ASTRONOMY

Chapter 11 THE GIANT PLANETS
Chapter 12 RINGS, MOONS, AND PLUTO

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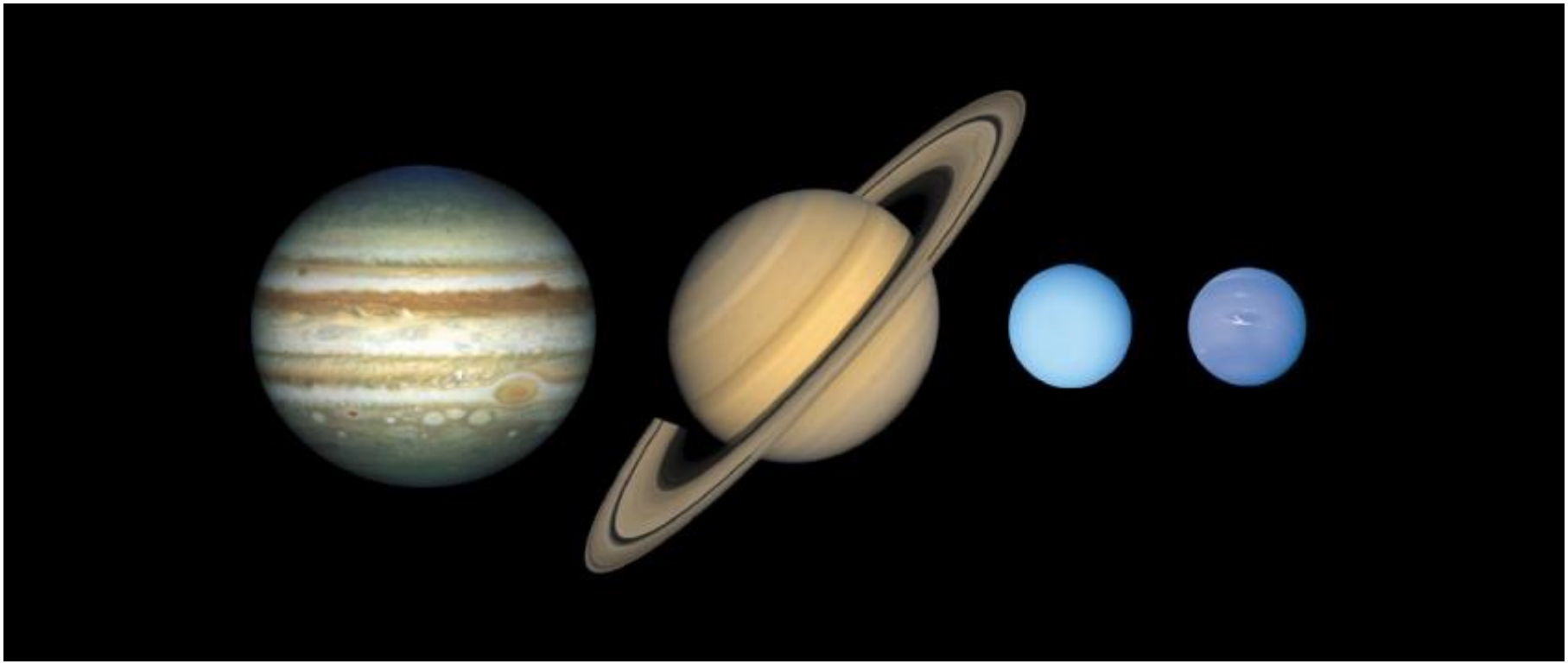
FIGURE 11.1



Giant Planets. The four giant planets in our solar system all have hydrogen atmospheres, but the warm gas giants, Jupiter and Saturn, have tan, beige, red, and white clouds that are thought to be composed of ammonia ice particles with various colorants called “chromophores.” The blue-tinted ice giants, Uranus and Neptune, are much colder and covered in methane ice clouds. (credit: modification of work by Lunar and Planetary Institute, NASA)

COMPOSITION OF THE JOVIAN PLANETS

Jupiter and Saturn are both made almost entirely of hydrogen and helium, with just a few percent of their masses in the form of hydrogen compounds and even smaller amounts of rock and metal.

- Their overall compositions are much more similar to the composition of the Sun than to the compositions of the terrestrial planets.

Uranus and Neptune are much smaller than Jupiter and Saturn, and while they also contain substantial amounts of hydrogen and helium, they are made primarily of hydrogen compounds such as water (H_2O), methane (CH_4), and ammonia (NH_3), along with smaller amounts of metal and rock.

DIFFERENCES EXPLAINED BY NEBULAR THEORY

According to the Nebular Theory, the Jovian planets formed beyond the frost line where it was cold enough for hydrogen compounds to condense into ices.

Because hydrogen compounds were so much more abundant than metal and rock, some of the ice-rich planetesimals of the outer solar system grew large enough for their gravity to draw in the hydrogen and helium gas that surrounded them.

All four Jovian planets are thought to have grown from ice-rich planetesimals of about the same mass—roughly 10 times the mass of Earth.

Therefore their differences in composition must stem from the amounts of hydrogen and helium gas that they captured.

DIFFERENCES EXPLAINED BY NEBULAR THEORY

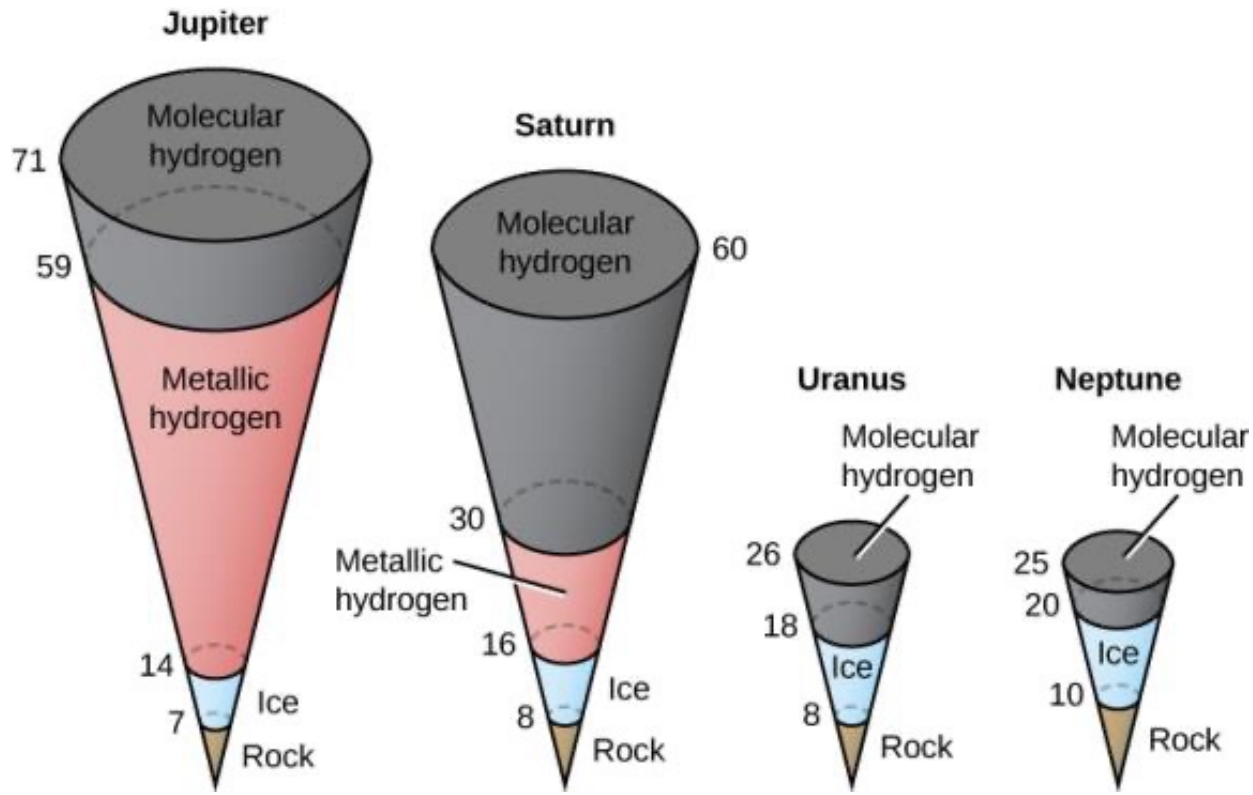
Jupiter and Saturn captured so much hydrogen and helium gas that these gases now make up the vast majority of their masses.

Uranus and Neptune pulled in much less hydrogen and helium gas, leaving their bulk compositions similar to the compositions of the ice-rich planetesimals around which they grew.

But if they all started from planetesimals of about the same size, why did Uranus and Neptune pull in so much less gas?

The answer likely lies in their distance from the Sun: Because the density of the solar nebula was lower at greater distances, it took longer for planetesimals to accrete at the distances of Uranus and Neptune than at the distances of Jupiter and Saturn.

FIGURE 11.7



Internal Structures of the Jovian Planets. Jupiter and Saturn are composed primarily of hydrogen and helium (but hydrogen dominates), but Uranus and Neptune consist in large part of compounds of carbon, nitrogen, and oxygen. (The diagrams are drawn to scale; numbers show radii in thousands of kilometers.)

FIGURE 11.10

Jupiter's Colorful Clouds. The vibrant colors of the clouds on Jupiter present a puzzle to astronomers: given the cool temperatures and the composition of nearly 90% hydrogen, the atmosphere should be colorless. One hypothesis suggests that perhaps colorful hydrogen compounds rise from warm areas. The actual colors are a bit more muted, as shown in **Figure 11.2**. (credit: modification of work by Voyager Project, JPL, and NASA)

CLOUDY ATMOSPHERES

The Jovian planets all have very cloudy atmospheres, but their clouds are different from those on Earth.

Clouds form when a gas condenses to make tiny liquid droplets or solid flakes.

Earth's atmosphere contains only one ingredient that can condense into clouds: water vapor.

The Jovian planets have several gases that can condense to form clouds.

Because different gases condense at different temperatures, these planets have distinctive cloud layers at different altitudes.

For example, Jupiter has three primary cloud layers:

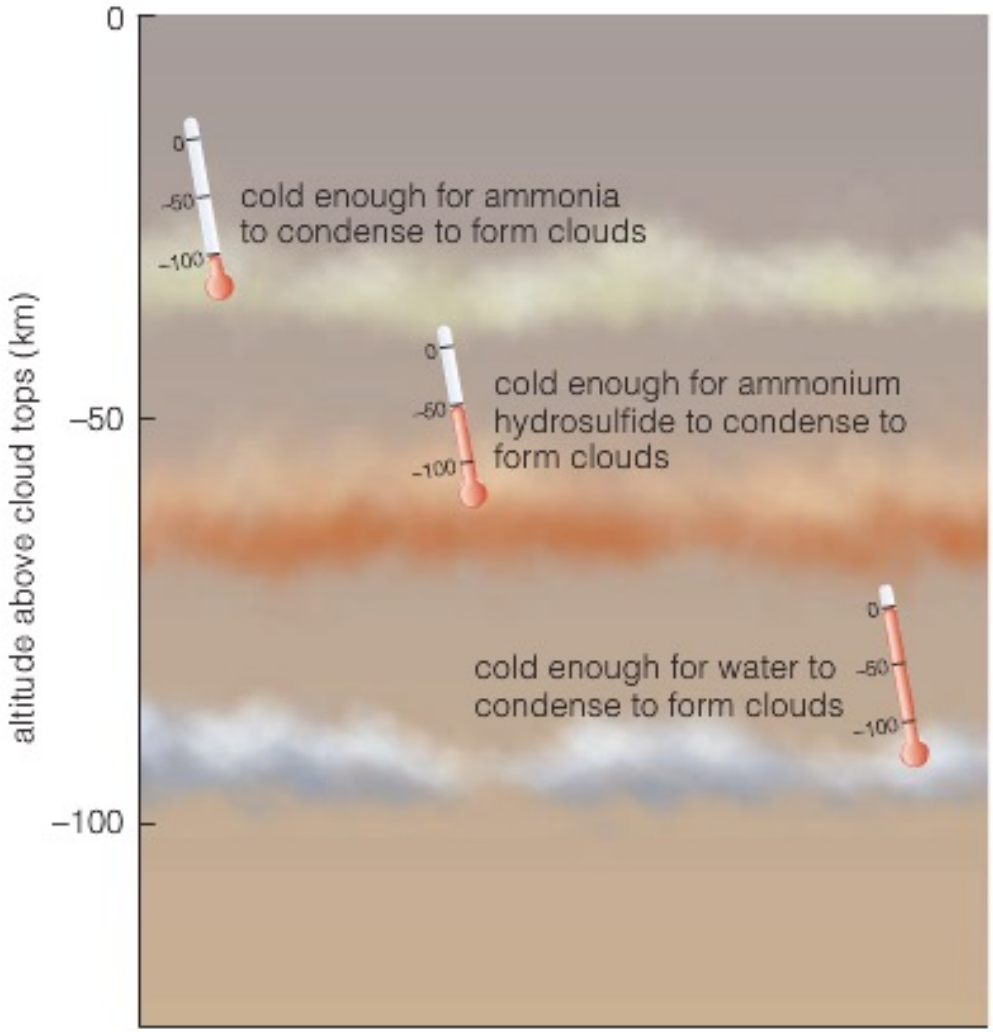
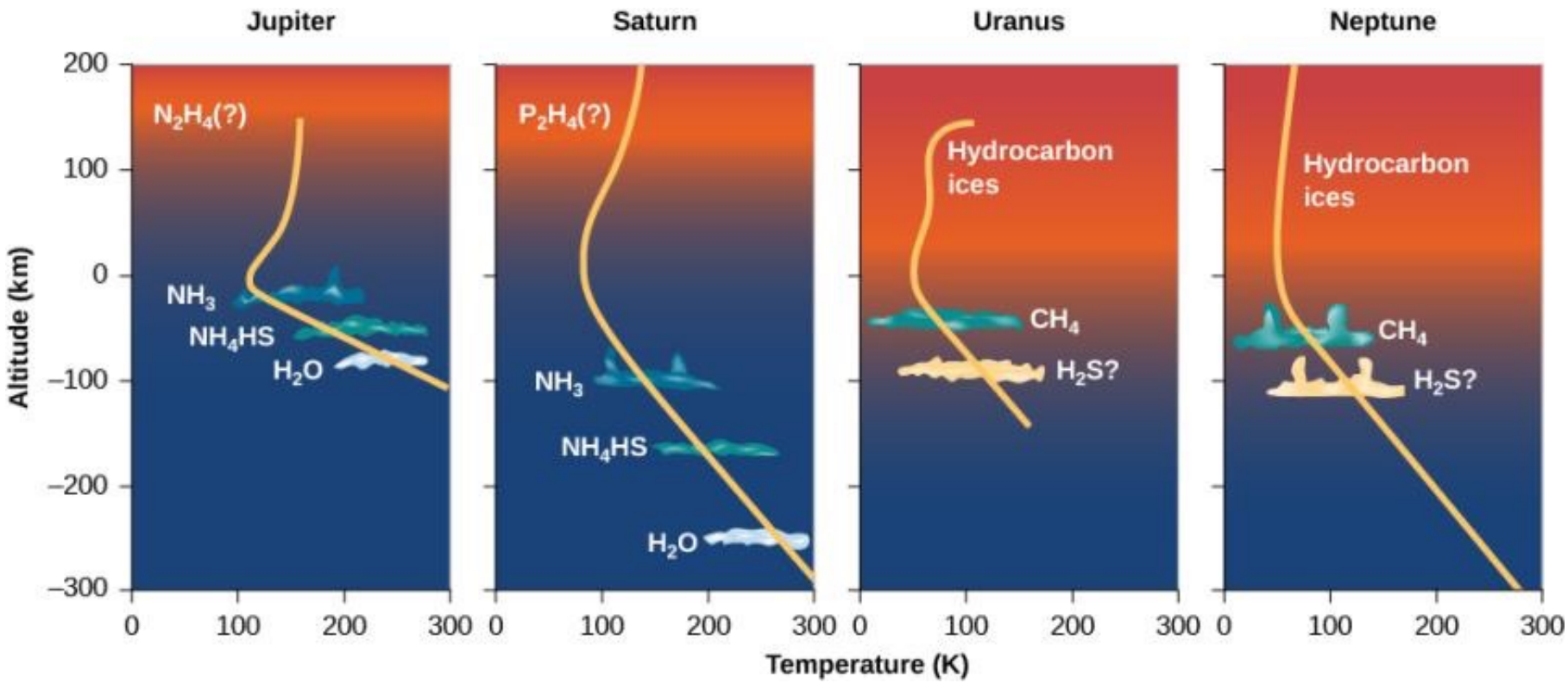


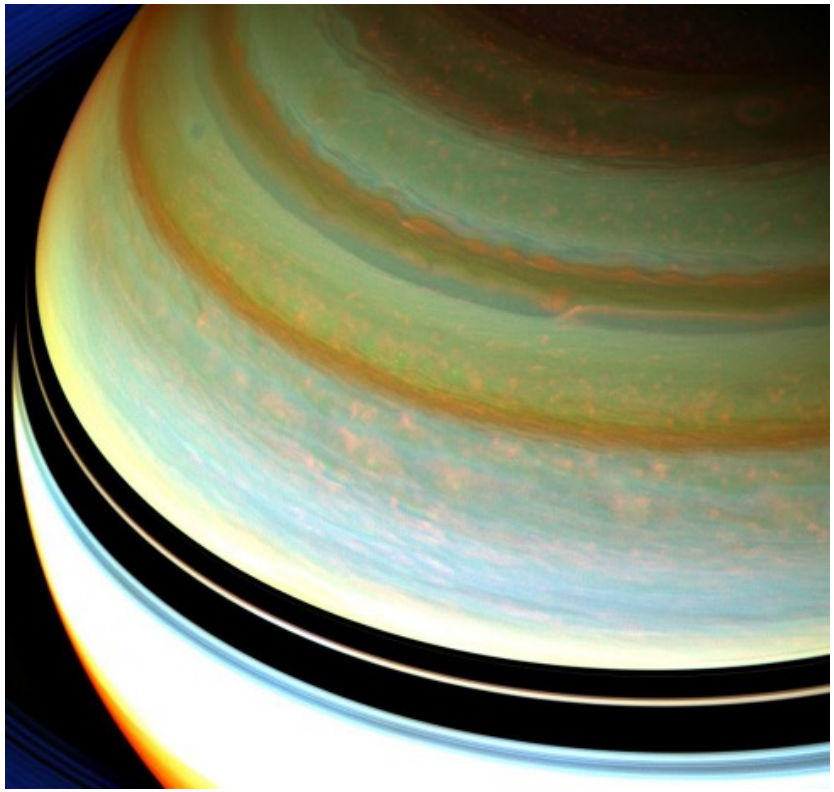
Figure 6.3 | This diagram shows how different cloud layers form at different altitudes in Jupiter's atmosphere. The different layers form because temperature is lower at higher altitudes; different gases condense at different temperatures. (The tops of the ammonia clouds are usually considered the zero altitude for Jupiter, which is why lower altitudes are negative.)

FIGURE 11.12



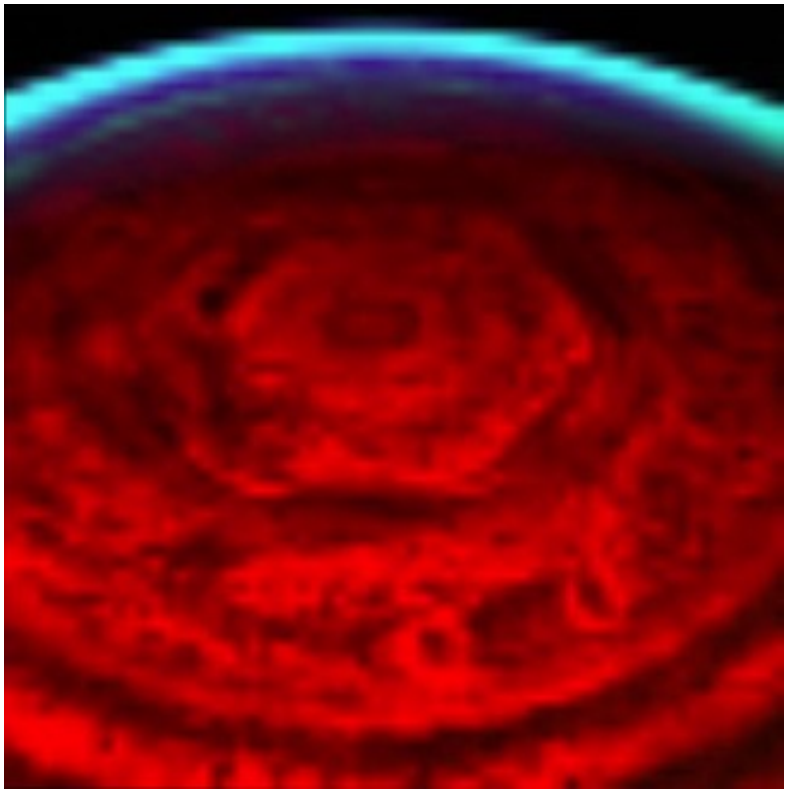
Atmospheric Structure of the Jovian Planets. In each diagram, the yellow line shows how the temperature (see the scale on the bottom) changes with altitude (see the scale at the left). The location of the main layers on each planet is also shown.

FIGURE 11.13



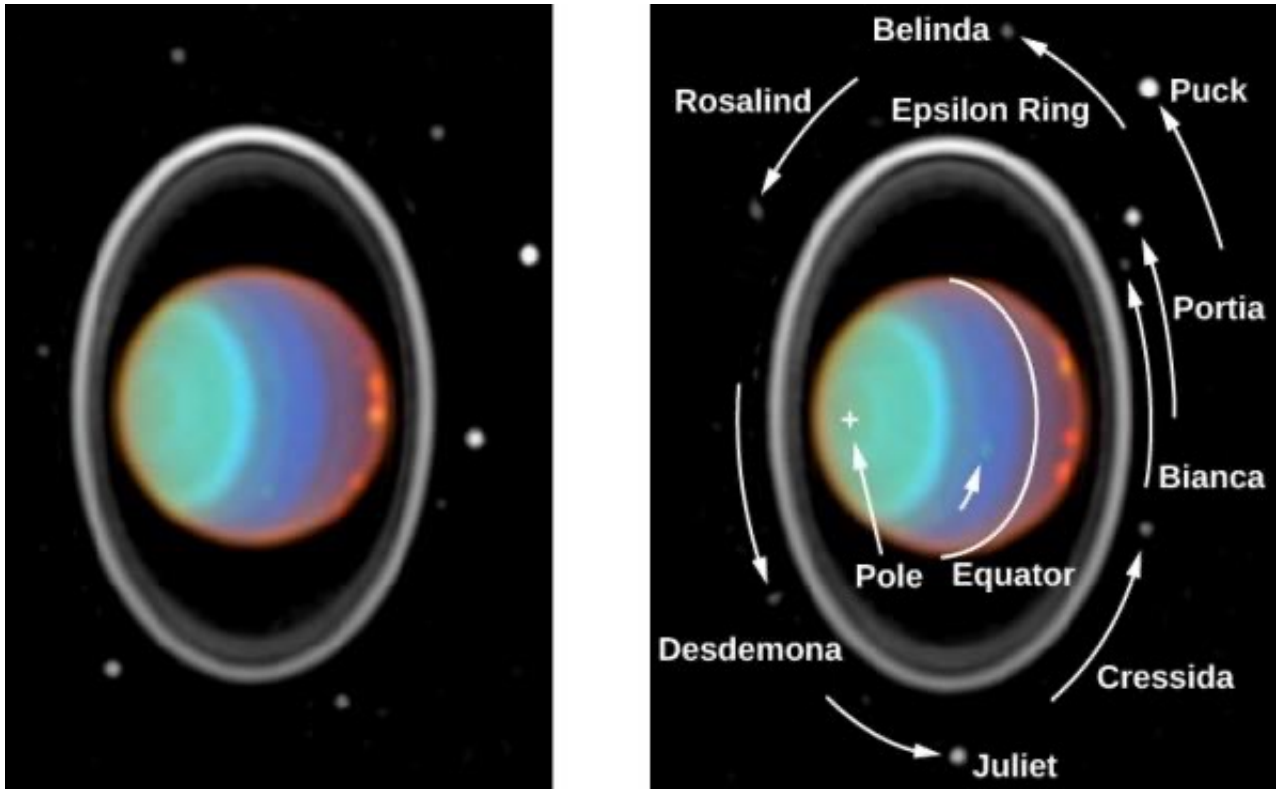
Cloud Structure on Saturn. In this Cassini image, colors have been intensified, so we can see the bands and zones and storms in the atmosphere. The dark band is the shadow of the rings on the planet. (credit: NASA/JPL-Caltech/Space Science Institute)

FIGURE 11.14



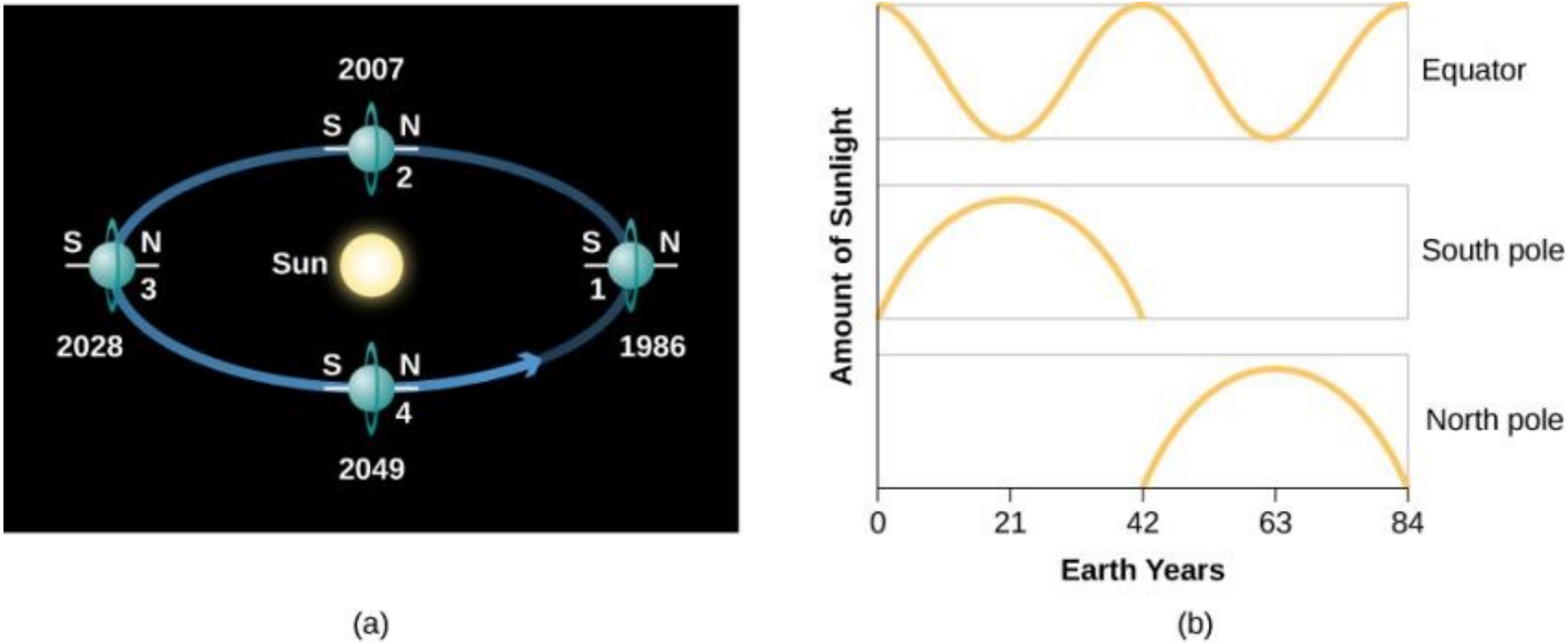
Hexagon Pattern on Saturn's North Pole. In this infrared nighttime image from the Cassini mission, the path of Saturn's hexagonal jet stream is visible as the planet's north pole emerges from the darkness of winter. (credit: NASA/JPL/University of Arizona)

FIGURE 11.5



Infrared Image of Uranus. The infrared camera on the Hubble Space Telescope took these false-color images of the planet Uranus, its ring system, and moons in 1997. The south pole of the planet (marked with a "+" on the right image) faces the Sun; its green color shows a strong local haze. The two images were taken 90 minutes apart, and during that time the five reddish clouds can be seen to rotate around the parallel to the equator. The rings (which are very faint in the visible light, but prominent in infrared) and eight moons can be seen around the equator. This was the "bull's eye" arrangement that Voyager saw as it approached Uranus in 1986. (credit: modification of work by Erich Karkoschka (University of Arizona), and NASA/ESA)

FIGURE 11.6

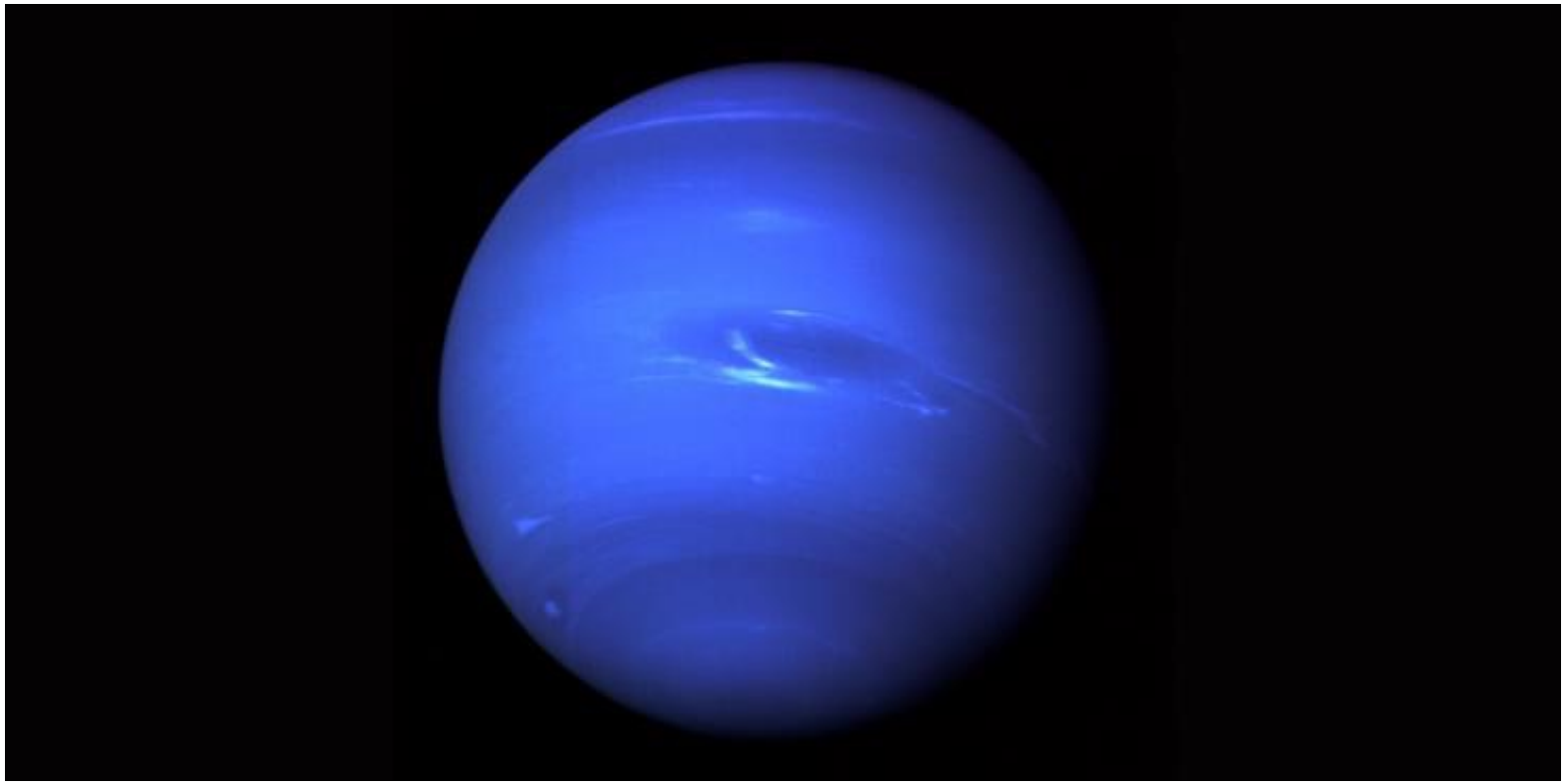


Strange Seasons on Uranus.

(a) This diagram shows the orbit of Uranus as seen from above. At the time Voyager 2 arrived (position 1), the South Pole was facing the Sun. As we move counterclockwise in the diagram, we see the planet 21 years later at each step.

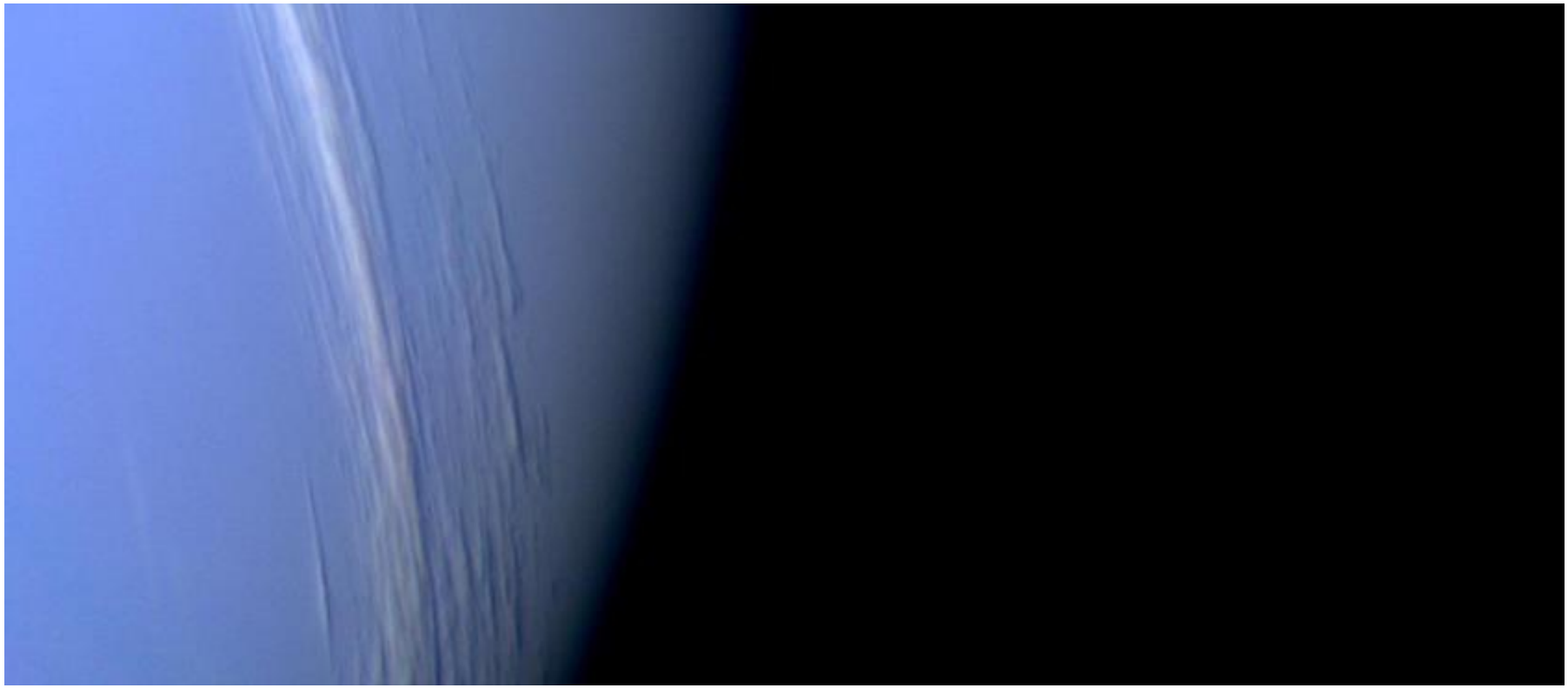
(b) This graph compares the amount of sunlight seen at the poles and the equator of Uranus over the course of its 84-year revolution around the Sun.

FIGURE 11.15



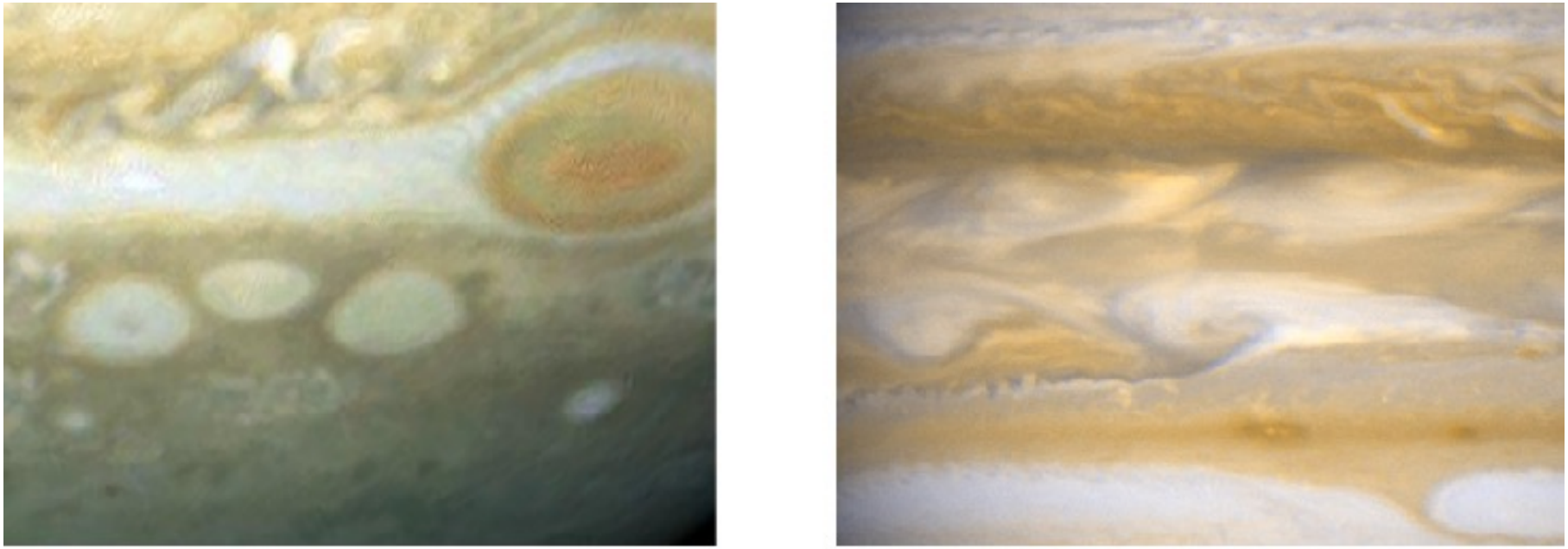
Neptune. The planet Neptune is seen here as photographed by Voyager in 1989. The blue color, exaggerated with computer processing, is caused by the scattering of sunlight in the planet's upper atmosphere. (credit: modification of work by NASA)

FIGURE 11.16



High Clouds in the Atmosphere of Neptune. These bright, narrow cirrus clouds are made of methane ice crystals. From the shadows they cast on the thicker cloud layer below, we can measure that they are about 75 kilometers higher than the main clouds. (credit: modification of work by NASA/JPL)

FIGURE 11.18



(a) (b)

Storms on Jupiter. Two examples of storms on Jupiter illustrate the use of enhanced color and contrast to bring out faint features.

(a) The three oval-shaped white storms below and to the left of Jupiter's Great Red Spot are highly active, and moved closer together over the course of seven months between 1994 and 1995.

(b) The clouds of Jupiter are turbulent and ever-changing, as shown in this Hubble Space Telescope image from 2007. (credit a: modification of work by Reta Beebe, Amy Simon (New Mexico State Univ.), and NASA; credit b: modification of work by NASA, ESA, and A. Simon-Miller (NASA Goddard Space Flight Center))

FIGURE 11.19

Jupiter's Great Red Spot. This is the largest storm system on Jupiter, as seen during the Voyager spacecraft flyby. Below and to the right of the Red Spot is one of the white ovals, which are similar but smaller high-pressure features. The white oval is roughly the size of planet Earth, to give you a sense of the huge scale of the weather patterns we are seeing. The colors on the Jupiter image have been somewhat exaggerated here so astronomers (and astronomy students) can study their differences more effectively. See **Figure 11.2** to get a better sense of the colors your eye would actually see near Jupiter. (credit: NASA/JPL)

MEDIUM AND LARGE JOVIAN MOONS

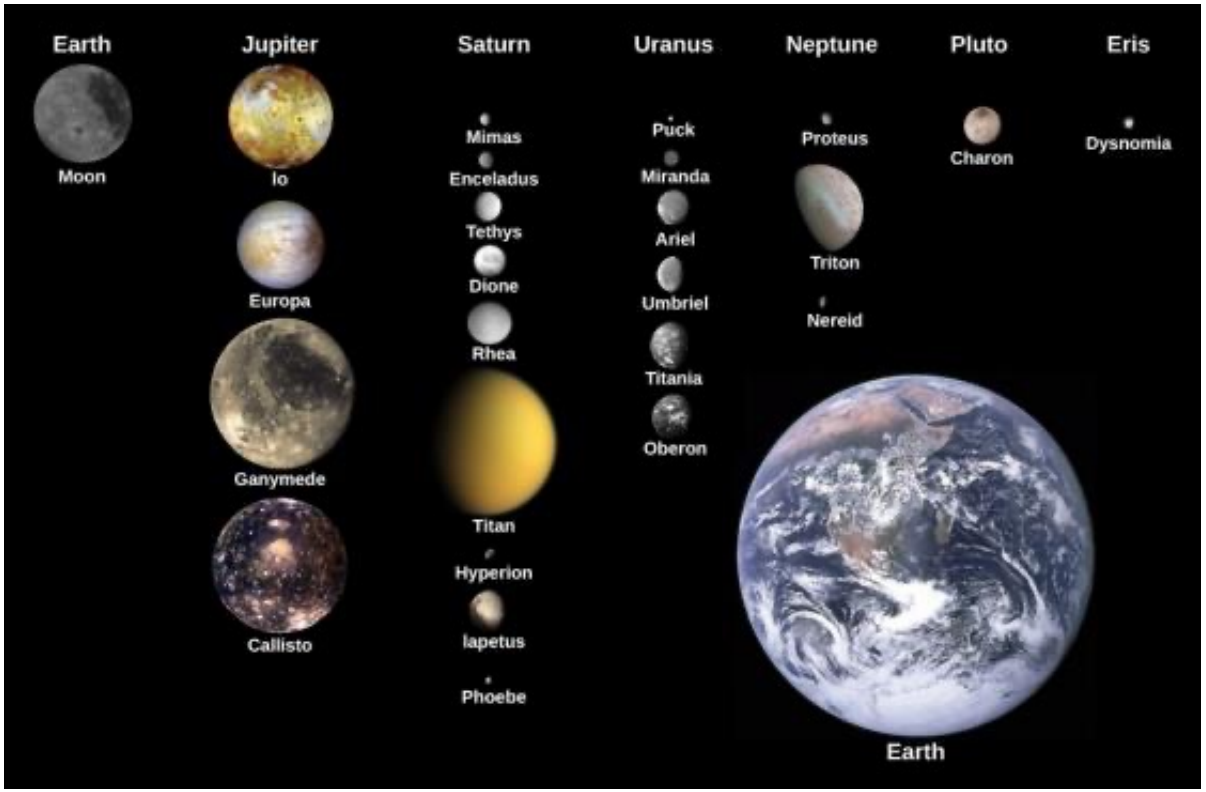
These worlds are all large enough for gravity to have shaped them into spheres, so they would qualify as dwarf planets or planets if they orbited the Sun independently.

Because they have solid surfaces, these moons are shaped by the same four geological processes as the terrestrial worlds—impact cratering, volcanism, tectonics, and erosion.

The most surprising aspect of these moons is their level of geological activity. Because even the largest of them are only slightly larger than the Moon and Mercury, we might expect all of these moons to be geologically dead, like those two terrestrial worlds.

Instead, we find evidence of tremendous past geological activity on the jovian moons, and some of them remain geologically active today.

FIGURE 12.2



Moons of the Solar System. This image shows some selected moons of our solar system and their comparison to the size of Earth's Moon and Earth itself. (credit: modification of work by NASA)

FIGURE 12.1

Jupiter Family. This montage, assembled from individual Galileo and Voyager images, shows a “family portrait” of Jupiter (with its giant red spot) and its four large moons. From top to bottom, we see Io, Europa, Ganymede, and Callisto. The colors are exaggerated by image processing to emphasize contrasts. (credit: modification of work by NASA)

THE GALILEAN SATELLITES

1) all orbit Jupiter

2) they all are tidally locked to Jupiter

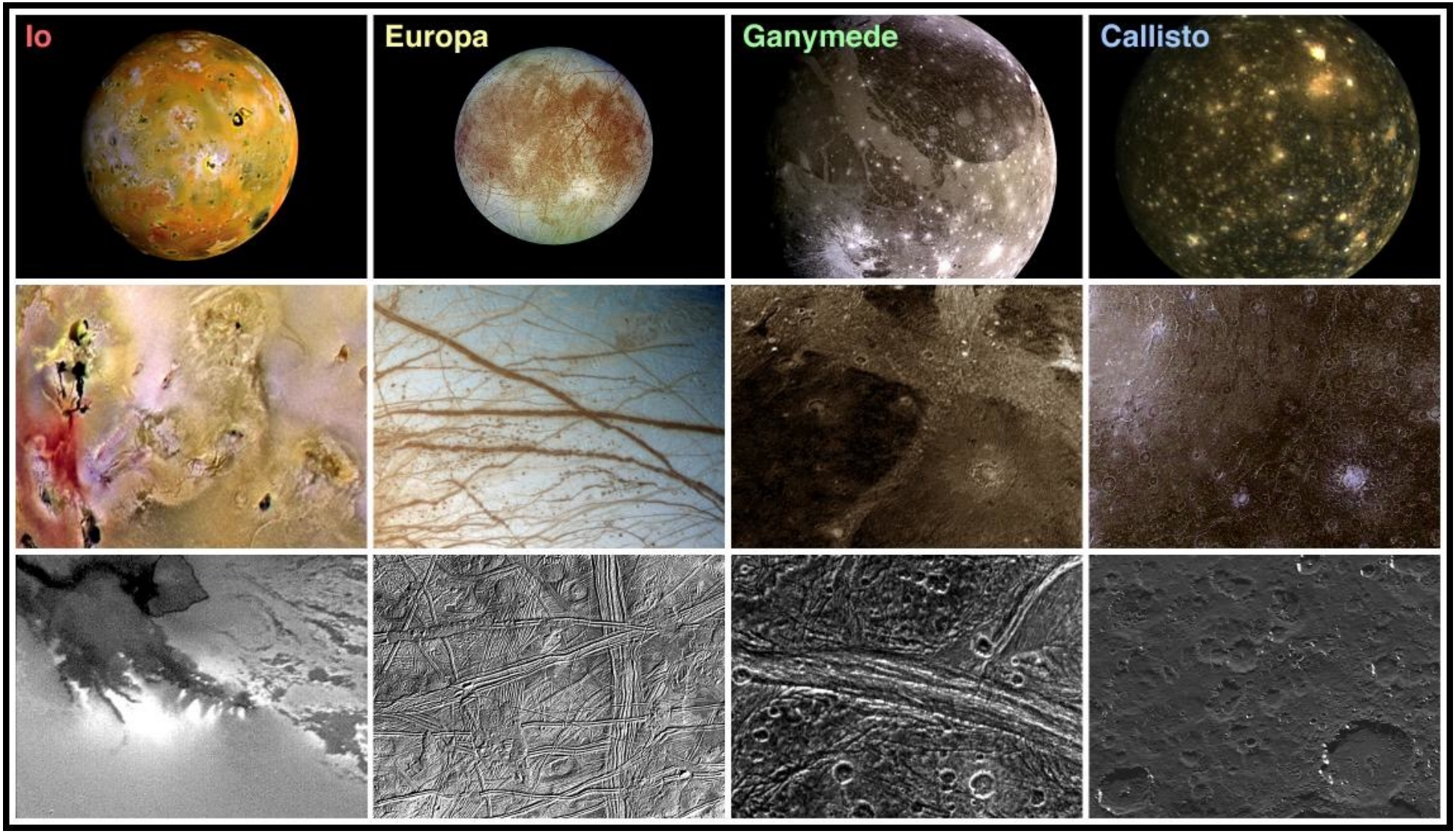
3) they all have size like or larger than our Moon

4) the inner moons have densities higher than outer moons (implies that Jupiter was much warmer in the past, such that the moons formed near Jupiter have less of the volatile elements such as CO_2 and H_2O)

	Io	Europa	Ganymede	Callisto
mean density (grams/cc)	3.4	3.1	1.9	1.8
	rock/silicates		ice/rock	

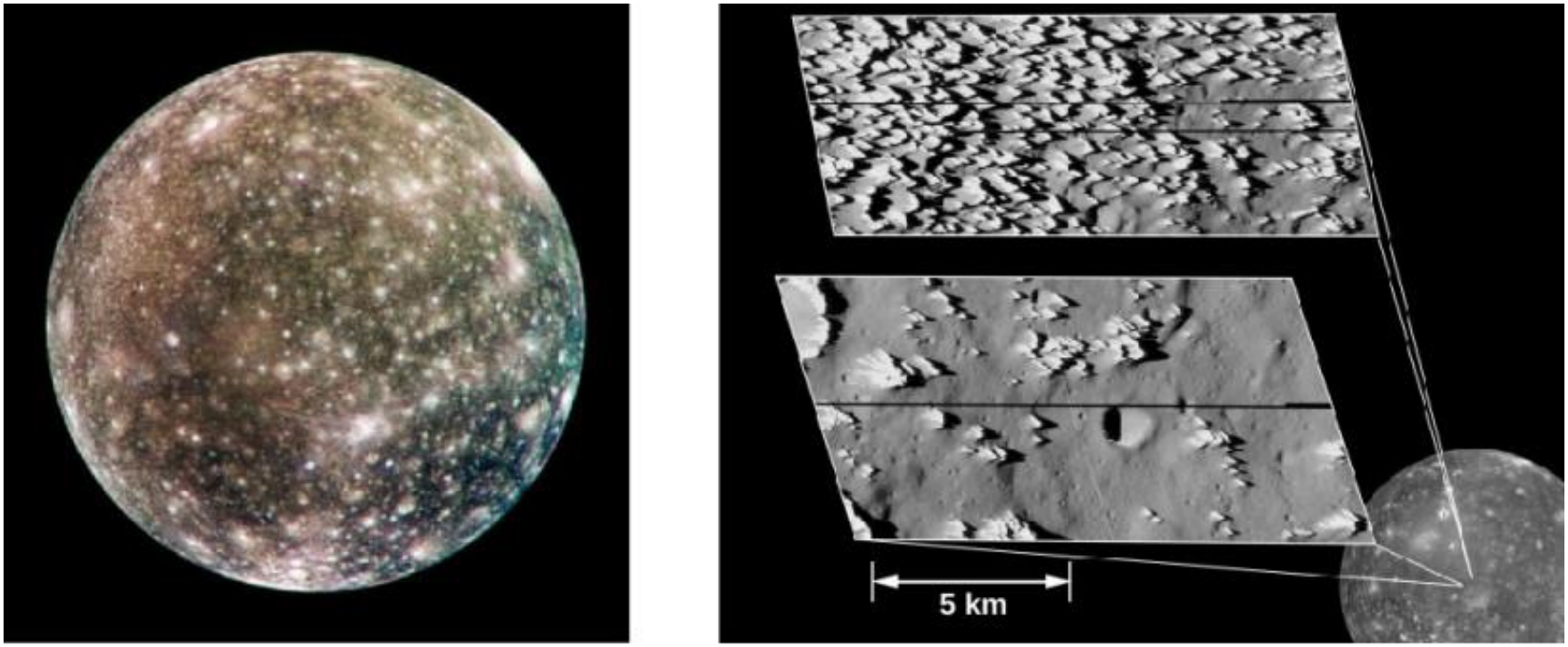
http://abyss.uoregon.edu/~js/ast121/lectures/lec13.html

LIKE A “MINI SOLAR SYSTEM” : CLOSER MOONS ARE ROCKY, HIGH DENSITY AND OUTER MOONS ARE ICY, LOW DENSITY



http://abyss.uoregon.edu/~js/ast121/lectures/lec13.html

FIGURE 12.3



(a) (b)

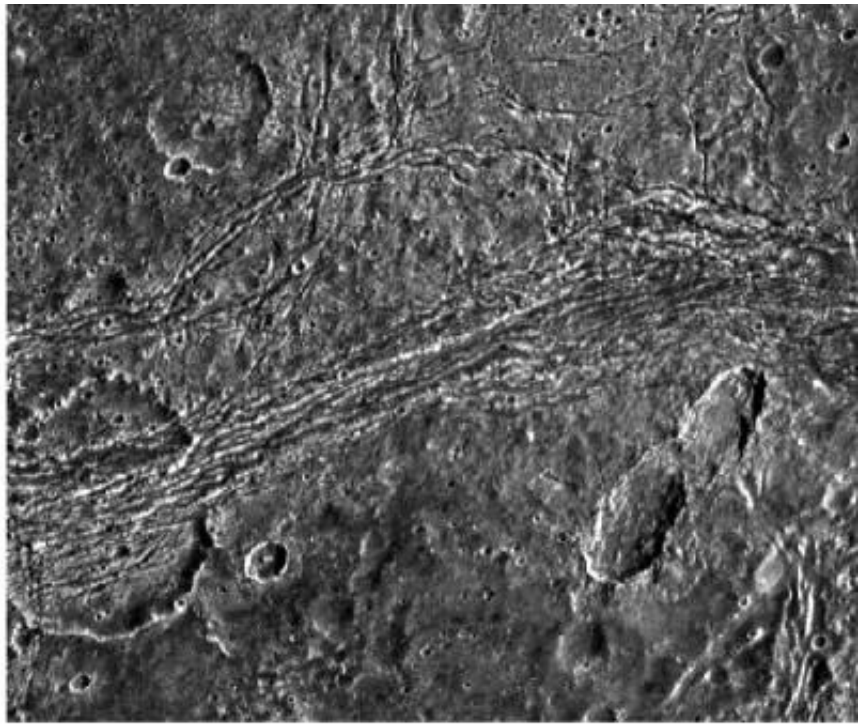
Callisto.

(a) Jupiter's outermost large moon shows a heavily cratered surface. Astronomers believe that the bright areas are mostly ice, while the darker areas are more eroded, ice-poor material.

(b) These high-resolution images, taken by NASA's Galileo spacecraft in May 2001, show the icy spires (top) on Callisto's surface, with darker dust that has slid down as the ice erodes, collecting in the low-lying areas. The spires are about 80 to 100 meters tall. As the surface erodes even further, the icy spires eventually disappear, leaving impact craters exposed, as shown in the lower image. (credit a: modification of work by NASA/JPL/DLR; credit b: modification of work by NASA/JPL/Arizona State University, Academic Research Lab)

FIGURE 12.4

(a)



(b)

Ganymede.

(a) This global view of Ganymede, the largest moon in the solar system, was taken by Voyager 2. The colors are enhanced to make spotting differences easier. Darker places are older, more heavily cratered regions; the lighter areas are younger (the reverse of our Moon). The brightest spots are sites of geologically recent impacts.

(b) This close-up of Nicholson Regio on Ganymede shows an old impact crater (on the lower left-hand side) that has been split and pulled apart by tectonic forces. Against Ganymede's dark terrain, a line of grooves and ridges appears to cut through the crater, deforming its circular shape. (credit a: modification of work by NASA/JPL/DLR; credit b: modification of work by NASA/JPL/Brown University)

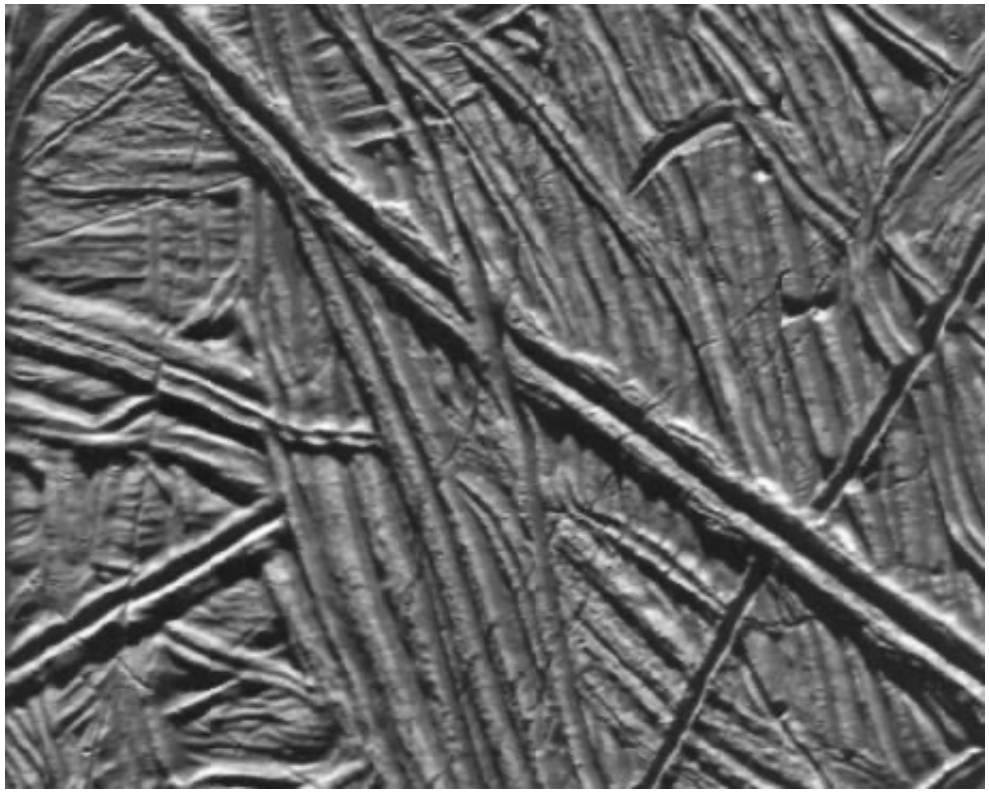
FIGURE 12.5

Evidence for an Ocean on Europa.

(a) A close-up of an area called Conamara Chaos is shown here with enhanced color. This view is 70 kilometers wide in its long dimension. It appears that Conamara is a region where Europa's icy crust is (or recently was) relatively thin and there is easier access to the possible liquid or slushy ocean beneath. Not anchored to solid crust underneath, many of the ice blocks here seem to have slid or rotated from their original positions. In fact, the formations seen here look similar to views of floating sea-ice and icebergs in Earth's Arctic Ocean.

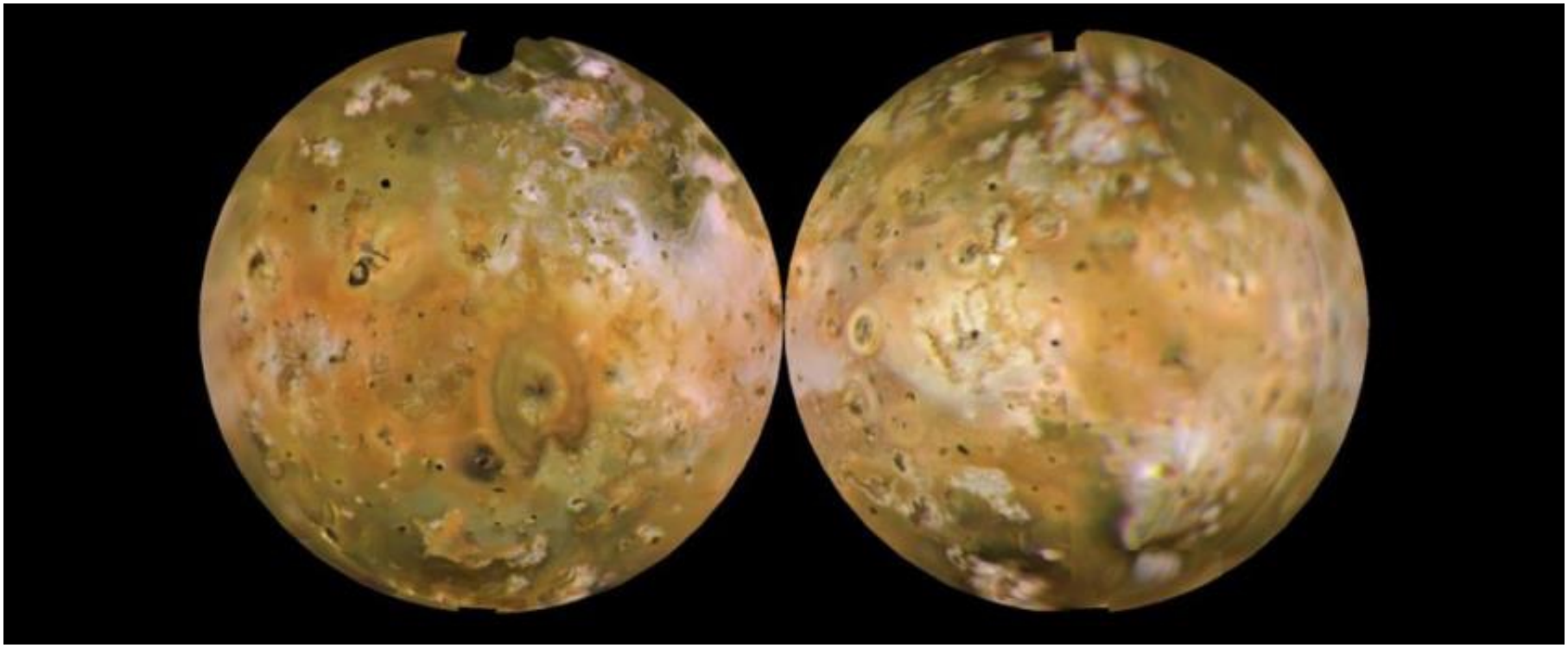
(b) In this high-resolution view, the ice is *wrinkled* and crisscrossed by long ridges. Where these ridges intersect, we can see which ones are older and which younger; the younger ones cross over the older ones. While superficially this system of ridges resembles a giant freeway system on Europa, the ridges are much wider than our freeways and are a natural result of the flexing of the moon. (credit a: modification of work by NASA/JPL/University of Arizona; credit b: modification of work by NASA/JPL)

FIGURE 12.6



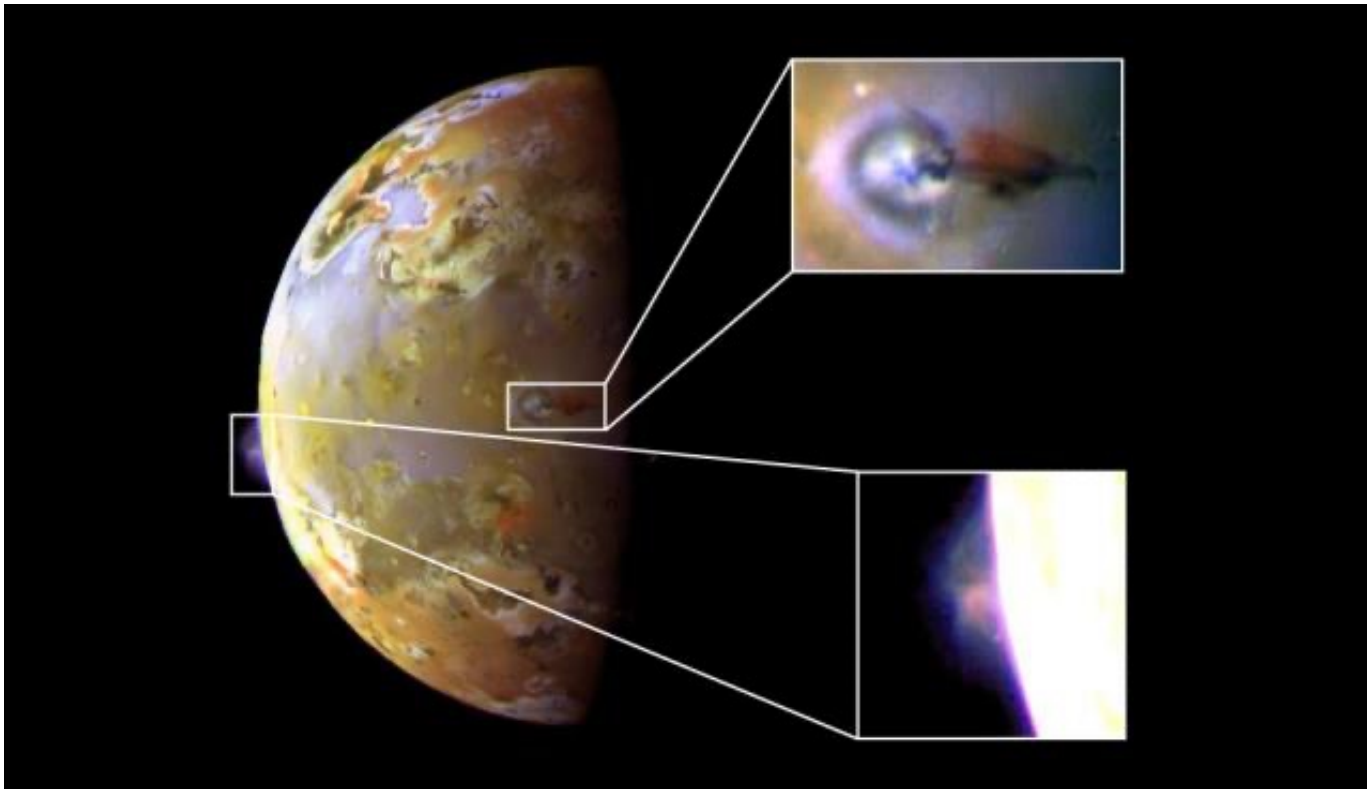
Very High-Resolution Galileo Image of One Young Double Ridge on Europa. The area in this picture is only 15 kilometers across. It appears to have formed when viscous icy material was forced up through a long, straight crack in the crust. Note how the young ridge going from top left toward bottom right lies on top of older features, which are themselves on top of even older ones. (credit: modification of work by NASA/JPL)

FIGURE 12.7



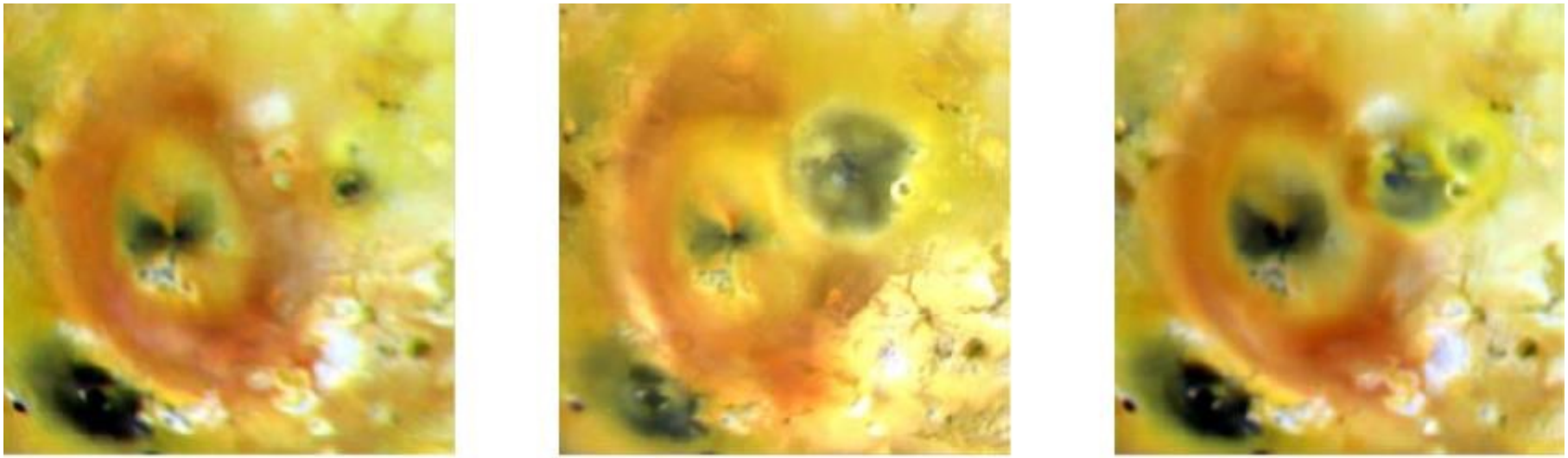
Two Sides of Io. This composite image shows both sides of the volcanically active moon Io. The orange deposits are sulfur snow; the white is sulfur dioxide. (Carl Sagan once quipped that Io looks as if it desperately needs a shot of penicillin.) (credit: modification of work by NASA/JPL/USGS)

FIGURE 12.8



Volcanic Eruptions on Io. This composite image from NASA's Galileo spacecraft shows close-ups (the two inset photos) of two separate volcanic eruptions on Jupiter's volcanic moon, Io. In the upper inset image, you can see a close up of a bluish plume rising about 140 kilometers above the surface of the volcano. In the lower inset image is the Prometheus plume, rising about 75 kilometers from Io's surface. The Prometheus plume is named for the Greek god of fire. (credit: modification of work by NASA/JPL)

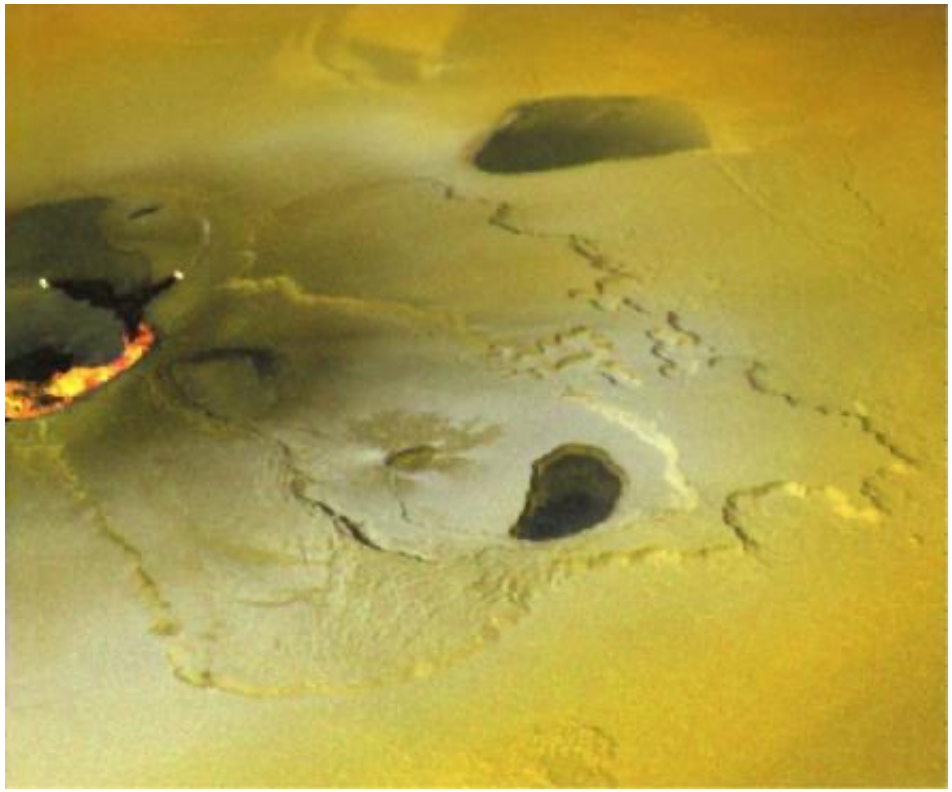
FIGURE 12.9



April 1997 September 1997 July 1999

Volcanic Changes on Io. These three images were taken of the same 1700-kilometer-square region of Io in April 1997, September 1997, and July 1999. The dark volcanic center called Pillan Patera experienced a huge eruption, producing a dark deposit some 400 kilometers across (seen as the grey area in the upper center of the middle image). In the right image, however, some of the new dark deposit is already being covered by reddish material from the volcano Pele. Also, a small unnamed volcano to the right of Pillan has erupted since 1997, and some of its dark deposit and a yellow ring around it are visible on the right image (to the right of the grey spot). The color range is exaggerated in these images. (credit: modification of work by NASA/JPL/University of Arizona)

FIGURE 12.10



Lava Fountains on Io. Galileo captured a number of eruptions along the chain of huge volcanic calderas (or pits) on Io called Tvashtar Catena in this false-color image combining infrared and visible light. The bright orange-yellow areas at left are places where fresh, hot lava is erupting from below ground. (credit: modification of work by NASA/JPL)

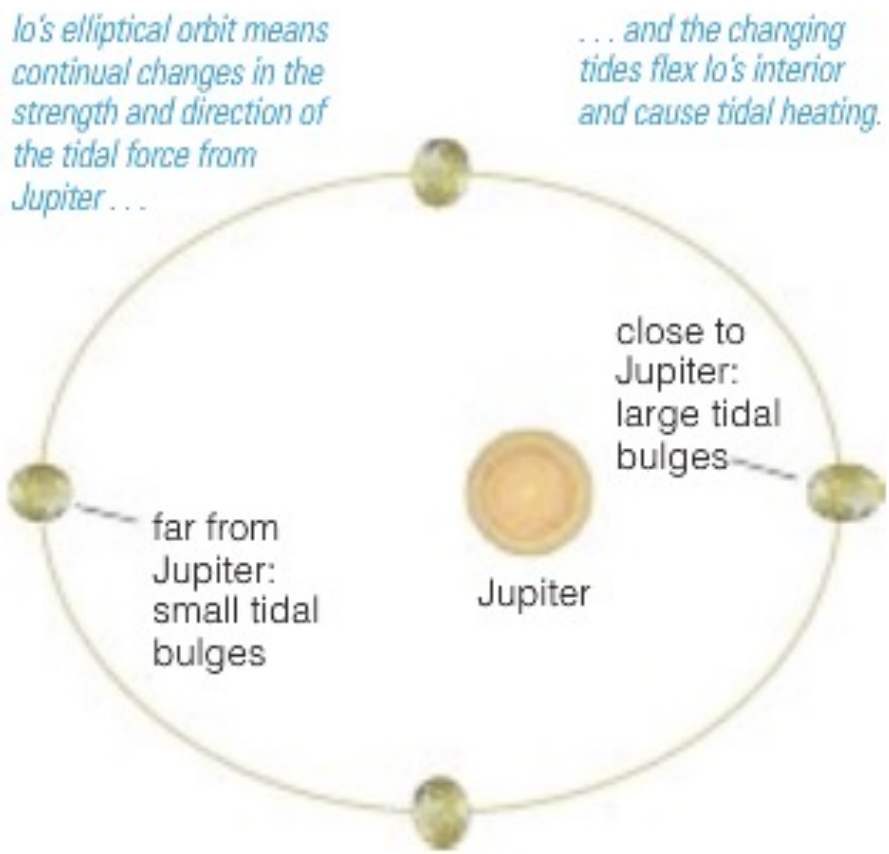
HOW CAN SUCH SMALL WORLDS HAVE SO MUCH GEOLOGICAL ACTIVITY?

Their geological activity can be traced to two major factors.

- First, because they formed in the cold outer solar system, the jovian moons have compositions that include substantial amounts of ice in addition to metal and rock, and much less heat is required for “ice geology” than for rock geology.

- Second, interactions between orbiting moons helps to create a source of heating, called tidal heating, that is not present in the terrestrial worlds.

TIDAL HEATING



a Tidal heating arises because Io's elliptical orbit (exaggerated in this diagram) causes varying tides.

Figure 6.10. Page 101. ***The Cosmic Perspective Fundamentals*. Publisher: Addison-Wesley.**

SATURN'S MOON TITAN

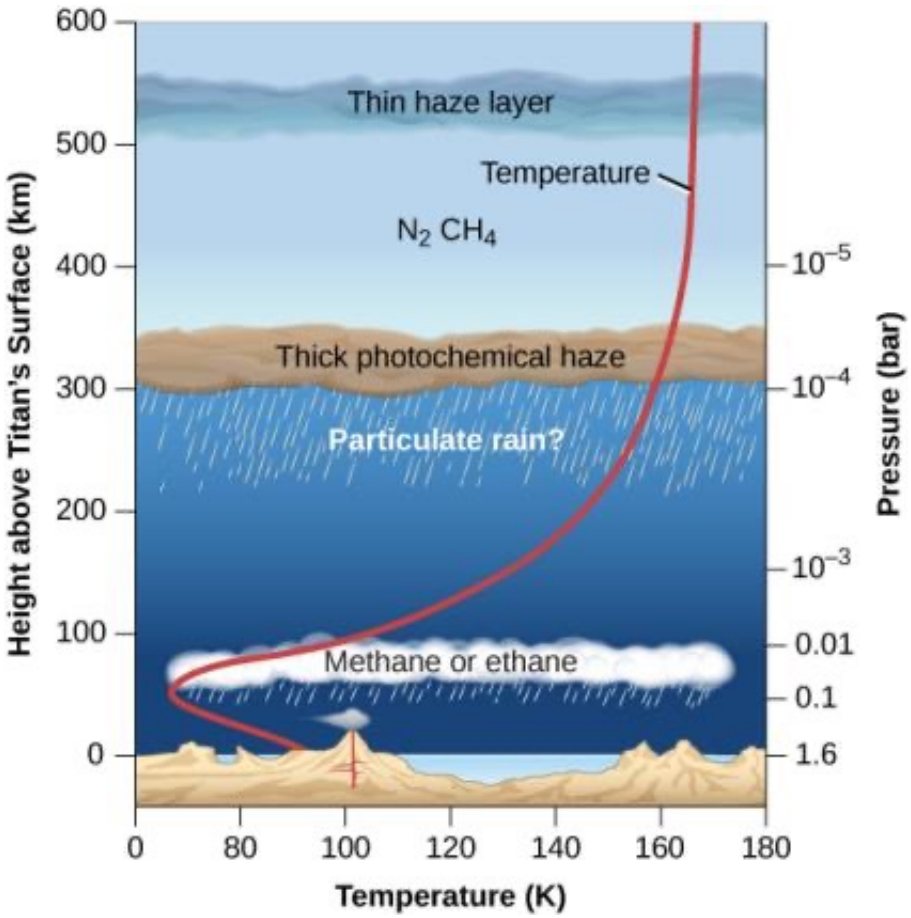
Titan is the second largest moon in the solar system (after Ganymede).

It is also unique among the moons of our solar system in having a thick atmosphere—so thick that it hides the surface from view, except at a few specific wavelengths of light.

The atmosphere is about 90% nitrogen, not that different from the 77% nitrogen content of Earth's atmosphere.

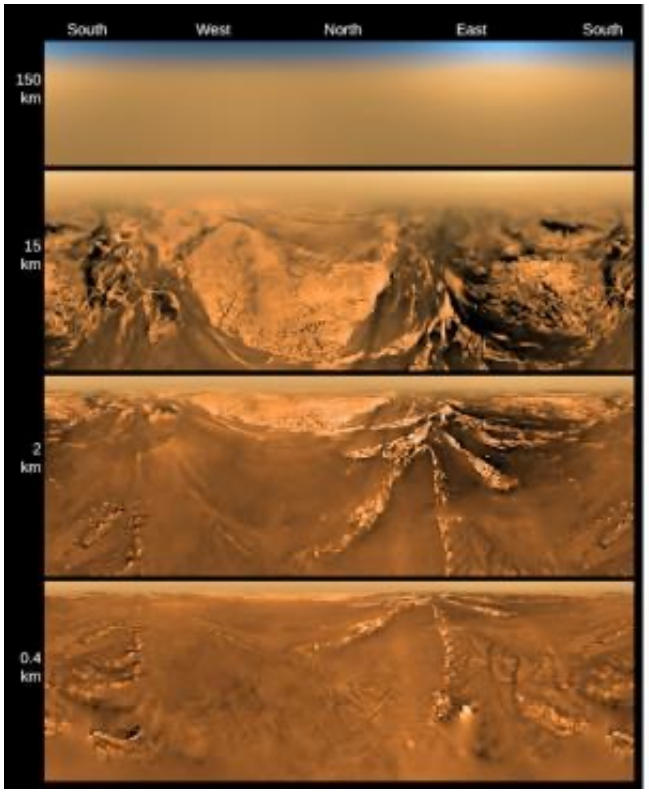
However, on Earth the rest of the atmosphere is mostly oxygen, while the rest of Titan's atmosphere consists of argon, methane (CH_4), ethane (C_2H_6), and other hydrogen compounds.

FIGURE 12.12



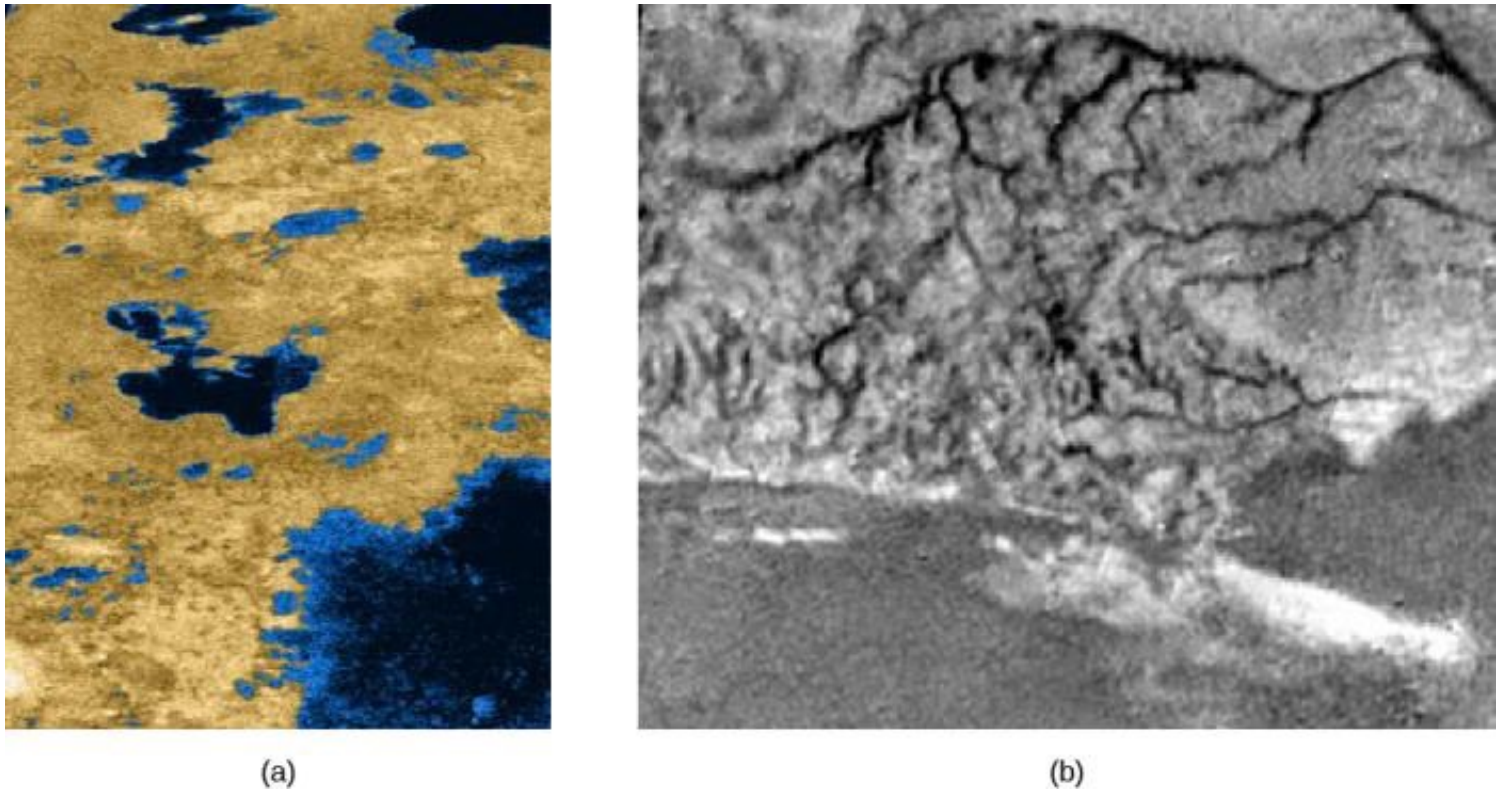
Structure of Titan's Atmosphere. Some characteristics of Titan's atmosphere resemble those of Earth's atmosphere, although it is much colder than our planet. The red line indicates the temperature of Titan's atmosphere at different altitudes.

FIGURE 12.13



Views of the Surface of Titan. The left image shows the views of Titan from the descent camera, in a flattened projection, at different altitudes. The right image, taken after landing, shows a boulder-strewn surface illuminated by faint reddish sunlight. The boulders are composed of water ice. (credit left: modification of work by ESA/NASA/JPL/University of Arizona; credit right: modification of work by ESA/NASA/JPL/University of Arizona; processed by Andrey Pivovarov)

FIGURE 12.14



Titan's Lakes.

(a) This Cassini image from a September 2006 flyby shows the liquid lakes on Titan. Their composition is most likely a combination of methane and ethane. (Since this is a radar image, the colors are artificially added. The dark blue areas are the smooth surfaces of the liquid lakes, and yellow is the rougher solid terrain around them.)

(b) This mosaic of Titan's surface from the Cassini-Huygens mission shows in detail a high ridge area and many narrow, sinuous erosion channels that appear to be part of a widespread network of "rivers" carved by flowing hydrocarbons. (credit a: modification of work by NASA/JPL-Caltech/USGS; credit b; modification of work by NASA/JPL/ESA/University of Arizona)

GEOLOGIC ACTIVITY ON SATURN'S OTHER MOONS

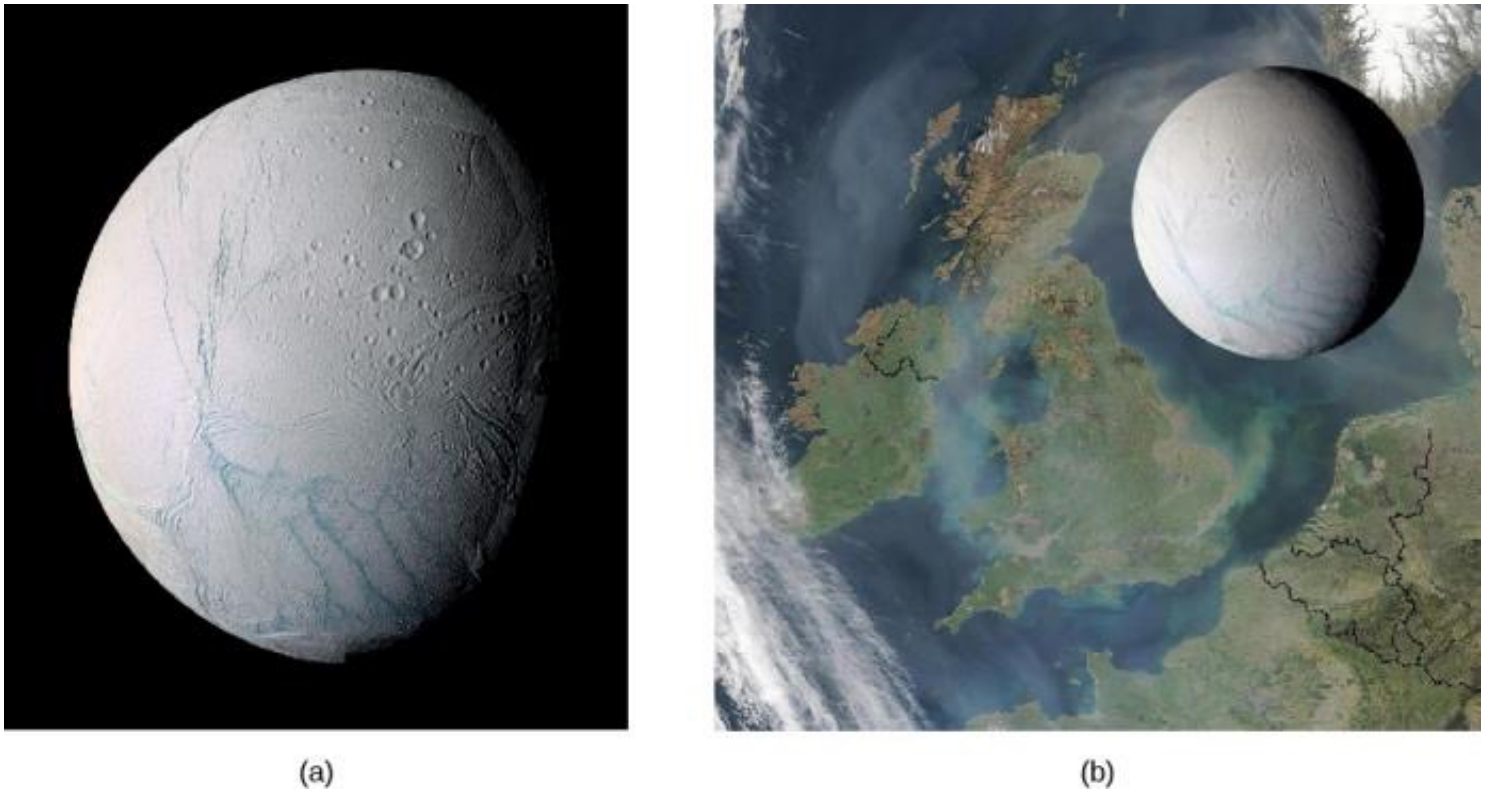
Each of Saturn's six medium-size moons shows evidence of substantial geological activity in its past.

Most amazingly, one moon—Enceladus—shows clear evidence of ongoing geological activity, despite being barely 500 kilometers across, small enough to fit inside the borders of Colorado.

Enceladus features strange grooves near its south pole that vent huge clouds of water vapor and ice crystals.These fountains are driven by internal heat, presumably due to tidal heating created by orbital resonances between Enceladus and other moons of Saturn.

Moreover, the fountains must have some subsurface source, which could potentially mean the existence of an underground reservoir of liquid water. In that case, there is a possibility that Enceladus could harbor life.

FIGURE 12.28

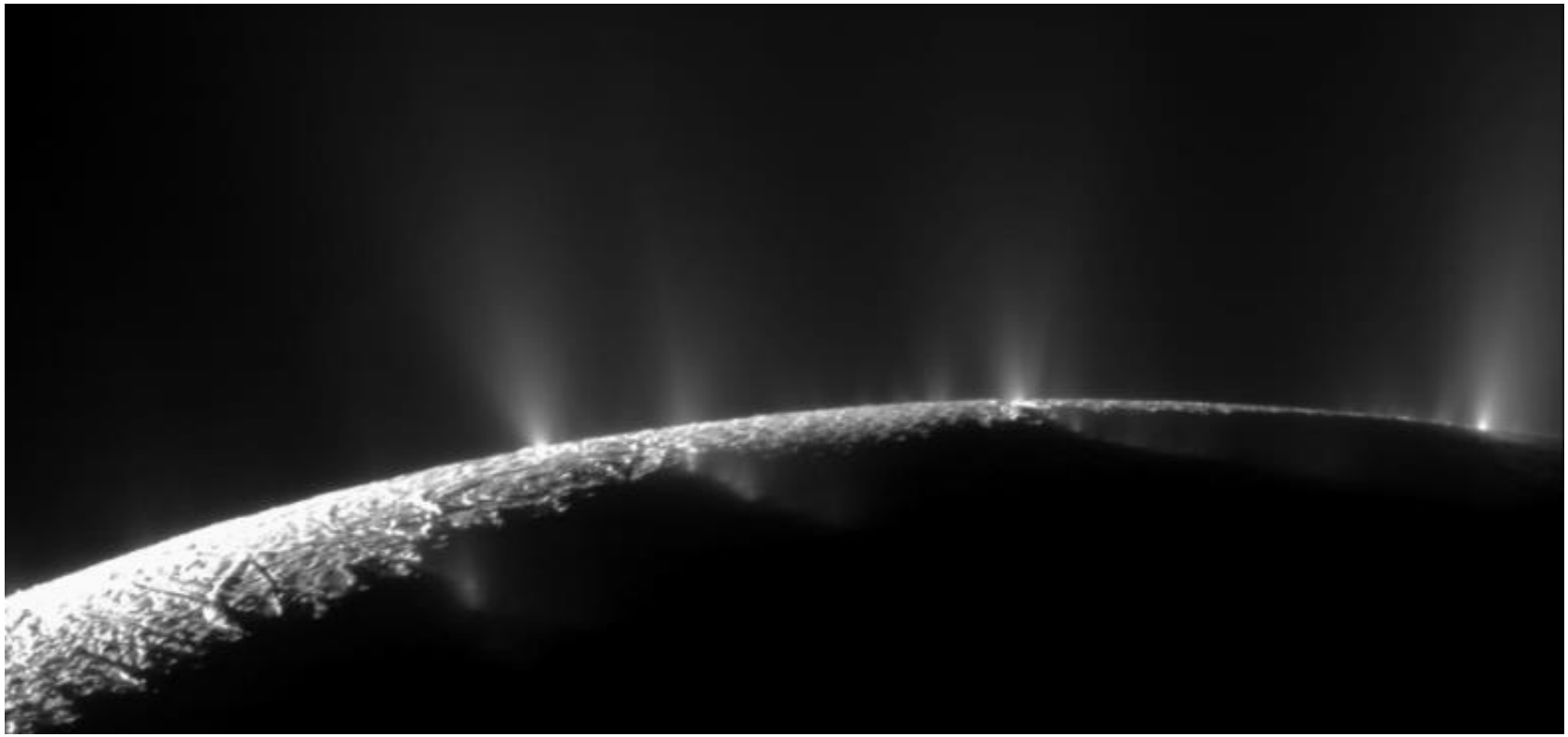


Enceladus.

(a) This image shows both smooth and cratered terrain on Saturn's moon, and also "tiger stripes" in the south polar region (lower part of image). These dark stripes (shown here in exaggerated color) have elevated temperatures and are the source of the many geysers discovered on Enceladus. They are about 130 kilometers long and 40 kilometers apart.

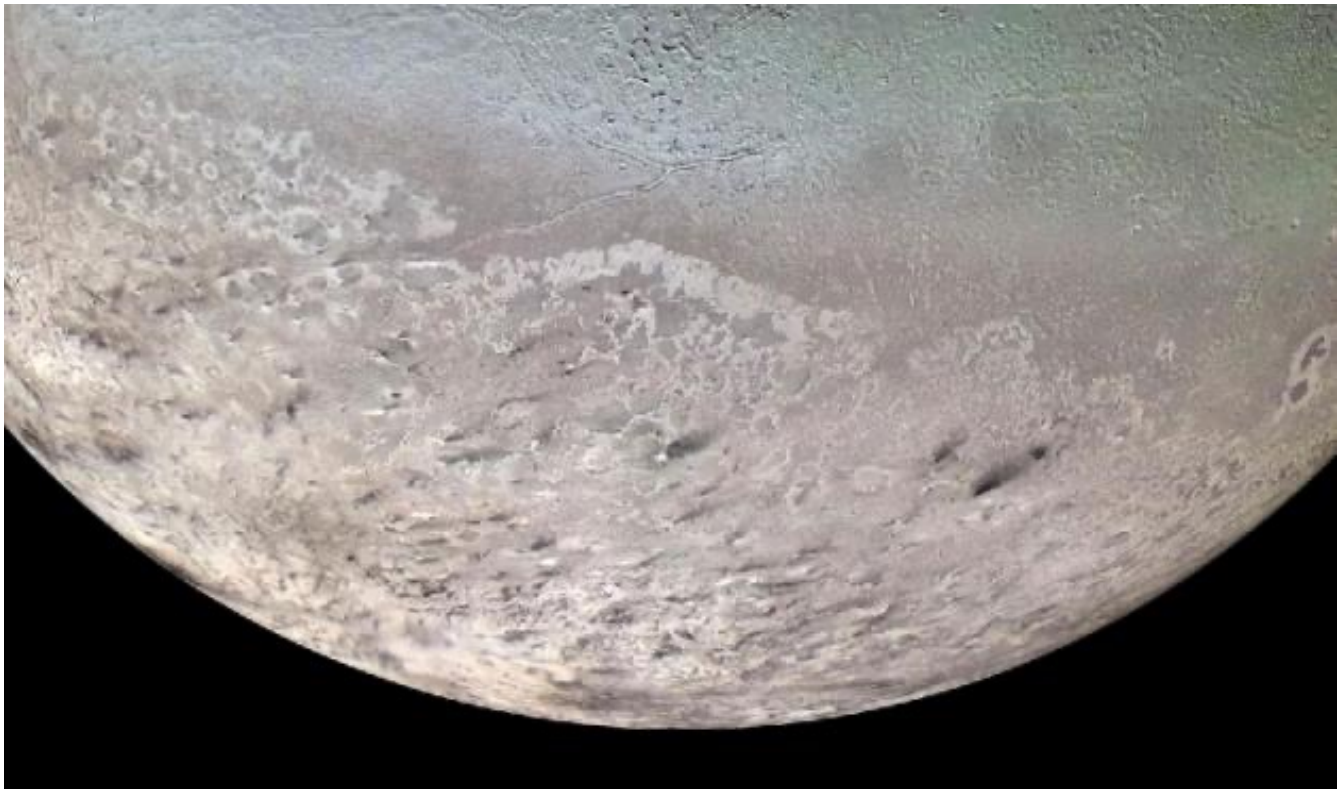
(b) Here Enceladus is shown to scale with Great Britain and the coast of Western Europe, to emphasize that it is a small moon, only about 500 kilometers in diameter. (credit a, b: modification of work by NASA/JPL/Space Science Institute)

FIGURE 12.29



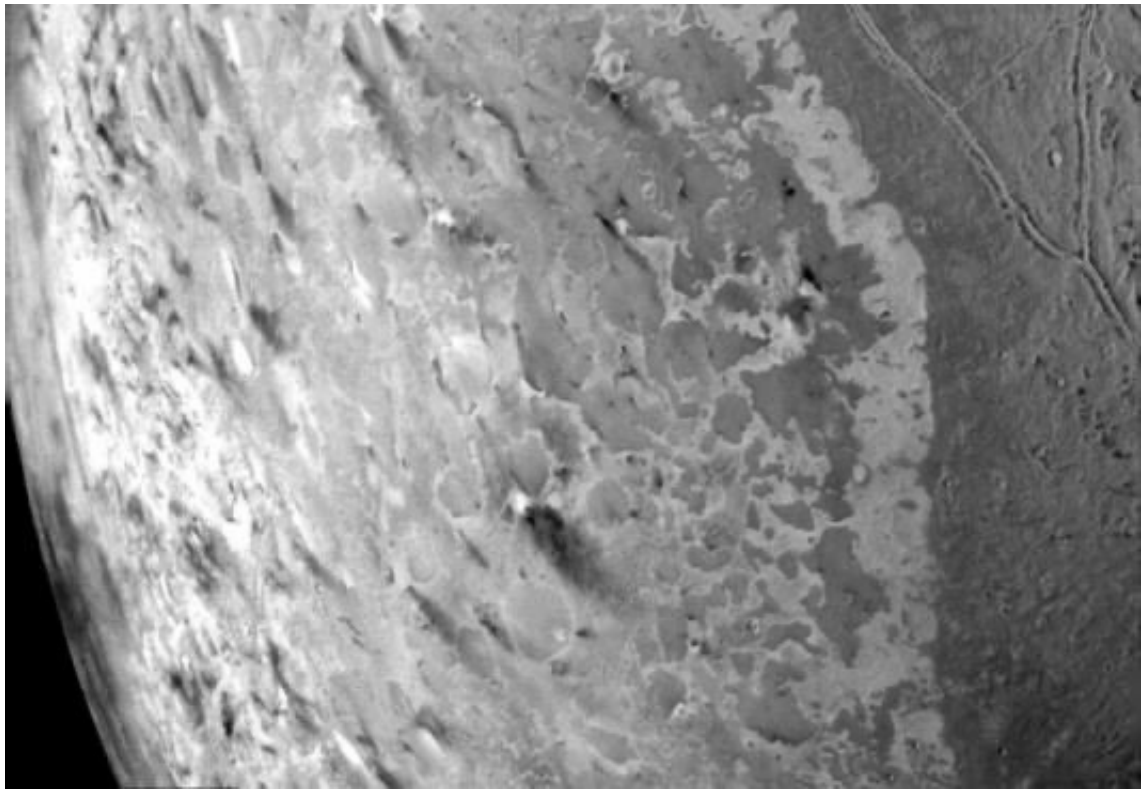
Geysers on Enceladus. This Cassini image shows a number of water geysers on Saturn's small moon Enceladus, apparently salty water from a subsurface source escaping through cracks in the surface. You can see curved lines of geysers along the four "tiger stripes" on the surface. (credit: modification of work by NASA/JPL/Space Science Institute)

FIGURE 12.15



Neptune's Moon Triton. This mosaic of Voyager 2 images of Triton shows a wide range of surface features. The pinkish area at the bottom is Triton's large southern polar cap. The south pole of Triton faces the Sun here, and the slight heating effect is driving some of the material northward, where it is colder. (credit: modification of work by NASA/JPL/USGS)

FIGURE 12.16



Triton's Geysers. This close-up view shows some of the geysers on Neptune's moon Triton, with the long trains of dust pointing to the lower right in this picture. (credit: modification of work by NASA/JPL)

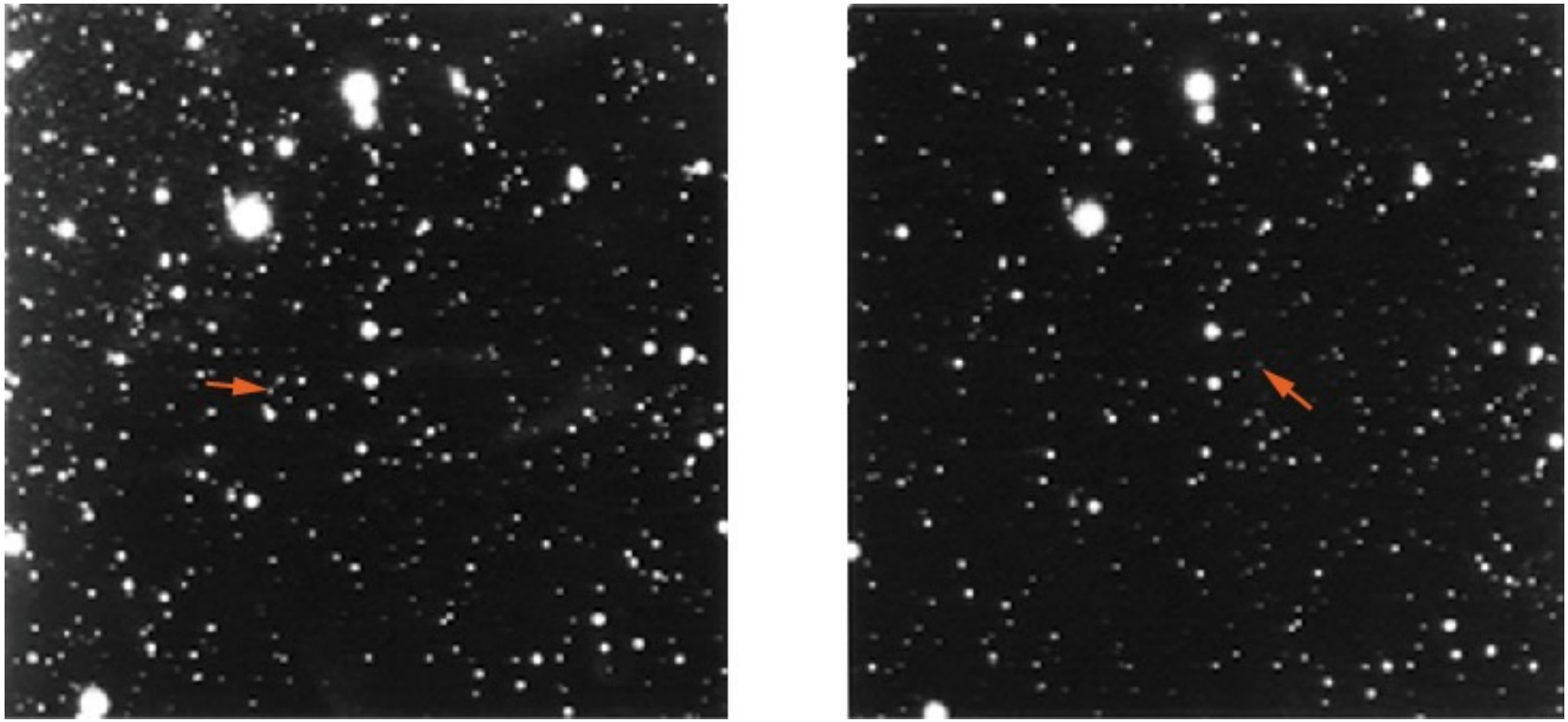
FIGURE 12.19

Clyde Tombaugh (1906–1997).

(a) Tombaugh is pictured on his family farm in 1928 with a 9-inch telescope he built.

(b) Here Tombaugh is looking through an eyepiece at the Lowell Observatory. (credit b: modification of work by NASA)

FIGURE 12.17

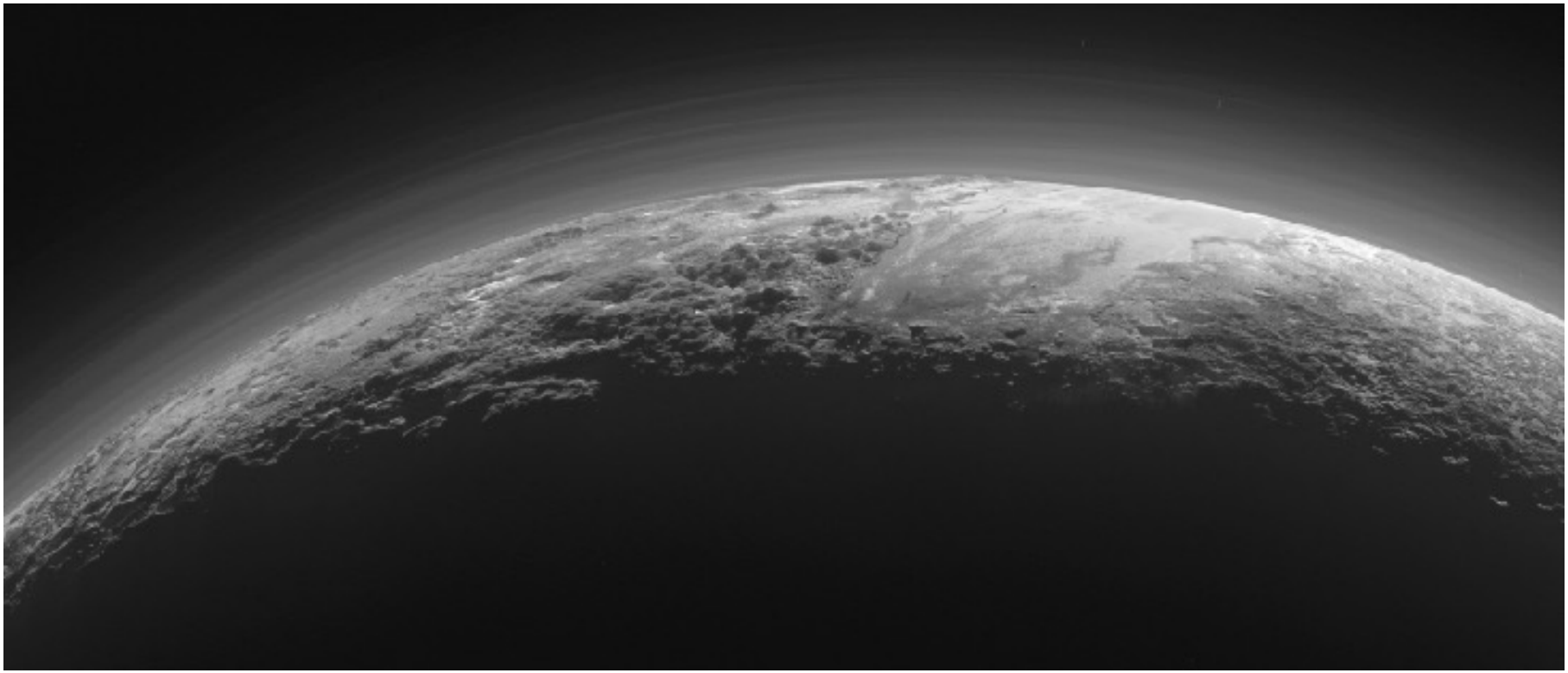


Pluto's Motion. Portions of the two photographs by which Clyde Tombaugh discovered Pluto in 1930. The left one was taken on January 23 and the right on January 29. Note that Pluto, indicated by an arrow, has moved among the stars during those six nights. If we hadn't put an arrow next to it, though, you probably would never have spotted the dot that moved. (credit: modification of work by the Lowell Observatory Archives)

FIGURE 12.18

Comparison of the Sizes of Pluto and Its Moon Charon with Earth. This graphic vividly shows how tiny Pluto is relative to a terrestrial planet like Earth. That is the primary justification for putting Pluto in the class of dwarf planets rather than terrestrial planets. (credit: modification of work by NASA)

FIGURE 12.20



Haze Layers in the Atmosphere of Pluto. This is one of the highest-resolution photos of Pluto, taken by the New Horizons spacecraft 15 minutes after its closest approach. It shows 12 layers of haze. Note also the range of mountains with heights up to 3500 meters. (credit: modification of work by NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute)

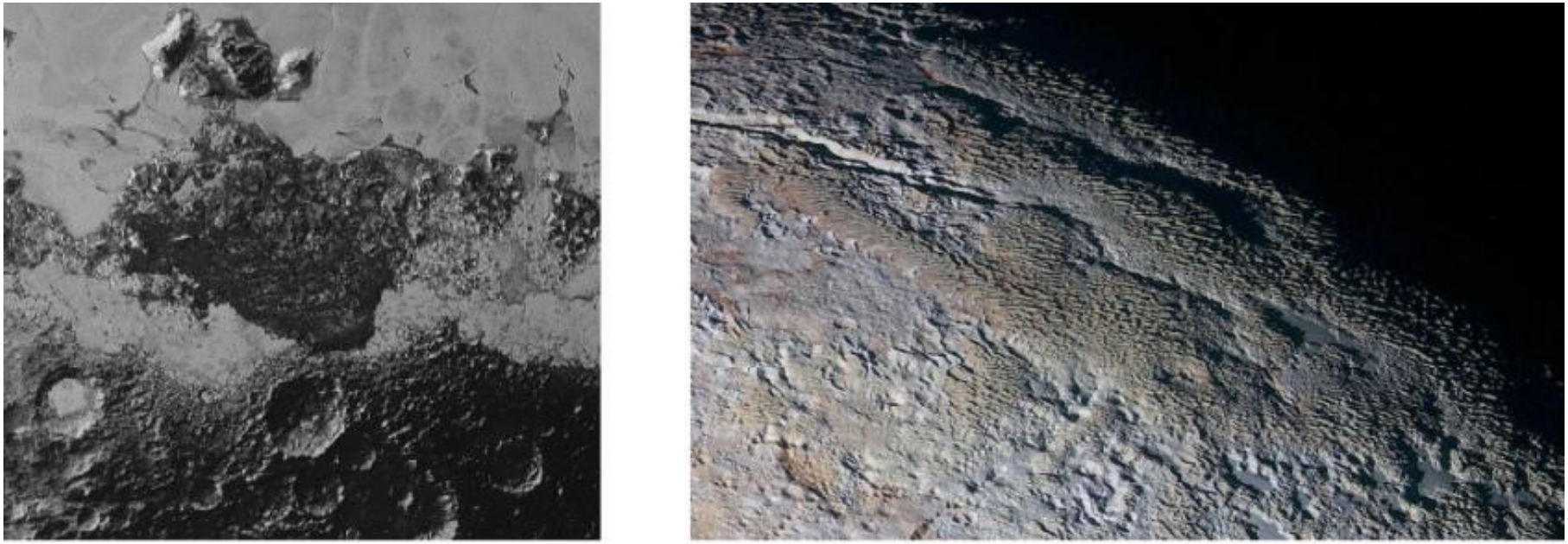
FIGURE 12.21

Global Color Image of Pluto. This New Horizons image clearly shows the variety of terrains on Pluto. The dark area in the lower left is covered with impact craters, while the large light area in the center and lower right is a flat basin devoid of craters. The colors you see are somewhat enhanced to bring out subtle differences. (credit: modification of work by NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute)

FIGURE 12.22

Diversity of Terrain on Pluto. This enhanced color view of a strip of Pluto's surface about 80 kilometers long shows a variety of different surface features. From left to right, we first cross a region of "badlands" with some craters showing, and then move across a wide range of mountains made of water ice and coated with the redder material we saw in the previous image. Then, at right, we arrive at the "shoreline" of the great sea of frozen nitrogen that the mission scientists have nicknamed the "Sputnik Plains." This nitrogen sea is divided into mysterious cells or segments that are many kilometers across. (credit: modification of work by NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute)

FIGURE 12.23



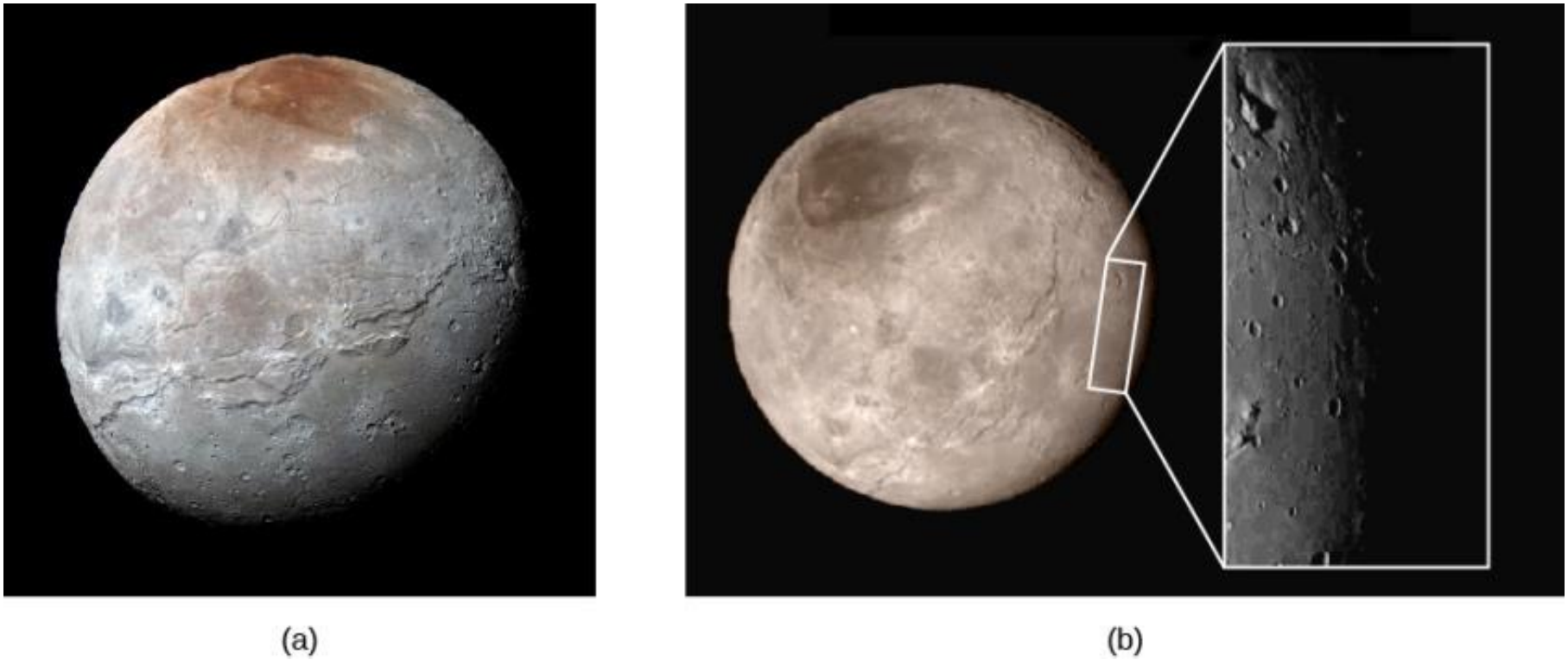
(a) (b)

Diversity of Terrains on Pluto.

(a) In this photo, about 250 kilometers across, we can see many different kinds of terrain. At the bottom are older, cratered highlands; a V-shaped region of hills without cratering points toward the bottom of the image. Surrounding the V-shaped dark region is the smooth, brighter frozen nitrogen plain, acting as glaciers on Earth do. Some isolated mountains, made of frozen water ice, are floating in the nitrogen near the top of the picture.

(b) This scene is about 390 kilometers across. The rounded mountains, quite different from those we know on Earth, are named Tartarus Dorsa. The patterns, made of repeating ridges with the more reddish terrain between them, are not yet understood. (credit a, b: modification of work by NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute)

FIGURE 12.24

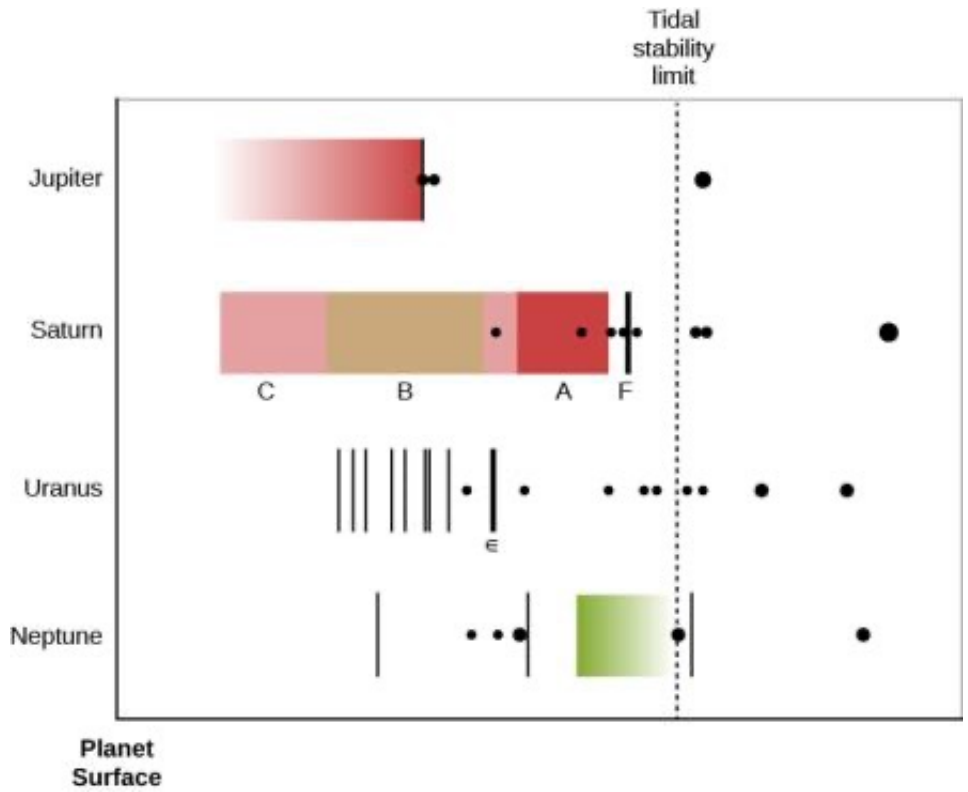


Pluto's Large Moon Charon.

(a) In this New Horizons image, the color has been enhanced to bring out the color of the moon's strange red polar cap. Charon has a diameter of 1214 kilometers, and the resolution of this image is 3 kilometers.

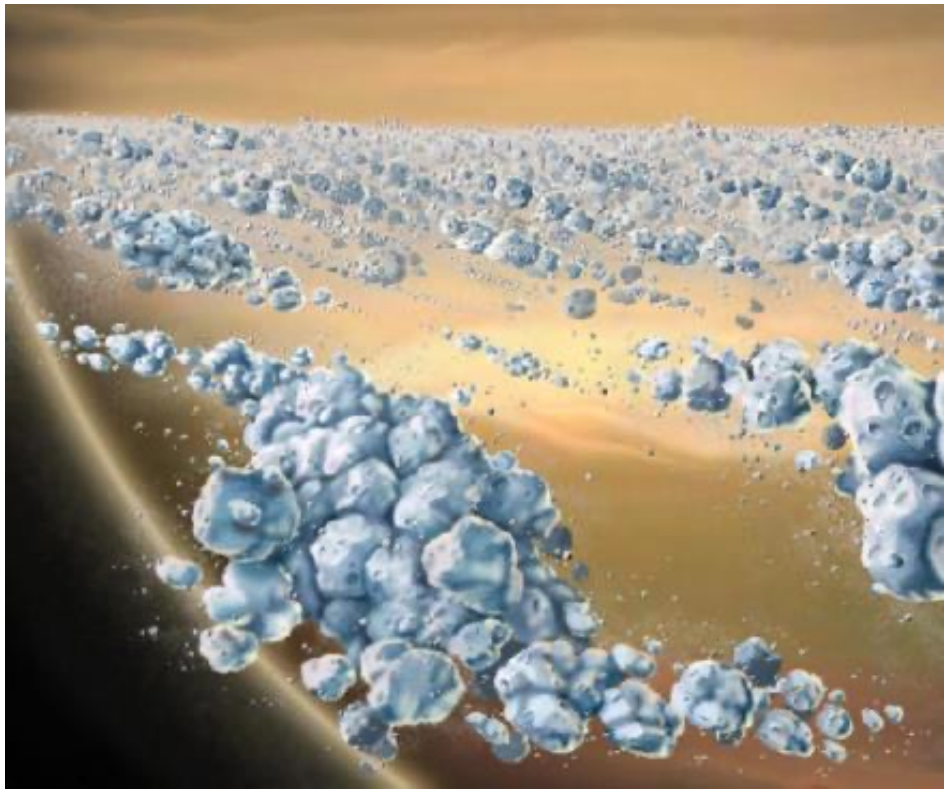
(b) Here we see the moon from a slightly different angle, in true color. The inset shows an area about 390 kilometers from top to bottom. Near the top left is an intriguing feature—what appears to be a mountain in the middle of a depression or moat. (credit a, b: modification of work by NASA/JHUAPL/SwRI)

FIGURE 12.25



Four Ring Systems. This diagram shows the locations of the ring systems of the four giant planets. The left axis represents the planet's surface. The dotted vertical line is the limit inside which gravitational forces can break up moons (each planet's system is drawn to a different scale, so that this stability limit lines up for all four of them). The black dots are the inner moons of each planet on the same scale as its rings. Notice that only really small moons survive inside the stability limit.

FIGURE 12.27



Artist's Idealized Impression of the Rings of Saturn as Seen from the Inside. Note that the rings are mostly made of pieces of water ice of different sizes. At the end of its mission, the Cassini spacecraft is planning to cut through one of the gaps in Saturn's rings, but it won't get this close. (credit: modification of work by NASA/JPL/University of Colorado)

SATURN'S RINGS

Each individual ring particle orbits Saturn independently in accord with Kepler's laws, so the rings are much like a collection of vast numbers of tiny moons.

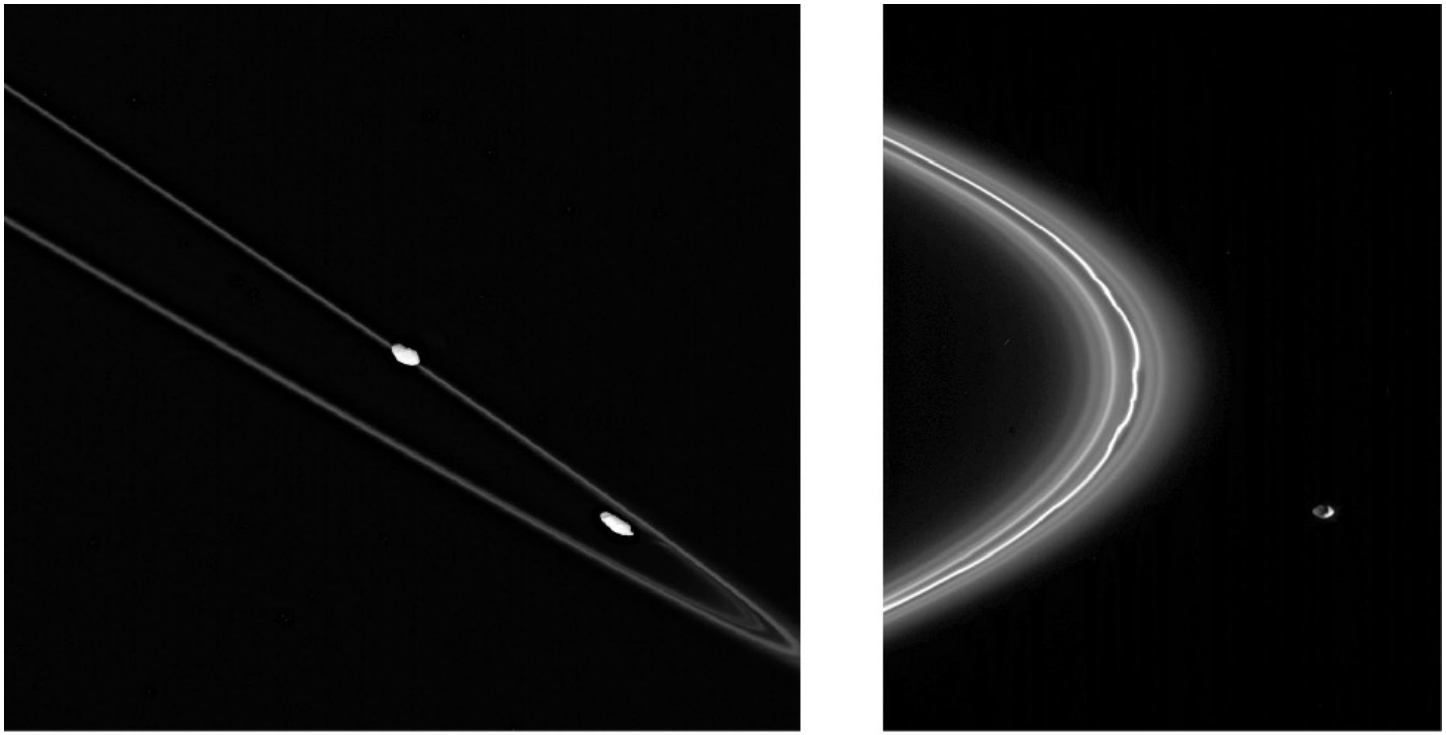
Close-up photographs show an astonishing number of rings, as well as gaps, ripples, and other features in the rings.

Scientists are still struggling to explain all these features, but some general ideas are now clear.

Rings and gaps are caused by particles bunching up at some orbital distances and being forced out at others.

This bunching happens when gravity nudges the orbits of ring particles in some particular way. One source of nudging comes from small moons located within the gaps in the rings themselves, sometimes called gap moons.

FIGURE 12.32



(a) (b)

Saturn's F Ring and Its Shepherd Moons.

(a) This Cassini image shows the narrow, complex F Ring of Saturn, with its two small shepherd moons Pandora (left) and Prometheus (right).

(b) In this closer view, the shepherd moon Pandora (84 kilometers across) is seen next to the F ring, in which the moon is perturbing the main (brightest) strand of ring particles as it passes. You can see the dark side of Pandora on this image because it is being illuminated by the light reflected from Saturn. (credit a, b: modification of work by NASA/JPL/Space Science Institute)

ORBITAL RESONANCE

Ring particles also may be nudged by the gravity of larger, more distant moons. For example, a ring particle orbiting about 120,000 kilometers from Saturn's center will circle the planet in exactly half the time it takes Saturn's moon Mimas to orbit.

Every time Mimas returns to a certain location, the ring particle will also be at its original location and therefore will experience the same gravitational nudge from Mimas.

The periodic nudges reinforce one another and clear a gap in the rings—in this case, the large gap visible from Earth (the Cassini division).

This type of reinforcement due to repeated gravitational nudges is called an orbital resonance; the name comes from the idea that the repeated nudges resonate with one another, amplifying their effects.

WHERE DO RINGS COME FROM?

Scientists once guessed that ring particles might be chunks of rock and ice left over from the time at which the planets formed, but we now know that particles of the size we find in the rings today could not have survived for billions of years.

Ring particles are continually being ground down in size, primarily by the impacts of the countless sand-size particles that orbit the Sun—the same types of particles that become meteors in Earth's atmosphere and cause micrometeorite impacts on the Moon.

WHERE DO RINGS COME FROM?

New ring particles must be continually replacing those that are destroyed.

The most likely source is the numerous small moonlets—moons the size of gap moons—that formed in the disks of material orbiting the young jovian planets.

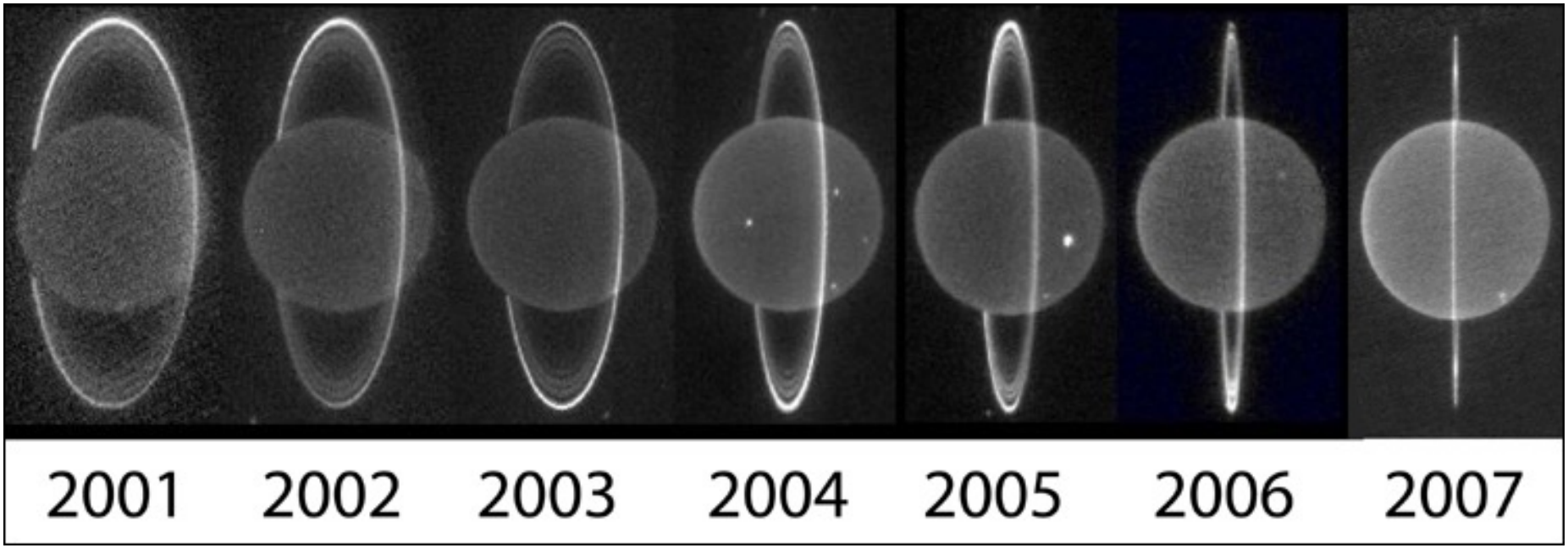
Tiny impacts are gradually grinding away these small moonlets, like the ring particles themselves, but they are large enough to still exist despite 4.5 billion years of such sandblasting.

WHERE DO RINGS COME FROM?

These impacts contribute ring particles in two ways:

- First, each tiny impact releases particles from a small moonlet's surface, and these released particles become new dust-size ring particles.
- Second, occasional larger impacts can shatter a small moonlet completely, creating a supply of boulder-size ring particles.

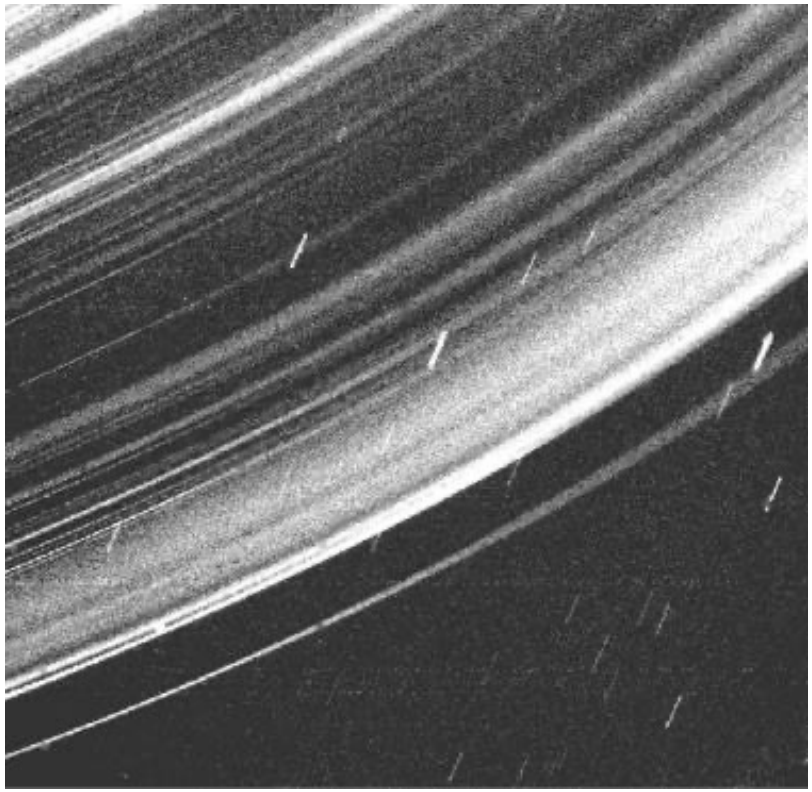
THE RINGS OF URANUS



Infrared images showing the change in appearance of Uranus's rings as seen from Earth. Credit: I. de Pater & H. Hammel/Keck Observatory

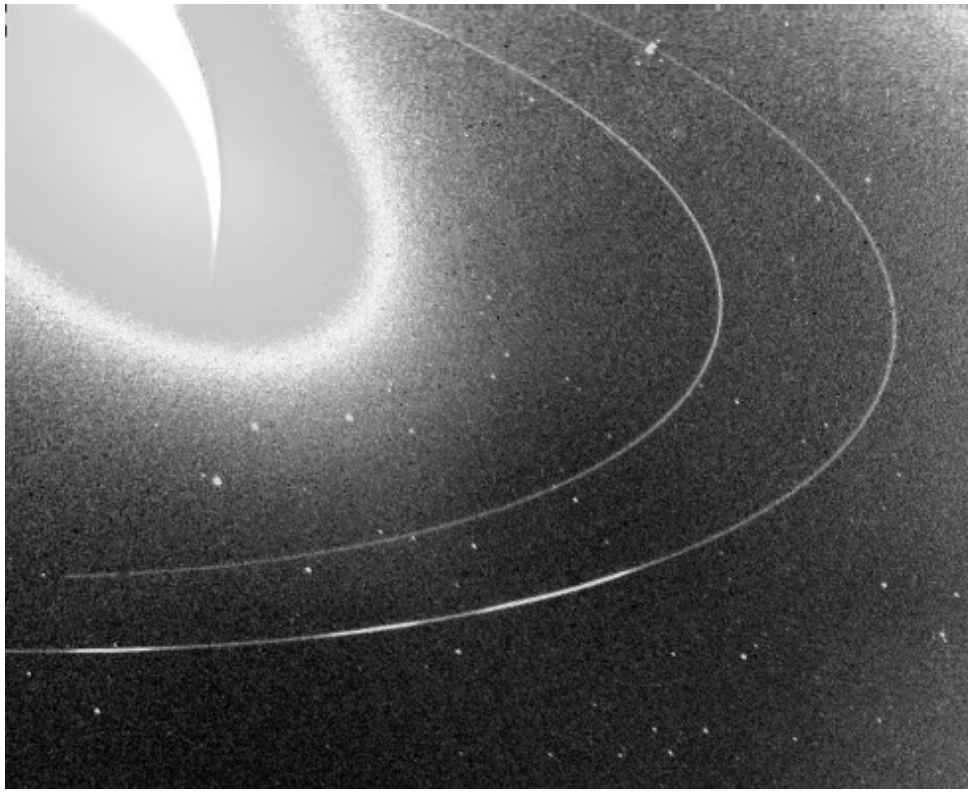
http://www.daviddarling.info/encyclopedia/U/Uranus_rings.html

FIGURE 12.30



Rings of Uranus. The Voyager team had to expose this image for a long time to get a glimpse of Uranus' narrow dark rings. You can see the grainy structure of "noise" in the electronics of the camera in the picture background. (credit: modification of work by NASA/JPL)

FIGURE 12.31



Rings of Neptune. This long exposure of Neptune's rings was photographed by Voyager 2. Note the two denser regions of the outer ring. (credit: modification of work by NASA/JPL)