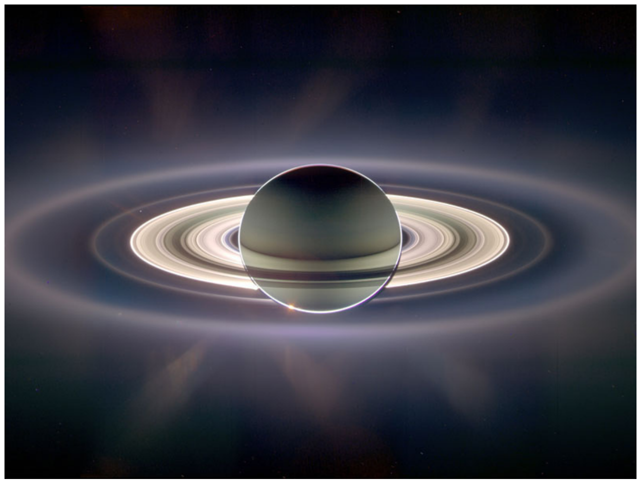
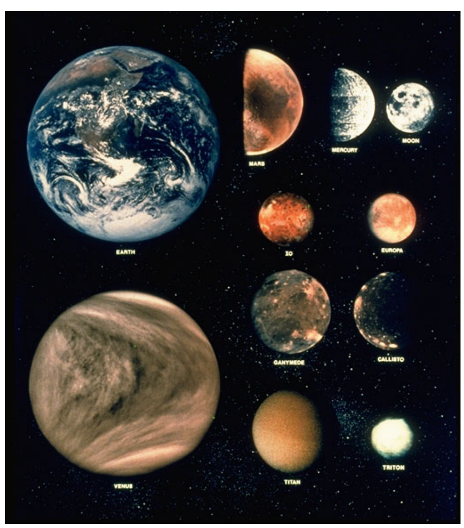
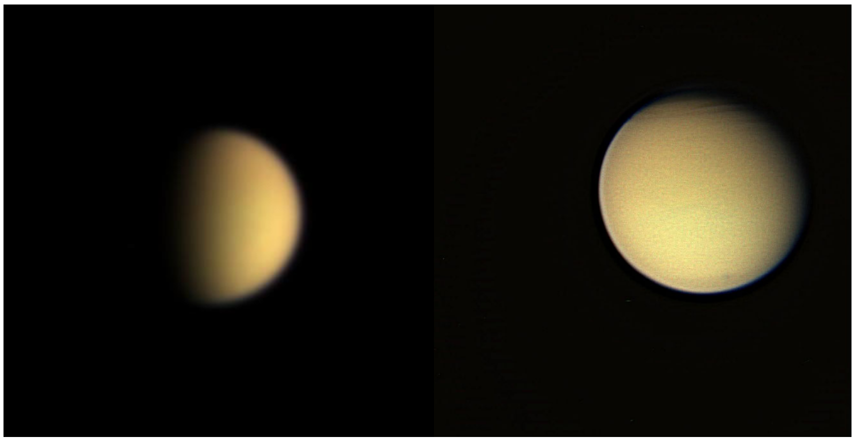
The Moons of Saturn



Size Comparison



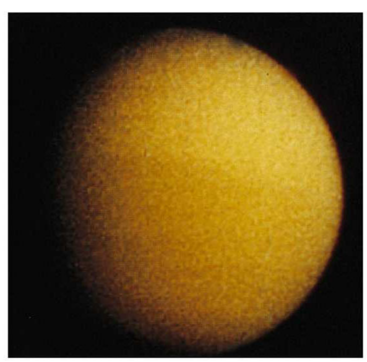
Titan by Voyager and Cassini



Titan

Titan is almost as big as Ganymede, and **it is the only moon with a thick atmosphere**.

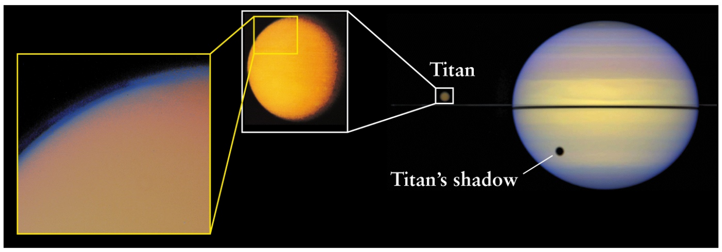
The Voyager 1 flyby of Saturn was designed to yield as much info as possible about Titan. It flew behind this moon, so that its radio signal traversed successive paths through Titan's atmosphere. The measured surface pressure was **1.5 bars**, higher than that on any planet except Venus.



Titan

The composition of **Titan's atmosphere** is primarily **Nitrogen**, with methane and argon amounting to small percentages. There are small amounts of carbon monoxide, various hydrocarbons, and nitrogen compounds such as hydrogen cyanide (HCN).

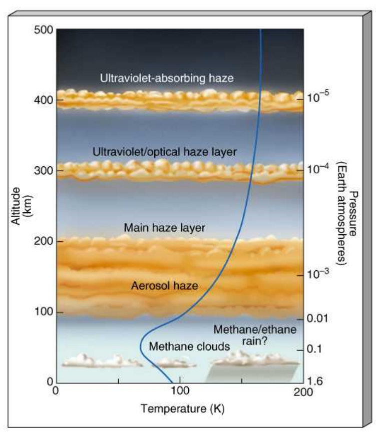
The discovery of HCN was particularly interesting, since this molecule is the starting point for formation of some of the components of DNA.



Titan

There are multiple cloud layers on **Titan**. The lowest are in the troposphere, within the bottom 10 km of the atmosphere; these are condensation clouds composed of **methane (CH_4).**

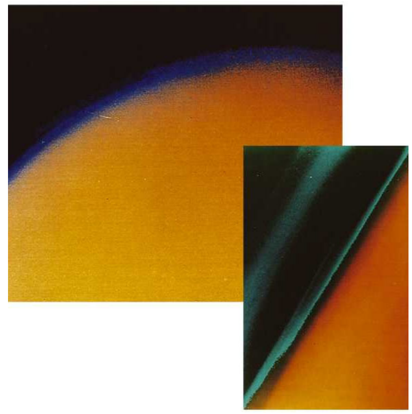
Methane plays the same role in Titan's atmosphere as water does on the Earth; the gas is only a minor constituent of the atmosphere, but it condenses to form the major clouds.



Titan

Much higher, photochemical reactions have produced a dark **reddish haze or smog** consisting of complex organic chemicals.

Formed at an altitude of several hundred km, this aerosol slowly settles downward. It has probably built up a deep layer of tar-like organic chemicals on the moon's surface.

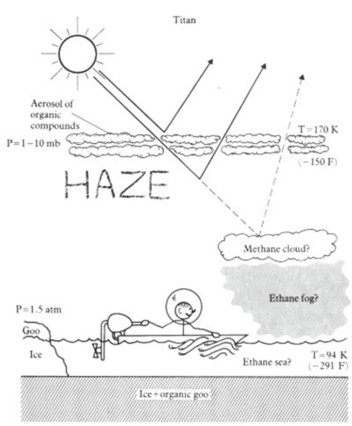


Titan

The surface temperature is **90 K**.

There might be seas of liquid methane CH_4 and ethane C_2H_6. Organic compounds are chemically stable at these temperatures.

Titan's surface could record a *chemical* history that goes back billions of years.



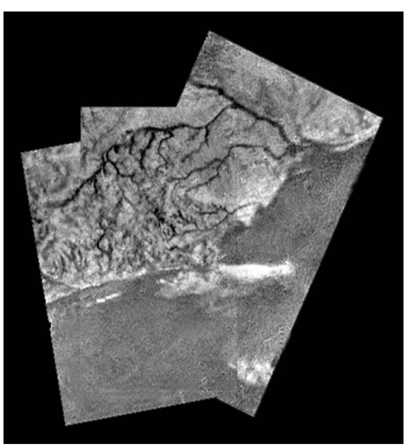
Huygen's Probe Results

The Huygens probe was launched by the Cassini spacecraft into Titan's atmosphere. Huygens saw evaporation by methane. It did not detect *liquid* methane, but most scientists inferred liquid methane by the data.

If there is liquid methane, then **Titan** would *probably* have a complete hydrological cycle, one where it rains methane.

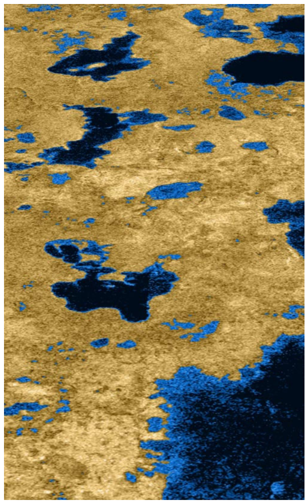
Because the ground is so cold, methane would stay in liquid form on the surface and act very much like water does on Earth. It would evaporate, condense, form clouds, and rain back down onto Titan, creating lakes, creeks, and springs.

Titan's Surface



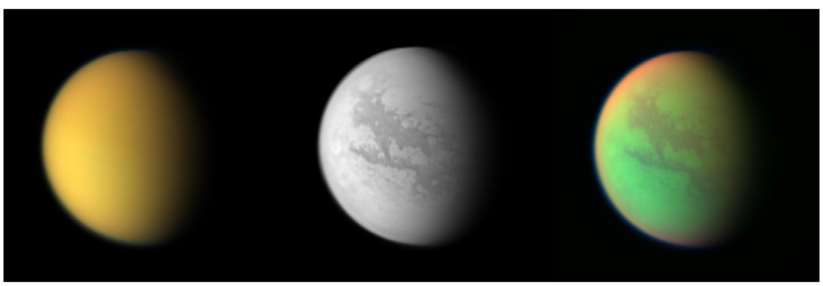
This mosaic of images taken by *Huygens* during its descent toward **Titan** shows a series of streams branching into a major river channel that pours into a still-larger outflow channel.

Low Reflectivities

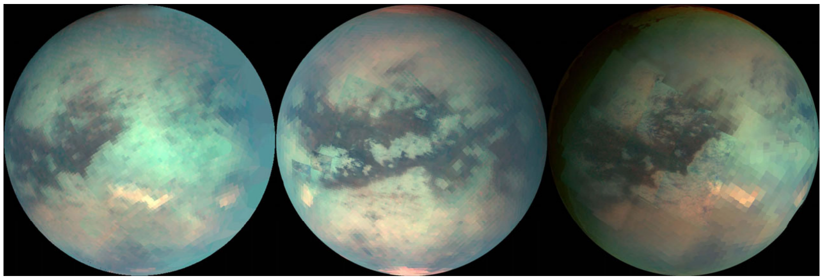


The vertical dimension is about 150 miles. The dark regions have low **radar reflectivity**, and these could be lakes of methane.

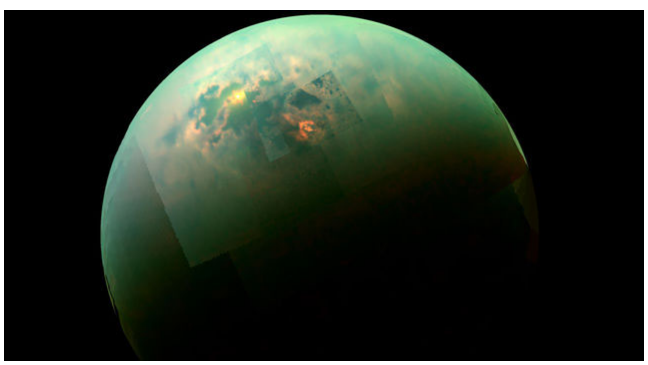
Views by Cassini



Views by Cassini



Titan

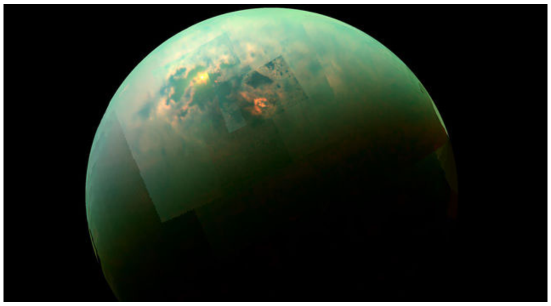


Cassini spacecraft caught a glimpse of bright sunlight reflecting off **hydrocarbon seas**.
October 31, 2014

Titan

An arrow-shaped complex of bright methane clouds hovers near the north pole. The clouds could be actively refilling the lakes with rainfall.

A "bathtub ring," or bright margin, around Kraken Mare – the sea containing the reflected sun glint – indicates that the sea was larger at some point, but evaporation has decreased its size.



Titan

Titan's seas are mostly liquid methane (CH_4) and ethane (C_2H_6).

Before Cassini's arrival, scientists suspected that Titan might have bodies of open liquid on its surface.

Cassini found only great fields of sand dunes near the equator and lower latitudes, but located lakes and seas near the poles, particularly in the north.

Titan

Why does **Titan** have an atmosphere but Callisto and Ganymede do not?

1. Part of the answer is Titan's greater distance from the Sun, producing cooler temperatures that slow down the molecules in the atmosphere and decrease their rate of escape.

2. But the primary reason must be that Titan outgassed from its interior more gas than was ever present on the two Jovian moons.

This difference probably relates to the changing composition of the solar nebula with distance from the Sun. Where Titan formed, small but significant amounts of methane and ammonia were present, while Ganymede and Callisto apparently had none. Subsequently, photo-chemical reactions dissociated most of the ammonia to release nitrogen, while the hydrogen escaped from Titan's atmosphere.

Medium Moons

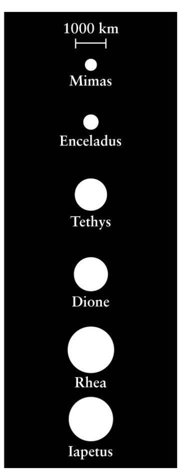
The six medium-sized moons of Saturn, together with the rings and about a dozen small moons, form a regular and tightly knit group. The moons are **Rhea**, **Dione**, **Tethys**, **Mimas**, **Enceladus**, and **Iapetus**. The latter two are rather unusual worlds.

Six Medium-Sized Moons

The composition of these six regular moons, with diameters between 400 and 1600 km, is about half water ice. Each of these moons has a surface that displays the spectral signature of water ice. Further, each has density of about 1.3 g/cm^3, close to the expected uncompressed density of an object composed half of water ice.

Unlike the Jovian system, there is no indication of a systematic variation in density and composition with distance from the planet. Evidently, Saturn was never hot enough to eliminate water ice from its inner moons, as Jupiter seems to have done.

Medium Moons



The largest in this group is **Rhea**, with a diameter of 1530 km, just half as large as Europa. Rhea, and its smaller cousins Mimas, Dione, and Tethys, are all **heavily cratered with bright surfaces of relatively clean water ice**. Although there are views of some tectonic cracking and resurfacing early in their histories, all four seem to have stabilized billions of years ago.

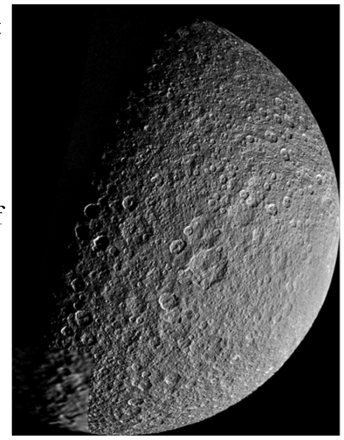
[The diagram to the left is wrong – Rhea is larger than Iapetus.]

Rhea

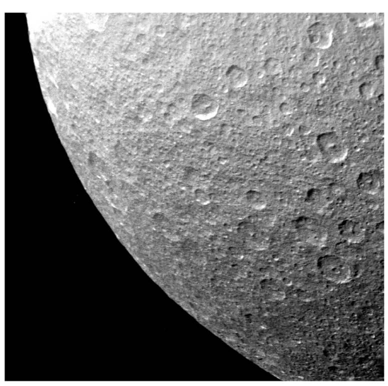
Rhea is the largest Saturn moon after Titan. Its diameter is 1530 km, just half as big as Europa, but it is 60% larger than the largest asteroid, Ceres.

Its density is only 1.3 g/cm^3, substantially lower than that measured for any solid body in the Solar System. This does not mean, however, that the composition of **Rhea** is much different from that of Titan or the large icy moons of Jupiter; rather the density is less primarily because of its smaller size.

Ice is a fairly compressible material, resulting in a higher density for large moons. Rhea has a less compressed interior, so it probably is composed of half water ice and half silicate minerals.



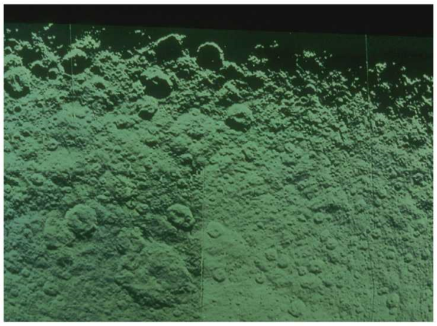
Rhea



Rhea is highly reflective (60%), and its IR spectrum is dominated by water ice. That this moon is nearly as bright as Europa might be taken as evidence that it too has occasionally resurfaced itself with fresh ice, but it is equally probable that the environment at Saturn is simply less dirty than at Jupiter.

If most of the impacting debris is icy, a moon's surface can remain relatively clean even after billions of years of exposure.

Rhea



The surface of **Rhea** is heavily cratered, and the craters look remarkably lunar like. At the low temperatures (~100 K), ice behaves very much like rock when a crater-forming impact takes place.

The colder ice is, the less plastic and the more brittle it becomes.

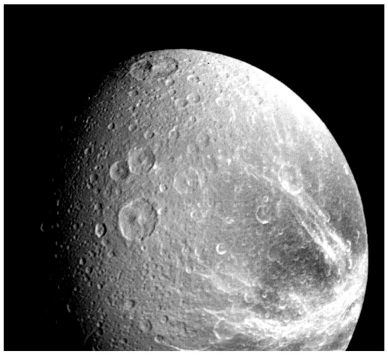
The crater density is similar to that of the lunar highlands. Further, there is little if any indication of internal geological activity to erase or distort craters. Lack of geological activity should not surprise us – **there should be no heat source for a small icy world out at the distance of Saturn.**

Rhea

In the midst of all this evidence of a dull history, however, **Rhea** does display one peculiarity. While its leading side – the hemisphere that faces forward in its orbit as it moves around Saturn – is unmarked except by craters, its trailing side shows **prominent streaks**.

It seems probable that they are the remnants of some long-ago episode of activity in which water was released from the interior and condensed on the surface.

Dione



Dione is darker and smaller than Rhea (1120 km) and slightly denser (1.4 g/cm^3), but in other respects it is a very similar icy world.

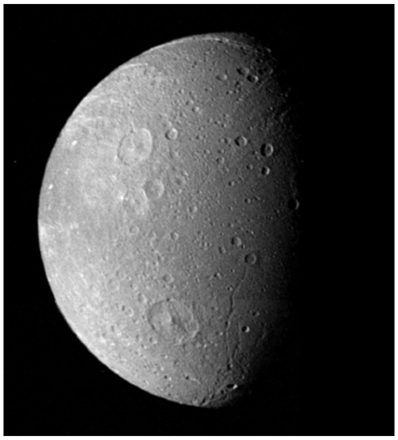
Its surface is heavily cratered, and on its trailing hemisphere the bright streaks ("**wispy terrain**") are even more prominent, reflecting up to 70% of the incident sunlight whereas the underlying surface reflects only half as much.

Dione

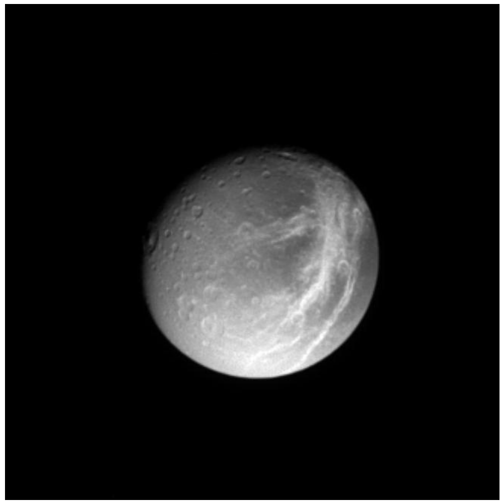
The most significant feature of **Dione** is its evidence of past **internal geologic activity**.

Over much of its surface, flooding or some other type of resurfacing has obliterated old craters, producing lower crater densities like that of the old lava plains of Mercury.

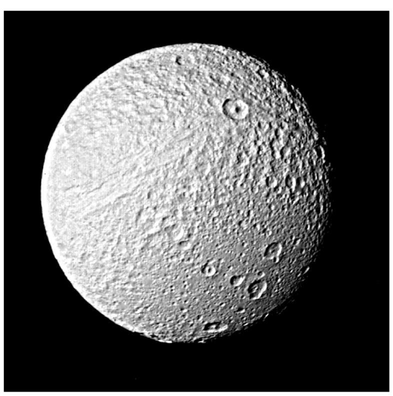
Also visible are valleys of unknown origin, apparently associated with the bright streaks. Perhaps the bright material are frozen gases along the rims of these cracks in the crust.

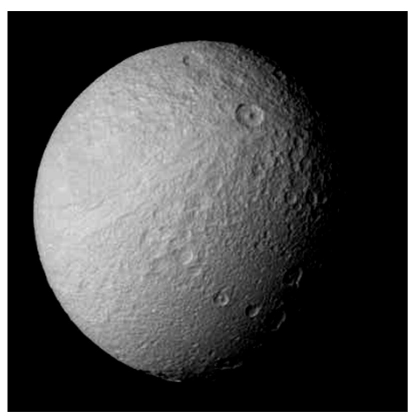


Dione



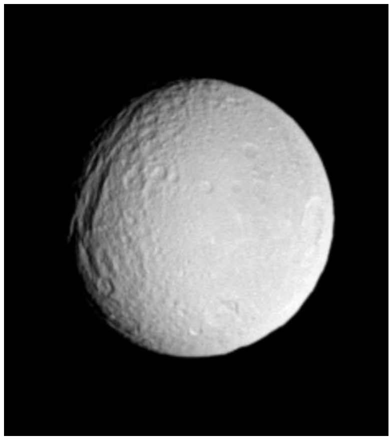
Tethys





Tethys is a close twin of Dione. It too has a mixture of surface terrains, some very heavily cratered, others modified by geologic activity. The surface reflectivity is very high at 80%.

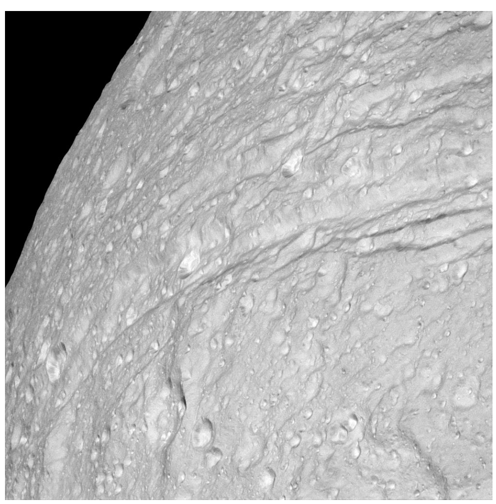
Tethys



Tethys has a **giant valley** that stretches three-quarters of the way around. Its surface area, which is ~100 km wide, is comparable to that of Valles Marineris.

Such a feature could have been formed if the interior expanded enough to increase the surface area by 10%, not an impossibly large figure for some kinds of water ice, but why the surface cracked in only one place is a mystery.

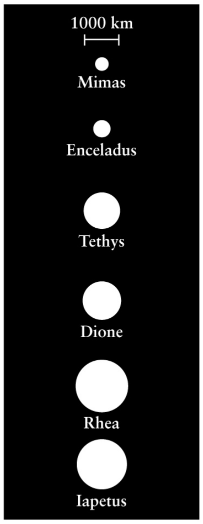
Tethys



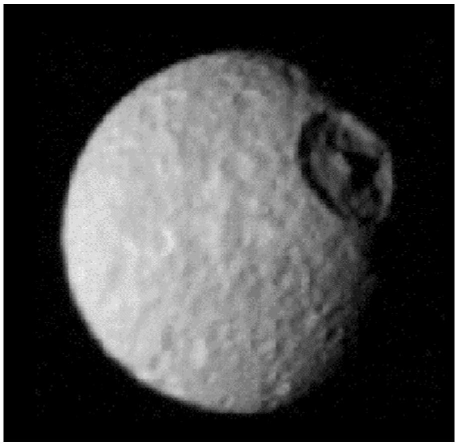
Mimas and Enceladus

The innermost of the medium-sized moons of Saturn, **Mimas** and **Enceladus**, form a pair as do Tethys and Dione. Both have diameters of about 500 km, and both have experienced the same environmental effects.

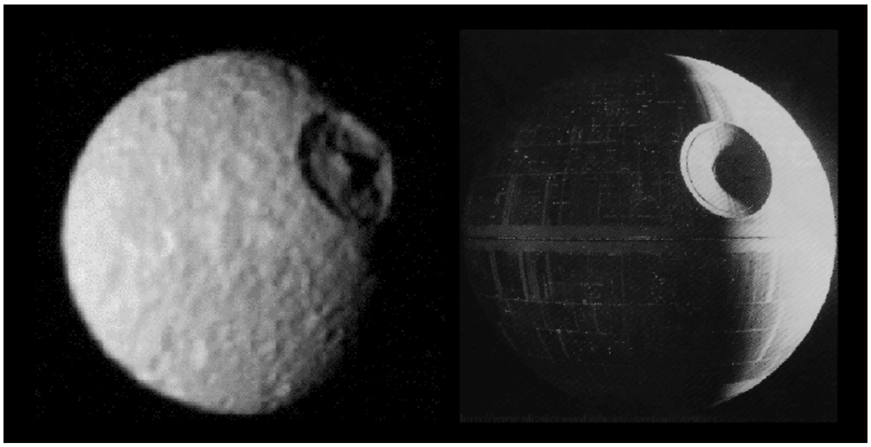
Yet they are very different.



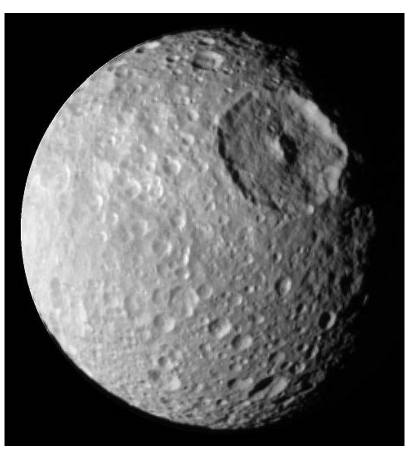
Mimas



Mimas



Mimas



Mimas is heavily cratered and shows little evidence of internal activity. Its most notable feature is a single very large crater, which has a diameter about one-third that of the moon itself.

This is one of the largest craters in the Solar System, not in absolute size, but in relation to the size of the body struck. The energy released by such an impact was not quite sufficient to shatter and disrupt Mimas itself.

Comparison of Moons

These four moons of Saturn (**Rhea**, **Dione**, **Tethys**, and **Mimas**) have many things in common.

> They all have surfaces of relatively pure water ice, and from their densities we can infer a bulk composition that is about one-half water ice as well.
>
> All are heavily cratered, testifying to a heavy meteoroidal bombardment.

However, both Dione and Tethys show evidence of a surprising amount of past geological activity, which may have occurred only during the earliest period of planetary history.

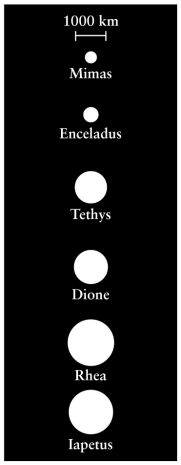
Comparison of Moons

Relative to the Galilean moons, these four inner moons make up a compact group. It is interesting to ponder the effects of being so close to Saturn.

The most important influence of the giant planet is **gravitational**. Meteoroids are pulled inward, converging toward the planet and increasing both the impact rate and the impact speeds for the inner moons. The closer a moon is to Saturn, the larger these effects.

Thus the same flux of impacts that will just build up a heavily cratered surface on Rhea will result in a much more severe pounding of Mimas.

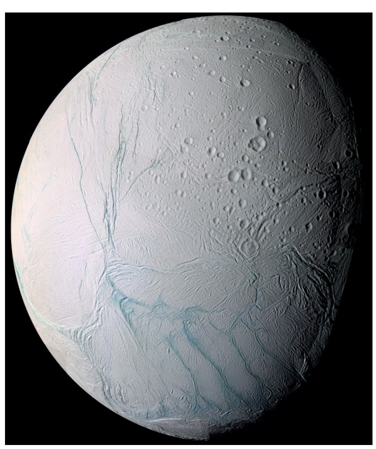
Enceladus



Because of their similar sizes, one would expect Mimas and **Enceladus** to resemble each other. Both are icy bodies with diameters of about 500 km, and both are close enough to Saturn to have experienced similar heavy bombardment by comets.

But they are not alike at all; in fact, **Enceladus** offers some major challenges to understanding the Saturn system.

Enceladus

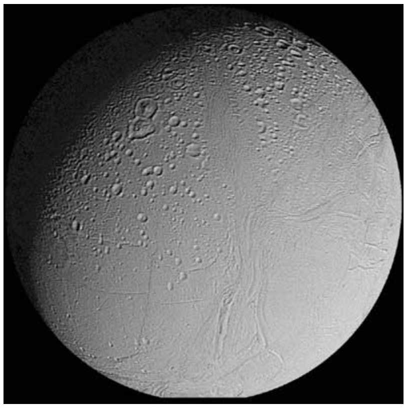


Even from a distance, **Enceladus** looks strange.

Its surface is blindingly white, reflecting nearly 100% of the incident sunlight.

As far as is known, **Enceladus** has the highest reflectivity of any naturally occurring surface in the Solar System. The high albedo results in a low surface temperature of ~55 K.

Enceladus



Over much of its surface, all impact craters have been erased, a sure sign of high levels of geological activity.

It appears that these smooth plains are no more than a few hundred million years old. Some of these plains also show ridges and flow marks. This is strong evidence for water volcanism.

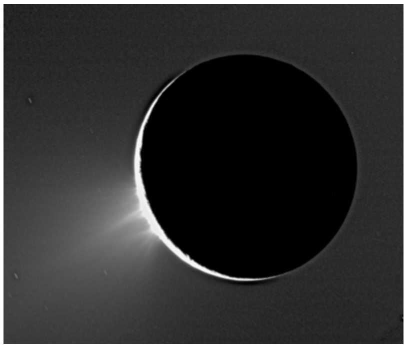
Many individual craters have been deformed by plastic flow in the crust, the result of higher temperatures below the surface.

Enceladus has Geysers

The Cassini spacecraft detected **geysers**.

It is tempting to compare **Enceladus** to Io. The activity rate on Enceladus is much lower, but it is much smaller.

Both objects present essentially the same problem: to find a relatively large source of internal heating that is capable of maintaining geologic activity in spite of the rapid escape of heat from the interior.

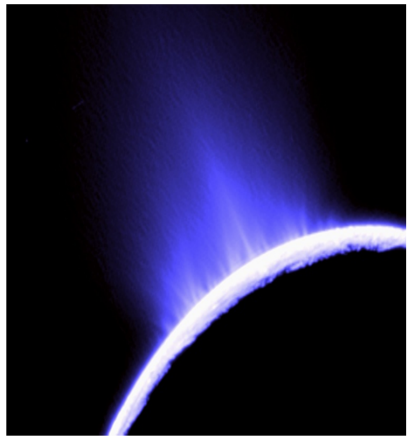


Enceladus

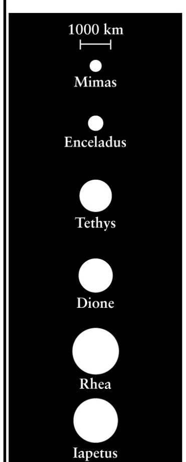
For Io, the mechanism is tidal heating. Can this also be it for **Enceladus**?

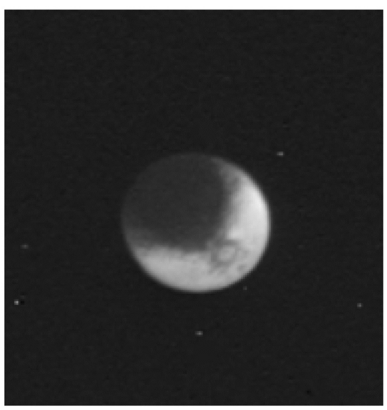
The difficulty is that no nearby moons force **Enceladus** to revolve in a non-circular orbit the way Io is affected by Europa and Ganymede.

No good scenario has been derived that explains Enceladus internal heating.



Iapetus





Iapetus presents a different set of mysteries.

Ever since its discovery in 1671 by Jean Cassini, the strangeness of **Iapetus** has been recognized by astronomers.

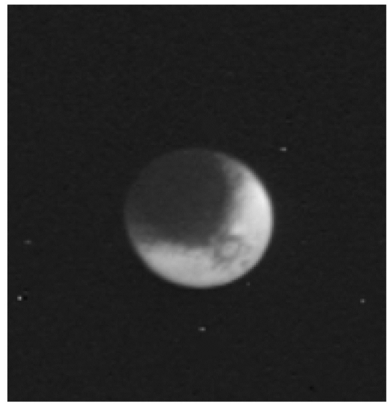
It is a two-faced moon with a dark leading hemisphere and a bright trailing one.

Iapetus

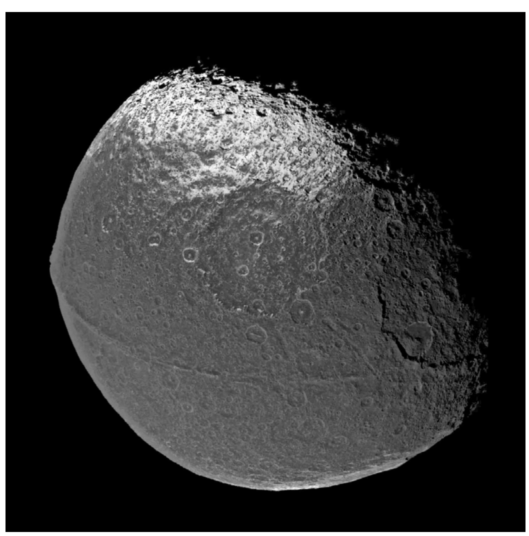
Since **Iapetus** always keeps the same face toward its planet, one sees the brightness vary dramatically as it moves around its orbit, presenting first its dark side, then its bright side.

The latter is water ice with a high reflectivity of ~50%. The dark side, however, is covered with a reddish-black material, probably organic in composition, that reflects only 3% of the incident sunlight.

The contrast is like that between black asphalt and fresh snow.



Iapetus

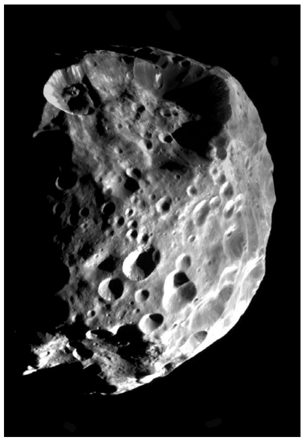


Medium Moons

Small Satellites

There are several dozen known small satellites of Saturn. The ones that have been imaged are heavily cratered, icy in composition, and irregularly shaped. However, some have interesting orbits.

Phoebe

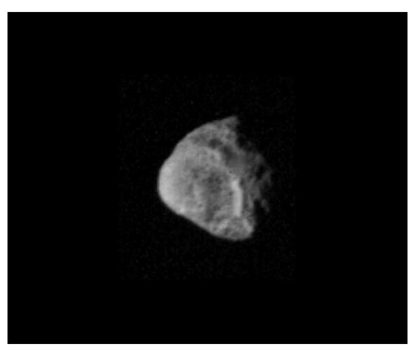


Hyperion

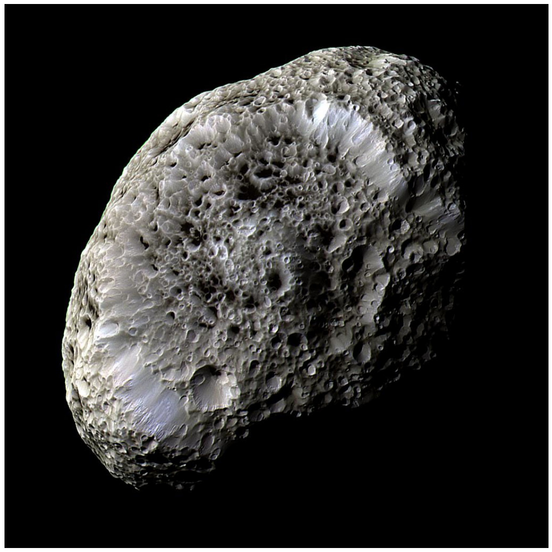
Hyperion has a very strange rotation.

It does not have a well-defined period of rotation.

It is in a state of **chaotic rotation**, in which gravitational interactions with Titan cause it to exchange angular momentum between its orbit about Saturn and its rotation.



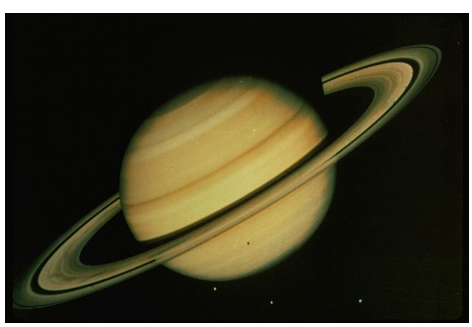
Hyperion



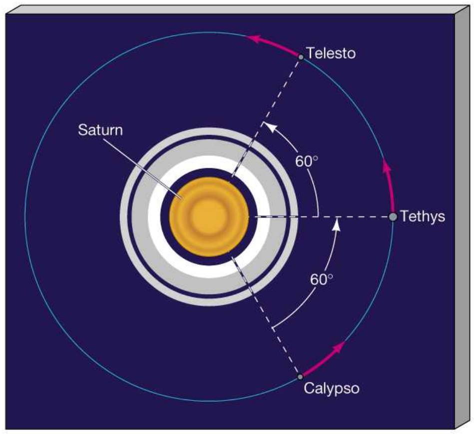
Interesting Interactions

Moon and Moon

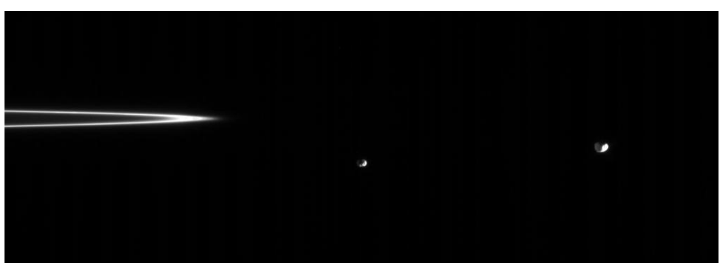
Moon(s) and Ring(s)



Telesto, Tethys, and Calypso



Janus & Epimethius



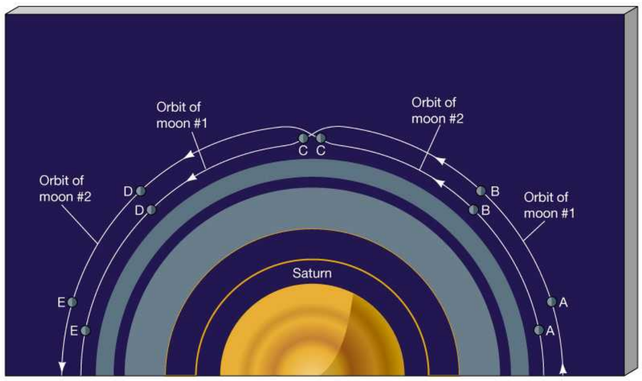
Janus and **Epimethius** are **co-orbital** – they occupy nearly the same orbit around Saturn.

If they had exactly the same period, they could avoid each other, but such a state is dynamically impossible. The inner moon catches up with the outer at a speed of ~9 m/s. The orbits differ by about 50 km, but they are more than 100 km across, so they cannot pass.

Janus & Epimethius

Janus and **Epimethius** interact gravitationally, ***exchanging*** **orbits**.

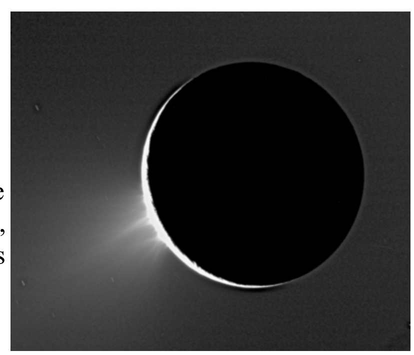
Their relative motion then reverses, and they pull apart. This intricate maneuver repeats about once every four years.



Enceladus and the E Ring

Enceladus seems to be the source of a ring around Saturn, appropriately called the E Ring.

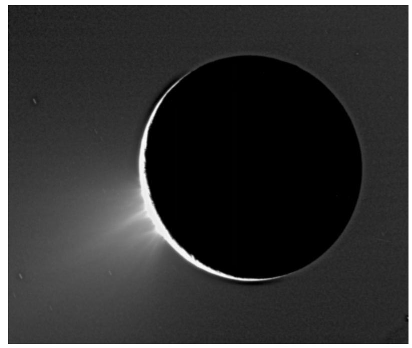
This faint, tenuous cloud of very small, spherical particles fills much of the space between the orbits of Mimas, **Enceladus**, and Tethys, with its maximum brightness at the orbit of Enceladus.



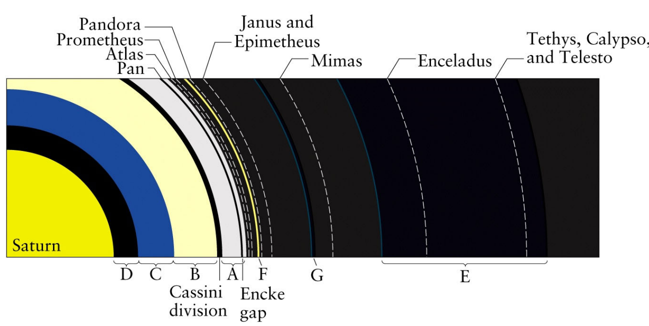
Enceladus and the E Ring

Since the E-ring particles are so small, they cannot survive for long in their present orbits; instead, radiation pressure would be expected to disperse them like the dust in the tail of a comet.

There must be a continuing source of particles or the E ring is young, having been formed by some recent event.



Moons and Rings



Most of the structure in the rings owes its existence to the gravitational effects of satellites. If there were no satellites, the rings would probably be flat and featureless (or not exist at all). The sharp edges, as well as the fine structure, of rings are due to the satellites.

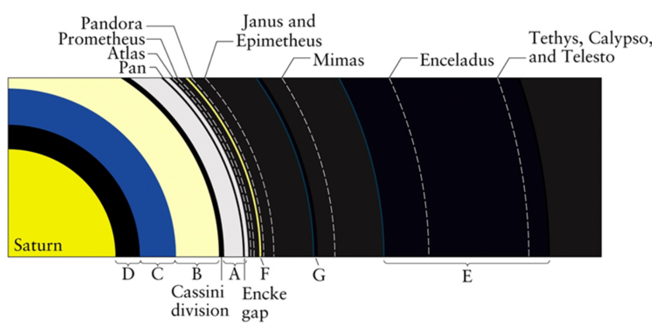
Satellite-Ring Interactions

The existence of some of the gaps and of the sharp outer edge of the A ring results from gravitational resonances with **Mimas** and the two co-orbital inner moons. A **resonance** takes place when two objects have orbital periods that are exact ratios of each other, such as 1:2, 1:3, etc.

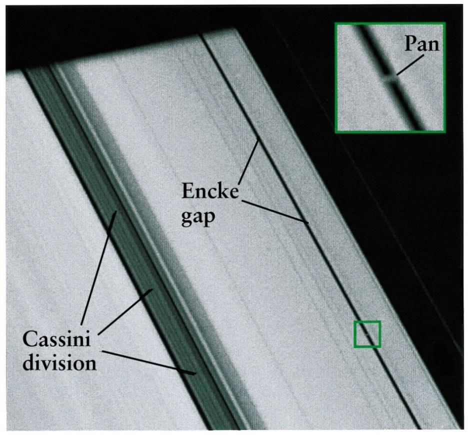
For example, any particle in the gap at the inner side of the Cassini Division would have a period exactly one-half that of Mimas. Such a particle would be nearest Mimas in the same part of its orbit every second revolution. The repeated tugs of Mimas, acting always in the same direction, would perturb the particles, forcing it into a new orbit that does not represent a resonance with a satellite.

Resonances

Resonances can form gaps by ejecting material with periods that are an exact multiple of satellite periods, but they can also lead to circumstances in which the boundary of a ring is stabilized by these gravitational effects. Such is the case for the sharp outer edge of the A ring of Saturn, which is in a 7:6 resonance with the two co-orbital moons, Janus and Epimethius.

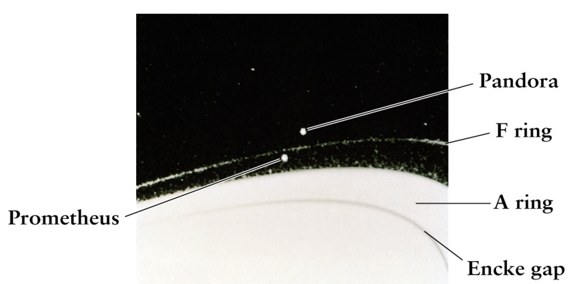


Pan and Encke Gap



Shepherd Satellites

Small moons that orbit very close to rings can also control their shape and position. This is the case for the F ring, which is bounded by the orbits of Pandora and Prometheus. These two small objects are referred to as **Shepherd Satellites**, since their gravitation serves to "shepherd" the ring particles and keep them confined to a narrow ribbon.



Shepherd Satellites

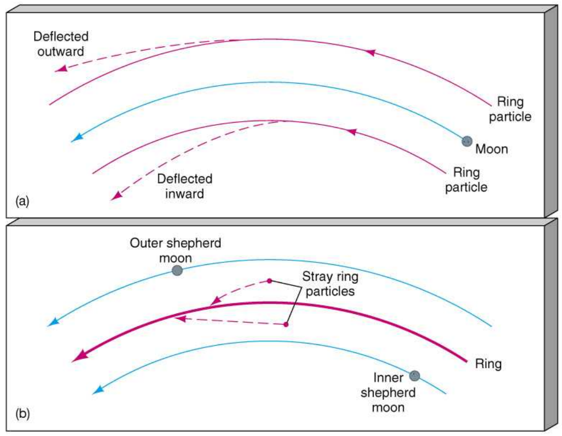


table 15-3 Saturn's Satellites

	Distance from center of Saturn (km)	(Saturn radii)	Orbital period (days)	Size (km)	Density (kg/m^3)
Pan	133,570	2.22	0.573	20	—
Atlas	137,640	2.28	0.602	20 × 20 × 20	—
Prometheus	139,350	2.31	0.613	140 × 100 × 80	—
Pandora	141,700	2.35	0.629	110 × 90 × 70	—
Epimetheus	151,422	2.51	0.694	140 × 120 × 100	—
Janus	151,472	2.51	0.695	220 × 200 × 160	—
Mimas	185,520	3.08	0.942	392	1400
Enceladus	238,020	3.95	1.370	500	1200
Tethys	294,660	4.89	1.888	1060	1200
Calypso	294,660	4.89	1.888	34 × 28 × 26	—
Telesto	294,660	4.89	1.888	24 × 22 × 22	—
Dione	377,400	6.26	2.737	1120	1400
Helene	377,400	6.26	2.737	36 × 32 × 30	—
Rhea	527,040	8.74	4.518	1530	1300
Titan	1,221,850	20.25	15.945	5150	1880
Hyperion	1,481,000	24.55	21.277	410 × 260 × 220	—
Iapetus	3,561,300	59.02	79.331	1460	1200
Phoebe	12,952,000	214.7	550.48^{R}	220	—

This table lists some facts about 18 of Saturn's satellites. In 2000 ten additional small satellites (S/2000 S1 through S/2000 S10) were discovered and confirmed; their orbits are still tentative as of this writing (early 2001) and do not appear in this table.

All the larger satellites are spherical, and their diameters are listed in the Size column. For the smaller satellites, which are not spherical, three dimensions—width, length, and height—are given. The masses, and hence the densities, of the smaller satellites are not yet known.

Of the moons for which rotation rates are known, almost all rotate synchronously (that is, the rotation period is the same as the orbital period, so the moon always keeps the same face toward Saturn.) The exceptions are Phoebe and Hyperion.

The F ring shepherds are Prometheus and Pandora. Janus and Epimetheus are called co-orbital satellites, because they move in almost the same orbit. Tethys, Calypso, and Telesto are also co-orbital satellites, as are Dione and Helene. In the latter two cases, the tiny satellites occupy specific locations along the orbits of the larger moons, where a balance exists between the gravitational pulls of Saturn and the larger moon. We will discuss these locations, called the Lagrangian points, in Chapter 17.

The superscript R on the orbital period of Phoebe means that it orbits Saturn in a retrograde direction.