Kobe Science Cafe

New Horizons

Flyby: 2015 July 14

James Imamura
University of Oregon
Eugene, OR United States

Cafe Nescafe, Sannomiya
Kobe, Japan
September 14, 2015

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Pluto was discovered in 1930 and announced as the ninth planet in our Solar System. Its largest moon, Charon, was discovered in 1978. Charon is about half Pluto's size and the Pluto/Charon system is, in fact, sometimes considered a binary planet system. In 2006, Pluto was demoted to dwarf planet status by the International Astronomical Union just after the launch of the Pluto probe New Horizons. New Horizons oblivious to this, continued on in its mission providing our first close-up look of Pluto and Charon last July revealing many surprising results such as chasms, ice mountains, and plains. The results indicate that Pluto and Charon have undergone recent geology. In our talk, we will discuss briefly the history of Pluto and then consider several of the surprising results of New Horizons and their implications in more detail.

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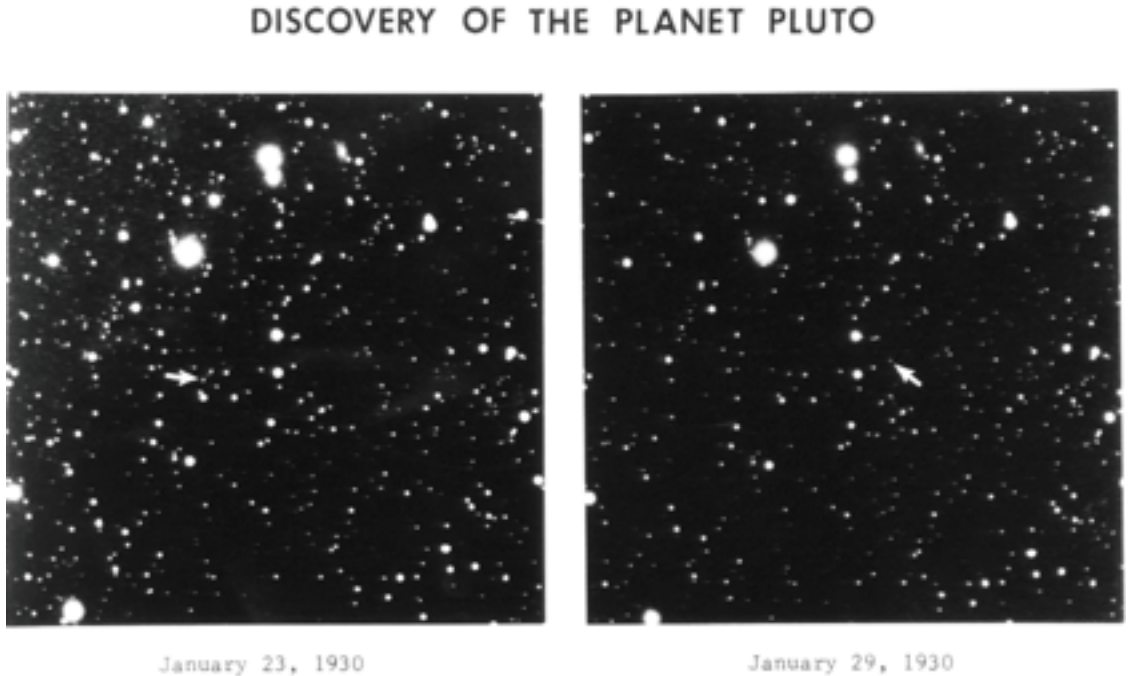
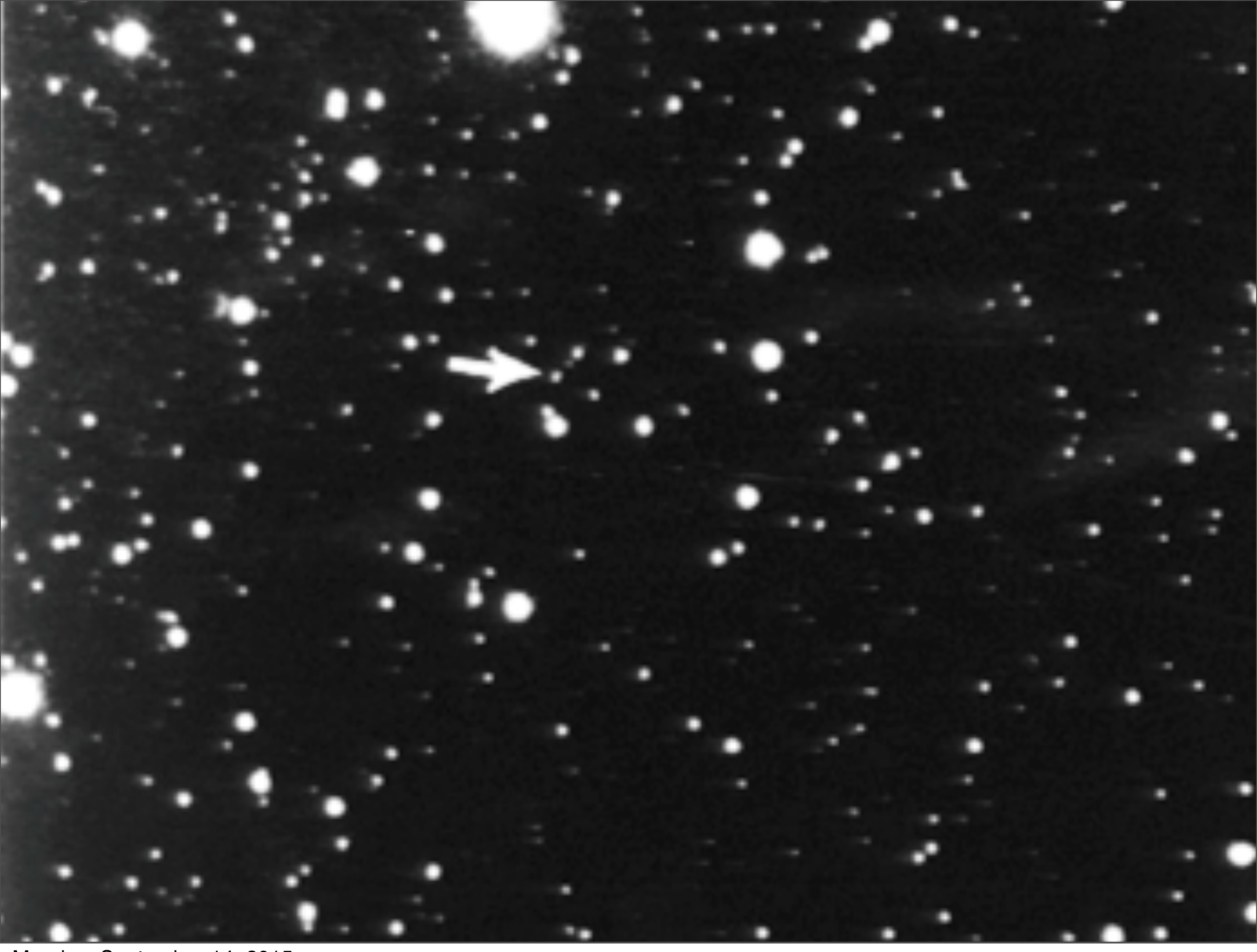


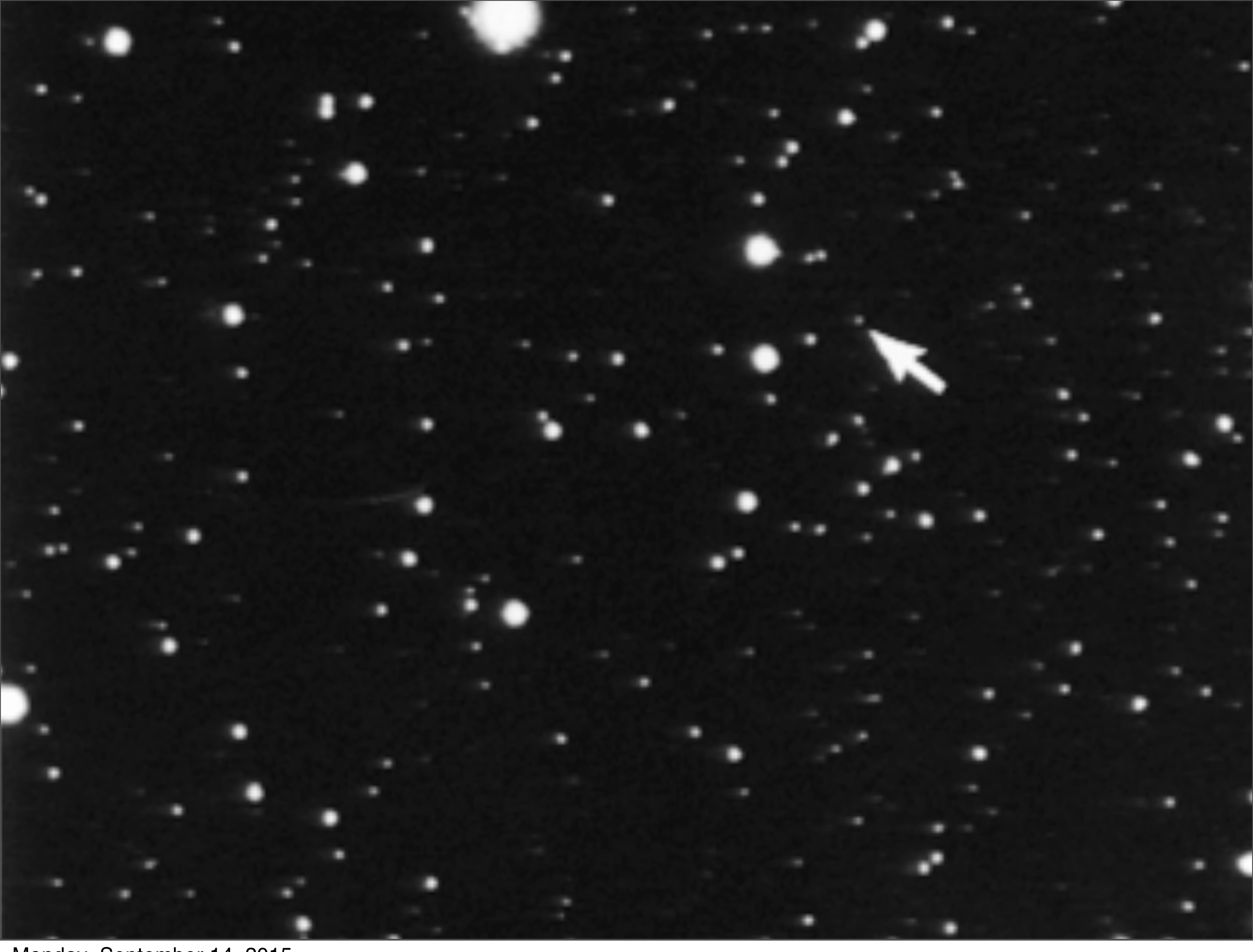
Upper left: Clyde Tombaugh, discover of Pluto

Left: The Astrograph composed of 3 lenses each 0.33 m

Above: Plates taken by Tombaugh using the Astrograph (and blinked) to reveal Pluto (see arrows)



Monday, September 14, 2015



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Charon	James W. Christy	June 22, 1978	largest moon of Pluto

Charon is around 1/2 the size of Pluto and is largefor a planetary satellite. Pluto and Charono are sometimes referred to a binary planetary system.

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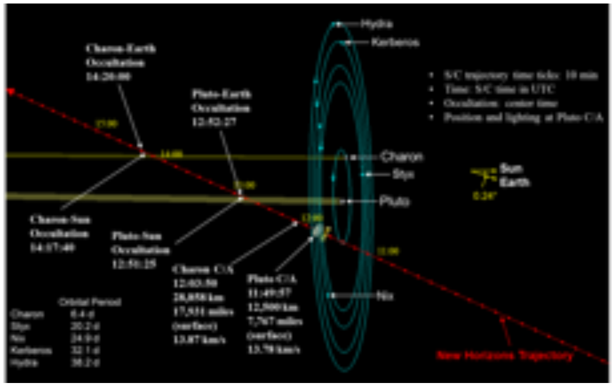

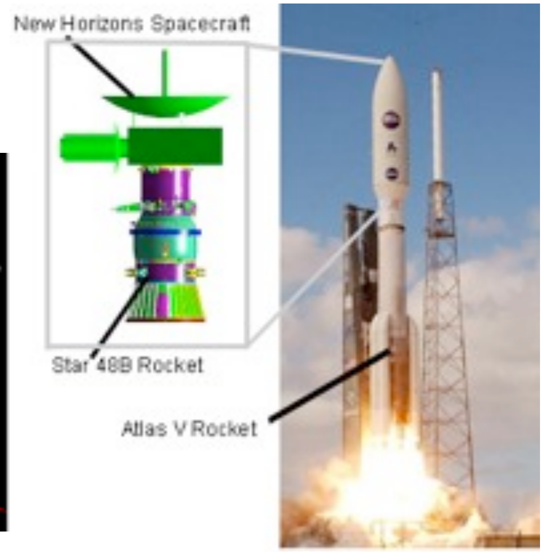

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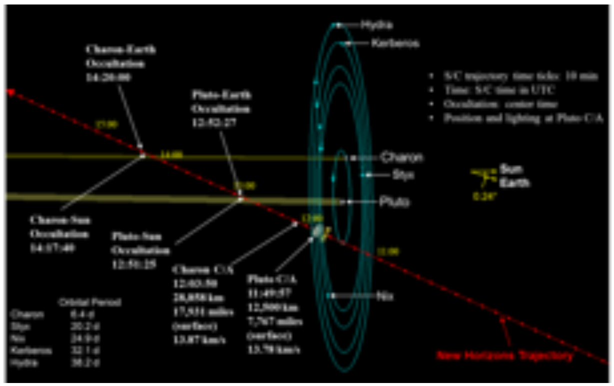

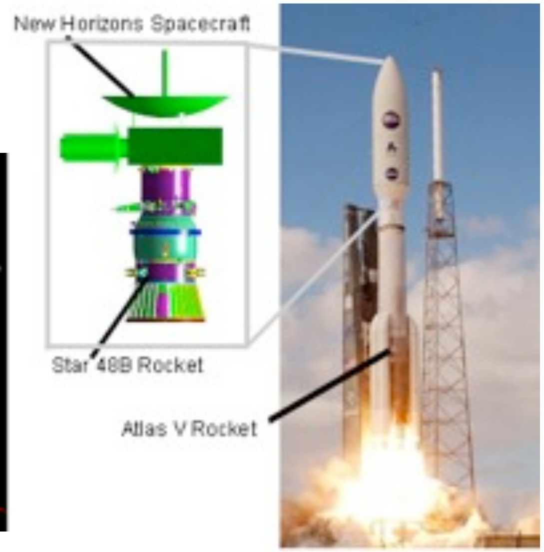

IAU Commission August 24, 2006 Demoted by 246 astronomers!

IAU Resolution: Definition of a "Planet" in the Solar System

Contemporary observations are changing our understanding of planetary systems, and it is important that our nomenclature for objects reflect our current understanding. This applies, in particular, to the designation "planets". The word "planet" originally described "wanderers" that were known only as moving lights in the sky. Recent discoveries lead us to create a new definition, which we can make using currently available scientific information.

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RESOLUTION 5A

The IAU therefore resolves that planets and other bodies in our Solar System, except satellites, be defined into three distinct categories in the following way:

(1) A "planet" [1] is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape [2], (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.

(3) All other objects [3], except satellites, orbiting the Sun shall be referred to collectively as "Small Solar-System Bodies".

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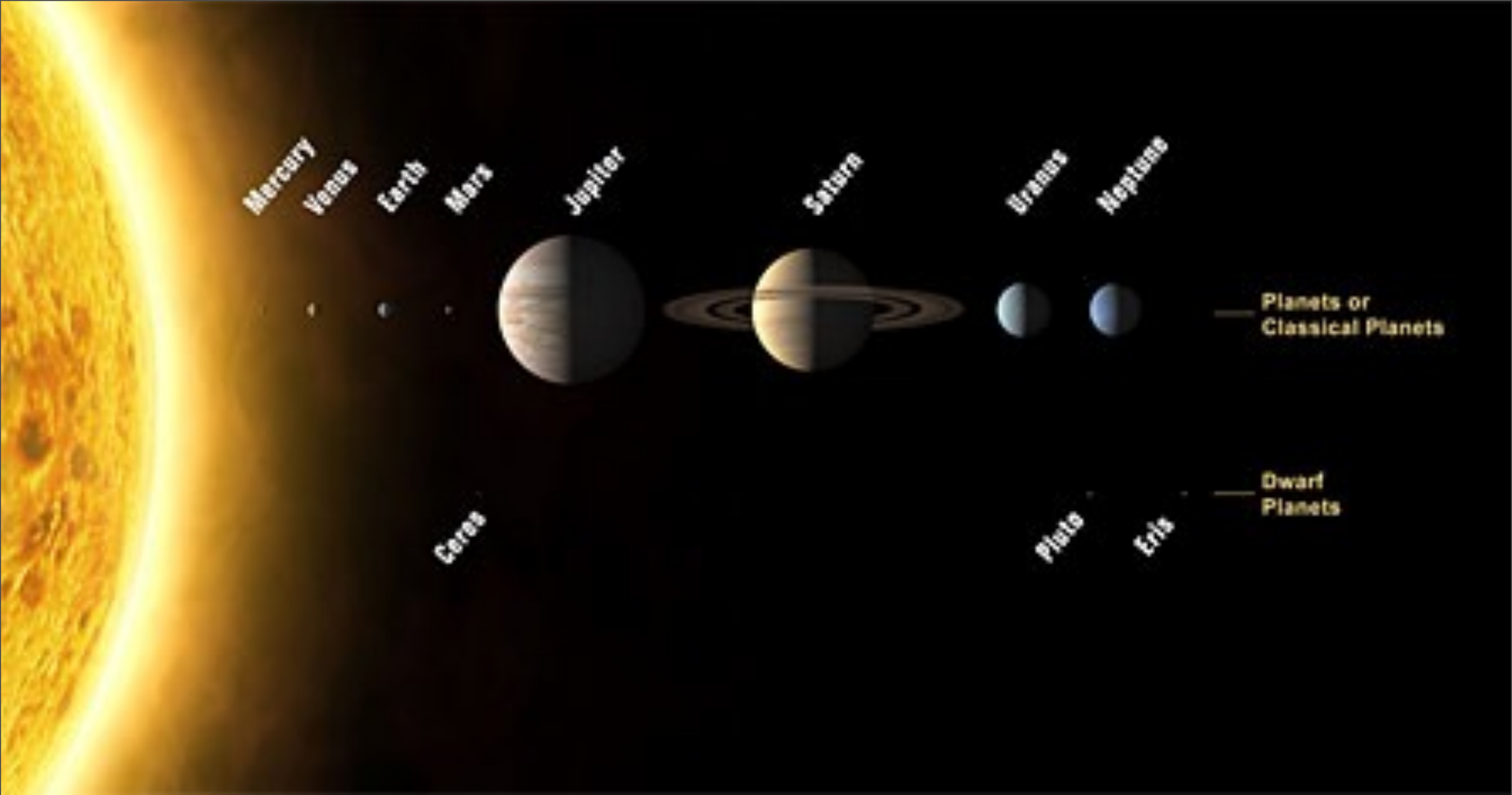
RESOLUTION 6A

The IAU further resolves: Pluto is a "dwarf planet" by the above definition and is recognized as the prototype of a new category of trans-Neptunian objects.



The Solar System contains 8 major planets and 3 dwarf planets, naturally broken into 3 types: (1) Low-mass Terrestrial (solid rocky) planets; (ii) High-mass Jovian (gaseous, h-he) planets; and (iii) rock/ice planets. The breakdown is understood based on the condensation properties of the protoSolar disk and the location of the Snowline.

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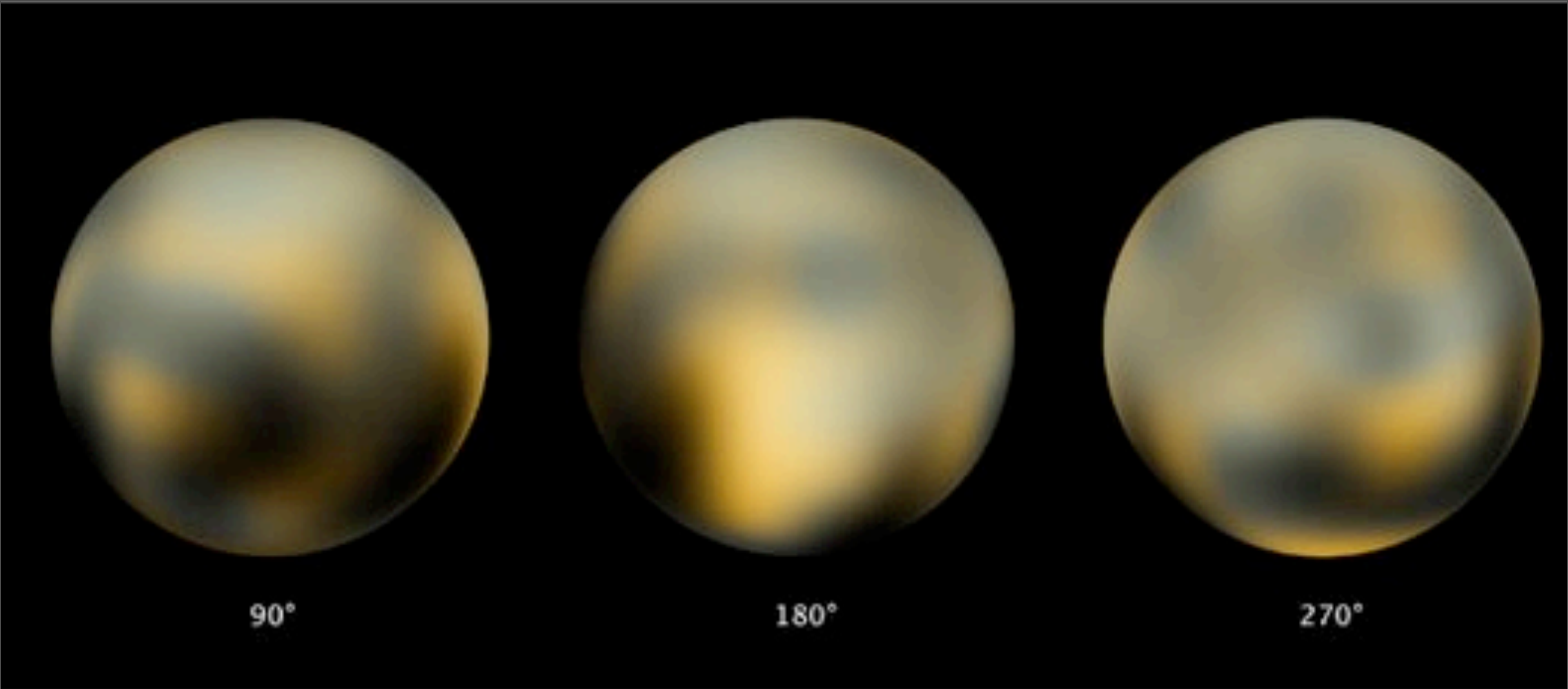
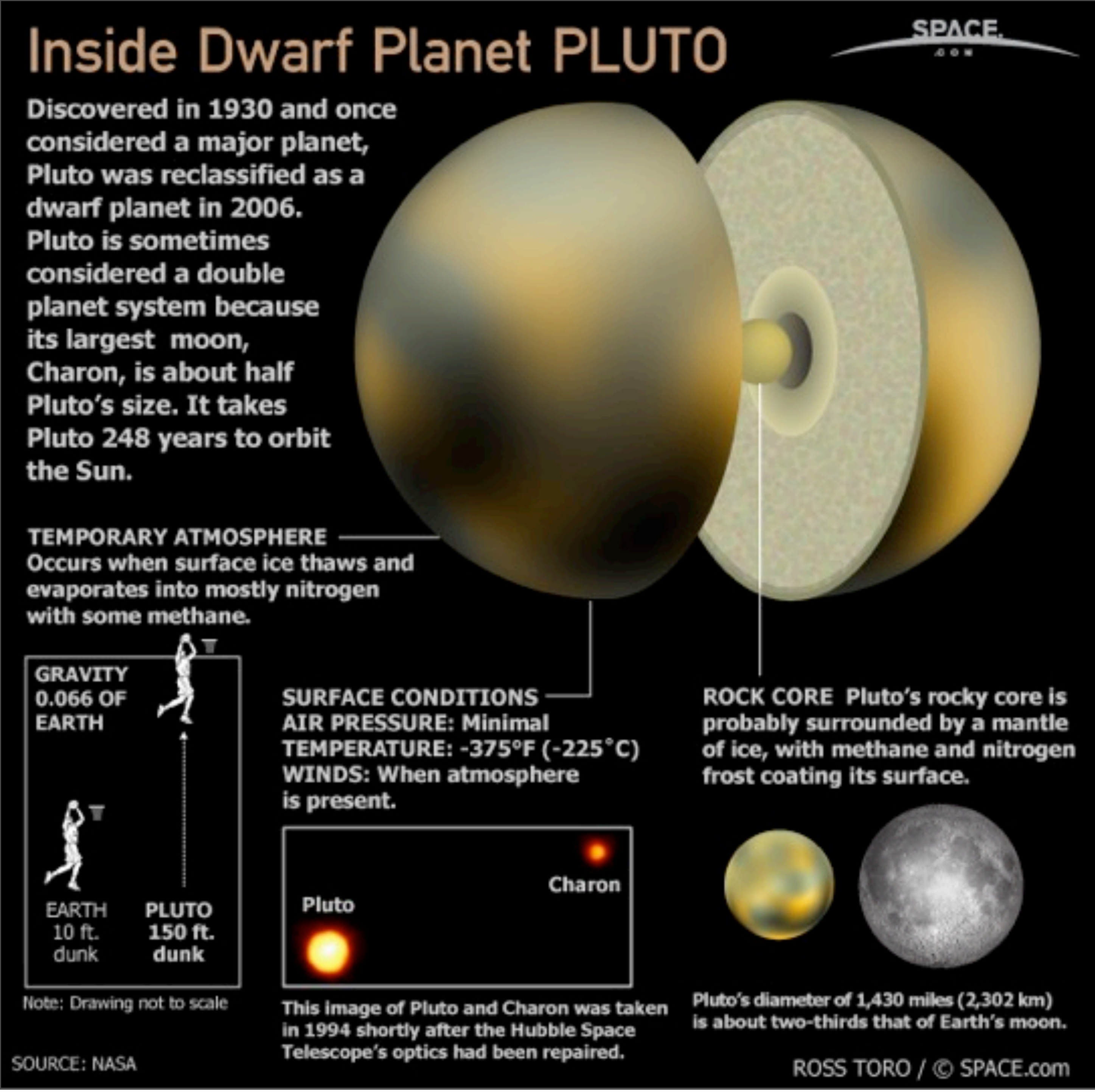
Charon	James W. Christy	June 22, 1978	largest moon of Pluto
	New Horizons	January 19, 2006	launch
	IAU Commission	August 24, 2006	Demoted by 246 astronomers!
	New Horizons	July 14, 2015	Flyby through Pluto/Charon system
		September 4, 2015	image transfer begins
		January 1, 2019	Kuiper Belt (if funded, 2016)

Comment: Pluto's orbital period about the Sun is 248 years

PLUTO, CHARON, and moons



Little is known about Pluto's size and surface conditions. It has diameter 1,473 miles less than one-fifth that of Earth or only about two-thirds as the Moon. Pluto's interior probably consists of a rocky core surrounded by a mantle of water ice, with more exotic ices such as methane and nitrogen frost coating its surface. NASA's Hubble Space Telescope (above) revealed evidence Pluto's crust contains complex organic molecules. Chemicals such as nitrogen and methane may lay frozen beneath the icy crust. When Pluto is closer to the sun, its surface ices thaw and temporarily form a thin atmosphere, mostly of nitrogen, with some methane. Pluto's low gravity, which is a little more than one-twentieth that of Earth's, causes this atmosphere to extend much higher in altitude than Earth's. When farther away from the sun, most of Pluto's atmosphere is thought to freeze and all but disappear. Still, in the time that it does have an atmosphere, Pluto can apparently experience strong winds. Pluto's surface is one of the coldest places in the solar system at roughly -225 C. For a long time, astronomers knew little about its surface because of its distance from Earth, but the Hubble Space Telescope returning images of a planet that appears reddish, yellowish and grayish in places, with a curious bright spot near the equator that might be rich in carbon monoxide frost. Hubble has shown that Pluto has grown redder over time, seasonal changes?



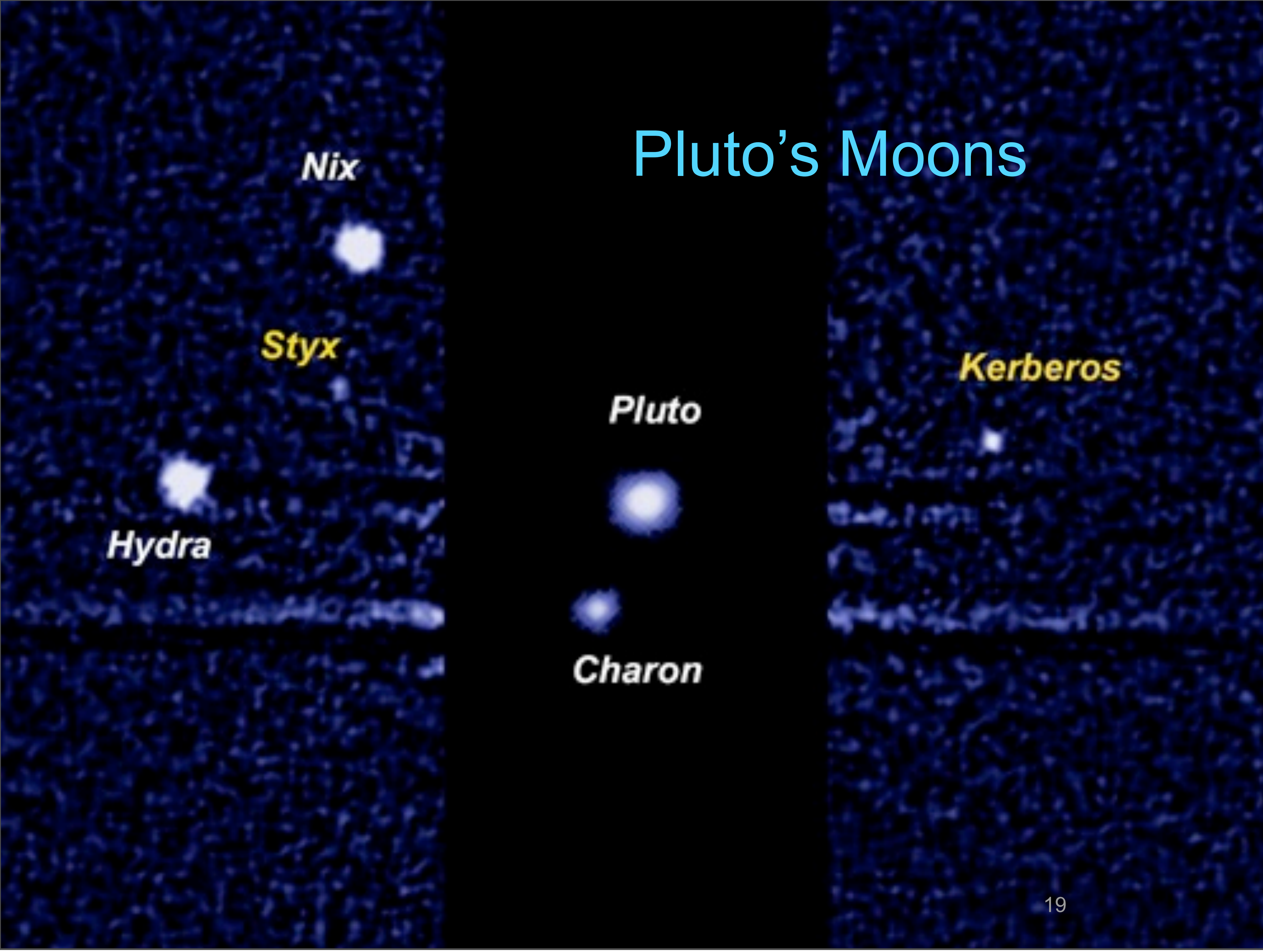
ATMOSPHERE:
98 % nitrogen + small amounts of methane with pressure 0.00001 Atm.

MAGNETIC FIELD: It remains unknown whether Pluto has a magnetic field, but its small size and slow rotation suggest it has little to none.

INTERIOR: Average density 2.02 g/cc. Probably a mixture of 70 percent rock and 30 percent water ice.Likely has a rocky core surrounded by a mantle of water ice, with more exotic ices such as methane and nitrogen frost coating its surface.

In 1978, astronomers discovered Pluto had a large moon nearly half its size, Charon, named for the demon who ferried souls to the underworld in Greek mythology. Astronomers refer to Pluto and Charon as a binary dwarf planet system. Pluto and Charon are 12,200 miles apart, Charon is 1/12th of Pluto's mass and 1/2-1/3 its radius. Charon's orbit around Pluto takes 6.4 Earth days, and one rotation also takes 6.4 Earth days. Charon presents the same face to Pluto. Pluto also rotates with a period of 6.4 days and so Charon hovers over one spot above Pluto's surface. Pluto appears reddish, Charon seems grayish. Astronomers suggest Pluto is covered with nitrogen and methane while Charon is covered with water ice. *Charon may have once had a subsurface ocean*. The Pluto-Charon system is tipped on its side in relation to the sun, it orbits nearly in Pluto's equatorial plane. Pluto's rotation is retrograde — it spins backward, from east to west.

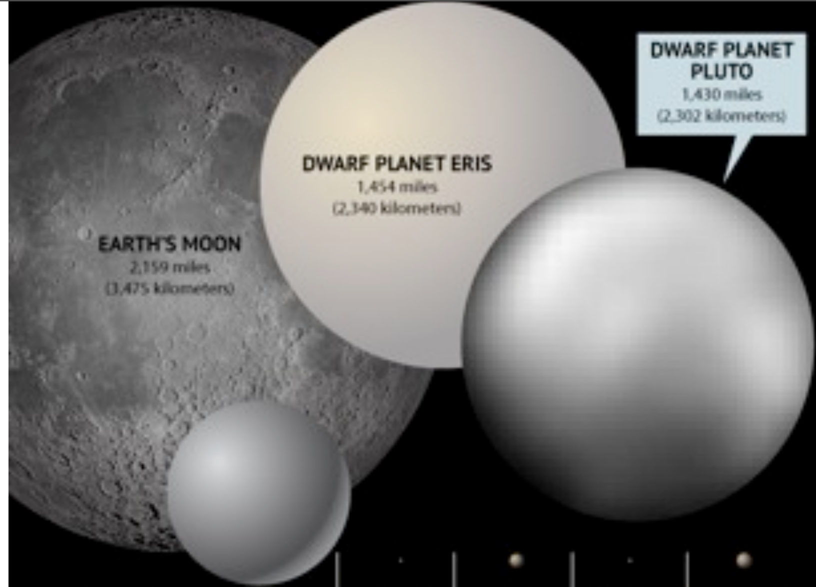
Pluto’s Moons



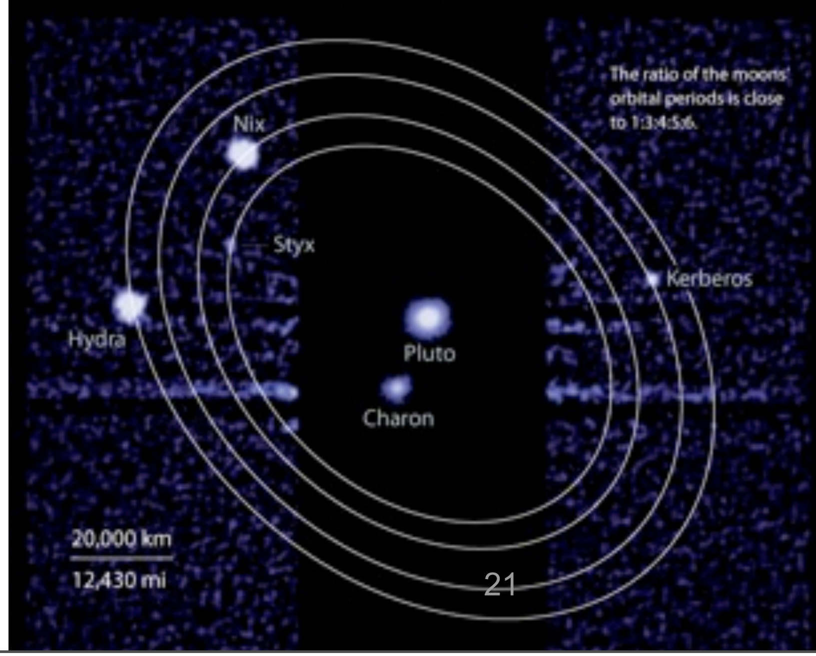
Pluto and Charon are seen circling a central gravitational point known as the barycenter, which accounts for the wobbling motion. Since Charon is 1/12th the mass of Pluto the center of mass between the two actually lies a bit outside Pluto's radius, making their little gravitational "dance" readily apparent. (The same effect happens with the Earth and Moon too, but since the barycenter lies 1,700 km below Earth's surface it's not nearly as obvious.)

"The image sequence showing Charon revolving around Pluto set a record for close range imaging of Pluto—they were taken from 10 times closer to the planet than the Earth is," said New Horizons mission Principal Investigator Alan Stern, of the Southwest Research Institute. "But we'll smash that record again and again, starting in January, as approach operations begin."

In 2005, as scientists photographed Pluto with the Hubble Space Telescope and discovered two other moons, named Nix and Hydra. These two are two to three times farther away from Pluto than is Charon, and are thought to be just 50 to 100 km wide. A fourth moon, Kerberos, was found in 2011. This moon is estimated to be 13 to 34 km in diameter. P4, another moon, has orbit between Nix and Hydra. On July 11, 2012, a fifth moon Styx, was discovered, fueling the debate about Pluto's status as a planet. The four newly spotted moons may have formed from the collision that created Charon, hurled away from Pluto by the gravity of the massive moon.



PLUTO'S MOONS:	CHARON	STYX	NIX	KERBEROS	HYDRA
Year of discovery	1978	2012	2005	2011	2005
Diameter	648 miles (1,043 kilometers)	6-15 mi (10-25 km)	31-62 mi (50-100 km)	8-21 mi (13-34 km)	31-62 mi (50-100 km)
Orbital period (Earth days)	6.4	20.2	24.9	32.2	38.2



- Analysis of Hubble Space Telescope data shows that Nix and Hydra wobble unpredictably. Scientists believe the other two small moons, Kerberos and Styx, are likely in a similar situation, pending further study
- "Hubble has provided a new view of Pluto and its moons revealing a cosmic dance with a chaotic rhythm," said John Grunsfeld, associate administrator of NASA's Science Mission Directorate in Washington, D.C. "When the New Horizons spacecraft flies through the Pluto system we'll get a chance to see what these moons look like up close and personal."
- Why the chaos? Because the moons orbit in a dynamically shifting gravitational field caused by Pluto and Charon, as they orbit each other. The variable gravitational field induces torques that send the smaller moons tumbling in unpredictable ways. This torque is strengthened by the fact the moons are football shaped rather than spherical in shape.

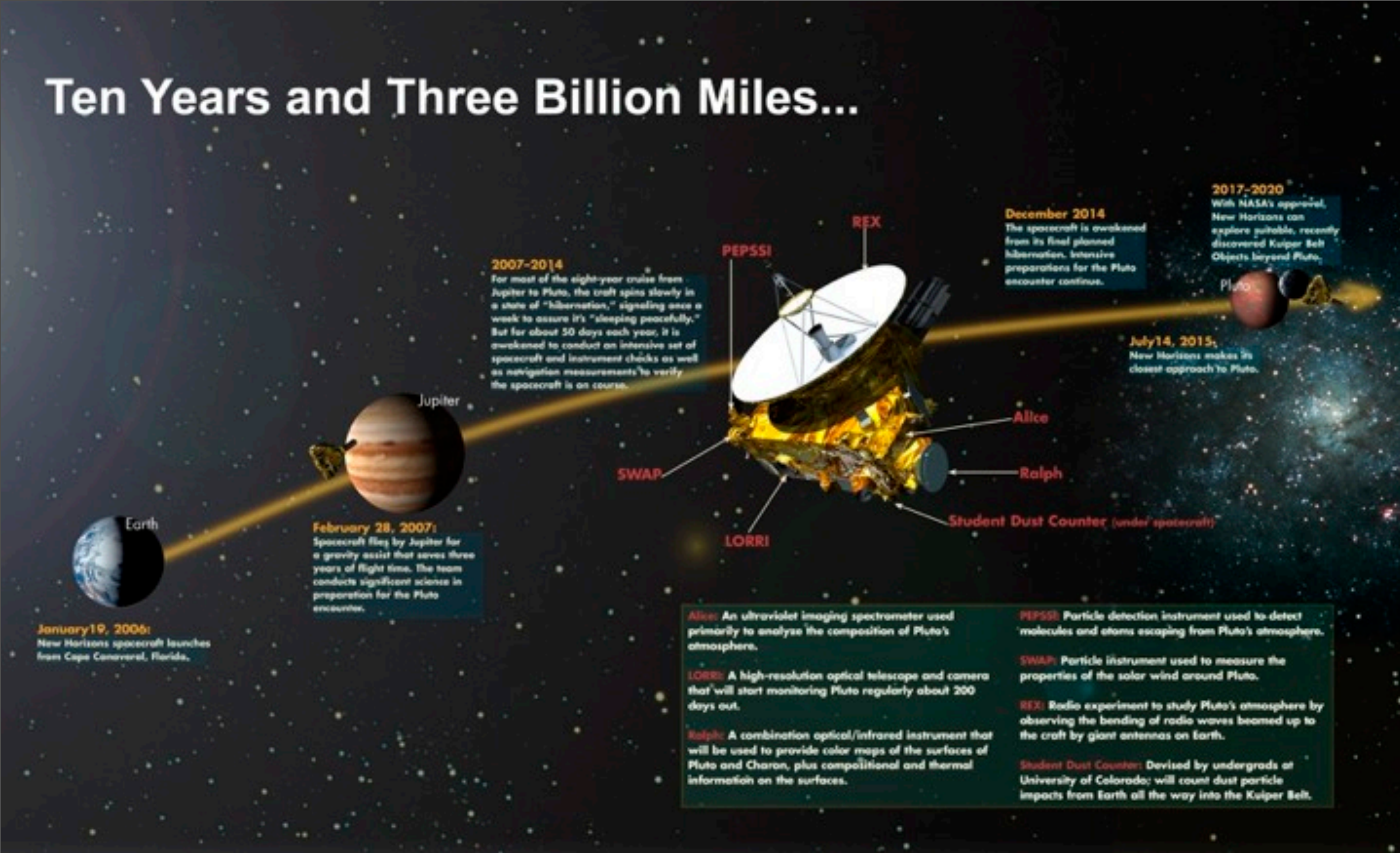
New Horizons

Launch: January 19, 2006

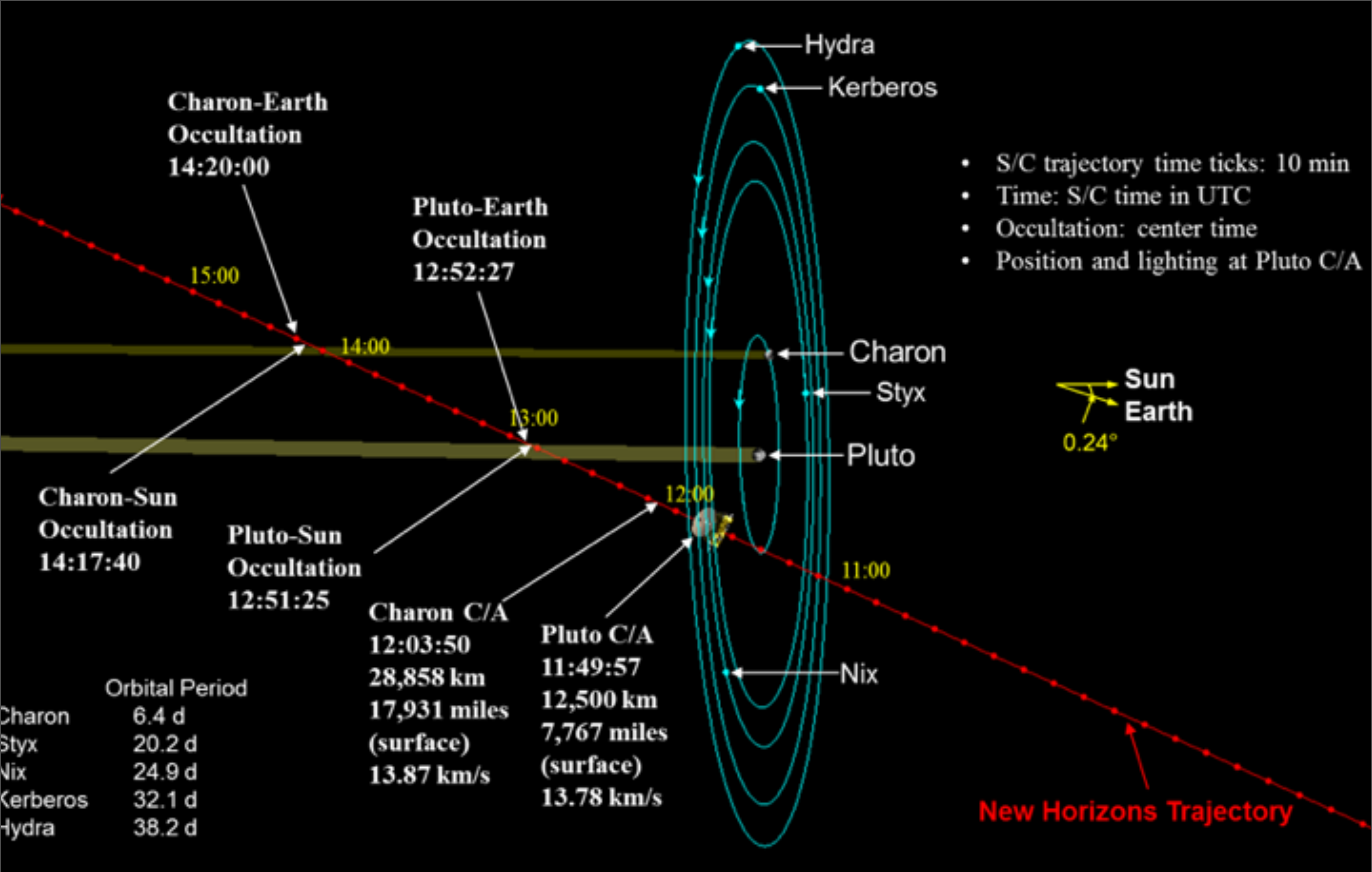
Power: A radioisotope thermoelectric generator (RTG) provided about 250 W, 30 V DC at launch, predicted to drop ~5% every 4 years to 200 W in 2015. The RTG was a spare from the Cassini mission. The RTG contains 10.9 kg (24 lb) of plutonium-238 oxide pellets. Each pellet is clad in iridium, then encased in a graphite shell. The mission parameters and observation sequence are modified for the reduced wattage, still, not all instruments can operate simultaneously. Tne Department of Energy estimated the chances of a launch accident that would release radiation into the atmosphere at 1 in 350 It was estimated that a worst-case scenario of total dispersal of on-board plutonium would spread the equivalent radiation of 80% the average annual dosage in North America from background radiation over an area with a radius of 105 km.

Computer and Communications: New Horizons has two computer systems. The Command and Data Handling system and the Guidance and Control processor. Each system is duplicated for redundancy. The processor used for its flight computers is the Mongoose-V, a 12 MHz radiation-hardened version of the MIPS R3000 CPU. On July 4, 2015 there was a CPU safing event caused by over-assignment of commanded science operations.

Telecommunications and data handling. Communication with New Horizons is via X band. The craft had a communication rate of 38 kbit/s at Jupiter; the rate is approximately 1 kbit/s at Pluto. New Horizons recorded data to its solid-state buffer during encounter to transmit to Earth later. Data storage was done on two solid-state recorders (one primary, one backup) holding up to 8 gigabytes each. Only one buffer load for an encounter can be saved. New Horizons will require more than 1 year after it has left the vicinity of Pluto to transmit the data back to Earth.



New Horizons path from the Earth to the Pluto system



New Horizons path through the Pluto system (July, 2015)

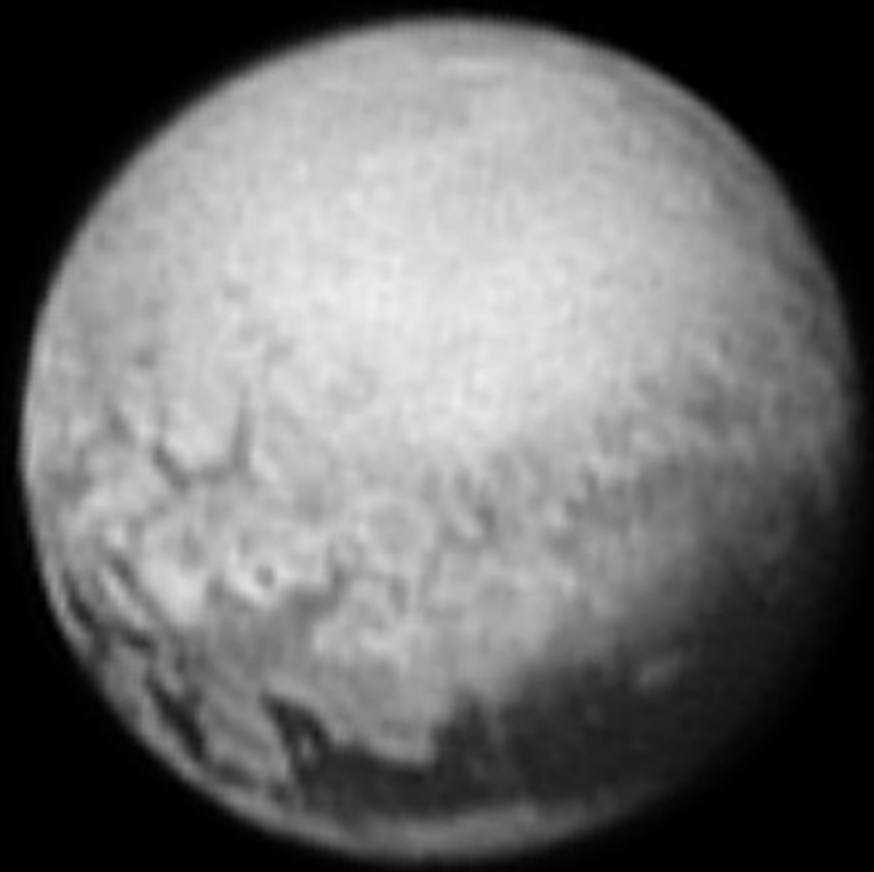
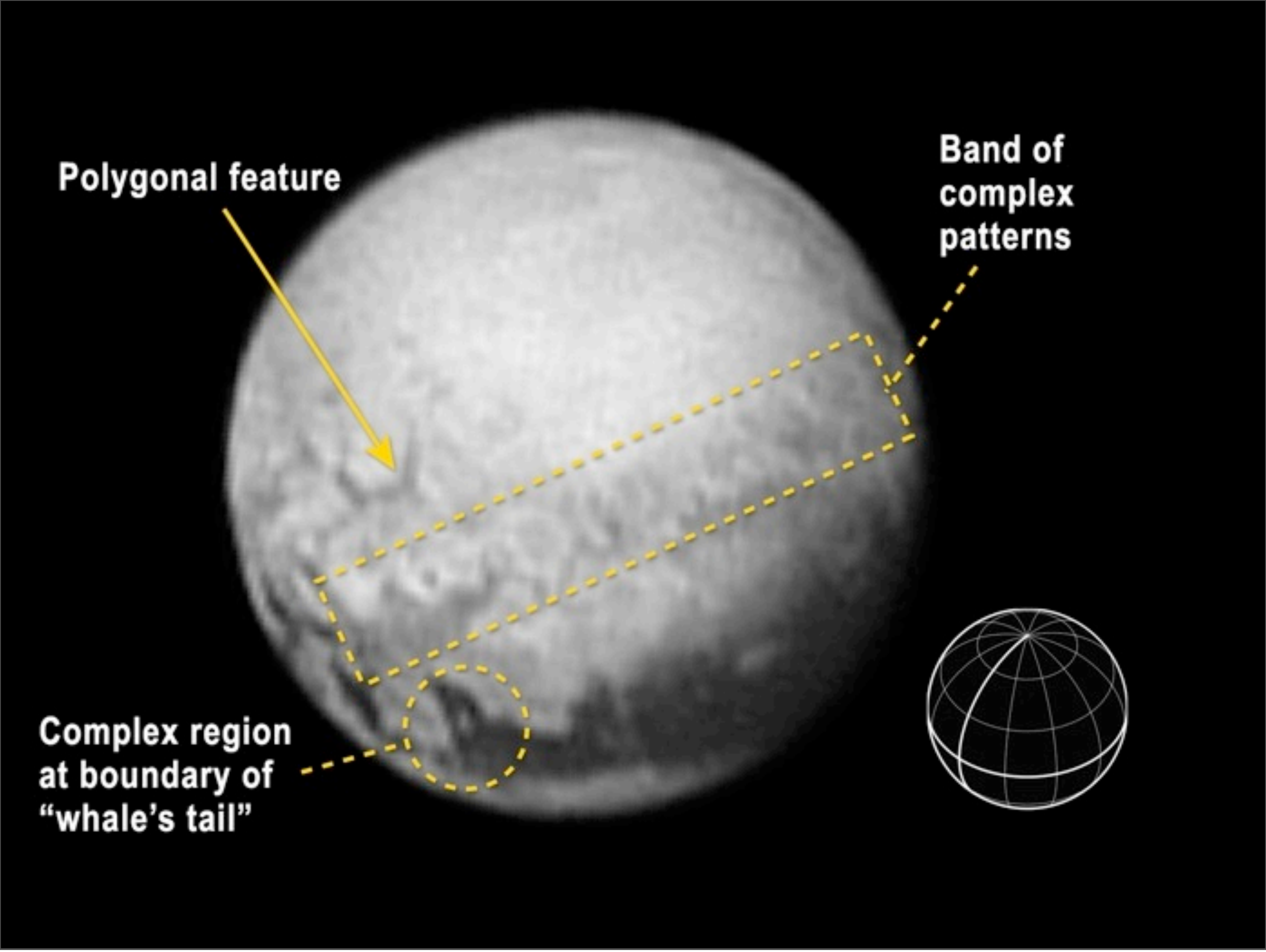
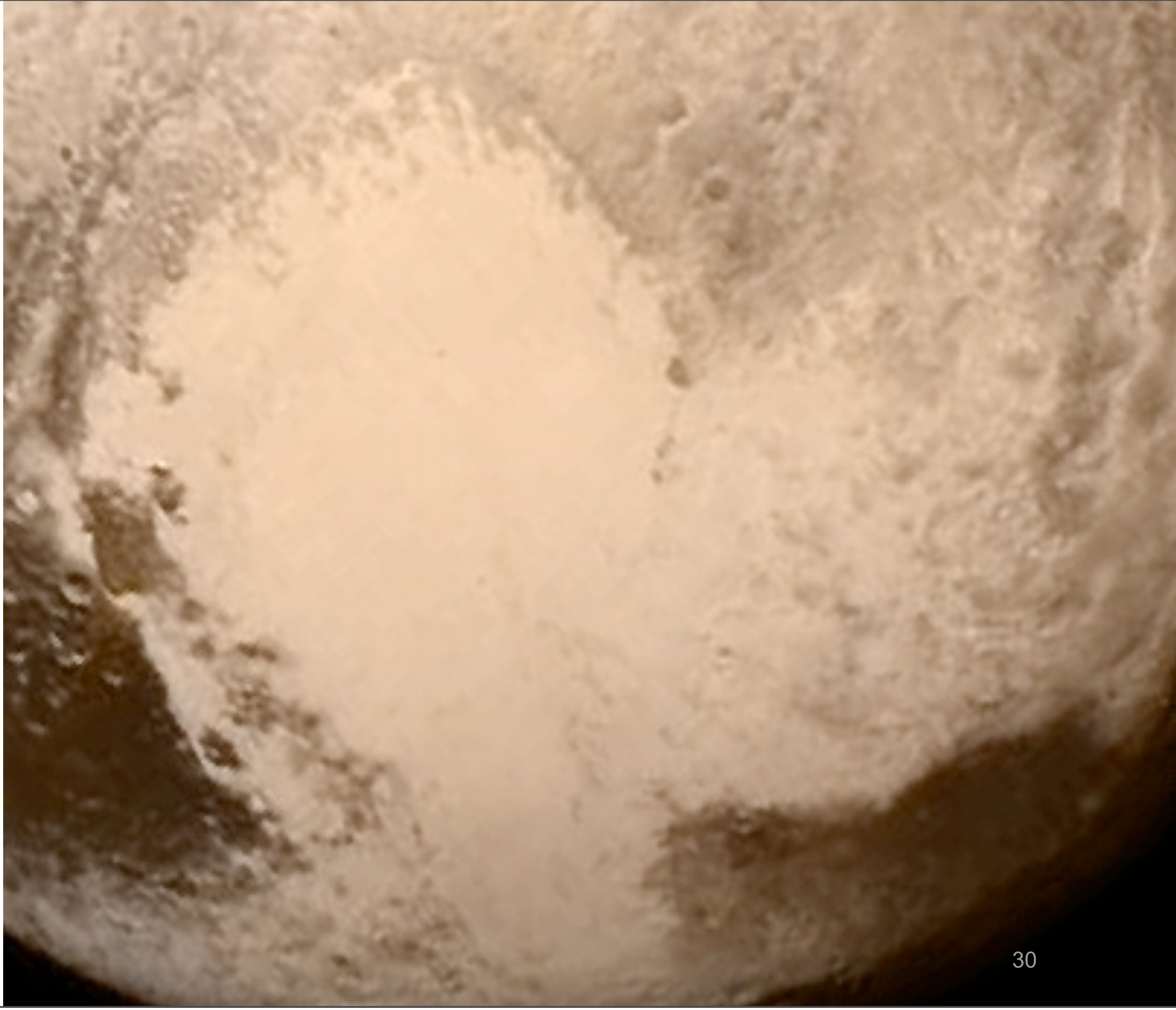
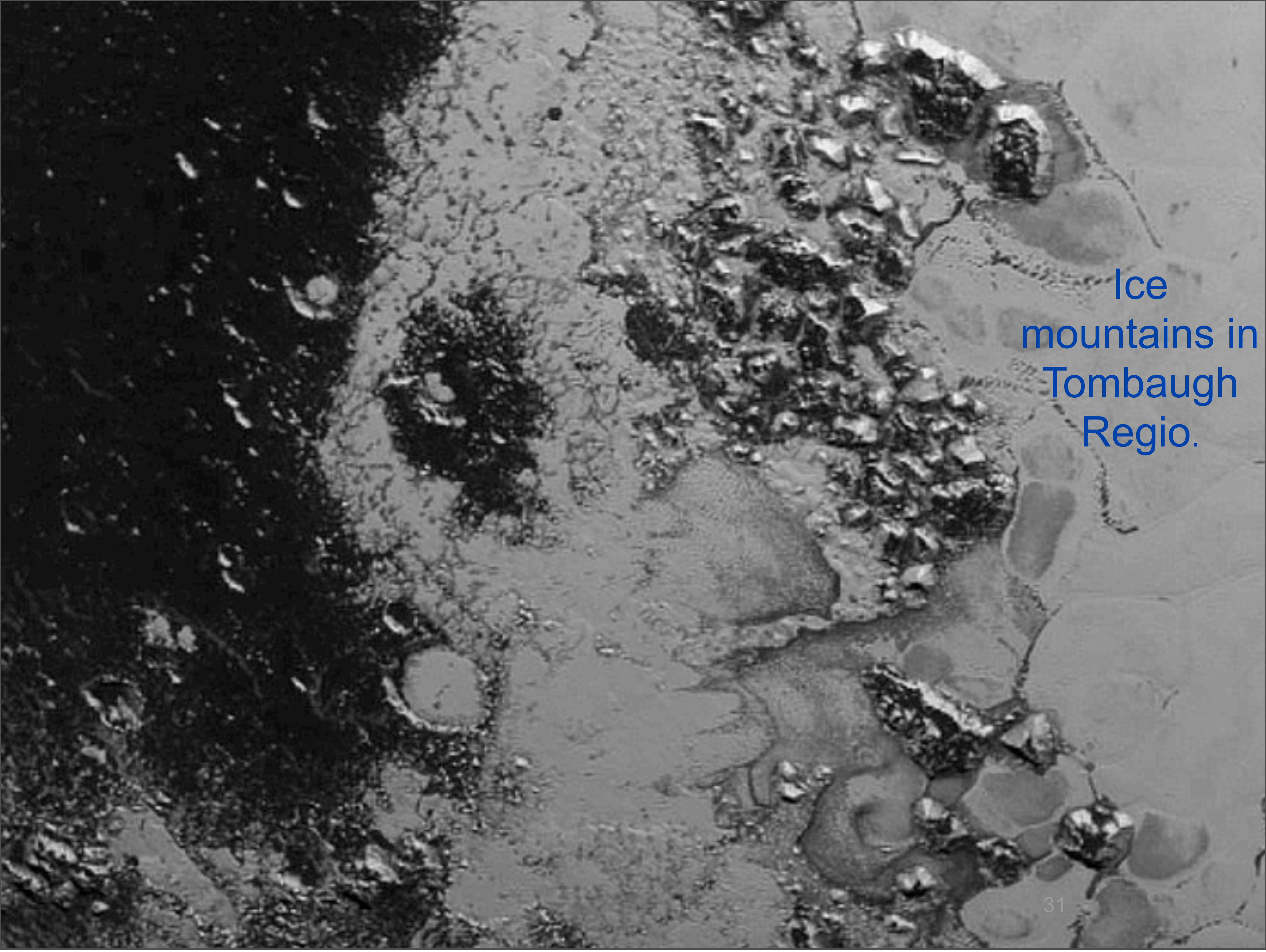


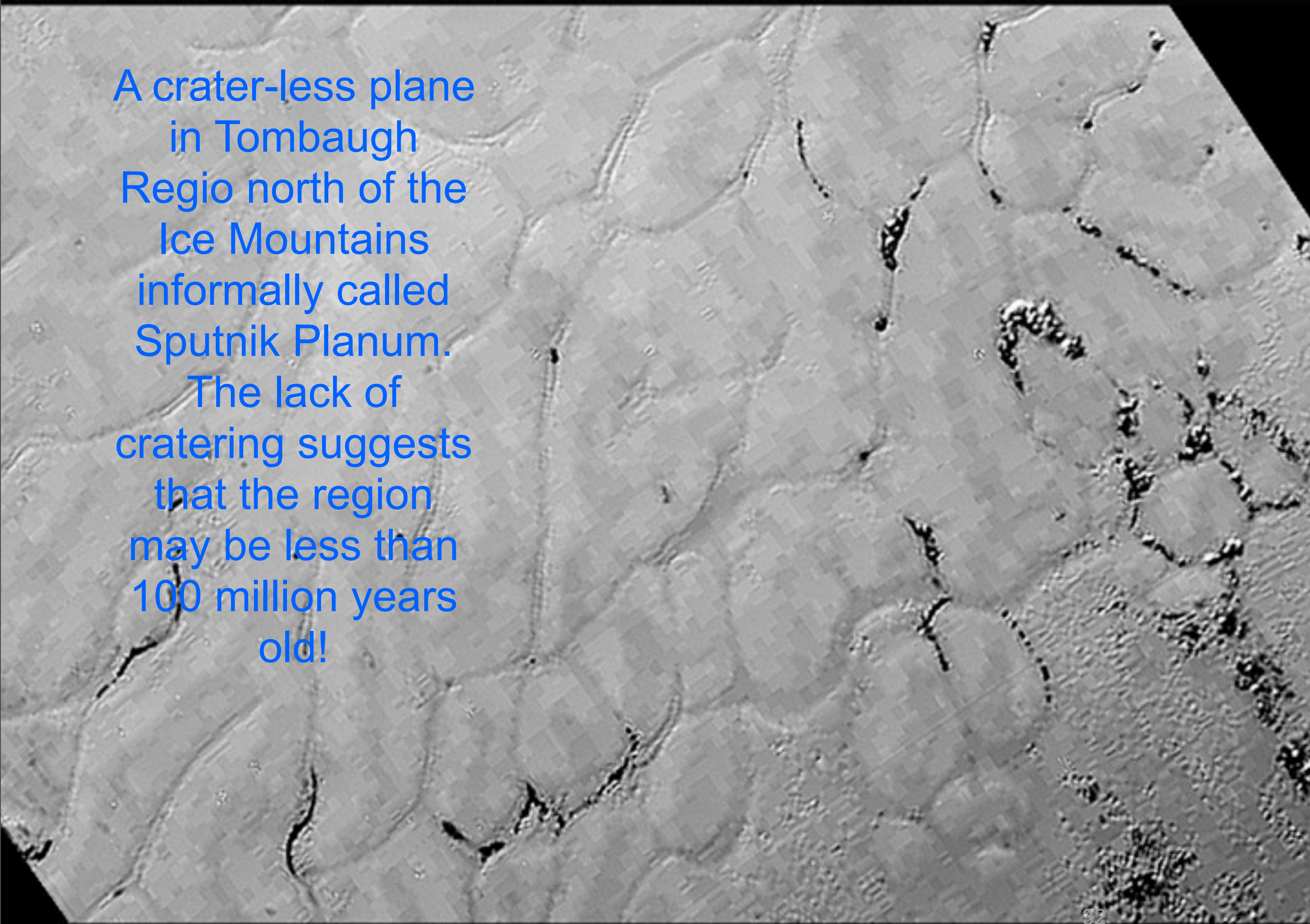
Image from New Horizons taken on July 9, 2015 from 5.4 million kilometers away. The annotation on the next page indicates features described in the text, and includes a reference globe showing Pluto's orientation in the image, with the equator and central meridian in bold.

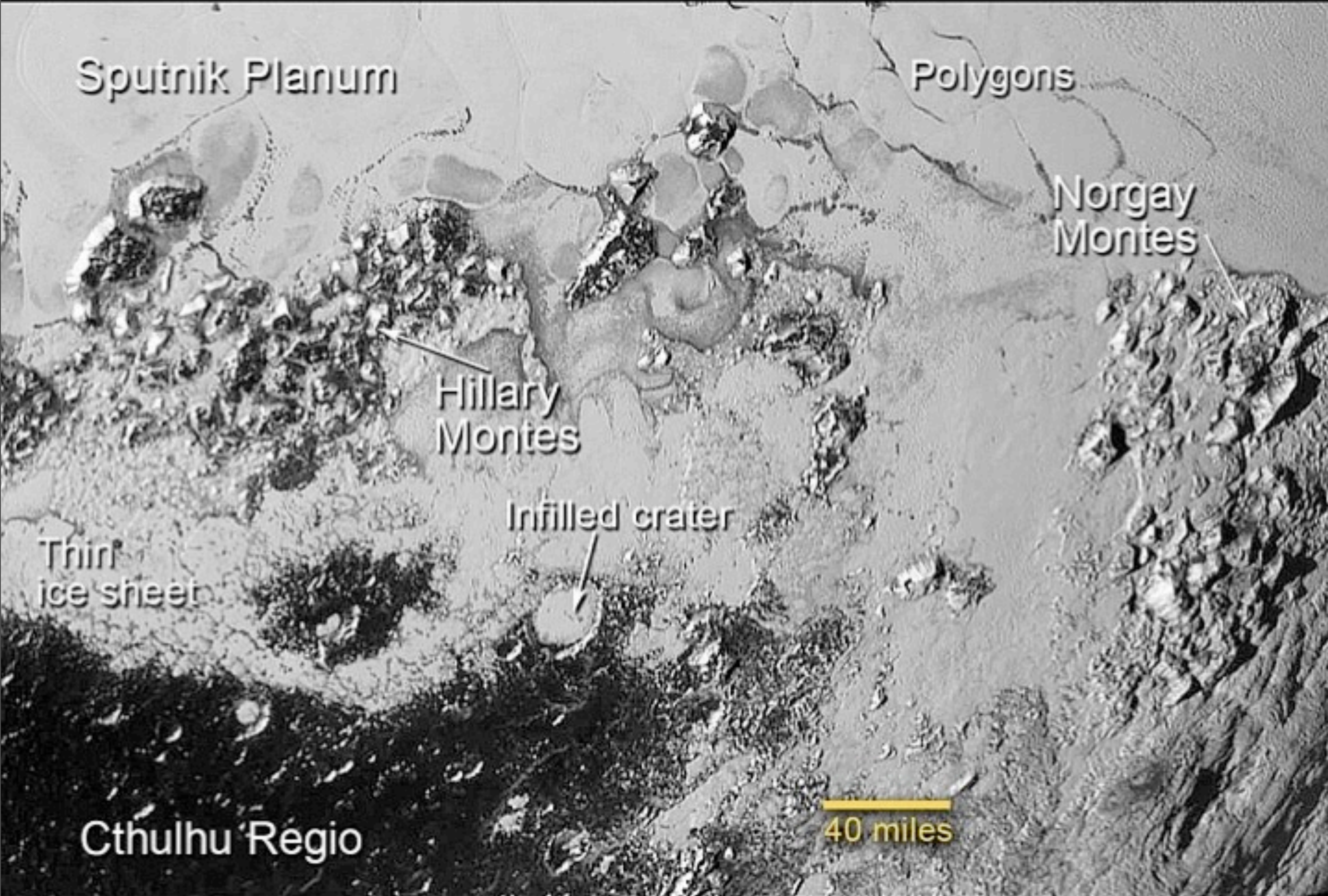

Polygonal feature
Band of
complex
patterns
Complex region
at boundary of
“whale’s tail”

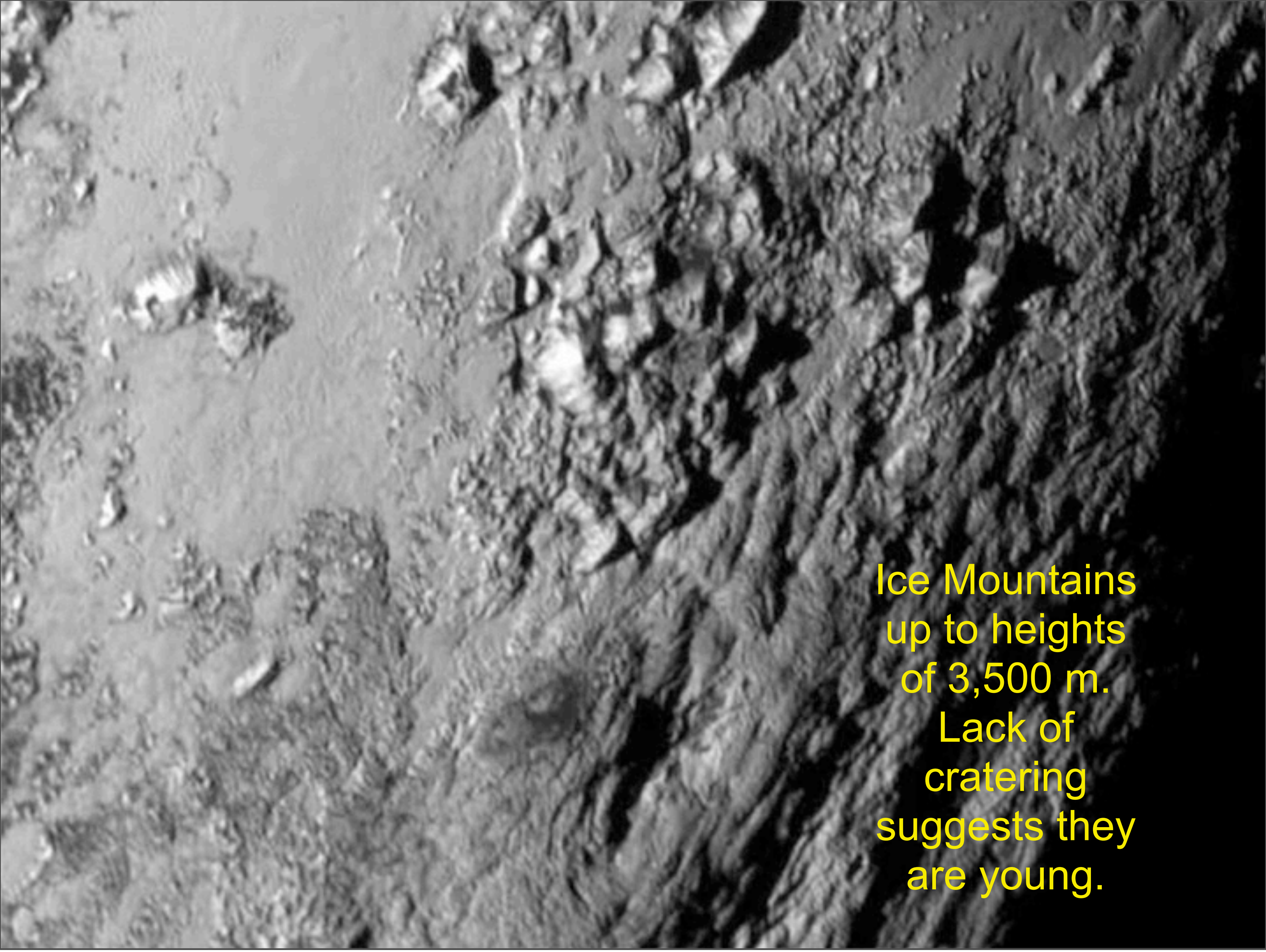
July 13, 2015, when New Horizons was 760,000 km from Pluto, about twice the Earth-Moon separation. The large heart-shaped region near the the bottom of the figure is Tombaugh Regio.

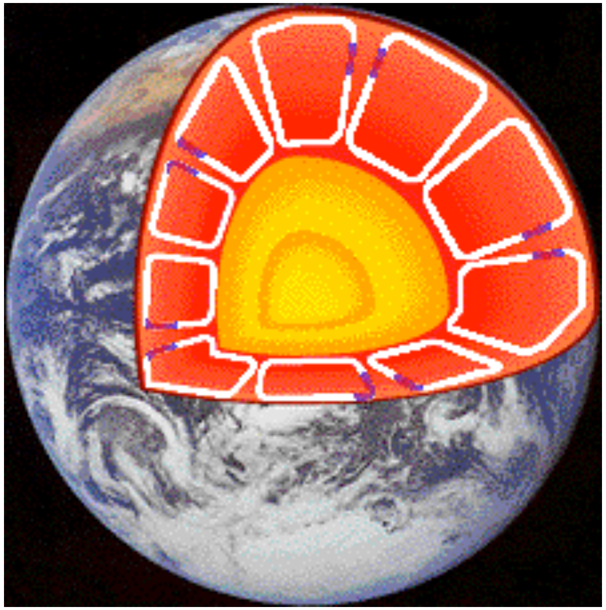



Ice
mountains in
Tombaugh
Regio.


A crater-less plane in Tombaugh Regio north of the Ice Mountains informally called Sputnik Planum. The lack of cratering suggests that the region may be less than 100 million years old!


Sputnik Planum
Polygons
Norgay
Montes
Hillary
Montes
Infilled crater
Thin
ice sheet
Cthulhu Regio
40 miles


Ice Mountains
up to heights
of 3,500 m.
Lack of
cratering
suggests they
are young.

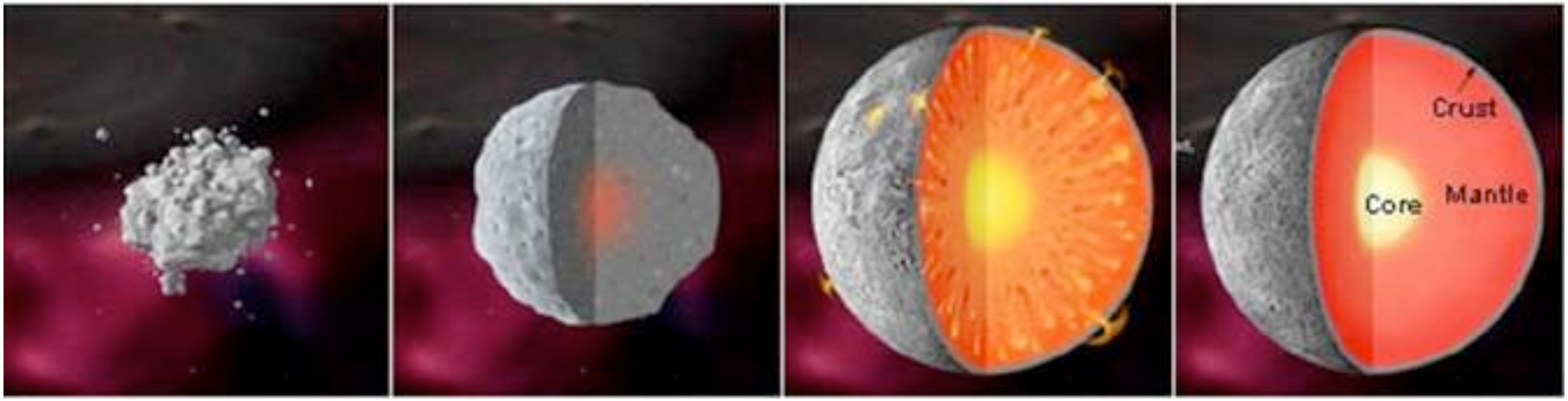


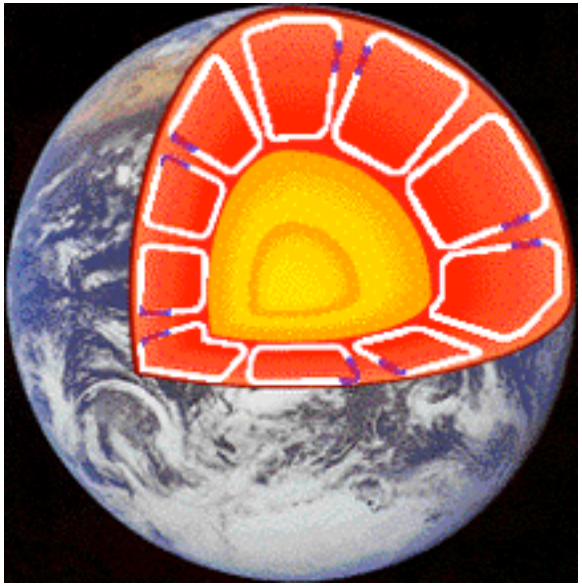
Geology on Pluto

Energy flow drives geology.

Cooling lifetime = energy store/loss rate:

$$\tau = (R^3 \mathrm{Number}/3)/(R^2 \mathrm{Power}) \propto R$$





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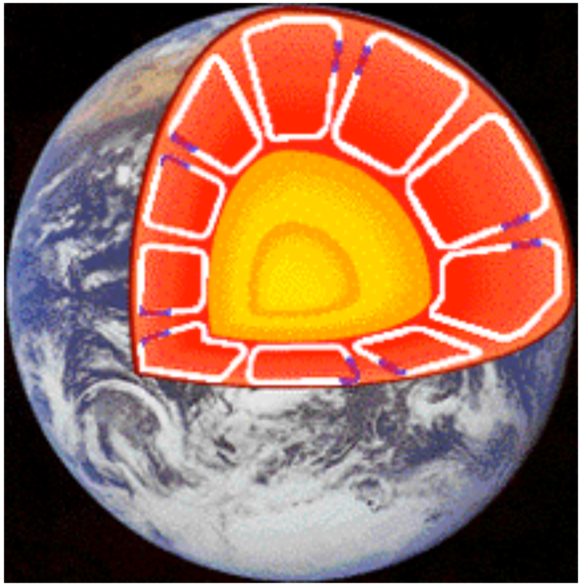
The heat contained in a planet is the left-over heat from its formation. We estimate this from the initial temperature of the planet's interior. Because the temperature is a measure of the average kinetic of an atom or molecule, the total energy is then given by the number of atoms and molecules, N.



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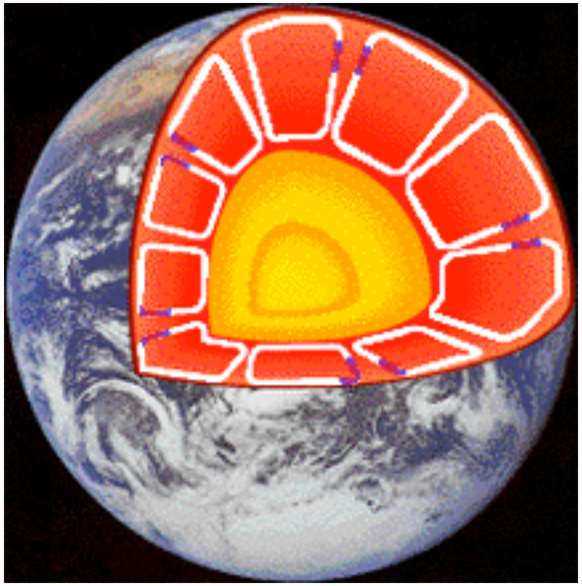
The continued heating due to radioactive decay is determined by how many radioactive elements there are in the planet. This will be some fraction of the total number, say αN.



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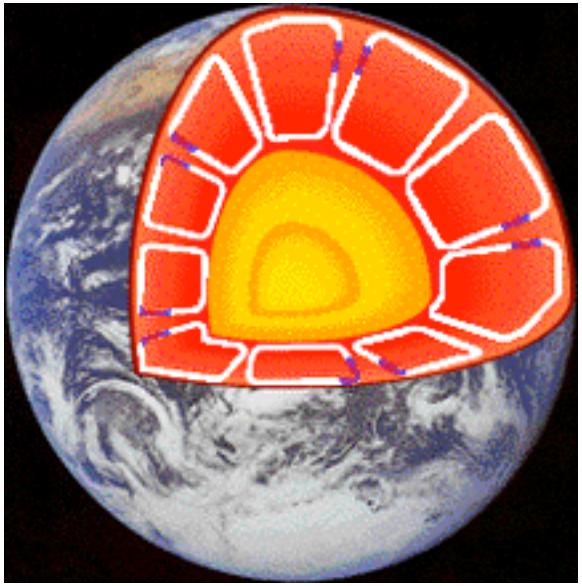
Further energy could be added by material falling onto the planet (important for Saturn).



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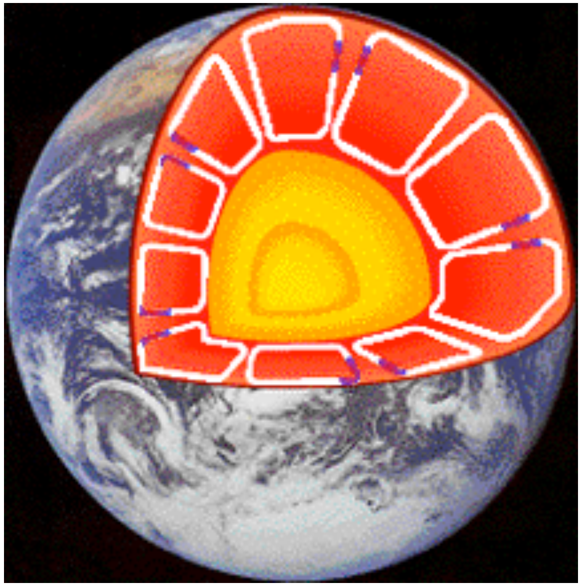
The planet loses energy from its surface which depends on the surface area of the planet.



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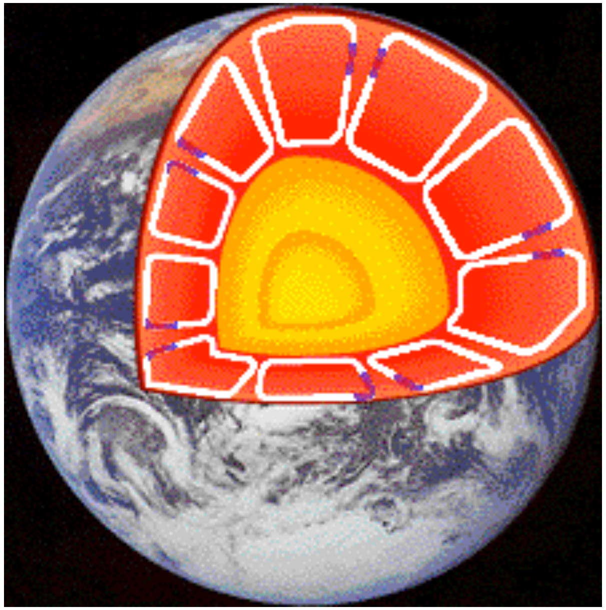
This leads to the cooling lifetime τ given above. The larger the size of the planet, the more slowly it cools and remains hot and so supports geology.



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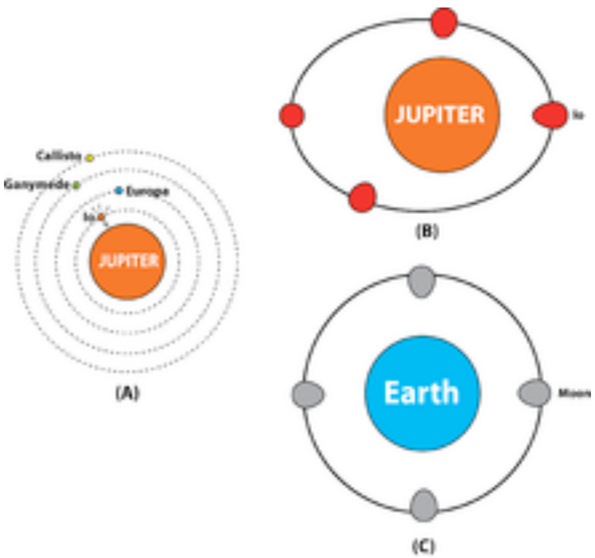
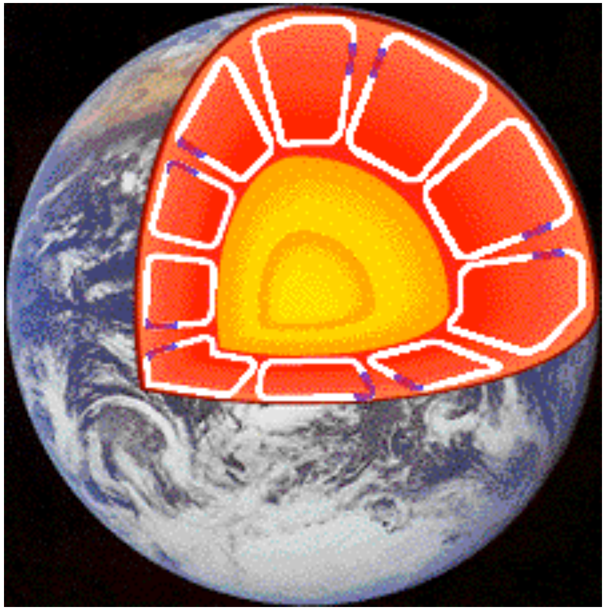
Because of the smalll size of Pluto, the cooling lifetime is short and so, unless there is another source of heating, active geology is not likely. Tidal heating as between Jupiter and Io?





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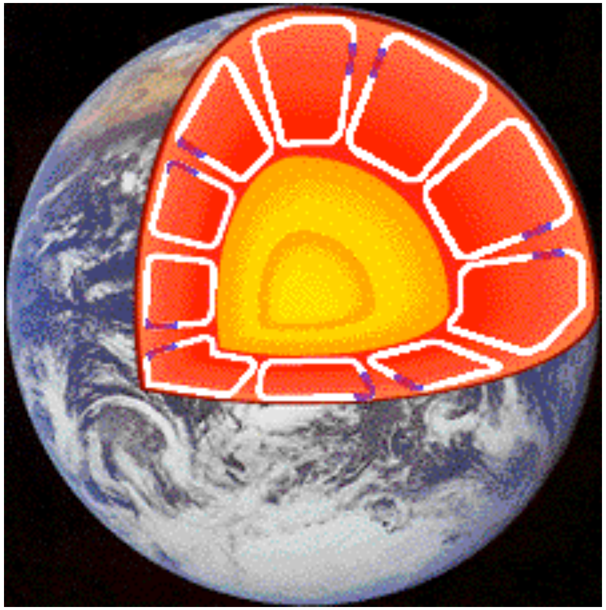
Tidal heating is not likely; the eccentricity of Pluto and Charon's orbit is 0.003-0.008 and so the orbit is very nearly circular.



Geology on Pluto

Energy flow drives geology.

Cooling lifetime = energy store/loss rate:

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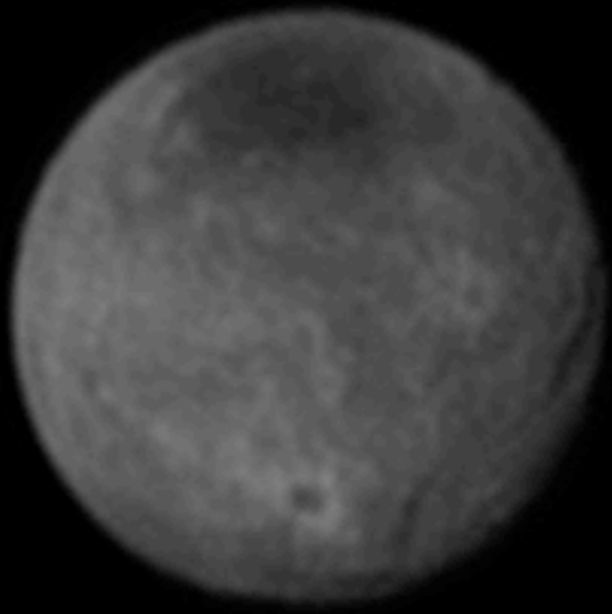
Tidal heating is not likely; the eccentricity of Pluto and Charon's orbit is 0.003-0.008 and so the orbit is very nearly circular.

The geology of Pluto was likely driven by the decay of radioactive nuclei, heat left-over from its violent birth, or perhaps, interestingly, from the energy released during the transition of liquid water to ice.



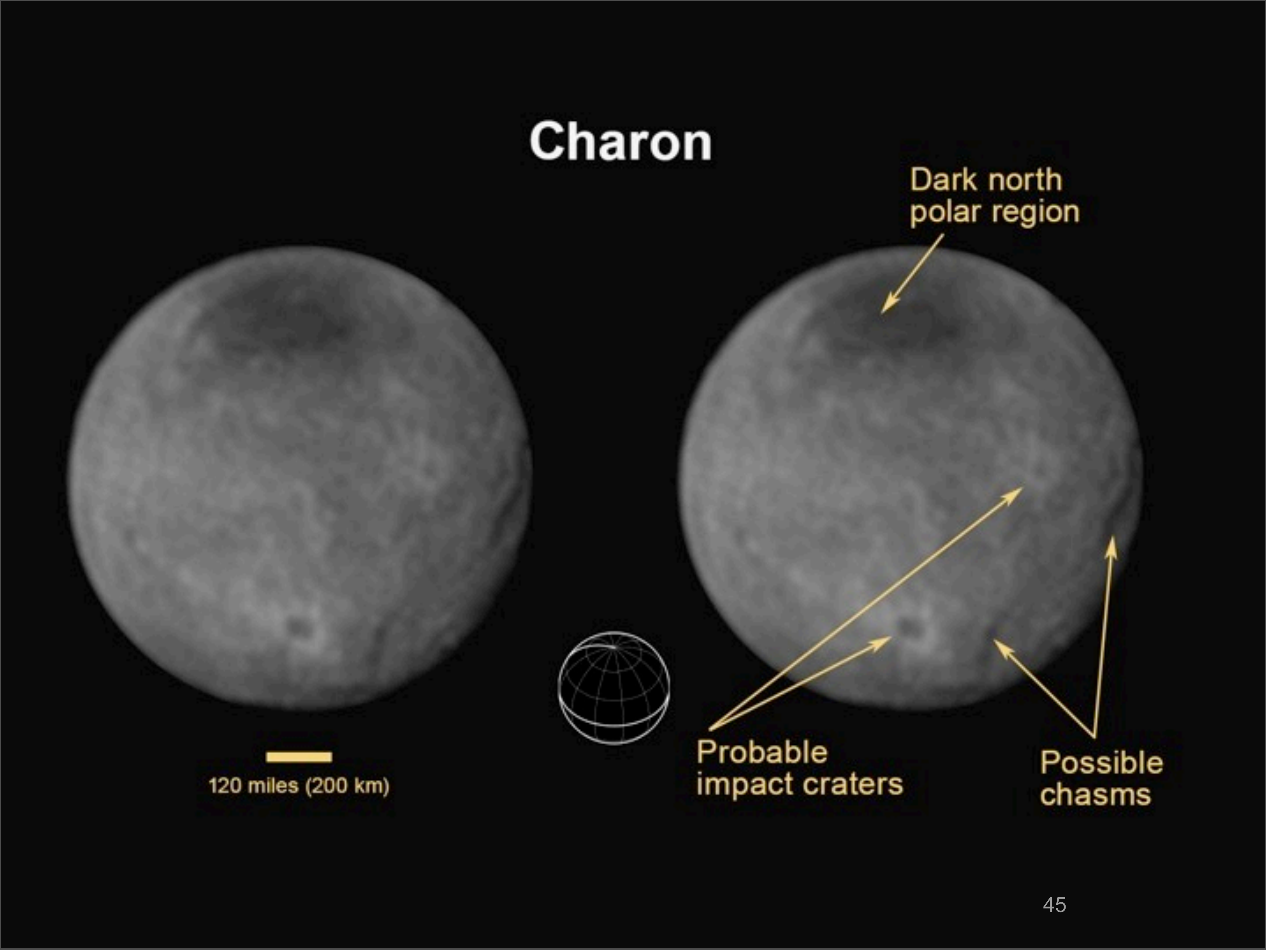
Geology on Charon

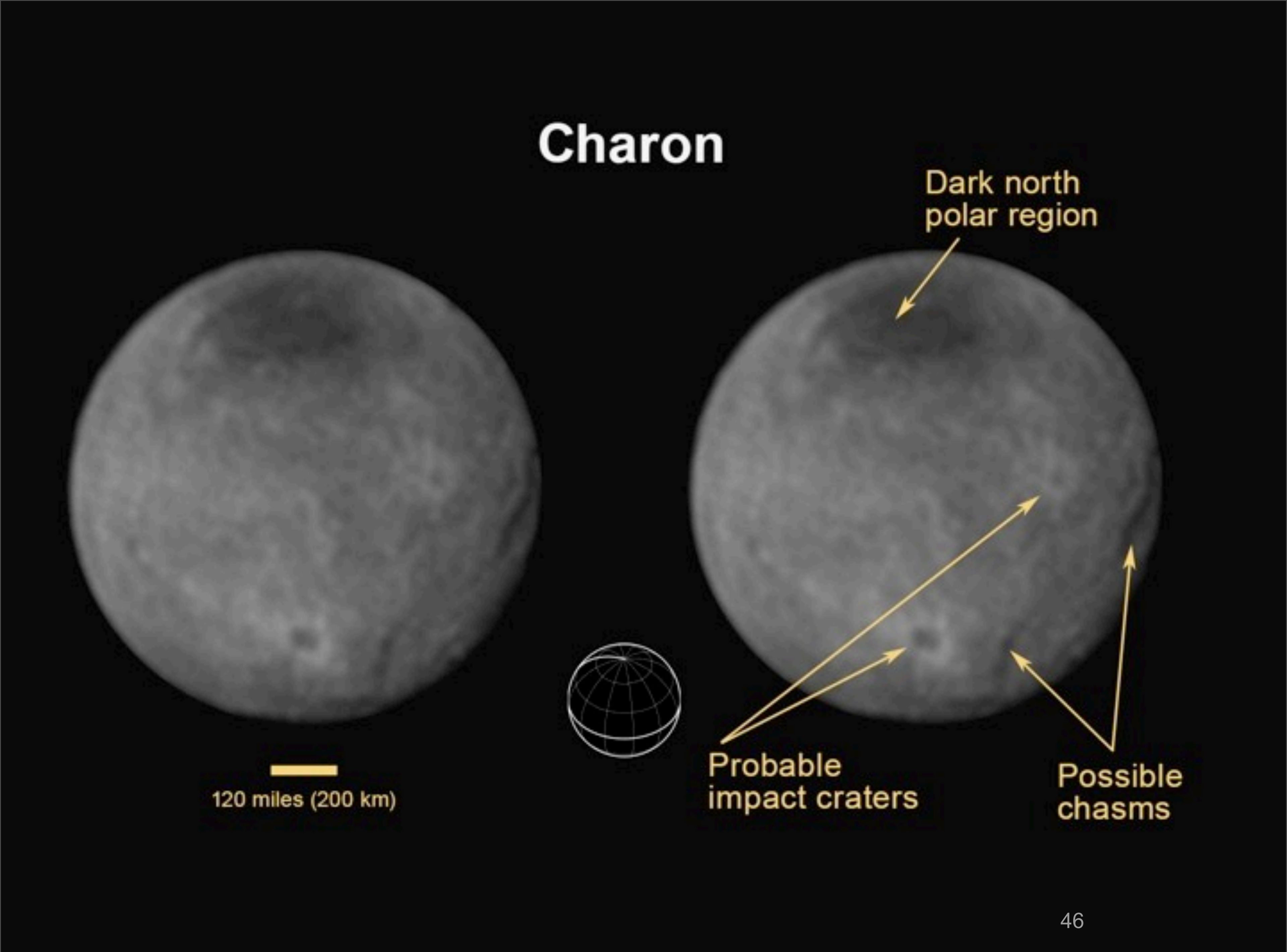
Energy flow drives geology.

Cooling lifetime = energy store/loss rate:

$$\tau = (R^3N/3)/(R^2 Power) \propto R$$

Images from New Horizons reveal chasms and craters on Charon. See next page for an annotated figure of Charon. The most pronounced chasm lies in the southern hemisphere and is longer and deeper than the Grand Canyon. This is the first example of a surface disruption on Charon. The largest crater seen on Charon is ~100 km across. Signs of geology!


Charon
Dark north polar region
120 miles (200 km)
Probable impact craters
Possible chasms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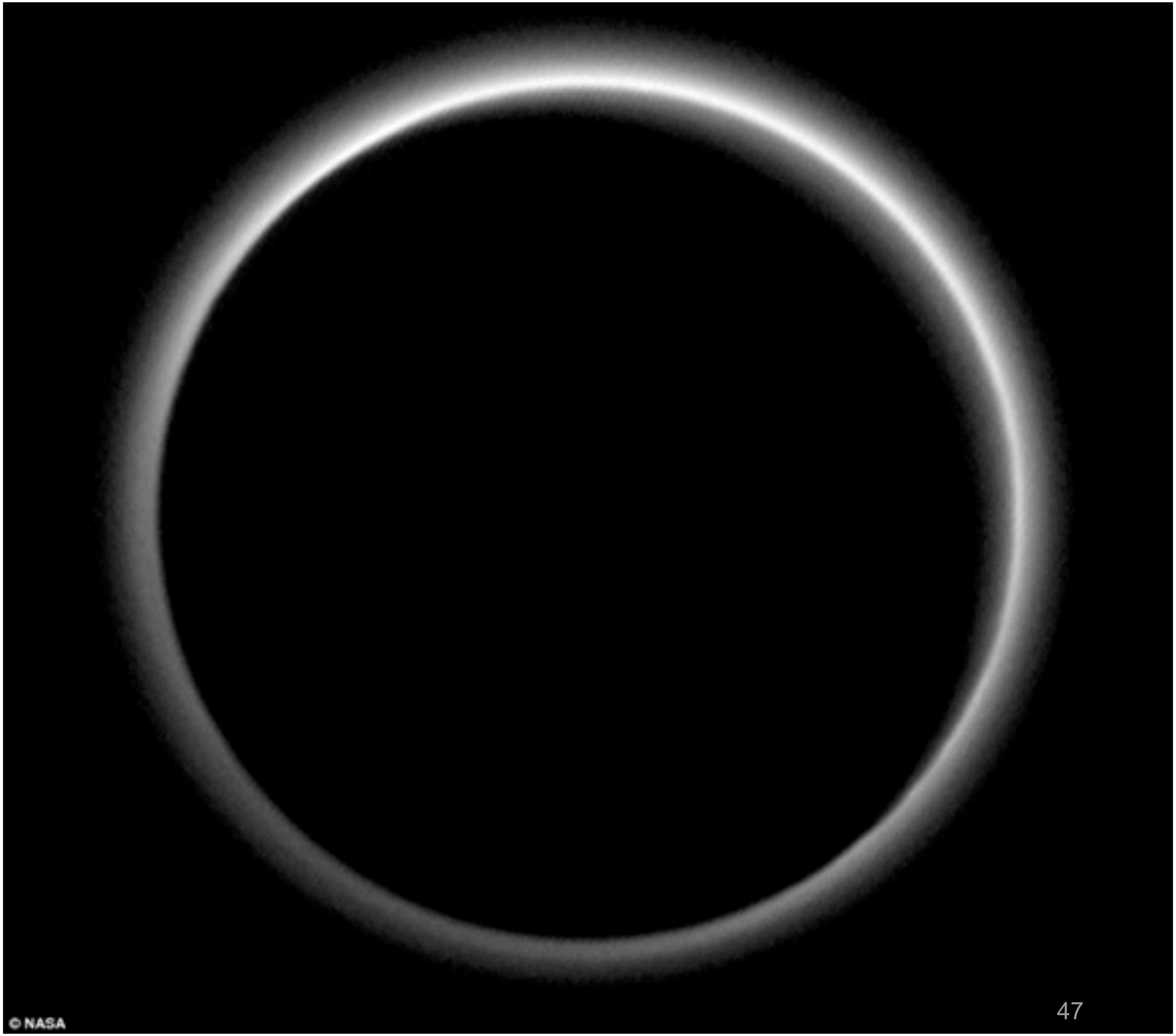
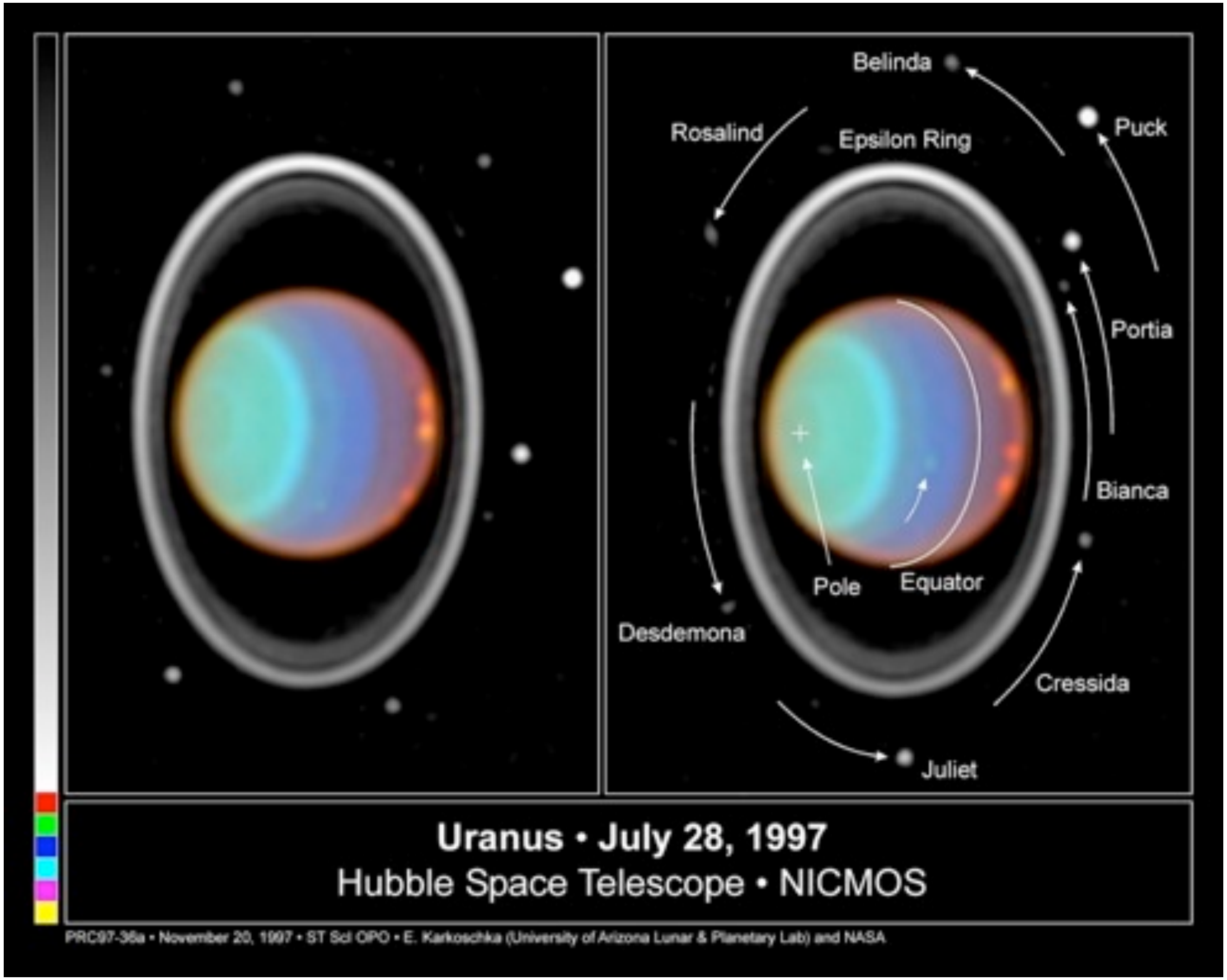

© NASA

The escape speed from Pluto is very small, v_e ~ 1.2 km/s, compare to the Earth where the escape speed is 11.2 km/s. The temperature on Pluto is ~ -220 to -230 Centrigrade. At these temperatures nitrogen molecules move at average speeds of ~2 km/s and will quickly be lost from Pluto.

It will be interesting to see how winds flow on Pluto. For example, on Uranus where the spin axis has inclination 97^o the winds circulate about the poles while the sub-Solar points are still hottest.

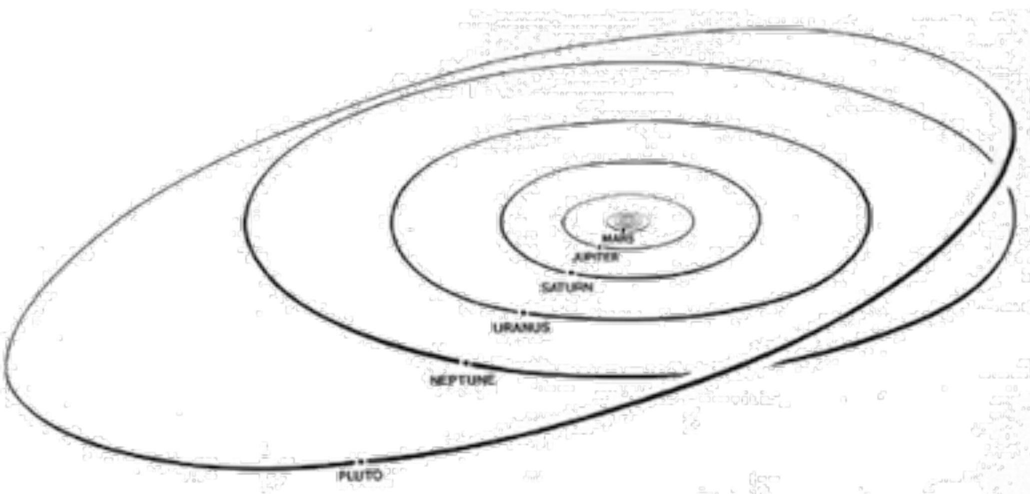


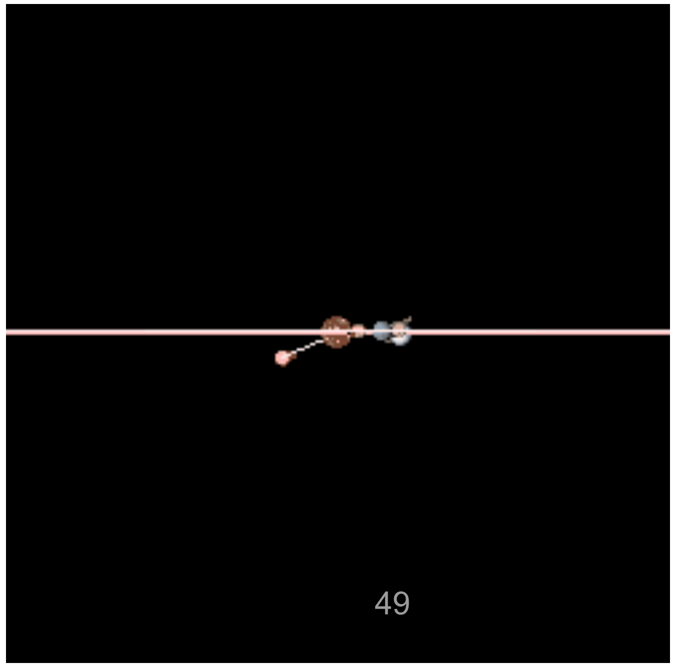
The seasons on Pluto will also be interesting. In the case of Pluto it is thought that seasonal variations will be driven by the large difference between perihelion and aphelion distances unlike on the Earth, because of Pluto's large ε.

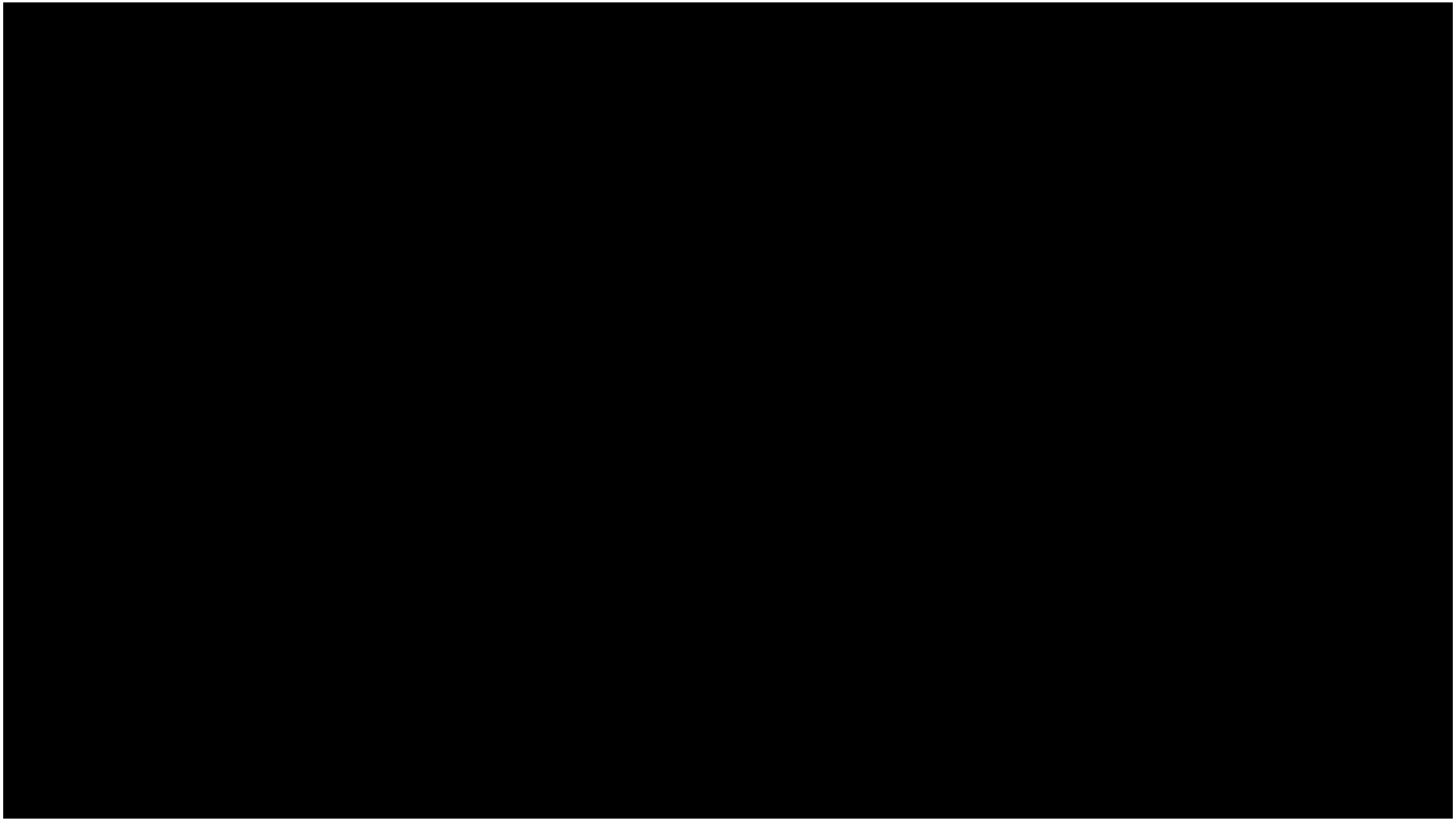
ATMOSPHERE OF PLUTO

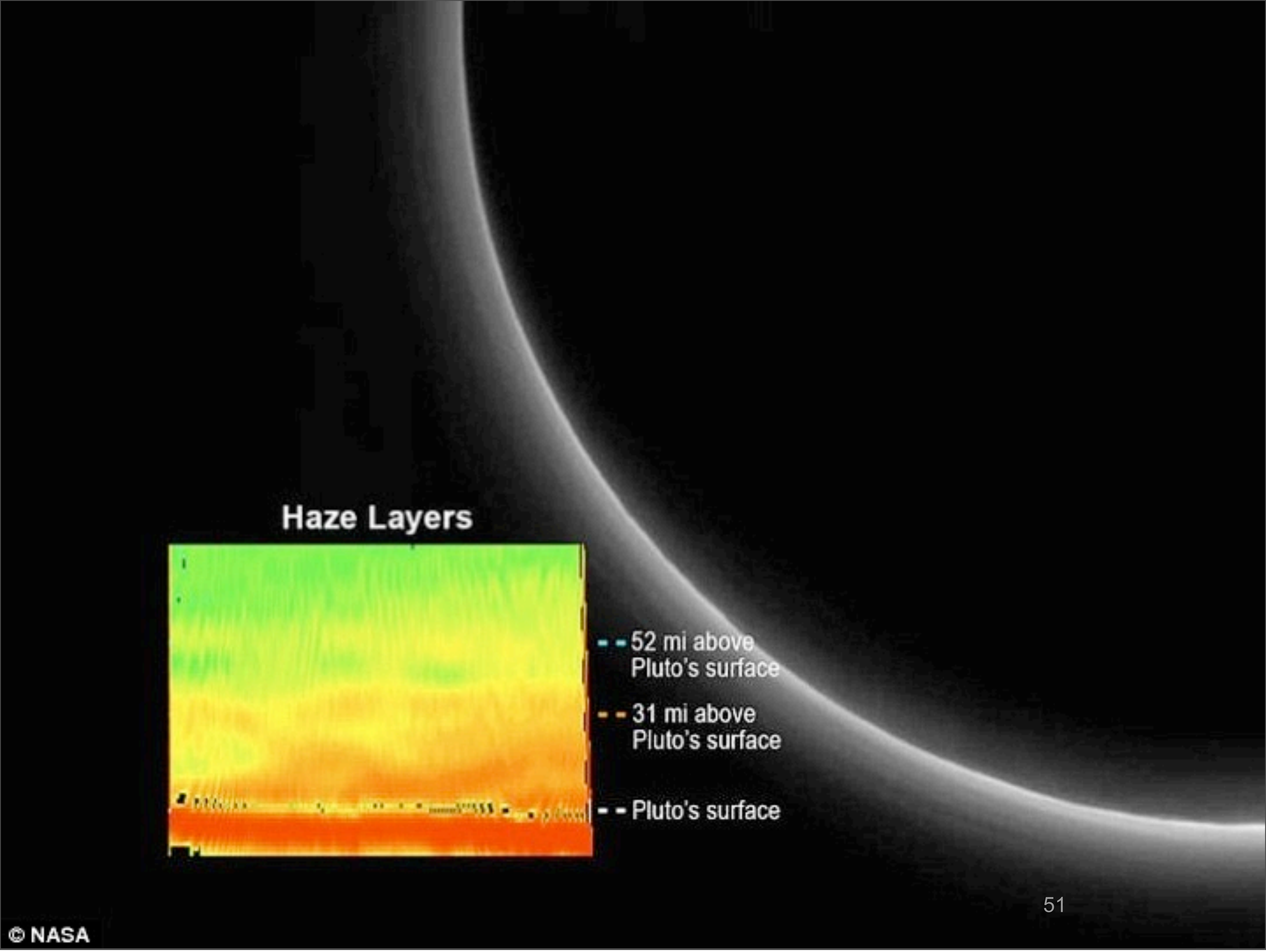
Pluto's highly elliptical orbit can take it more than 49 times as far out from the sun as Earth. (Pluto's orbital eccentricity, ε = 0.248 and orbital inclination i = 17.2°.) Pluto is actually closer to the Sun than is Neptune for 20 years out of it's 248 year long orbit. Until 1999 when Pluto crossed Neptune's orbit again became the farthest planet from the Sun, until it was demoted to the status of dwarf planet. Average distance from the sun: 5,906,380,000 km — 30.171 times that of Earth

Pluto has rotation period 6.39 days with an inclination of 122° (retrograde).

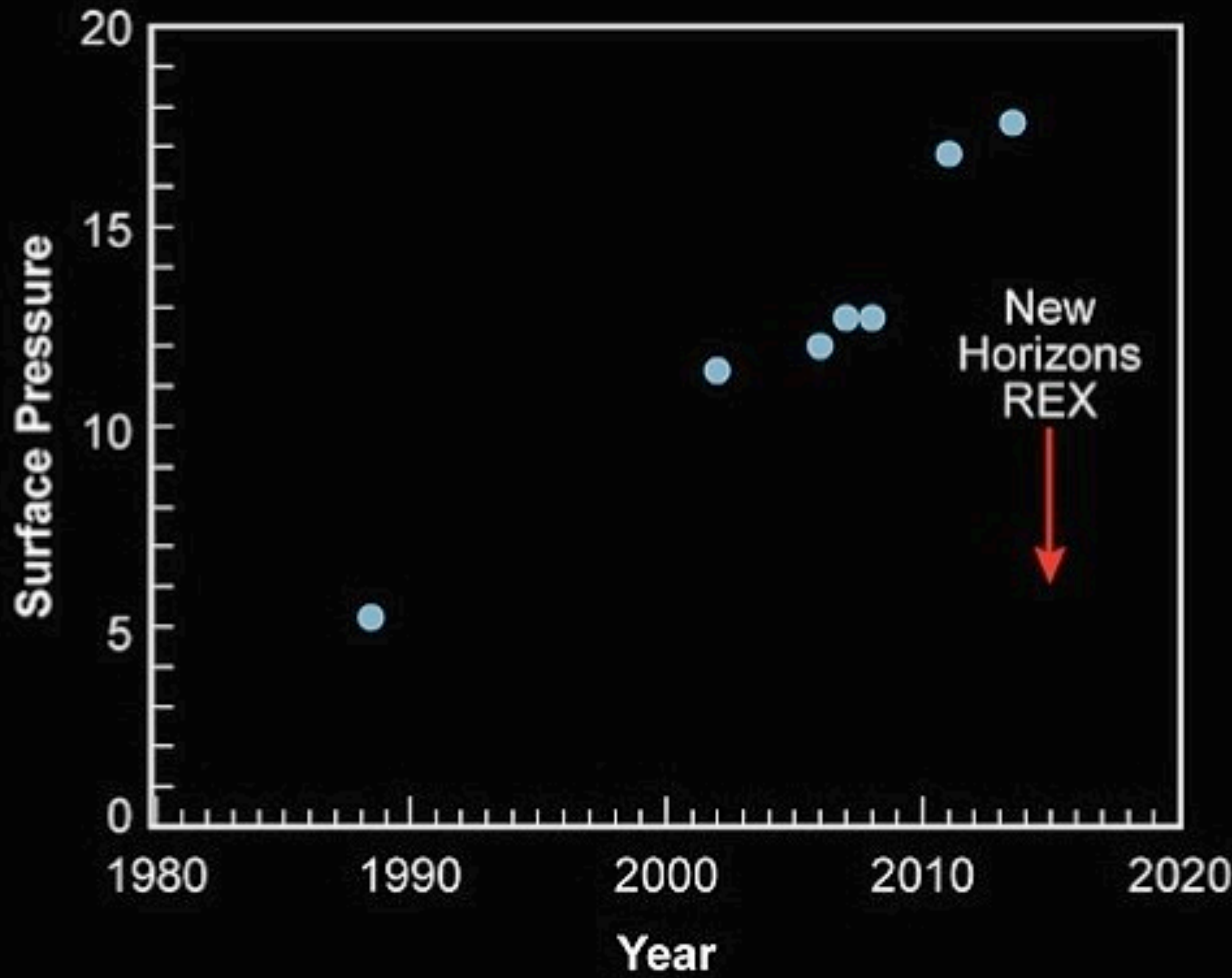


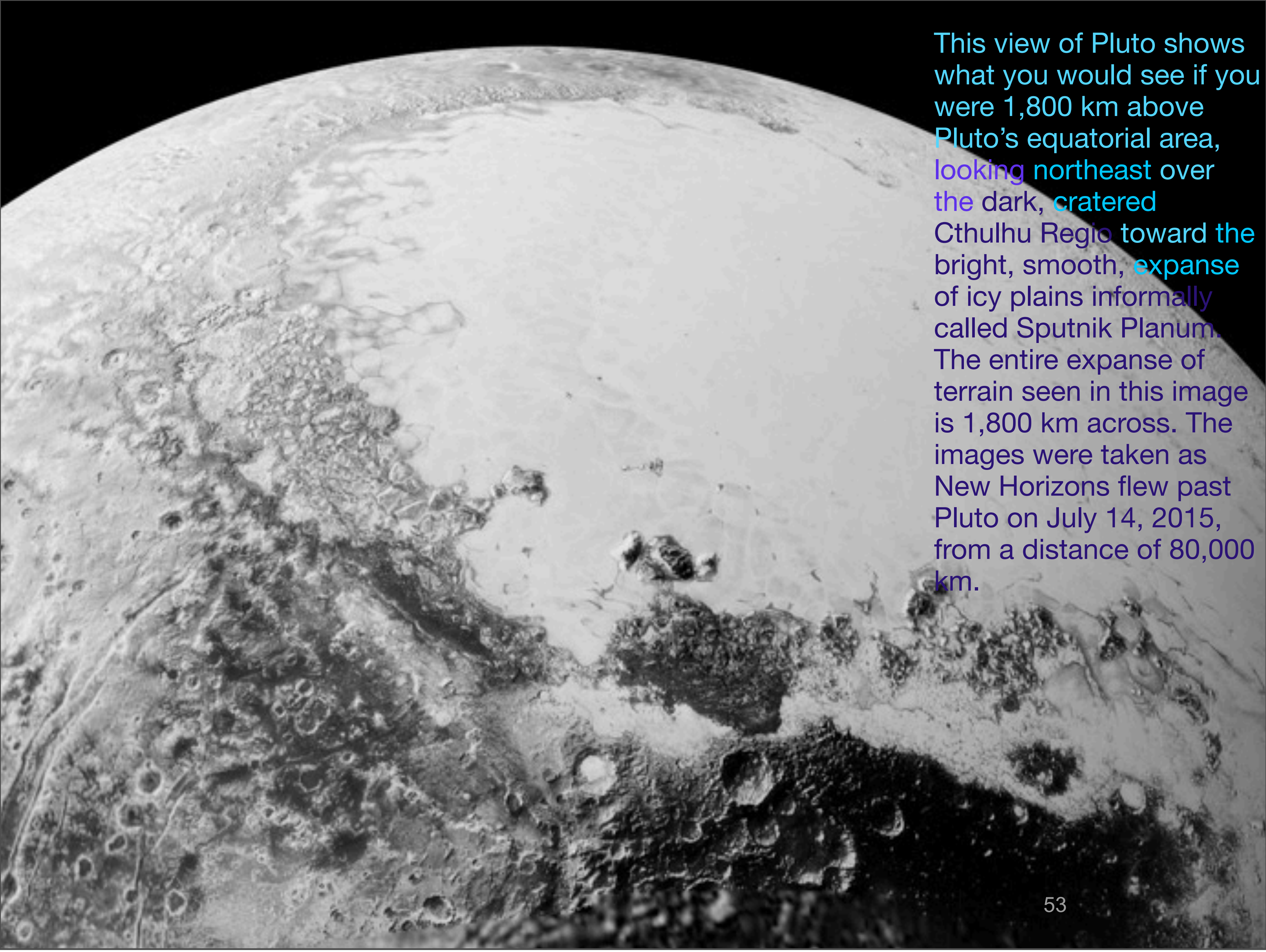




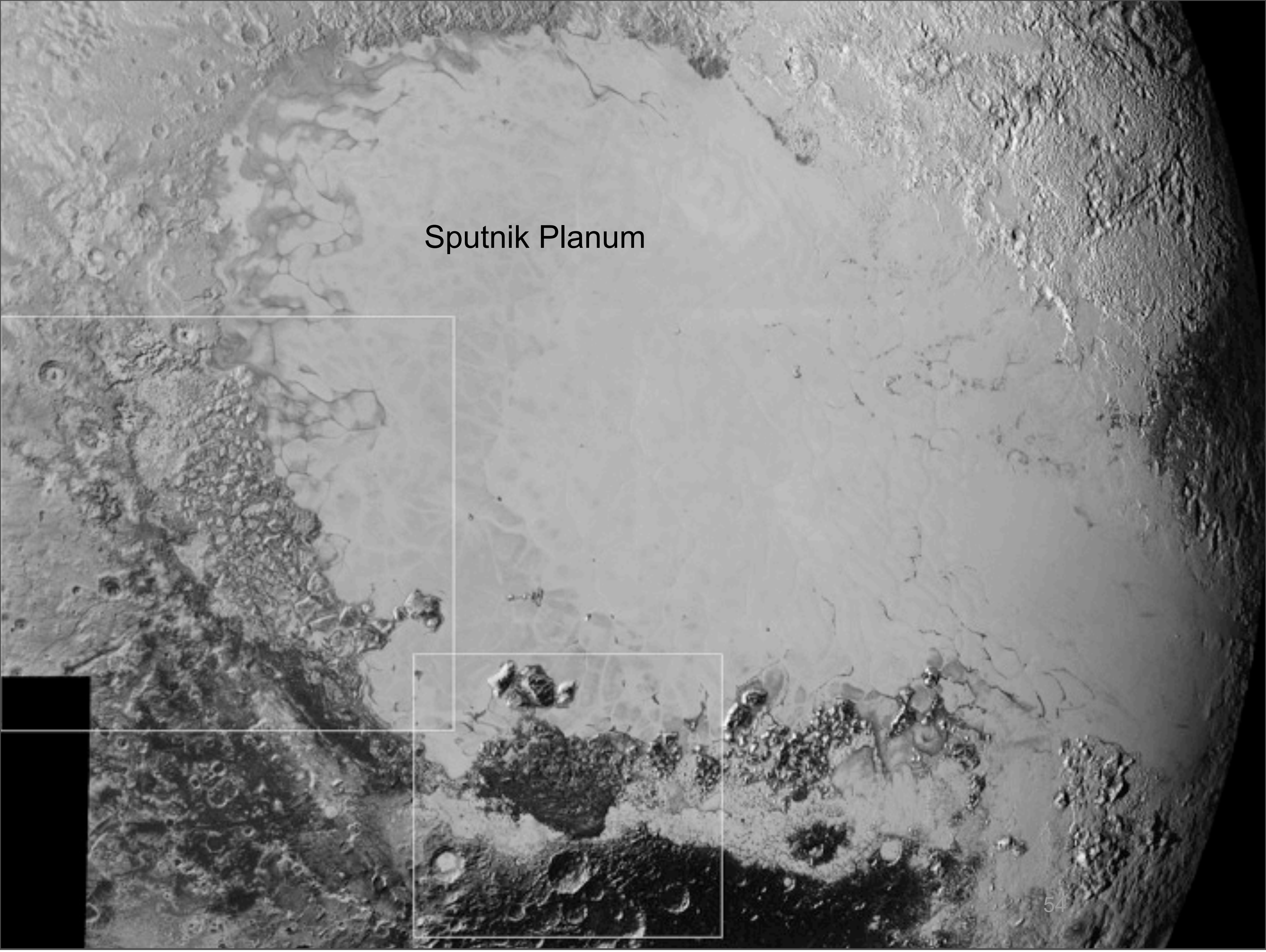

Haze Layers
52 mi above Pluto's surface
31 mi above Pluto's surface
Pluto's surface
© NASA

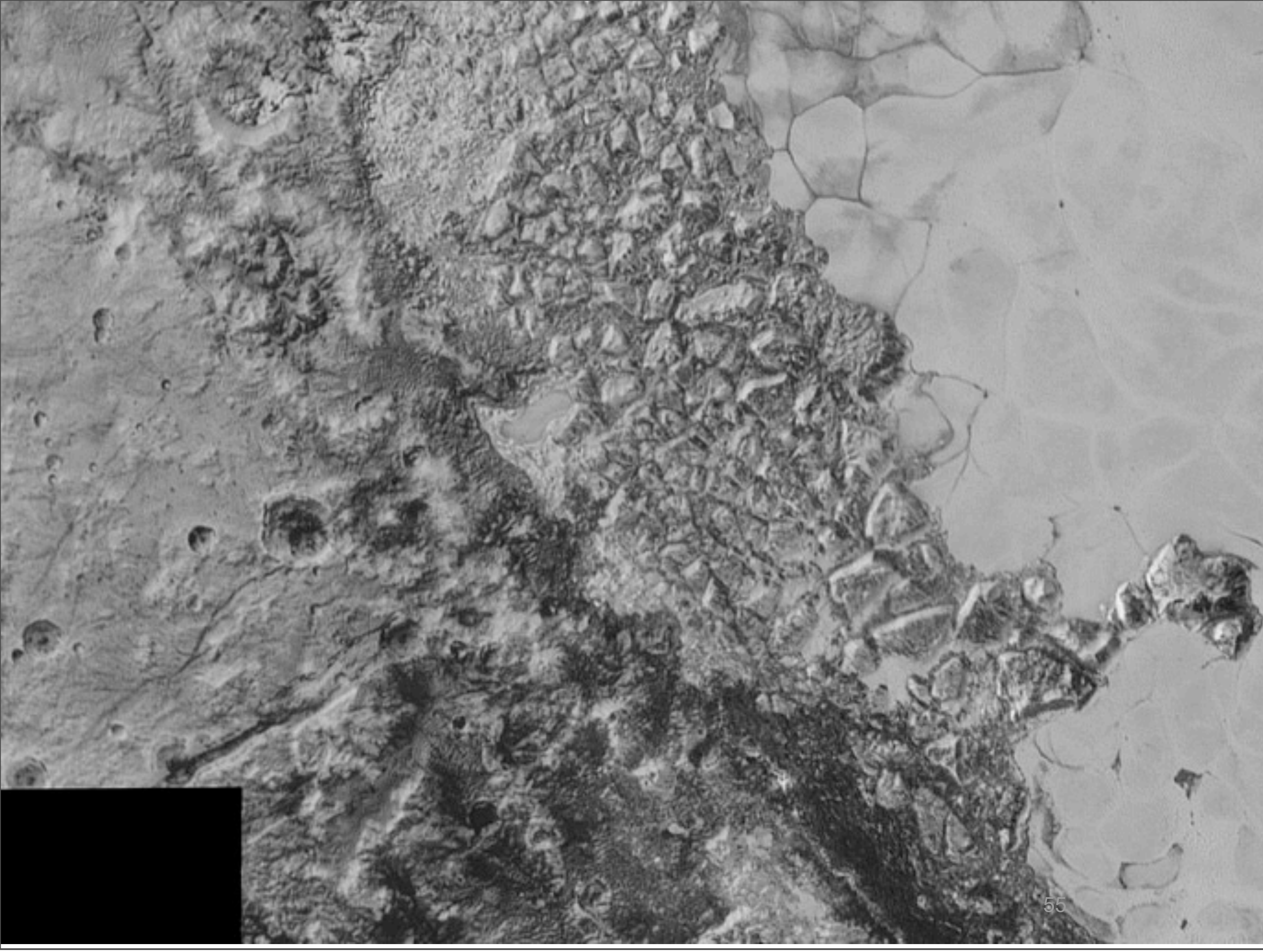
Changes in Pluto's Surface Pressure

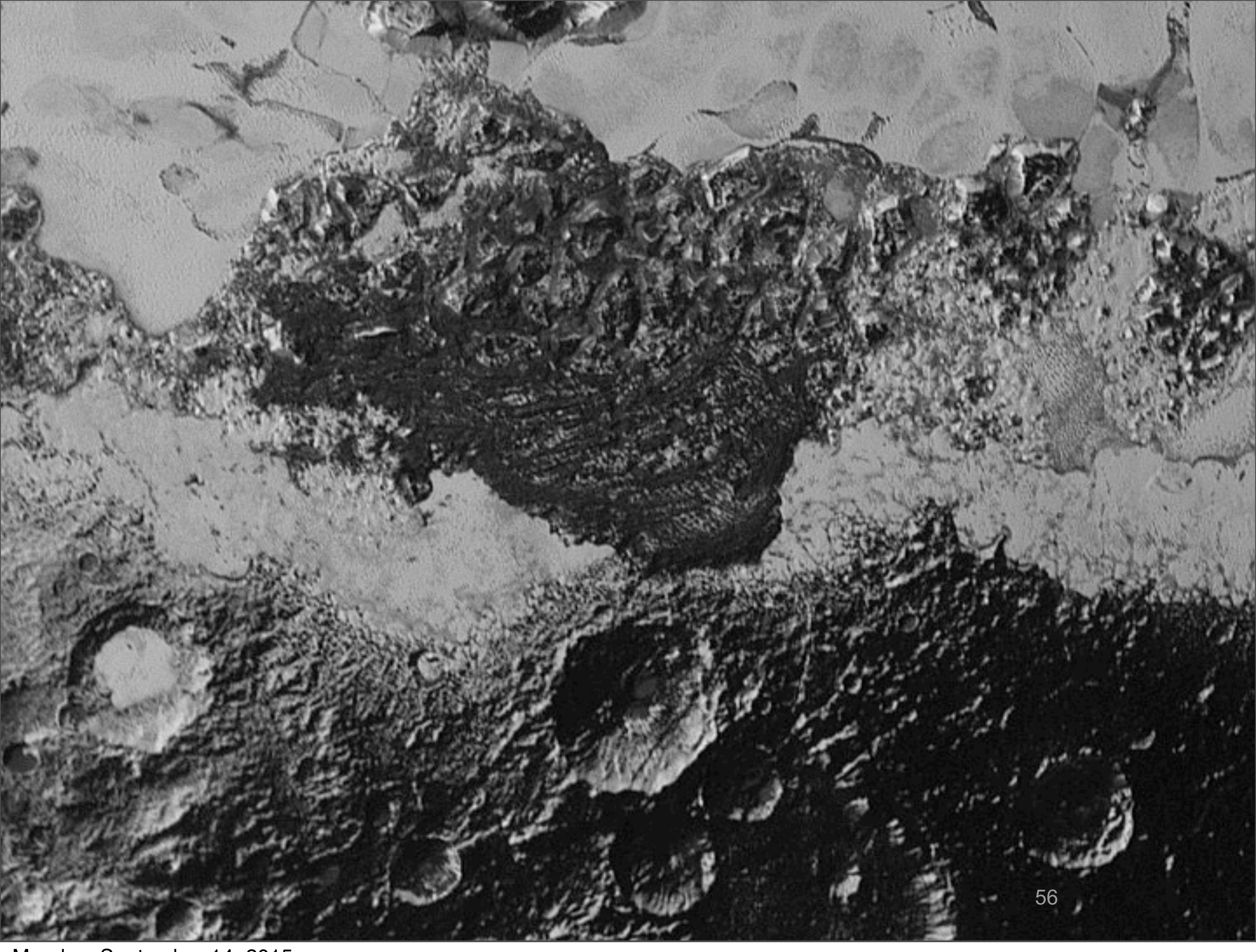


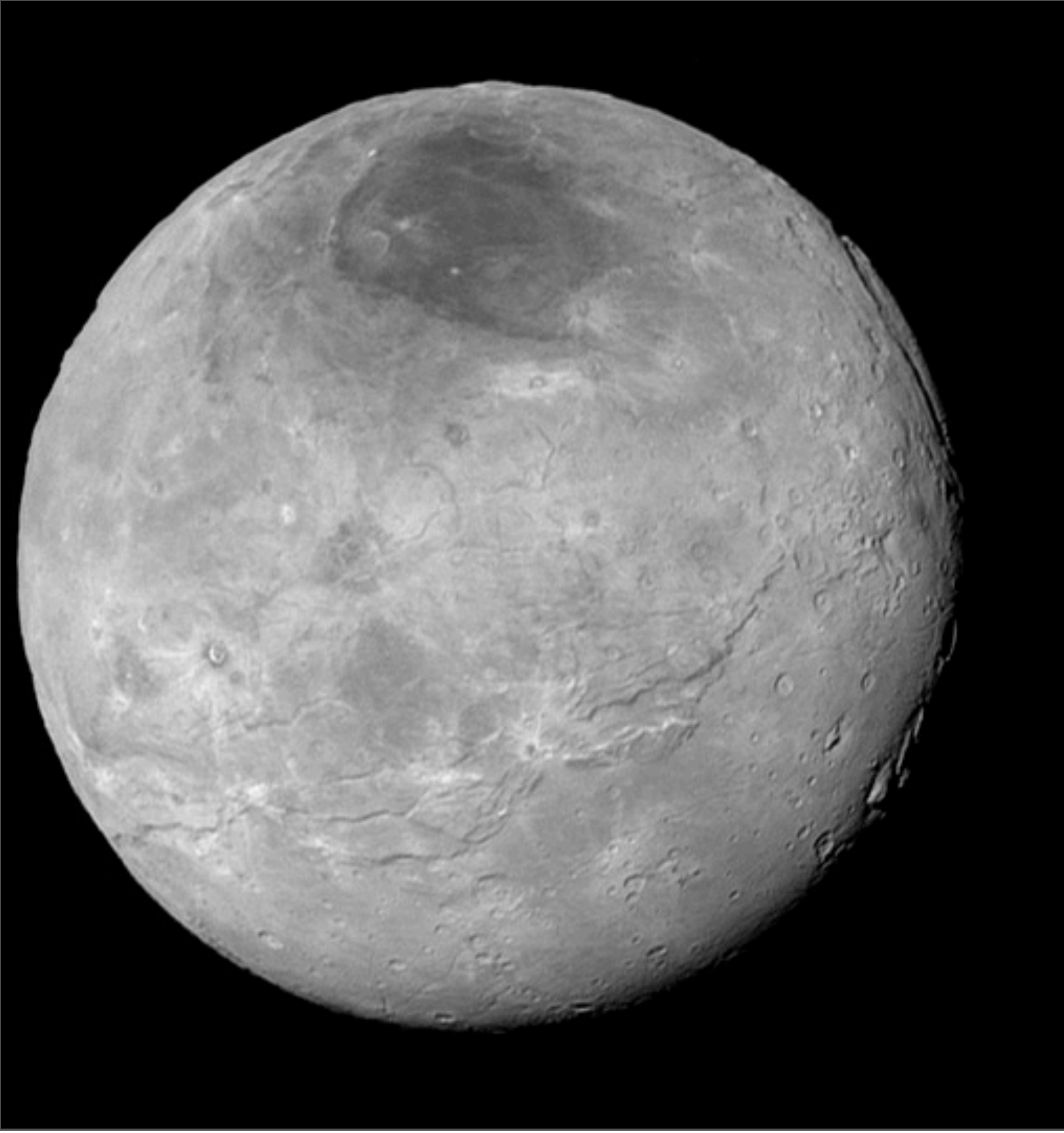


This view of Pluto shows what you would see if you were 1,800 km above Pluto's equatorial area, looking northeast over the dark, cratered Cthulhu Regio toward the bright, smooth, expanse of icy plains informally called Sputnik Planum. The entire expanse of terrain seen in this image is 1,800 km across. The images were taken as New Horizons flew past Pluto on July 14, 2015, from a distance of 80,000 km.

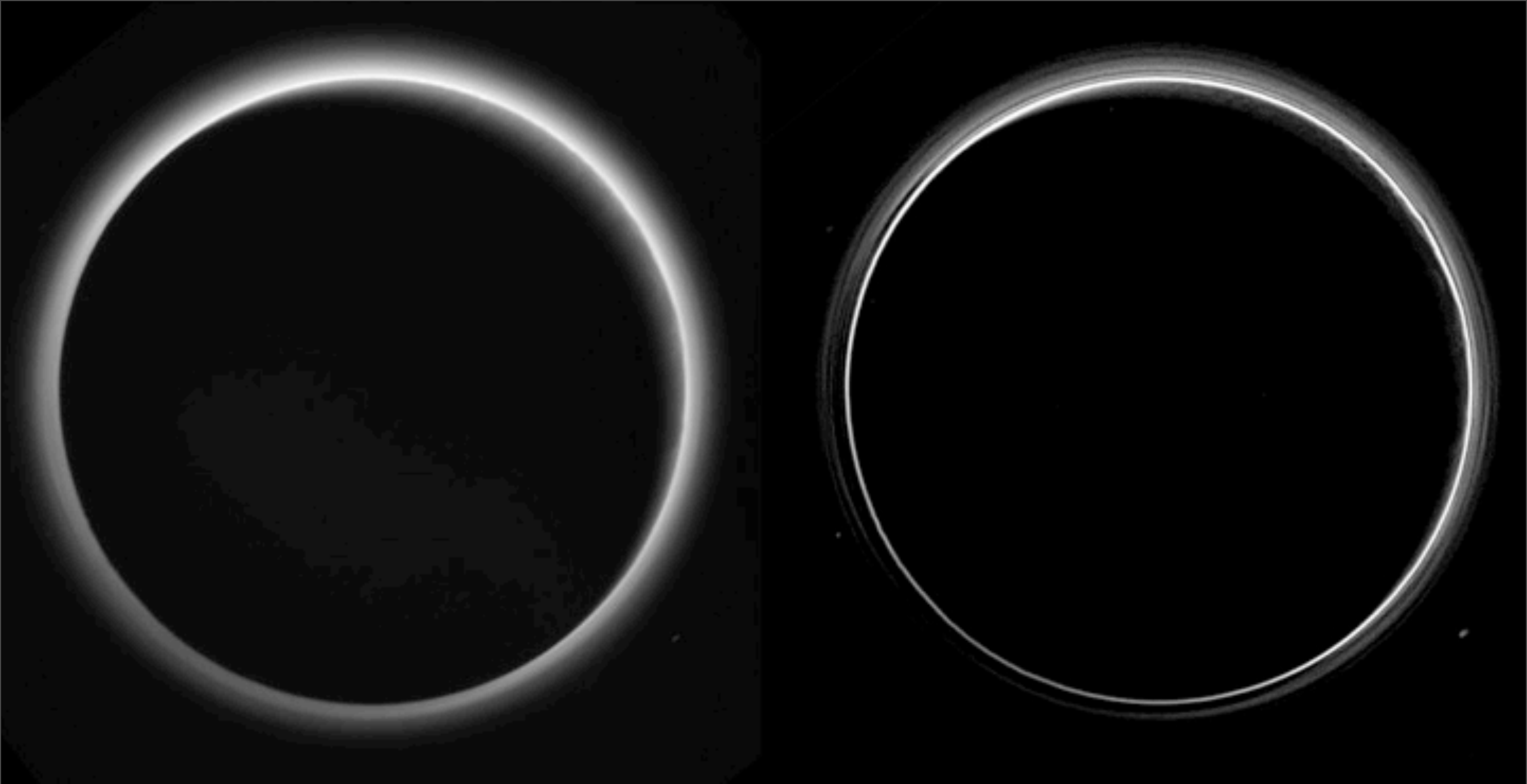

Sputnik Planum



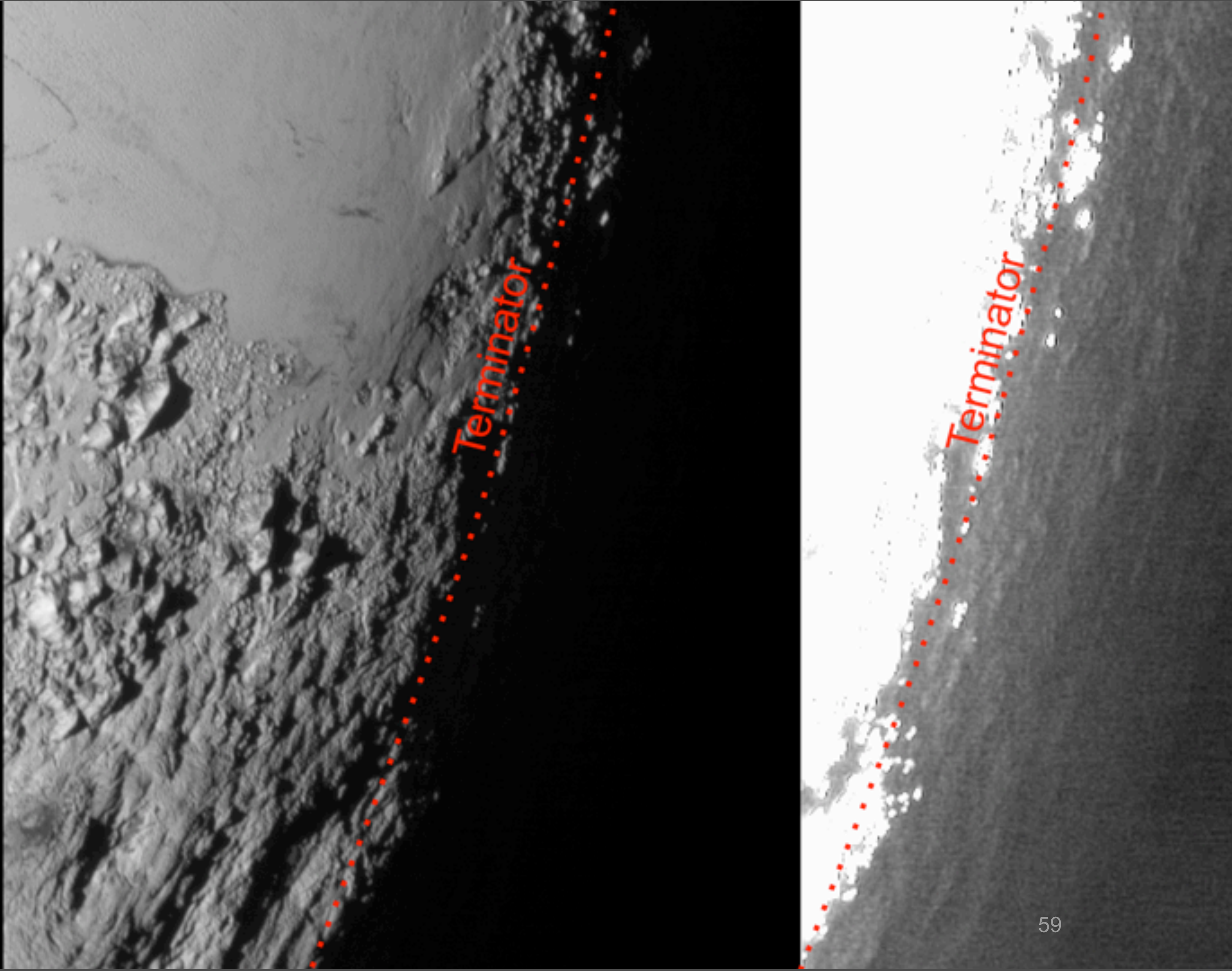




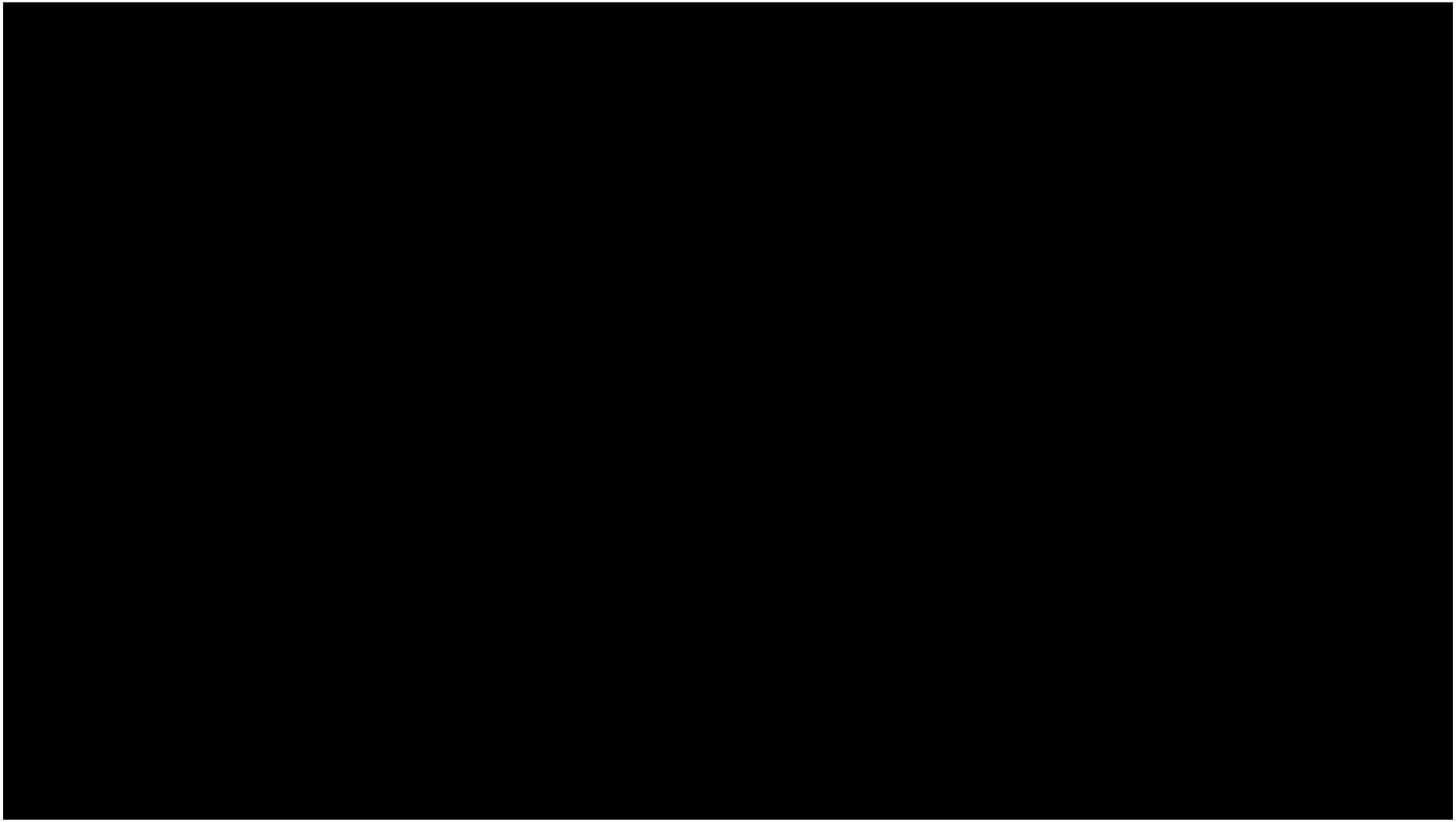
This image of Pluto's largest moon Charon, taken by NASA's New Horizons spacecraft 10 hours before its closest approach to Pluto on July 14, 2015 from a distance of 470,000 km Charon displays a complex geological history, including tectonic fracturing; relatively smooth, fractured plains in the lower right; several enigmatic mountains surrounded by sunken terrain features on the right side; and heavily cratered regions in the center and upper left portion of the disk. There are also complex reflectivity patterns on Charon’s surface, including bright and dark crater rays, and the conspicuous dark north polar region at the top of the image. The smallest visible features are 4.6 km in size

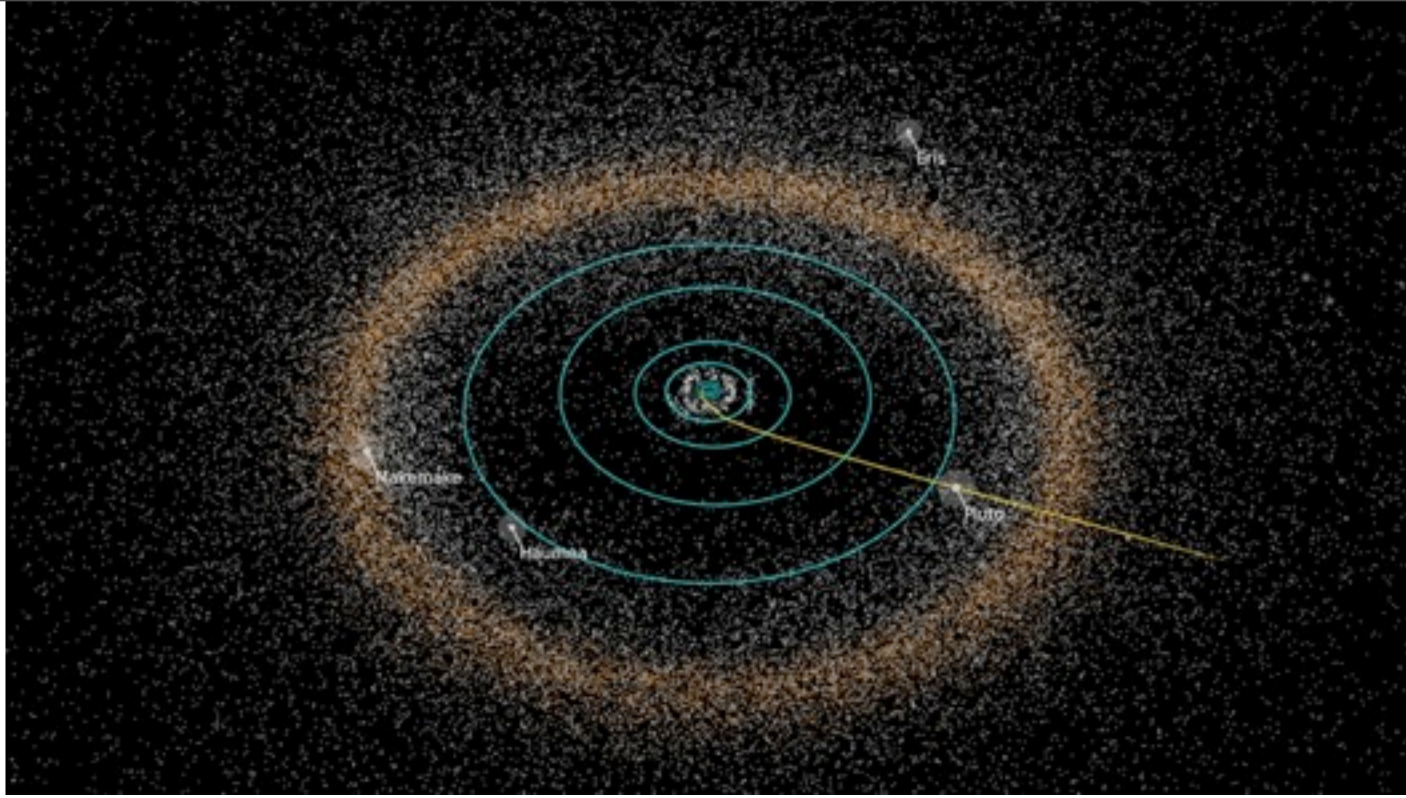


Two images of Pluto's haze layers, taken by New Horizons as it looked back at Pluto's dark side nearly 16 hours after close approach, from a distance of 770,000 km, at a phase angle of 166 degrees. Pluto's north is at the top, and the sun illuminates Pluto from the upper right. The left version has had only minor processing, while the right version has been specially processed to reveal a large number of discrete haze layers in the atmosphere. In the left version, faint surface details on the narrow sunlit crescent are seen through the haze in the upper right of Pluto's disk, and subtle parallel streaks in the haze may be crepuscular rays- shadows cast on the haze by topography such as mountain ranges on Pluto, similar to the rays sometimes seen in the sky after the sun sets behind mountains on Earth.

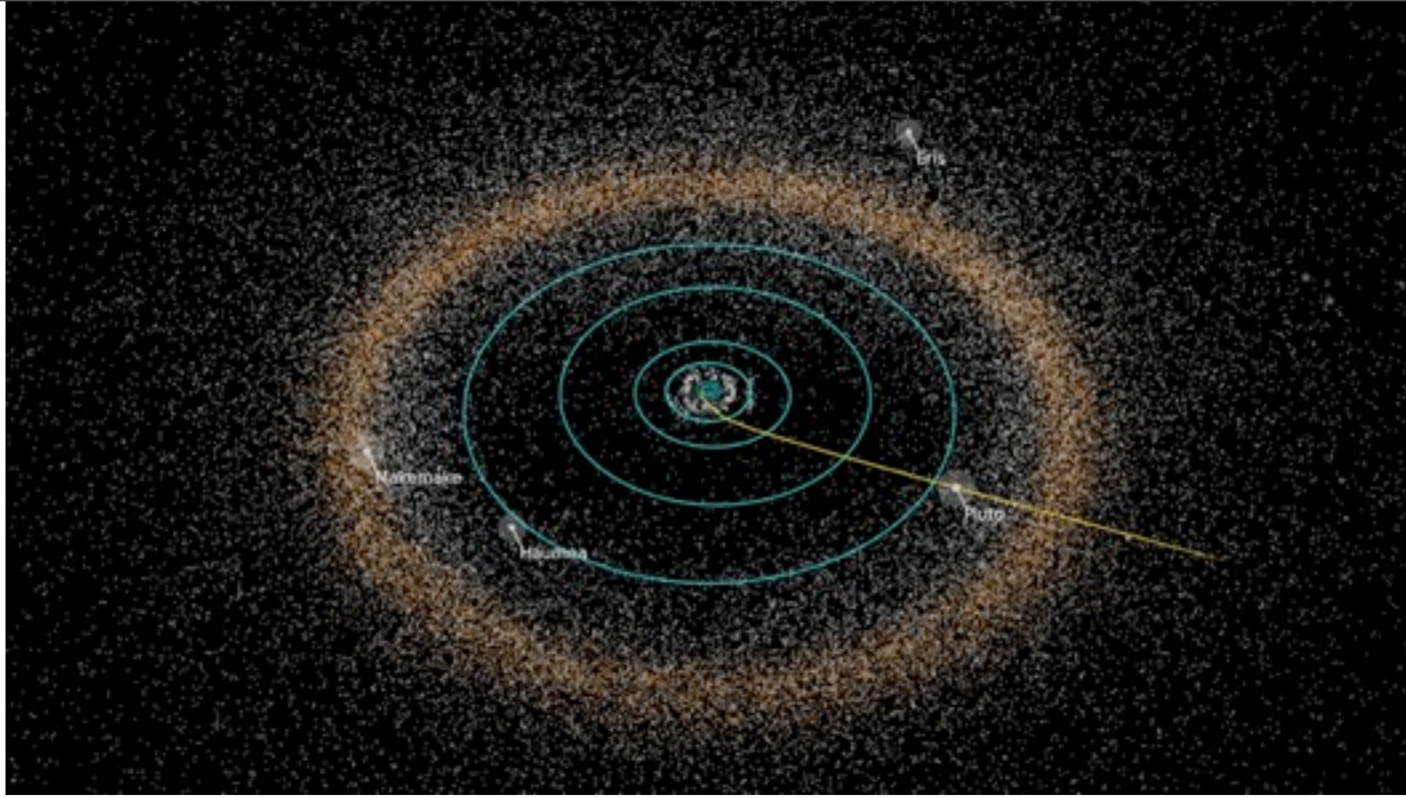

Terminator
Terminator

KUIPER BELT and OORT CLOUD





1. "Cold Classical" KBOs: "Cold" does not temperature but the orderly and unperturbed orbits of these objects. Cold Classical KBOs occupy a narrow region about 6 AU wide, between 42 and 48 AU from the Sun, and about 7 AU thick, and they tend to be smaller and redder than other KBOs, so they might have a different origin.



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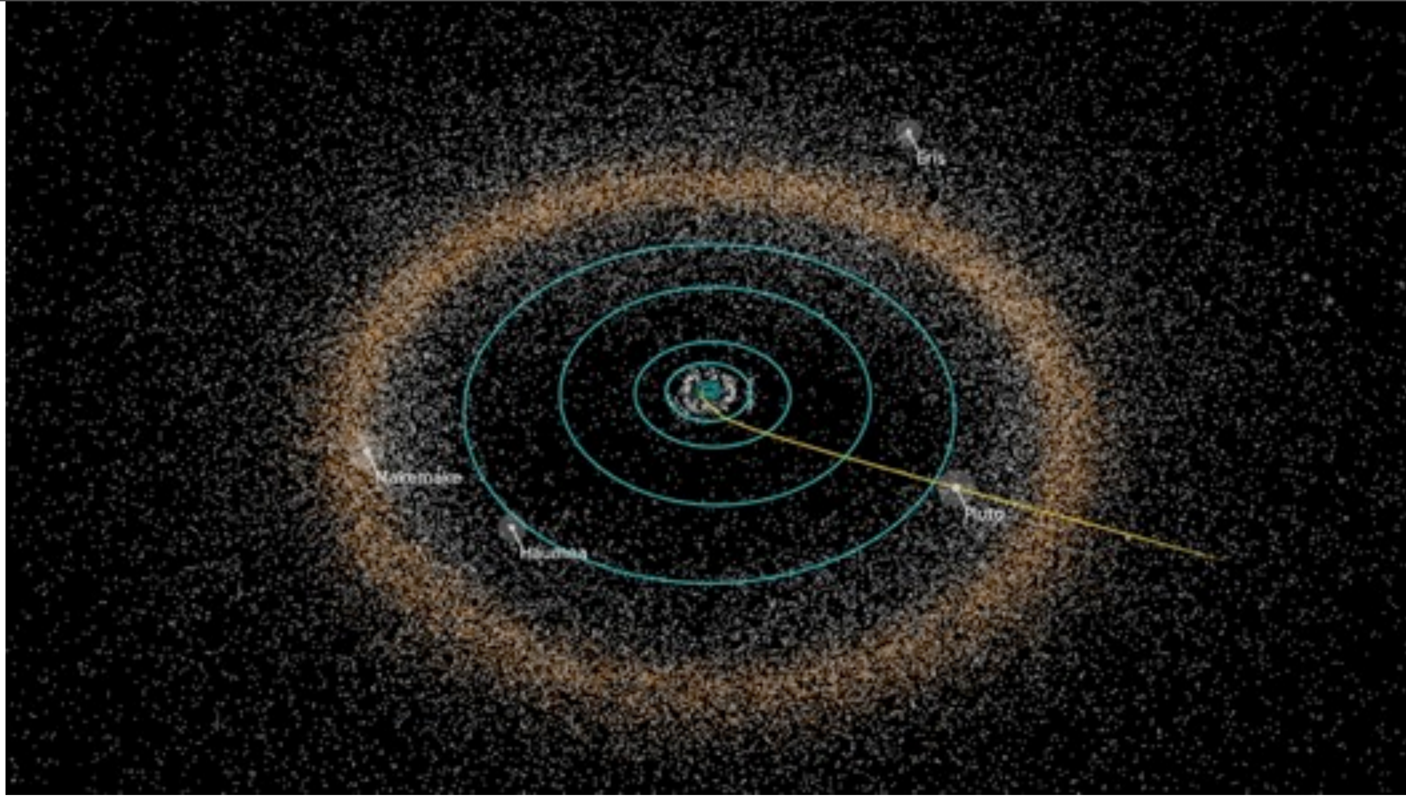
2. "Hot Classical" KBOs: Again, "hot" refers to the wilder orbits of these objects. Though they have a similar average distance from the Sun than Cold Classical KBOs, their eccentric and inclined orbits cause them to stray much farther from that average position. Like most KBOs, their sizes and colors vary, and they include larger and grayer objects than Cold Classicals.



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3. Resonant KBOs have fallen under the influence of Neptune, and orbit in resonance with that planet. 3:2 resonant objects, which include Pluto, make two orbits for every three of Neptune's. These are sometimes called "Plutinos," or "little Plutos." 2:1 objects are farther from the Sun and orbit once for every two orbits of Neptune.

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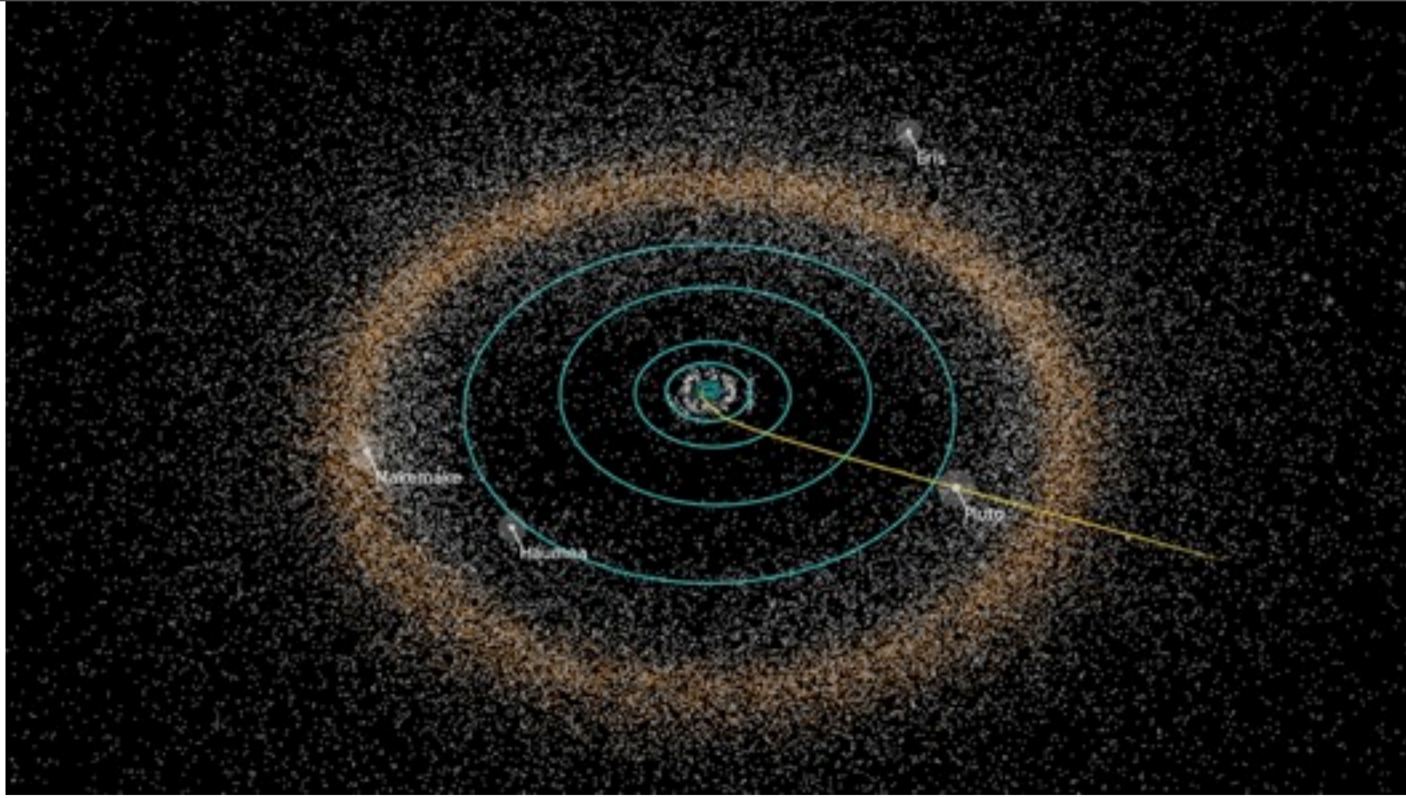

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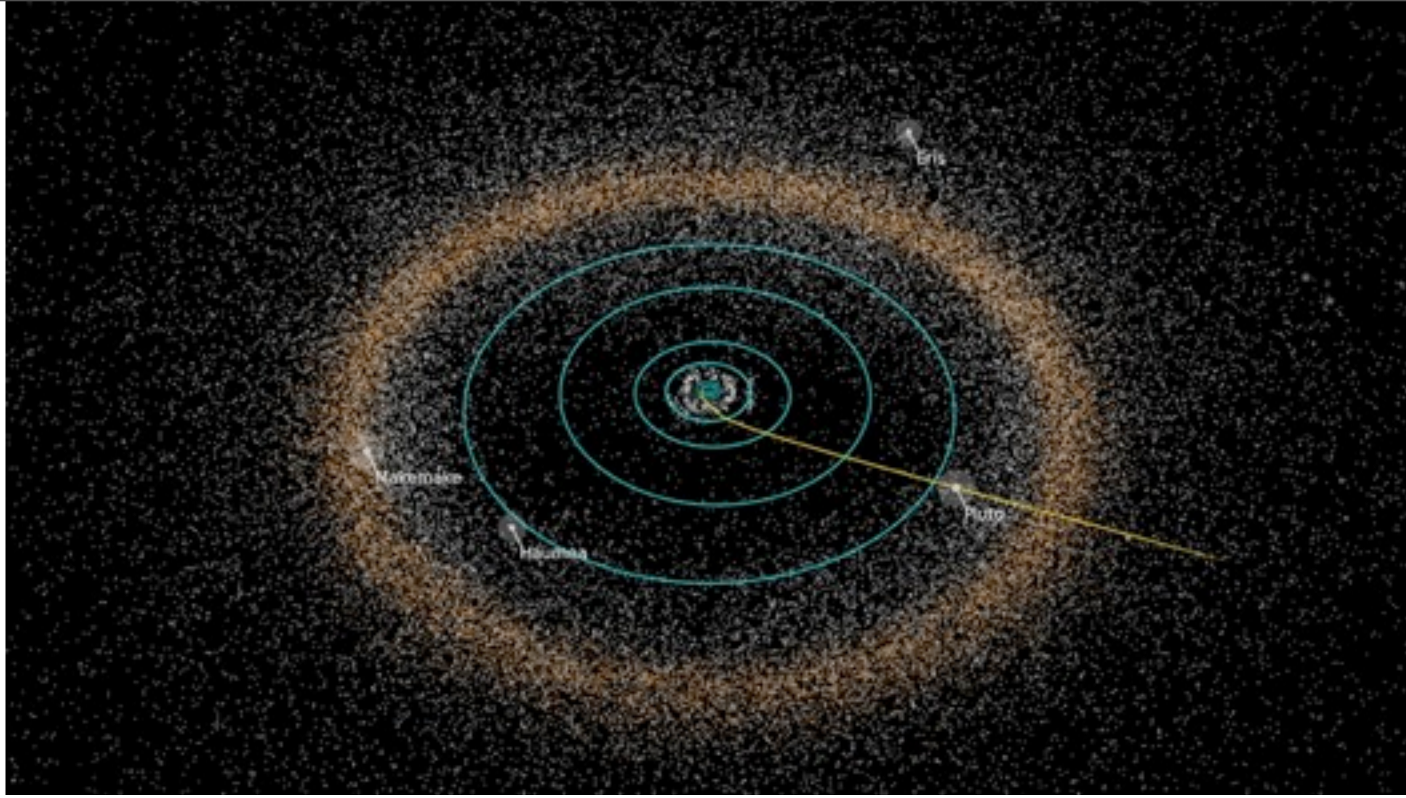
4. Scattered KBOs have probably wandered too close to Neptune in the past, and Neptune's gravity has knocked them into crazy orbits, sometimes taking them hundreds of AU from the Sun at their most distant and bringing them closer to the Sun than Neptune at their closest.



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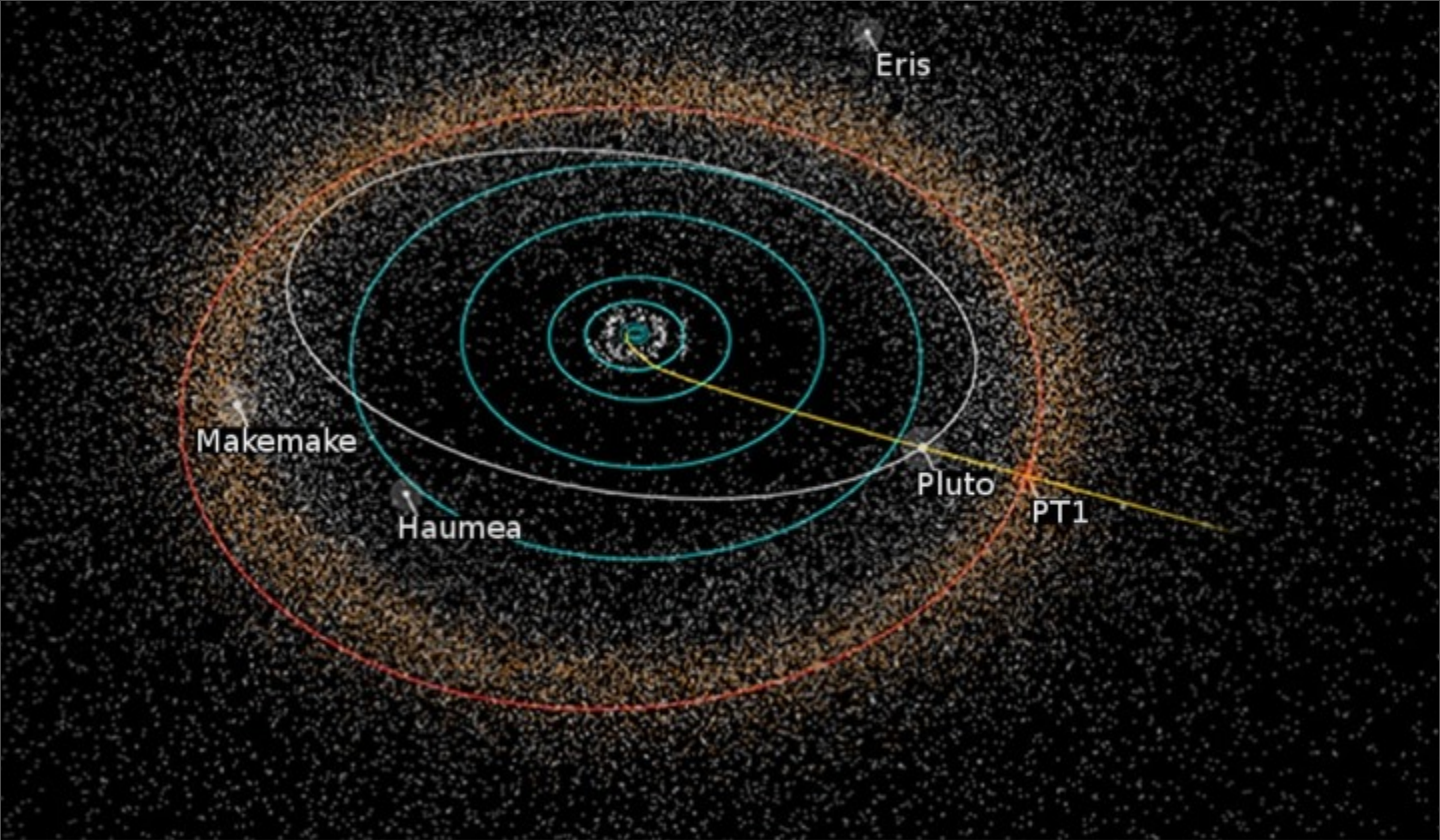
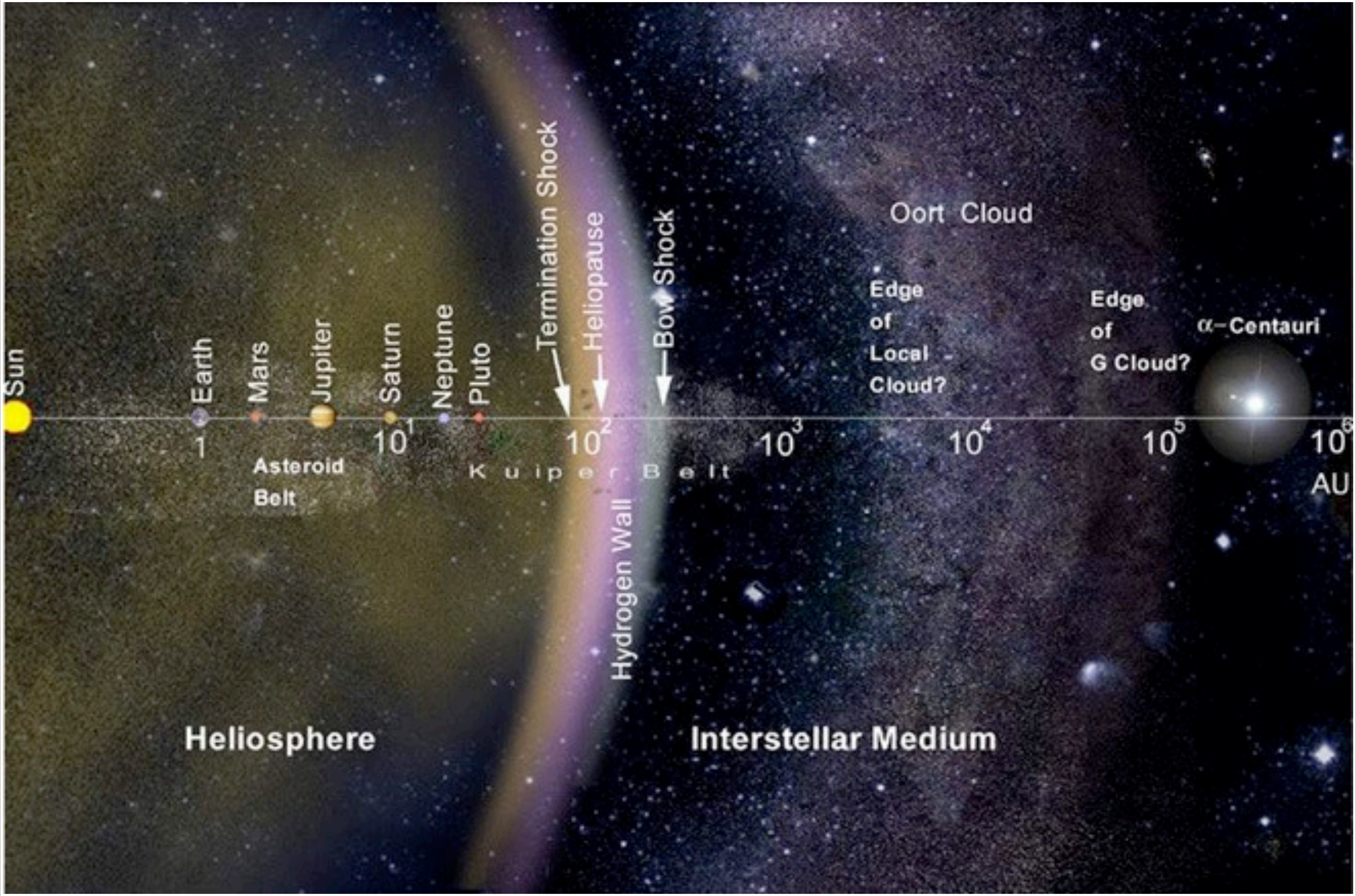
5. The last category is so new that so far it has only two known members — called Sedna and 2012 VP113 — and no group name yet. In fact, it may end up not being considered part of the Kuiper Belt at all. Sedna orbits farther from the Sun than any other known KBO, never coming closer than 76 AU and reaching 1,000 AU at the most distant point of its 12,000-year orbit. Sedna is at least half the size of Pluto, and is probably one of the largest members of a huge population of undiscovered objects.

Pluto and Eris are the largest Kuiper Belt objects, with diameters of about 1,400 miles (2,380 kilometers). There are six other known KBOs with diameters of approximately 600–900 miles (1,000–1,500 kilometers), including Charon. Scientists believe additional KBOs in the 600–1,200 mile (1,000–2,000 kilometer) size range will be found, but most KBOs are much smaller. Kuiper Belt Objects exhibit different reflectivity and colors. Pluto is very bright, with a reflectivity of 60%. For comparison, Earth's Moon is only 10%. The high reflectivity of Pluto implies the existence of relatively fresh ice or snow, which might be expected from recent condensation of volatiles from the atmosphere or even geologic activity.



Pluto and Eris are the largest Kuiper Belt objects, with diameters of about 2,380 kilometers. Subject to approval (funding), New Horizons has chosen a potential Kuiper Belt target 2014 MU69--PT1 (Potential Target 1). 2014 MU69 is thought to orbit where it formed 4.6 billion years ago and hasn't suffered much evolution because it is so far from the Sun. It is only 45 kilometers across and is probably similar to the objects which coalesced to form Pluto. The flyby is scheduled for January 1, 2019.

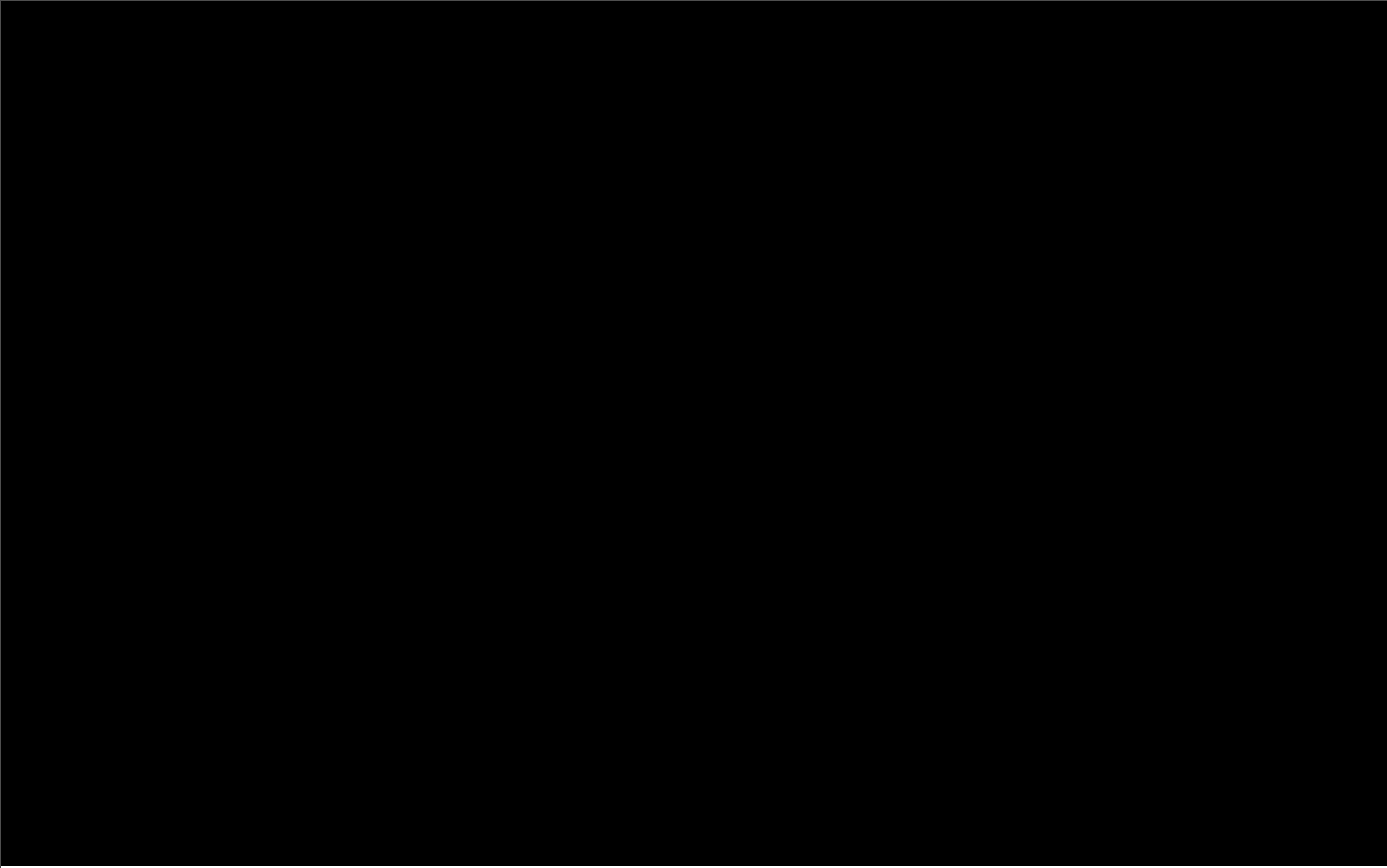

Sun
Earth
Mars
Jupiter
Saturn
Neptune
Pluto
Termination Shock
Heliopause
Bow Shock
Oort Cloud
Edge of Local Cloud?
Edge of G Cloud?
α−Centauri
1
10^1
10^2
10^3
10^4
10^5
10^6
AU
Asteroid Belt
Kuiper Belt
Hydrogen Wall
Heliosphere
Interstellar Medium

OORT CLOUD

Comet McNaught C/2009 R1
(2010)

Comet West (1976)

Comets are classified into two main families depending on their orbits around the Sun. Oort Cloud comets come from a roughly spherical-shaped region between 10,000 and 100,000 AU from the Sun and typically have orbital periods of about a million years. Jupiter family comets have orbits strongly influenced by Jupiter's gravity and usually need less than 20 years to travel once around the Sun. When the solar system formed nearly 4.6 billion years ago, about 10% of the comets that formed near the giant planets (perhaps a trillion total) were ejected into the Oort Cloud. Subsequent gravitational perturbations by the galactic tide and nearby passing stars send some of the Oort Cloud comets toward the Sun, creating the "new comets" we see today. In contrast, Jupiter family comets are thought to be byproducts of collisions between KBOs. They're literally chips off the old blocks, pieces of KBOs, pulled into the inner solar system by Jupiter's and Neptune's gravity. Nearly 150 short-period comets are now classified as "JFCs."



Johns Hopkins link to New Horizons website, http://pluto.jhuapl.edu/