Solar System Sites that might support life

Saturn and its Moons Titan & Enceladus

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Alien life on Saturn? NASA 'to reveal MAJOR breakthrough with habitable ocean discovery' NASA could be about to announce a major alien breakthrough on one of Saturn's moons.

By Jess Bell / Published 12th April 2017

Saturn Moons -82 [2020]

- Saturn was the outermost planet known to ancient astronomers. Named after the father of Jupiter in Greek and Roman mythology.
- Saturn orbits the Sun at almost twice the distance of Jupiter, with an orbital semi-major axis of 9.54 A.U. (1430 million km) and an orbital eccentricity of 0.06.
- The planet's sidereal orbital period of 29.5 Earth years was the longest natural unit of time known to the ancient world.

- At opposition, when Saturn is at its brightest, it can lie within 8 A.U. of the Earth.
- However, its great distance from the Sun still makes it considerably fainter than either Jupiter or Mars.
- Saturn ranks behind Jupiter, the inner planets, and several of the brightest stars in the sky in terms of apparent brightness.

- Less than one-third the mass of Jupiter, Saturn is still an enormous planet, at least by terrestrial standards.
- As with Jupiter, Saturn's many moons allowed an accurate determination of the planet's mass long before the arrival of the *Pioneer* and *Voyager* missions.
- Saturn's mass is 5.6×10^{26}kg, or 95 times the mass of Earth.

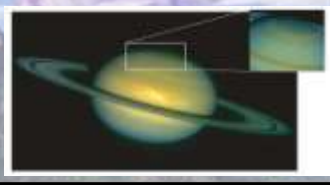
- From Saturn's distance and angular size, the planet's radius--and hence the average density--quickly follow.
- Saturn's equatorial radius is 60,000 km, or 9.4 Earth radii.
- The average density then is 700 kg/m^3 (0.7 g/cm^3)--less than the density of water (which is 1000 kg/m^3).
- Here we have a planet that would float in the ocean--if Earth had one big enough!

- Saturn's low average density indicates that, like Jupiter, it is composed primarily of hydrogen and helium.
- Saturn's lower mass, however, results in lower interior pressure, so that these gases are less compressed than in Jupiter's case.
- Saturn, like Jupiter, rotates very rapidly and differentially.
- The rotation period at high planetary latitudes (determined by tracking weather features observed in Saturn's atmosphere) is 10^h40^m.

- The rotation period at the equator is 10^h14^m, about 26 minutes shorter.
- Because of Saturn's lower density, this rapid rotation makes Saturn even more flattened than Jupiter.
- Saturn's polar radius is only 54,000 km, about 6000 km less than the equatorial radius.
- Careful calculations show that this degree of flattening is less than would be expected for a planet composed of hydrogen and helium alone.

- Astronomers believe that Saturn also has a rocky core, perhaps twice the mass of Jupiter's.
- Saturn's best-known feature is its spectacular *ring system.*
- Because the rings lie in the equatorial plane, their appearance (as seen from Earth) changes in a seasonal manner.

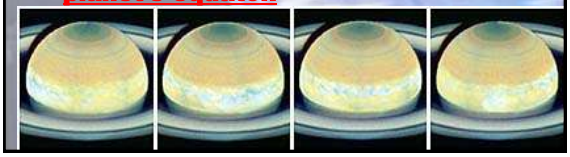
- Saturn is much less colorful than Jupiter.
- Saturn shows yellowish and tan cloud belts that parallel the equator, but these regions display less atmospheric structure than do the belts on Jupiter.
- No obvious large "spots" or "ovals" adorn Saturn's cloud decks.
- Bands and storms do exist, but the color changes that distinguish them on Jupiter are largely absent on Saturn



- Astronomers finally made the first accurate determinations of the hydrogen and helium content in the late 1960s.
- These Earth-based measurements were later confirmed with arrival of the *Pioneer* and *Voyager* spacecraft in the 1970s.
- Saturn's atmosphere consists of molecular hydrogen (92.4 %), helium (7.4 %), methane (0.2 %), & ammonia (0.02 %).
- In Saturn's cold upper atmosphere, most ammonia is in the solid or liquid form, with relatively little of it present as a gas to absorb sunlight and create spectral lines.

- As on Jupiter, hydrogen and helium dominate--these most abundant elements never escaped from Saturn's atmosphere because of the planet's large mass and low temperature.
- However, the fraction of helium on Saturn is far less than is observed on Jupiter (where, as it is found, helium accounts for nearly 14% of the atmosphere) or in the Sun.

- In September 1990, Amateur Astronomers detected a large white spot in Saturn's southern hemisphere, just below the equator.
- In November of that year, when the *Hubble Space Telescope* imaged the phenomenon in more detail, the spot had developed into a band of clouds completely encircling the planet's equator.



- Infrared measurements indicate that Saturn's surface (i.e, cloud-top) temp. is 97 K, substantially higher than the temperature at which Saturn would reradiate all the energy it receives from the Sun.
- In fact, Saturn radiates away almost three times more energy than it absorbs.
- Thus Saturn, like Jupiter, has an internal energy source.
- But the explanation behind Jupiter's excess energy--that the planet has a large reservoir(basin/tank) of heat left over from its formation--doesn't work for Saturn.

- Saturn is smaller than Jupiter and so must have cooled more rapidly--rapidly enough that its original supply of energy has long ago been used up.
- What then is happening inside Saturn to produce this extra heat?
- The explanation for this strange state of affairs also explains the mystery of Saturn's apparent helium deficit.
- At the temperatures and high pressures found in Jupiter's interior, liquid helium dissolves in liquid hydrogen.

- In Saturn, where the internal temperature is lower, the helium doesn't dissolve so easily and tends to form droplets instead.
- The phenomenon is familiar to cooks, who know that it is generally much easier to dissolve ingredients in hot liquids than in cold ones.
- Saturn probably started out with a fairly uniform solution of helium dissolved in hydrogen.
- But the helium tended to condense out of the surrounding hydrogen, much as water vapor condenses out of Earth's atmosphere to form a mist (fog/smog).

- The amount of helium condensation was greatest in the planet's cool outer layers, where the mist turned to rain about 2 billion years ago.
- A light shower of liquid helium has been falling through Saturn's interior ever since.
- This helium precipitation is responsible for depleting the outer layers of their helium content.
- So we can account for the unusually low abundance of helium in Saturn's atmosphere--much of it has rained down to lower levels.
- But what about the excess heating?

- The answer is simple: As the helium sinks toward the center, the planet's gravitational field compresses it and heats it up.
- The gravitational energy thus released is the source of Saturn's internal heat.
- In the distant future, the helium rain will stop, and Saturn will cool until its outermost layers radiate only as much energy as they receive from the Sun.

- **When that happens, the temperature at Saturn's cloud tops will be 74 K.**
- **As Jupiter cools, it too may someday experience helium precipitation in its interior, causing its surface temperature to rise once again.**

- Careful measurements of Saturn's energy budget (balance of energy absorbed versus energy radiated) show that the planet radiates 1.5–2.5 times more energy into space than it receives from the Sun.
- This radiated energy indicates that the planet must have an internal heat source. Scientists accept that Saturn draws its extra energy from two sources:

  (1) heat left over from the planet's formation approximately 4.5 billion years ago, still radiating out into space, and
  (2) the "raining out" of atmospheric helium.
- Just as water condenses in terrestrial clouds to produce rain, droplets of liquid helium form in Saturn's atmosphere.

- As these droplets fall through Saturn's atmosphere they acquire kinetic energy.
- This energy is absorbed into deeper layers where the droplets meet resistance and slow their fall, and the temperature in those regions increases.
- This thermal energy is eventually circulated by convection back up through the higher layers of the atmosphere and radiated into space.
- The helium raining out of Saturn's upper layers is left over from the planet's formation; in about two billion more years all of Saturn's helium will have sunk deep into the planet, at which time heating by helium condensation will cease.

- Support for the helium-condensation model was obtained during the Voyager encounters, when it was found that the abundance of helium in Saturn's atmosphere was much lower than that observed in Jupiter's.
- Upper-atmospheric depletion of helium has not yet occurred on Jupiter because its atmosphere has only recently become cool enough to permit helium condensation;
- On Saturn, in contrast, helium has been raining out for about two billion years, settling half the available helium toward the core

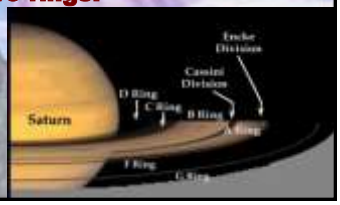
Ring Systems of Saturn

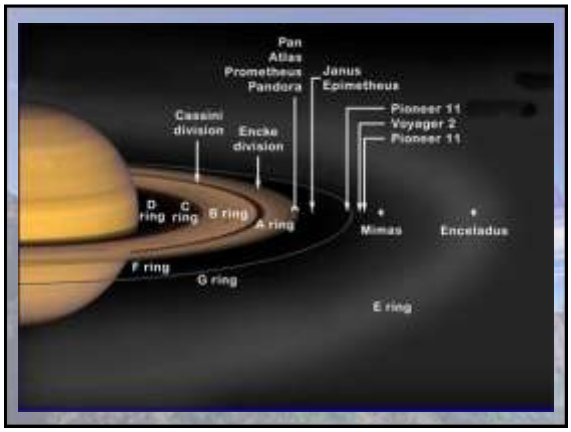
- **The most obvious aspect of Saturn's appearance is, of course, its planetary ring system.**
- **Astronomers now know that all the jovian planets have rings, but Saturn's are by far the brightest, the most extensive, and the most beautiful.**
- **Galileo saw them first in 1610, but he did not recognize what he saw as a planet with a ring.**

- **At the resolution of his small telescope, the rings looked like bumps on the planet, or perhaps components of a triple system of some sort.**
- **In 1659, the Dutch astronomer Christian Huygens realized what the "bump" was--a thin, flat ring, completely encircling the planet.**
- **In 1675, the French-Italian Astronomer Giovanni Domenico Cassini discovered the first ring feature, a dark band about two-thirds of the way out from the inner edge.**

- From Earth, the band looks like a gap in the ring. This "gap" is named the **Cassini Division**, in honor of its discoverer.
- Careful observations from Earth show that the inner "ring" is in reality also composed of two rings.

From the outside in, the three rings are known somewhat prosaically as the A, B, and C rings.





- The **Cassini Division** lies between **A** and **B.**
- A smaller gap, known as the **Encke Division,** is found in the outer part of the A ring. Its width is 270 km.
- Of the three main rings, the **B ring is brightest,** followed by the somewhat fainter A ring, and then by the almost translucent C ring.
- A more complete list of ring properties appears in Table.

TABLE 12-1 *The Rings of Saturn*

RING	INNER RADIUS (km)	INNER RADIUS (planet radii)	OUTER RADIUS (km)	OUTER RADIUS (planet radii)	WIDTH (km)
D	66,900	1.11	74,510	1.23	7,610
C	74,658	1.24	92,000	1.53	17,342
B	92,000	1.53	117,580	1.95	25,580
Cassini Division	117,580	1.95	122,170	2.03	4,590
A	122,170	2.03	136,775	2.27	14,605
Encke Division*	133,589	2.22	133,635	2.22	46
F	140,180	2.33	140,180	2.33	100
E	180,000	2.99	480,000	7.97	300,000

*The Encke Division lies within the A ring.

- The *Voyager* mission changed forever our view, revealing the rings to be vastly more complex than astronomers had imagined.
- As the *Voyager* probes approached Saturn, it became obvious that the main rings are actually composed of tens of thousands of narrow ringlets

What are Saturn's ring made of?"

- Radar observations and later *Voyager* studies of scattered sunlight showed that the diameters of the particles range from fractions of a millimeter to tens of meters, with most particles being about the size (and composition) of a large snowball on Earth.

Why are the rings so thin?

The answer seems to be that collisions between ring particles tend to keep them all moving in circular orbits in a single plane.

THE ORIGIN OF THE RINGS

- Two possible origins have been suggested for Saturn's rings.
- Astronomers estimate that the total mass of ring material is no more than 10^{15} tons-----enough to make a satellite about 250 km in diameter.
- If such a satellite strayed (lost) inside Saturn's Roche limit or was destroyed (perhaps by a collision) near that radius, a ring could have resulted.

- An alternative view is that the rings represent material left over from Saturn's formation stage 4.5 billion years ago.
- In this scenario, Saturn's tidal field prevented any moon from forming inside the Roche limit, and so the material has remained a ring ever since.
- Which is correct?

- All the dynamic activity observed in Saturn's rings suggests to many researchers that the rings must be quite young--perhaps no more than 50 million years old, or 100 times younger than the solar system.
- There is just too much going on for them to have remained stable for billions of years, so they probably aren't left over from the planet's formative stages.

- If this is so, then either the rings must be continuously replenished, perhaps by fragments of Saturn's moons chipped off by meteorites, or they are the result of a relatively recent, possibly catastrophic, event in the planet's system--perhaps a small moon that was hit by a large comet, or even by another moon.
- Astronomers normally prefer not to invoke catastrophic events to explain observed phenomena, but the more we learn of the universe, the more we realize that catastrophe probably plays an important role.
- For now, the details of the formation of Saturn's ring system simply aren't known.

THE ROCHE LIMIT

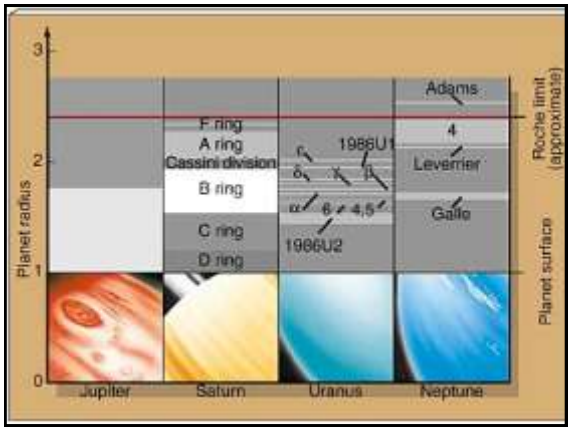
- But why a ring of particles at all?
- What process produced the rings in the first place?
- To answer these questions, consider the fate of a small moon orbiting close to a massive planet such as Saturn.
- The moon is held together by internal forces--its own gravity, for example.
- As we bring our hypothetical moon closer to the planet, the tidal force on it increases.

- The effect of such a tidal force is to stretch the moon along the direction to the planet--that is, to create a tidal bulge.
- Tidal force increases rapidly with decreasing distance from the planet.
- As the moon is brought closer to the planet, it reaches a point where the tidal force tending to stretch it out becomes *greater* than the internal forces holding it together.
- At that point, the moon is torn apart by the planet's gravity, as shown in Figure.

- The pieces of the satellite then pursue their own individual orbits around that planet, eventually spreading all the way around it in the form of a ring.
- The increasing tidal field of a planet first distorts, and then destroys, a moon that strays too close. (The distortion is exaggerated in the second and third panels.

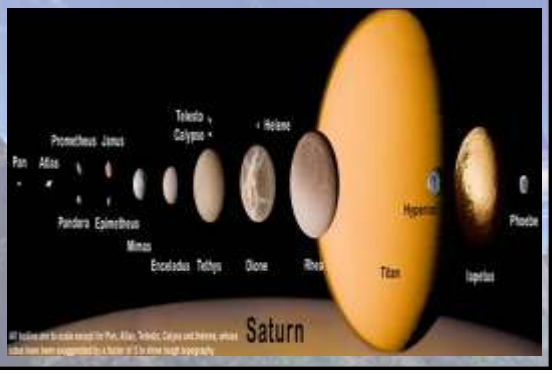
- For any given planet and any given moon, this critical distance, inside of which the moon is destroyed, is known as the *tidal stability limit*, or the **Roche limit**, after the nineteenth-century French mathematician Edouard Roche, who first calculated it.
- If our hypothetical moon is held together by its own gravity and its average density is the same as that of the parent planet (both reasonably good approximations for Saturn's larger moons), then the Roche limit is just 2.4 times the radius of the planet.

- Thus, for Saturn, no moon can survive within a distance of 144,000 km of the planet's center, about 7000 km beyond the outer edge of the A ring.
- The rings of Saturn occupy the region inside Saturn's Roche limit.
- Figure shows the location of the ring system of each jovian planet relative to the planet's Roche limit.
- Given the approximations in our assumptions, we can conclude that all of the rings are found within the Roche limit of their parent planet



- Notice that the calculation of this limit applies only to moons massive enough for their own gravity to be the dominant force binding them together.
- Sufficiently small moons can survive even within the Roche limit because they are held together mostly by interatomic (electromagnetic) forces, not by gravity.

Saturn's family



We May Have Just Found Proof of Alien Life on Saturn's Moon Titan

Matthew Loffhagen
Thursday, 01 February 2018 - 11:12AM

For years now, scientists have been *fascinated by the distant moon of Titan*, which orbits the planet Saturn. We know that *the moon has a lot in common with Earth*, suggesting that, if we're really lucky, Titan might just contain some form of alien life.

Now, scientists have been able to confirm that Titan's rich atmosphere contains at least one chemical compound that *could provide the basis of cellular life forms*.

- *NASA* has revealed the presence of vinyl cyanide, which could potentially be used in the structural makeup of cells in order to create living creatures
- This possibility has been speculated about for a long time now—
- Scientists first caught a glimpse of what might have been vinyl cyanide
- thanks to data provided by the -great Cassini space probe.
- Now, scientists have actually been able to confirm that a form of primordial soup exists on Titan.
- And that, under the right circumstances, life might be able to form and thrive/prosper even despite the harsh environment that exists on Saturn's moon.

- A researcher named *Maureen Palmer, working at NASA's Goddard Space* Flight Center, has managed to prove that **vinyl cyanide is present in one of Titan's lakes in such large quantities that it will naturally *get caught up in the methane cycle***, raining down on the entire moon and floating in the atmosphere.

We have yet to see any actual life forms that use vinyl cyanide as a core part of their anatomy.

- A team at Cornell University has recently proven that such creatures could potentially be possible, provided conditions are correct.
- With the right mix of ingredients swirling in the air on Titan, it's possible that life forms could eventually emerge.

- **Titan is the largest moon of Saturn.**
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- **It is the only moon known to have a dense atmosphere, planet-like atmosphere and the object in space other than Earth where clear evidence of stable bodies of surface liquid has been found.**
- **Titan similar to the Earth: Titan's 'water' is liquid methane, CH_4, better known on Earth as natural gas.**

- Regular Earth-water, H2O, would be frozen solid on Titan where the surface temp. is -180°C (-292°F).
- With Titan's low gravity and dense atmosphere, methane raindrops could grow twice as large as Earth's raindrops.
- Perhaps the most exciting of all Saturn's moons is Titan, discovered by Christian Huygens in 1655.
- Even through a large Earth-based telescope, Titan is visible only as a barely resolved reddish disk.

- Titan is larger than the planet Mercury and has an atmosphere rich in nitrogen..
- Its surface is obscured by haze but may be covered by hydrocarbons precipitated from the atmosphere.
- Methane (natural gas) or ethane (another hydrocarbon) liquids may exist at the surface

- Long before the *Voyager* missions, astronomers already knew (from spectroscopic observations) that the moon's reddish coloration is caused by something quite special–an atmosphere.
- So anxious were mission planners to obtain a closer look that they programmed *Voyager 1* to pass very close to Titan.
- *Voyager 1* was able to provide mission specialists with detailed atmospheric data, however.

- Scientists believe that Titan's internal composition and structure must be similar to Ganymede and Callisto because these three moons have quite similar masses and radii and hence average densities (Titan's density is 1900 kg/m^3).
- Thus, Titan probably contains a rocky core surrounded by a thick mantle of water ice. Despite *Voyager 1*'s close pass, the moon's surface remains a mystery.
- A thick, uniform haze layer, similar to the photochemical smog found over many cities on the Earth, envelops the moon and completely obscured the spacecraft's view.

- Titan's atmosphere is thicker and denser even than Earth's, and it is certainly more substantial than that of any other moon.
- Prior to *Voyager 1*'s arrival in 1980, only methane and a few other simple hydrocarbons had been conclusively detected on Titan.

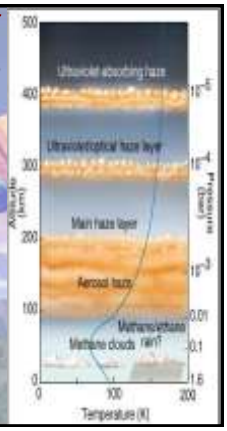
(Hydrocarbons are molecules consisting only of hydrogen and carbon atoms, of which methane, CH_4, is the simplest).

- Radio and infrared observations from the spacecraft showed that the atmosphere is actually made up mostly of nitrogen (~90%) & Argon (atmost 10%), with a few percent of methane.
- In addition, the complex chemistry in Titan's atmosphere maintains steady (but trace) levels of hydrogen gas, the hydrocarbons ethane & propane, and carbon monoxide.
- In fact, Titan's atmosphere seems to act like a gigantic chemical factory. Powered by the energy of sunlight, it is undergoing a complex series of chemical reactions that ultimately result in the observed smog and trace chemical composition.

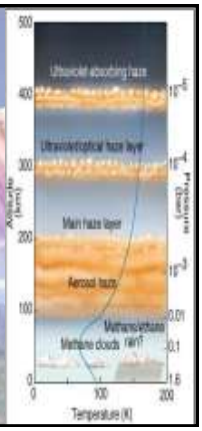
- **The upper atmosphere is thick with aerosol haze, and the unseen surface may be covered with organic sediment that has settled down from the clouds.**
- [An aerosol is a colloid of fine solid particles or liquid droplets, in air or another gas. Aerosols can be natural or artificial. Examples of natural aerosols are fog, forest exudates and geyser-steam. Examples of artificial aerosols are haze, dust, particulate air pollutants and smoke].
- **Speculation runs the gamut/range from oceans of liquid hydrocarbons, especially ethane, to icy valleys laden with petrochemical sludge.**

- **Future spacecraft exploration of Titan may present scientists with an opportunity to study the kind of chemistry thought to have occurred billions of years ago on Earth--the prebiotic chemical reactions that eventually led to life on our own planet.**

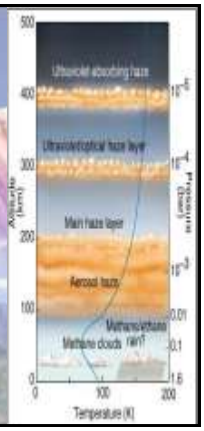
- **Based largely on *Voyager* measurements, Figure shows ~structure of Titan's atmosphere.**
- **Despite Titan's low mass (a little less than twice that of Earth's Moon) and hence its low surface gravity (one-seventh of Earth's), the atmospheric pressure at ground level is 60 percent *greater* than on Earth.**
- **Titan's atmosphere contains about 10 times more gas than Earth's.**
- **Because of Titan's weaker gravitational pull, the atmosphere extends some 10 times farther into space than does our own.**



- **The top of the main haze layer lies some 200 km above the surface, although there are additional layers, seen primarily through their absorption of ultraviolet radiation, at about 300 km and 400 km (Figure).**
- **Below the haze, the atmosphere is reasonably clear, although rather gloomy/dim, because so little sunlight gets through.**
- **The surface temperature is a frigid 94 K, roughly what we would expect simply on the basis of Titan's distance from the Sun.**



- **At the temperatures typical of the lower atmosphere, methane and ethane may behave rather like water on Earth, raising the possibility of methane rain, snow, and fog and even ethane oceans!**
- **At high altitudes, the temperature rises, the result of photochemical absorption of solar radiation.**
- **Why does Titan have such a thick atmosphere, when similar moons of Jupiter such as Ganymede and Callisto have none?**



- **The answer seems to be a direct result of Titan's greater distance from the Sun.**
- **The moons of Saturn formed at considerably lower temperature than those of Jupiter.**
- **Those conditions would have enhanced the ability of the water ice that makes up the bulk of Titan's interior to absorb methane and ammonia, both of which were present in abundance at those early times.**
- **As a result, Titan was initially laden/loaded with much more methane and ammonia gas than either Ganymede or Callisto.**

- As Titan's internal radioactivity warmed the moon, the ice released the trapped gases, forming a thick methane-ammonia atmosphere.
- Sunlight split the ammonia into hydrogen, which escaped into space, and nitrogen, which remained in the atmosphere. The methane, which was less easily broken apart, survived intact.
- Together with argon outgassed from Titan's interior, these gases form the basis of the atmosphere we see today.

Composition:

- The atmospheric composition in the stratosphere is 98.4% nitrogen—the only dense, nitrogen-rich atmosphere in the Solar System aside from Earth's—with the remaining 1.6%
- composed of mostly of
- methane (1.4%)
- & hydrogen (0.1–0.2%).

Size:

Titan is Saturn's largest satellite.

Diameter is 5150 km

Orbit.

Titan has an orbital period around Saturn of approximately 16 days.
Its distance from Saturn is approximately 1,220,000 kilometers.

Magnetic fields:

- Titan has *no magnetic field* and sometimes orbits outside of the Saturn magnetosphere.
- Because of this, Titan is exposed to intense solar winds, which may ionize and carry away some of its atmospheric molecules.

Water

- With the prevalence of carbon monoxide and carbon dioxide in Titan's atmosphere, scientists have long thought that liquid water might exist on Titan's surface.
-
- In 1998, the European Space Agency's Infrared Space Observatory (ISO) detected water vapor in the atmosphere of Titan.
- Due to Titan's huge distance from the Sun, the surface temperatures are seemingly too cold to support liquid water.

- But scientists say it is possible that an impact pool created by a comet or Meteroid could maintain liquid water for as long as 1,000 years —
- Perhaps long enough for life's chemical reactions to take place.
- On Titan, life might exist beyond the bounds of water-based chemistry.

- On Titan's surface, HCN can react to form long chains: one of which called polyimine- possible pre-biotic chemical key.
- On surface, instead of water, it is filled with liquid methane and ethane.
- The addition of UV radiation, complex molecules and polymer substances like can be generated.
- The reaction starts with dissociation of nitrogen and methane, forming HCN and C2H2. Further reactions have been studied extensively.

Tholins

- Tholins (after the Greek θολός (tholós) "hazy" or "muddy"; from the ancient Greek word meaning "sepia ink") are a class of heteropolymer molecules formed by solar ultraviolet irradiation of simple organic compounds such as methane or ethane, often in combination with nitrogen.

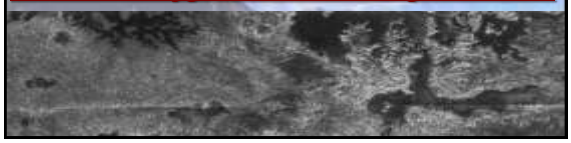
- In 2010, building blocks of DNA, RNA, amino acids are also found in atmosphere of titan.
- In April 2013, NASA reported that complex organic chemicals could arise on Titan based on studies simulating the atmosphere of Titan.
- In June 2013, PAHs were detected in the upper atmosphere of Titan.

This close up view of Titan shows dendritic drainage patterns associated with the collection of a liquid that flowed across the surface.

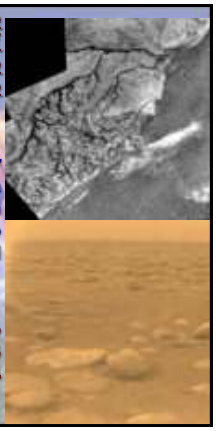
Wider trunk streams probably transported liquid and sedimentary particles (rock made of ice) to a large lake or sea with a smooth dark surface.

Methane precipitation probably fell from the atmosphere and was collected in these river valleys.

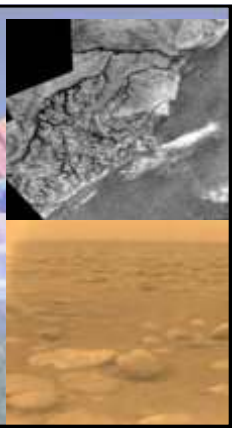
It is not know if the lake currently is filled with liquid. It may be dry now, like some of Earth's temporary lakes. Shoreline features at the top of the image indicate long-shore movement by waves. This detailed image is about 7 km across and shows an area near the Huygens landing site.



- In 2005, the Huygen's probe parachuted to the surface of Titan, studying its atmosphere & taking pictures of the surface.
- This color photo- taken after Huygens landed & shows a landscape littered/pitted with pebbles and fine-grained loose sediment, possibly transported & rounded by moving liquid.
- The two rocks just below the middle of the image are ~15 centimeters (left) and 4 centimeters (center) across.



- There is also evidence of erosion at the base of the larger cobblers, indicating possibly the result of scour/clean by the wind.
- The surface is darker than originally expected and is made of a mixture of water and hydrocarbon ice.



Space missions

Past:
- Pioneer 11
- Huygens

Present:
- Voyager 1 & 2
- Cassini

Future:
- Titan Saturn system Mission(TSSM)
- Titan Mare Explorer (TIME)
- Aerial Vehicle for In-situ and Airborne Titan Reconnaissance (AVIATR)
- Titan Lake In-situ Sampling Propelled Explorer (TALISE)

Enceladus

- Enceladus [on-CELL-ə-dəs] is the sixth-largest moon of Saturn.
- It is about 500 kms in diameter, about a tenth of that of Saturn's largest moon, Titan.
- Gravity: 0.113 m/s²
- Orbital period: 33 hours
- Surface pressure: trace, significant spatial variability
- Composition by volume: 91% water vapor; 4% nitrogen; 3.2% carbon dioxide; 1.7% methane
- Alternative names: Saturn II

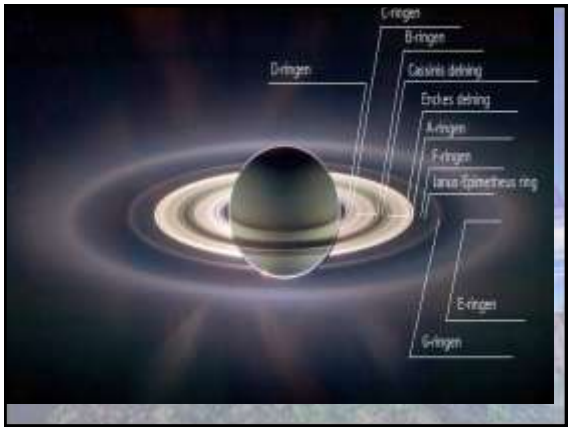
Saturn's family

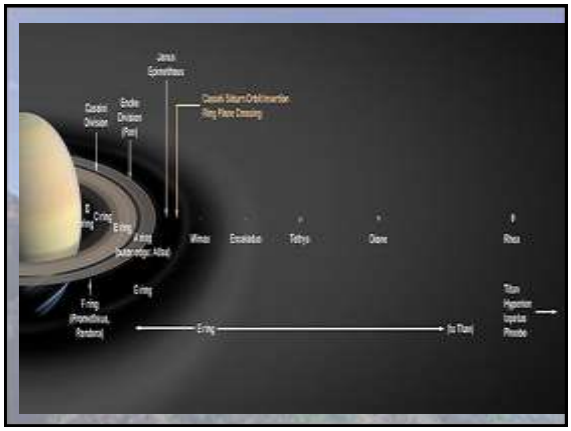
- For decades, scientists didn't know why Enceladus was the brightest world in the solar system, or how it related to Saturn's E ring.
- Cassini found that both the fresh coating on its surface, and icy material in the E ring originate from vent/emit connected to a global subsurface saltwater ocean that might host hydrothermal vents.

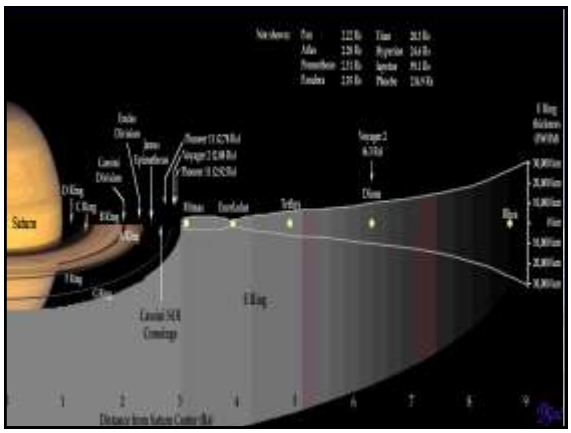
Enceladus is the source of Saturn's E rings

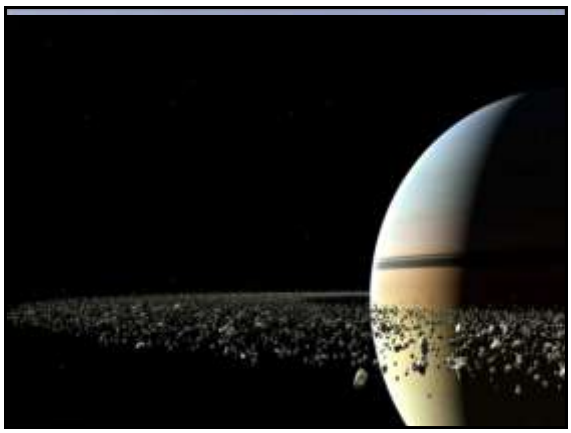
- Cassini has uncovered how Enceladus is spewing out water ice from geysers at its southern pole, scientists have an explanation for Saturn's E ring.
- This is Saturn's outermost ring, which consists of a diffuse cloud of particles stretching from Mimas to Titan.
- Cassini's magnetometer matched the signature of the ice geysers to the particles in the E-ring, linking one to the together.

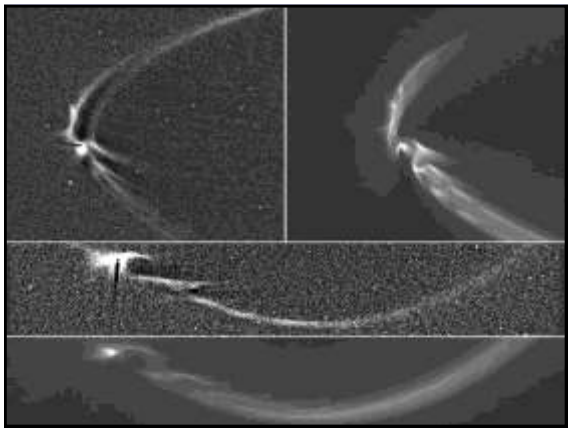
- Saturn's moon Enceladus is the source of Saturn's E-ring, confirms research
- Scientists show how a plume of icy water vapor bursting out of the South Pole of Enceladus replenishes the water particles that make up the E-ring and creates a dynamic water-based atmosphere around the small moon.
- The E-ring is Saturn's outermost ring and is composed of microscopic particles. It is very diffuse and stretches between the orbit of two of Saturn's moons, Mimas and Titan











Key Points

- Saturn's moon Enceladus is a small, icy body, but Cassini revealed this ocean world to be one of the solar system's most scientifically interesting destinations.
- Cassini discovered that geyser-like jets spew water vapor and ice particles from an underground ocean beneath the icy crust of Enceladus.
- With its global ocean, unique chemistry and internal heat, Enceladus has become a promising lead in our search for worlds where life could exist.

Geyser-like jets spew water vapor and ice particles from an underground ocean beneath the icy crust of Enceladus.

- Enceladus orbits just outside Mimas.
- Its size, mass, composition, and orbit are so similar to those of Mimas that one might guess that the two moons would also be very similar to one another in appearance and history.
- This is not so. Enceladus is so bright and shiny--it reflects virtually 100 percent of the sunlight falling on it
- Astronomers believe its surface must be completely coated with fine crystals of pure ice, which may be the icy "ash" of water "volcanoes" on Enceladus.

- Calculations indicate that the E ring is unstable because of the disruptive effects of the solar wind, supporting the view that volcanism on Enceladus continually supplies new particles to maintain the ring
- The moon bears visible evidence for large-scale volcanic activity.
- Much of its surface is devoid (lack) of impact craters, which seem to have been erased by what look like lava flows, except that the "lava" is water, temporarily liquefied during recent internal upheavals and now frozen again.

- In addition, the nearby thin cloud of small, reflective particles that makes up Saturn's E ring is known to be densest near Enceladus.
- Despite its similarity in size and location to Mimas, Enceladus, with its highly reflective icy surface and apparent water volcanism, looks very different.
- Apparently, the moon is still active but the cause of the volcanism is unexplained.

- **Why is there so much activity on a moon so small? No one knows……**
- **Attempts have been made to explain Enceladus's water volcanism in terms of tidal stresses. *(Recall the role that Jupiter's tidal stresses play in creating volcanism on Io.)***
- **However, Saturn's tidal force on Enceladus is only one quarter the force exerted by Jupiter on Io, and there are no nearby large satellites to force Enceladus away from a circular trajectory.**

It's thought that Enceladus may hold the right conditions for life, with rumored/supposed watery jets, hydrothermal activity, and a global ocean buried beneath its icy crust

Hydrothermal vents

- Underwater volcanoes at spreading ridges and convergent plate boundaries produce hot springs known as hydrothermal vents.
- Scientists first discovered hydrothermal vents in 1977 To their amazement, the scientists also found that the hydrothermal vents were surrounded by large numbers of organisms that had never been seen before. These biological communities depend upon chemical processes that result from the interaction of seawater and hot magma associated with underwater volcanoes.
- **Hydrothermal vents are the result of seawater percolating down through fissure/crack/gaps in the ocean crust in the vicinity of spreading centers or subduction zones (places on Earth where two tectonic plates move away or towards one another). The cold seawater is heated by hot magma and reemerges to form the vents. Seawater in hydrothermal vents may reach temperatures of over 700° Fahrenheit.**
- Hot seawater in hydrothermal vents does not boil because of the extreme pressure at the depths where the vents are formed

Possibility of Life

- **It's thought that Enceladus may hold the right conditions for life, with rumoured watery jets, hydrothermal activity, and a global ocean buried beneath its icy crust.**
- **The possible discovery of chemical activity inside hydrothermal vents is tantalizing/exciting to scientists as life on Earth started in such deep-sea crevasses.**
- **'Hydrothermal vents have been found in many locations on Earth where superheated water from deep within the planet reaches the ocean,**

- **'Due to the temperatures and pressure of these vents, some very interesting chemistry occurs.**
- **'Many astrobiologists have suggested that such hydrothermal vents may be where life first originated on our planet.'**
- **On Earth, these vents are home to microorganisms that have adapted to glean/collect energy from chemicals rather than the sun.**

- **Keith Cowing claimed scientists have discovered chemical activity on the icy moon.**
- **He wrote in Astrobiology (April 13, 2017) "Nasa will announce evidence that hydrothermal activity on the floor of an ice-covered ocean on Saturn's moon Enceladus is most likely creating methane from carbon dioxide".**
- **"The process is indicative of possible habitable zones within the ocean of Enceladus.'**
- **"Before we go any further, 'habitable' does not mean 'inhabited'."**

- NASA bases this determination on the amount of hydrogen in plumes originating from the moon's south pole.
- The large amount of hydrogen is strongly suggestive of a constant hydrothermal process wherein the ocean under the surface of Enceladus is interacting with rock and organic compounds.
- The amount of hydrogen present is in disequilibrium i.e. if there was not a process that was constantly generating hydrogen the observed hydrogen levels would likely be lower than what is seen. Something is pumping it out.

- Saturn's moon Enceladus is known to have an ocean beneath its icy surface.
- This small moon constantly sprays its ocean's contents into space from vents at its south pole from a region referred to as the "tiger stripes" due to the appearance of the location.
- The Cassini spacecraft has actually flown through these plumes many times and sampled their composition. Based on these plume studies it has been previously determined that the ocean of Enceladus interacts with a rocky bottom.

·During the final - and closest (30 miles/49 km) - flyby by Cassini of Enceladus on 28 October 2015 (E21) the spacecraft's Ion and Neutral Mass Spectrometer (INMS) was configured so as to best understand the amount of hydrogen in the plumes.

·A significant amount was found. Something is creating this hydrogen.

·The precise mechanism of this process is not known but hydrothermal activity is highly suspected. (Cassini Orbiter Ion and Neutral Mass Spectrometer (INMS) level 1A high and the low sensitivity counter data archive)

Enceladus Imagery Suggests Subsurface Ocean Of Liquid Water
Press Release - Source: NASA-Posted March 14, 2017

- A new study in the journal Nature Astronomy reports that the south polar region of Saturn's icy moon Enceladus is warmer than expected just a few feet below its icy surface.
- This suggests that Enceladus' ocean of liquid water might be only a couple of miles beneath this region -- closer to the surface than previously thought.
- The excess heat is especially pronounced over three fractures that are not unlike the "tiger stripes" -- prominent, actively venting fractures that slice across the pole -- except that they don't appear to be active at the moment.

·Seemingly dormant fractures lying above the moon's warm, underground sea point to the dynamic character of Enceladus' geology, suggesting the moon might have experienced several episodes of activity, in different places on its surface.

·The finding agrees with the results of a 2016 study by a team independent of the Cassini mission that estimated the thickness of Enceladus' icy crust.

·The studies indicate an average depth for the ice shell of 11 to 14 miles (18 to 22 kilometers), with a thickness of less than 3 miles (5 kilometers) at the south pole.

·Finding temperatures near these three inactive fractures that are unexpectedly higher than those outside them adds to the intrigue of Enceladus," said Cassini Project Scientist Linda Spilker at NASA's Jet Propulsion Laboratory, Pasadena, California.

·What is the warm underground ocean really like and could life have evolved there?

·These questions remain to be answered by future missions to this ocean world."

NASA's Dragonfly Will Fly Around Titan Looking for Origins, Signs of Life

This illustration shows NASA's Dragonfly rotorcraft-lander approaching a site on Saturn's exotic moon, Titan. Taking advantage of Titan's dense atmosphere and low gravity, Dragonfly will explore dozens of locations across the icy world, sampling and measuring the compositions of Titan's organic surface materials to characterize the habitability of Titan's environment and investigate the progression of prebiotic chemistry

- NASA has announced that our next destination in the solar system is the unique, richly organic world Titan. Advancing our search for the building blocks of life, the Dragonfly mission will fly multiple sorties to sample and examine sites around Saturn's icy moon.
- Dragonfly will launch in 2026 and arrive in 2034. The rotorcraft will fly to dozens of promising locations on Titan looking for prebiotic chemical processes common on both Titan and Earth.
- Dragonfly marks the first time NASA will fly a multi-rotor vehicle for science on another planet; it has eight rotors and flies like a large drone. It will take advantage of Titan's dense atmosphere – four times denser than Earth's – to become the first vehicle ever to fly its entire science payload to new places for repeatable and targeted access to surface materials.

- Titan is an analog to the very early Earth, and can provide clues to how life may have arisen on our planet.
- During its 2.7-year baseline mission, Dragonfly will explore diverse environments from organic dunes to the floor of an impact crater where liquid water and complex organic materials key to life once existed together for possibly tens of thousands of years.
- Its instruments will study how far prebiotic chemistry may have progressed.
- They also will investigate the moon's atmospheric and surface properties and its subsurface ocean and liquid reservoirs. Additionally, instruments will search for chemical evidence of past or extant life.

The alien factor: Saturn moon able to support life, say NASA scientists

- It appears to have the conditions necessary for life unveiling new findings made by its unmanned Cassini spacecraft.
- Cassini has detected hydrogen molecules in vapour plumes emanating from cracks in the surface of Enceladus, a small ocean moon coated in a thick layer of ice, the US space agency said.

- The plumes have led scientists to infer that hydrothermal chemical reactions between the moon's rocky core and its ocean - located under the ice crust - are likely occurring on Enceladus.
- On Earth, those chemical reactions allow microbes to flourish in hot cracks in the planet's ocean floors -- depths sunlight cannot reach -- meaning the moon could also nourish life.
- Now, Enceladus is high on the list in the solar system for showing habitable conditions," said Hunter Waite, one of the study's leading researchers.

We are looking in a way that we never thought possible before for environments in our solar system which may have Alien (harbor life) today."