Roger Freedman • Robert Geller • William Kaufmann III

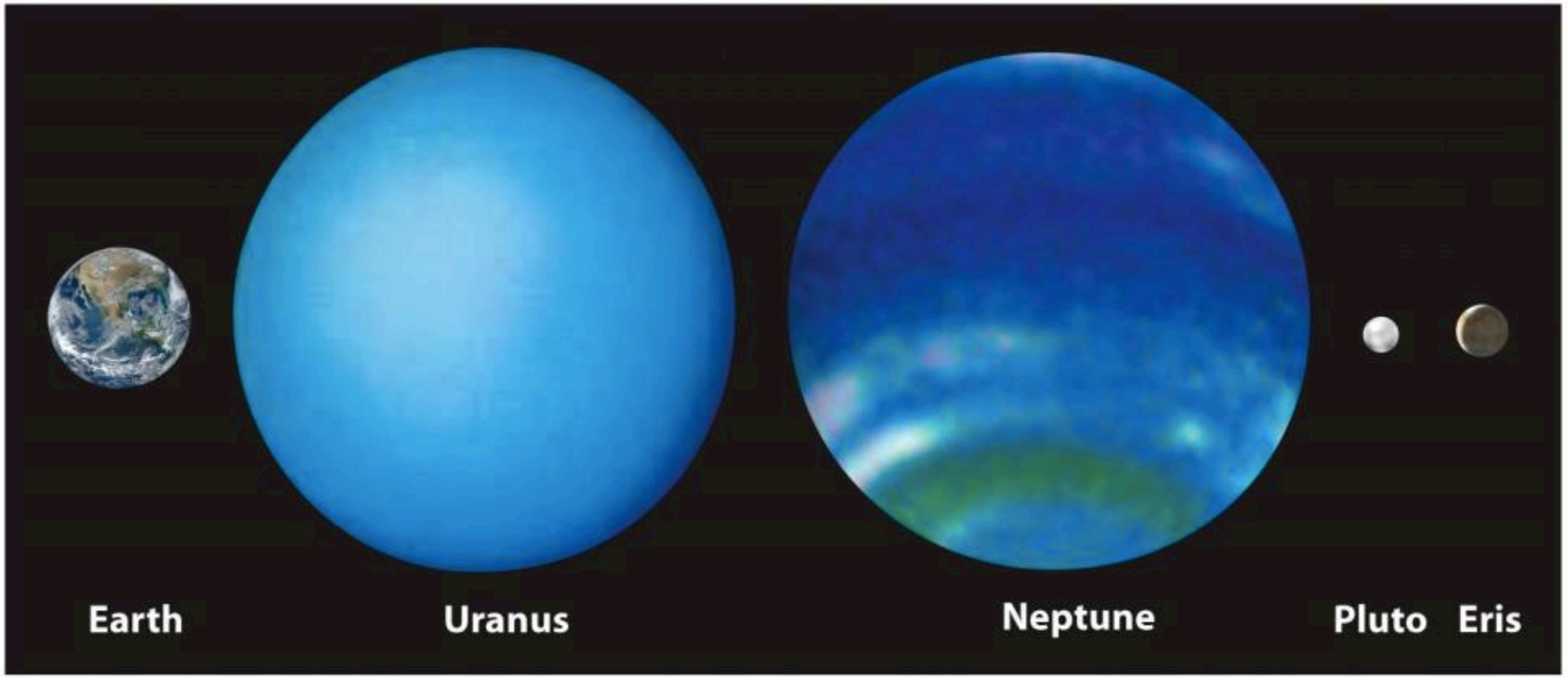
Universe

Tenth Edition

Chapter 14

Uranus, Neptune, Pluto and the Kuiper Belt: Remote Worlds

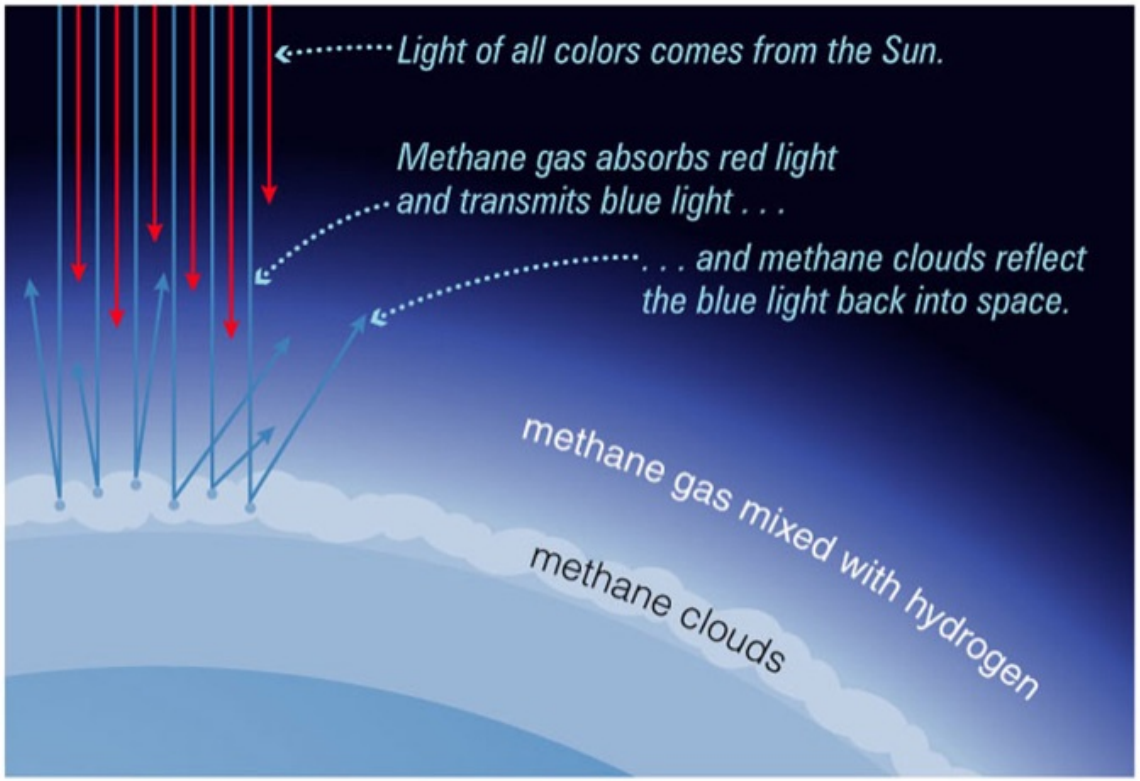
14-1: Uranus was discovered by chance but Neptune's existence was predicted by applying Newtonian mechanics



Chapter 14 Opener
Universe, Tenth Edition
Alan Stern, Southwest Research Institute; Marc Buie, Lowell Observatory; NASA; and ESA

Uranus: 1781 Neptune: 1846 Pluto: 1930 Eris: 2005

Methane on Uranus and Neptune



- Methane gas of Neptune and Uranus absorb red light but transmit blue light
- Blue light reflects off methane clouds, making those planets look blue

TABLE 14-1 Uranus Data

Average distance from the Sun:	19.194 AU = 2.871×10^9 km
Maximum distance from the Sun:	20.017 AU = 2.995×10^9 km
Minimum distance from the Sun:	18.371 AU = 2.748×10^9 km
Eccentricity of orbit:	0.0429
Average orbital speed:	6.83 km/s
Orbital period:	84.099 years
Rotation period (internal):	17.24 hours
Inclination of equator to orbit:	97.86°
Inclination of orbit to ecliptic:	0.77°
Diameter:	51,118 km = 4.007 Earth diameters (equatorial)
Mass:	8.682×10^{25} kg = 14.53 Earth masses
Average density:	1318 kg/m^3
Escape speed:	21.3 km/s
Surface gravity (Earth = 1):	0.90
Albedo:	0.56
Average temperature at cloudtops:	−218°C = −360°F = 55 K
Atmosphere composition (by number of molecules):	82.5% hydrogen (H_2), 15.2% helium (He) 2.3% methane (CH_4)

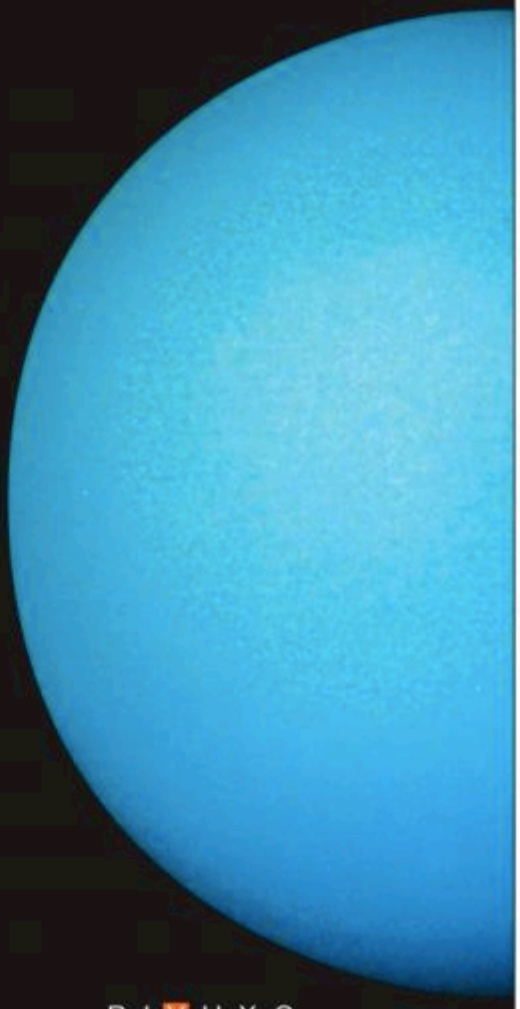


Table 14-1
Universe, Tenth Edition

TABLE 14-2 Neptune Data

Average distance from the Sun:	30.066 AU = 4.498×10^9 km
Maximum distance from the Sun:	30.367 AU = 4.543×10^9 km
Minimum distance from the Sun:	29.765 AU = 4.453×10^9 km
Eccentricity of orbit:	0.010
Average orbital speed:	5.5 km/s
Orbital period:	164.86 years
Rotation period (internal):	15.97 hours
Inclination of equator to orbit:	29.56°
Inclination of orbit to ecliptic:	1.77°
Diameter:	49,528 km = 3.883 Earth diameters (equatorial)
Mass:	1.024×10^{26} kg = 17.15 Earth masses
Average density:	1638 kg/m^3
Escape speed:	23.5 km/s
Surface gravity (Earth = 1):	1.1
Albedo:	0.51
Average temperature at cloudtops:	−218°C = −360°F = 55 K
Atmosphere composition (by number of molecules):	79% hydrogen (H_2), 18% helium (He), 3% methane (CH_4)

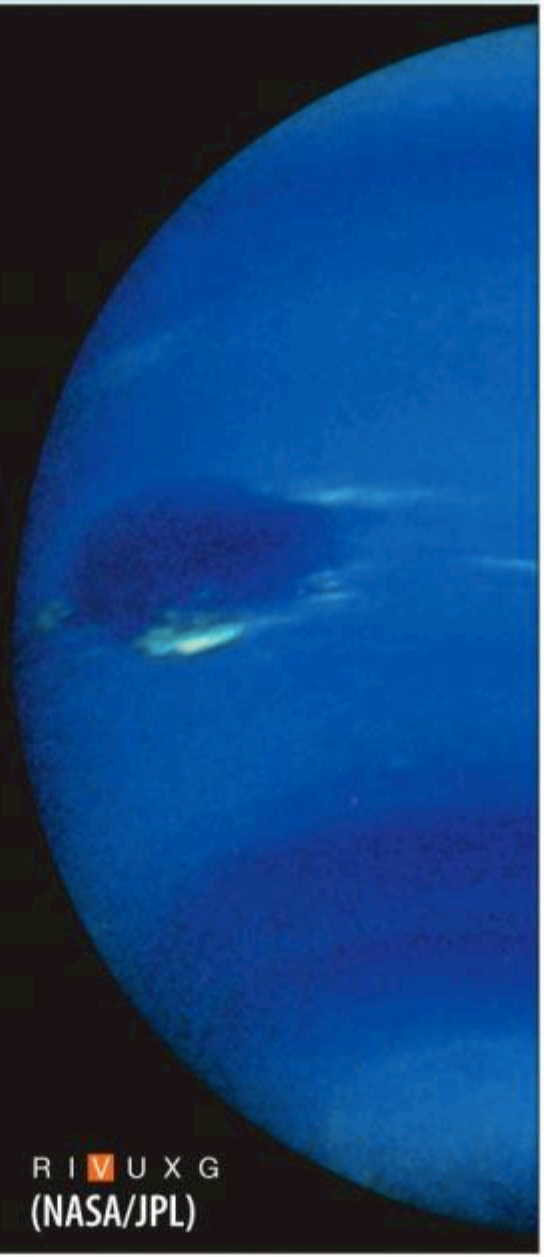


Table 14-2
Universe, Tenth Edition

14-2: Uranus is nearly featureless and has an unusually tilted axis of rotation

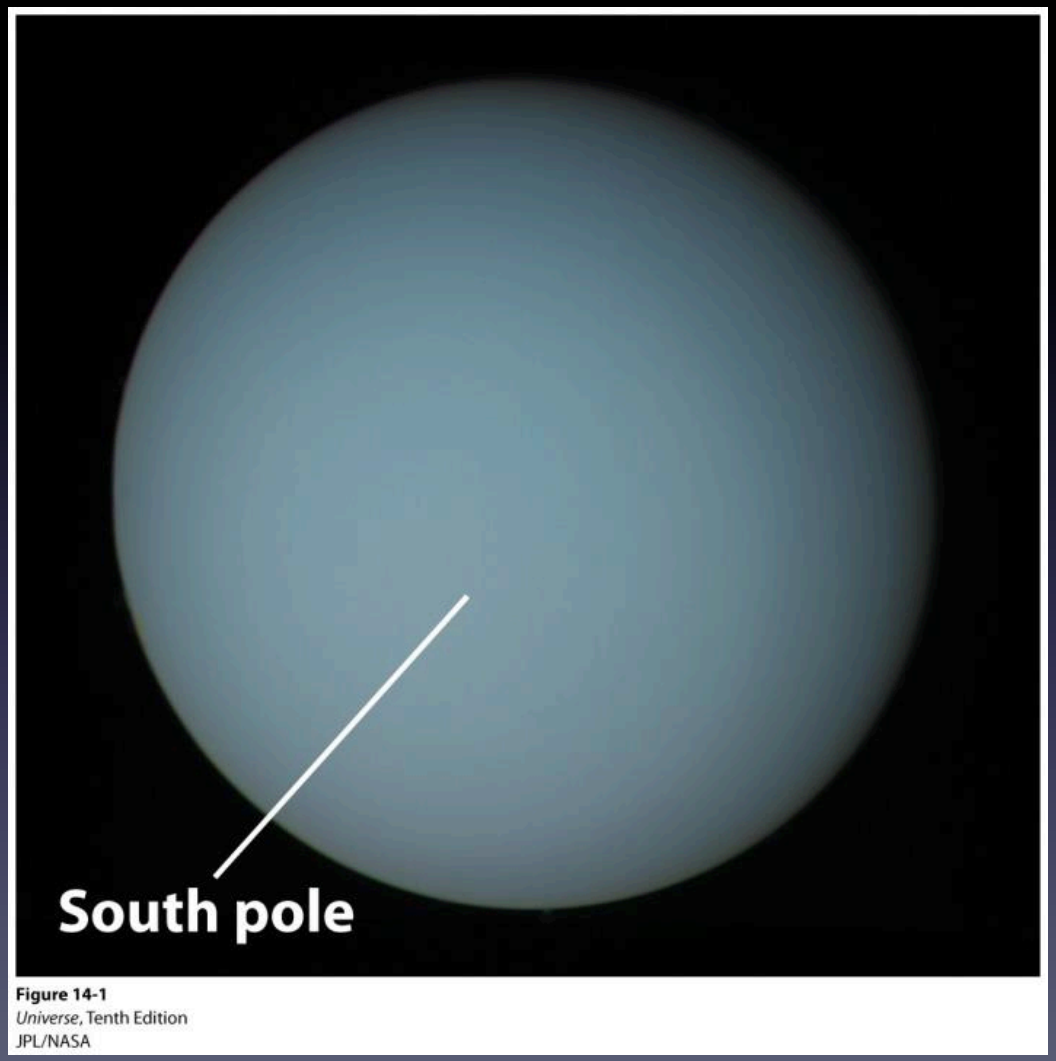
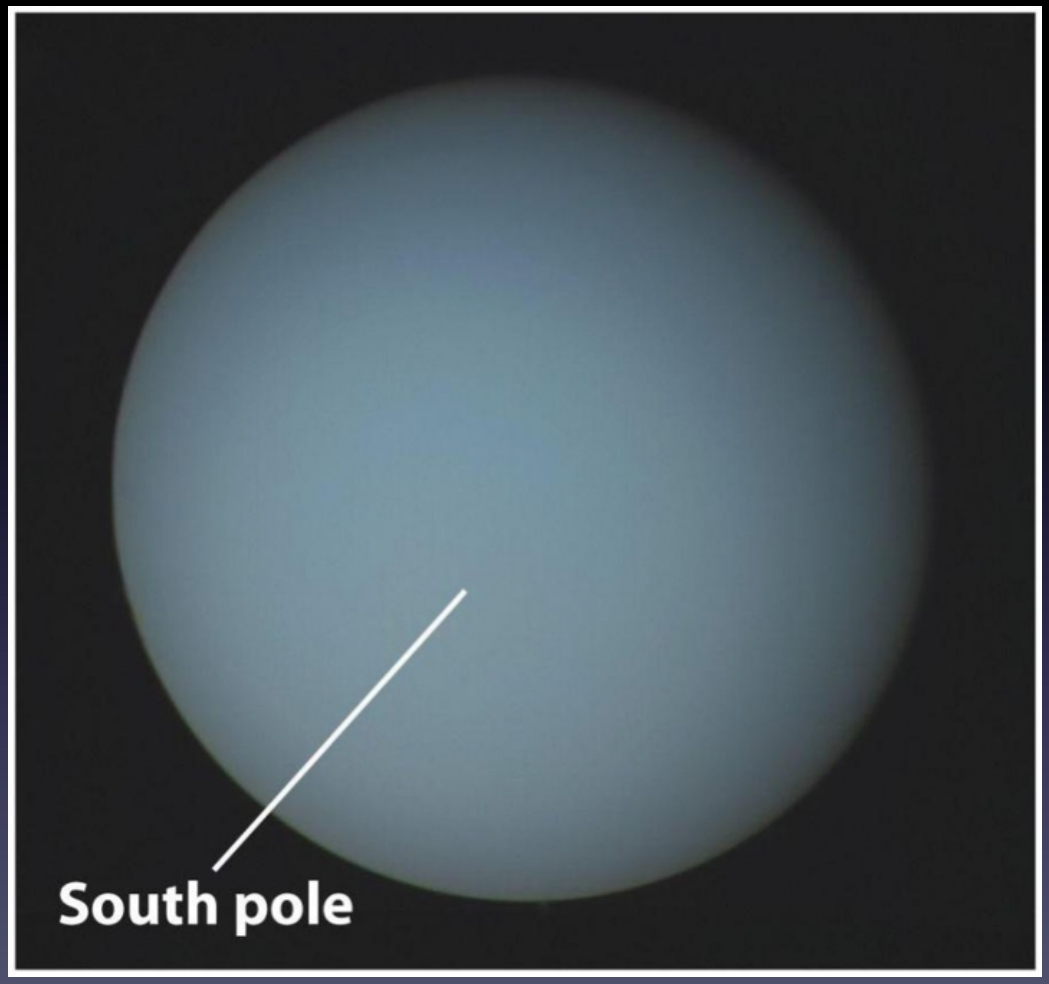


Figure 14-1
Universe, Tenth Edition
JPL/NASA

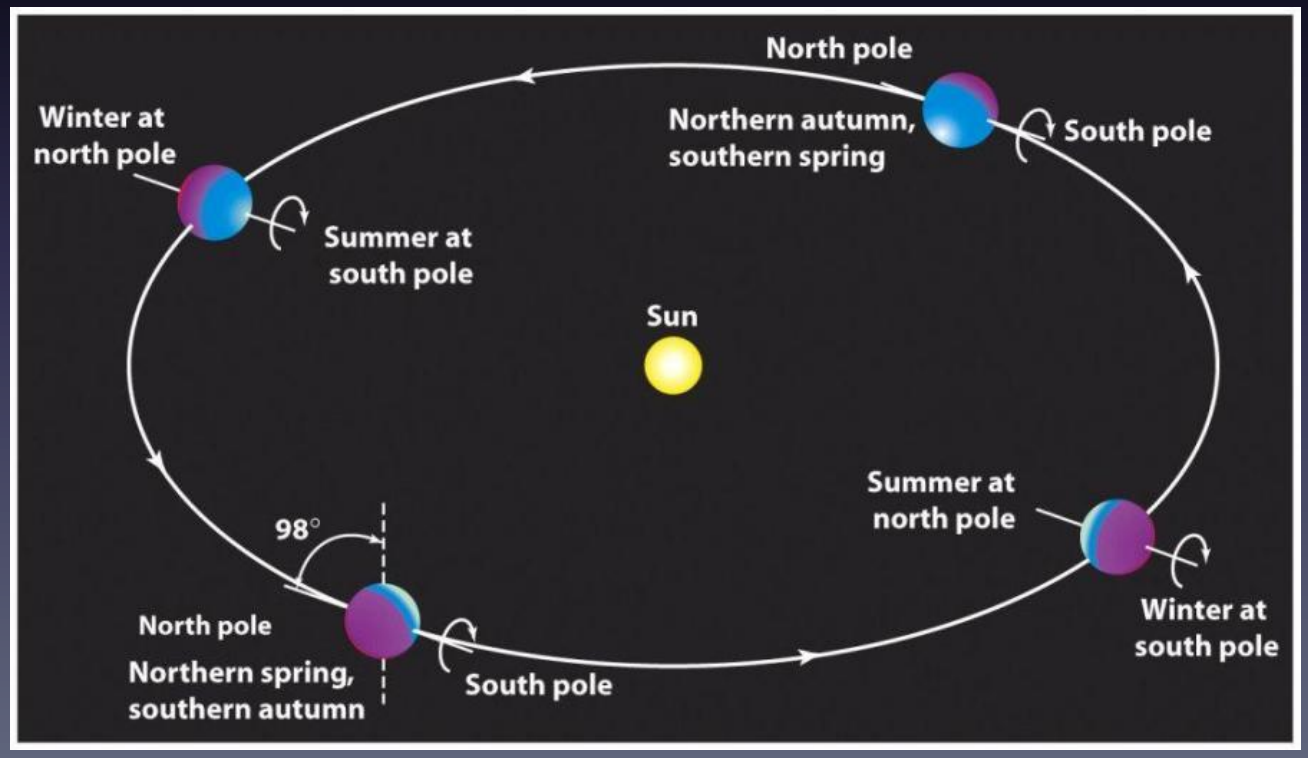
Uranus from *Voyager 2*

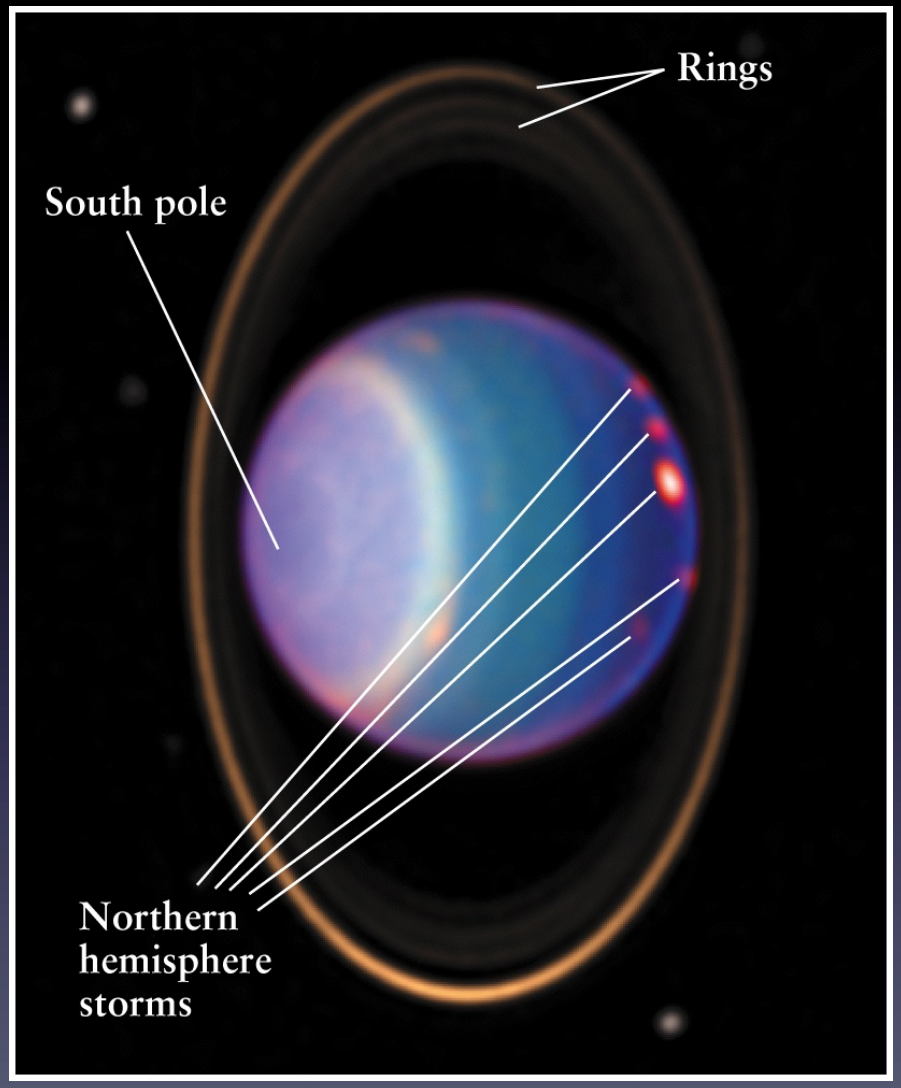
Uranus



- 1986: Voyager 2 flyby -- Uranus had its South Pole to the Sun
- No weather patterns visible – no internal heat source

- Extreme axial tilt: (84 year orbit)
  - Uranus alternately has a pole, then its equator pointed at the Sun
- Extreme changes in heating
  - Extreme seasonal changes (21 yr seasons)





- In 2005ish, Hubble Space Telescope took this UV photo
- Uranus now has its equator to the Sun
- Storms are breaking out in the previously shadowed Northern hemisphere

14-3: Neptune is a cold, bluish world with Jupiterlike atmospheric features

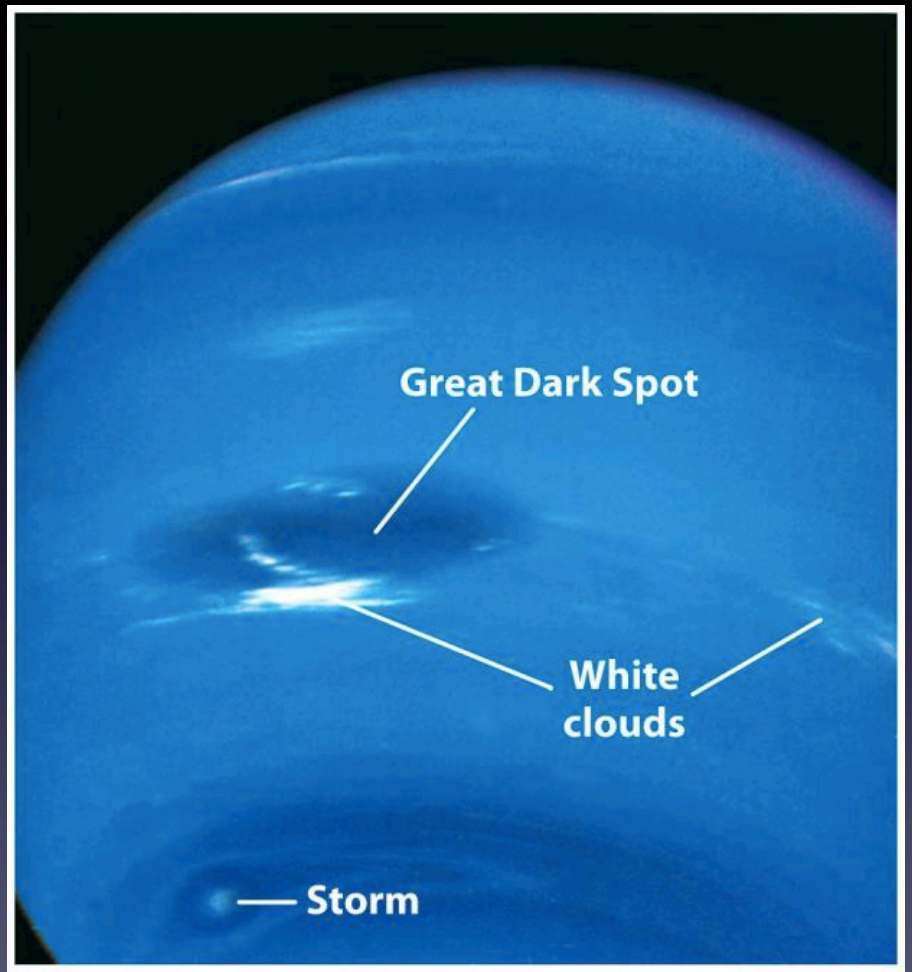


Figure 14-4
Universe, Tenth Edition
NASA/JPL

Neptune from *Voyager* 2

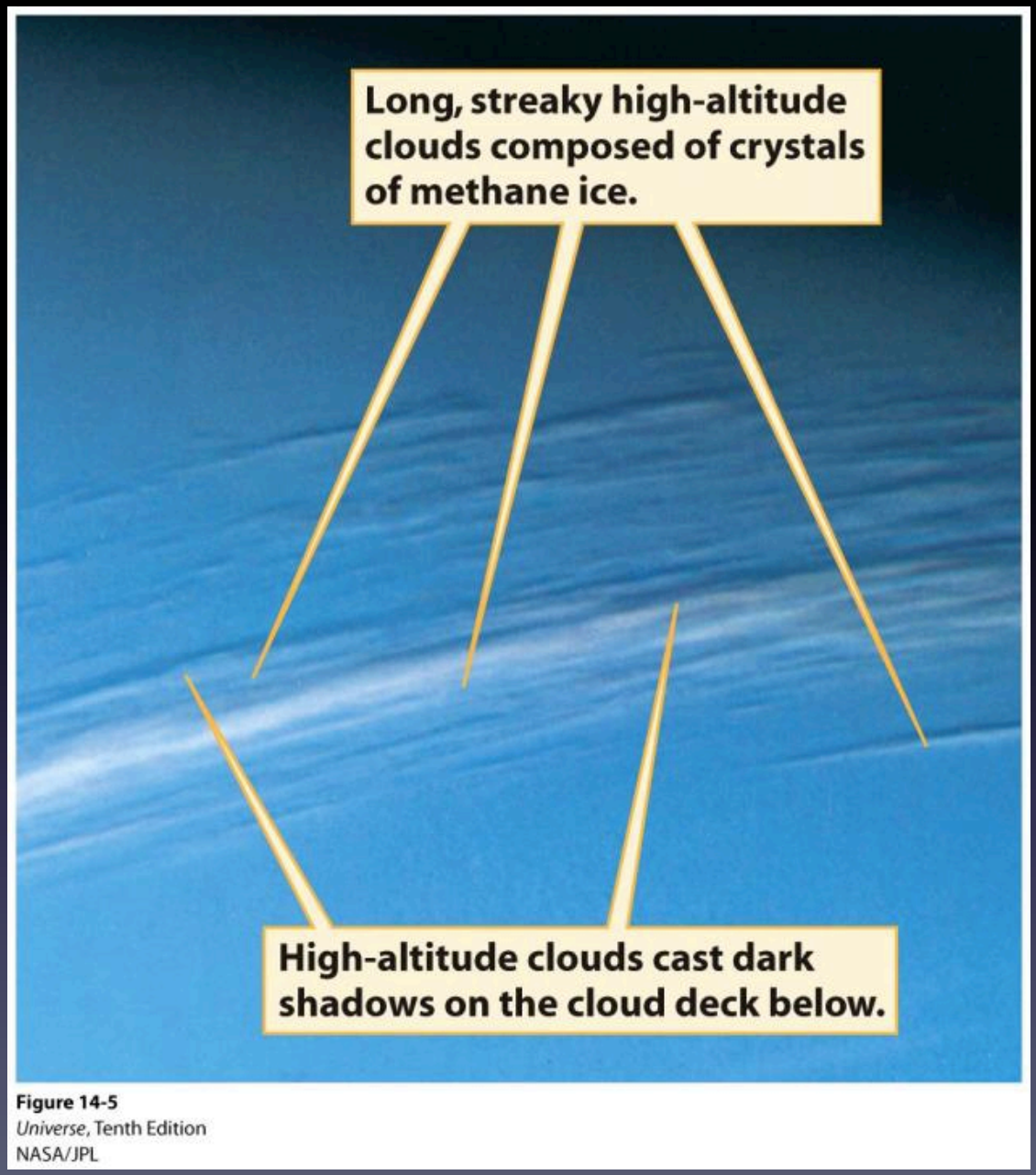


Figure 14-5
Universe, Tenth Edition
NASA/JPL

Cirrus Clouds over Neptune

Neptune has an internal heat source that drives its weather

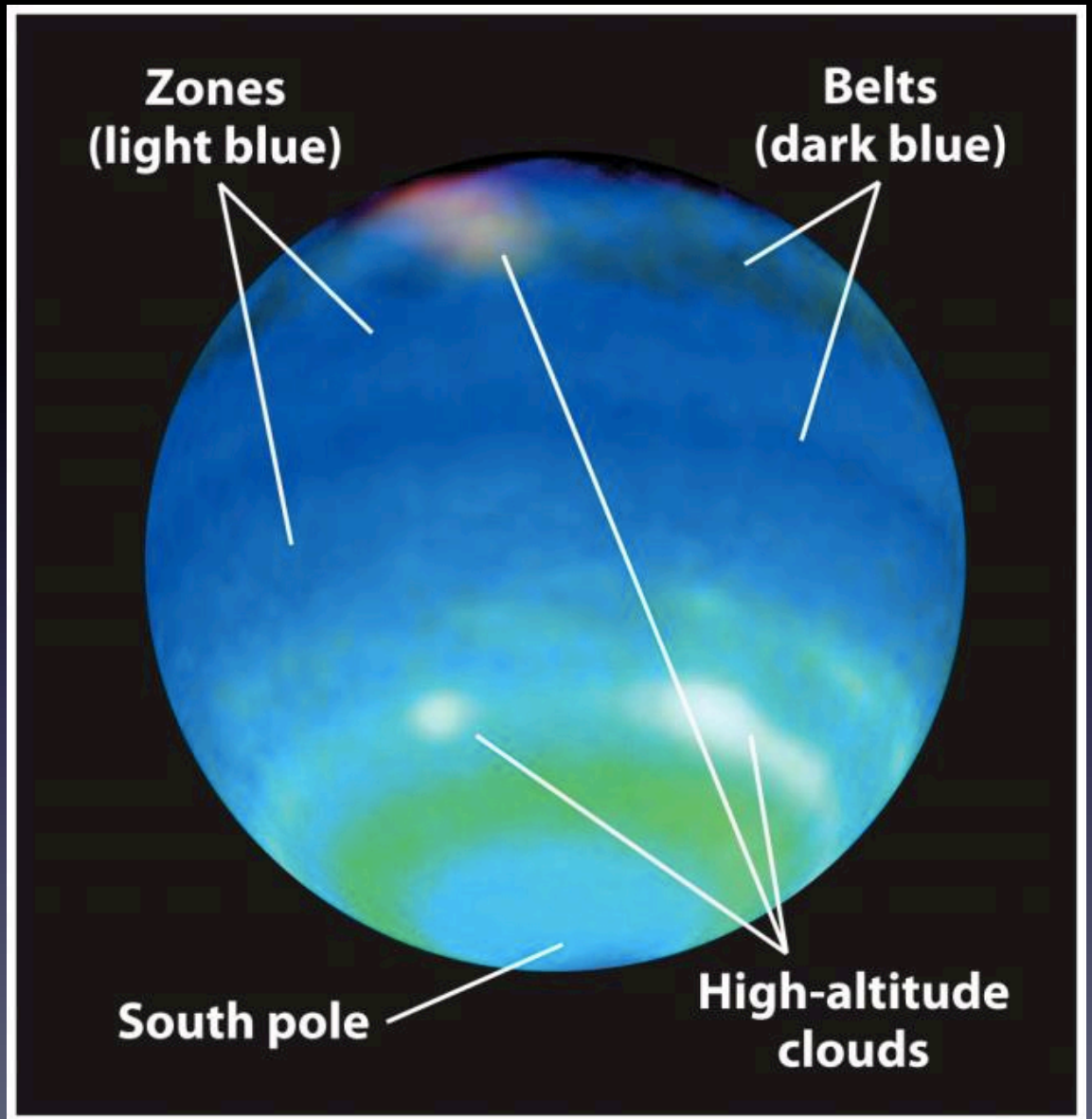


Figure 14-6
Universe, Tenth Edition
Lawrence Sromovsky, University of Wisconsin-Madison; STScI/NASA

14-4: Uranus and Neptune contain a higher proportion of heavy elements than Jupiter and Saturn

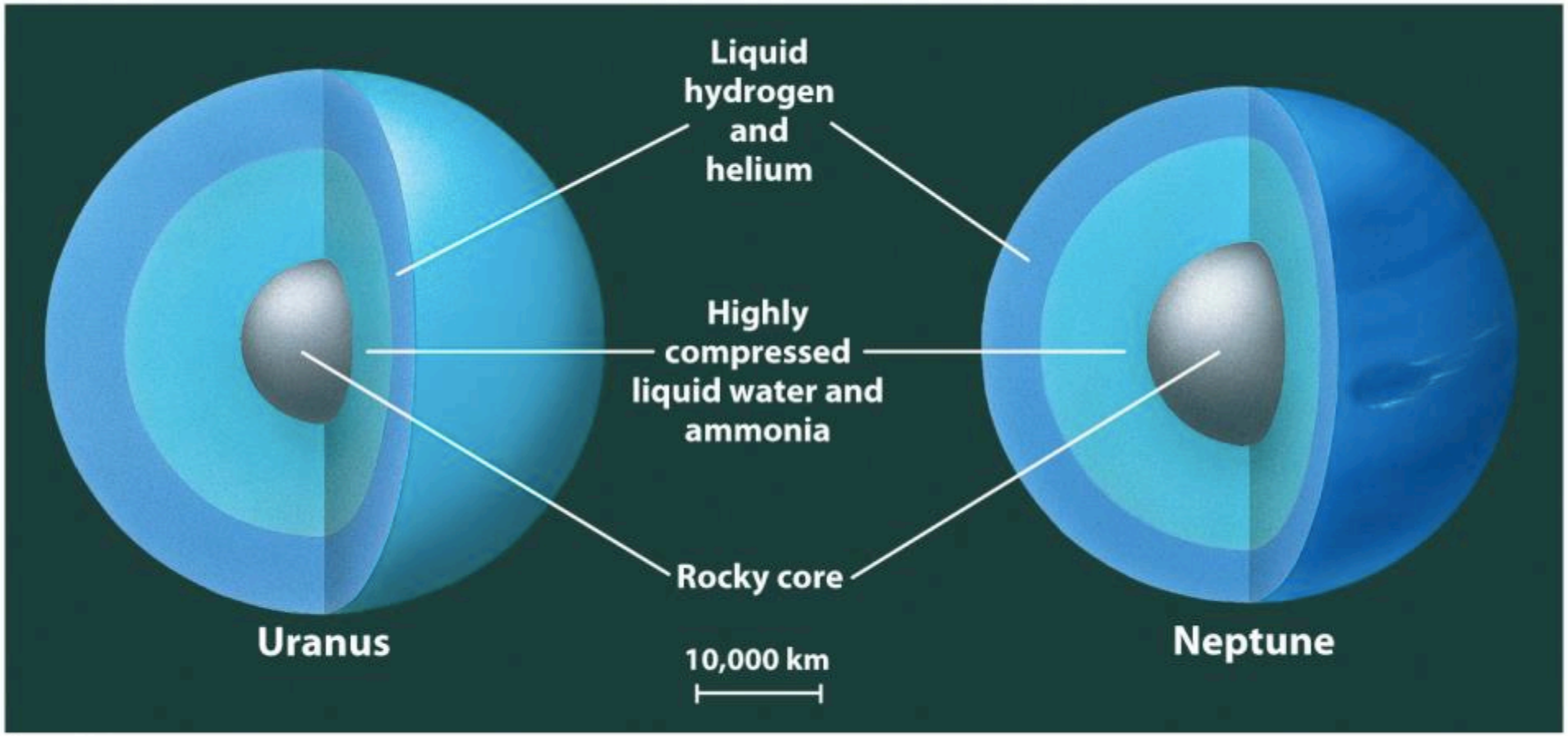


Figure 14-7
Universe, Tenth Edition

The Internal Structures of Uranus and Neptune

Formation of Uranus and Neptune

- Higher density than Jupiter and Saturn because they have less H, He. Why?
- Solar Nebula was too thin to form gas giants beyond Saturn.
- How do Uranus and Neptune even exist?!

Formation of Uranus and Neptune

- Hypothesis: Uranus and Neptune formed closer in, were gravitationally nudged outward before they accreted large atmospheres of H, He.

Magnetic Fields originate in liquid water/ammonia layer (?)

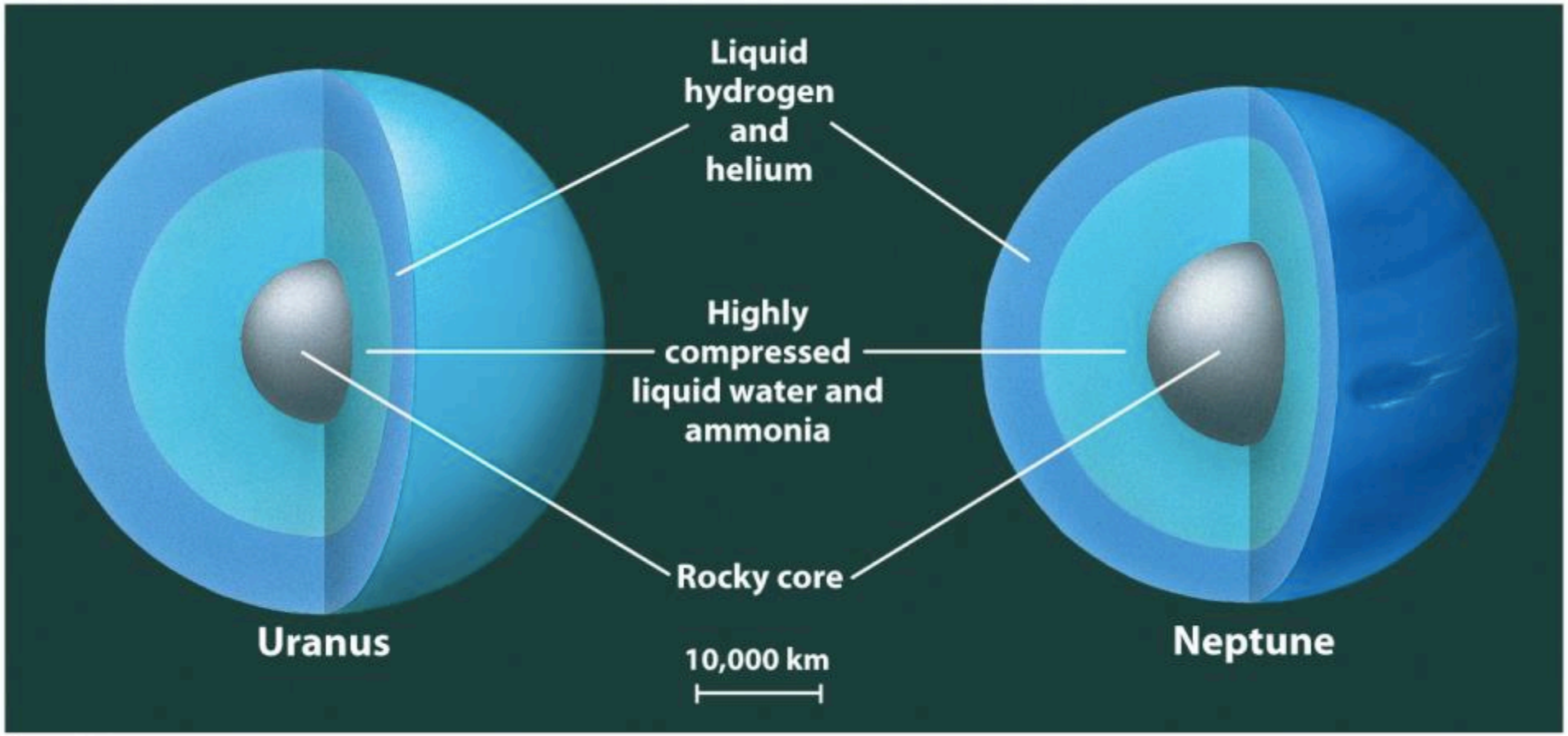


Figure 14-7
Universe, Tenth Edition

The Internal Structures of Uranus and Neptune

14-5: The magnetic fields of both Uranus and Neptune are oriented at unusual angles

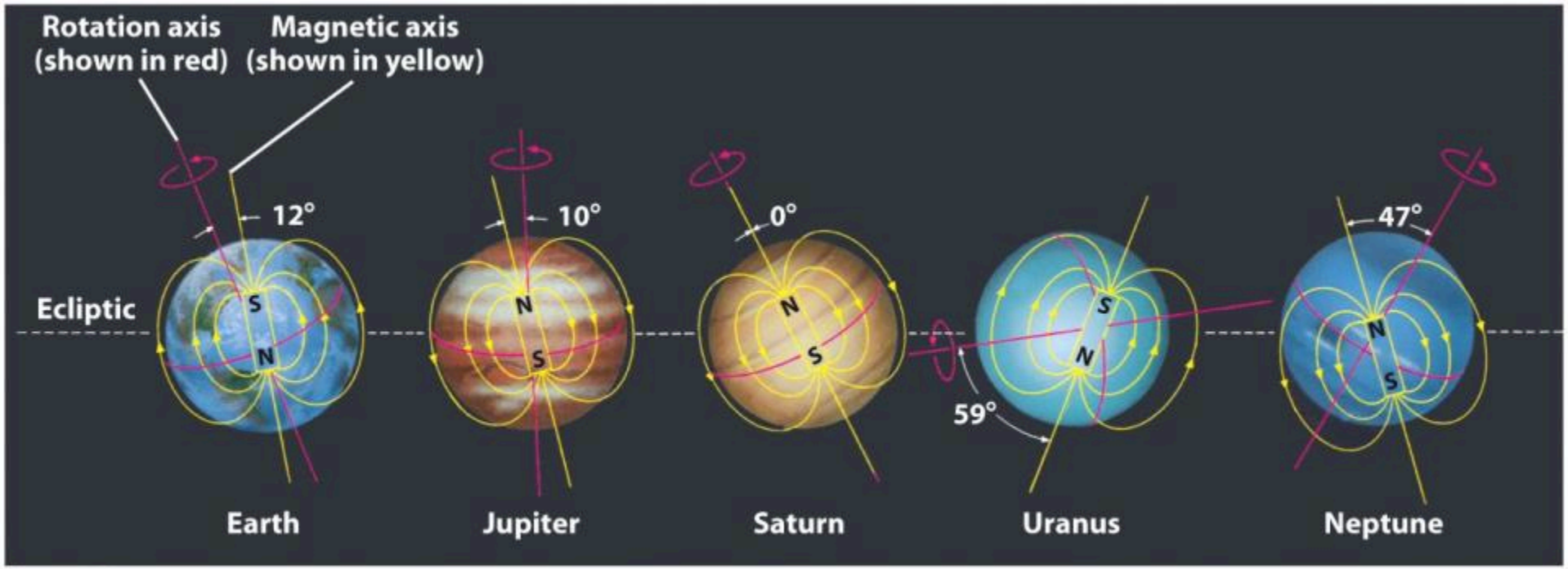
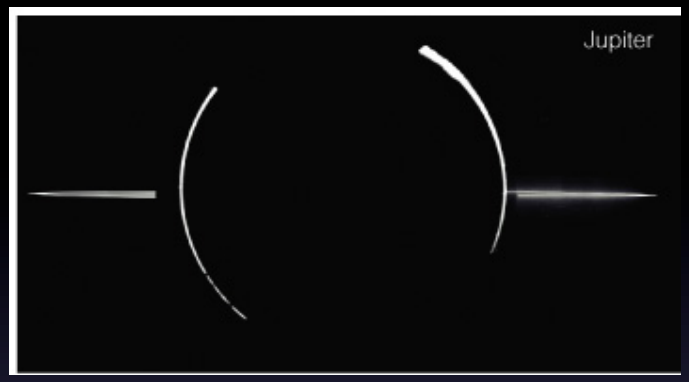


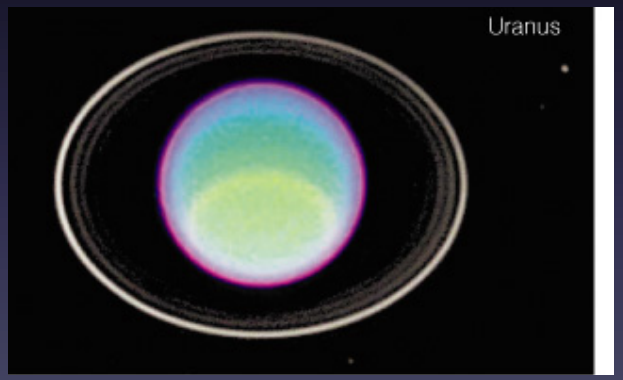
Figure 14-8
Universe, Tenth Edition

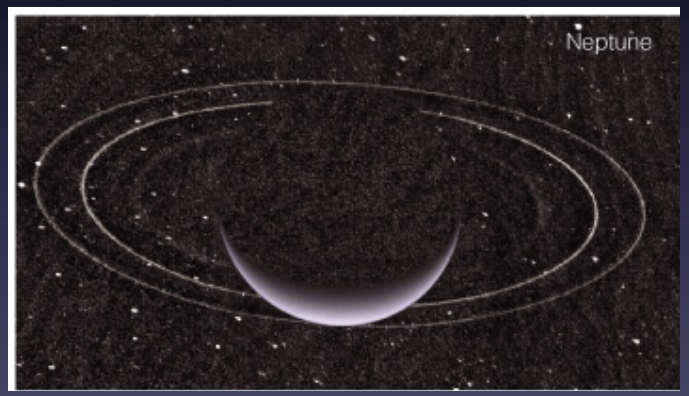
Hypotheses:

- Undergoing reversal?
- Collisions?
- Capture of Triton (Neptune only)

Jovian Ring Systems



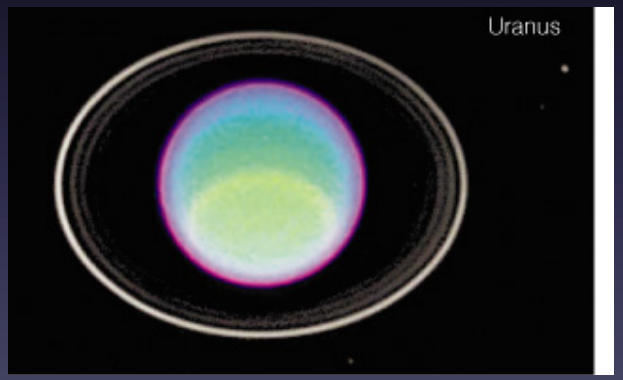


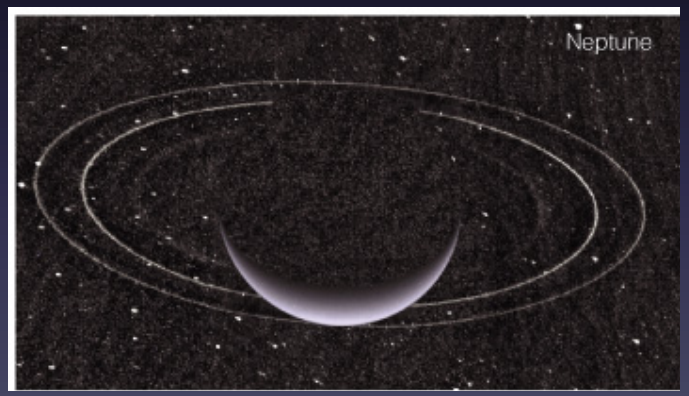


- All four jovian planets have ring systems
- Others have smaller, darker ring particles than Saturn

Uranus and Neptune's Rings

- Radiation darkened methane ice, small particles





14-6: Uranus and Neptune each has a system of thin, dark rings

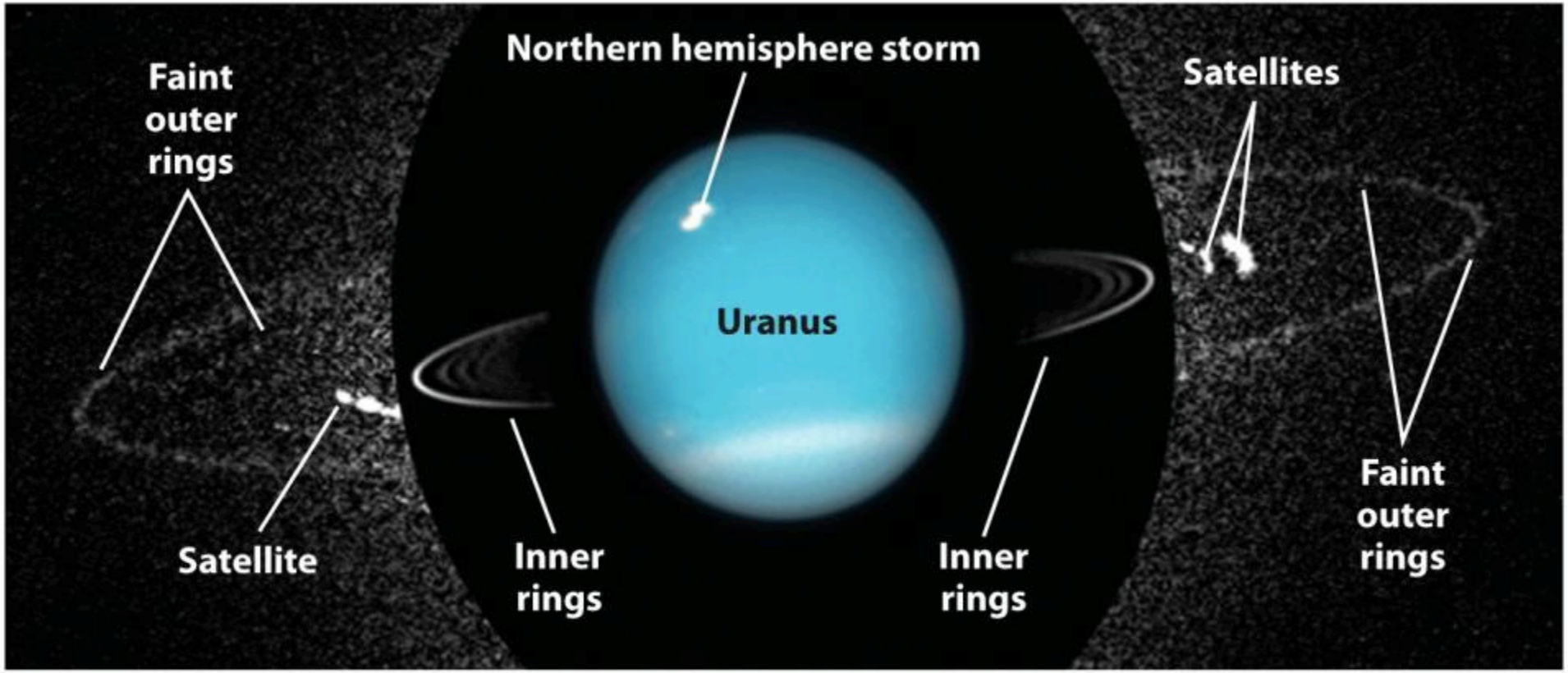


Figure 14-10
Universe, Tenth Edition
NASA; ESA; and M. Showalter, SETI Institute

Uranus:

Outer rings beyond Roche limit – one from small moon Mab?

Neptune:

Rings in 2003 fainter than in 1989: losing particles? Slowly vanishing?

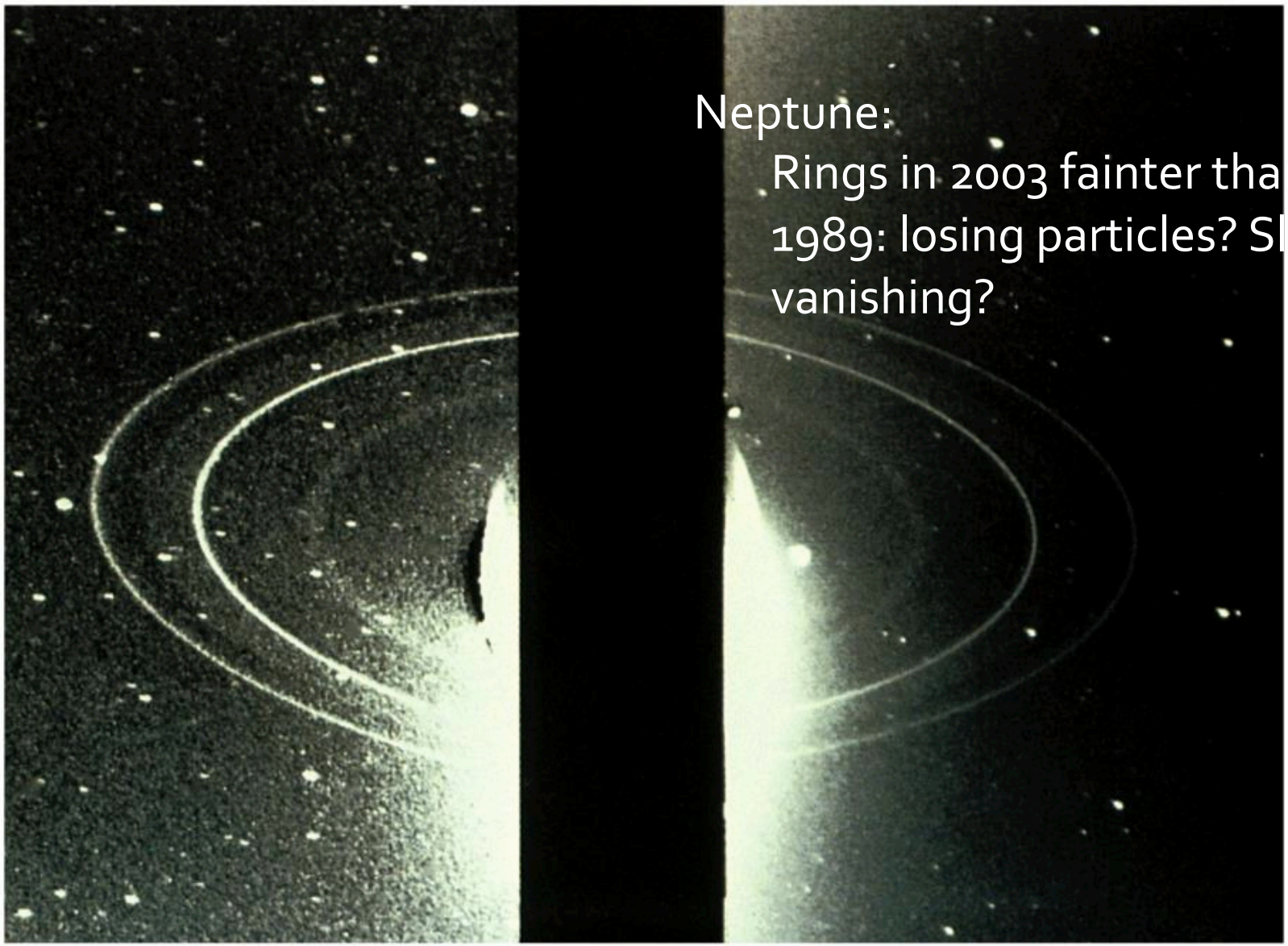


Figure 14-12
Universe, Tenth Edition
NASA

Neptune's Rings

14-7: Uranus's larger and smaller satellites

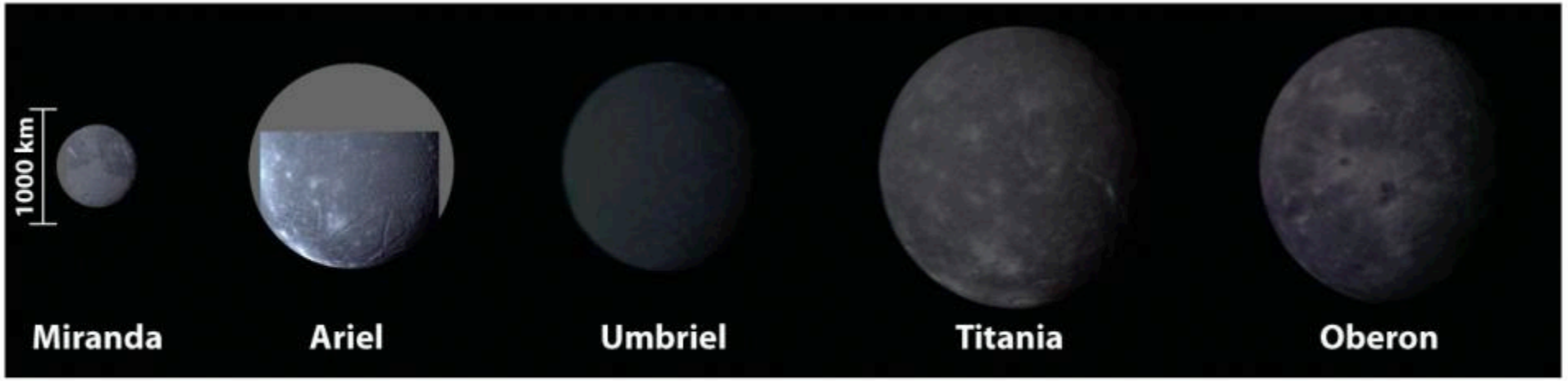


Figure 14-13
Universe, Tenth Edition
NASA/JPL-Caltech/R. Hurt [SSC]

- Varying amounts of geological activity
  - Ariel and Titania: evidence of tectonics/ice volcanism – past internal heating (tidal)
  - Umbriel and Oberon: little/none

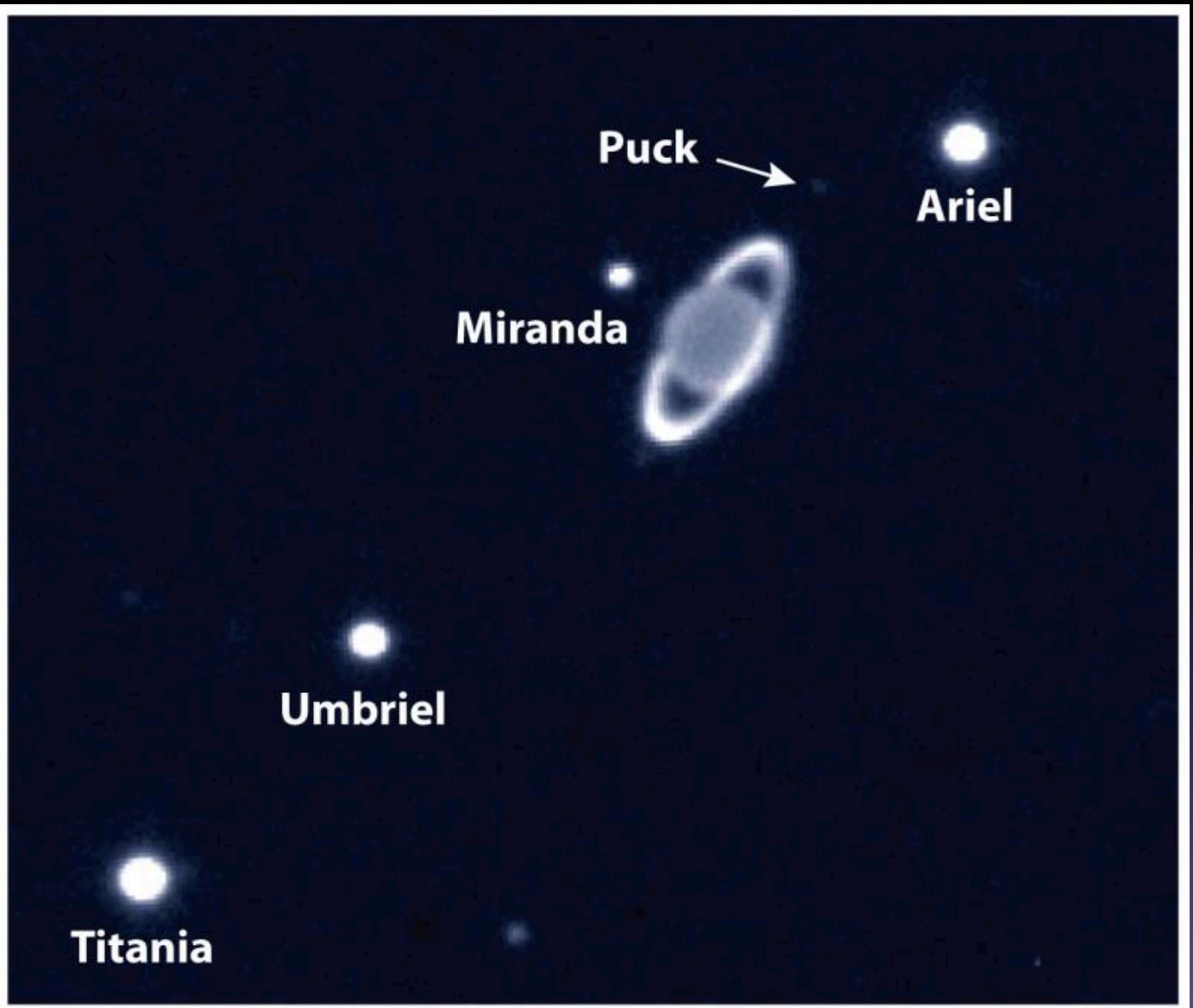


Figure 14-14b
Universe, Tenth Edition
European Southern Observatory

Uranus's Rings and Moons

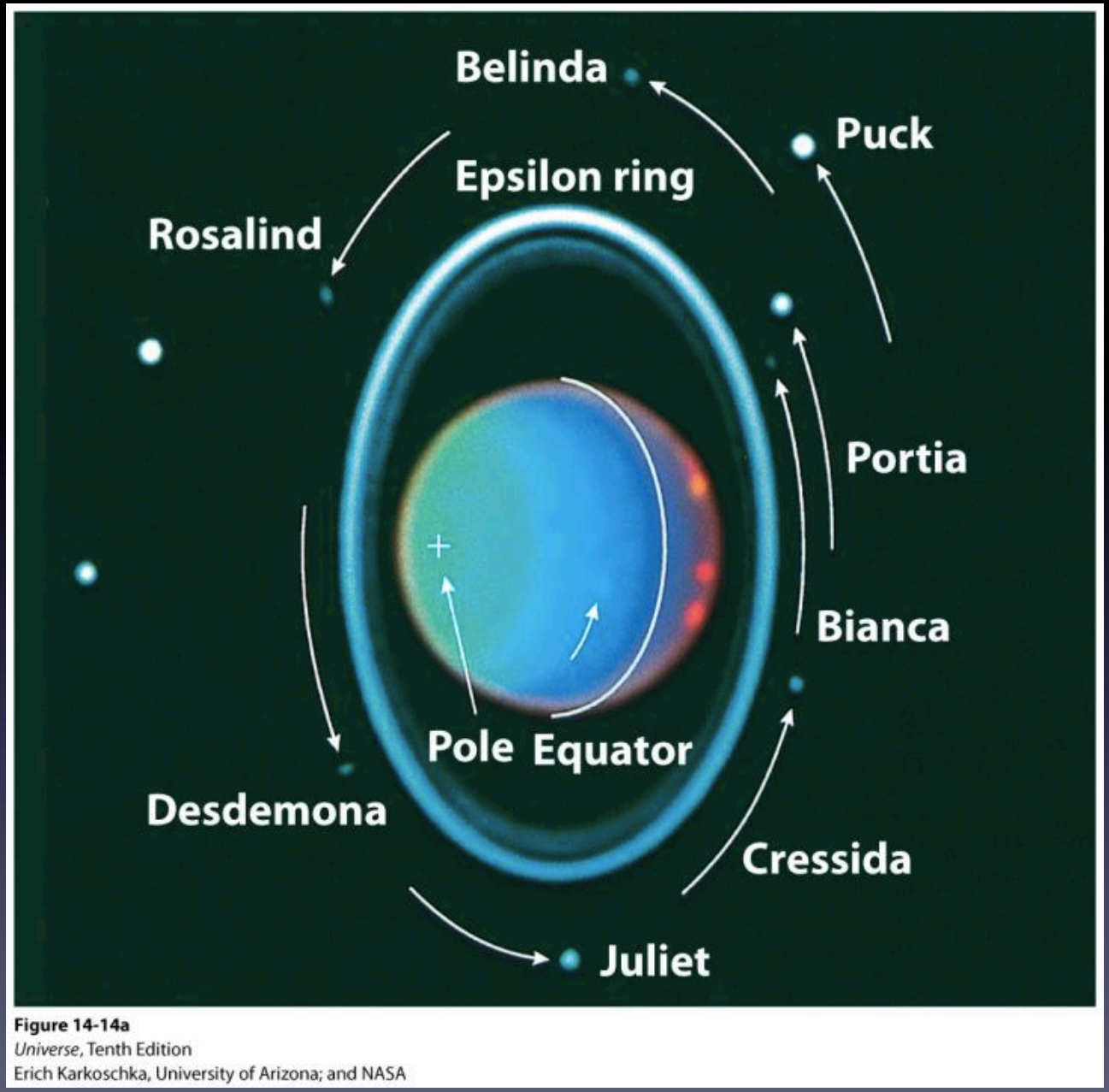
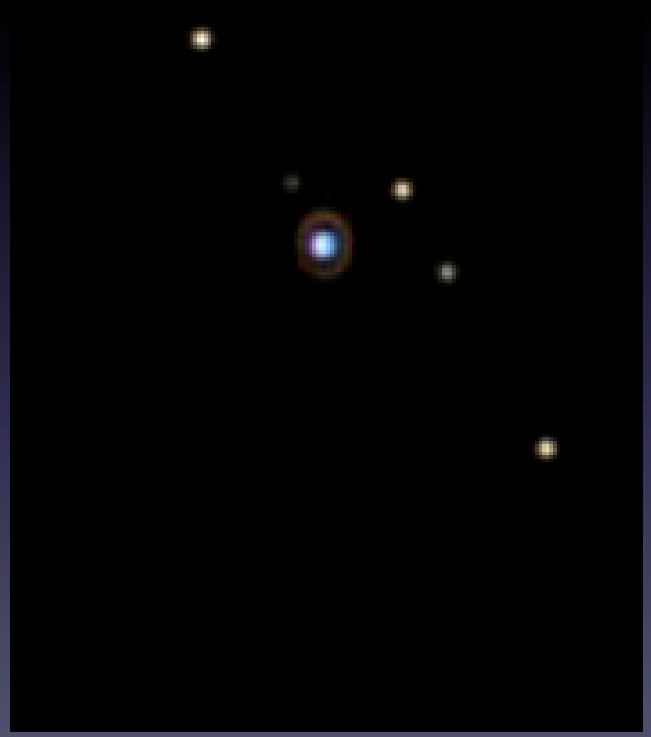


Figure 14-14a
Universe, Tenth Edition
Erich Karkoschka, University of Arizona; and NASA

Uranus's Rings and Moons


Aug 1
94

Miranda

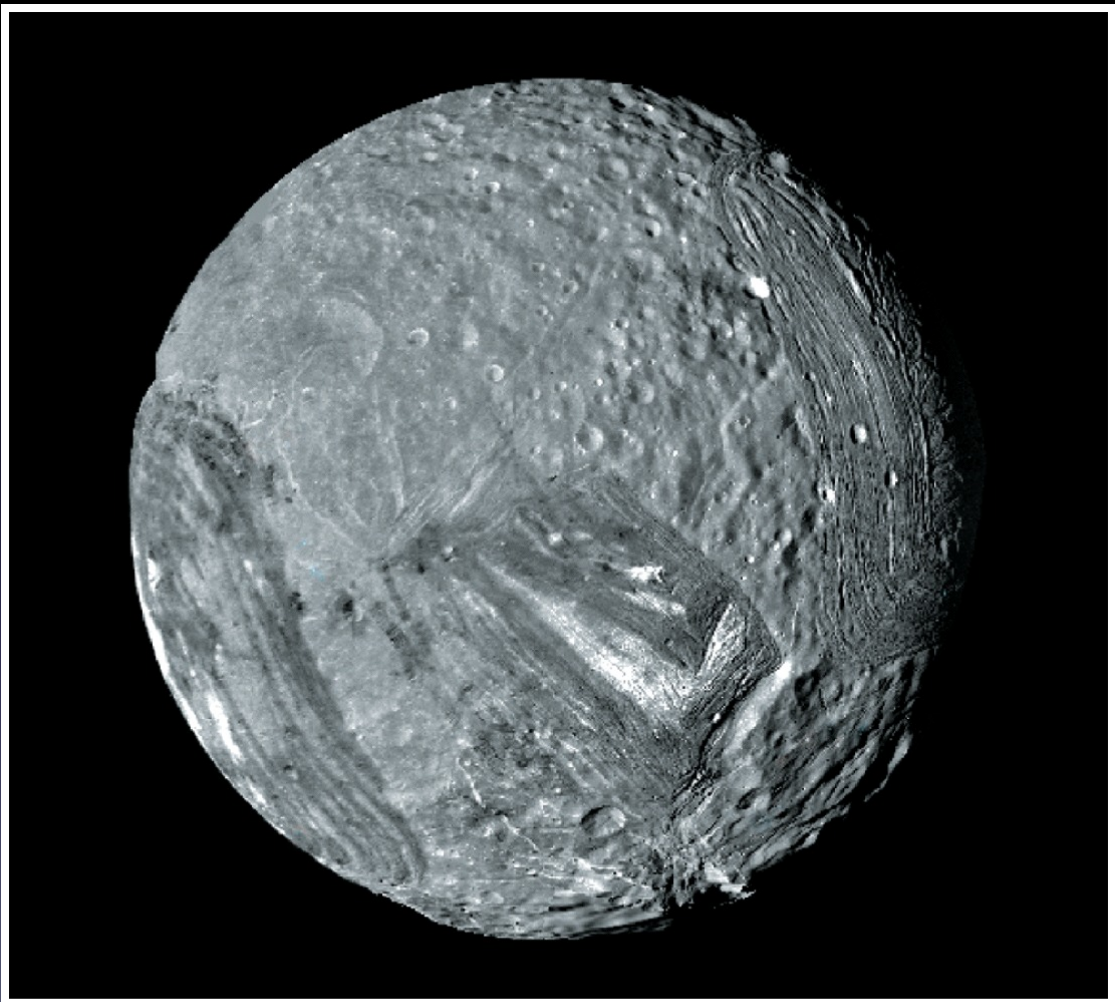


Figure 14-15
Universe, Tenth Edition
NASA/JPL

- Huge cliffs
- Jumbled terrain
- Episode of tidal heating in past from long-ago orbital resonance with Umbriel or Ariel?
- Cooled before it finished differentiating?

Uranus's Small Moons

- 9 small outer moons: retrograde orbits – captures
- 13 small inner moons: prograde
  - Orbits are changing!
  - Due to close encounters – all will collide within 100 million years so less than 100 million years old
  - Origin unknown: possibly from fragmentation of other moons?

What happened to Uranus?

- Orbits of large moons (prograde, in equatorial plane) show they probably formed in place (post impact)
  - Any large impact(s) would have been while Uranus was still forming (proto-Uranus nebula)
  - Such a large impact would be highly rare so it would be unusual
- Source of tilt not really known

14-8: Neptune's satellite Triton is an icy world with a young surface and a tenuous atmosphere

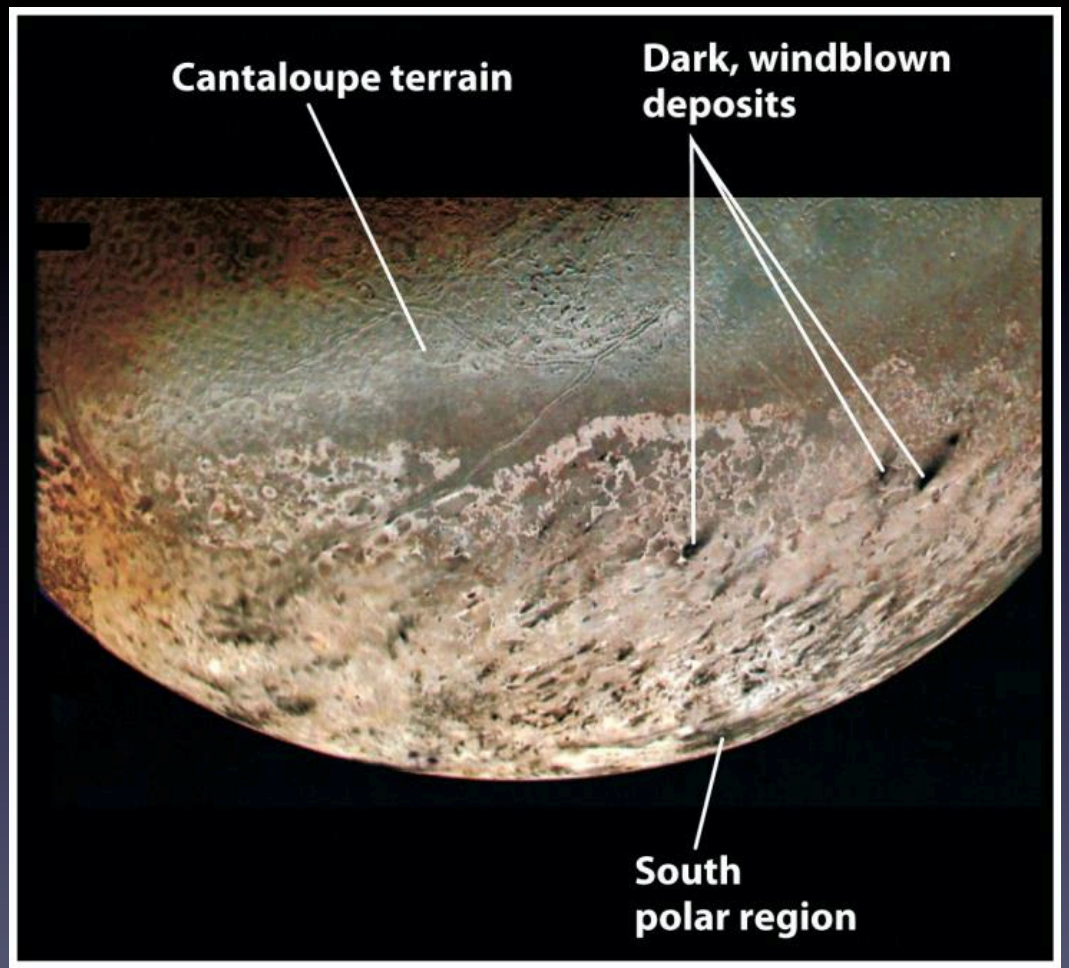
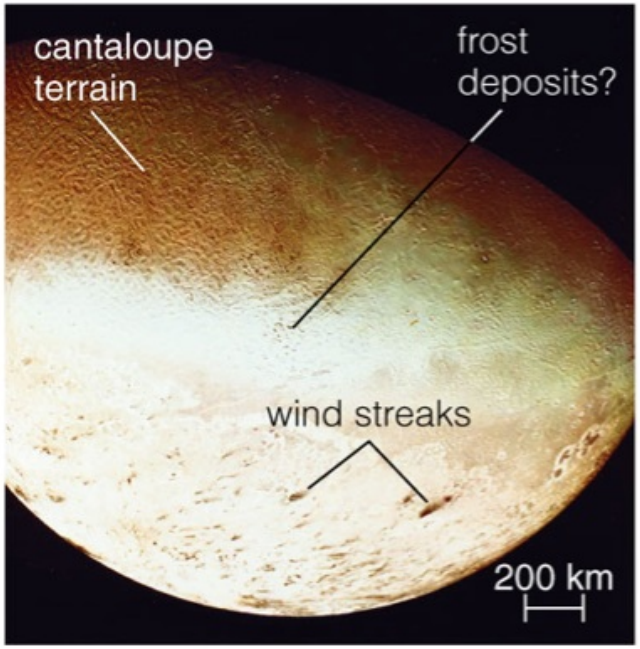


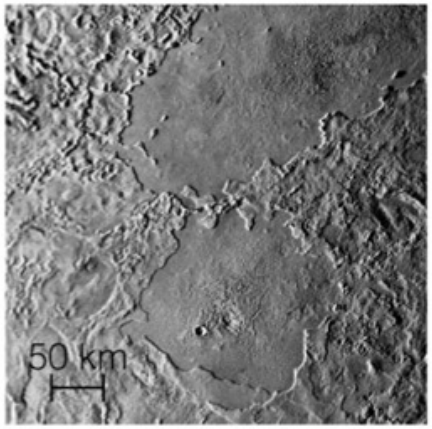
Figure 14-16
Universe, Tenth Edition
NASA/JPL

Triton

Neptune's Moon Triton



Triton's southern hemisphere as seen by *Voyager 2*.

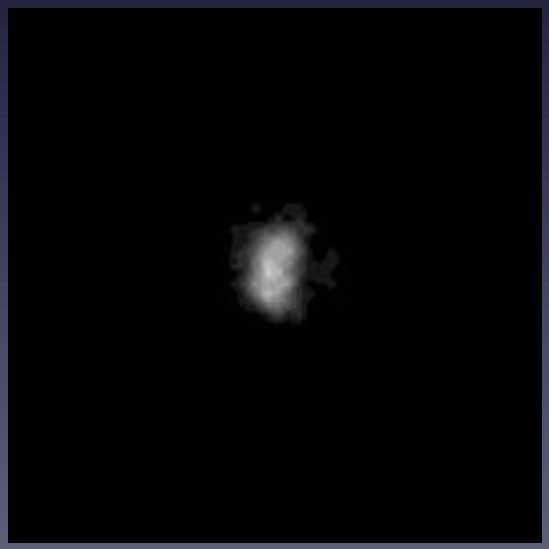


This close-up shows lava-filled impact basins similar to the lunar maria, but the lava was water or slush rather than molten rock.

- Similar to Pluto, but larger
- Captured into orbit:
  - orbits in retrograde, inclined orbit
  - Spiraling in: will be torn apart
- Evidence for past geological activity
  - from tidal heating as orbit changed

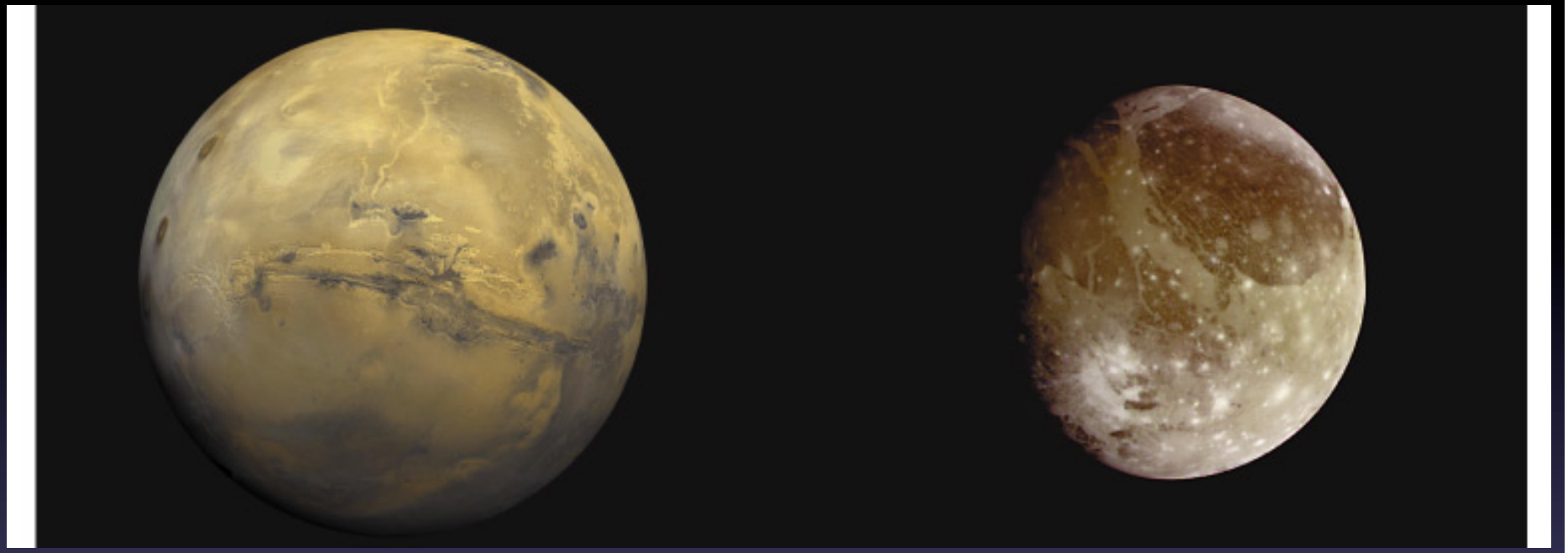
Neptune's Moon Nereid

- Small, discovered 1949
- Highly eccentric, inclined prograde orbit
  - Disturbed when Triton was captured?



Voyager 2 image

Rocky Planets vs. Icy Moons



- Rock melts at higher temperatures
- Only large rocky planets have enough heat for activity

- Ice melts at lower temperatures
- Tidal heating can melt internal ice, driving activity

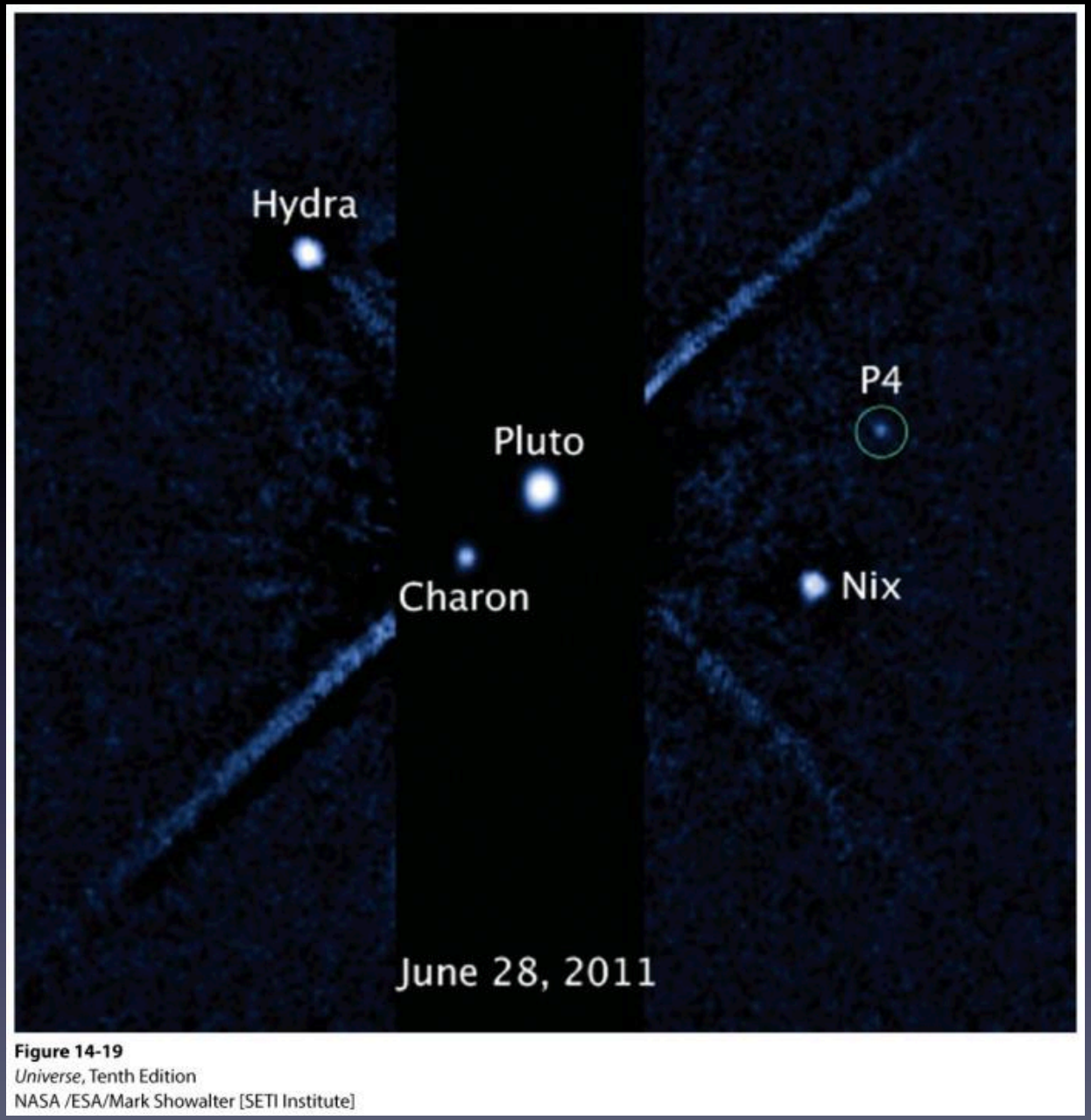


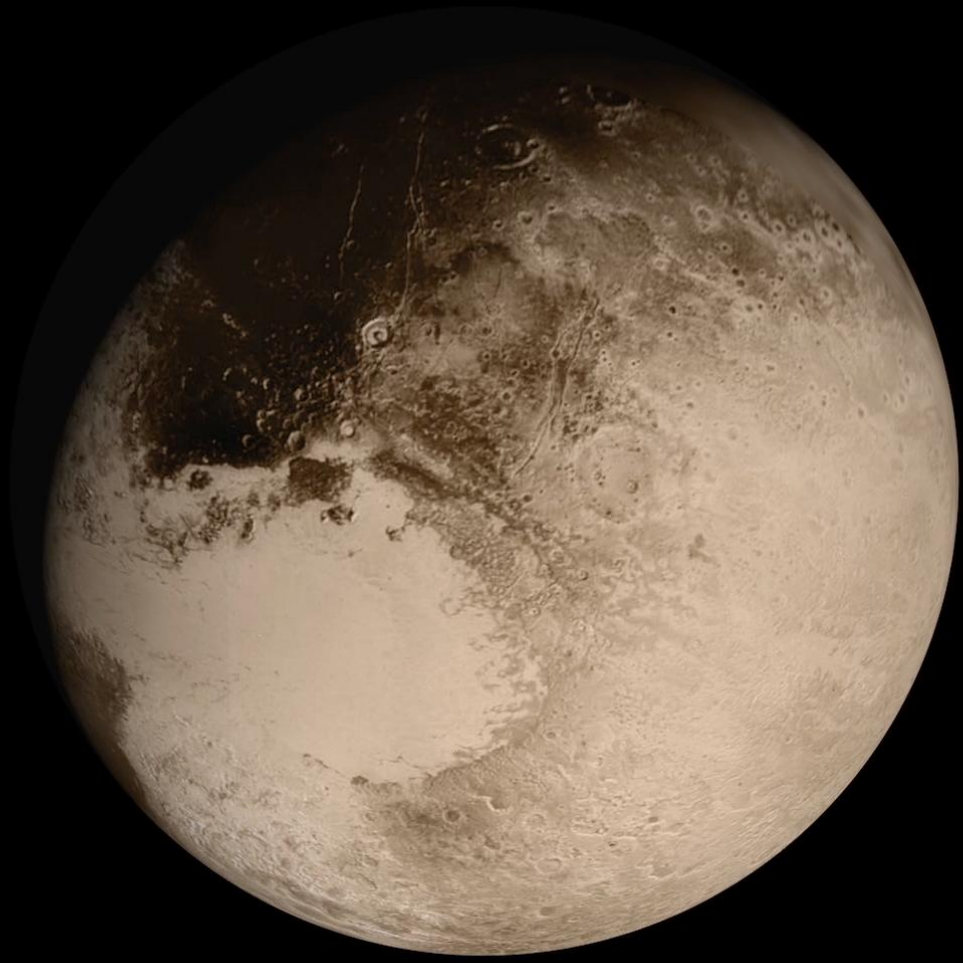
Figure 14-19
Universe, Tenth Edition
NASA /ESA/Mark Showalter [SETI Institute]

Pluto and Its Satellites

Pluto

- Discovered 1930, reclassified 2006
- Elliptical orbit (0.25), inclined 17°
  - Passes inside Neptune's orbit (1979-1999)
  - In ~2:3 orbital resonance with Neptune: will never collide
- Rotation axis tilted 119°: technically retrograde rotation
- Synchronous rotation with large, close moon Charon

Pluto



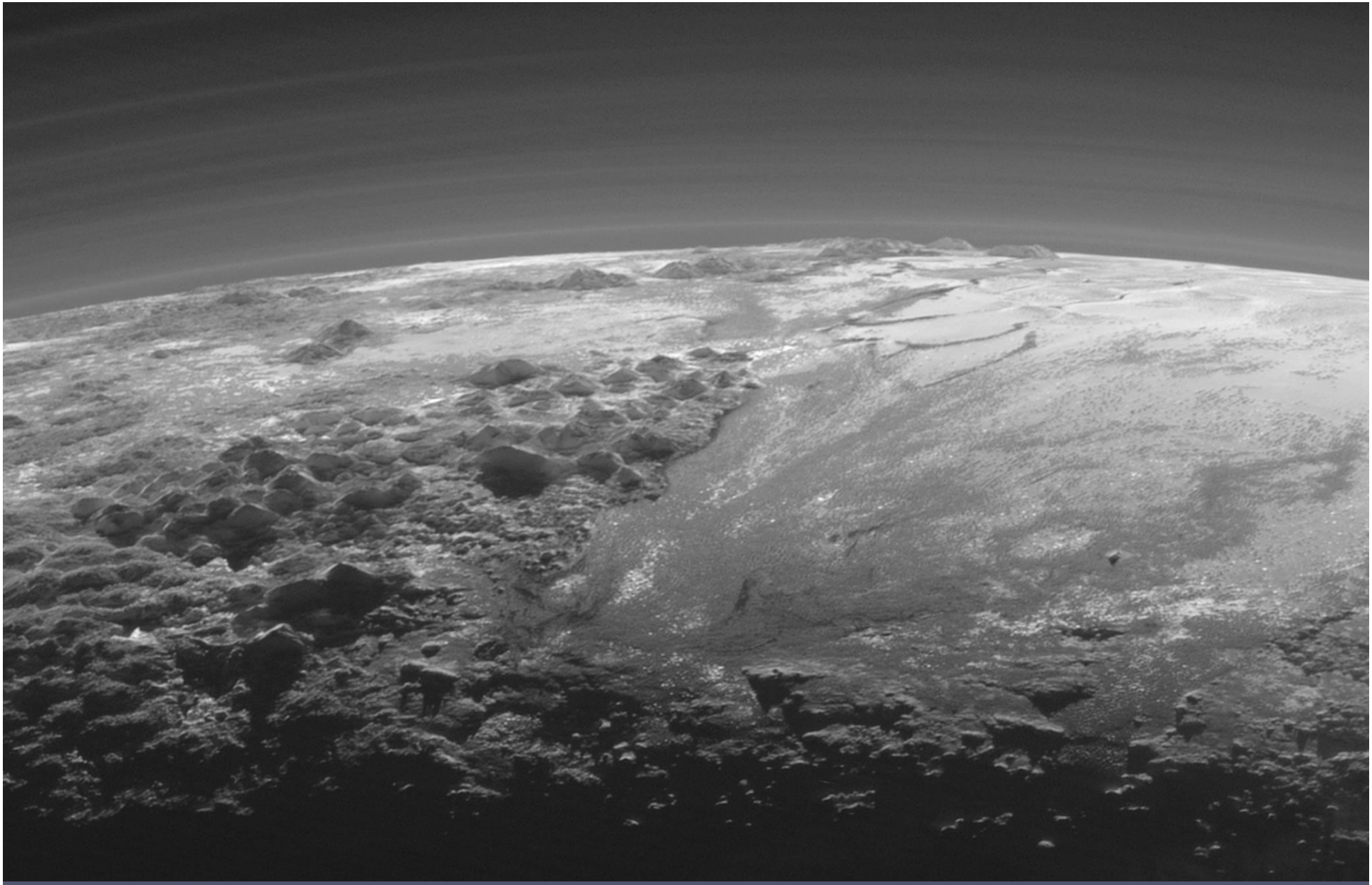
NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Pluto

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Pluto's Surface

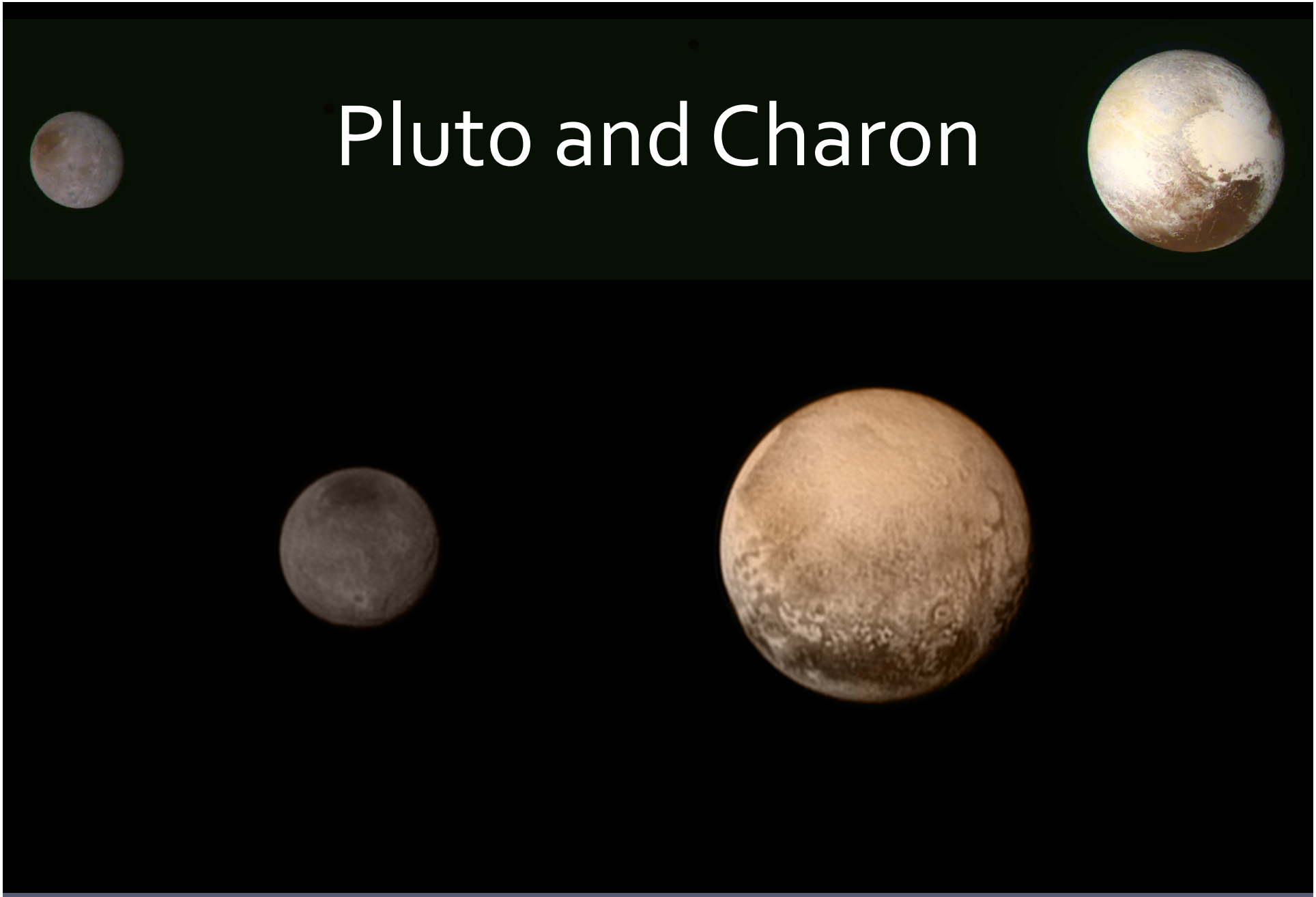
- Nitrogen, Methane, CO ices
  - Patches of water ice just discovered
- Ices evaporate (sublimate): form thin escaping atmosphere
- Evidence of ice tectonics "recently"
  - Cause of internal heating unknown!



Pluto's Atmosphere (and ice mountains!)

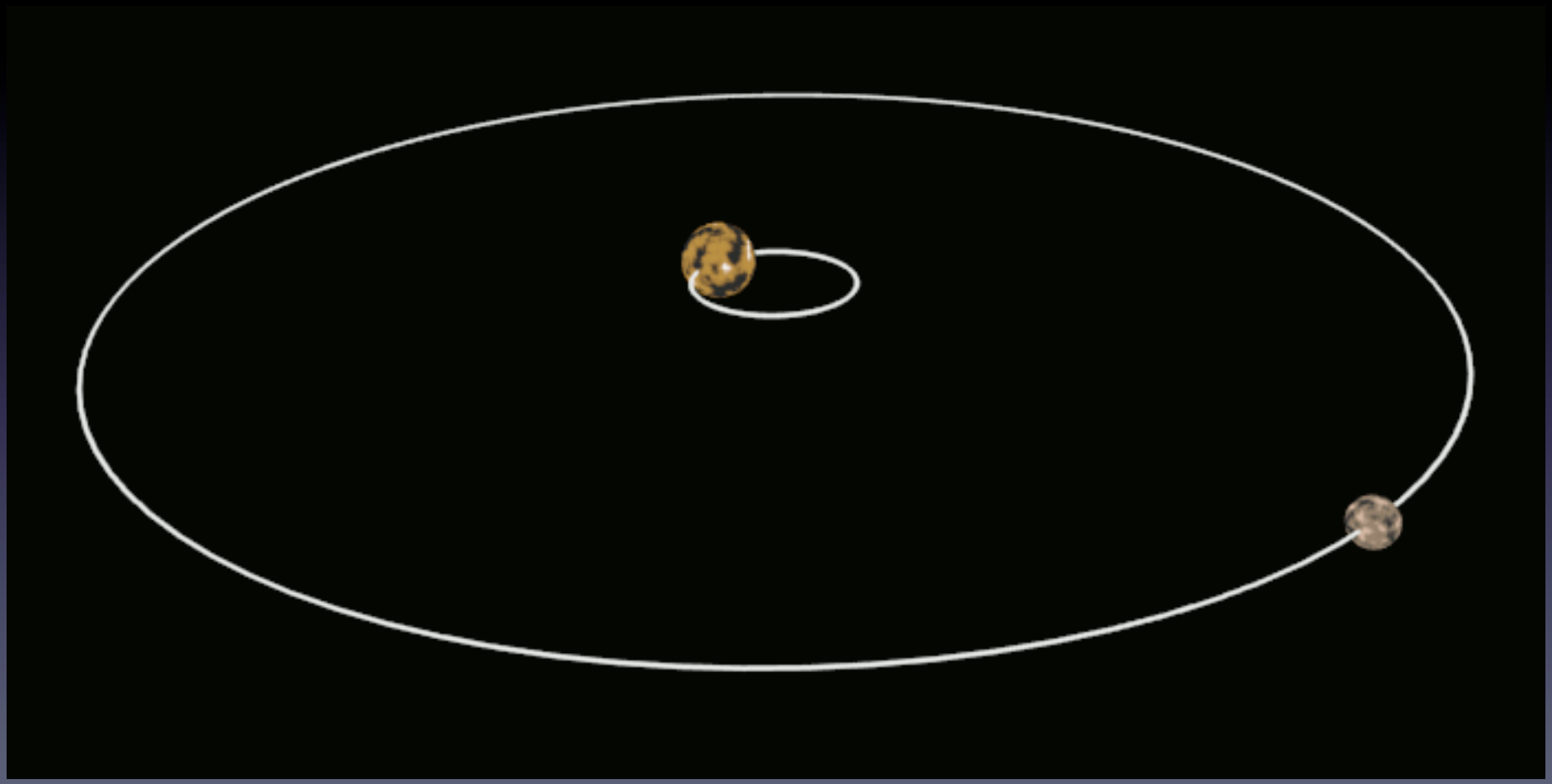
NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Pluto and Charon



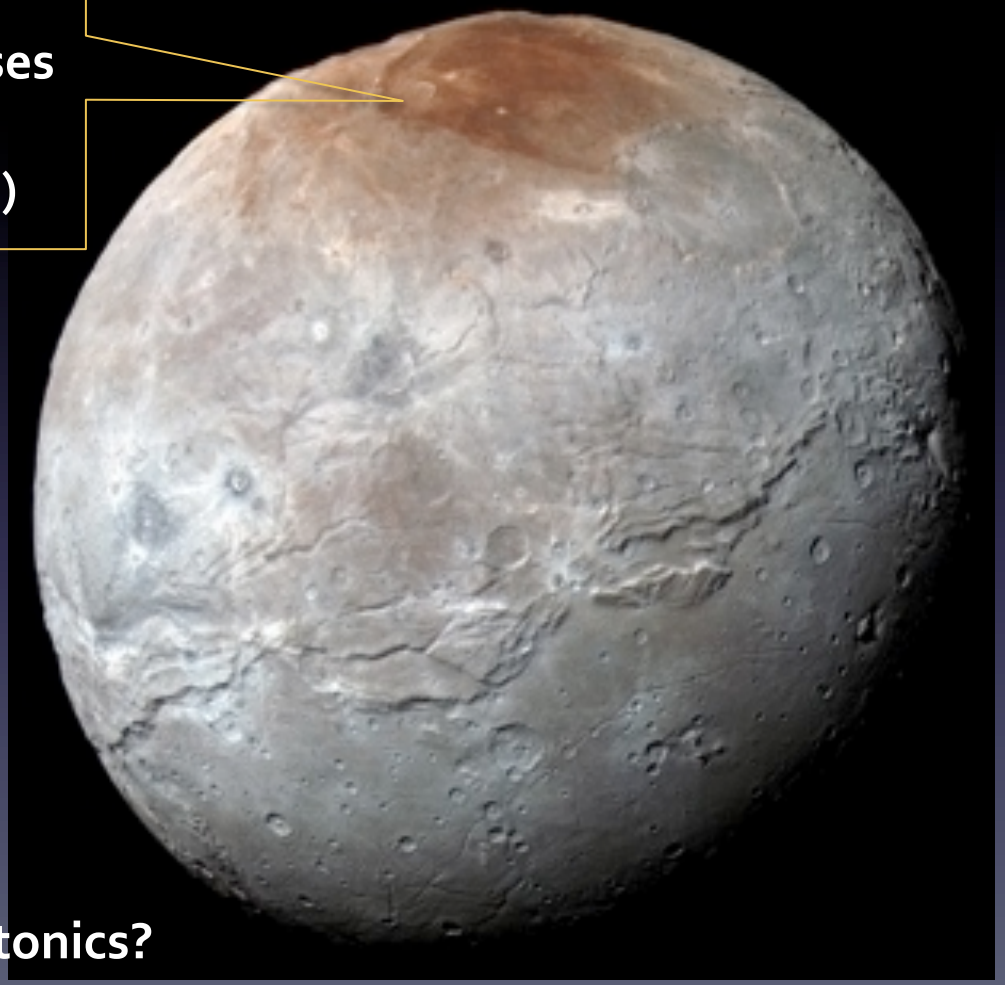
NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Pluto-Charon Orbits



wikimediacommons

Charon



Evidence of ice tectonics?

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Charon's Surface

- Mostly water ice
- Dark north region (condensed gases from Pluto's escaping atmosphere)
- Few craters, especially in southern hemisphere
  - Ice tectonics, cryovolcanoes, massive resurfacing?
- Probably differentiated?

14-10: Trans-Neptunian Objects and Pluto's Reclassification

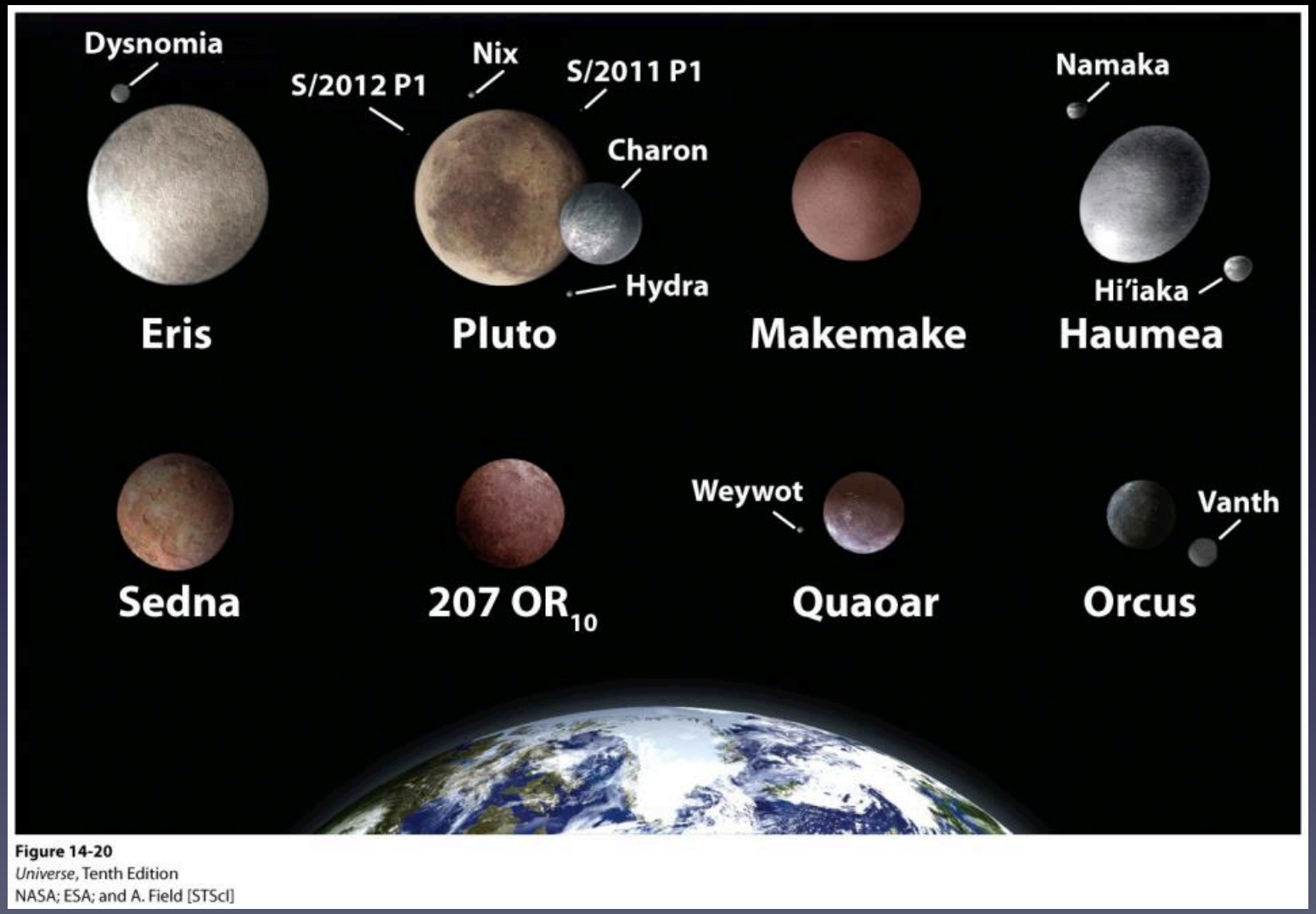


Figure 14-20
Universe, Tenth Edition
NASA; ESA; and A. Field [STScI]

The Largest Trans-Neptunian Objects

Pluto's Origin

- Residual planetesimal (Kuiper Belt Object)
- As Neptune migrated outward, gravitationally perturbed objects in proto-Kuiper belt
  - Captured Triton
  - Scattered some into "scattered disk" population (like Eris)
  - Helped cause era of bombardment that cratered objects?
- Affected Pluto's orbit – larger, more eccentric, tilted

Wikipedia

Key Ideas

- **Discovery of the Outer Planets:** Uranus was discovered by chance, while Neptune was discovered at a location predicted by applying Newtonian mechanics.
- **Atmospheres of Uranus and Neptune:** Both Uranus and Neptune have atmospheres composed primarily of hydrogen, helium, and few percent methane.
- Methane absorbs red light, giving Uranus and Neptune their greenish-blue color.
- No white ammonia clouds are seen on Uranus or Neptune. Presumably the low temperatures have caused almost all the ammonia to precipitate into the interiors of the planets. All of these planets' clouds are composed of methane.

Key Ideas

- Much more cloud activity is seen on Neptune than on Uranus. This is because Uranus lacks a substantial internal heat source.
- **Interiors and Magnetic Fields of Uranus and Neptune:** Both Uranus and Neptune may have a rocky core surrounded by a mantle of water and ammonia. Electric currents in these mantles may generate the magnetic fields of the planets.
- The magnetic axes of both Uranus and Neptune are steeply inclined from their axes of rotation. The magnetic and rotational axes of all the other planets are more nearly parallel. The magnetic fields of Uranus and Neptune are also offset from the centers of the planets.

Key Ideas

- **Uranus's Unusual Rotation:** Uranus's axis of rotation lies nearly in the plane of its orbit, producing greatly exaggerated seasonal changes on the planet.
- This unusual orientation may be the result of a collision with a planet-like object early in the history of our solar system. Such a collision could have knocked Uranus on its side.
- **Ring Systems of Uranus and Neptune:** Uranus and Neptune are both surrounded by systems of thin, dark rings. The low reflectivity of the ring particles may be due to radiation-darkened methane ice.

Key Ideas

- **Satellites of Uranus and Neptune:** Uranus has five satellites similar to the moderate-sized moons of Saturn, plus at least 22 more small satellites. Neptune has 13 satellites, one of which (Triton) is comparable in size to our Moon or the Galilean satellites of Jupiter.
- Triton has a young, icy surface indicative of tectonic activity. The energy for this activity may have been provided by tidal heating that occurred when Triton was captured by Neptune's gravity into a retrograde orbit.
- Triton has a tenuous nitrogen atmosphere.

Key Ideas

- **Dwarf Planet:** An object orbiting the Sun (but is not a moon) with enough mass to gravitationally pull itself into a spherical shoape, yet not enough gravity to clear out planetesimals from its surroundings.
- This term was introduced in 2006 to help reclassify Pluto as a dwarf planet
- **Trans-Neptunian Object:** An object that orbits the Sun (other than planets and comets) and on average orbits at a distance greater than Neptune.
- More than a thousand icy worlds have been discovered beyond Neptune. Pluto and Charon are part of this population.
- Most trans-Neptunian objects lie in a band called the Kuiper belt that extends from 30 to 50 AU from the Sun. Neptune's gravity shapes the orbits of objects within the Kuiper belt.