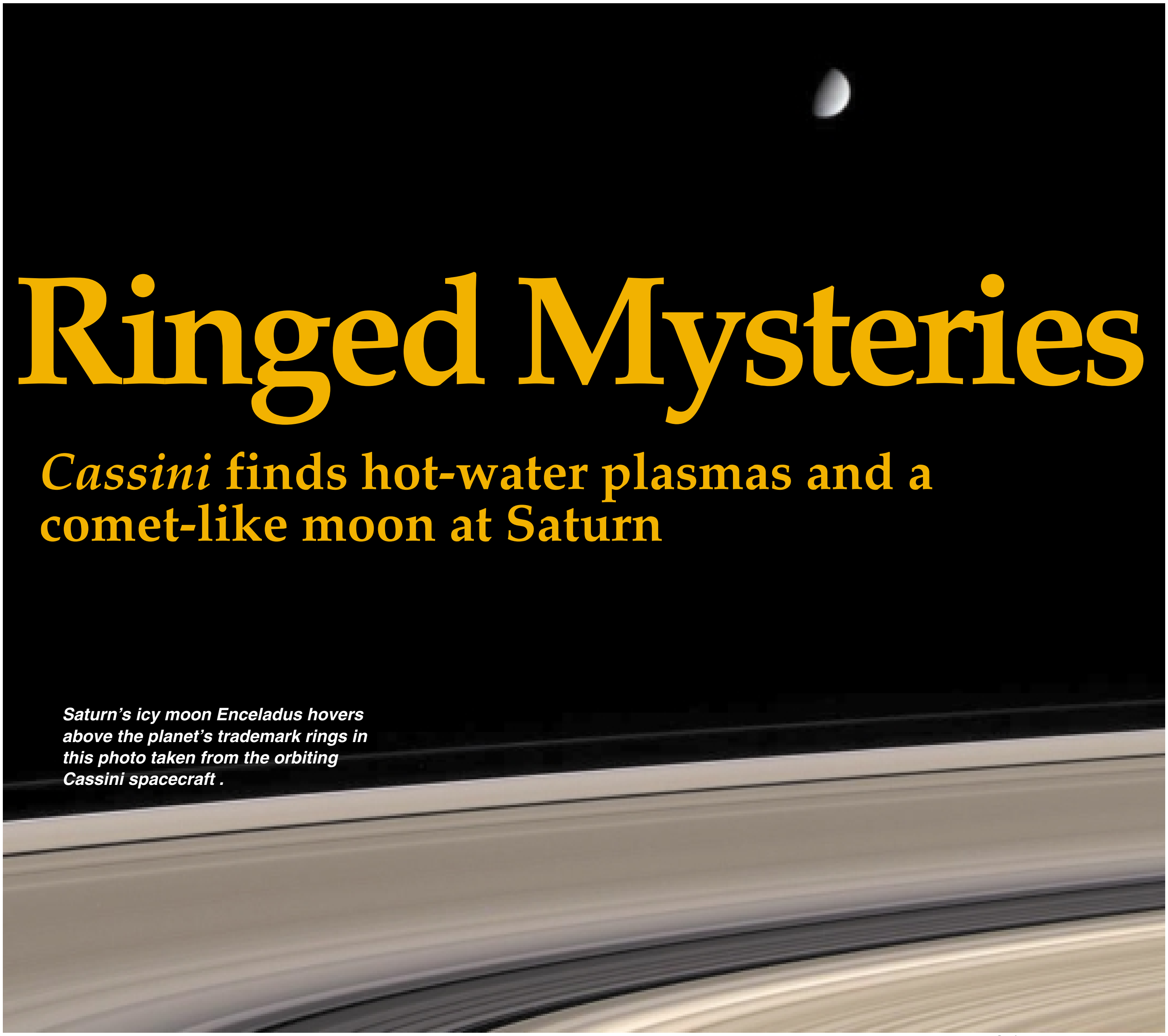
Ringed Mysteries

Cassini finds hot-water plasmas and a comet-like moon at Saturn



Saturn's icy moon Enceladus hovers above the planet's trademark rings in this photo taken from the orbiting Cassini spacecraft .

NASA/JPL

By David T. Young, Ph.D.

NASA's flagship planetary spacecraft *Cassini* entered orbit around Saturn on July 1, 2004. Since then it has beamed back startling images of the ringed system accompanied by an intriguing sketch of complex plasmas and electromagnetic fields that engulf the planet, most of its satellites and all of the rings. Although plasmas are largely invisible to the eye, *Cassini* scientists are finding that they play an important role in the tangled dynamics of the saturnian system.

Southwest Research Institute (SwRI) leads a team of approximately 40 scientists and engineers from six countries who are responsible for operating the Cassini Plasma Spectrometer (CAPS) and analyzing the data it returns from Saturn (see "Mission Saturn," *Technology Today*, Summer 2004). CAPS, which was developed and built between 1990 and 1997, is one of 12 state-of-the-art instruments carried by the three-ton *Cassini* spacecraft.

So far *Cassini* has executed 18 out of a planned total of 76 orbits, flying within a thousand miles of five of Saturn's 31 known moons, and more distantly, past another dozen. Spacecraft cameras have sent back striking images of the surface of Titan and the bizarre, sponge-like craters of the tiny, chaotically rotating moon Hyperion. The tiny, supposedly dead moon Enceladus was recently caught spewing ice crystals out of cold geysers located near the south pole. While these images hold truly surprising details, SwRI scientists are finding that the invisible plasma worlds of icy Enceladus and hydrocarbon-rich Titan are equally fascinating.

Like the Earth, Saturn has a magnetic field that reaches far out into space, creating a magnetosphere that traps any charged particles (plasma) created within it. Confined to magnetic field lines, plasma shed by the icy satellites or Titan's ionosphere is accelerated and swept along by the magnetic field as it tries to rotate at the same angular speed as Saturn. This can result in plasma velocities of up to 400,000 miles per hour. At those speeds, the plasma slams into satellite surfaces or Titan's atmosphere, knocking out atoms and creating still more plasma. In this way the plasma within the magnetosphere is regenerative — but how this critical process works is very much an open question.

Titan's Organic Ionosphere

Over the past year *Cassini* made several flybys of Titan at altitudes of about 1,000 kilometers (km), close enough to be inside the ionosphere of the only moon in the solar system that has one. In addition to measuring the significant contribution that the magnetosphere makes to ionizing the gases in Titan's ionosphere, CAPS data have shown that the chemistry of the ionosphere is much more complicated than it originally was thought to be.

Titan's atmosphere consists roughly of 98 percent molecular nitrogen, 2 percent methane and less than 1 percent of hydrocarbon compounds with molecular weights as high as 100 atomic mass units and above (molecular nitrogen has a weight of 28). Using the high-resolution ion beam spectrometer on CAPS, team members have found that more than 10 percent of the ionosphere is made up of ionized hydrocarbon molecules of the form $C_nH_m^+$. While the existence of overlapping chemical peaks in the spectrometer makes exact identification difficult, the ionized species are chemically similar to compounds such as ethylene, propyne and diacetylene.

A second very surprising result is the finding that Titan's exotic chemistry also creates negatively charged ions of hydrocarbon compounds at a rate of about 0.1 percent of the total. Prior to arrival at Saturn, theorists had modeled the chemistry of Titan's ionosphere, predicting a host of compounds of the sort now detected by CAPS. They did not, however, predict the existence of negatively charged ions. The importance of these to the chemistry of Titan is not yet known.

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Icy Enceladus

On July 14 *Cassini* swooped over the surface of Enceladus at an altitude of 110 miles and a speed of 17,500 miles per hour. During approach and departure phases of the flyby, CAPS measured a large deflection in the direction of flow of the high-speed plasma carried by the rotating magnetosphere. In the same way that an obstacle deflects the flow of a liquid around it, some deflection of the plasma flow was expected. However scientists were surprised to find deflection of the flow starting at a disproportionate distance of 30 Enceladus radii (1 Enceladus radius = 270 km) from the tiny moon. (For perspective, imagine how unusual it would be if the bow-wave of a boat extended 30 boat-widths out from the bow.) Apparently Enceladus' broad region of influence on the plasma flow is caused by ionization and acceleration of the expanding cloud of water vapor seen venting from the so-called "tiger stripes" near the moon's southern pole. Measurements made with CAPS have allowed team members to estimate that about 200 pounds of plasma in the form of water ions is being added to the flow every second.

Because Titan's atmosphere is almost entirely nitrogen, scientists anticipated they would find an abundance of nitrogen

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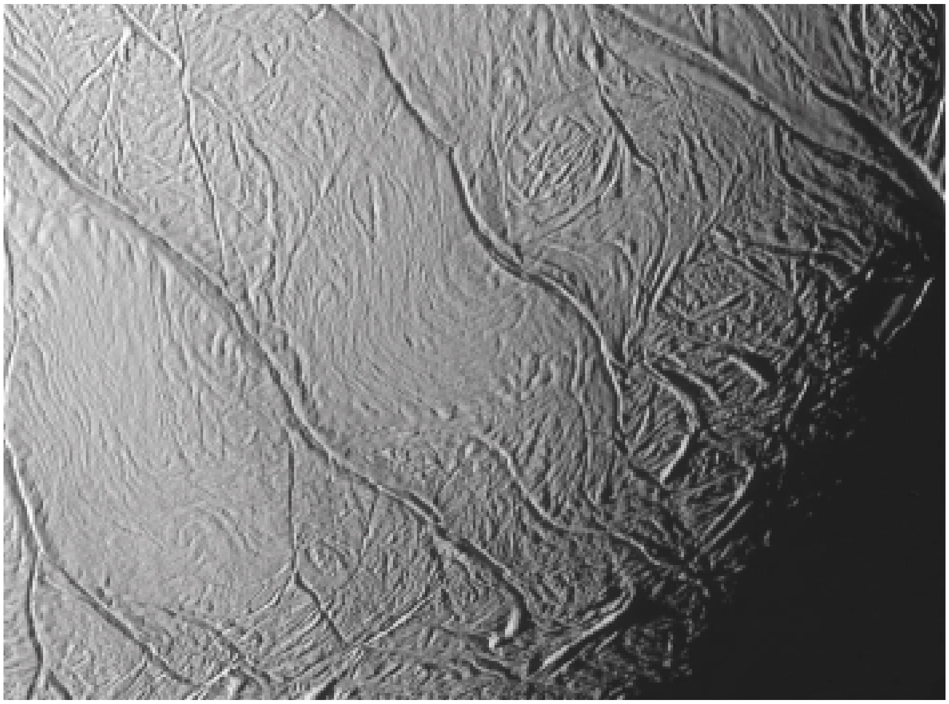
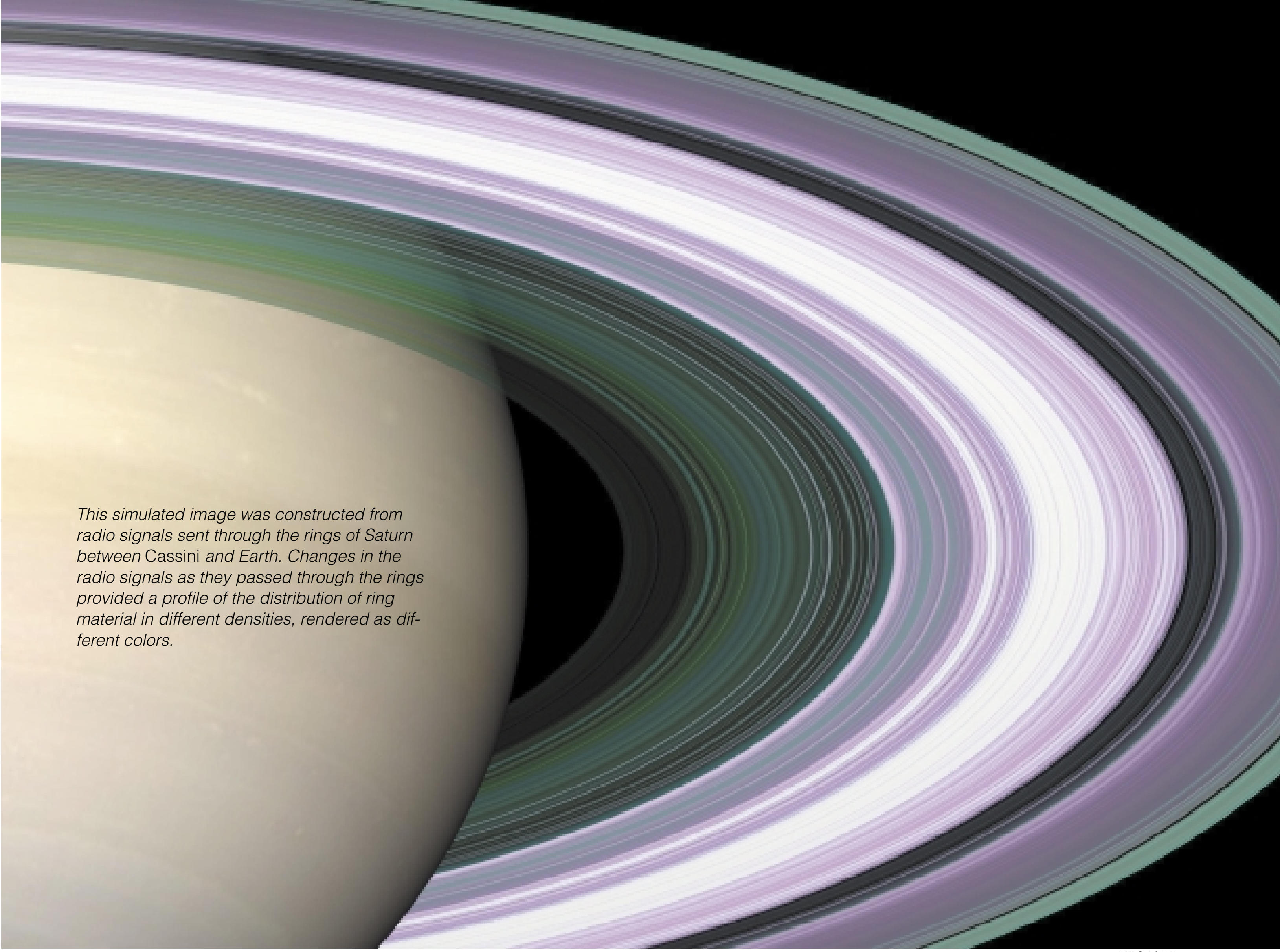


A close-up view of Saturn's moon Enceladus shows a distinctive pattern of continuous, ridged, slightly curved and roughly parallel faults within the moon's southern polar latitudes. These features, informally referred to as "tiger stripes," are thought to be the source of water vapor venting, leading to ionized water molecules observed by CAPS.



This simulated image was constructed from radio signals sent through the rings of Saturn between Cassini *and Earth. Changes in the radio signals as they passed through the rings provided a profile of the distribution of ring material in different densities, rendered as different colors.*

NASA/JPL

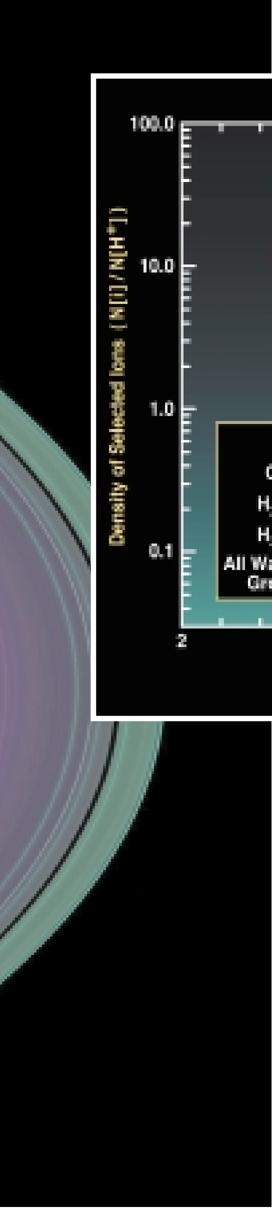
ions scattered throughout Saturn's magnetosphere. That, in fact, is not the case; nitrogen ions are found to be comparatively rare. Instead, the magnetosphere is dominated by plasma composed almost entirely of ionized water and water products, including O^+, OH^+, H_2O^+ and H_3O^+. The source of the water group ions is now seen to be almost entirely coming from the venting of Enceladus. One unusual aspect of the relative abundances of the water group ions is that they are similar to those found in cometary comas observed near 1 astronomical unit (1 AU equals the distance from Earth to the sun). Most of the ionization near 1 AU comes from solar ultraviolet (UV) photons, whereas at Saturn, located at 9.5 AU, the source of ionization has to be the rotating plasma itself, not solar UV. Why the two very different source situations produce similar results is under investigation.

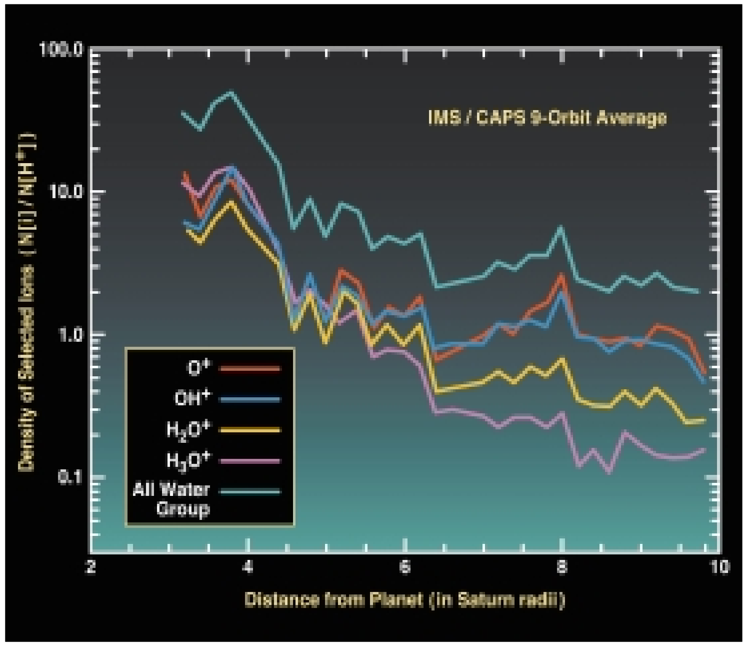
One last peculiarity about the distribution of plasma puzzles the CAPS team. Although there isn't much nitrogen in the plasma circulating around Saturn's magnetosphere, there is some — and unexpectedly, it's most abundant deep in the magnetosphere, near the orbit of Enceladus. What's more, the energy of the nitrogen ions is roughly the same as that of the water group ions, indicating that they all were picked up by the rotating magnetic field at about the same distance from Saturn, somewhere in the vicinity of Enceladus' orbit. This leads some scientists to suggest that the nitrogen may have come from primordial ammonia embedded in the ice early in the formation of the solar system. The venting observed on Enceladus may signal the presence of subsurface ammonia "anti-freeze" mixed in with the water-ice, which would allow gases to be produced and vented in an otherwise frozen environment. If that is the case, then the results from CAPS provide indirect evidence for geological activity deep inside Enceladus.

Over the Rings

One of the mysteries that *Cassini* investigators hoped to answer was that of the suspected, but unproven, presence of an ionosphere of charged particles above Saturn's rings. During *Cassini's* insertion into orbit last July, the spacecraft flew directly over the main rings — giving CAPS and other instruments the closest look yet at the rings, an event that will not be repeated during the remainder of the *Cassini* tour. The CAPS observations indicate that there is indeed an ionosphere not only over, but also beneath the rings.

While the rings themselves are composed largely of water ice with small amounts of silicate and organic "dirt" mixed in, CAPS investigators studying the rings' plasma environment detected the presence not of water ions, as might be expected, but of molecular oxygen ions. The oxygen is made by ultraviolet light





Ion mass spectrometer data from CAPS during nine orbits of Saturn illustrate the dominance of water ions in the magnetosphere. While Earth's magnetosphere is made up mostly of protons from the solar wind, at Saturn the magnetosphere is made up of more water ions than protons — up to 30 times more at locations close to the planet. Such an abundance of water ions previously had been seen only at comets, whose nuclei consist primarily of water ice. One clue to comet-like chemistry at Saturn is the large abundance of the hydronium ion (H_3O^+), which is made by the collision of charged and uncharged water molecules. Other plasma chemistry components vary greatly between comets and Saturn, however.

striking the ring particles, whereas water ions found in the E ring are generated through the plasma bombardment cycle. Even though the basic ingredient in both cases is ice, the chemical and physical processes are sufficiently different to yield plasmas with very different compositions.

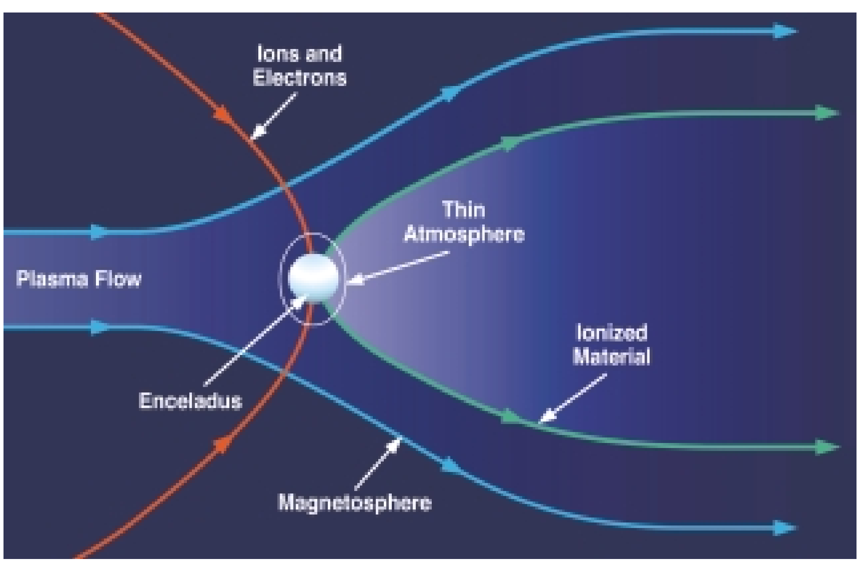
Into the Future

In its first 18 months orbiting Saturn, *Cassini* has raised far more questions than answers. For the CAPS team, the magnetosphere is still a big place that *Cassini* has come nowhere near exploring to its fullest. Up to now the mission has been confined to orbits close to the equatorial plane and to the dayside of the huge magnetosphere. Over the next year, the spacecraft's orbital inclination will be raised through a series of maneuvers involving gravitational assists from Titan. As the second-largest moon in the solar system, Titan is massive enough to boost the orbit of *Cassini* to inclinations that will carry it over Saturn's unexplored auroral regions. From this vantage point, the cameras will image the aurora while CAPS probes for beams of electrons and ions that scientists think might be at the heart of the auroral process. These orbital gymnastics will also permit *Cassini* to visit the vast regions of Saturn's magnetically active magnetotail — the region where plasma from Titan, Enceladus and other sources gets flushed out of the magnetosphere and into the solar wind.

It goes without saying that before the mission is over, *Cassini* scientists will want to get as close as possible to the enigmatic surfaces of the moons and rings by flying just over the crater tops. Such maneuvers, at altitudes as low as 15 miles, carry increased risk of collision with the surface. However, toward the end of *Cassini's* mission there are good arguments for allowing a more daring approach to flight operations. A two-year extension of the mission is technically feasible and is under study by the *Cassini* team. CAPS and the other 11 instruments, plus the spacecraft's guidance and propulsion systems, are performing effectively. With the current operational strategy there will be enough fuel on board to extend the planned four-year mission for another two years, adding perhaps another 30 orbits.

Approximately 25 years before *Cassini,* the two *Voyager* spacecraft made a fast, cursory survey of the saturnian system. Yet even today, Voyager data are still consulted for clues to the riddle of the ringed world. With only 18 out of a planned 76 orbits completed in the nominal mission, it seems safe to say that data collected today by CAPS and the other *Cassini* instruments will be analyzed for at least 25, if not 50 or more years into the future. ❖

Questions about this article? Contact Young at (210) 522-5510 or dyoung@swri.org To discuss this article online see www.swri.org/forums



Plasma flow from Saturn's rotating magnetosphere is swept towards Enceladus (blue arrows) and deflected around it by the planet's piled-up magnetic field (not shown). More energetic ions and electrons (red arrows) are able to penetrate all the way to the surface, where they knock out and ionize materials from Enceladus (light green arrows). The oval above the surface of Enceladus indicates its thin atmosphere.