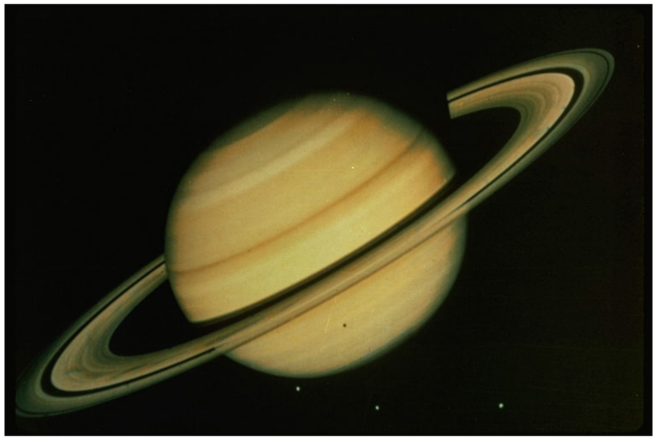
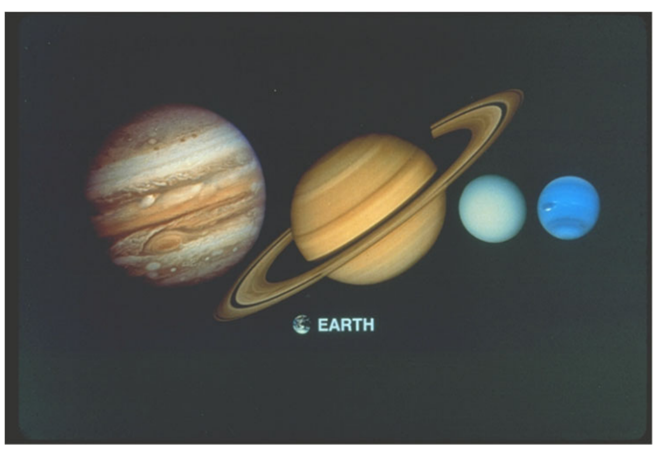
Saturn



The Gem

The Jovian Planets



Exploration

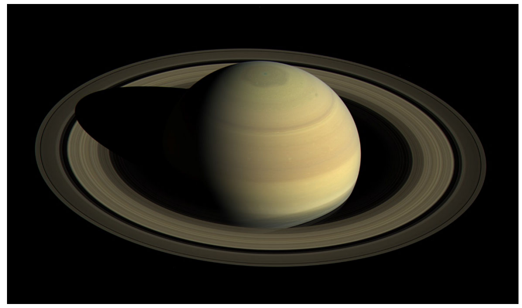
Pioneer 11 in 1979.

Primarily took a few pictures and measured magnetic field.

Voyagers 1, 2 in 1980 & 1981.

The Voyagers carried 11 instruments.

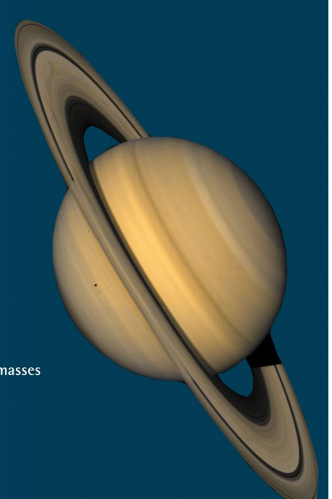
Cassini from 2004 to 2017.



NASA

Table 15-1 Saturn Data

Average distance from Sun:	9.572 AU = 1.432×10^9 km
Maximum distance from Sun:	10.081 AU = 1.508×10^9 km
Minimum distance from Sun:	9.063 AU = 1.356×10^9 km
Eccentricity of orbit:	0.053
Average orbital speed:	9.64 km/s
Orbital period:	29.37 years
Rotation period:	$10^h\ 13^m\ 59^s$ (equatorial) $10^h\ 39^m\ 25^s$ (internal)
Inclination of equator to orbit:	26.73°
Inclination of orbit to ecliptic:	2.48°
Diameter:	120,536 km = 9.449 Earth diameters (equatorial) 108,728 km = 8.523 Earth diameters (polar)
Mass:	5.685×10^{26} kg = 95.16 Earth masses
Average density:	687 kg/m^3
Escape speed:	35.5 km/s
Surface gravity (Earth = 1):	0.92
Albedo:	0.46
Average temperature at cloudtops:	−180°C = −292°F = 93 K



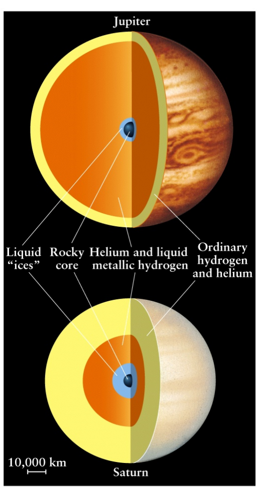
(USGS/JPL/NASA)

Appearance and Rotation

Saturn is a beautifully ringed planet. Unlike Jupiter, there are few distinct details in its cloud patterns. More fundamental is the rotation of the mantle and core, as indicated by variations in the magnetic field.

The period of Saturn is **$10^h 40^m$** and it experiences **differential rotation**.

Composition and Structure

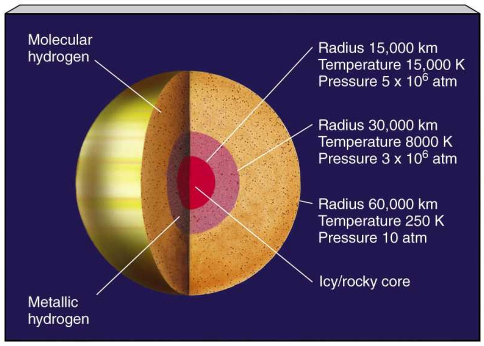


Universe by Freedman, Geller, and Kaufmann

The internal structure is different than that of the terrestrial planets. At depths of about 30 thousand km below the clouds, pressures become so high that hydrogen changes from gaseous to a liquid state. **Still deeper, this liquid hydrogen can act like a metal.**

Saturn has only a small volume of metallic hydrogen, but most is liquid. The core is composed of heavier materials. Presumably the original rock-and-ice bodies.

Interior Structure



Astronomy Today by Chaisson and McMillan

Icy/Rocky Core	15,000 km
Liquid, Metallic H Mantle	15,000 km
Gaseous H Atmosphere	30,000 km

Internal Heat Source

Saturn's internal heat source is about half as large as that of Jupiter's, which means (since its mass is only about one-quarter as great) that it is producing ***twice as much*** energy per kg of material. Since Saturn should have much less primordial heat, there must be another source at work.

This source is believed to be the **separation of helium from hydrogen** in the interior. In the liquid hydrogen mantle, the heavier helium forms drops that sink toward the core, releasing gravitational energy. In effect, Saturn is still **differentiating**.

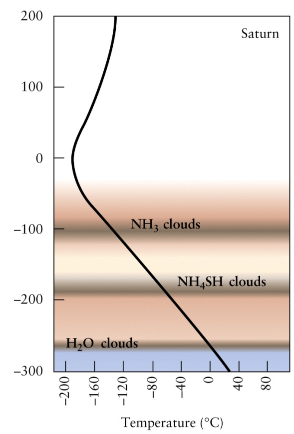
This **precipitation of helium** is possible in Saturn because it is cooler than Jupiter – at temperatures in Jupiter's interior, hydrogen and helium remain well mixed.

Atmosphere and Clouds

Composition is primarily H and He, although methane (CH_4) and ammonia (NH_3) were identified first.

At the temperatures and pressures of the upper atmospheres of Saturn, methane remains a gas, but ammonia can condense to produce clouds. The ammonia cloud deck marks the upper edge of the convective troposphere; above it is the cold stratosphere.

Saturn's atmosphere has only about half as much helium as does Jupiter's, the result of the precipitation of helium that contributes to its internal heat source.



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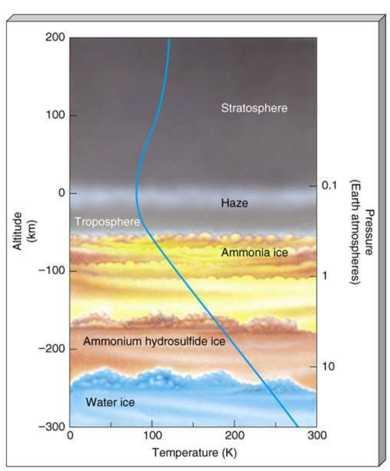
Atmosphere and Clouds



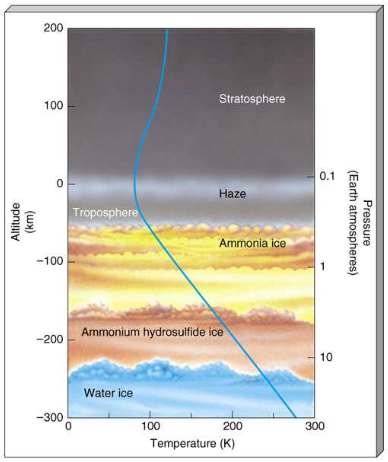
Astronomy Today by Chaisson and McMillan

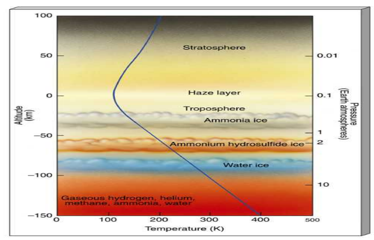
Temperature at the cloud tops is about **100 K**.

Because the ammonia clouds lie deeper on Saturn (than Jupiter), they are more difficult to see, and the overall appear-ance is much more bland.

Above the visible ammonia clouds is a layer of haze.

Atmosphere and Clouds

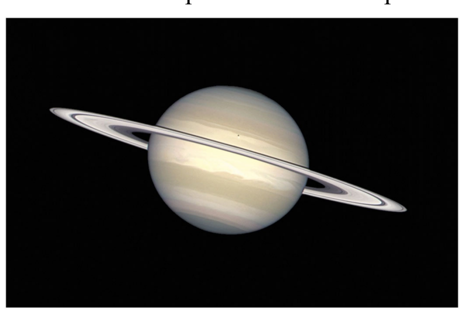




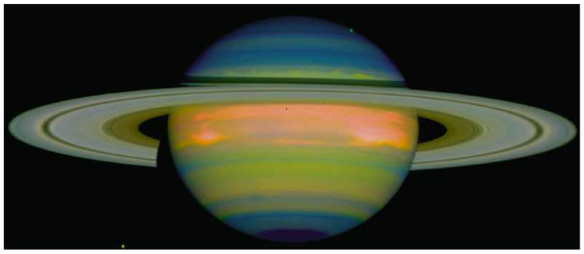
Astronomy Today by Chaisson and McMillan

Bands and Zones

The light zones on Saturn are regions of upwelling air, capped by white ammonia cirrus clouds. They apparently represent the tops of upward-moving convection currents. The darker belts are regions where the cooler atmosphere moves downward. They are darker because there are fewer ammonia clouds and it is possible to see deeper in the atmosphere.



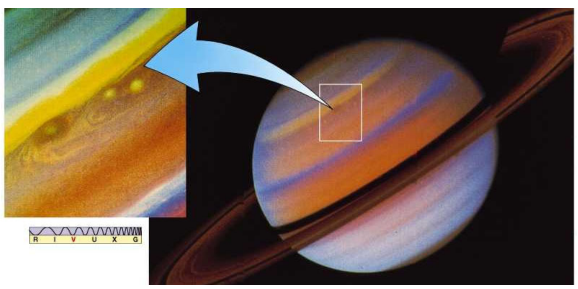
Bands and Zones



The bands and zones are harder to see on Saturn, than on Jupiter, because the clouds lie at a significantly lower level in the atmosphere. There is also a layer of haze above the clouds.

False colors are used to bring out the appearance of the bands and zones.

Atmospheric Structure



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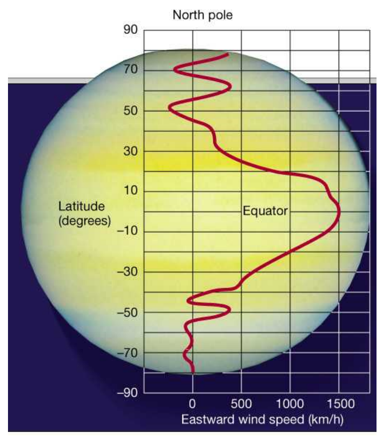
More structure can be seen through the use of false colors.

Bands and Zones

More fundamental than these bands are the underlying east-west patterns in the atmosphere, which do not appear to change, even over decades.

The main such feature on Saturn is an eastward-flowing equatorial jet stream with a speed of 1500 km/hr.

At higher latitudes there are alternating east- and west-moving winds.



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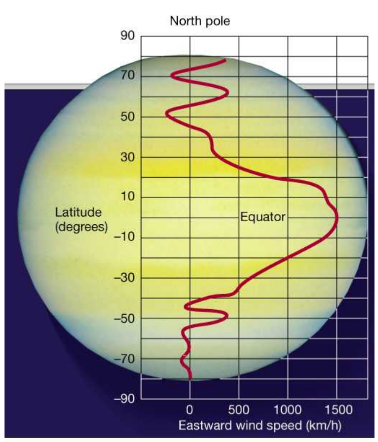
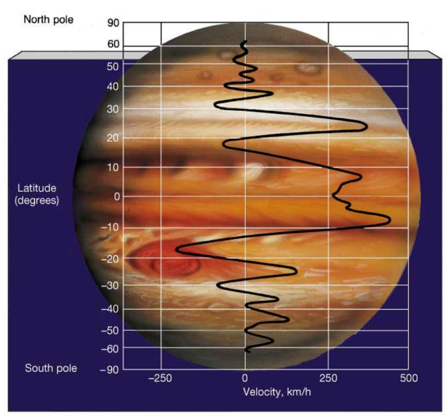
Bands and Zones





Astronomy Today by Chaisson and McMillan

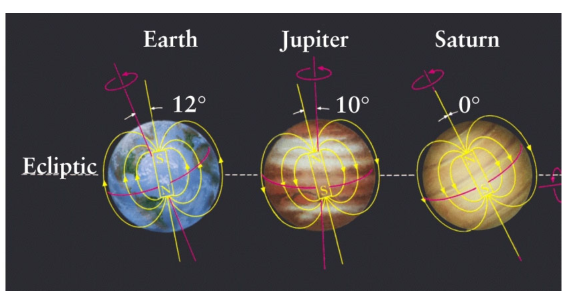
Storms

No storms were seen by Voyager but the Hubble Space Telescope has spotted some.

The white feature near the equator is a giant storm. It formed when warm gases rose upward, then cooled, causing gaseous ammonia to crystallize. This storm lasted several months.

Magnetosphere

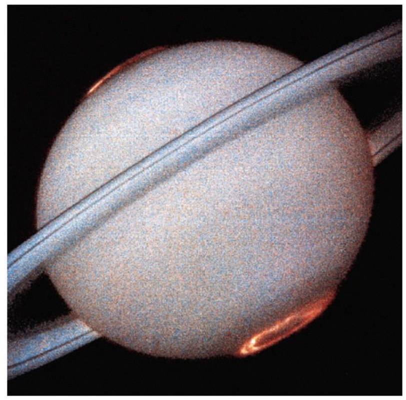
Saturn does not emit strong synchrotron radiation, because its magnetosphere is depleted in electrons by collisions between electrons and its rings and inner satellites. But it does have a substantial magnetic field. Unlike the fields of the Earth and Jupiter, Saturn's field is almost perfectly aligned with its rotation axis.



Magnetosphere

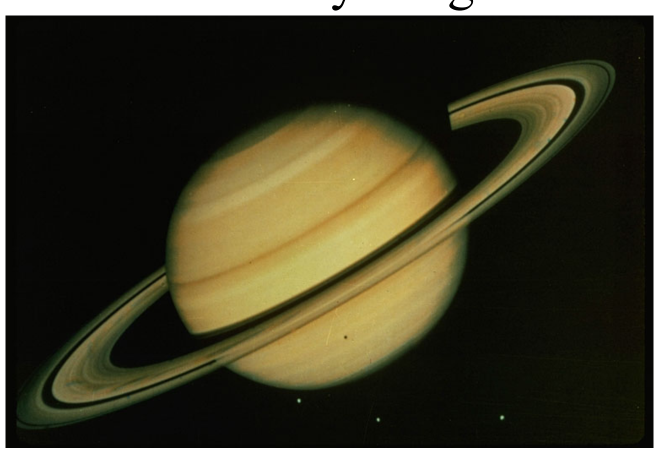
Saturn has a large interior region of metallic liquid hydrogen that acts like the liquid iron core of the Earth.

Although the detailed mechanisms may not be well understood, it seems to meet the conditions required for the generation of a planetary magnetic field in a spinning metallic core.



Astronomy Today by Chaisson and McMillan

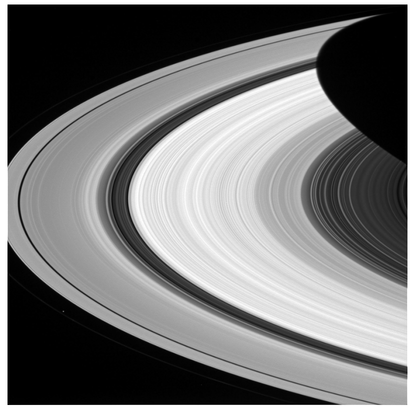
Planetary Rings



Rings in General

A ring is a collection of vast numbers of particles, each obeying Kepler's Laws as it follows its own orbit around the planet.

Thus the inner particles orbit faster than those farther out, and the ring as whole does not rotate as a solid body.



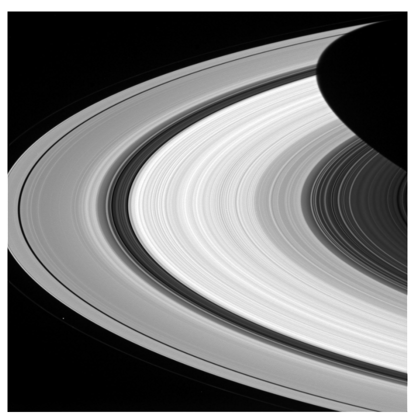
NASA

Rings in General

If the particles were widely spaced, they would move independently.

However, in the rings of Saturn the particles are loose enough to one another to exert mutual gravitational influence, and occasionally even to rub together or bounce off.

Because of these interactions, phenomena such as waves can be produced.



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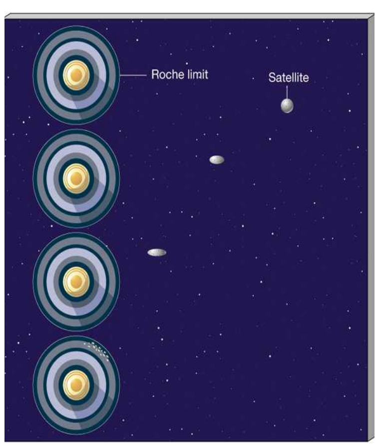
Ring Formation

Two theories:

(1) moon formed, then broke up, or
(2) moon never formed.

In either theory, tidal forces play a role. **Tidal force varies as the inverse cube of the separation between two bodies.** If objects approach too closely, their tidal bulges become so large that they are torn apart.

Roche Limit



Astronomy Today by Chaisson and McMillan

Around each planet there exists a tidal stability limit (Roche Limit ~ 2.5 planetary radii).

This is the distance within which a moon with no internal strength would be pulled apart by differential gravitational forces.

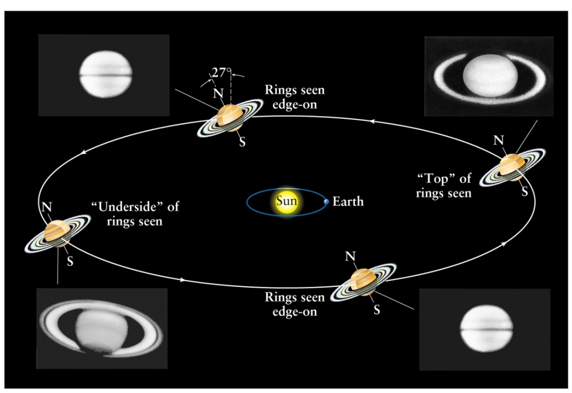
It is the distance within which the individual particles in a disk can not attract one another to form a moon.

Rings in General

This stability limit applies only to a moon with no intrinsic strength. A solid object held together by its own strength will not necessarily break up inside the limit. This is why some small moons (up to 100 km in diameter) are found orbiting within the four ring systems. If the moon is large enough, however, its intrinsic strength becomes less important in comparison to the differential tidal forces, and breakup is more likely.

For example, a person on the surface of the Earth is inside the Roche Limit but is not pulled apart because EM forces hold the person together. If a large body, held together by gravity though, gets too close to a large object, it can then be disrupted.

Ring Orientations



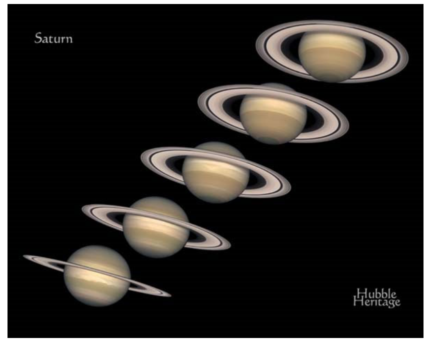
Universe by Freedman, Geller, and Kaufmann

The rings circle the planet in its equatorial plane, which is tilted 27°. During the synodic year, we see one side of the rings for 15 years, followed by the other side. Sometimes, the rings disappear from view.

Saturn’s Rings

The rings of Saturn are very broad but very thin. The width of the main ring is 70,000 km, but the thickness is only **20 m**.

The ring particles are composed primarily of **water ice**. They span a range of sizes from grains of sand up to house-sized boulders, but are primarily the sizes of blueberries.



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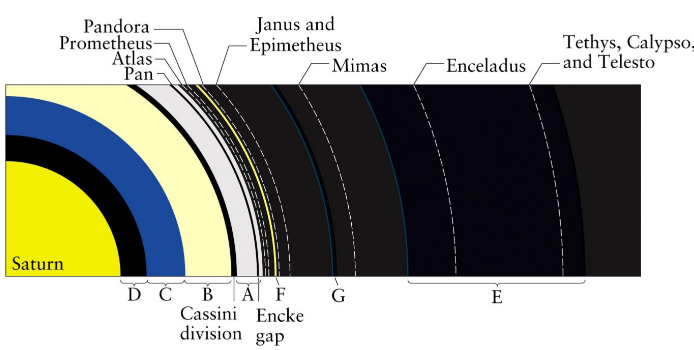
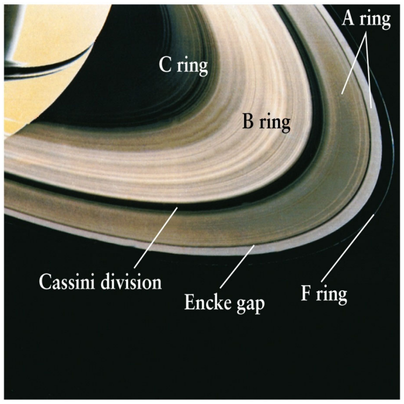
Saturn’s Rings

The three brightest rings visible from Earth are labeled (from outer to inner) the A, B, and C rings. The outer radius of the A ring is 136,780 km, with the inner edge of the C ring just 12,900 km above the cloud tops of Saturn.



Universe by Freedman, Geller, and Kaufmann

Saturn's Major Rings



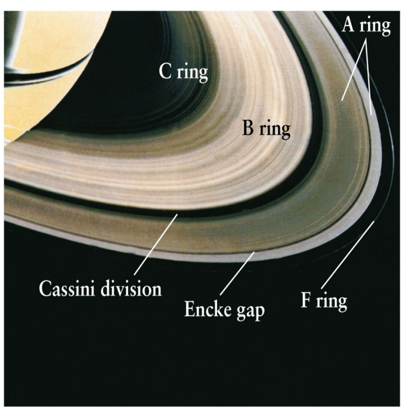
Universe by Freedman, Geller, and Kaufmann

The B ring is the brightest and has the most closely packed particles, while the A and C rings are translucent. The mass of the B ring is about equal to an icy moon 300 km in diameter.

The B and A rings are separated by a gap easily seen from the Earth called the *Cassini Division* (1675).

Although it looks empty from Earth, the Cassini Division contains many particles with considerable structure, including several true gaps.

Saturn's Major Rings



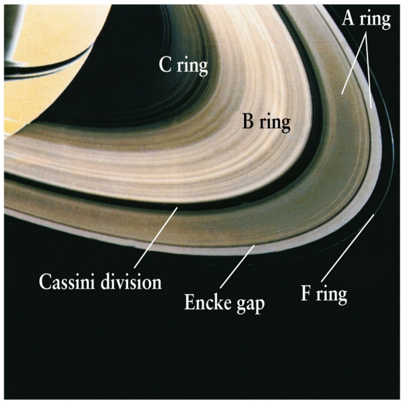
Universe by Freedman, Geller, and Kaufmann

The major B ring has no gaps, but it contains intricate structure, partly in the form of waves.

Each wave corresponds to alternating ringlets where the ring particles are bunched together or spread more thinly.

Waves (separated by about 10 km) look like the grooves in a phonograph record.

Saturn's Major Rings

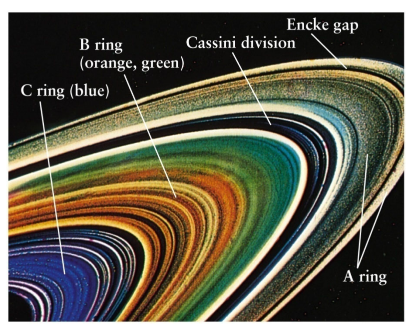


Universe by Freedman, Geller, and Kaufmann

The A ring has even more of this wave-like structure. However, the bulk of the structure in the A and B rings is not wave-like, but apparently random and irregular. This structure has not been satisfactorily explained.

Saturn's Major Rings

The rings have a great deal of complex structure, including about a dozen gaps, each tens to hundreds of km wide. Most of these gaps are associated with the Cassini Division (between the B and A rings).

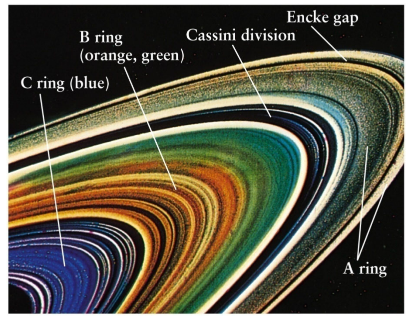


Saturn's Major Rings

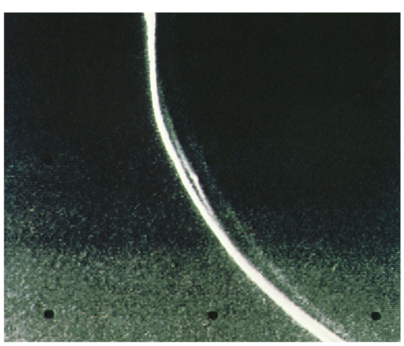
Some of these gaps contain ribbons of particles that do not share the circular orbits of the other ring particles.

For the ring as a whole to be eccentric, it is not sufficient that the individual particles have eccentric orbits; in addition, the major axes of these orbits must be aligned in space.

Some of these gaps have wavy edges, and one of the gap ringlets is kinky.



Saturn's F Ring



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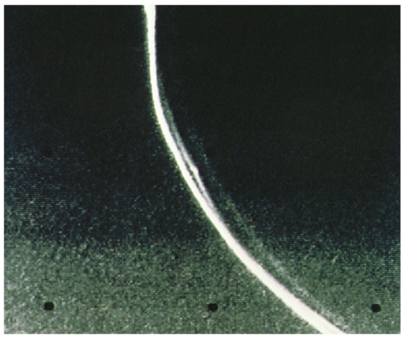
The Pioneer and Voyager spacecraft revealed additional rings not visible from Earth.

A faint D ring lies inside the C ring, and a very narrow F ring lies outside the A ring.

This ring has a mass equivalent to an icy moon a few km in diameter.

Saturn's F Ring



NASA

Within its 100-km width there are many ringlets, including a double bright ring with two components just a few hundred meters wide.

In some places, the F ring breaks up into two or three parallel strands, which some-times show bends or kinks.

Further, the F ring as a whole is **eccentric**.