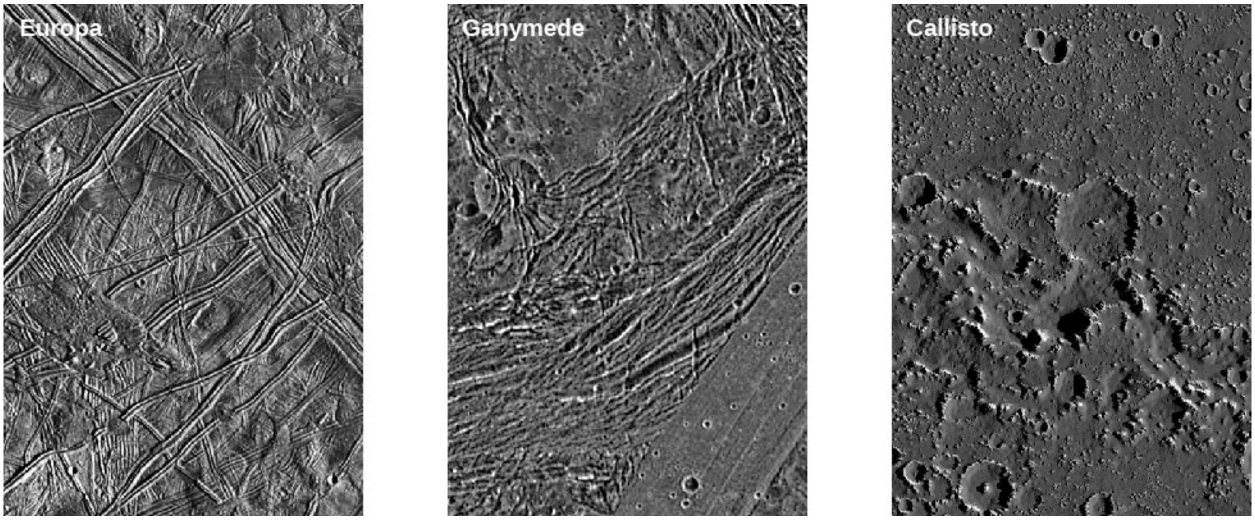



**Figure 12.11 Three Icy Moons.** These Galileo images compare the surfaces of Europa, Ganymede, and Callisto at the same resolution. Note that the number of craters (and thus the age of the surface we see) increases as we go from Europa to Ganymede to Callisto. The Europa image is one of those where the system of cracks and ridges resembles a freeway system. (credit: modification of work by NASA/JPL/DLR)

# 12.3 TITAN AND TRITON

## Learning Objectives

By the end of this section, you will be able to:

- Explain how the thick atmosphere of Titan makes bodies of liquid on its surface possible
- Describe what we learned from the landing on Titan with the Huygens probe
- Discuss the features we observed on the surface of Triton when Voyager 2 flew by

We shift our attention now to small worlds in the more distant parts of the solar system. Saturn's large moon Titan turns out to be a weird cousin of Earth, with many similarities in spite of frigid temperatures. The Cassini observations of Titan have provided some of the most exciting recent discoveries in planetary science. Neptune's moon Triton also has unusual characteristics and resembles Pluto, which we will discuss in the following section.

## Titan, a Moon with Atmosphere and Hydrocarbon Lakes

Titan, first seen in 1655 by the Dutch astronomer Christiaan Huygens, was the first moon discovered after Galileo saw the four large moons of Jupiter. Titan has roughly the same diameter, mass, and density as Callisto or Ganymede. Presumably it also has a similar composition—about half ice and half rock. However, Titan is unique among moons, with a thick atmosphere and lakes and rivers and falling rain (although these are not composed of water but of hydrocarbons such as ethane and methane, which can stay liquid at the frigid temperatures on Titan).

The 1980 Voyager flyby of Titan determined that the surface density of its atmosphere is four times greater than that on Earth. The atmospheric pressure on this moon is 1.6 bars, higher than that on any other moon and, remarkably, even higher than that of the terrestrial planets Mars and Earth. The atmospheric composition is primarily nitrogen, an important way in which Titan's atmosphere resembles Earth's.

Also detected in Titan's atmosphere were carbon monoxide (CO), hydrocarbons (compounds of hydrogen and carbon) such as methane ($CH_4$), ethane ($C_2H_6$), and propane ($C_3H_8$), and nitrogen compounds such as hydrogen cyanide (HCN), cyanogen ($C_2N_2$), and cyanoacetylene ($HC_3N$). Their presence indicates an active chemistry in which sunlight interacts with atmospheric nitrogen and methane to create a rich mix of organic molecules. There are also multiple layers of hydrocarbon haze and clouds in the atmosphere, as illustrated in **Figure 12.12**.

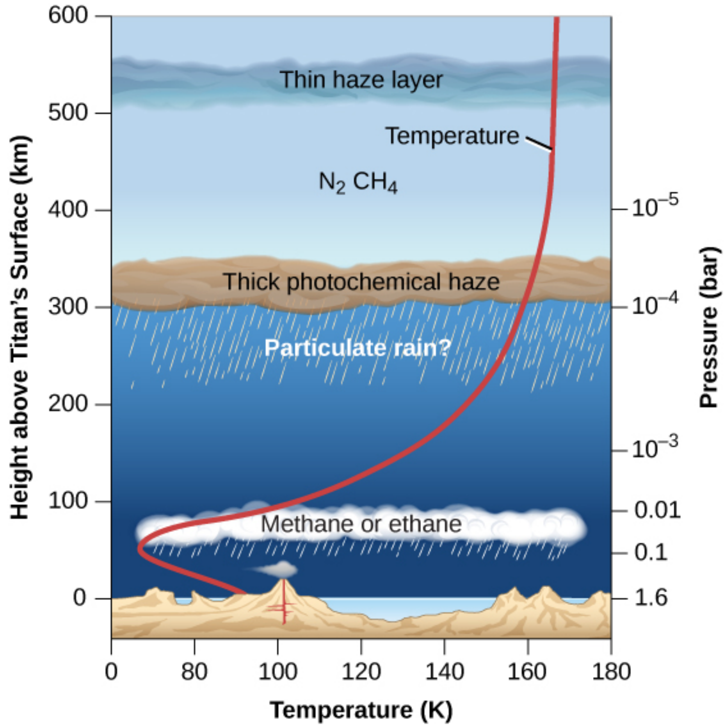



**Figure 12.12 Structure of Titan's Atmosphere.** Some characteristics of Titan's atmosphere resemble those of Earth's atmosphere, although it is much colder than our planet. The red line indicates the temperature of Titan's atmosphere at different altitudes.

These Voyager discoveries motivated a much more ambitious exploration program using the NASA Cassini Saturn orbiter and a probe to land on Titan called Huygens, built by the European Space Agency. The orbiter, which included several cameras, spectrometers, and a radar imaging system, made dozens of close flybys of Titan between 2004 and 2015, each yielding radar and infrared images of portions of the surface (see **Exploring the Outer Planets**). The Huygens probe successfully descended by parachute through the atmosphere, photographing the surface from below the clouds, and landing on January 14, 2005. This was the first (and so far the only) spacecraft landing on a moon in the outer solar system.

At the end of its parachute descent, the 319-kilogram Huygens probe safely touched down, slid a short distance, and began sending data back to Earth, including photos and analyses of the atmosphere. It appeared to have landed on a flat, boulder-strewn plain, but both the surface and the boulders were composed of water ice, which is as hard as rock at the temperature of Titan (see **Figure 12.13**).

The photos taken during descent showed a variety of features, including drainage channels, suggesting that Huygens had landed on the shore of an ancient hydrocarbon lake. The sky was deep orange, and the brightness of the Sun was a thousand times less than sunlight on Earth (but still more than a hundred times brighter than under the full moon on Earth). Titan's surface temperature was 94 K (–179 °C). The warmer spacecraft heated enough of the ice where it landed for its instruments to measure released hydrocarbon gas. Measurements on the surface continued for more than an hour before the probe succumbed to the frigid temperature.

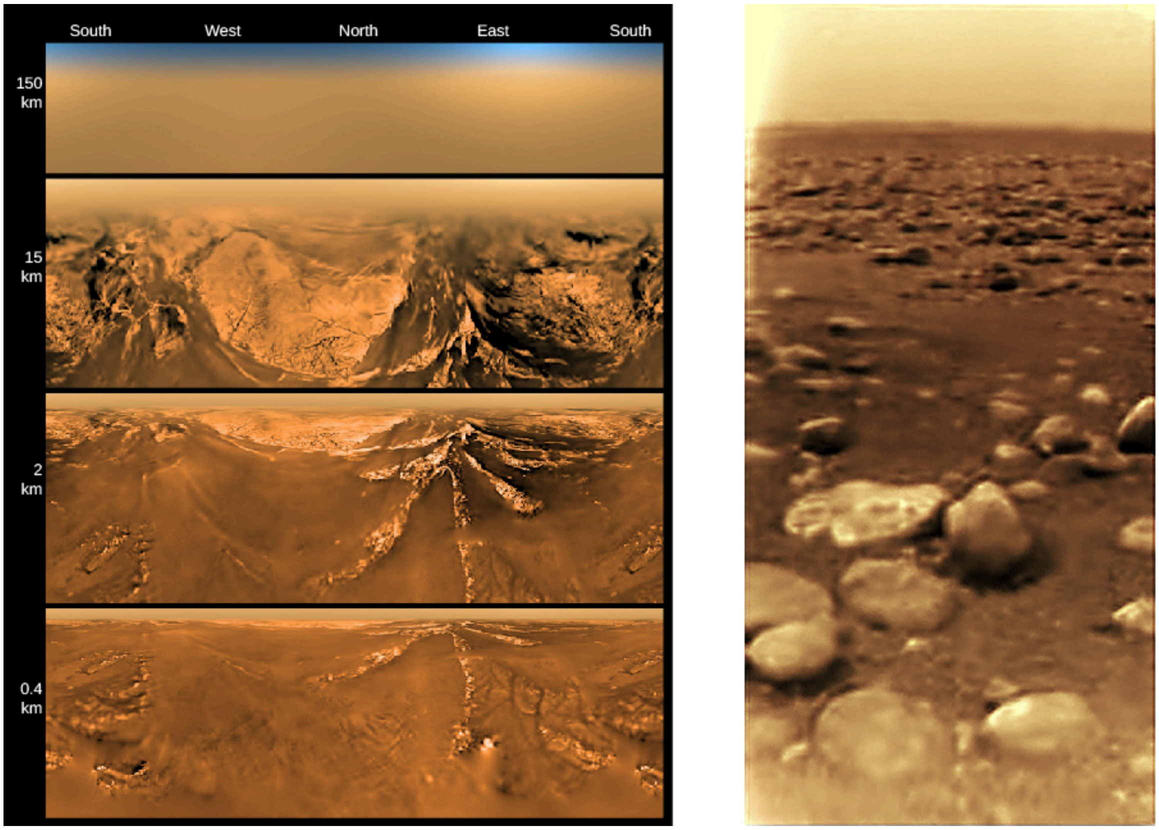
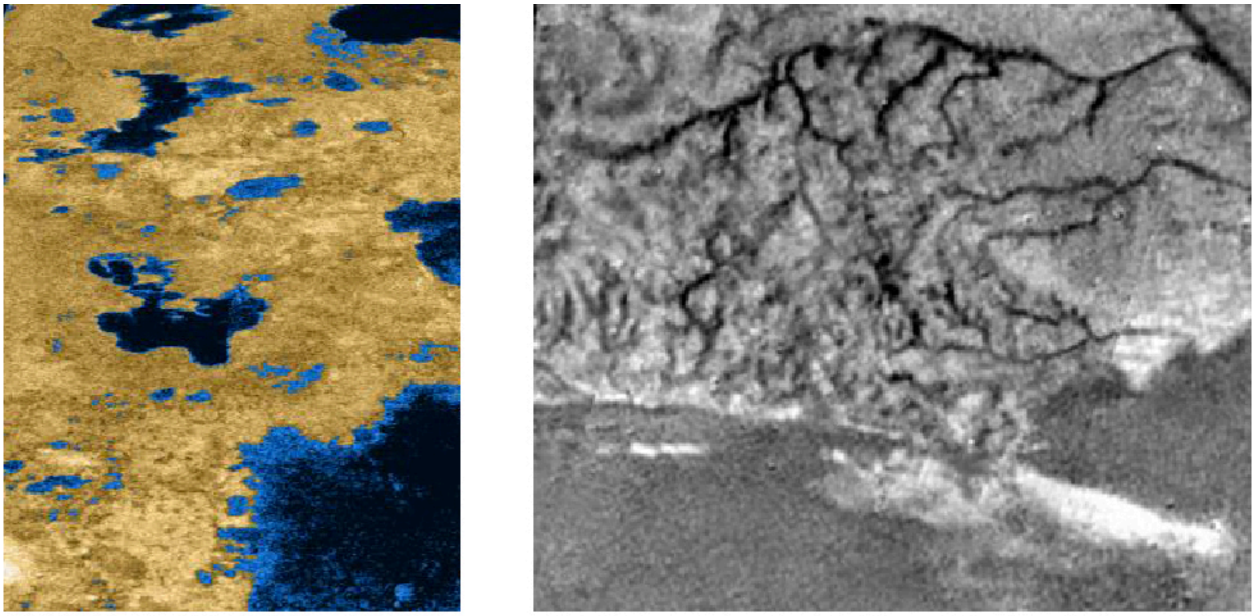



**Figure 12.13 Views of the Surface of Titan.** The left image shows the views of Titan from the descent camera, in a flattened projection, at different altitudes. The right image, taken after landing, shows a boulder-strewn surface illuminated by faint reddish sunlight. The boulders are composed of 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)

Radar and infrared imaging of Titan from the Cassini orbiter gradually built up a picture of a remarkably active surface on this moon, complex and geologically young (Figure 12.14). There are large methane lakes near the polar regions that interact with the methane in the atmosphere, much as Earth's water oceans interact with the water vapor in our atmosphere. The presence of many erosional features indicates that atmospheric methane can condense and fall as rain, then flow down valleys to the big lakes. Thus, Titan has a low-temperature equivalent of the water cycle on Earth, with liquid on the surface that evaporates, forms clouds, and then condenses to fall as rain—but on Titan the liquid is a combination of methane, ethane, and a trace of other hydrocarbons. It is a weirdly familiar and yet utterly alien landscape.



(a) (b)

**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)

These discoveries raise the question of whether there could be life on Titan. Hydrocarbons are fundamental for the formation of the large carbon molecules that are essential to life on our planet. However, the temperature on Titan is far too low for liquid water or for many of the chemical processes that are essential to life as we know it. There remains, though, an intriguing possibility that Titan might have developed a different form of low-temperature carbon-based life that could operate with liquid hydrocarbons playing the role of water. The discovery of such “life as we don’t know it” could be even more exciting than finding life like ours on Mars. If such a truly alien life is present on Titan, its existence would greatly expand our understanding of the nature of life and of habitable environments.

## LINK TO LEARNING

The Cassini mission scientists and the visual presentation specialists at NASA’s Jet Propulsion Laboratory have put together some nice films from the images taken by Cassini and Huygens. See, for example, the **Titan approach (https://openstax.org/l/30Titan)** and the **flyover (https://openstax.org/l/30Titan2)** of the Northern lakes district.

## Triton and Its Volcanoes

Neptune’s largest moon Triton (don’t get its name confused with Titan) has a diameter of 2720 kilometers and a density of 2.1 g/cm$^3$, indicating that it’s probably composed of about 75% rock mixed with 25% water ice. Measurements indicate that Triton’s surface has the coldest temperature of any of the worlds our robot representatives have visited. Because its reflectivity is so high (about 80%), Triton reflects most of the solar energy that falls on it, resulting in a surface temperature between 35 and 40 K.

The surface material of Triton is made of frozen water, nitrogen, methane, and carbon monoxide. Methane and nitrogen exist as gas in most of the solar system, but they are frozen at Triton’s temperatures. Only a small quantity of nitrogen vapor persists to form an atmosphere. Although the surface pressure of this atmosphere is only 16 millionths of a bar, this is sufficient to support thin haze or cloud layers.

Triton’s surface, like that of many other moons in the outer solar system, reveals a long history of geological evolution (**Figure 12.15**). Although some impact craters are found, many regions have been flooded fairly recently by the local version of “lava” (perhaps water or water-ammonia mixtures). There are also mysterious regions of jumbled or mountainous terrain.

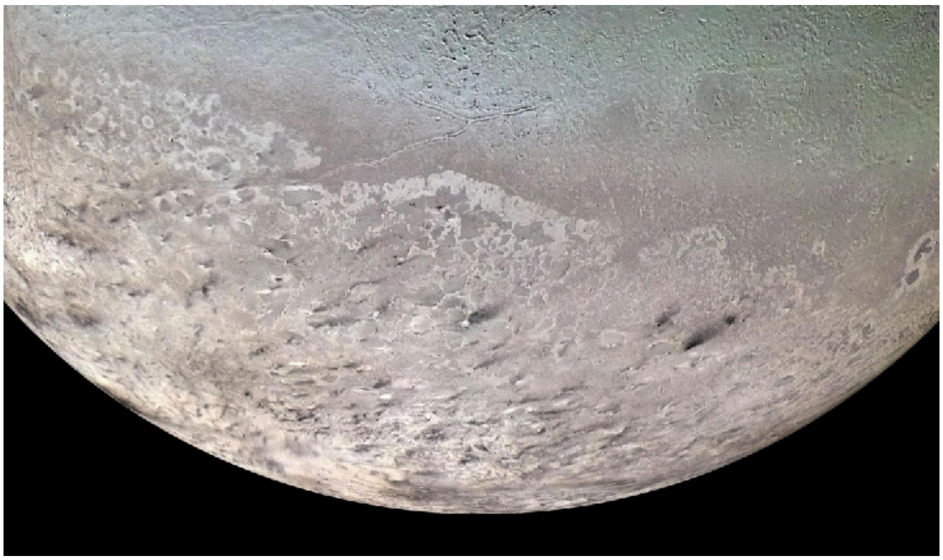


**Figure 12.15 Neptune’s Moon Triton.** This mosaic of Voyager 2 images of Triton shows a wide range of surface features. The pinkish area at the bottom is Triton’s large southern polar cap. The south pole of Triton faces the Sun here, and the slight heating effect is driving some of the material northward, where it is colder. (credit: modification of work by NASA/JPL/USGS)

The Voyager flyby of Triton took place at a time when the moon’s southern pole was tipped toward the Sun, allowing this part of the surface to enjoy a period of relative warmth. (Remember that “warm” on Triton is still outrageously colder than anything we experience on Earth.) A polar cap covers much of Triton’s southern hemisphere, apparently evaporating along the northern edge. This polar cap may consist of frozen nitrogen that was deposited during the previous winter.

Remarkably, the Voyager images showed that the evaporation of Triton’s polar cap generates geysers or volcanic plumes of nitrogen gas (see **Figure 12.16**). (Fountains of such gas rose about 10 kilometers high, visible in the thin atmosphere because dust from the surface rose with them and colored them dark.) These plumes differ from the volcanic plumes of Io in their composition and also in that they derive their energy from sunlight warming the surface rather than from internal heat.

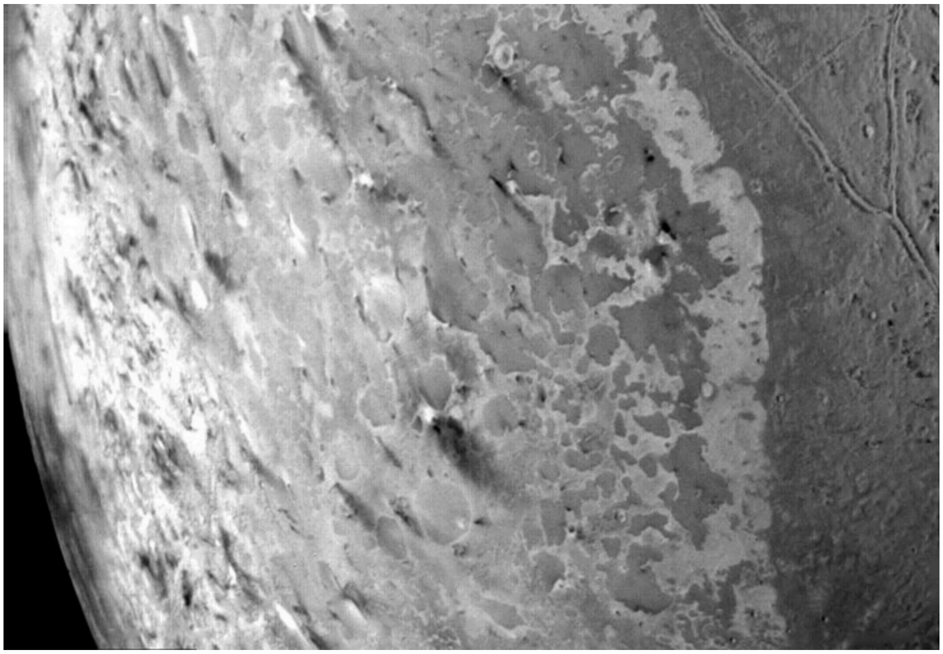


**Figure 12.16 Triton's Geysers.** This close-up view shows some of the geysers on Neptune's moon Triton, with the long trains of dust pointing to the lower right in this picture. (credit: modification of work by NASA/JPL)

# 12.4 PLUTO AND CHARON

## Learning Objectives

By the end of this section, you will be able to:

- Compare the orbital characteristics of Pluto with those of the planets
- Describe information about Pluto's surface deduced from the New Horizons images
- Note some distinguishing characteristics of Pluto's large moon Charon

Pluto is not a moon, but we discuss it here because its size and composition are similar to many moons in the outer solar system. Our understanding of Pluto (and its large moon Charon) have changed dramatically as a result of the New Horizons flyby in 2015.

## Is Pluto a Planet?

Pluto was discovered through a careful, systematic search, unlike Neptune, whose position was calculated from gravitational theory. Nevertheless, the history of the search for Pluto began with indications that Uranus had slight departures from its predicted orbit, departures that could be due to the gravitation of an undiscovered "Planet X." Early in the twentieth century, several astronomers, most notably Percival Lowell, then at the peak of his fame as an advocate of intelligent life on Mars, became interested in searching for this ninth planet.

Lowell and his contemporaries based their calculations primarily on tiny unexplained irregularities in the motion of Uranus. Lowell's computations indicated two possible locations for a perturbing Planet X; the more likely of the two was in the constellation Gemini. He predicted a mass for the planet intermediate between the masses of Earth and Neptune (his calculations gave about 6 Earth masses). Other astronomers, however, obtained other solutions from the tiny orbital irregularities, even including one model that indicated two planets beyond Neptune.

At his Arizona observatory, Lowell searched without success for the unknown planet from 1906 until his death