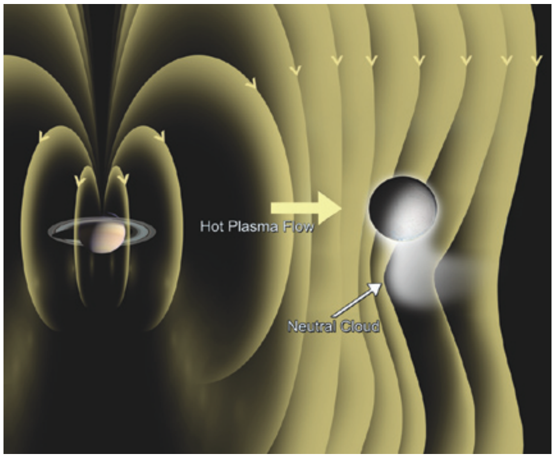
A Nice Place to Visit?

by Douglas L. Smith

If you saw last month's headlines, you know that Enceladus is the hottest little moon around Saturn. The March 10 issue of *Science* carried a slew of papers from the Cassini mission, and the front-page news was that this tiny, bitterly cold world seems to have liquid water literally right underfoot. Some scientists even mentioned the L-word, putting Enceladus on the very short list of places that might harbor our next of kin. Here's the full story.

Saturn's sixth-largest moon has an equatorial diameter of 504 kilometers—a little farther than the drive from Pasadena to Las Vegas—and is the most reflective object in the solar system. It is entirely coated with something shiny, and Dale Cruikshank of the University of Hawaii identified water ice on its surface back in 1980. Voyager 2 got a look at Enceladus in 1981, but "didn't have the instruments to determine the surface's composition," says Torrence Johnson, a senior research scientist and the chief planetary scientist for the Solar System Exploration Directorate at the Jet Propulsion Laboratory, a member of the Voyager imaging science team, and now a member of Cassini's imaging team. (The Jet Propulsion Lab built and is operating the Voyagers and Cassini; Caltech manages JPL for NASA.) Voyager did find Enceladus's northern hemisphere to be heavily cratered, enough to be nearly as old as the solar system itself, while other regions are very smooth and therefore relatively young—perhaps just a few hundred million years old. Voyager got a pretty good look from the north pole to down past the equator, but only a glimpse farther south.

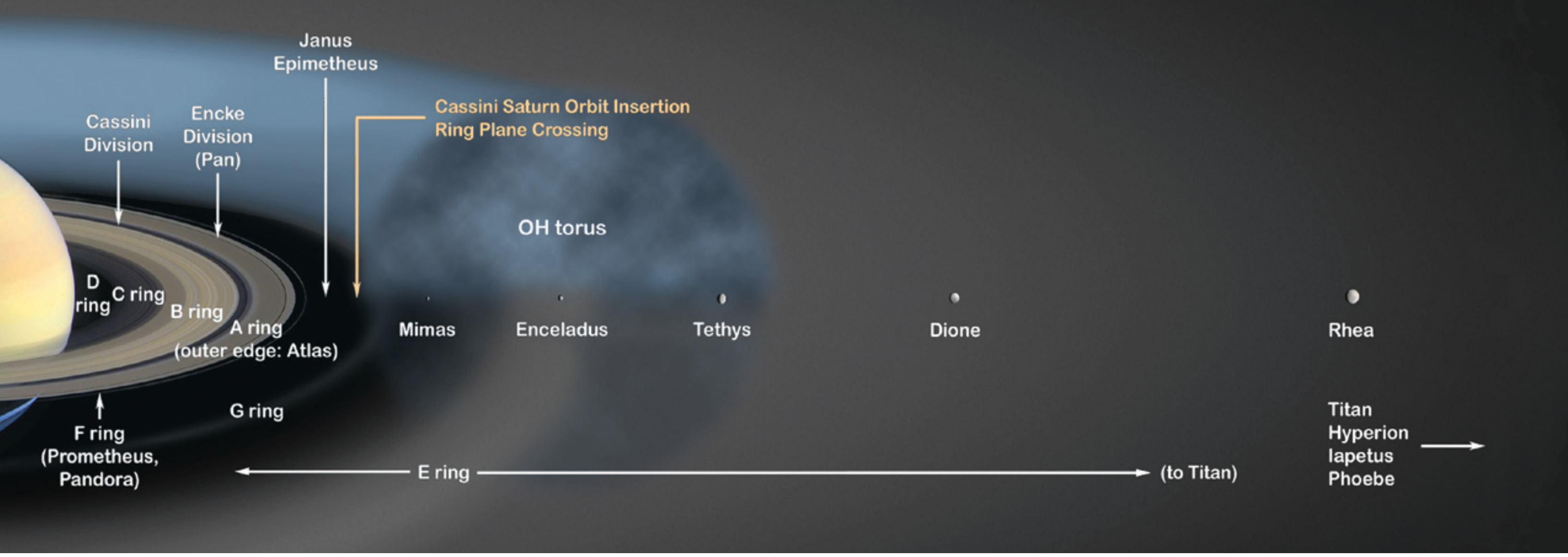


Saturn's magnetic field is embedded in a plasma, or cloud of charged particles, that's draped around Enceladus in a way that suggests it's colliding with something coming from the moon's southern hemisphere. Cassini's magnetometer also picked up oscillations, caused by ionized molecules spiraling along the field's lines, at a frequency characteristic of water vapor. The magnetometer was built and is operated by a team based at Imperial College, London, England.

Cassini has confirmed that the whole moon is frosted with very pure water—new-fallen snow, essentially. The moon's dazzling brightness, says Bonnie Buratti, a principal scientist at JPL and a member of Cassini's Visible and Infrared Mapping Spectrometer (VIMS) science team, "reflects freshness. Add any little impurity, a bit of space dust, and it gets dimmer and dimmer." But with an average temperature of 67 kelvins (–206° C), Enceladus is far too cold to be making snow, so a debate has been going on since the '80s—is the bright stuff coming from Saturn's E ring, which shares Enceladus's orbit, or is Enceladus the source of the E ring, which then coats the moon?

Says Andrew Ingersoll, Caltech's Anthony Professor of Planetary Science and a member of Cassini's imaging team, "The mysterious E ring, which has been glimpsed, on and off, throughout the 20th century, seems to reach its maximum density at about the orbit of Enceladus. And we knew from the way the ring particles scatter light that they're micron-sized." (A micron is one millionth of a meter.) Beacuse they are so small, they must be continually replenished. Otherwise they would disappear in as little as 50 years, because molecules would be knocked off their surface by the plasma trapped in Saturn's magnetosphere.

Furthermore, Enceladus's orbit plows right along the center of a vast, diffuse donut-shaped cloud, or torus, of neutral OH molecules, discovered with the Hubble Space Telescope in 1993. About a kilogram's worth of ice particles per second would keep the E ring going, and the OH torus needs a supply of some 100 kilograms of OH per second.



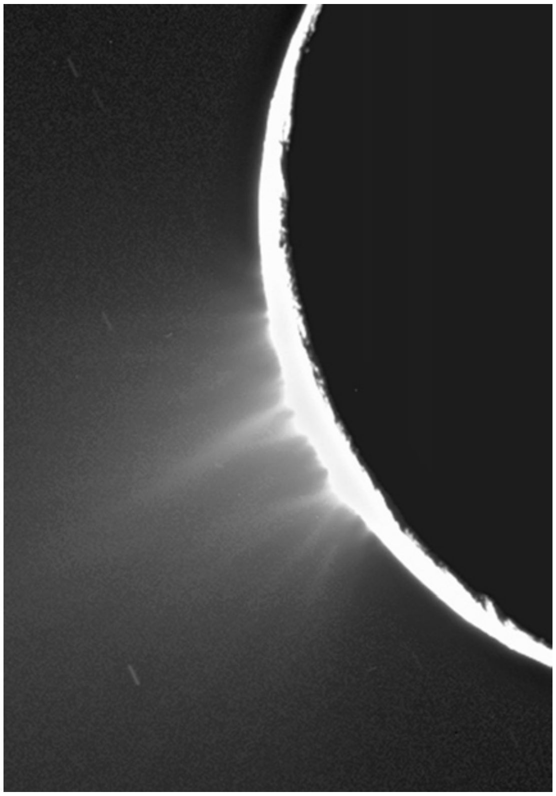
Above: Saturn, its rings, and some of its moons. The diffuse E ring is much broader than the classical ring system, extending for more than a million kilometers between the orbit of Mimas and that of Titan, which, at this scale, lies some nine inches to the right of this page. The OH torus, like the E ring, is densest at Enceladus's orbit. Neither really has a sharp boundary, but instead each trails off into space.

Also, Saturn's magnetosphere is filled with oxygen and hydrogen ions of unexplained origin. If you put all this together, there could be a boatload of water coming from Enceladus.

Cassini arrived at Saturn on June 30, 2004, to explore this and other mysteries. The mission includes contributions from 17 nations—some on the school-bus-sized orbiter and the rest on the European Space Agency's Huygens probe, which landed on the methane-drenched, planet-sized moon Titan on January 14, 2005. Cassini follows a wildly looping orbit, allowing its dozen instruments to get repeated, intimate views of all of Saturn's major moons and a number of the minor ones while also making a detailed examination of the planet and its rings.

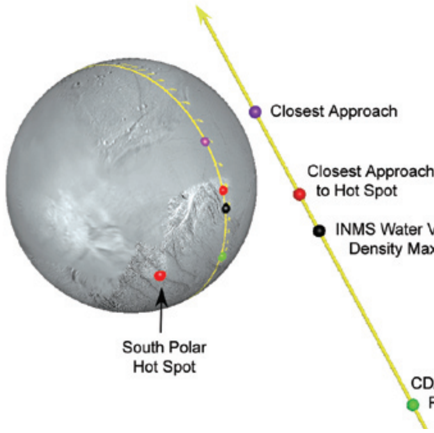
Cassini's first two Enceladus flybys, on February 17 and March 9, 2005, were equatorial passes. On the first one, the magnetometer found that Saturn's magnetic field draped around Enceladus in a way that hinted at a tenuous atmosphere. The second flyby showed that the atmosphere was confined to the southern hemisphere, and the magnetometer discovered ionized forms of water such as H_3O^+ streaming from the vicinity of the south pole. Then a photo shot on May 20 revealed parallel sets of dark features, dubbed "tiger stripes," in the south polar region. Each stripe is about 130 kilometers long, and they're spaced some 35 kilometers apart.

So Cassini's third flyby, on July 14, 2005, was altered to buzz the south polar region at an altitude of some 170 kilometers. And behold—it found a huge plume of water hanging over Enceladus's south polar region. The Ultraviolet Imaging Spectrograph, or UVIS, discovered the plume by looking at a star whose light would pass through the plume if one existed. And indeed, the star dimmed as some of its light was absorbed, and a comparison of spectra taken outside the plume with one from the thick of it proved it to be water vapor. Another instrument, the Ion and Neutral Mass Spectrometer, or INMS, confirmed this; VIMS follow-up



This picture was shot on November 27, 2005, approximately broadside to the plume, which is backlit by the sun. A dozen or so jets of material can be seen shooting into space like a very wimpy comet. Cassini's cameras were designed and built at JPL, but the imaging team is based at the Space Science Institute in Boulder, Colorado. The imaging science team leader is Carolyn Porco (MS '79, PhD '83).

The July flyby in 3-D, and its projection onto Enceladus's surface.



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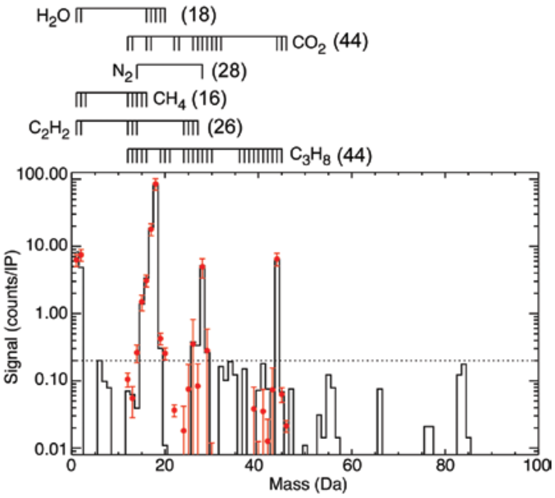
observations on November 26 found particles of water ice averaging 10 microns in the plume and determined that the E ring is made of water ice as well, the latter with an average particle size of three microns.

As Cassini sped by, UVIS also measured the plume's column density, which allows the vapor's escape rate to be estimated—5×10^{27} molecules, or more than 150 kilograms, of water per second, which is plenty to provide for the OH torus. Comets' tails are also mixtures of gas and dust, says Candice Hansen, a research scientist at JPL and a coinvestigator on the UVIS team, and although "comparing Enceladus to a comet is perhaps skating on thin ice, a comet that is not very dusty at all still has about 10 percent as much dust as gas. If you apply that to our 150 kilograms per second you get 15 kilograms per second, more than enough to re-supply the E ring." (UVIS was built by, and the team is based at, the University of Colorado at Boulder.)

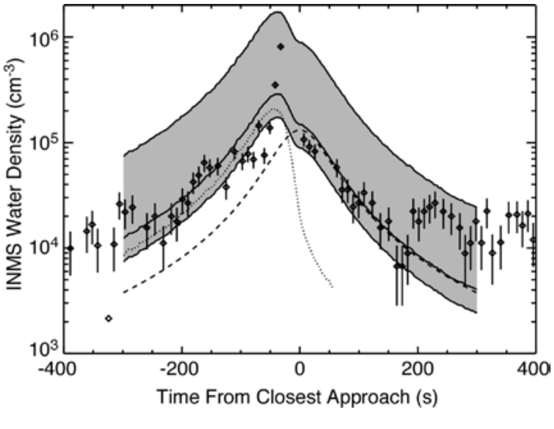
Meanwhile, the INMS and the Cosmic Dust Analyzer (CDA) were measuring the gases and particles that the spacecraft was actually flying through. (The INMS began seeing the plume at 4,000 kilometers out.) Cassini crossed over the south pole before its closest approach to the surface of Enceladus, which allowed discrimination between a global and a local source for the plume. A global source, such as ice molecules chipped from the surface by particles in Saturn's magnetosphere, or lots of tiny vents all over the place that we can't yet see, would have shown up as a broad peak centered on the point of closest approach—the lower the altitude, the denser the stuff should hang all over the moon. But a local source would have peaked when the detector was nearest the source, regardless of the altitude.

According to the INMS, the plume is 91 percent water vapor, 3.2 percent carbon dioxide, and 1.1 percent methane, with possible traces of acetylene and propane. The readings peaked when Cassini was

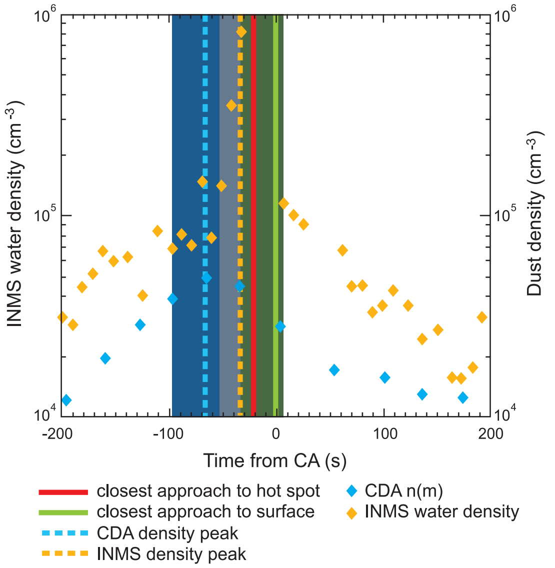


Above: The average INMS spectrum for altitudes below 500 kilometers. The branched bars labeled H_2O, etc., above the data show what masses you would expect to see if the chemical named were present; the numbers in parentheses are the chemicals' molecular weights. The INMS was built by NASA's Goddard Space Flight Center in Greenbelt, Maryland, and the operations team is headquartered at the University of Michigan, Ann Arbor.

Below: INMS water density measurements (diamonds with error bars) compared to the predicted density from a global-source model (dashed line) and a polar model (dotted line). The solid line in the middle of the gray region is the sum of these two models, and the gray envelope itself shows the density fluctuations possible if the outbound data are the remnants of a gusher a few hours old.



A tiny little moon that has been in the deep freeze since its creation has got no business showing any signs of life whatsoever, let alone spewing ice geysers to a height of its own diameter.



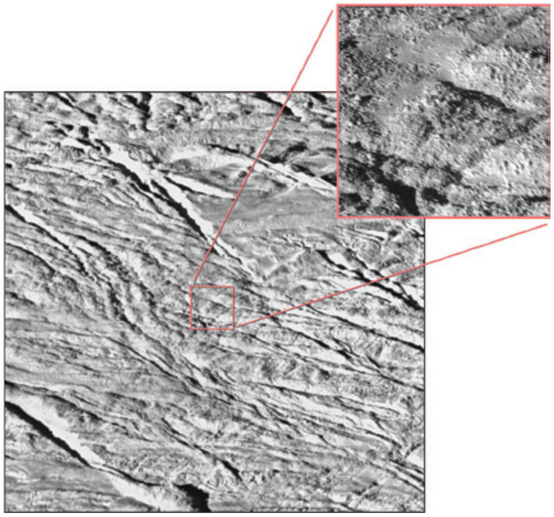
The density peaks from the INMS and the CDA came at different times. The blue band is the uncertainty in the CDA peak, the green band is the uncertainty in the INMS peak, and the gray band is the overlap between the two uncertainties. The CDA was built by scientists at the Max Planck Institute in Heidelberg, Germany, and the University of Chicago; the head honcho hangs his hat in Heidelberg.

nearest to the south pole, about 35 seconds before closest approach to the surface. But the plume's source doesn't appear to be exclusively polar—the best fit to the data has a roughly 50 percent global contribution. (This, however, is far too tenuous to be detectable as an "atmosphere," even by occultation of starlight.) The INMS measured 1.5 to 4.5 $\times 10^{26}$ molecules per second, or some four to 11 kilograms per second, which is not enough to supply the OH torus. But the measurements don't fall off on the outbound leg the way the models say they should; instead, they flatten out. If the plume spurts every few hours, and this plateau is the undissipated residue from an earlier gusher, the source rate could be up to eight times higher than what was observed—about 80 kilograms per second, which is close enough to 100 for government work. (Or planetary science, for that matter—at least it gets you in the ballpark.)

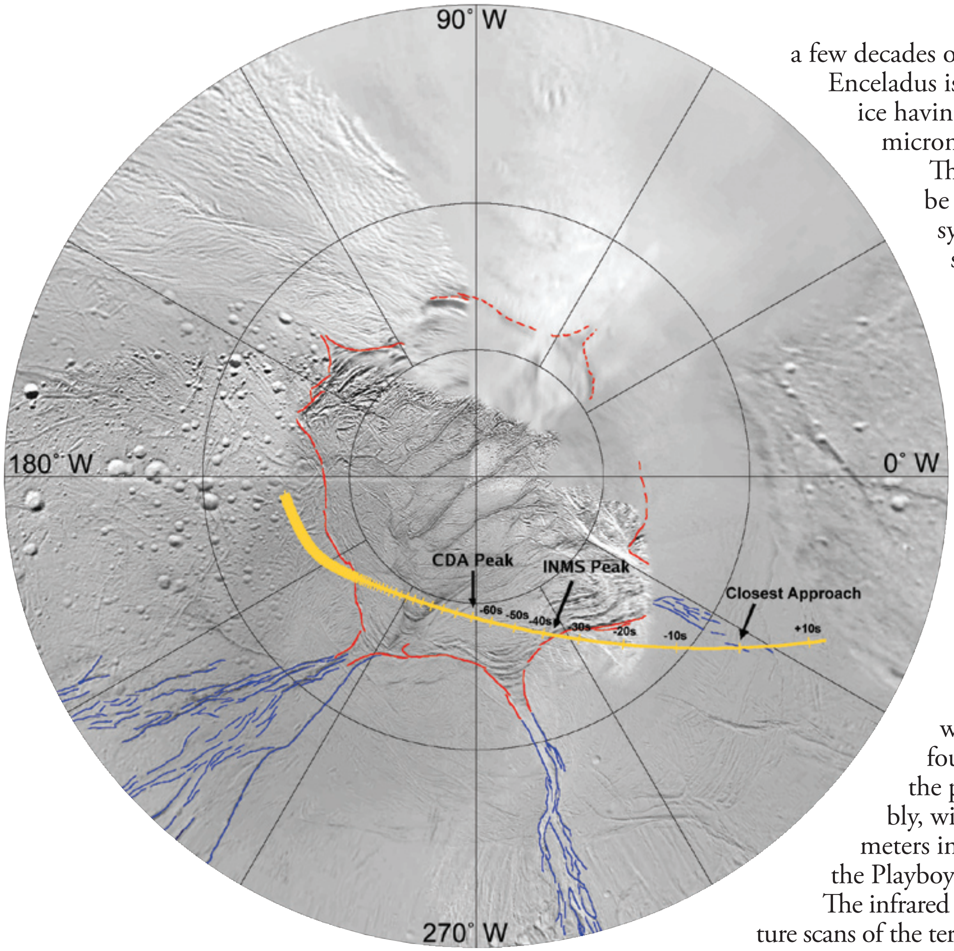
The Cosmic Dust Analyzer's High Rate Detector sees particles of two microns in radius or larger. It found particles with radii of up to 10 microns, and the peak—of four particles per second—was about one minute before closest approach, although there was a significant increase over background from 10 minutes before closest approach to 10 minutes after. But because the CDA peak came earlier than the INMS peak, the CDA folks calculate that the local source supplies about five times as many particles as the global one. The differing peak times also suggest that the gas and the particles act independently of each other after leaving the vents.

A tiny little moon that has been in the deep freeze since its creation has got no business showing any signs of life whatsoever, let alone spewing ice geysers to a height of its own diameter. The propulsive gas requires a rock-bottom minimum temperature, somewhere below that frozen landscape, of 200 K, says Ingersoll, "which is incredibly hot for a body which, if its surface is in equilibrium with the sunlight, is going to be below 70 kelvins." The sun is only 23 degrees above the horizon at the south pole, and it's about 100 times dimmer than it is on Earth. Cassini's Composite Infrared Spectrometer, or CIRS, reaffirmed Voyager's global average temperature readings, and also took a close look at an 80-kilometer-diameter region centered on the north pole, which hasn't seen the light of day since 1995. It's a brisk 33 K there, and that's an *upper* limit.

Which brings us to the tiger stripes. Close-up photos show them to be fissures some 500 meters deeper than the surrounding plains and a couple of kilometers wide, flanked by ridges about 100 meters high. Their bluish tint betrays relatively large particles of crystalline ice—100 to 300 microns, according to the Visible and Infrared Mapping Spectrometer. (The larger an ice crystal, the deeper its absorption in the near-infrared, so the bluer the light it reflects. This is why icebergs and pack ice on Earth have a distinctly bluish cast—they are made of larger ice crystals than, say, snow.) The larger, bluer ice crystals also lie on the surrounding plains, making each dark stripe about seven kilometers across. The crystal size is significant, says Ingersoll, "because if you put a crystal of 100 microns in size anywhere in the Saturnian system and come back a little while later, it will have turned into amorphous ice just due to the bombardment of radiation. So in other words, this is youthful ice." In fact, it may only be



The large picture shows a swath of hummocky terrain in what may be the transition between a tiger stripe and the surrounding plain. The resolution is about 37 meters per pixel. The inset shows the best-yet glimpse of the surface, at a resolution of four meters per pixel but somewhat blurred by Cassini's motion. Each of those little blobs is a block of ice tens of meters in size—a few are 100 meters across.



This composite of Cassini and Voyager images shows Enceladus's southern hemisphere all the way up to the equator, with latitude and longitude lines every 30 degrees. The tiger stripes are squarely in the middle of the picture, surrounding the south pole. The red lines are the chain of fractures at 55° south (marked with dashed lines where inferred on the Voyager pictures) that separate the older, cratered surface from younger terrain. The blue lines are the fractures running north from the Y-shaped features, and the folds between the arms of the Ys are visible as ripples. The yellow line marks Cassini's path over the surface, with tick marks every 10 seconds before and after the point of closest approach.

a few decades old. (VIMS says the rest of Enceladus is covered with amorphous ice having a grain size of 50 to 150 microns.)

The tiger stripes turn out to be part of a larger fracture system. The whole region south of about 55° S is bounded by a continuous chain of fractures and ridges, also bluish in parts, that meet at Y-shaped features. Between the arms of the Ys, the terrain is folded into belts standing hundreds of meters tall, and the stems of the Ys are more bluish fissures that go north into the midlatitudes.

And an extreme close-up, with a resolution of about four meters per pixel, shows the place is covered, inexplicably, with boulders of ice 20 to 50 meters in size—ice cubes as big as the Playboy Mansion, in other words.

The infrared spectrometer took temperature scans of the terrain the camera was shooting, and found a series of hot spots designated A to G. (Source C, incidentally, is very close to the south pole.) These spots are on or near the tiger stripes, and their thermal spectra are not those of blackbodies, meaning that the temperature in CIRS's field of view is not uniform. For instance, a little shoulder in the spectrum of D, the hottest spot, implies that some 4.6 percent of the radiometer's footprint—about 25 square kilometers, or the equivalent of a 250-meter-wide strip along a 100-kilometer-long fracture, is actually at 145 kelvins. (There is some

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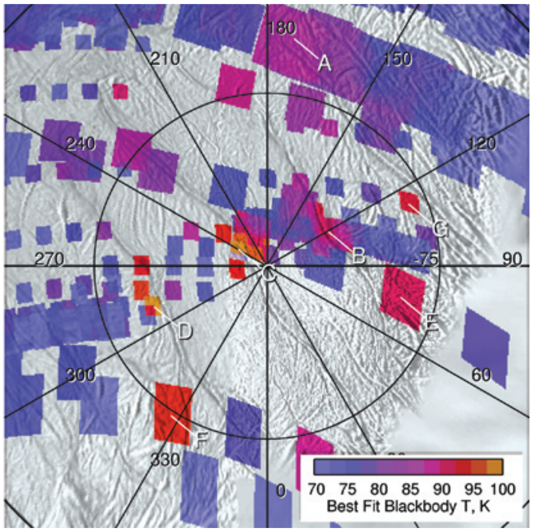
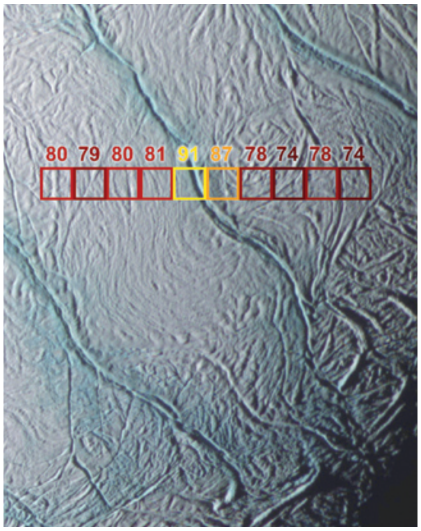




Right: CIRS made a temperature map of a fair piece of the south polar region, including the seven hot spots marked A – G. CIRS was built and is run by the Goddard Space Flight Center. Far right: In this close-up of hot spot B, each colored square is a single CIRS measurement of a patch of ground six kilometers across, at wavelengths from nine to 16.5 microns. The numbers show the average temperature for each square.

uncertainty in that estimate, as the smaller the "filling factor," that is, the 4.6 percent, the higher the temperature needs to be in that filled area. So the temperature could be as high as 180 K.)

One is almost tempted to say this is boiling hot. Which is not that far off the mark—the Cassini team's best explanation is the "Cold Yellowstone" model, in which a reservoir of liquid water is venting to space through fissures in Enceladus's crust. "A bit like the Yellowstone area, but with about a tenth the heat flow," is how Johnson puts it. The heat radiated by a 145 K hot spot implies a temperature of 273 kelvins, the melting point of water, a mere 20 meters below the surface. The imaging team takes a different route to a similar conclusion: They start with Enceladus's weak gravity, which is about one percent of Earth's, and calculate how much pressure the overlying ice would have to exert to reach water's triple point—where solid, liquid, and vapor coexist—and hence how thick the ice would need to be in order to weigh that much. Seven meters will do the trick.

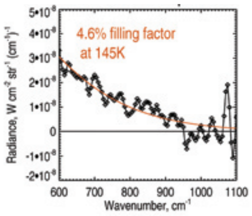
This is not as outrageous a claim as it may seem—the CIRS measurements of the entire south polar region show that it is giving off, at the very least, four more gigawatts of thermal energy than can be accounted for by reradiated sunlight.

The water is kept liquid by the pressure of the ice cap above it, but, like the aftermath of a bungled assault with a bottle opener on a non-twist-off beer, foam escapes through whatever gaps it finds. Any water caught up in the gas freezes into ice particles, and the lot comes shooting out the top. Some of it gets lofted into space at supersonic speeds, twice Enceladus's escape velocity of 235 meters per second, feeding the E ring and the OH torus; the rest falls back as snow.

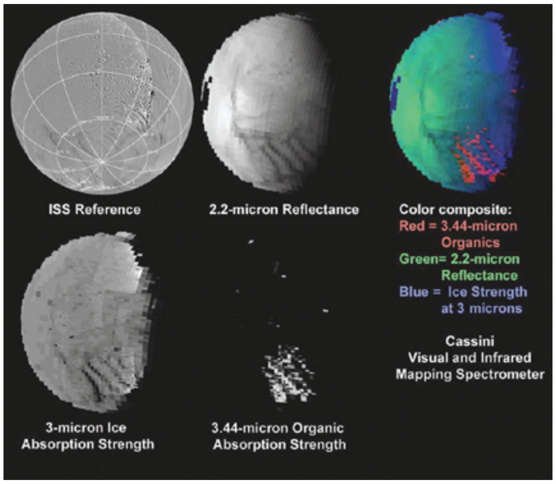
How Enceladus's cockles got warmed is anybody's guess. Since the moon's northern hemisphere is, geologically speaking, dead as a doornail, the mechanism is clearly a local—or at best regional—process. Various theories conjure past orbital resonances, librations (wobbles of Enceladus's rotational axis), or orbital eccentricities—none of which are happening now—that squeezed the poor satellite like a Koosh ball to melt its interior. And the imaging team found that Enceladus *is* out of round—or, to be perfectly accurate, out of elliptical—by +400 meters at 50° south latitude and –400 meters at the south pole. The north-south fractures running from the midlatitudes, as well as the ring at 55° south latitude that those fractures join, could have occurred when Enceladus began to bulge, since the crust would have cracked to accommodate the shifting fluid below.

Another alternative, proposed by Caltech-JPL postdoc Julie Castillo and others, posits that Enceladus coalesced at just the right time in the solar system's evolution to have collected a lot of aluminum-26. Aluminum-26 has a half-life of only 720,000 years, says Castillo, and its rapid decay would have put out an awful lot of heat, which could have partially melted the rocky core. This, in turn, would have heated the underside of the ice and "melted enough of it to create hydrothermal vents like the ones along the mid-ocean ridges on Earth. And with Enceladus's low gravity, it would be easy for warm water to work its way up to the surface." The mystery of what's driving the geysers is not unlike the story of plate tectonics—Alfred Wegener proposed in 1915 that Earth's continents were drifting apart, and it then took another 47 years to establish how.

After the first few million years, other decaying radioisotopes might help keep the chill from Enceladus's south polar interior. Cassini's measurements of the moon's mass and density are both higher than Voyager's. This means the core is bigger than previously thought, which implies that it could be putting out two or three times more heat than had been plausible before. But most of the heat comes from the tidal flexing induced by Saturn's gravitational field.



The tail of the infrared spectrum for hot spot D. The red line is the best-fit graybody spectrum.



The VIMS data at wavelengths absorbed by organics (red) and small-grained crystalline ice (blue). The 2.2 micron reflectance is a sort of calibration—a band that is the same for amorphous and for crystalline ice. The VIMS was built by JPL with contributions from the Italian Space Agency, and operations are based at the University of Arizona in Tucson.

But there's one more feature of interest, as Sherlock Holmes might say. The Visual and Infrared Mapping Spectrometer surveyed the materials on Enceladus's surface, and found simple organic molecules such as acetylene along the tiger stripes.

Which raises a possibility that has everyone all atwitter: Life. "This is the most exciting thing to come out of Cassini," says Yuk Yung, professor of planetary science. "It's very much like the biblical story of Saul, who went out to look for his donkeys and found a kingdom." Yung is a coinvestigator on Cassini for the study of organic molecules on Saturn's moon Titan—a line of work that he actually began back in the Voyager days. "Titan is what we call prebiotic. It has the precursors of life. It is a natural laboratory for all this complex organic chemistry, some of which we are still trying to figure out. And then we have Enceladus, where we think Titan's evolution has taken another step forward, and may have moved to the point of spontaneous generation of life."

As far as we know, life demands three things. The first, of course, is liquid water. The second (we'll get to the third a bit later) is an oxidation-reduction, or redox, cycle: a set of chemical reactions in which electrons are liberated from inorganic matter to carry out the business of life. Some earthly bacteria use a sulfur cycle, others use iron. (Photosynthesis is out of the question—it's a tad too dark out there.) Yung thinks that life on Enceladus could be powered by H_2O_2, hydrogen peroxide, which is easily made by irradiating water molecules with electrons or ultraviolet photons, and has been found at 0.13 percent abundance on the surface of Jupiter's moon Europa—another iceball suspected of having a subsurface ocean. Hydrogen peroxide has not been seen yet on Enceladus, but, says Yung, "We haven't been looking hard enough."

Peroxide-eating bacteria once existed on Earth, Yung believes. He bases this claim on work he and Joe Kirschvink (BS, MS '75), the Van Wingen Professor of Geobiology, have been doing on an era of global glaciation. In 1997, Kirschvink and grad student Dave Evans (MS '94, PhD '98) discovered that glaciers extended to within a few degrees of the equator some 2.2 billion years ago—one of two episodes that Kirschvink has dubbed "Snowball Earth." (See *E&S* No. 2, 1997.) The global average temperature would have plunged to 223 K, yet some bacteria managed to survive. Says Yung, "Snowball Earth was very much like things are now out in the outer solar system. And under those conditions, you can create lots of hydrogen peroxide, which will be trapped in the ice." On Earth, the ice melted relatively suddenly, and huge amounts of oxygen were released. Life at that time was anaerobic, and oxygen would have been a deadly poison. (See *E&S* No. 4, 2005.) Most everything died, but some bacteria evolved an enzyme called superoxide dismutase, which breaks down hydrogen peroxide, says Yung. While no peroxide-munching bugs exist today, Yung points out that a yeast named *Hansenula polymorpha* is able to snack on H_2O_2. "So the biosphere figured out how to deal with this oxygen-containing substance before it ever had to deal with molecular oxygen, and that was a necessary precursor to oxygen-releasing photosynthesis. Otherwise, whatever was producing oxygen would have been killed in the process." Yung and Kirschvink are collaborating on future Enceladus work.

Life's third prerequisite, which is far less obvious, is a geological cycle. Life requires rocks to have been weathered into clay, says Yung, because "in order to create life, you need to create all these complex molecules. DNA, the genetic code, gives us the blueprint now, but in the beginning, everything had to self-assemble." It's like building an arched bridge of stone—the Romans couldn't just stack rocks on top of one another so that the piles leaned out from each bank and met in midstream. A scaffolding was needed to hold the rocks in place until the keystone went in and the whole thing became self-supporting. James Ferris at Rensselaer Polytechnic Institute has shown that montmorillonite, a

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fairly common clay mineral, can serve as a template that rapidly assembles short strands of RNA out of individual nucleic acids. It's quite a leap from a string of a few dozen nucleotides to an RNA system that can copy itself and could charitably be called alive, but you've got to start somewhere. "Clay is nature's catalyst," says Yung.

At some 70 kilometers down, Enceladus's stony core is far too deeply buried to do any good, but not to worry—Yung's rocks fall from the sky. A continual rain of micrometeorites pummels the surface; Enceladus would be as dark as Saturn's other moons if it were not for the snow from the south pole. The snowfall gradually buries the micrometeorites, and Yung calculates they'd be 20 meters deep in a mere 20,000 years. And once they come into contact with the liquid water, they'd turn to clay in another million years or so—a blink of an eye, in geologic time.

Says Yung, "Other than Earth, Enceladus is the only place in our solar system that meets these three conditions. Mars has evidence that in the past there was a hydrological cycle, and there is sedimentary rock. Life could have started on Mars, but certainly not today. Europa is believed to have an ocean under the ice, but everything is sealed. It's a closed system. Joe has pointed out that Europa's oceans would be in thermodynamic equilibrium after only a couple of million years, and once that happens, there is no redox potential and no life." But "not everyone is so pessimistic," says JPL's Torrence Johnson. "Since Europa's surface is young, there must be some overturn and exchange between surface and ocean." It's not really a closed system, he says, and electron-donating molecules made on the surface—that hydrogen peroxide again—"may supply the energy for life. Likewise, ocean-floor hydrothermal vents might provide chemical nutrients." Most people think of hydrogen peroxide as an oxidant, or electron acceptor, as it is when you buy it over the counter as an antiseptic. But, depending on what it is paired with, it can also act as a reductant, that is, as an electron donor. "That's the amazing thing about hydrogen peroxide," says Yung. "It's so versatile."

But we're not out of the woods yet. Or in a position to start growing trees, if you prefer. Life needs the right mix of chemical elements in order to get started, and one of them, nitrogen, has not yet been found on Enceladus. No ammonia has been seen on the surface so far, yet one would expect to find it if amino acids were being made. Worse, there's no sign of ammonia in the plume. But even if ammonia is never found, all is not lost—the best prebiotic gas mixture for making life's necessities, says Yung, is actually methane, water, and nitrogen in the form of N_2. There's an unidentified peak in the mass spectrometer data at mass 28, which is just where N_2 would register, that accounts for four percent of the plume. It's not yet clear that this peak is nitrogen and not carbon monoxide, which has the same molecular weight and is found in about four percent abundance in cometary gases. But the plume's ultraviolet spectrum sets an upper limit for carbon monoxide at less than one percent, and Titan's atmosphere is mostly nitrogen, so that's the way the INMS team is leaning.

And the best part is that these hypothetical bugs are *right there*. Seven meters down is the equivalent of having water in the subbasement: descend two flights of stairs, and you're ready to mop it up. But getting a probe to land on Enceladus's surface (or Europa's, for that matter) will take some doing—any spacecraft in orbit around a giant planet will need a big rocket and a lot of fuel to slow itself down enough to be captured by a tiny moon's weak gravity. That's a lot of weight to be flinging into the solar system's outer reaches, and "NASA is not planning any large, 'flagship-' class missions in the next five years or so, given the current budget reductions. So don't look for anything until 2015 or beyond," Johnson sighs.

Meanwhile, Cassini's next flyby will occur on March 12, 2008. The trajectory will be lowered to part Enceladus's hair—a 25-kilometer altitude has been proposed—but the point of closest approach will be equatorial. The spacecraft will still pass within 200 kilometers of the plume source, says the University of Michigan's J. Hunter Waite Jr., the INMS team leader, which will give a tenfold better signal-to-noise ratio and may allow N_2 to be distinguished from carbon monoxide. And the infrared spectrometer team's John Spencer, of the Southwest Research Institute, says, "We'll get an excellent view of the south pole as we speed away, except that Enceladus goes into Saturn's shadow right after our closest approach and we'll be looking in the dark. So we won't get any good visible-light images of the south pole, but we should get superb infrared data. If there really is liquid water in those cracks we might, if we're lucky, see temperatures as high as 273 K." That's the final close pass of the four-year primary mission, but Cassini will keep an eye on the geysers from afar. A two-year extended mission has already won preliminary approval, with Enceladus sharing top billing with Titan as the moon attractions. □