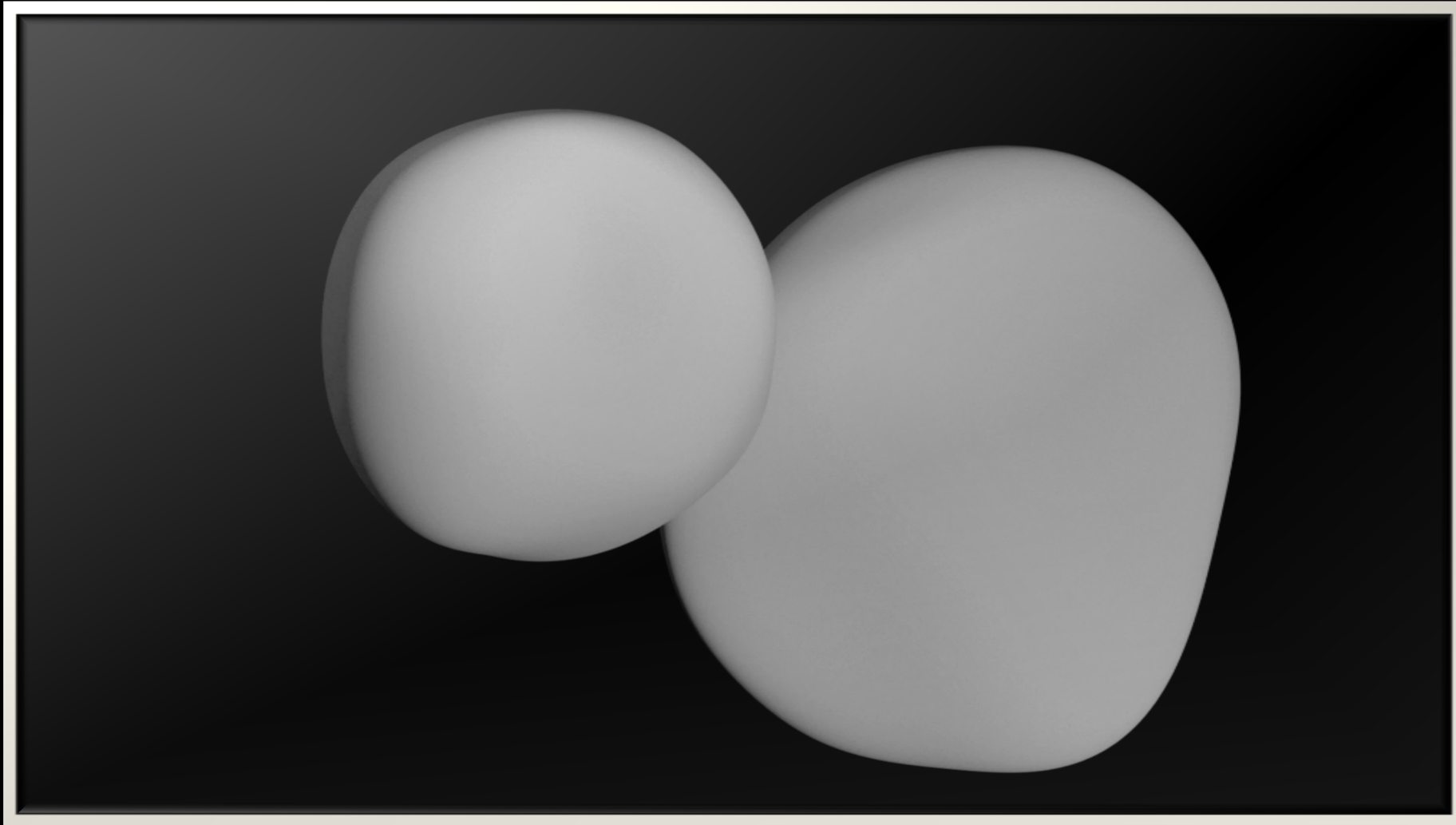


As seen by New Horizons

# Approach Imaging

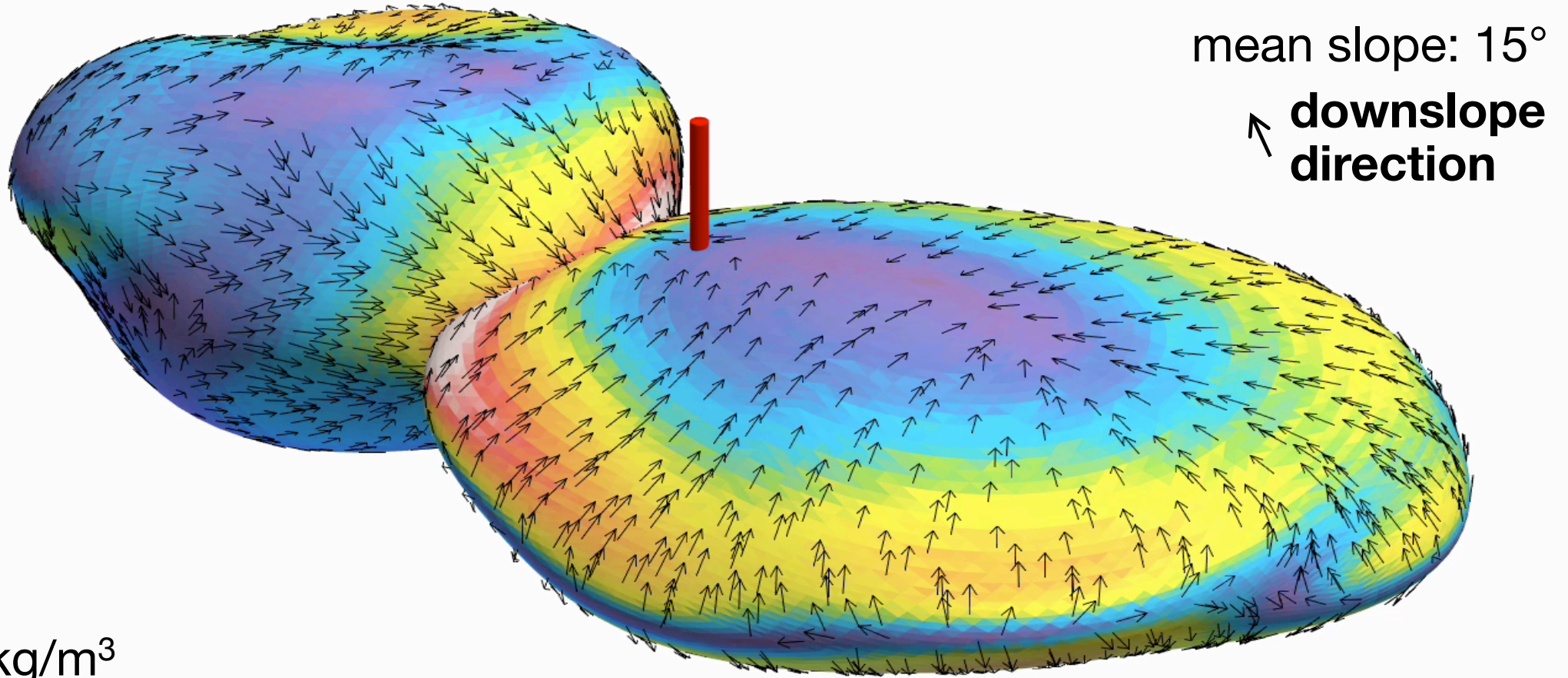


# Face-On vs Edge-On Views





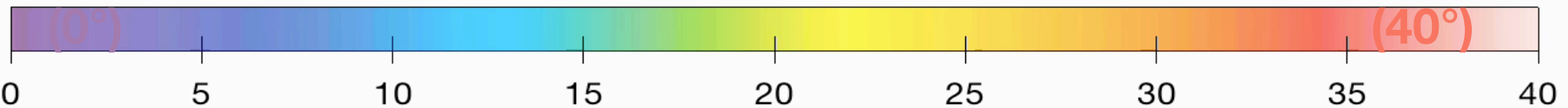
# hill slopes on 2014 MU69



Density: 500 kg/m<sup>3</sup>  
Rotation period: 15.9 hours

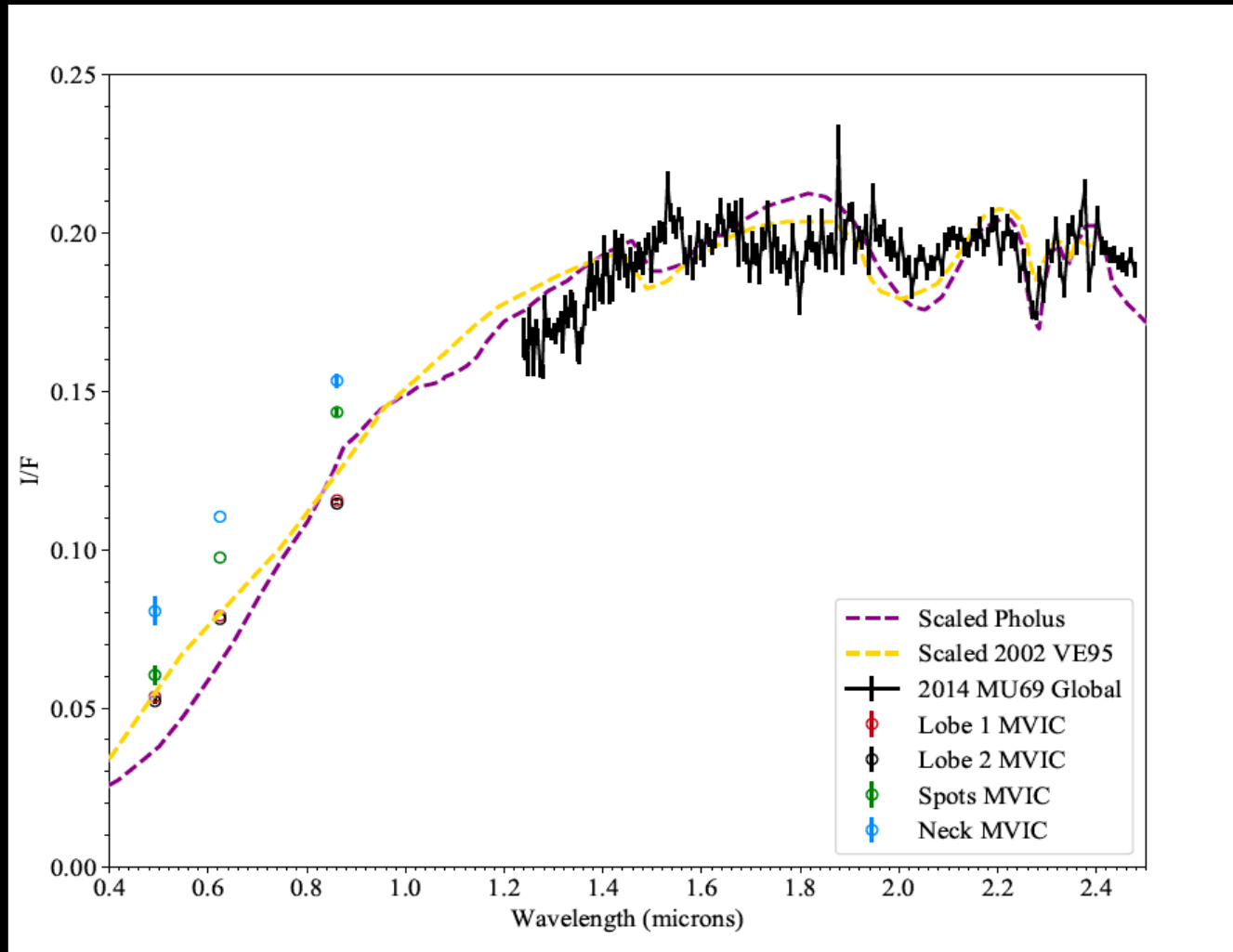
flat slopes

steep slopes

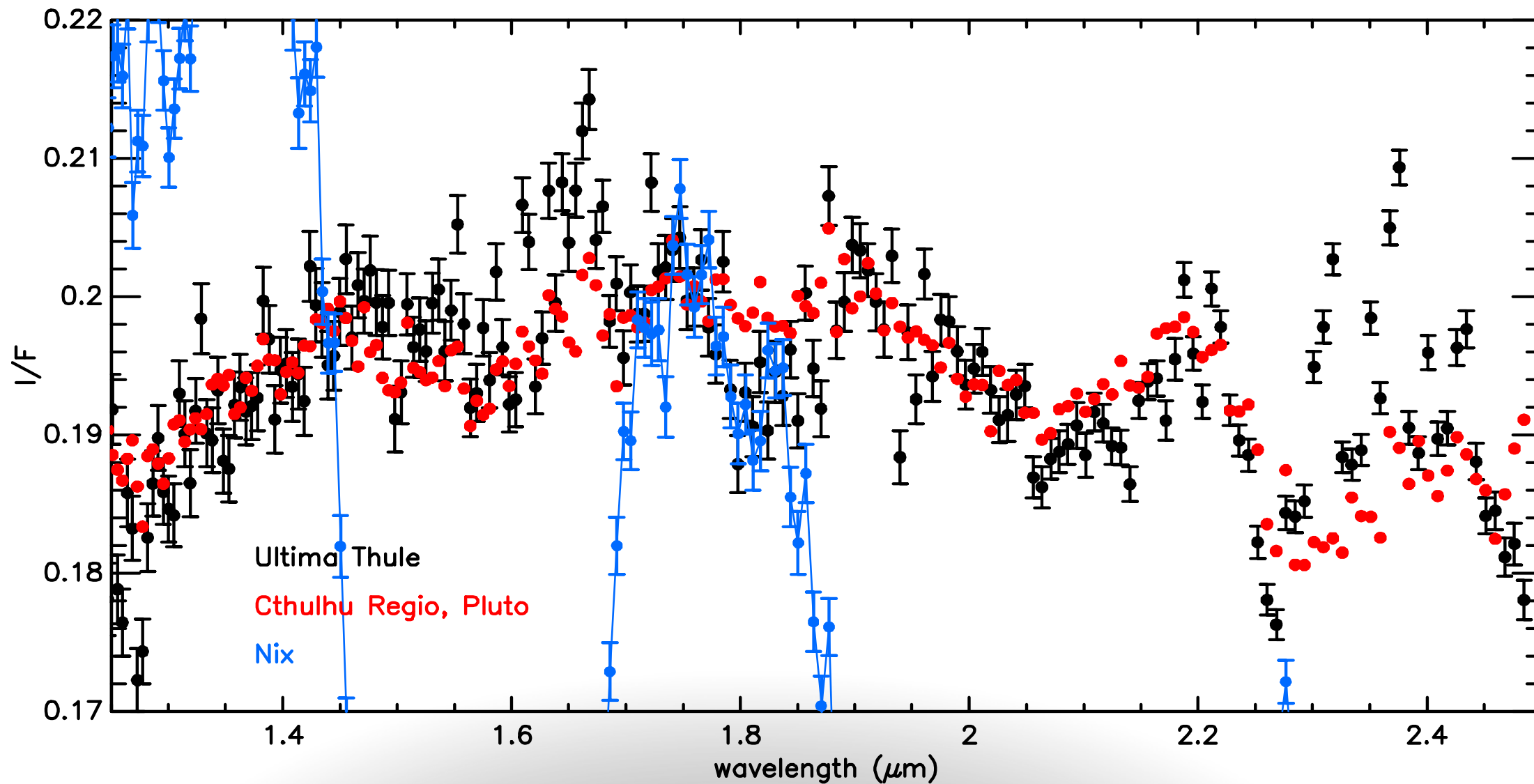


# Composition Results: MVIC + LEISA

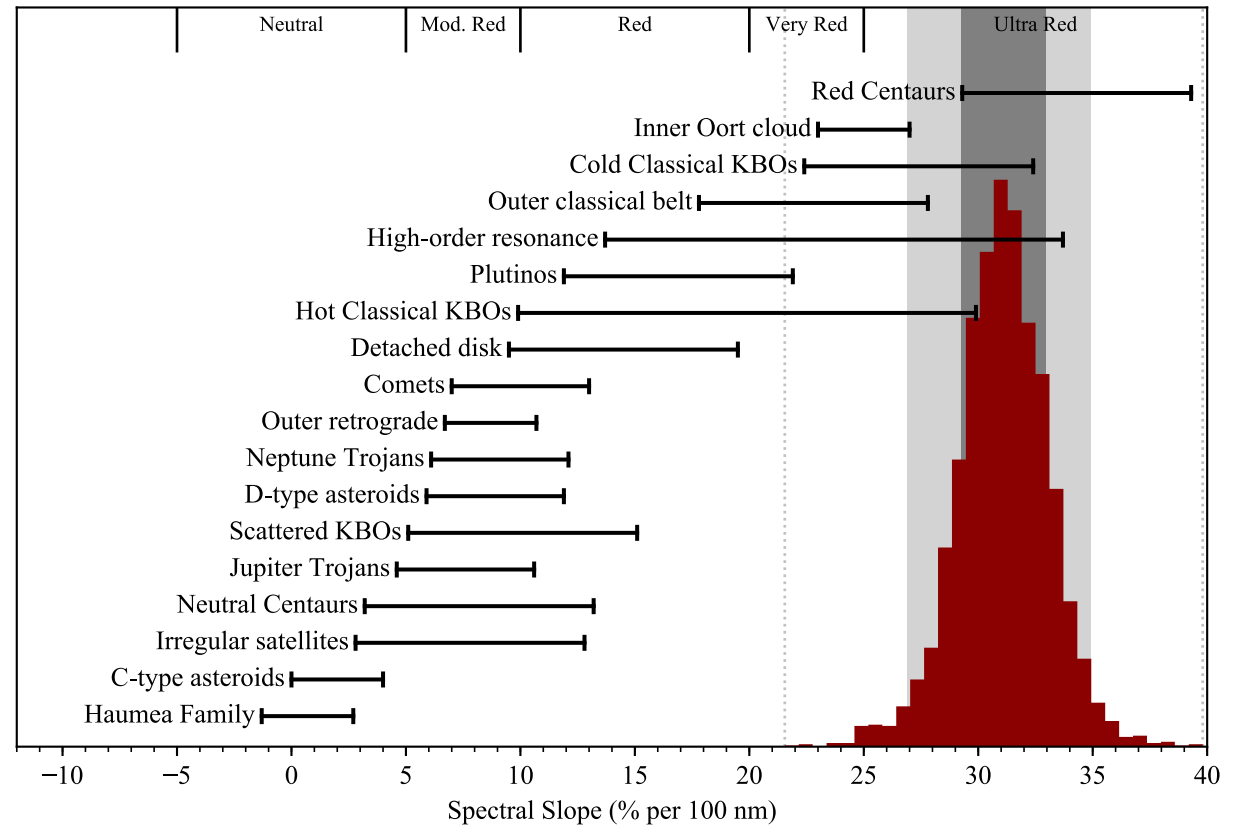
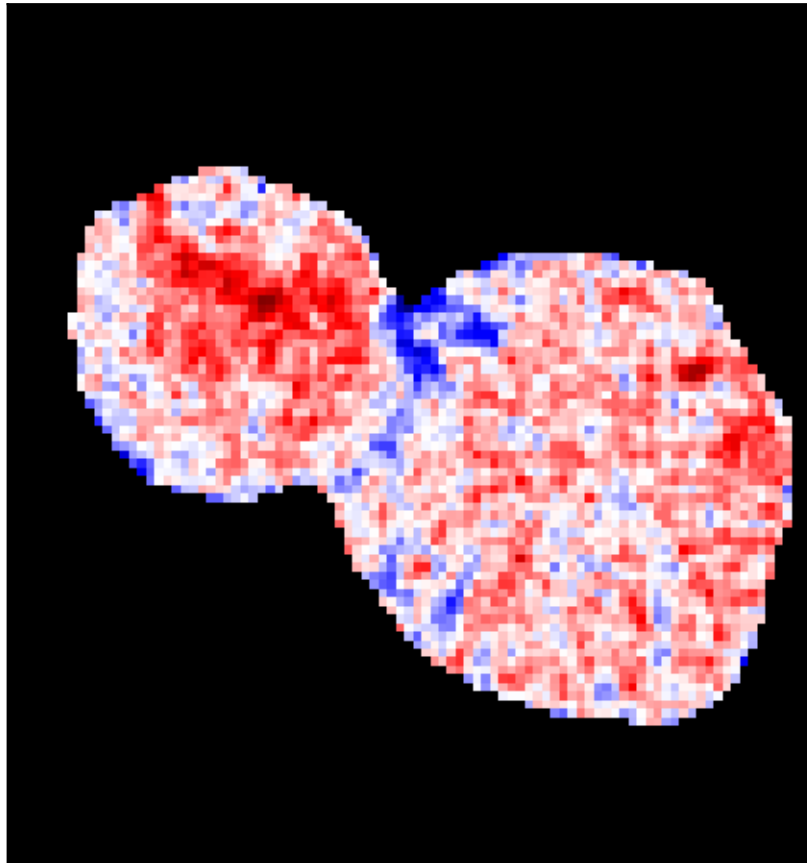
- Red spectrum typical of Cold Classical KBOs
- But UT spectrum looks similar to spectra of the Centaur Pholus and the Plutino VE95
- Possible detection of H<sub>2</sub>O ice?
- Possible detection of CH<sub>3</sub>OH ice?



# IR spectrum of integrated spectrum of 2014 MU69



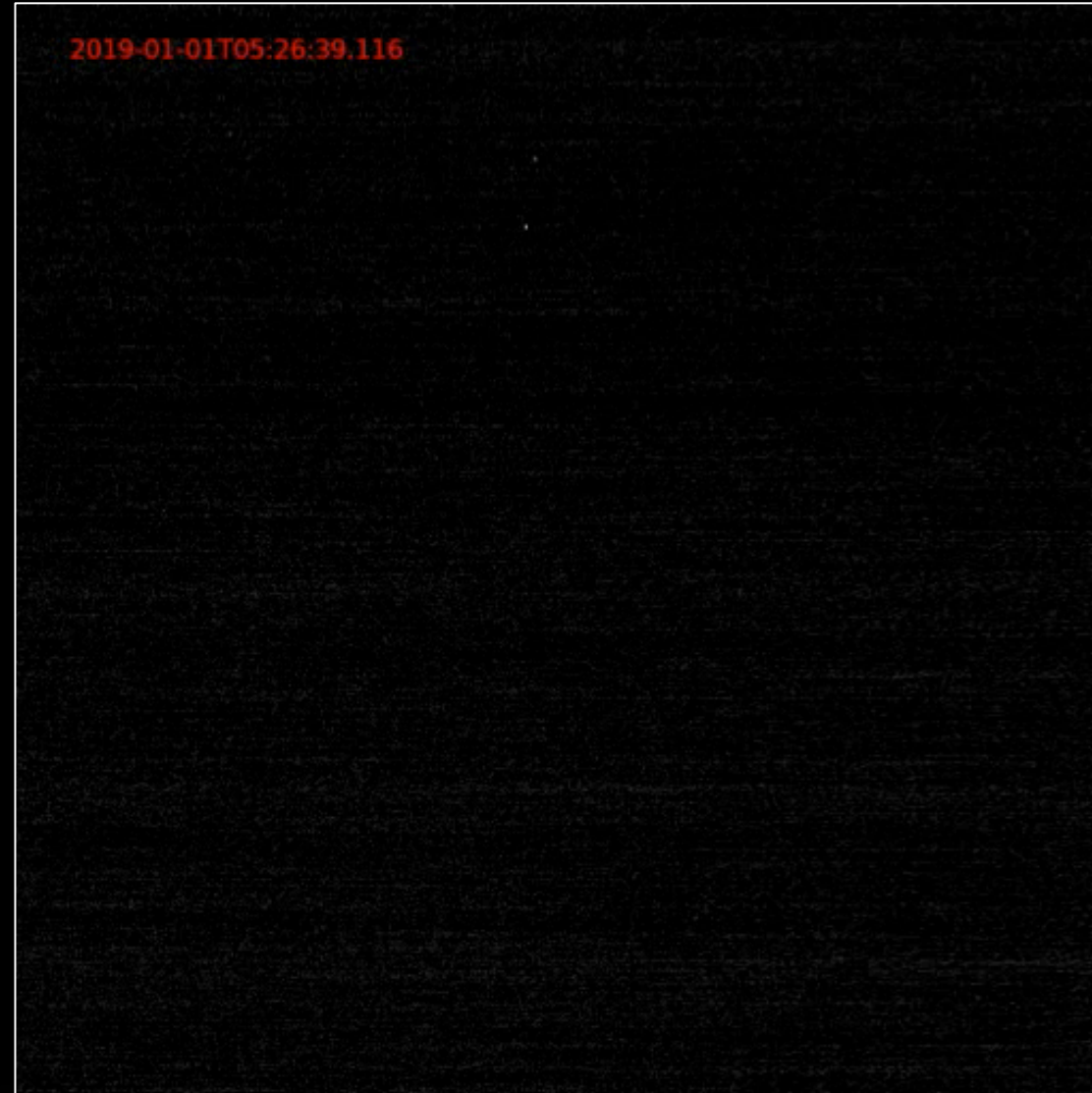
# UT's surface colour variatoinis



# Stereo View of Ultima Thule



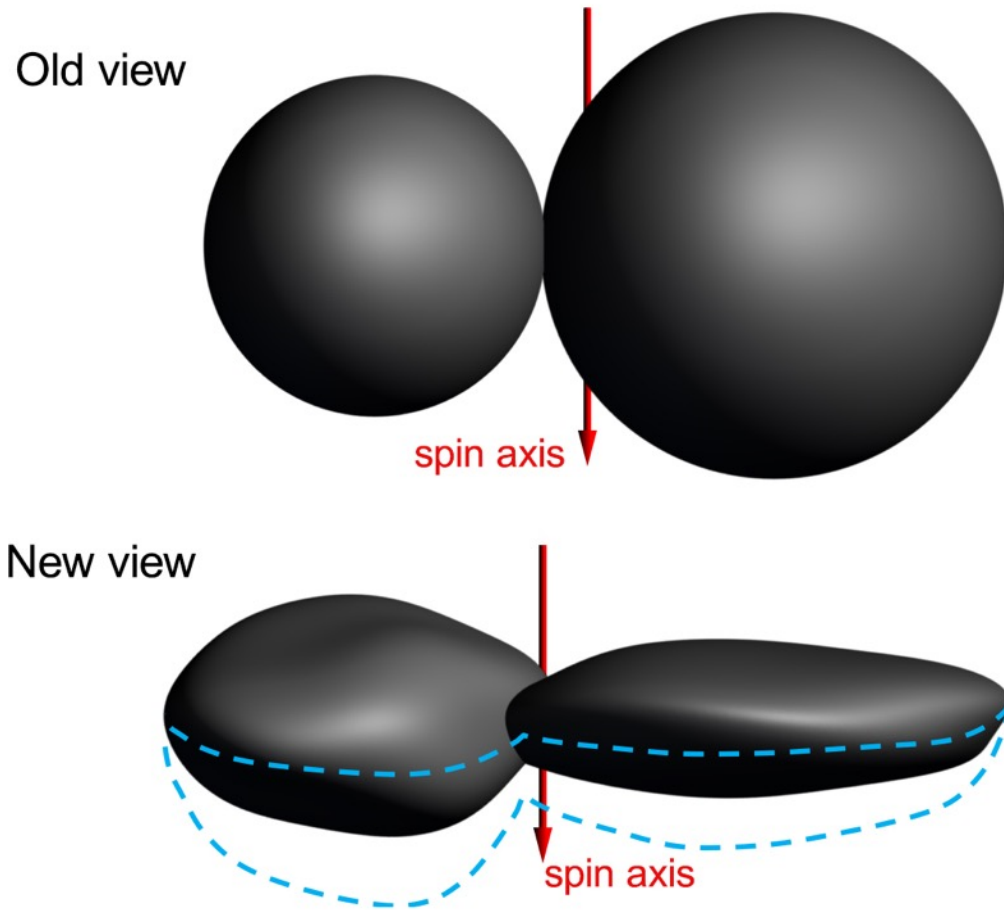
# UT Streaking Across the LORRI FOV



# UT Streaking Across the LORRI FOV



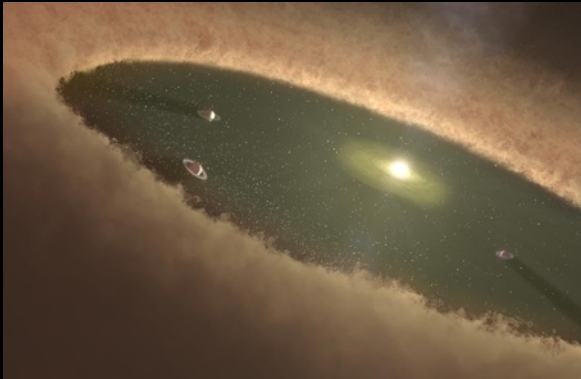
# Ultima Thule's True Shape



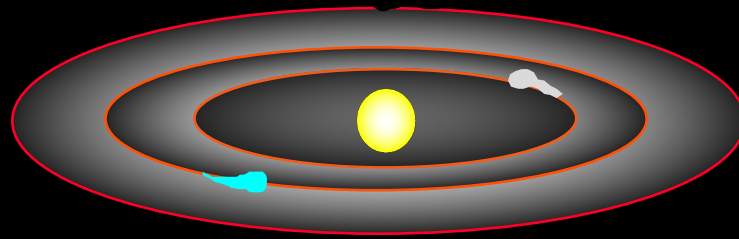


# Building Planetary Systems

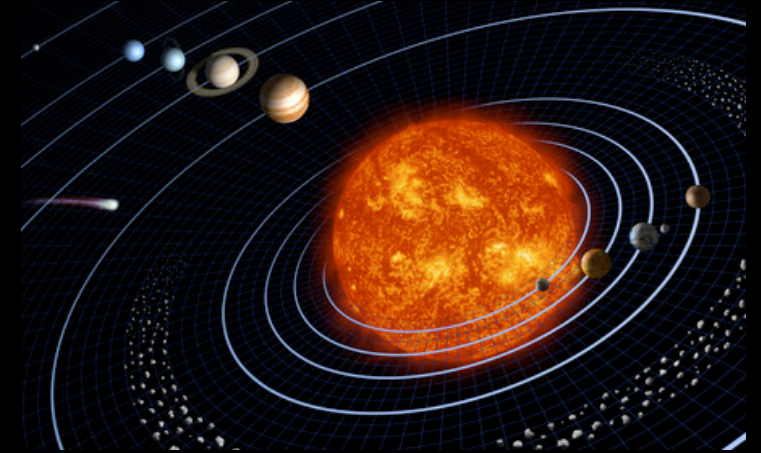
Primordial Disk:  
Dust + Gas → Comets,  
Gas Giants



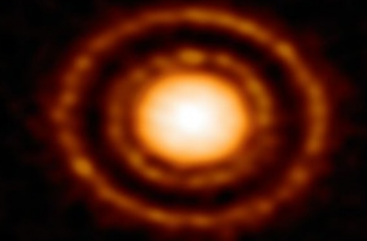
Terrestrial Planet Disk  
Forming Asteroids, Earths



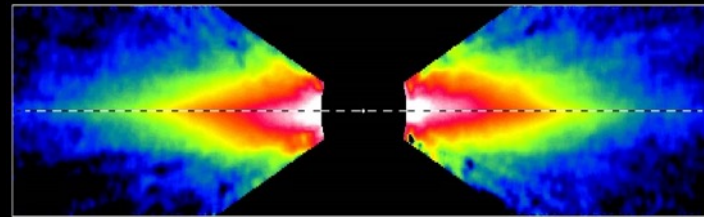
Mature Solar Systems:  
Planets, KBOs, Asteroids,  
Comets



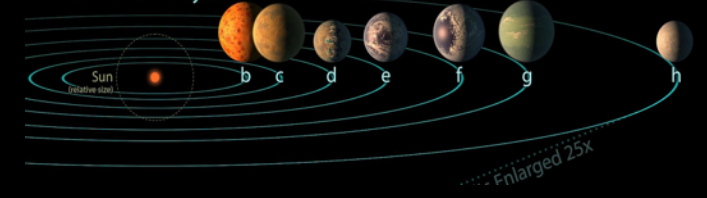
Size of Pluto's Orbit



AS 209 in Ophiuchus

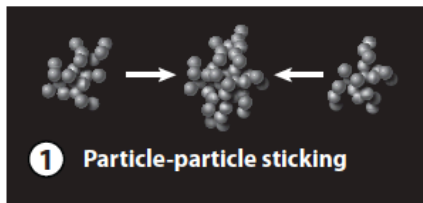
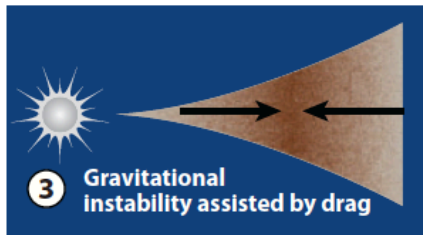
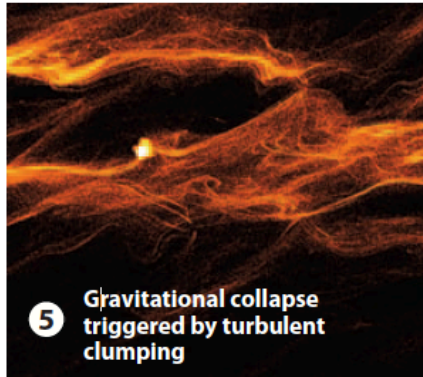


Beta Pic

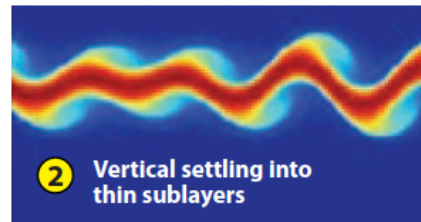
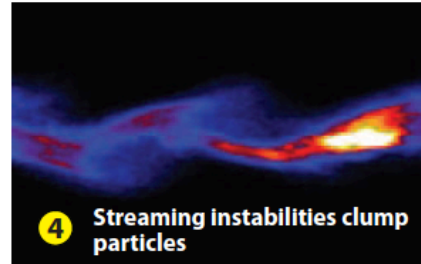
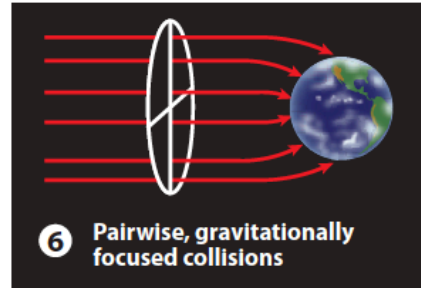
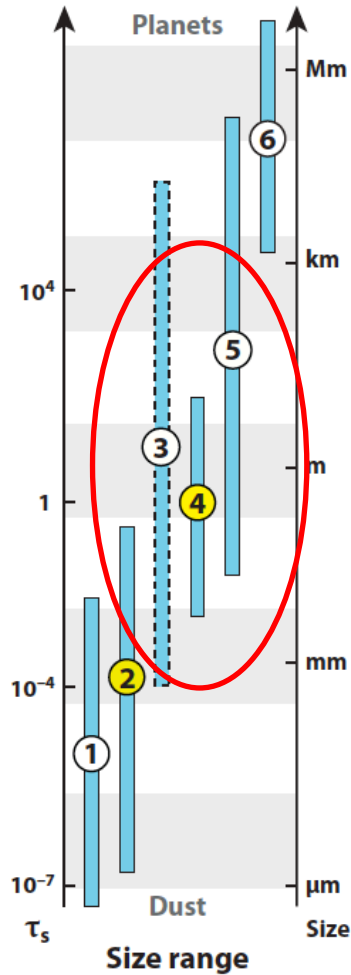


TRAPPIST-1 System

# Building Planetesimals & Planets

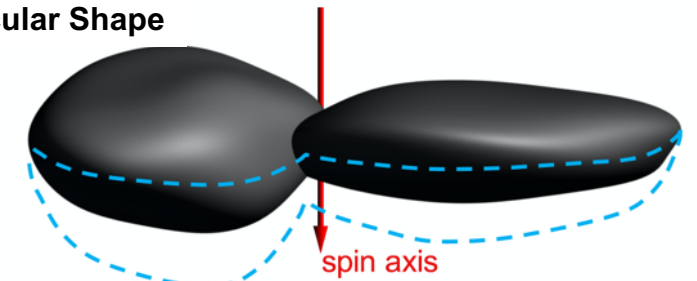


○ Growth    ● Concentration



## Explain This

Lenticular Shape



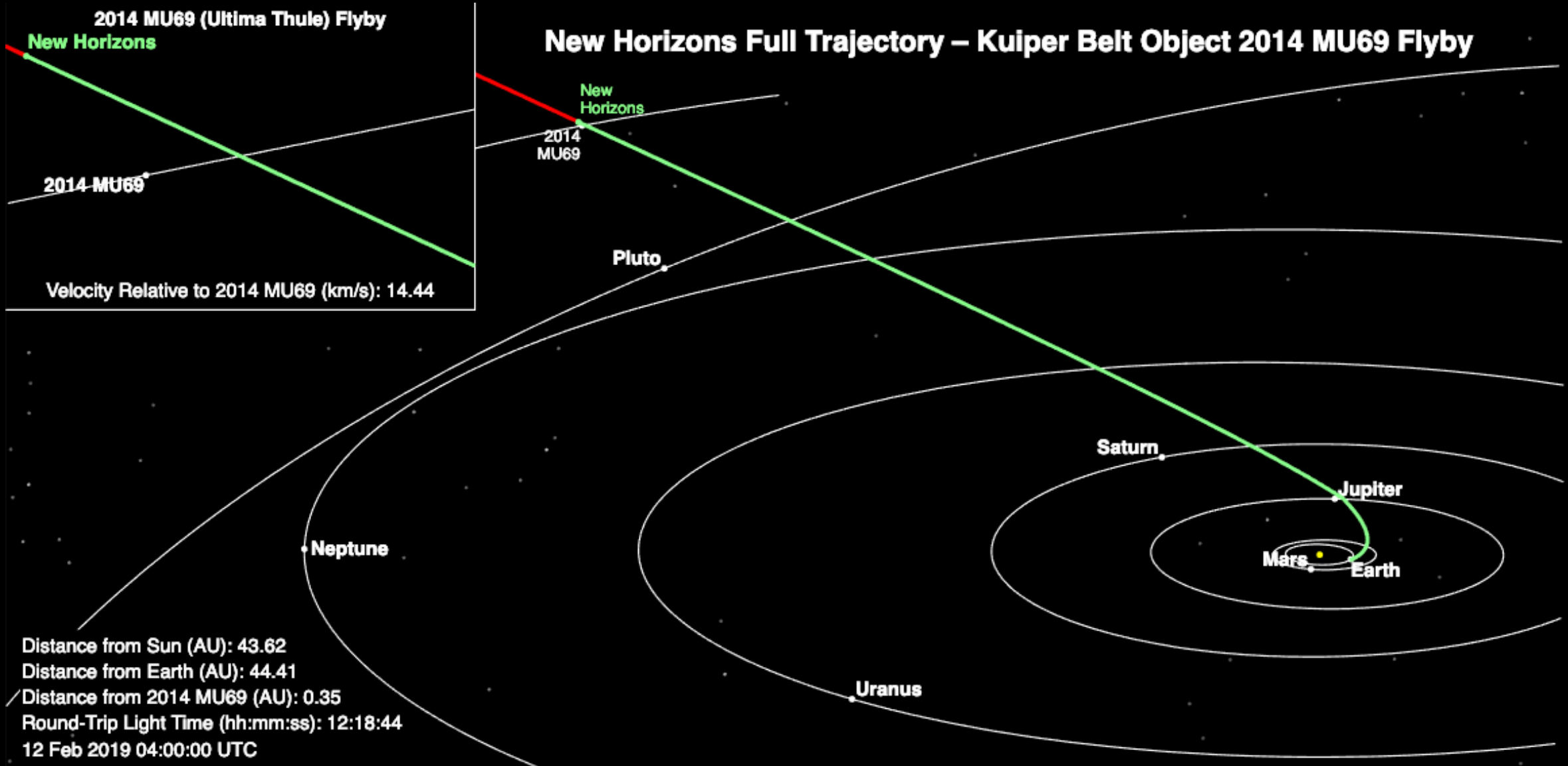
Chiang & Youdin 2010



*Think of New Horizons as a time machine that has transported us to the beginning of the solar system, to a place where we can observe the primordial building blocks of the planets.*

# New Horizons is 32.5 million miles past Ultima

## New Horizons Full Trajectory – Kuiper Belt Object 2014 MU69 Flyby



# The Extended Mission Continues

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Can we find another KBO flyby target?

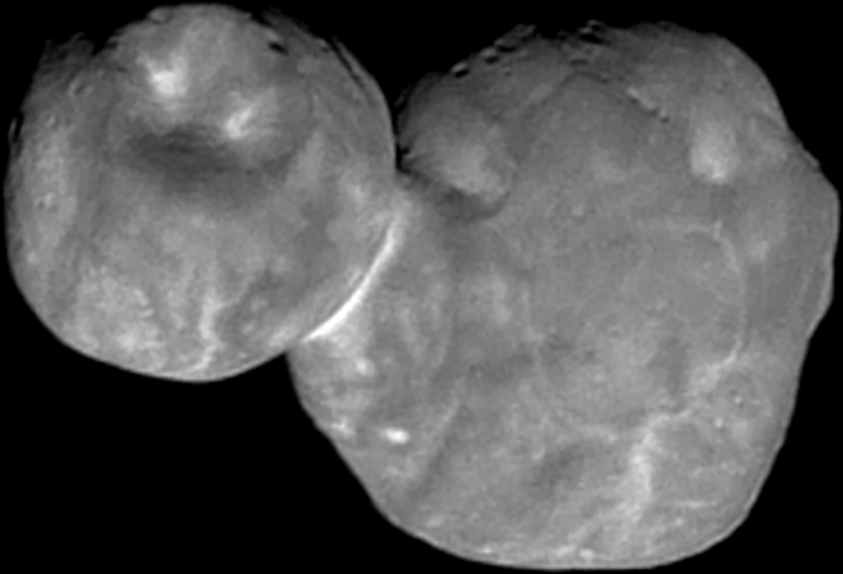
Estimated Power Runout – Mid 2030s

And approaching 100 AU from the Sun

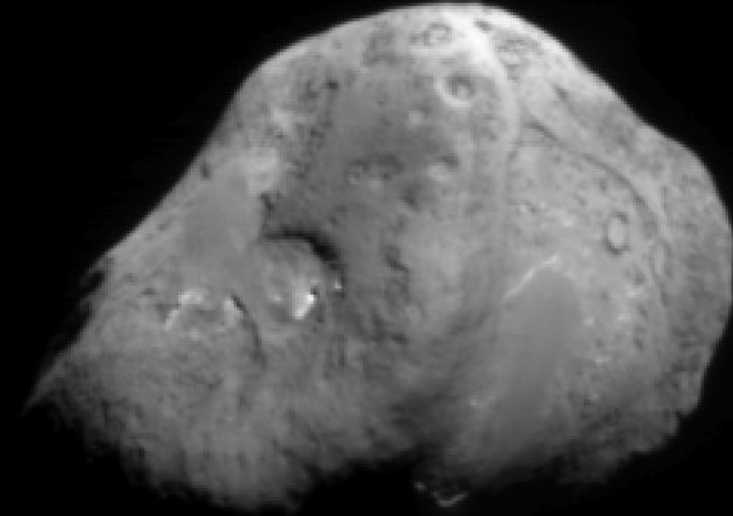
**Thank You!**

# BACKUP

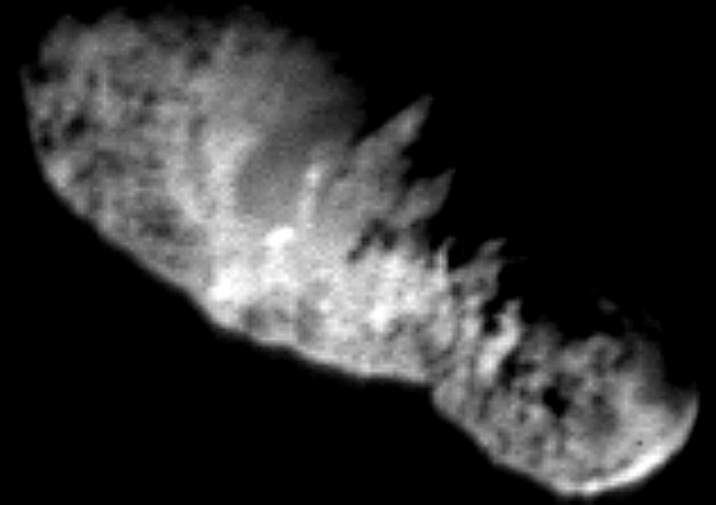
**(486958) 2014 MU69 (*Ultima Thule*)**  
33 x 17 km



**9P/Tempel : 7.6 x 4.9 km**



**19P/Borrelly : 8 x 4 km**



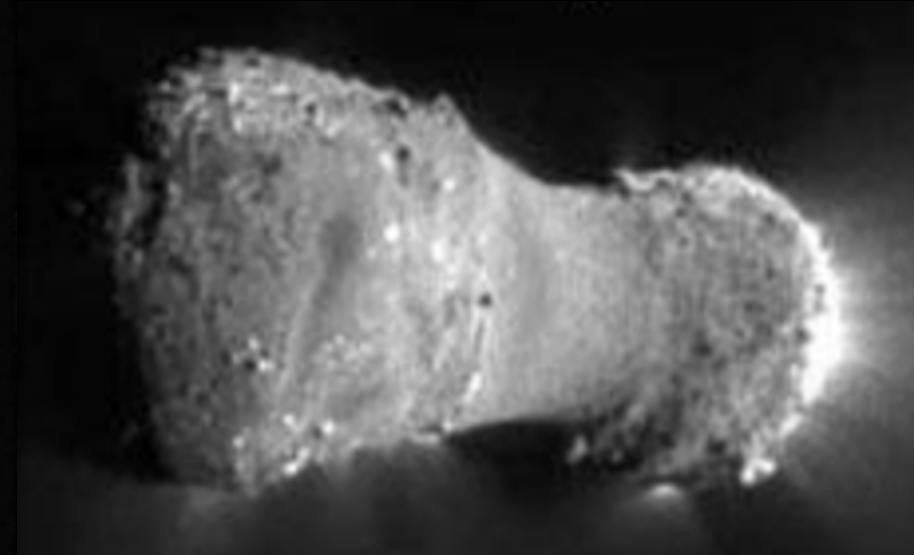
**67P/CG : 4.1 x 3.2 x 2.5 km**



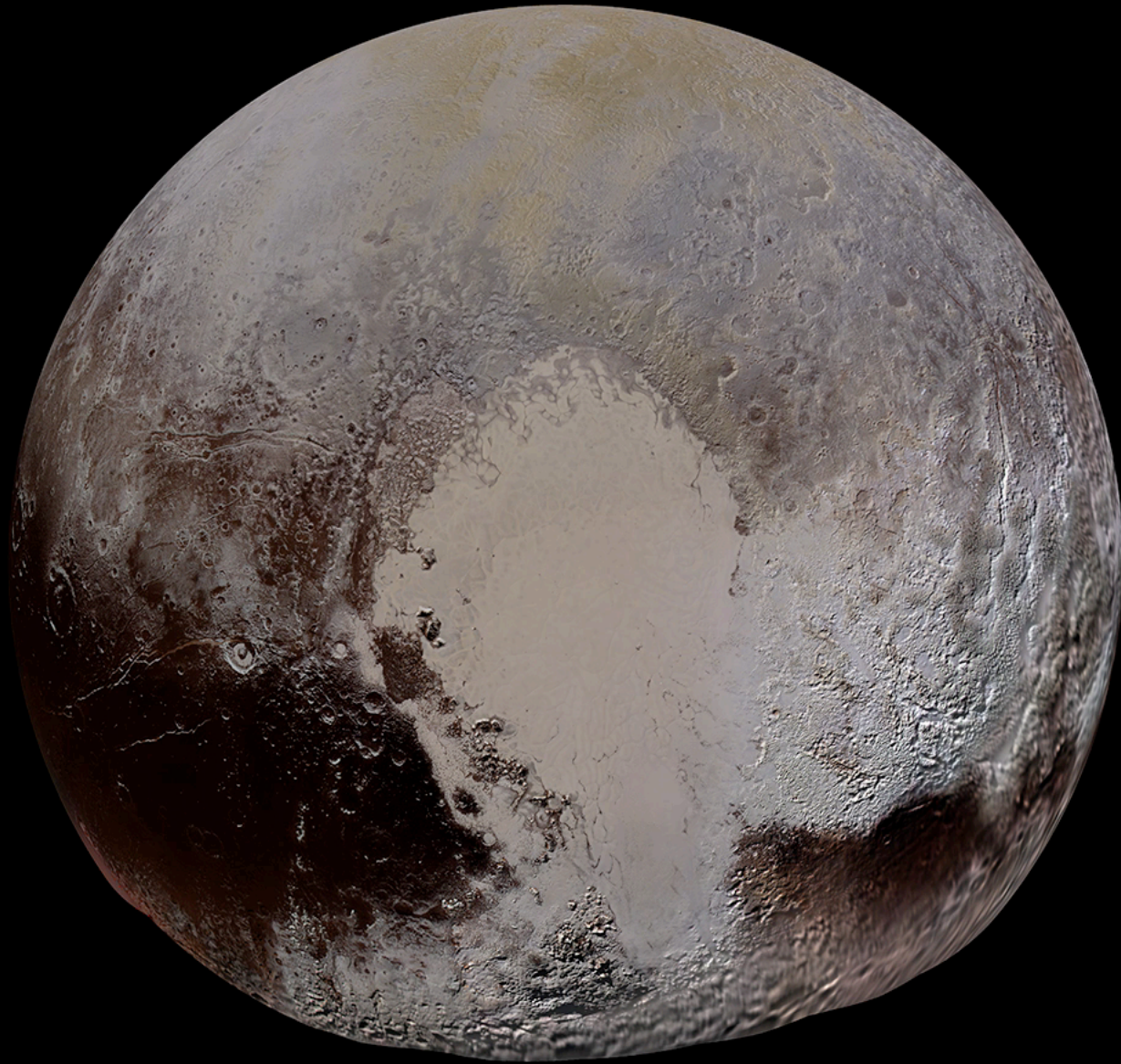
**81P/Wild : 5.5 x 4.0 x 3.3 km**

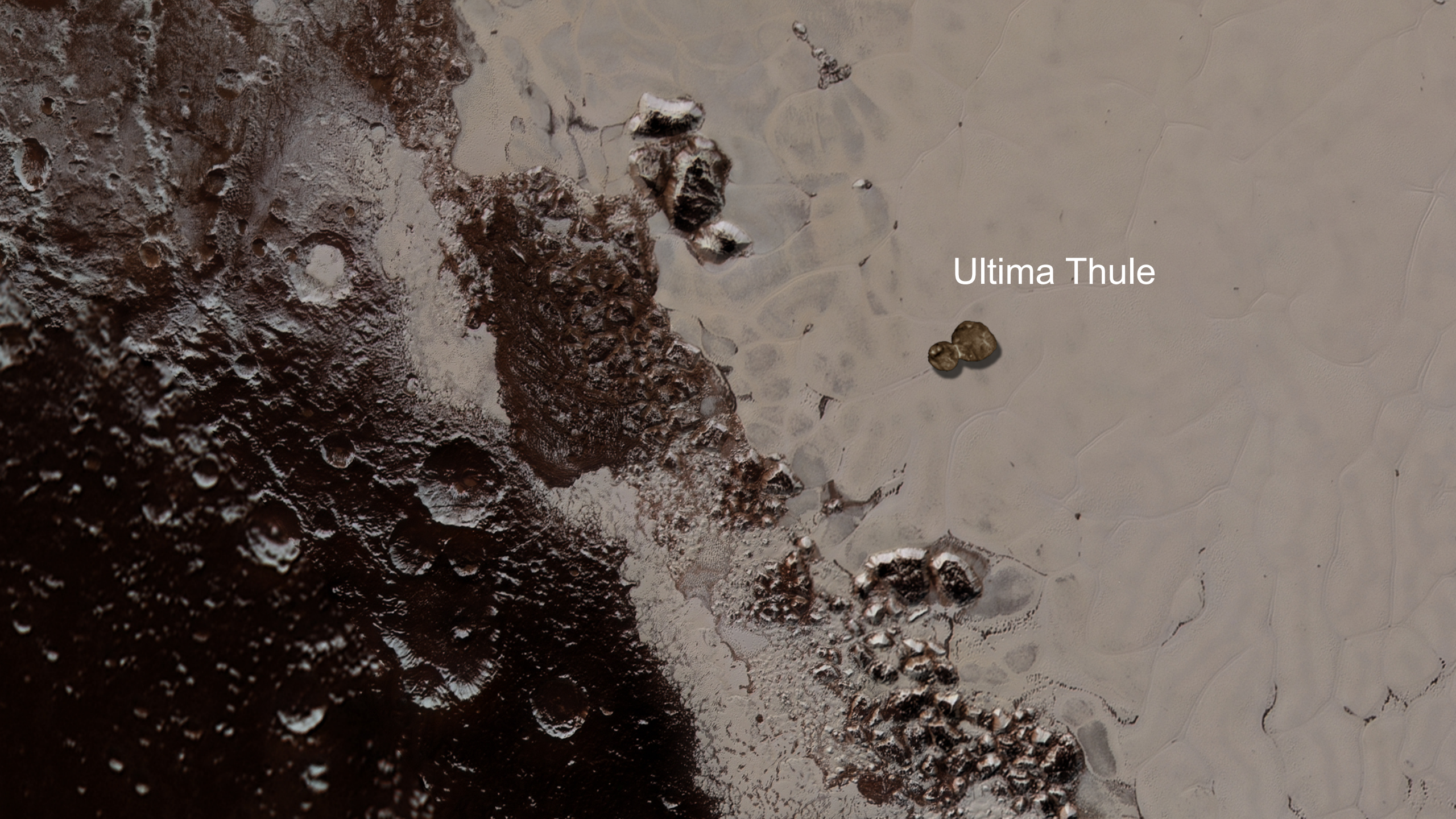


**103P/Hartley : 2.2 x 0.5 km**









Ultima Thule

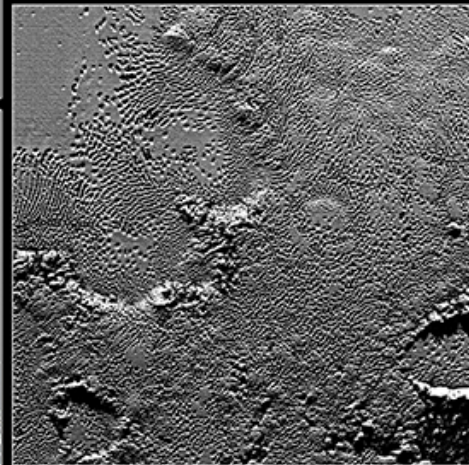
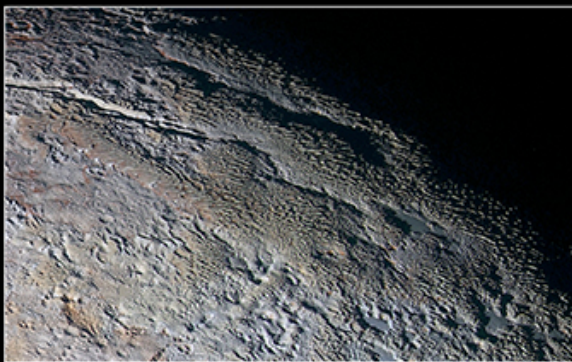
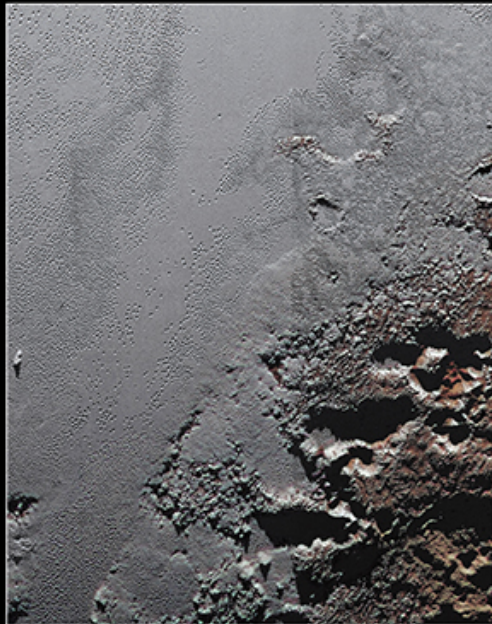
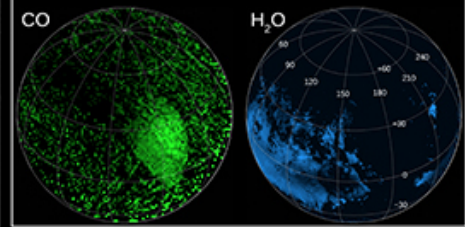
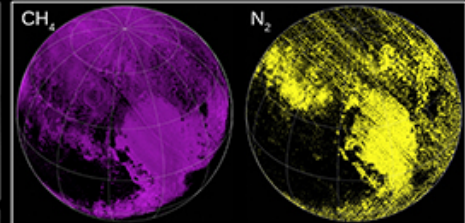
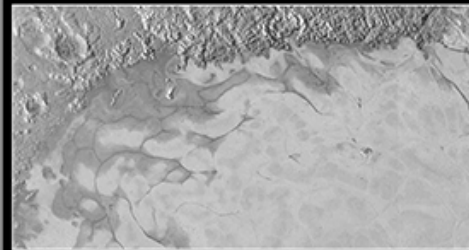
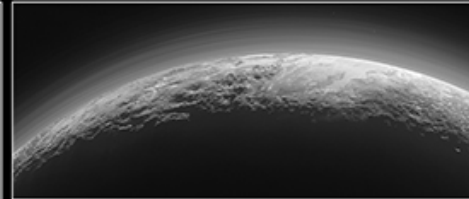
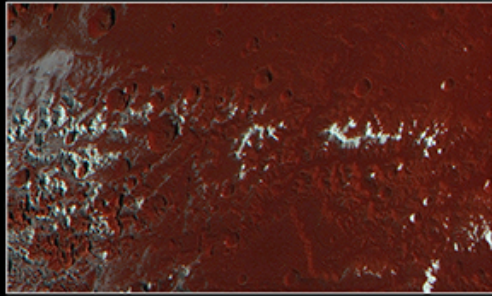
**2015:  
First Mission  
to Explore the  
Pluto System**



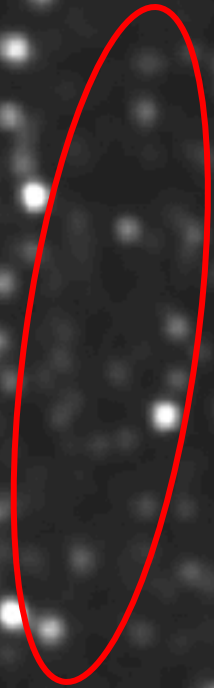
# Highlights of the Pluto Flyby



## Year of Pluto Top Ten Images

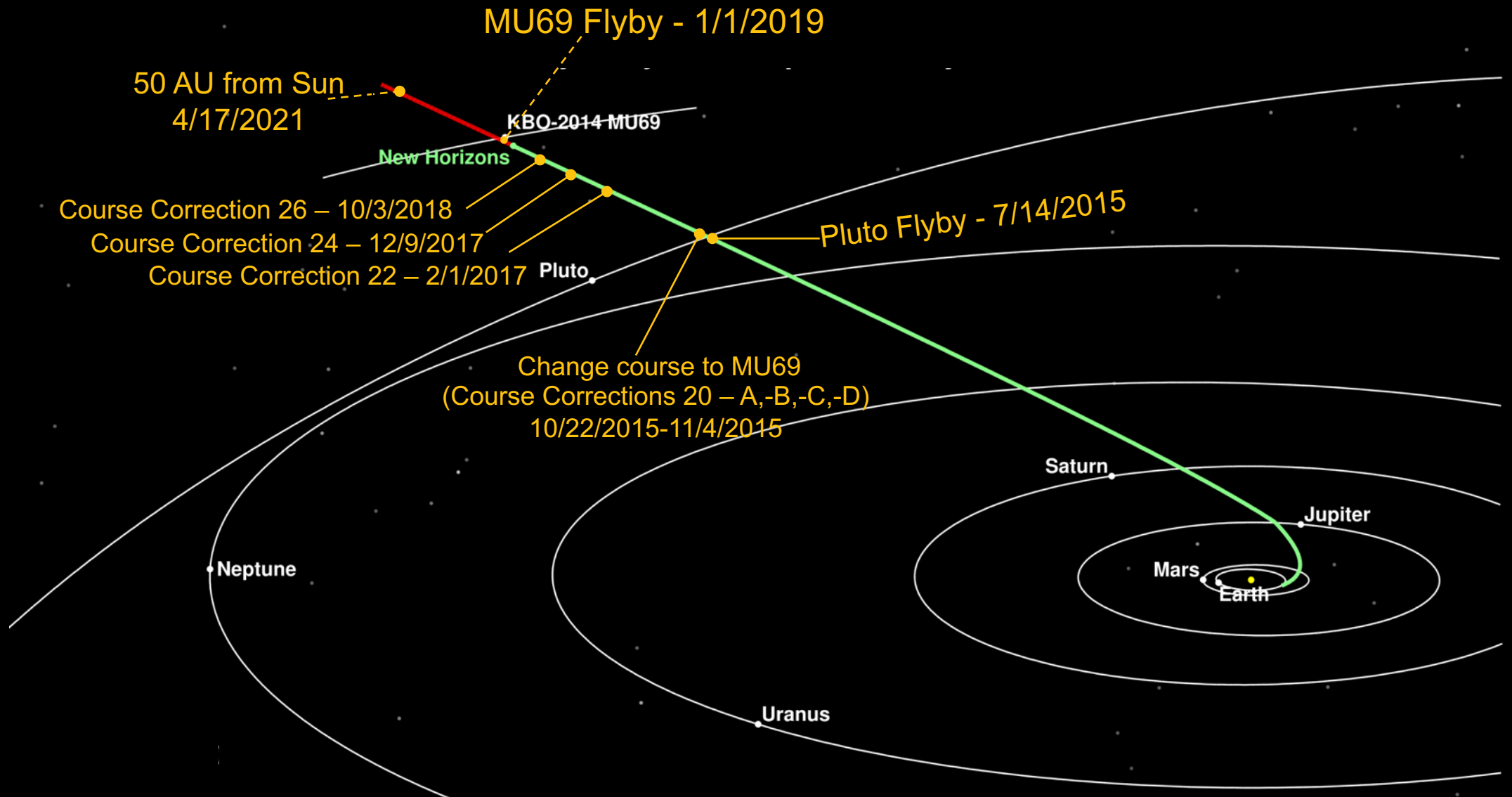


# Tracking Ultima Thule

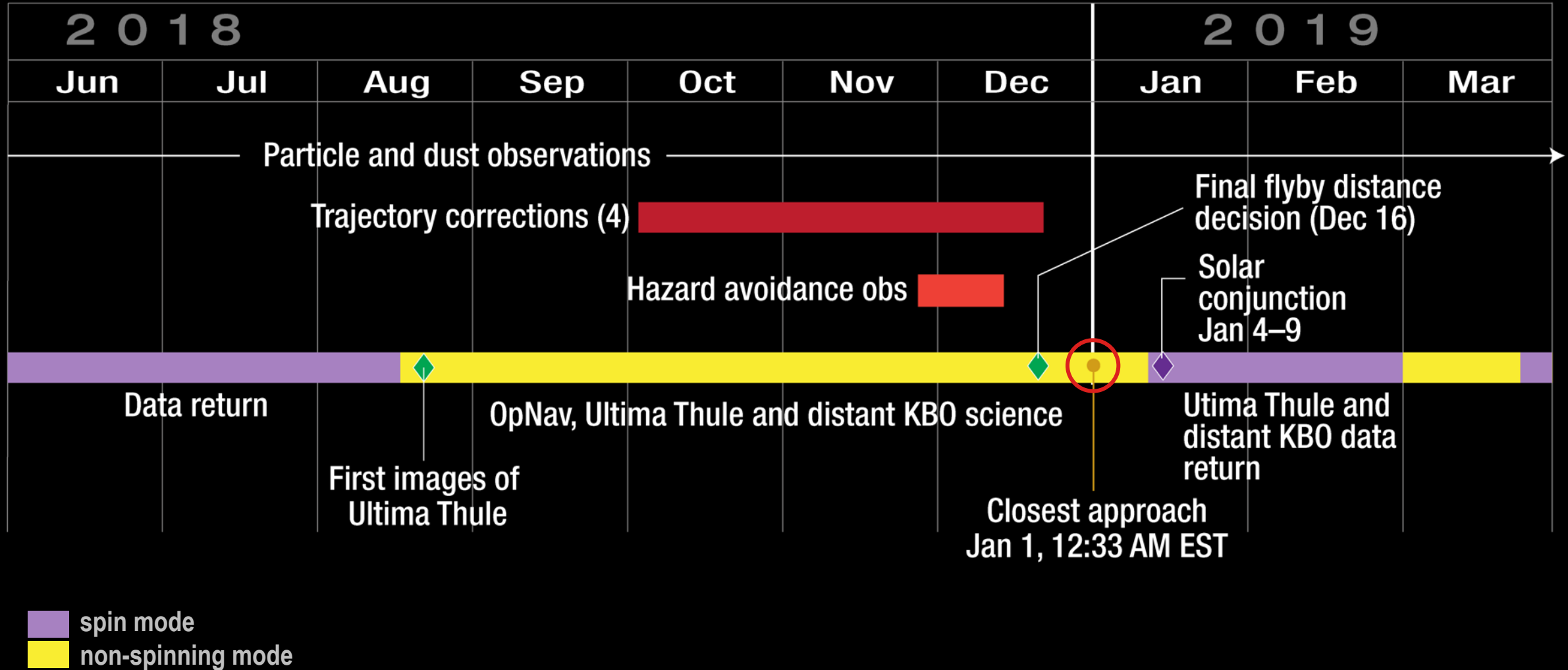


2018-12-06 10:31

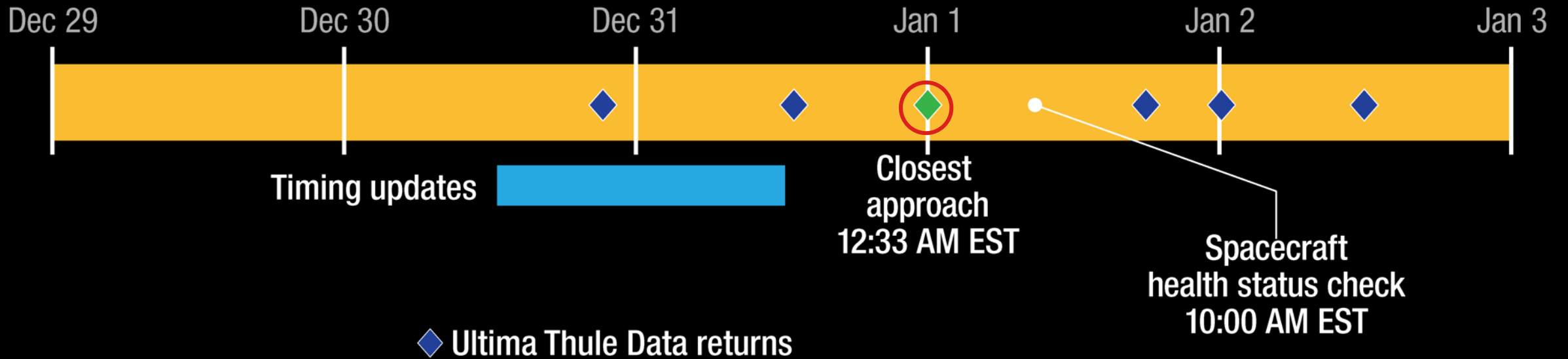
# New Horizons Trajectory



# Approaching Ultima Thule



# Flying By Ultima Thule



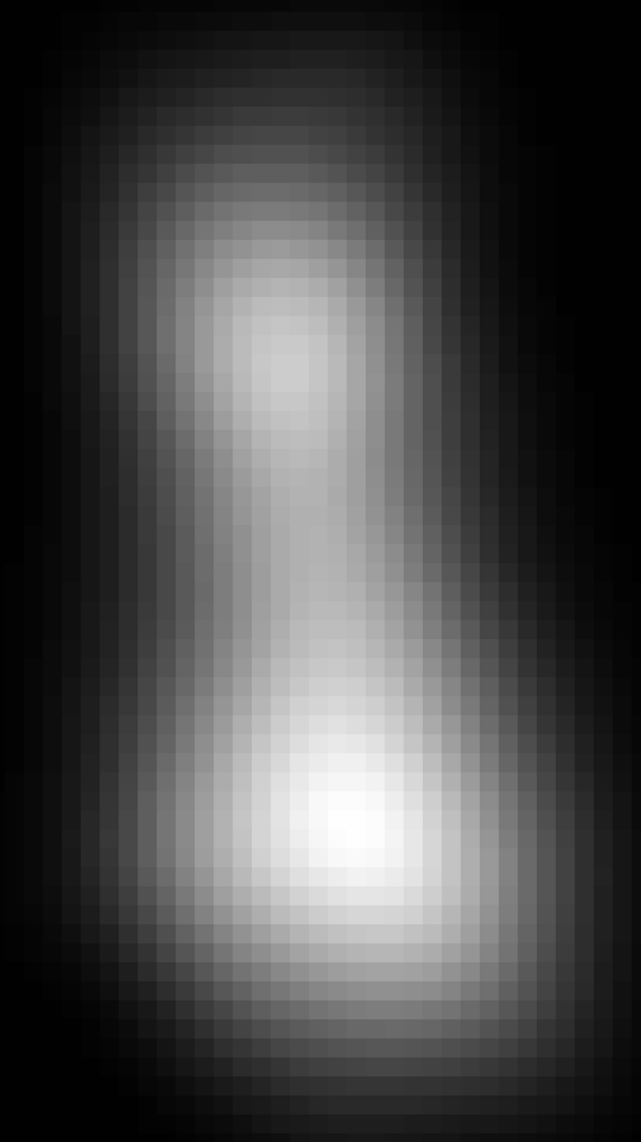


# **Ultima Thule Flyby Success**

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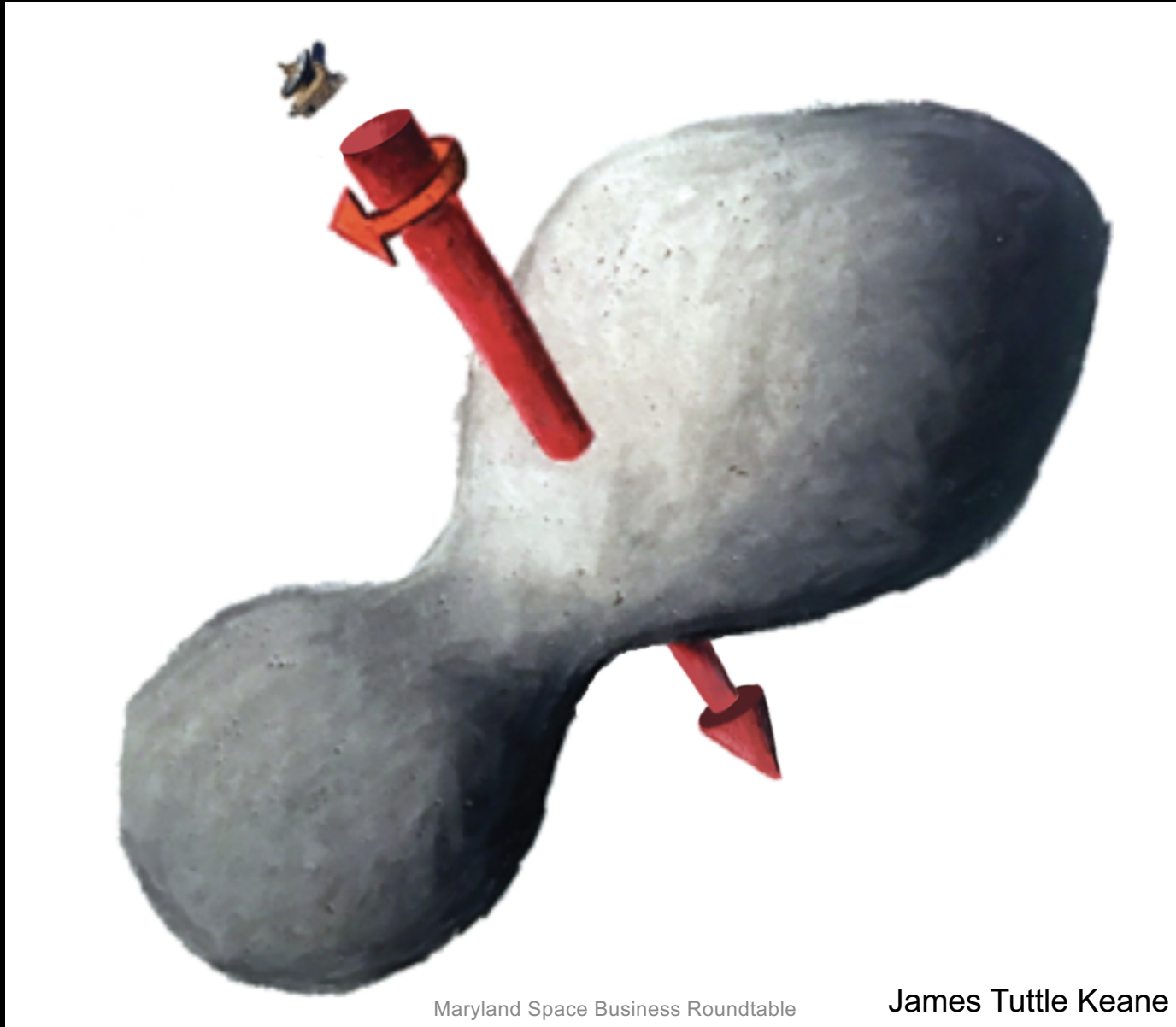
**1 January 2019**

# The Shape of Ultima Thule



**10  
miles**

# Bowling Pin, Spin, and Pole

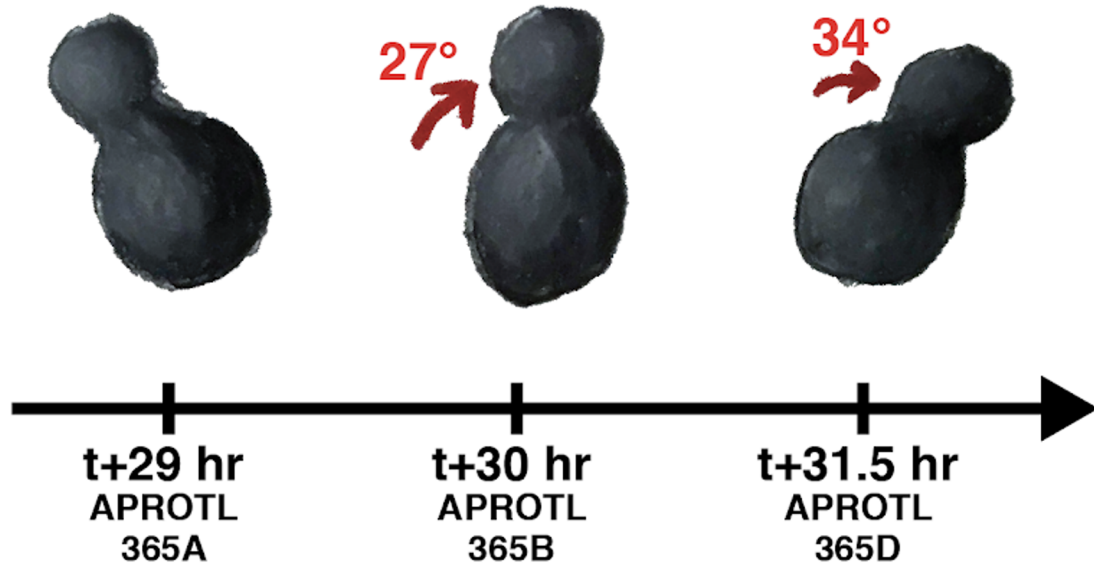


# Rotation of Ultima Thule

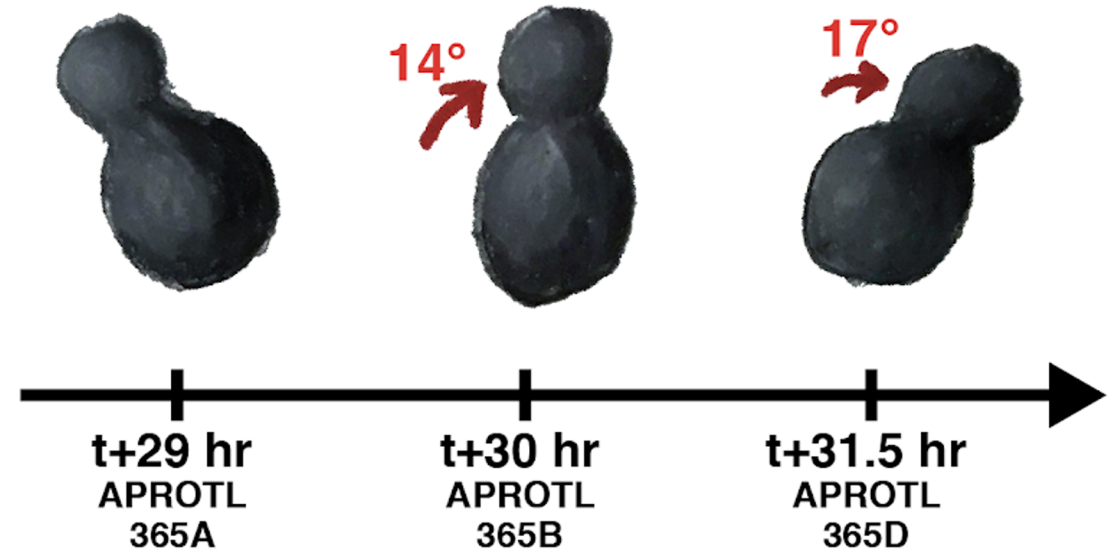


# Two Possible Rotation Periods

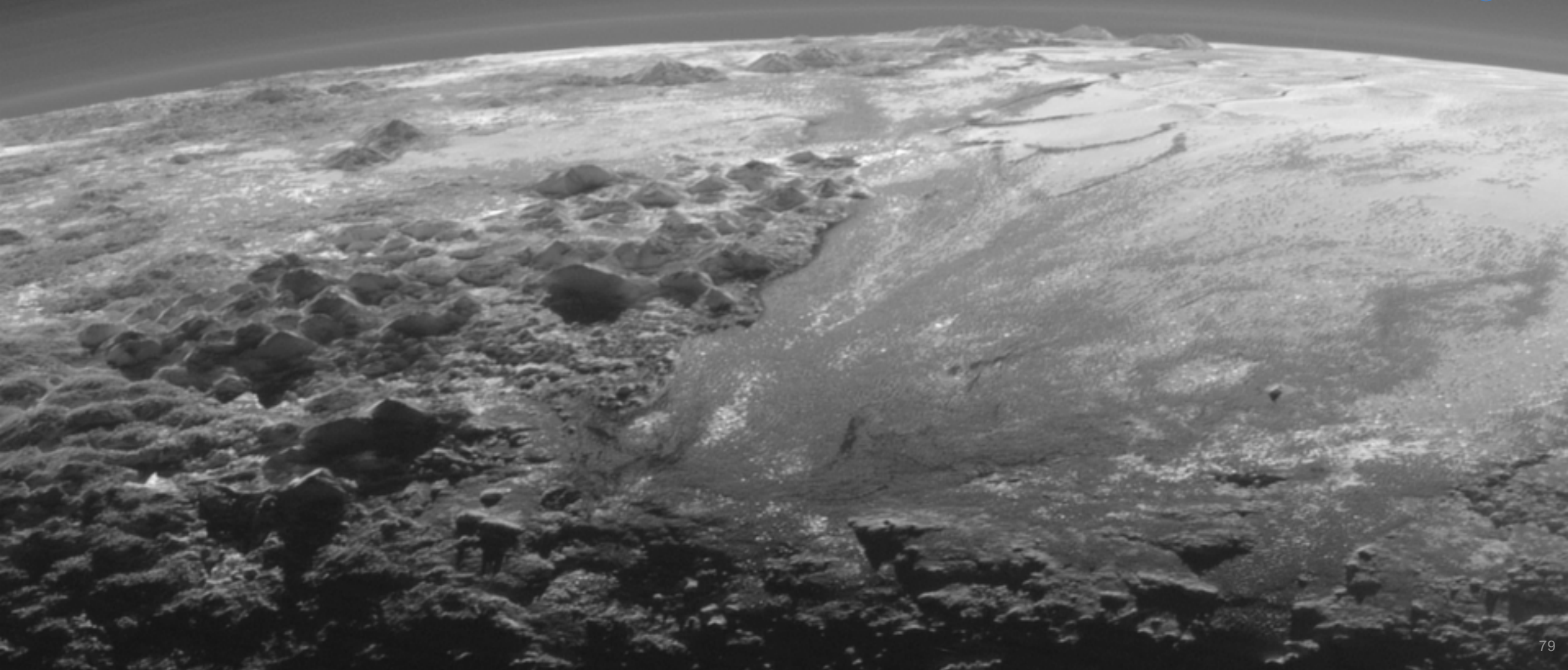
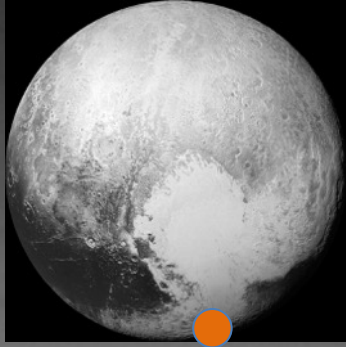
15 hour period:



30 hour period:



# Mountains and Glaciers and Haze, *Oh My!*



# **First Results**

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**2 January 2019**

# A Contact Binary: Unlike Asteroids and Comets

**Thule**

**Ultima**

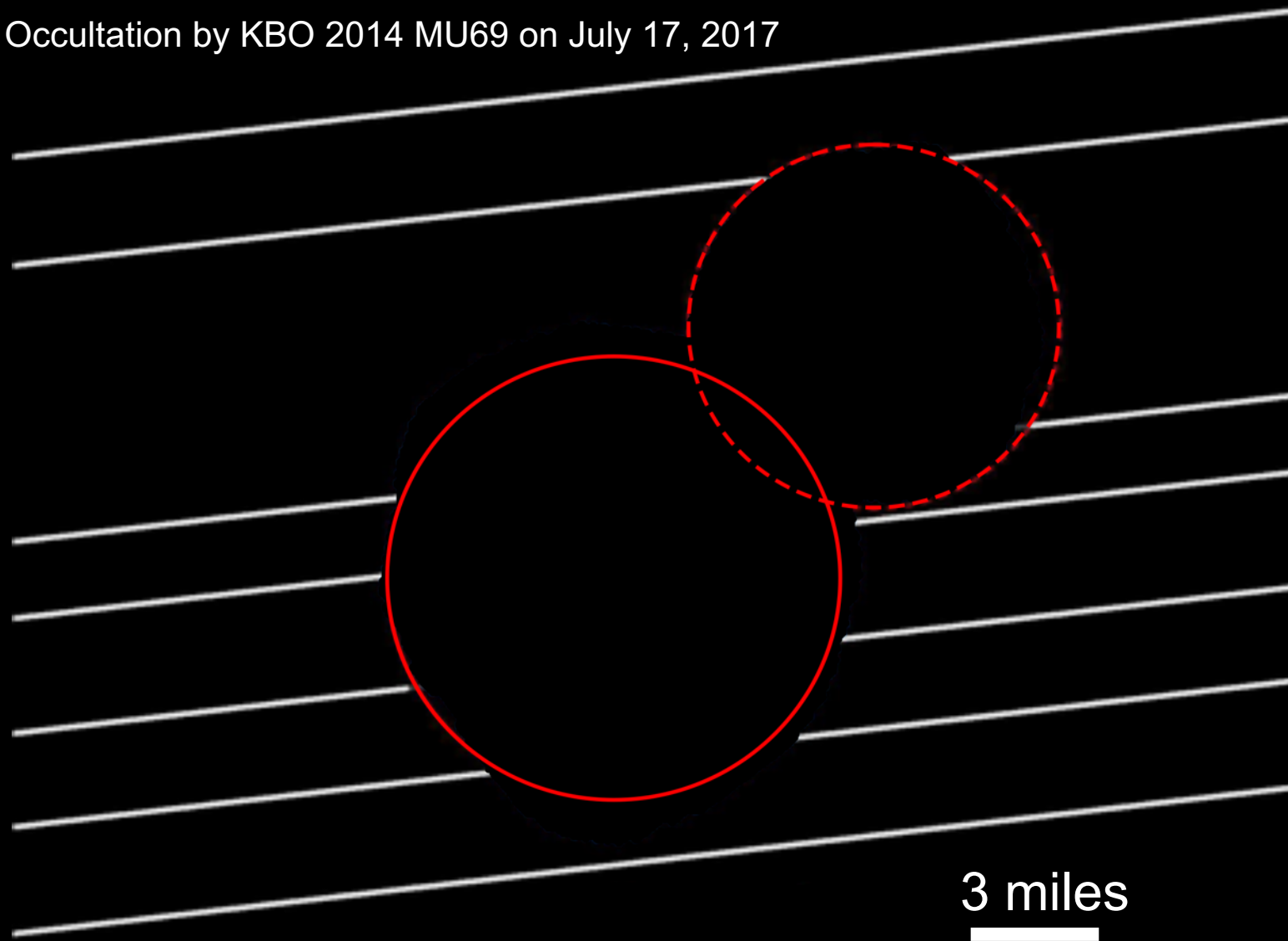


21 miles  
(33 km)



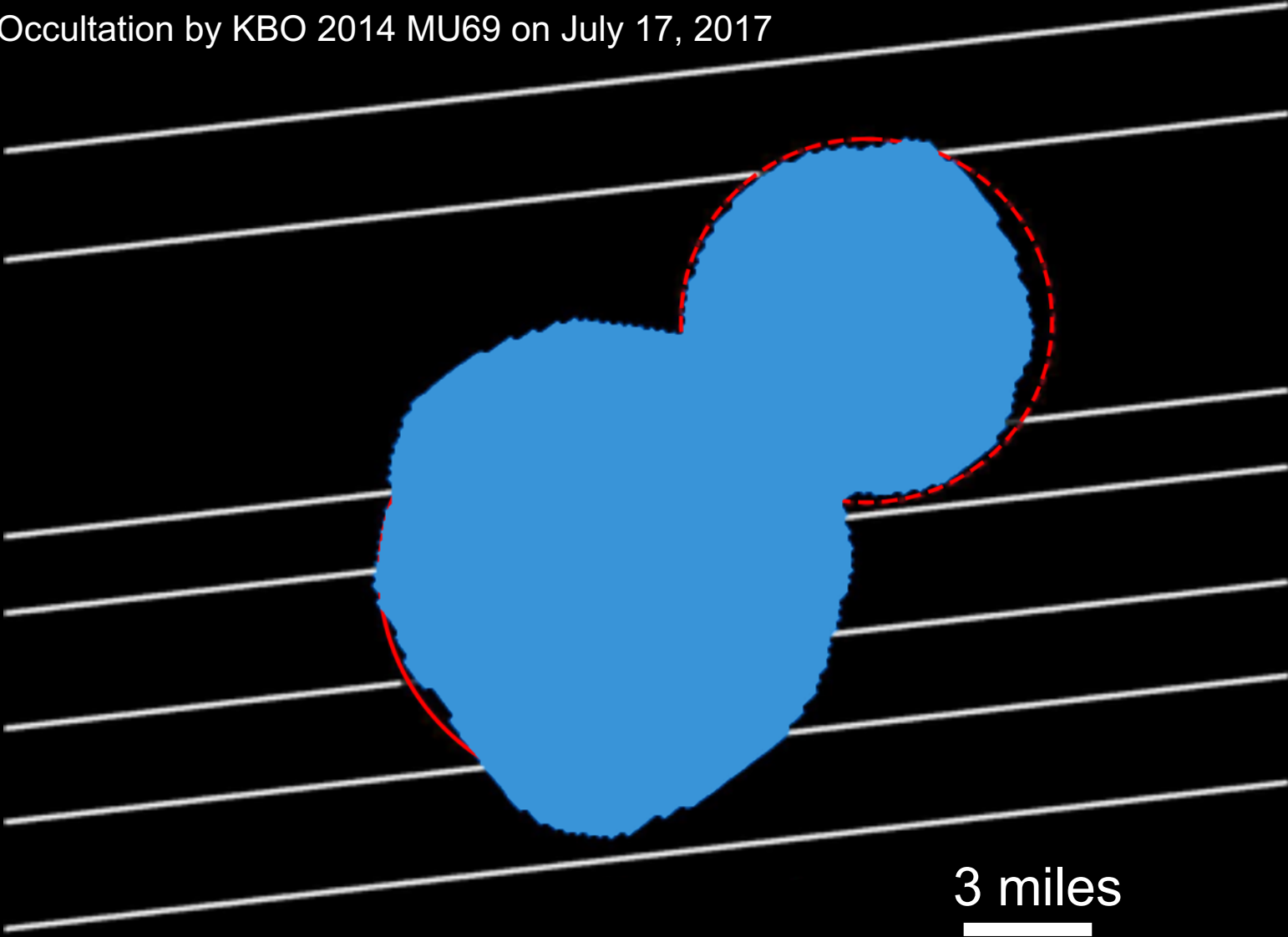
# Occultation Profile and Size Matches

Occultation by KBO 2014 MU69 on July 17, 2017

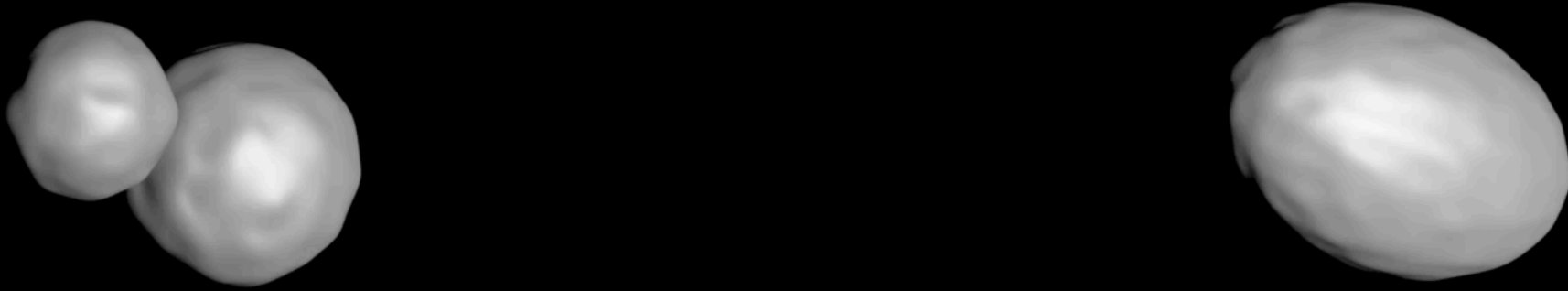


# Occultation Profile and Size Matches

Occultation by KBO 2014 MU69 on July 17, 2017



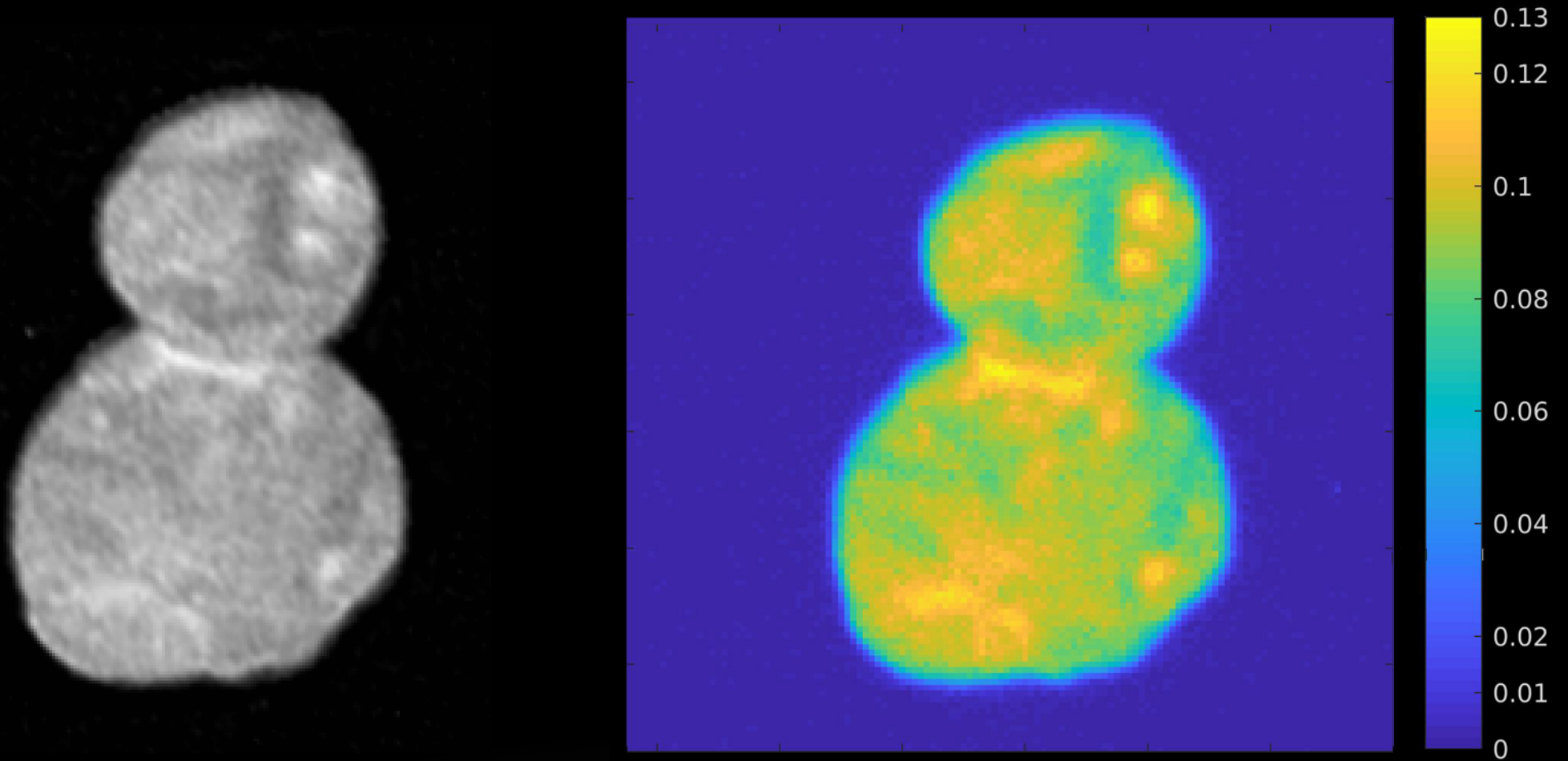
# Rotation Period $15 \pm 1$ hours



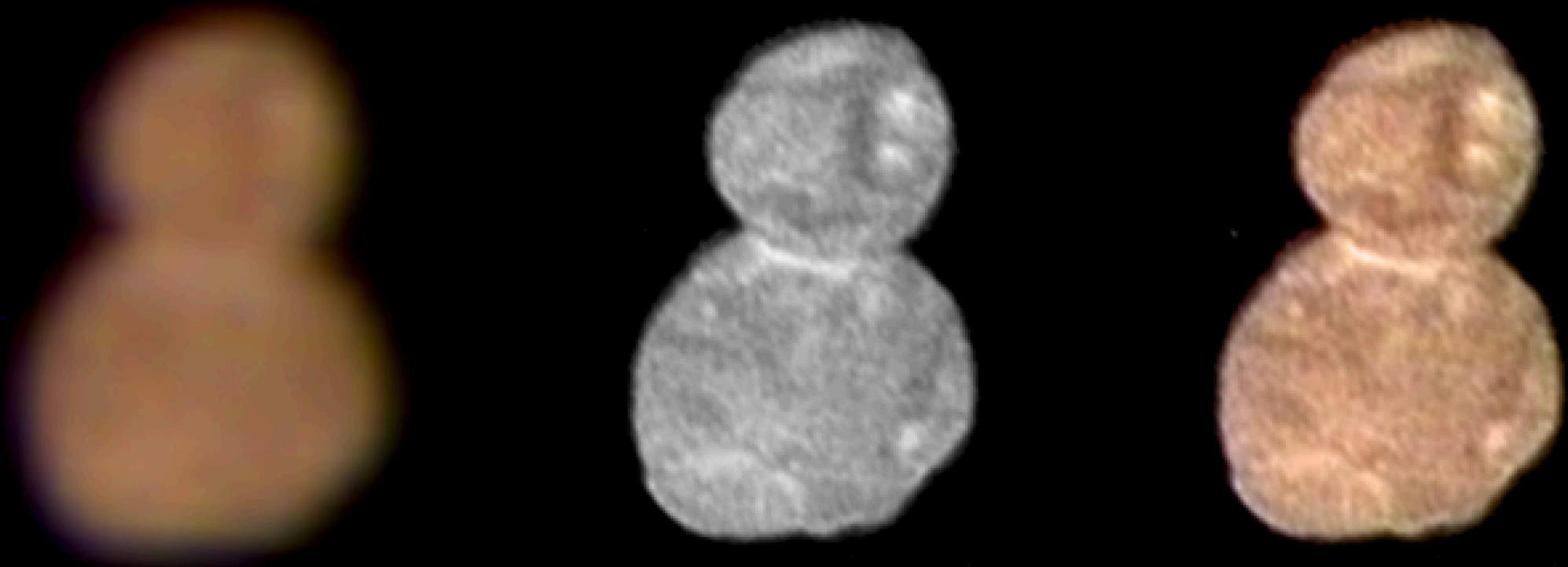
Light Curve

Time

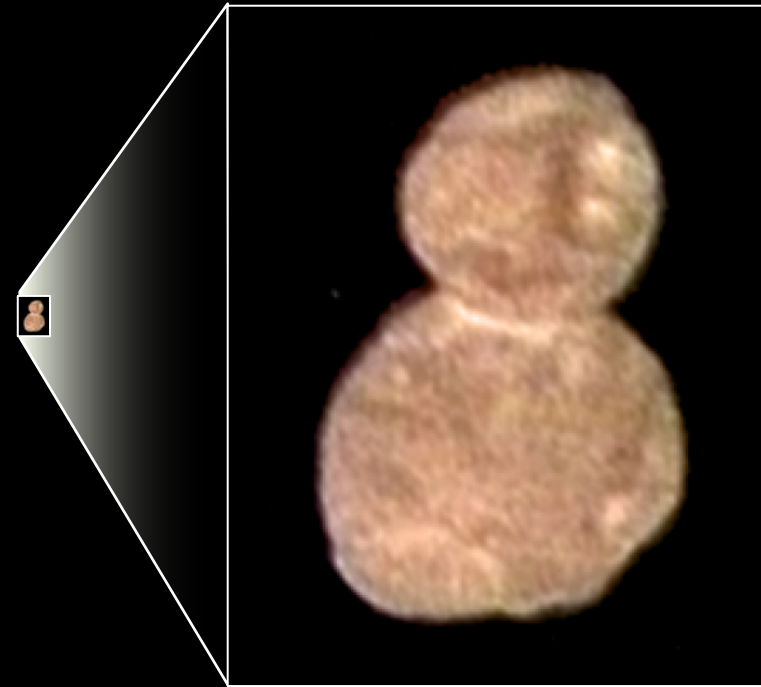
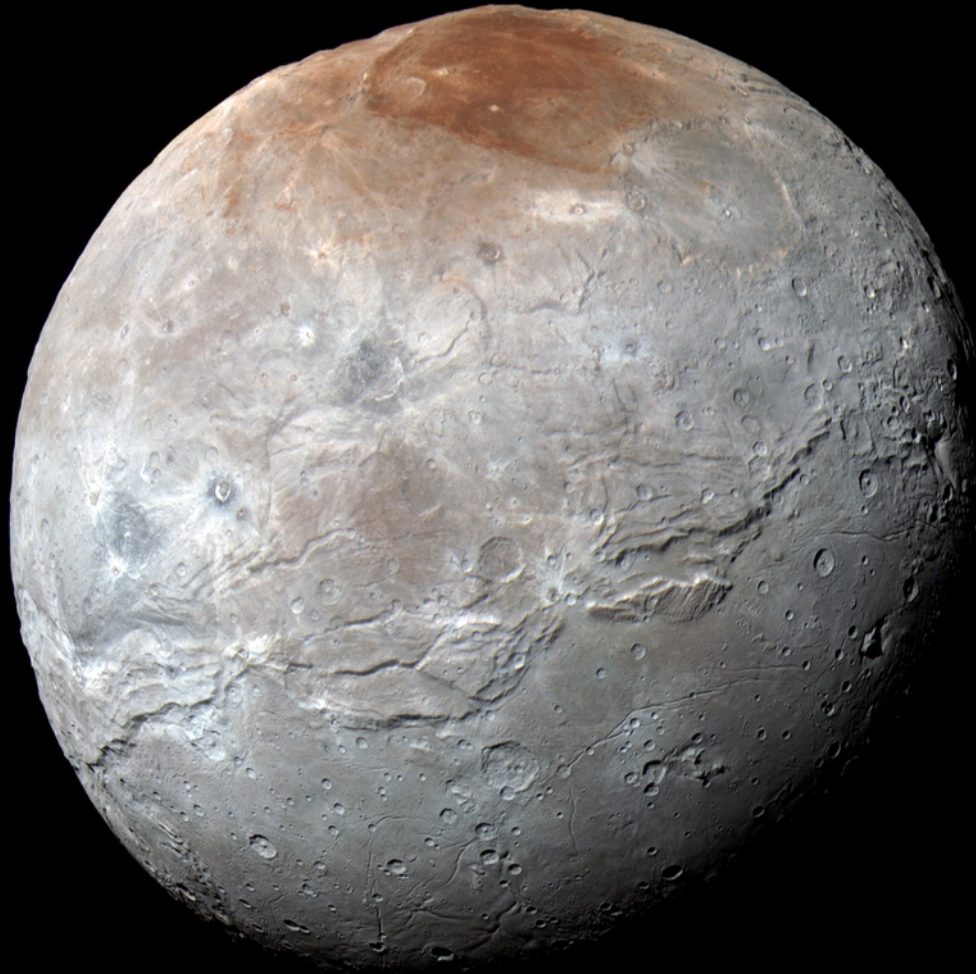
# Reflectivity Variations

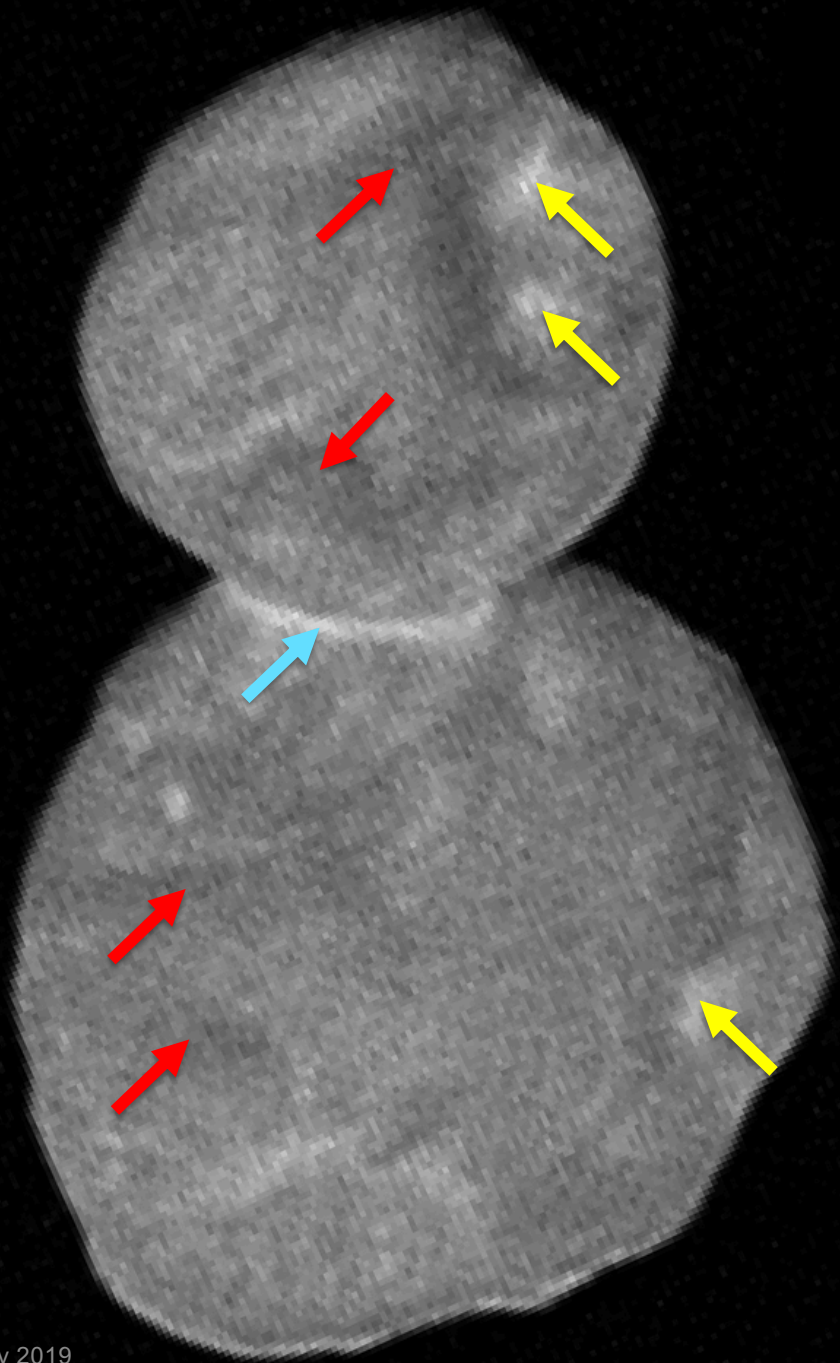


# Color Variation



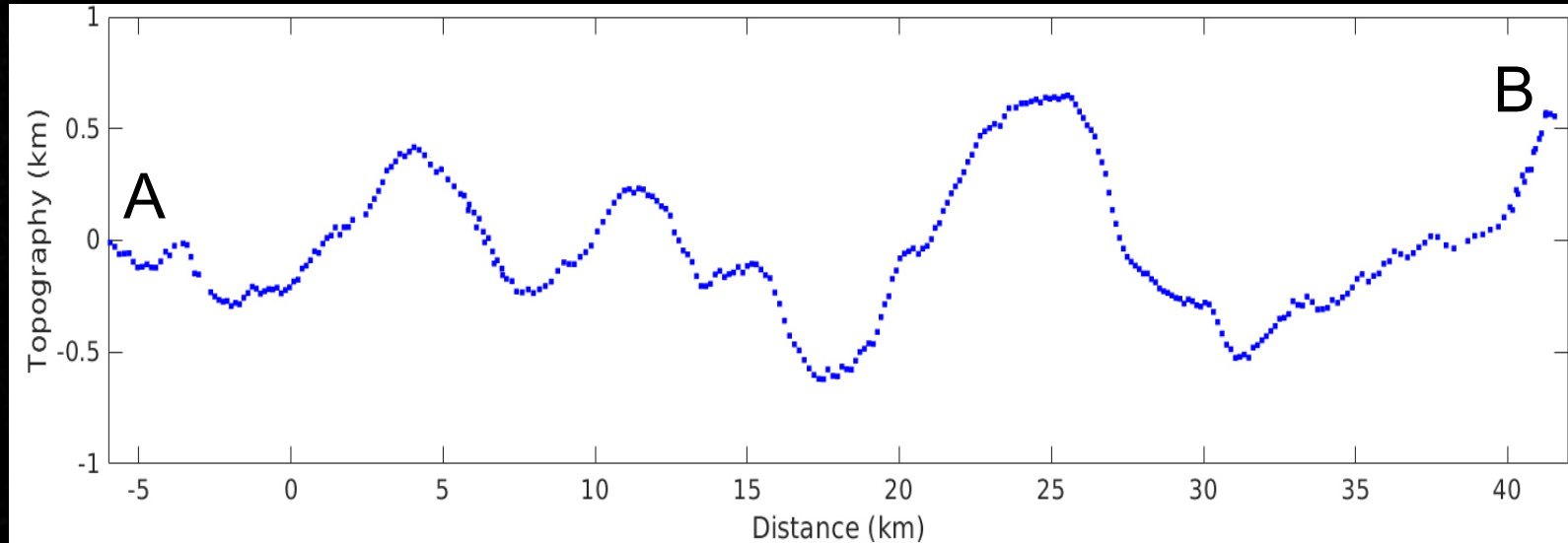
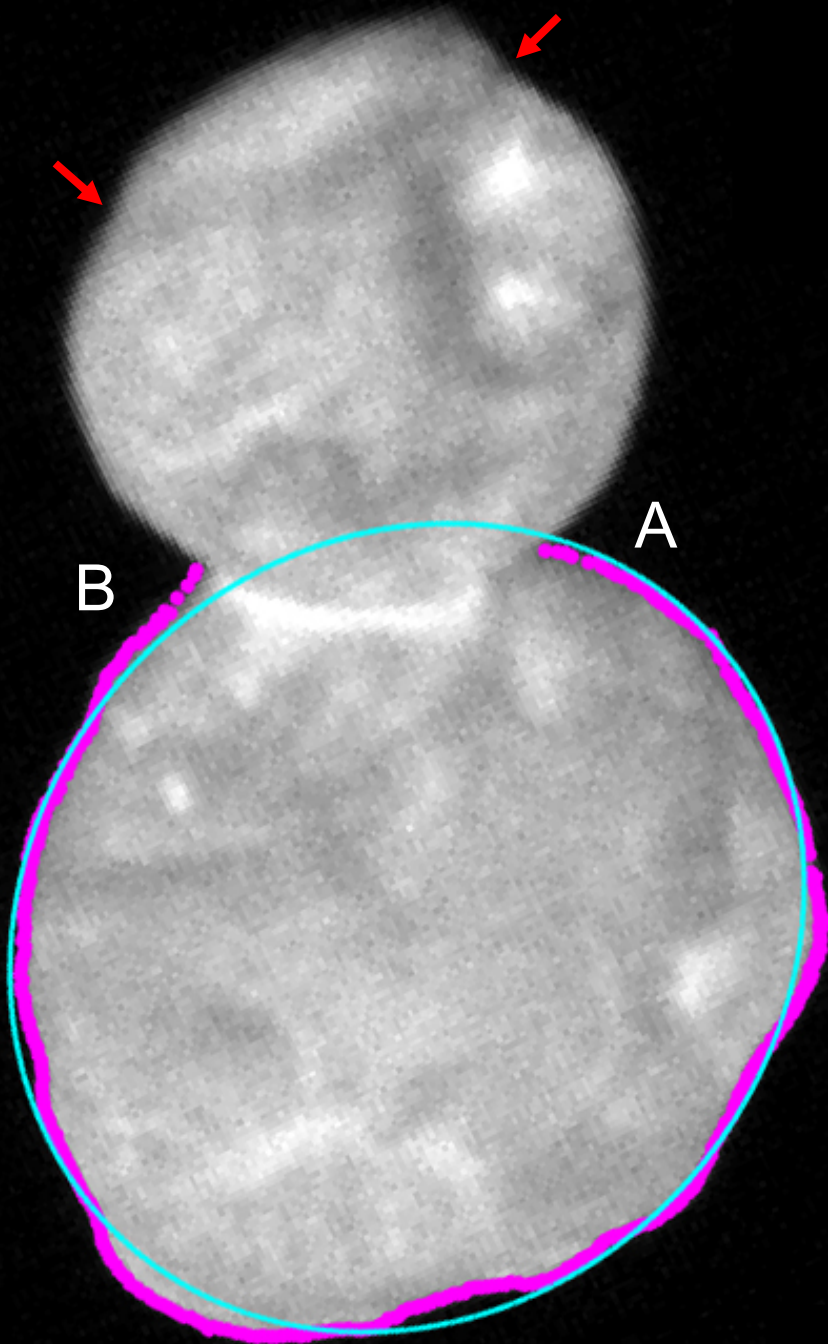
# Comparisons with the Pluto System





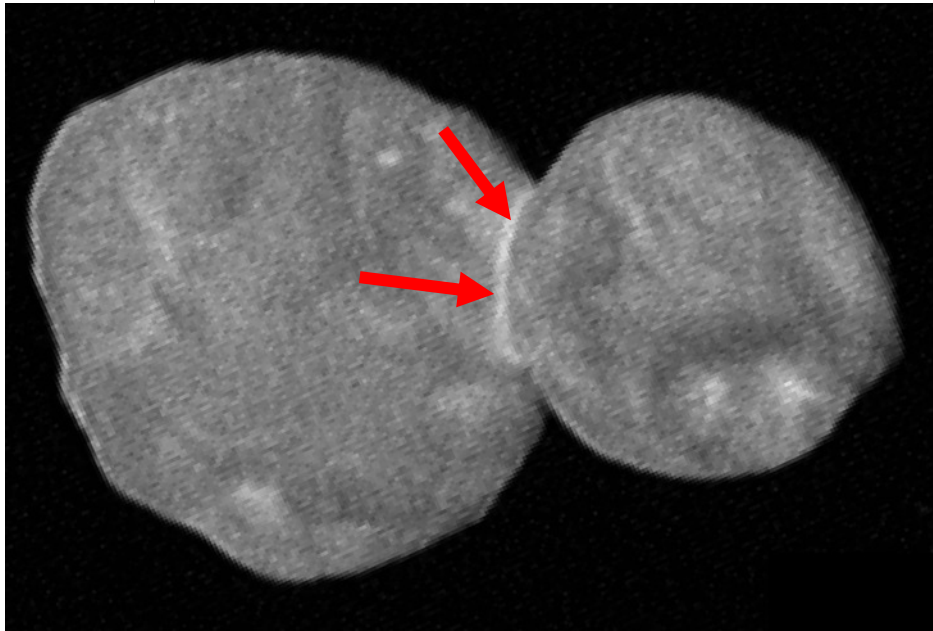
- Mottled appearance
- Brighter (yellow arrows) and darker regions (red arrows)
- Remarkable “neck” (blue arrow)
- No obvious impact craters
- Hills and ridges?

- Ultima limb topography is  $>1$  km.
- Origins of topography are currently unclear (for instance, hills or crater rims).
- Red arrows point to apparent “divots” connected by a dark, elongated marking.

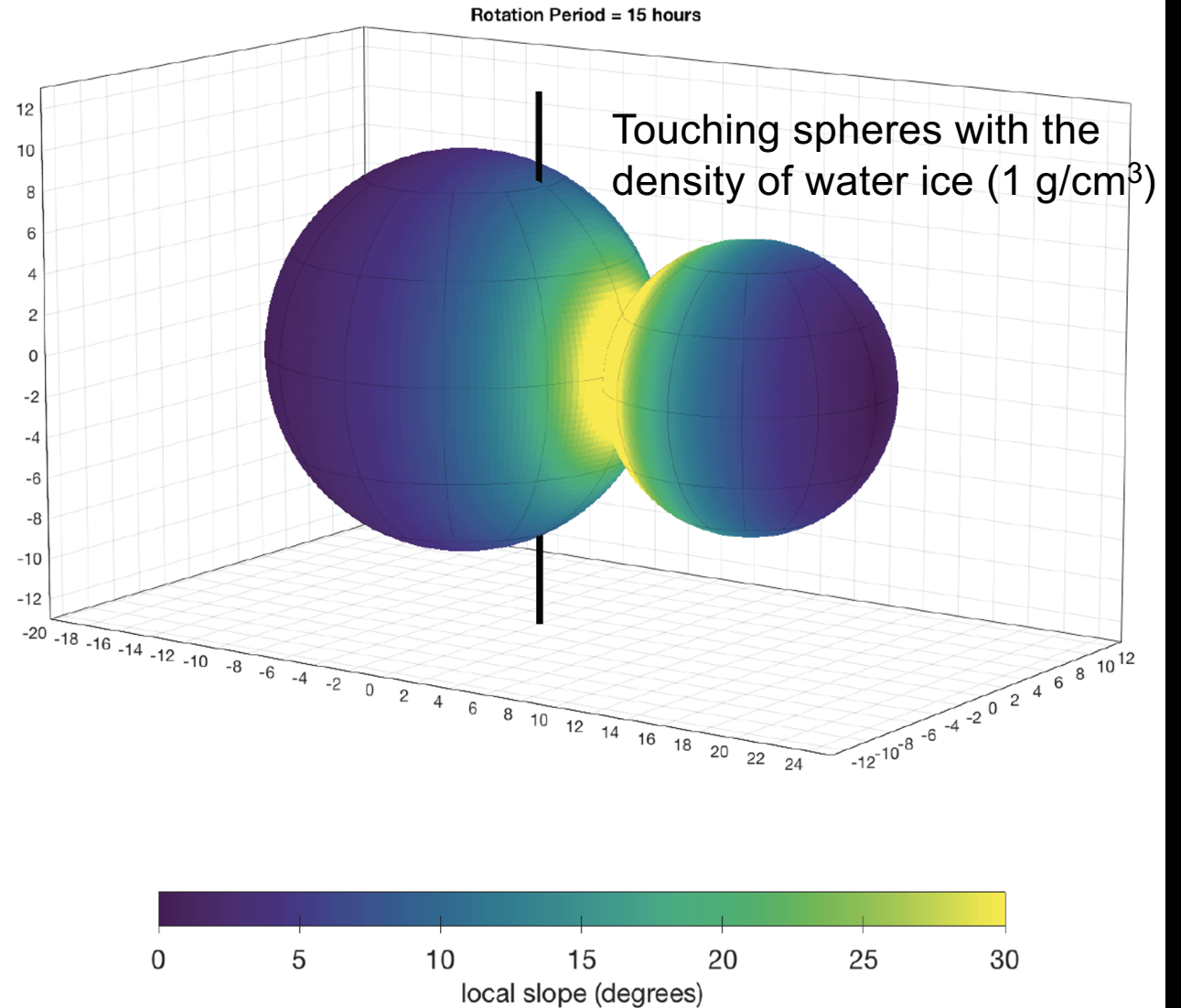




# Surface Slopes



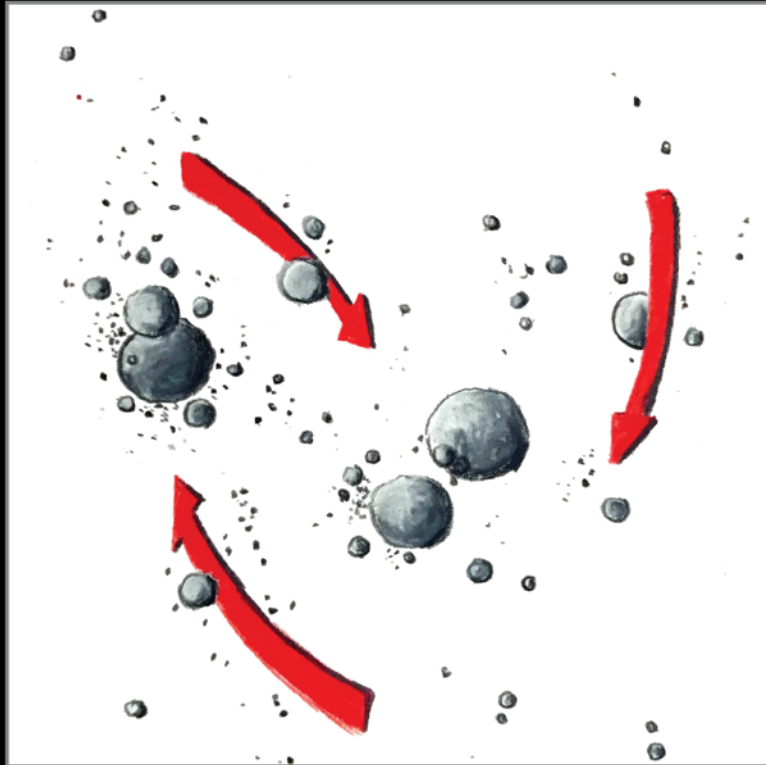
The "neck" corresponds to the steepest slopes.



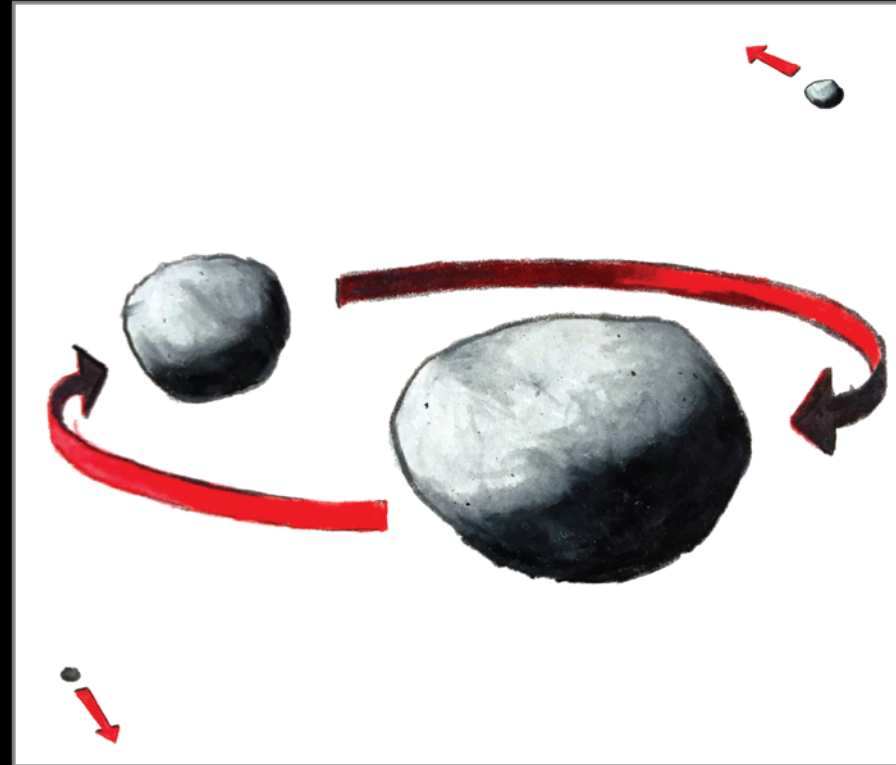
# The Formation of Ultima Thule

About 4.5 billion years ago

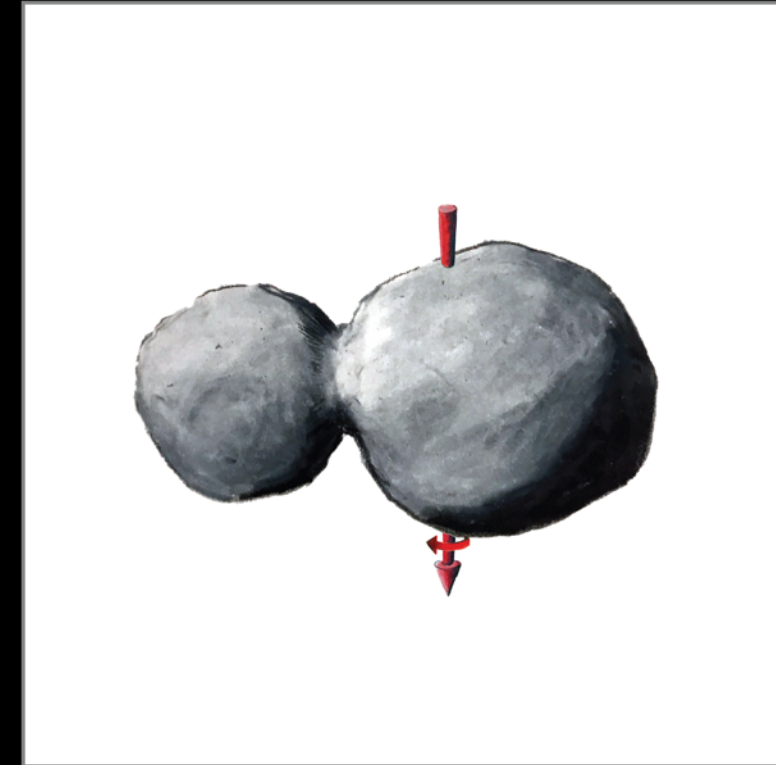
1 January 2019



A rotating cloud of small, icy bodies starts to coalesce.



Eventually two larger bodies remain: Ultima and Thule.

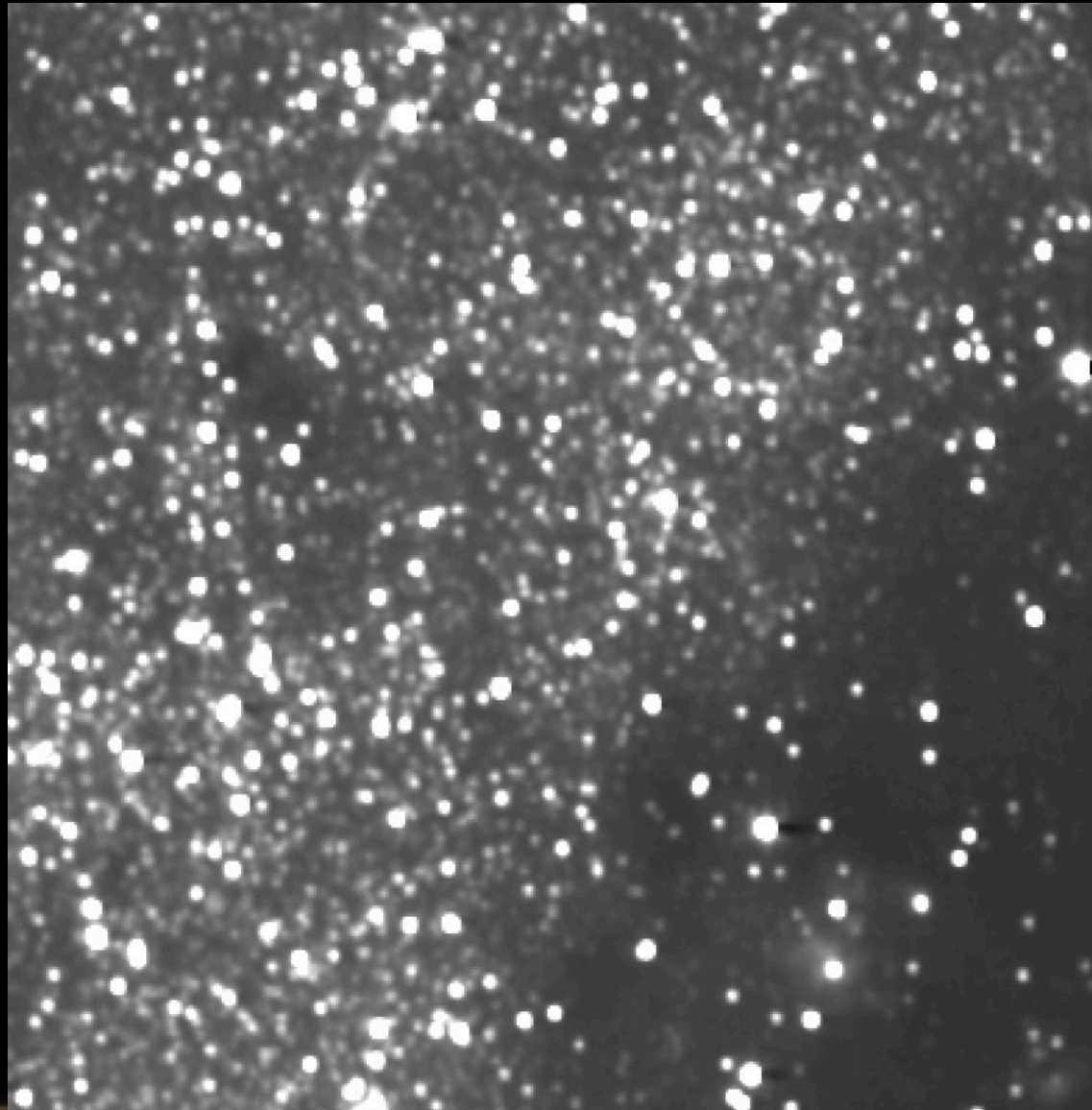


Ultima and Thule slowly spiral closer until they touch, forming the bi-lobed object we still see today.

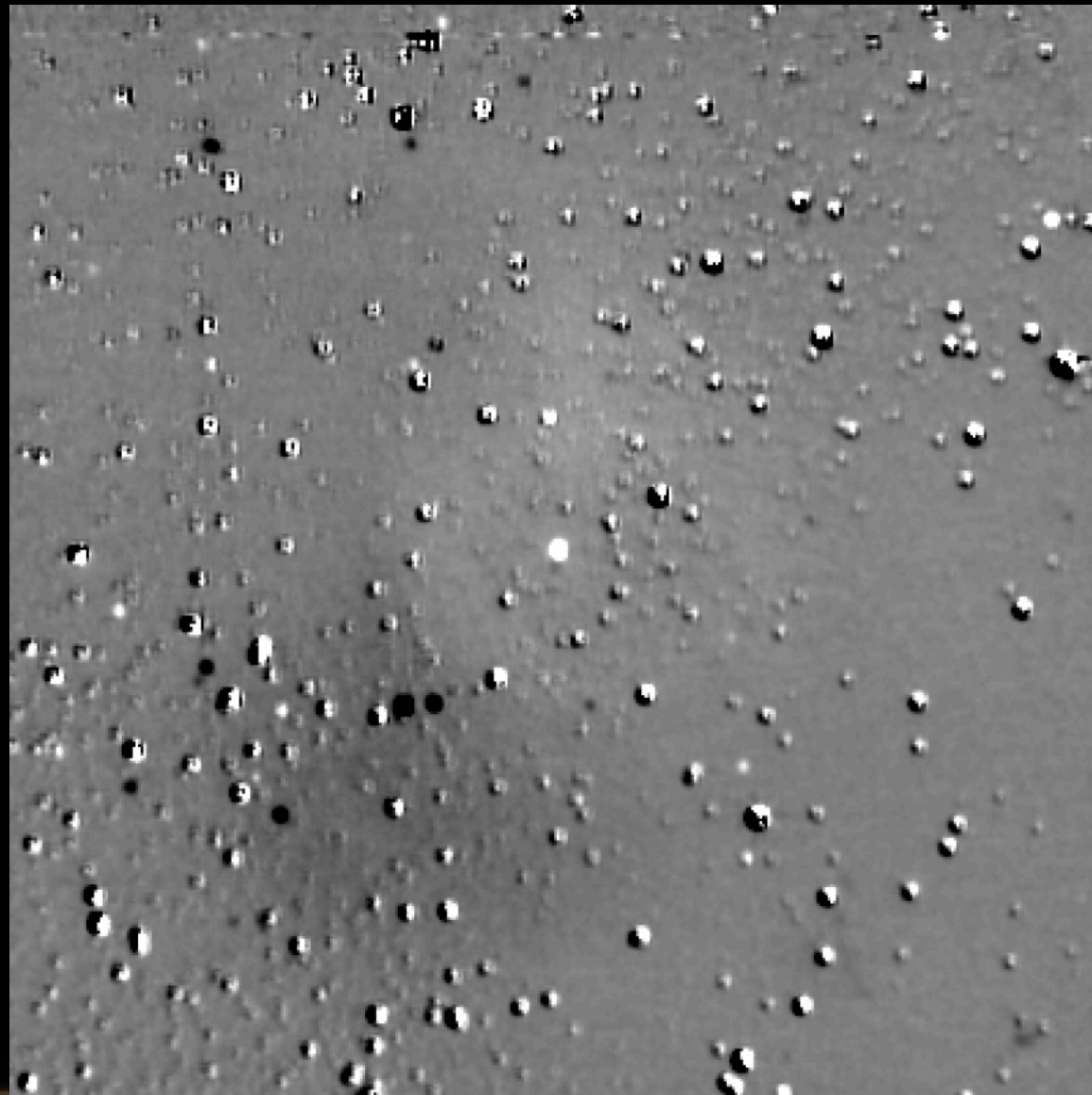
NASA / JHUAPL / SwRI / James Tuttle Keane



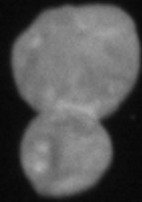
# Search Image: Original



# Search Image: Processed



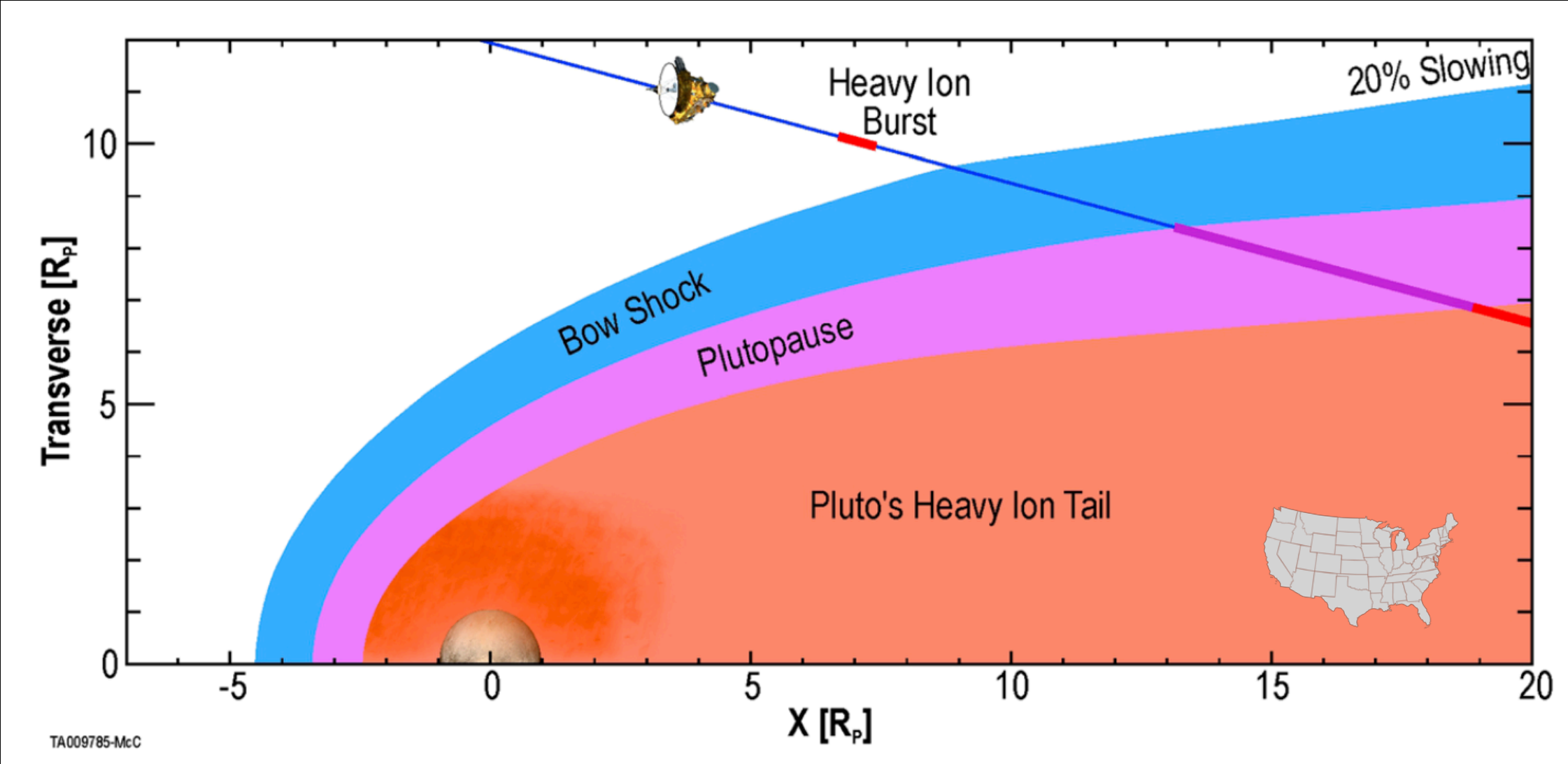
# Close Approach Image: Original



# Close Approach Image: Brightened



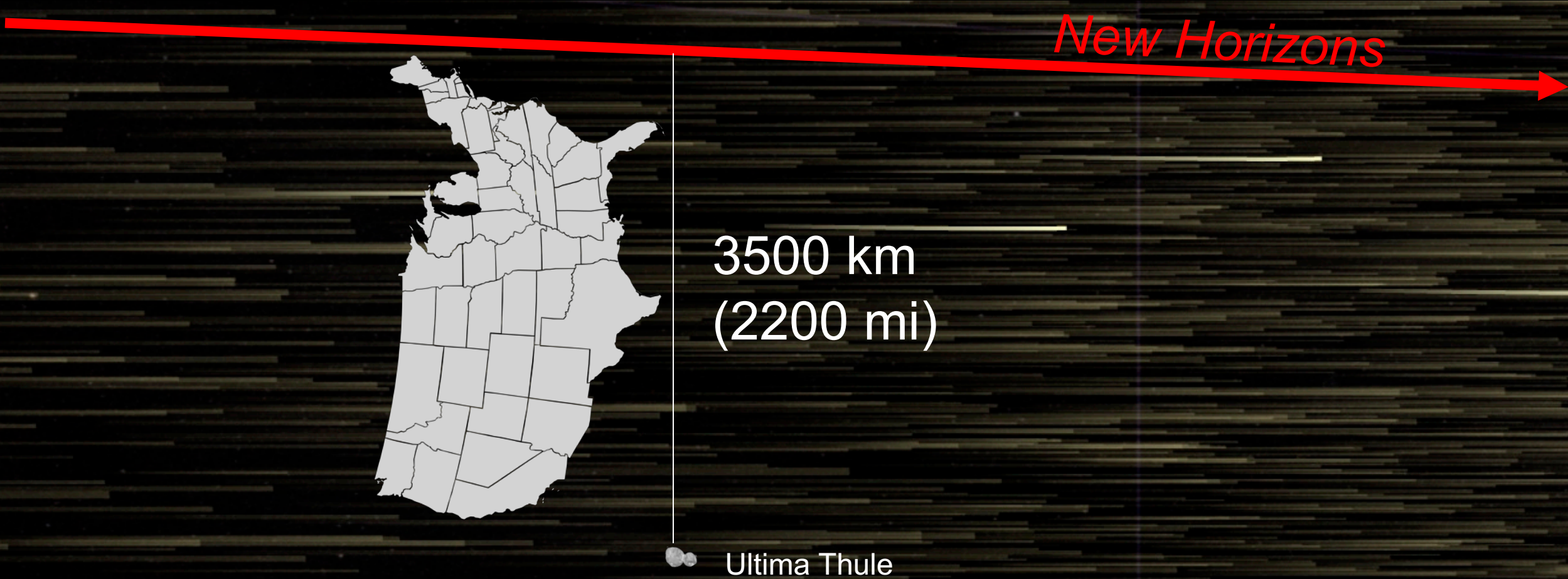
# Solar Wind Interaction With Pluto



TA009785-McC



# Solar Wind Interaction With Ultima Thule

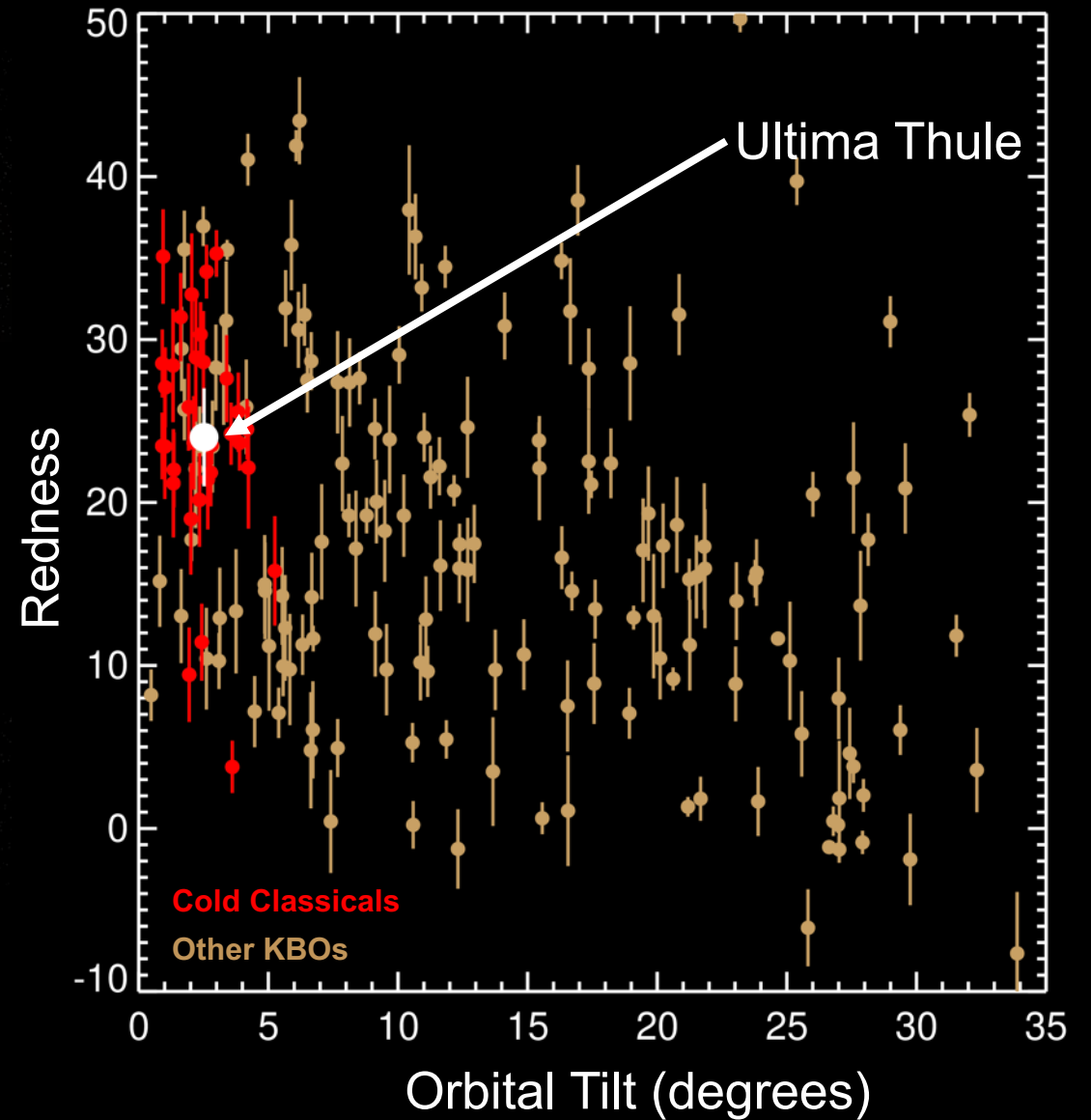
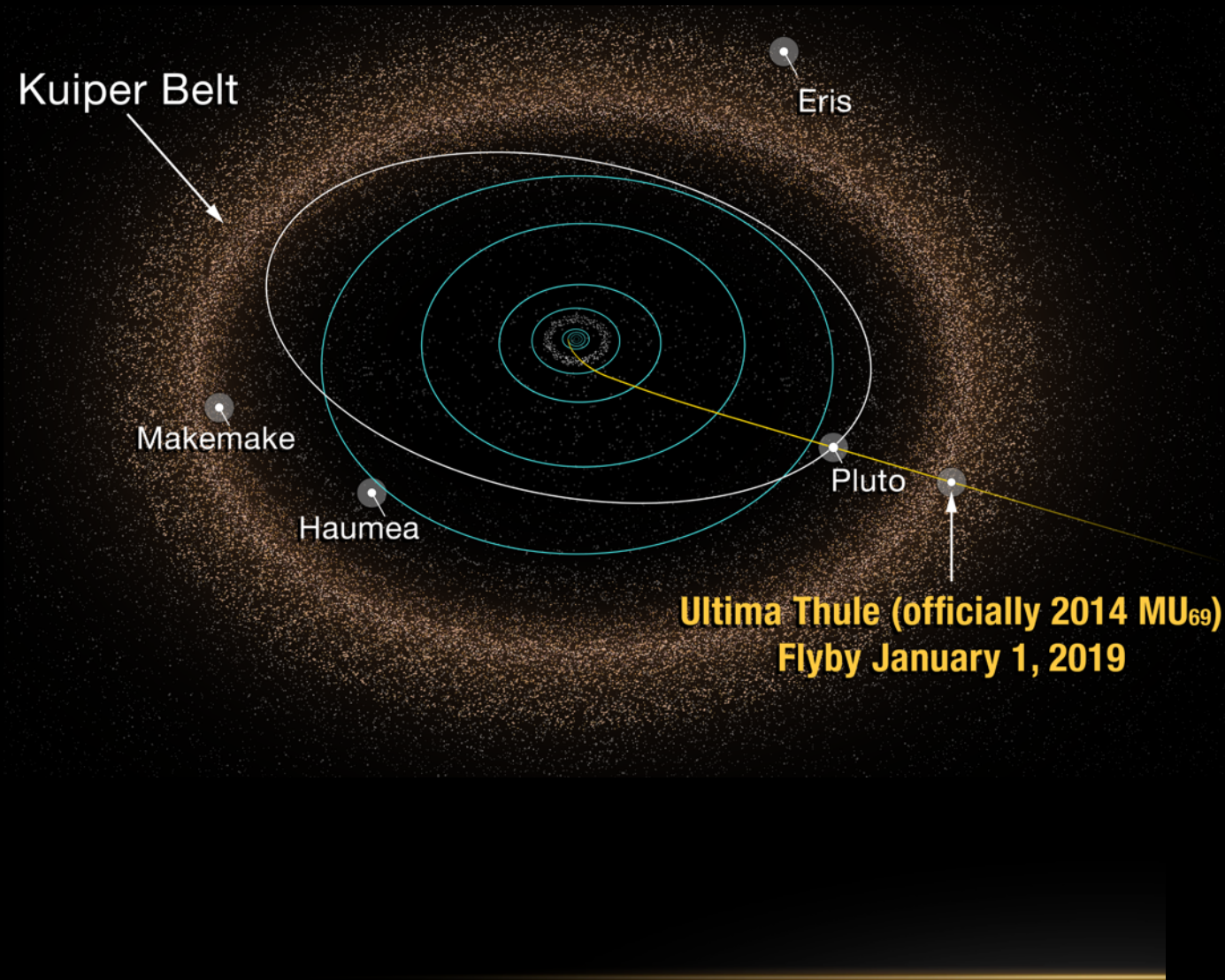


# Solar Wind Impacts Ultima Thule





# Ultima Thule's Color



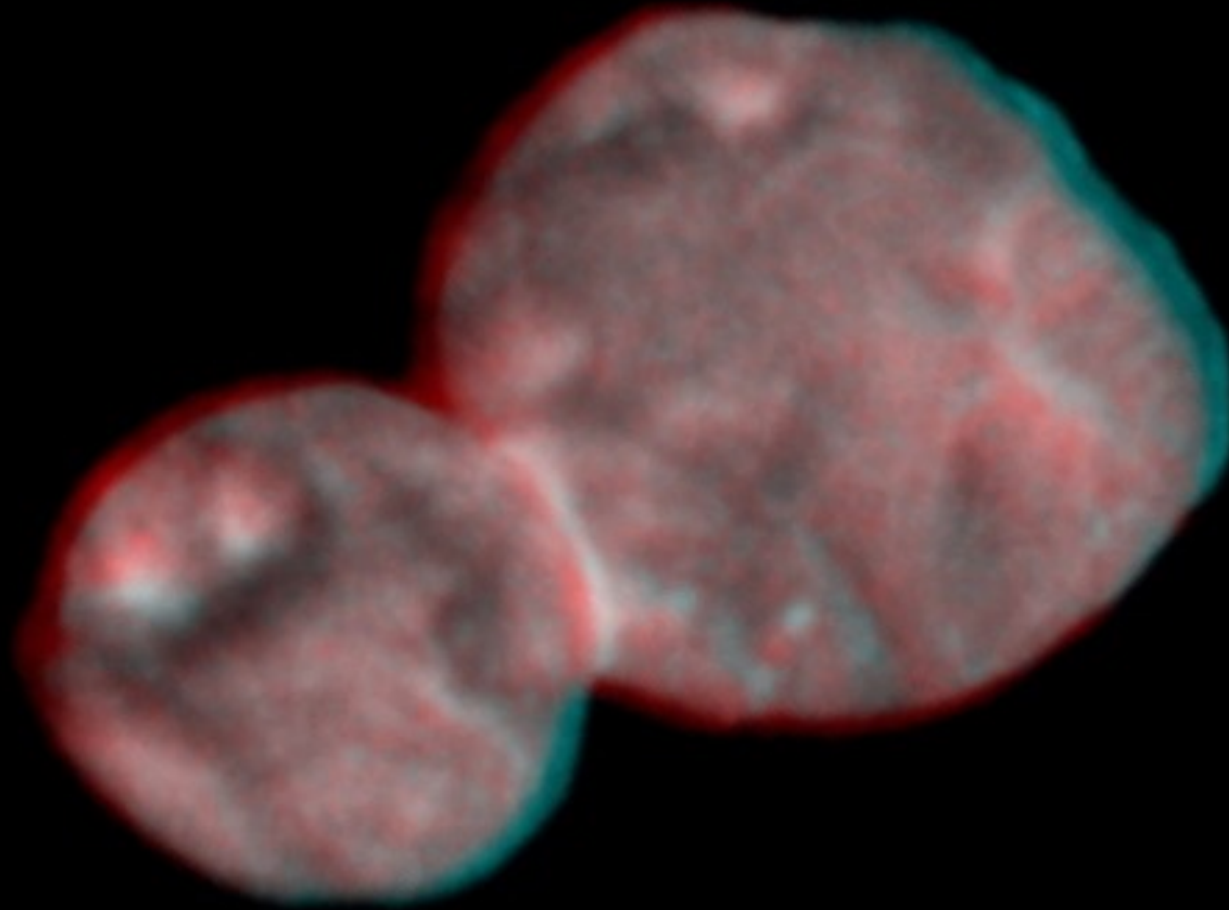
# Correlated Colors of Binaries



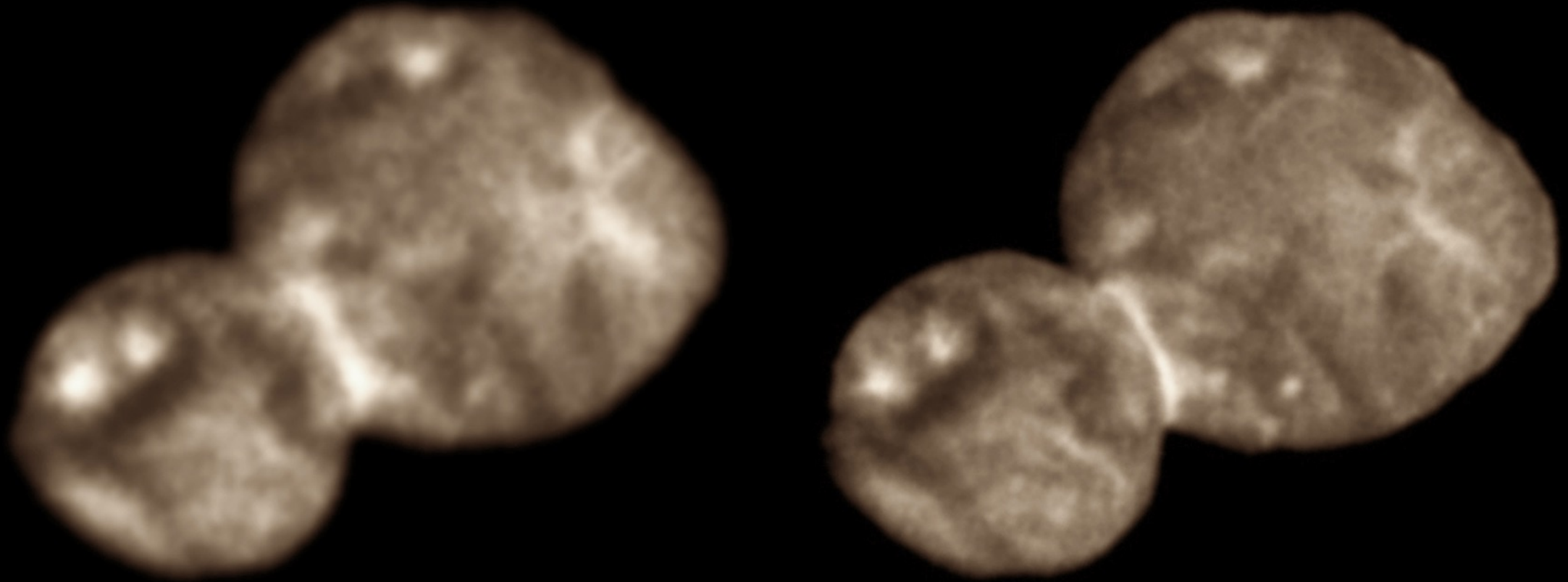
MVIC Color

- Ultima and Thule show the same average color
- Consistent with forming as a result of the merger of two objects accreted locally
- The primary and secondary components of binary systems in the Kuiper Belt present the same coloration

# Ultima Thule Stereo Anaglyph



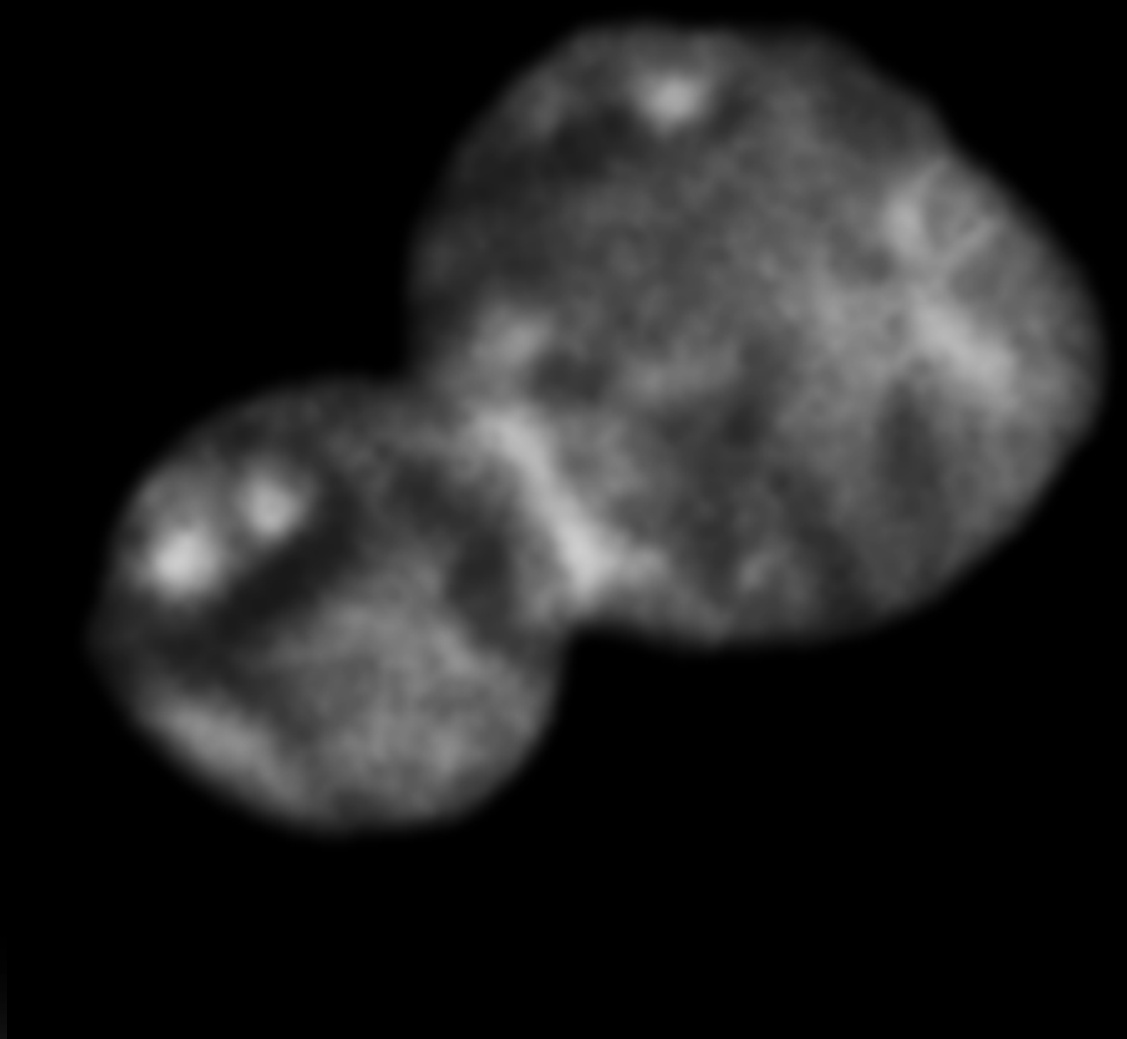
# Ultima Thule Left-Right Stereo



Credit: Dr. Brian May

# Rotation “Movie”

- Thule closer to New Horizons in second image
- 30 minutes between images
- More topography peeks around edge of Ultima





# **Beyond Ultima Thule ...**

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**23 January 2019**