Cassini visits Enceladus – New light on a bright world

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"If you turned Enceladus off, you would probably turn off the E Ring." – Linda Spiker,
Cassini deputy project scientist

The Cassini spacecraft begins its journey to Saturn
http://saturn.jpl.nasa.gov/multimedia/images/images.cfm?subCategoryID=5
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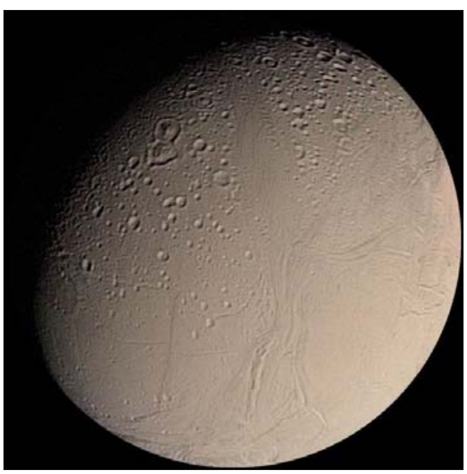
Prelude: The Cassini-Huygens mission and the Enceladus flybys

The *Cassini* spacecraft has made several close flybys of one of Saturn's moons, Enceladus. One of the flybys, made in July 2005, has revealed unexpected characteristics of this natural satellite that have changed what scientists had previously understood about this deceptively unassuming and little-known Saturn moon.

Discovery of Enceladus, *Voyager* observations, and *Cassini*'s arrival

Discovery. Enceladus, the sixth-largest moon of Saturn, was discovered by astronomer and telescope-maker Frederick William Herschel (1738-1822). In 1789, after about two years of work, Herschel completed his largest telescope. It had a 48-inch (1.2-meter) aperture and was the world's largest telescope for over 50 years. With it, Herschel discovered Saturn's sixth known moon, Enceladus, on August 28th, 1789. On September 17th of that same year he also discovered Saturn's seventh known moon, Mimas.



Enceladus from Voyager
http://en.wikipedia.org/wiki/Image:Enceladus_from_Voyager.jpg
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***Voyager* observations.** Until the two *Voyager* spacecraft and the *Pioneer 11* spacecraft passed near it in the early 1980s, very little was known about this small moon besides the identification of water ice on its surface. The two *Voyager*s showed that Enceladus is only about 505 kilometers (505 km, about 314 miles) in diameter, seven times smaller than the Earth's Moon, and reflects almost 100% of the sunlight that strikes it [1]. *Voyager 1* was the first spacecraft to obtain images of Enceladus and was the first spacecraft to fly past it. It did so on November 12, 1980, at a distance of 202,000 km [2]. The distant images had very poor spatial resolution, but they did reveal a highly reflective surface that

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seemed devoid of impact craters, indicating a youthful surface [3]. Because impact cratering is common to most solar system bodies, a smooth surface seems to indicate a geologically active exterior undergoing occasional renewal, which would tend to cover over or erase evidence of past cratering. *Voyager 1* also confirmed that Enceladus was embedded in the densest part of Saturn's diffuse E Ring, leading Voyager scientists to suggest that Saturn's E Ring consisted of particles vented from volcanic activity on Enceladus [3].

Voyager 2 passed closer to Enceladus (87,010 km) on August 26, 1981, allowing much higher resolution images [2]. They revealed a surface with different regions of vastly different ages, with a heavily cratered mid- to high-northern latitude region, and a lightly cratered region closer to the equator. This geologic diversity contrasts with the ancient heavily cratered surface of Mimas, which is slightly smaller than Enceladus. The geologically youthful terrains came as a great surprise to the scientific community, because no theory was then able to predict that such a small (and cold, compared to Jupiter's highly active moon Io) celestial body could bear signs of such activity. However, *Voyager 2* failed to determine whether Enceladus was currently geologically active, with occasional surface renewal, or whether it was the source of the E Ring [1].

***Cassini*'s arrival.** The answer to these and other mysteries would have to wait until the arrival of the *Cassini* spacecraft on July 1, 2004, when it went into orbit around Saturn. Given the results from the *Voyager 2* images, Enceladus was considered a priority target by the Cassini mission planners, and several targeted flybys within 1,500 km of the surface were planned, as well as numerous "non-targeted" opportunities within 100,000 km of Enceladus. These encounters are listed in the tables below:

Successful Cassini *flybys of Enceladus*

Dates	**Closest distance from Enceladus (km)**
February 17, 2005	1,264
March 9, 2005	500
March 29, 2005	64,000
May 21, 2005	93,000
July 14, 2005	175
October 12, 2005	49,000
December 24, 2005	94,000
January 17, 2006	146,000

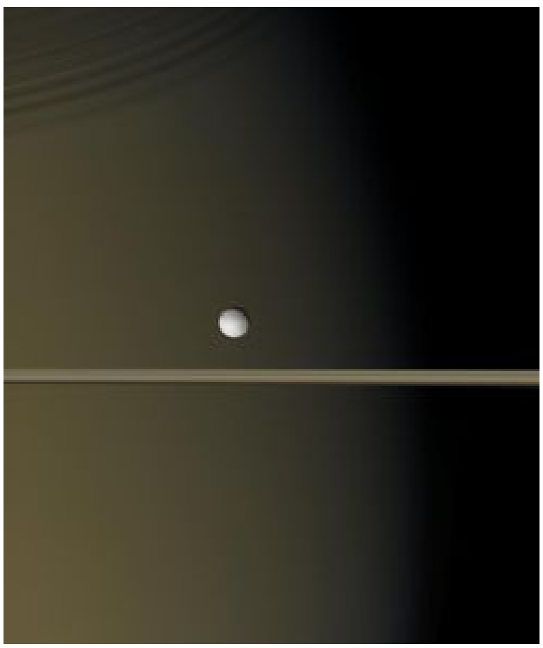
Planned Cassini *flybys of Enceladus (as of July 2006)*

Dates	**Closest distance from Enceladus (km)**
September 9, 2006	40,000
November 9, 2006	95,000
June 28, 2007	90,000
September 30, 2007	98,000
March 12, 2008	23
June 30, 2008	101,000

So far, three close flybys of Enceladus have been performed (those of February 17th, March 9th, and July 14th, 2005), yielding significant information concerning Enceladus' surface, as well as the discovery of water vapor venting from the geologically active South Polar Region. These discoveries have prompted the adjustment of Cassini's flight plan to allow closer flybys of Enceladus, including an encounter in March 2008, which will take the probe to within 23 km of the moon's surface [5].

Enceladus – Name and characteristics

Name. Saturn's moon Enceladus is named after the Greek mythological figure who was one of the Gigantes, the enormous children of Gaia (Earth). During the battle between the Gigantes and the Olympian gods, Enceladus was disabled by a spear thrown by the goddess Athena. He was buried on the island of Sicily, under Mount Etna, of which the volcanic fires were believed to be Enceladus' breath, and its tremors to be caused by him rolling his injured side beneath the mountain [7]. As it turned out, the name proved to be rather appropriate once the results of the *Voyager* and *Cassini* spacecraft observations became known.



Enceladus against Saturn [NASA]
http://en.wikipedia.org/wiki/Image:Enceladus_against_Saturn.jpg
Wikipedia, the free encyclopedia

Satellite characteristics. Enceladus is one of Saturn's major inner satellites, and it is the 14th satellite when ordered by distance from Saturn. Enceladus orbits at a distance of 238,000 km from Saturn's center and 180,000 km from its surface, requiring 32.9 hours to revolve once around the planet. Like most of the larger satellites of Saturn, Enceladus rotates synchronously with its orbital period, keeping one face pointed toward Saturn at all times, as in the case of the Moon in relation to Earth [1].

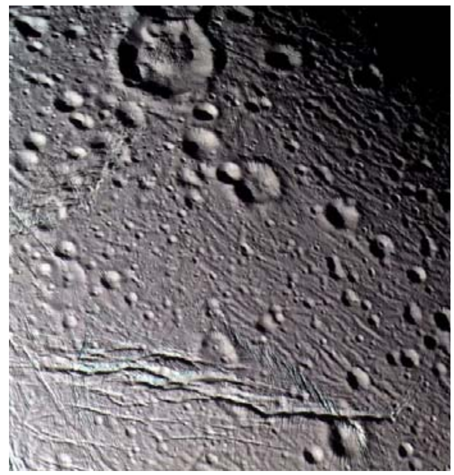
Enceladus orbits within the densest part of the E Ring, which is the widest and outermost ring of Saturn. Saturn's E Ring, an extremely wide but very diffuse disk of microscopic icy or dusty material [1], stretches nearly 200,000 miles from its inside edge to its outer bound and is so faint that scientists didn't discover it until about the mid 1970s. At that time, a curious thing was noticed: the ring was brightest around Enceladus, which, along with some of Saturn's other moons, wades through the E Ring's plane of debris while orbiting the planet [9]. This observation caused some scientists to suspect that Enceladus was somehow supplying material for the ring. Although this was a strange idea at the time, the fact that the E Ring existed at all was evidence for it [9]. Numerous mathematical models have shown Saturn's E ring to be unstable, with a lifespan between

10,000 and 1,000,000 years, and so the particles composing it need to be constantly replenished. Since Enceladus orbits inside the narrowest and highest density location of the E Ring, several theories have posited Enceladus as the main source of particles for the E Ring. *Cassini*'s flyby has proven this hypothesis [1].

The evidence now seems to show that two sources from Enceladus feed Saturn's E Ring: (1) a cryovolcanic plume in Enceladus's South Polar Region and (2) the meteoritic bombardment of Enceladus, which raises dust particles from its surface. In cryovolcanism water and other volatiles are the materials erupting from a volcano, rather than silicate rock, which erupts from conventional [at least on earth] volcanoes [1].

Voyager 2 was the first spacecraft to observe Enceladus's surface in detail. Examinations resulting from the highest resolution imagery taken by the spacecraft revealed at least five different types of terrain, including several regions of cratered terrain, regions of smooth (young) terrain, and lanes of ridged terrain often bordering the smooth areas [4]. In addition, extensive linear cracks and scarps were observed. Given the relative lack of craters on the smooth plains, these regions are probably less than a few hundred million years old. Accordingly, Enceladus must have been recently active with "water volcanism" or other processes that renew the surface. The fresh clean ice that dominates its surface gives Enceladus the most reflective surface of any body in the solar system [6]. Because Enceladus reflects so much sunlight, the mean surface temperature at noontime only reaches -198 degrees Celsius (-198 C , or -324 F), which is somewhat colder than other Saturnian satellites [8].

Right: False-color view of Enceladus' surface, showing several tectonic and crater degradation styles. Taken by *Cassini* on 9 March 2005. [NASA photo]



EN004 Painting on the walls
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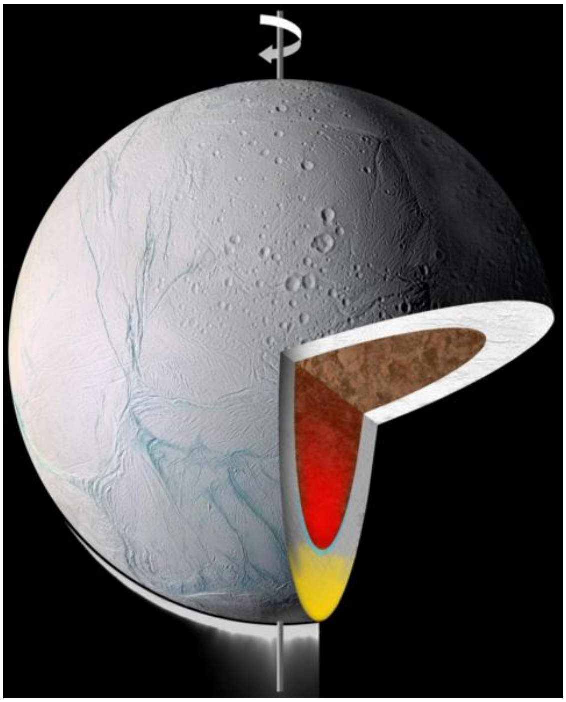
Much of Enceladus's surface is covered with craters at various densities and levels of degradation, much like many other solar system bodies that have endured impact cratering. In addition, *Voyager 2* found several types of tectonic features on Enceladus, including troughs, scarps, and belts of grooves and ridges [4]. Recent results from *Cassini* suggest that the dominant deformation style on Enceladus results from tectonics.

Cassini sheds new light on Enceladus

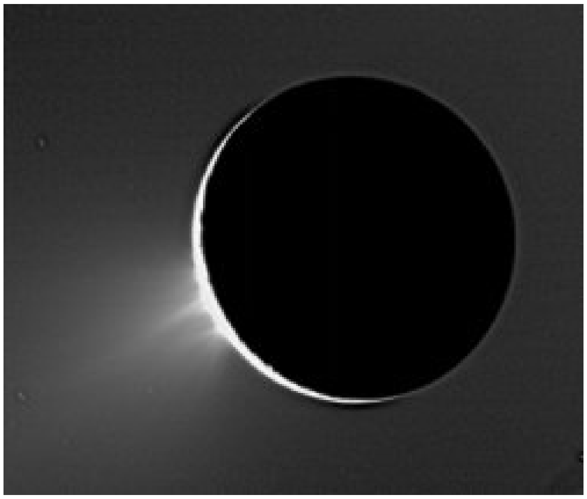
Internal structure model. Prior to the Cassini mission, relatively little was known about the interior of Enceladus. However, results of recent *Cassini* flybys have provided much needed information for models of Enceladus's interior. These include a better determination of the mass and triaxial ellipsoid shape, high-resolution observations of the surface, and new insights on Enceladus's geochemistry [1]. The figure and caption below gives a proposed model that summarizes some of these findings.



Left: Model of the interior of Enceladus based on recent *Cassini* findings. The inner silicate core is shown in brown, the outer water-ice-rich mantle is shown in white, and the yellow and red colors in the mantle and core, respectively, represent a proposed diapir under the south pole. [16]

Enceladus
http://en.wikipedia.org/wiki/Enceladus_%28moon%29
Wikipedia, the free encyclopedia

Cryovolcanism, geysers, and the feeding of the E Ring. During the three close encounters with Enceladus by *Cassini* on February 17, March 9, and July 14, 2005, cryovolcanism was discovered on Enceladus. On the February 17^{th} encounter, data from the magnetometer on board *Cassini* provided the first hints when it found evidence for an atmosphere on the moon. An increase in the power of ion cyclotron waves near Enceladus was detected by the magnetometer. The ion cyclotron waves were produced by ionization of particles near Enceladus [1]. They showed, by way of the frequency of the waves, that the particles consisted of ionized water vapor [13]. The next two encounters showed that the gases in Enceladus's atmosphere are concentrated over the South Polar Region, with the density greatly decreasing with distance away from the pole [13]. The Ultraviolet Imaging Spectrograph (UVIS) on board *Cassini* confirmed this result by observing two stellar occultations during the February 17^{th} and July 14^{th} encounters [1].

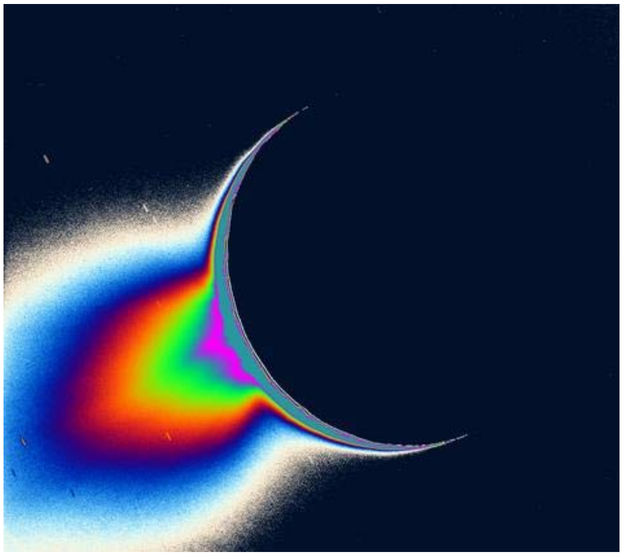


Fountains of Enceladus PIA07758 [NASA/JPL photo]
http://en.wikipedia.org/wiki/Image:Fountains_of_Enceladus_PIA07758.jpg
Wikipedia, the free encyclopedia

On July 14, 2005, the *Cassini* spacecraft made its closest flyby yet of Enceladus. The flyby came within 175 km (109 miles) of the moon's icy surface and flew through the gas cloud emanating from the South Polar Region. Instruments such as the Ion and Neutral Mass Spectrometer (INMS) and the Cosmic Dust Analyzer (CDA) allowed for the direct sampling of the plume of gases. The INMS detected water vapor and minor components like molecular nitrogen (N_2), methane (CH_4), and carbon dioxide (CO_2) [14]. The CDA confirmed the satellite as the primary source for the E Ring when it detected a large increase in the number of particles near Enceladus [1]. *Cassini* revealed an unexpected hot spot on the satellite's south pole. The finding revealed that Enceladus is geologically active, and that what was supposed to be the moon's coldest region turned out to be its warmest. Because of its orientation to the sun, scientists expected the moon's south pole to be about -198 C (-324 F), but what *Cassini* revealed instead was that it was over 110 K (-261 F). Since solar heating alone could not account for this difference, scientists think that internal heating is occurring. [9]

Images taken by *Cassini* in November 2005 by the Imaging Science Subsystem (ISS) instrument visually confirmed the February 17th and July 14th measurements and observations by showing streams of fine icy particles rising from the moon's south pole [12], suggesting they originated from warm zones in the region. *Cassini* passed through the plume, which stretched up to 300 miles above Enceladus's surface [10], nearly as great a distance as Enceladus's diameter. The instruments aboard *Cassini* measured the plume's makeup and found water vapor and icy particles [10]. A team of researchers led by NASA Cassini scientist Candice Hansen-Koharcheck at the Jet Propulsion Laboratory in Pasadena, California, believe the plume may have been erupting continuously for 15 years, and appears to replenish the E Ring with material and provide the source of oxygen and hydrogen permeating Saturn's neighborhood. "It's definitely the water, there's no doubt about it," said Hansen-Koharcheck.

In addition to the hot spot found on the south pole of Enceladus, *Cassini* also revealed that "icy veins" found on the moon's surface are actually a series of fractures. What is more, the fractures appear to be active, violently spewing a slushy jet of warm water and ice into space. Together, the venting fractures and hot spot provide strong evidence for



Fountains of Enceladus [NASA/JPL]
http://www.solarviews.com/eng/enceladu.htm
Views of the Solar System

geologic activity on Enceladus. If true, the findings could explain how Saturn's E Ring becomes continuously supplied with microscopic particles of ice and dust [9].

Before *Cassini*'s findings, Enceladus was thought to have no geological activity (i.e., to be geologically dead), and so there could be no spouting fountains of water and ice on the moon's surface. It was therefore thought that impacts on the surface were the most likely source of particles for the E Ring. The discovery of the hot spot on the moon's south pole is critical because it provides the moon with an engine to drive the geysers and volcanoes [9] that could sustain the E Ring with a constant supply of ice and dust particles. According to Linda Spiker, Cassini's deputy project scientist, "If you turned Enceladus off, you would probably turn off the E Ring." [11]. The discovery also puts Enceladus with Jupiter's Io and Neptune's Triton in the class of geologically active moons [10].

It is currently unclear why the south pole of Enceladus is so active, but one theory is that radioactive material left over from the moon's formation billions of years ago is acting as a heat source, according to Spiker. Another theory is that a change in the moon's spin (rotation) rate caused fractures to form on its surface. If, at one time, Enceladus had moved in closer to Saturn, it would have had to spin more quickly in order to synchronize its rotation period with its orbit around Saturn, which is a natural tendency for planetary satellites. Spiker says, "that change in spin might have caused the cracking seen at the south pole." It is still unknown how or when this event might have occurred. [9]

Astrobiological implications. In March 2006 NASA announced that the high-resolution Cassini images of Enceladus show icy jets and lofty plumes expelling large quantities of particles at high speed. Scientists think the jets spout from near-surface pockets of liquid water. The very strong evidence for the presence of liquid water has led to the tantalizing question of whether so small and cold a body as Enceladus could provide conditions suitable for living organisms [15].

According to Chris McKay, a planetary scientist at the NASA Ames Research Center in Moffett Field, California, there are three reasons why Enceladus is very interesting for astrobiology. The moon's activity suggests that there must be some sort of subsurface energy source, possibly gravitational tidal effects, and that this energy source is concentrated and not a global diffuse heating. This may imply liquid water below the surface. When added up, (1) a concentrated energy source, (2) liquid water, and (3) perhaps evidence of methane makes Enceladus a key target for astrobiology. According to McKay, further observations of the plume and more detailed measurements of the dust emitted would be ideal. He adds that the detection of carbon- and nitrogen-containing particles would be key factors. McKay explains, "clearly the Saturn system with organic rich Titan and water-active Enceladus is on the first rank of targets for astrobiology. We should start planning a combined Enceladus lander and Titan balloon mission." [15]

Conclusion

In the spring of 2008, *Cassini* is slated for another chance to look at Enceladus, flying within some 220 miles (350 kilometers) of the satellite. The end of *Cassini*'s "Prime Mission" is June 30, 2008, four years after arrival at Saturn. The opportunity exists for placing *Cassini* in "extended mission" mode—but that's only if financial resources allow. [15]

Motivated by *Cassini*'s findings to date, attention is now turning to future observational roles of the interplanetary probe. One leading candidate is a sharper focus on astrobiology, even a "diving catch" to inspect in detail the makeup of those Enceladus plumes. [15]

"After what we've discovered with *Cassini*, if we don't get an extended mission, then there's no hope for anybody," said Carolyn Porco, the *Cassini* imaging team leader based at the Space Science Institute in Boulder, Colorado. [15]

Cassini scientists should know around the middle of 2007 whether or not *Cassini* will be given official approval for an extended mission. Then, within six months to a year after that, they will learn if the money is available to proceed beyond the nominal end of the mission, in mid-2008. [15]

"In the meantime, we are planning for such an extension ... thinking about what it is we really want and need to do," said Porco recently to SPACE.com. She added, "Certainly, one of the cardinal goals of extending *Cassini*'s tour of the Saturnian environment would be further exploration of Enceladus." [15]

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