# Voyager Beguiled by Jovian Carrousel

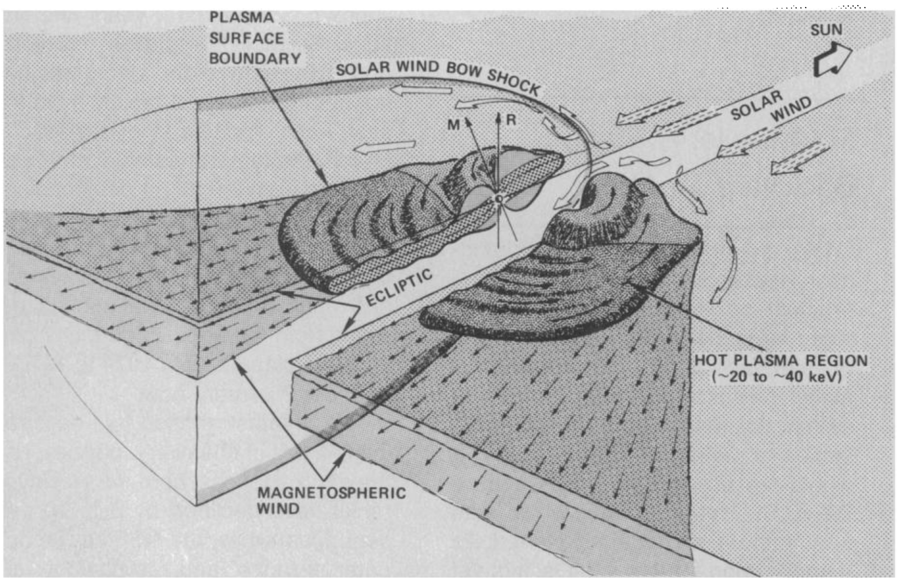
***With Io's volcanoes supplying particles and Jupiter's spinning providing energy, the Jovian magnetosphere differs from the earth's***

Active volcanoes pockmark the surface of Io, Jupiter's enchanting moon. Now, only a year after the volcanoes were discovered by the first Voyager spacecraft to pass Jupiter, scientists are convinced that they control the chemistry and influence the physics of Jupiter's magnetosphere. Both Voyagers found that the entire magnetosphere—the region that buffers Jupiter from the solar wind—is laced with sulfur and oxygen, elements that are spewed from the volcanoes at a rate of 1 ton per second.

Furthermore, the magnetosphere of Jupiter appears to be powered by the rapid rotation of the large planet. The particles added by Io whirl around as if they were riding a Jovian merry-go-round. Seemingly contradictory Voyager results, however, have sparked a lively controversy over just how perfectly the merry-go-round sweeps up the volcanic particles.

Although close-up observations of Jupiter are no longer being made—the Voyagers are well on the way to Saturn—detailed monitoring of the giant planet continues from the ground. Scientists used the data returned by the Voyagers to check the interpretation and accuracy of data obtained from the earth. Since Jupiter's position in the sky is now ideal for viewing, astronomers have been studying at length some processes observed only briefly during the encounters. The longer-term monitoring is paying off already. Researchers are getting a better idea of how variable and dynamic Jupiter's magnetosphere is, and they are even discovering phenomena that were missed by Voyager. Ultimately, what is learned from Jupiter may help astronomers use ground-based measurements to figure out the mystery behind the emissions of other rotating magnetized astrophysical objects, such as pulsars, that are too far away to be visited.

At the same time Voyager glimpsed Io's volcanoes, it found clues that Io might not be as prodigious a source of magnetospheric particles as the volcanic activity suggested. Ions and electrons, known as plasma, pervade the magnetosphere. On the basis of some Voyager measurements, George Siscoe of the University of California at Los Angeles surmised that an overwhelming majority of these charged particles should be produced near Io. Yet, according to Bill Sandel and Donald Shemansky of the University of Southern California's Earth and Space Sciences Institute in Tucson, other Voyager data show that ionization occurs near Io only 1 to 10 percent as fast as Siscoe inferred. Instead, the ions appear to be formed uniformly throughout a doughnut-shaped cloud—a torus—that traces Io's orbit around Jupiter.



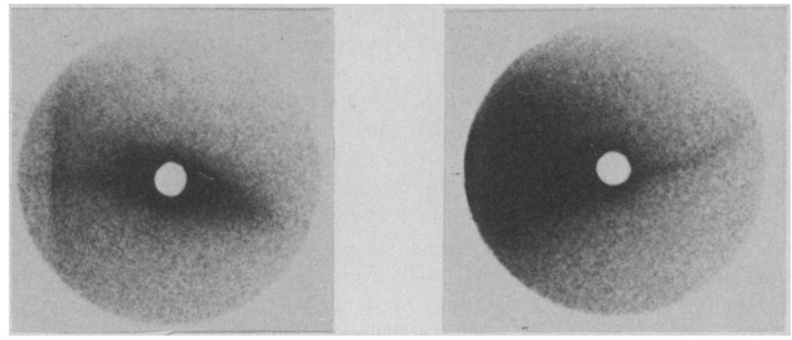

*A three-dimensional sketch of Jupiter's magnetosphere as conceived by some physicists after the Voyager encounters with Jupiter. Plasma spinning more or less along with Jupiter fills the space near the planet and is stretched on the nightside into a lumpy disk. Farther out, the magnetospheric wind streams away from Jupiter and the sun. [Source: Tom Krimigis, Johns Hopkins University]*

Nonetheless, experts believe Io to be the source of the magnetospheric plasma. Somehow, volcanic debris escapes Io's atmosphere, becomes dispersed in the torus, and is ionized there. Mechanisms stymied physicists until early this year, because in order to overcome Io's gravity, the neutral particles would have to travel much faster than they are ejected from the volcanoes. Charged particles in Io's atmosphere, however, would be readily swept up by Jupiter's magnetic field, which rotates past Io as the satellite orbits. (Io makes a circuit of Jupiter in 42.5 hours, while the giant planet and its magnetic field spin once in just under 10 hours.)

One way to get the volcanic material dispersed into the torus is to give it an electric charge, suggests Torrance Johnson of the Jet Propulsion Laboratory in Pasadena. Magnetospheric electrons bombarding microscopic dust in the volcanic plumes could charge those particles sufficiently for the Jovian magnetic field to extract them from Io's atmosphere. Once free, the dust could break up into atoms and molecules and become ionized, or "some particles may find their way to the Jovian ring," says Johnson. Measurements made near the earth by Eberhard Grün and Gregor Morfill of the Max-Planck Institute in Heidelberg confirm that tiny dust particles can accumulate a few thousand electrons in short order, and thereby become sufficiently charged to be carried off by Jupiter's magnetic field.

Alternatively, says Louis Lanzerotti of Bell Laboratories, energetic oxygen or sulfur ions crashing into the surface of Io could kick loose many neutral atoms giving them enough energy to escape Io's gravity. In the laboratory, Lanzerotti and Walter Brown of Bell bombarded sulfur dioxide ice with energetic oxygen ions and found that one ion can liberate several thousand speedy atoms. According to Thomas Hill of Rice University in Houston, Lanzerotti and Brown's experiment showed that this sputtering process "is much more efficient than anyone expected." Both electrons, for dust charging, and high-energy ions, for sputtering, are abundant in Jupiter's magnetosphere.

Occasional jets of neutral sodium that can be seen emanating from Io seem to support the idea that sputtering is a likely way to rip atoms from Io for later ionization in the torus. Although no hints of such jets were picked up by the Voyager spacecraft, they showed up this year on photographs taken by Carl Pilcher of the University of Hawaii. He says that the jets "come and go from night to night and from hour to hour."



*Two newly discovered sodium jets. Pilcher's original sodium jet (left) appears to stream 150,000 kilometers to the right from Io, which is blocked out by the white disk in the center. The linear feature directed toward Jupiter (to the left) is an edge-on view of Io's orbit, made visible by the neutral sodium pervading it. A few weeks later, Pilcher detected the puzzling jet (right), which has made him question the nature of the jets. It does not emanate directly from Io and appears to be bent. Although prominent to the right of Io in this picture, this jet disappeared within an hour. Jupiter lies to the left. [Source: Carl Pilcher, University of Hawaii]*

Pilcher favors sputtering as the mechanism for producing the jets because they are directional and localized. In addition, the atoms appear to be traveling at just the right speed. He speculates that the local magnetic field may allow a small patch of Io's surface to be bombarded for a short amount of time to produce the transient, local jets. Presumably sulfur and oxygen atoms are plucked from Io along with sodium. Pilcher sees only the sodium because he looks at Io at the wavelength of a very intense sodium emission line—the D line at 5890 angstroms.

"I'll probably live to regret calling these features jets," says Pilcher. He saw the first one in January, and "it looked as if it were streaming away from Io." Subsequently he has found other "linear features" that appear less jetlike. The strangest one is 200,000 kilometers long, kinked, and does not point directly at Io. This unusual feature disappeared within an hour of its discovery.

Pilcher cannot imagine how the kinked feature can be a jet from Io. He conjectures that it may mark a kinked, filamentous region where the chemical balance in the magnetosphere tipped temporarily in favor of neutral rather than ionized elements. He points out that the local abundance of neutral sodium, and therefore the brightness of the D-line radiation, depends on how much neutral sodium is injected, the rate at which atoms are ionized, and the rate at which ions are lost or neutralized. Whether the jets are sputtered from Io, or whether they are sensitive indicators of the chemical balance near Io, Pilcher's studies from an observatory on Hawaii's Mauna Kea volcano promise to shed light on the processes dispersing Io's volcanic debris into the torus and from there to the Jovian magnetosphere at large.

Hill notes that the material added continuously to the magnetosphere by Io ought to slow down the Jovian merry-go-round. To date, however, the Voyager data seem both to support and to repudiate this conjecture. Some data suggest that the magnetosphere slows down, while other measurements suggest that it does not. Although these conclusions are not directly contradictory, because they are based on different measurements made in different parts of the magnetosphere, experts admit that the two interpretations are hard to reconcile.

Jupiter's magnetic field, like the earth's, is tied to a magnetic dipole in the planet. Ideally, the magnetic field spins around at the same rate Jupiter rotates. Plasma is accelerated by the moving magnetic field until it circles Jupiter during the scant 10-hour rotation of the planet. In order to make the circuit of Jupiter in 10 hours, plasma far out in the magnetosphere must travel much faster than plasma closer in. Since the magnetic field weakens with distance from the planet, at some point it might be too weak to keep the plasma up to speed. There the drag of the plasma would slow the field, and both would take longer than 10 hours to make a circuit. (In the earth's magnetosphere, the motion of plasma is controlled by the earth's rotation only very close to the atmosphere and ionosphere; elsewhere the plasma flow is governed by the solar wind.)

Plasma particles are added to the magnetosphere at the orbit of Io, which is quite close to Jupiter, accelerated up to merry-go-round speed there, and subsequently drift off to the distant magnetosphere. The rotating magnetic field must do a lot of work to accelerate the particles to the ever faster velocities needed to keep pace with Jupiter's spinning. Therefore, Hill expected that distant particles would take longer than 10 hours to circle the giant planet—the farther out the particles, the longer they should take.

Herbert Bridge of Massachusetts Institute of Technology and his co-workers found that Hill's expectation was fulfilled. When the first Voyager spacecraft was closest to Jupiter—350,000 kilometers from the planet and just inside Io's orbit—the plasma was rotating as if it were rigidly attached to Jupiter. Outside Io's orbit, however, the plasma was not quite keeping pace with the planet's spinning. When the spacecraft was 2.8 million kilometers from the planet (but still well inside the magnetosphere), the plasma took 20 hours to circle Jupiter, says Bridge.

But a different Voyager instrument collected data which indicate that, although the flow varies, "by and large the plasma is rotating with the planet" deep in the magnetosphere, according to Tom Krimigis of Johns Hopkins University. Krimigis's data were obtained between 2 million and 5 million kilometers from Jupiter. He has not yet analyzed measurements made nearer the planet. Krimigis emphasizes that the speed and direction of plasma flow show great variability, "and this fact gives theorists some heartburn." "It is hard to understand how stuff not corotating at 1 million kilometers can be corotating again at 3 million kilometers," comments Hill.

The conflict is not likely to be resolved until the two experimental teams reduce data taken at the same time and place. Even then, the interpretations may not agree, because the two instruments collect different kinds of particles, which might behave differently for some elusive reason. Moreover, both investigators must make assumptions about the particles and their behavior in order to deduce a flow velocity and direction.

The Voyager radio-wave sensor, much to the surprise of its designers, made some observations that may tip the balance on the corotation controversy. Joseph Alexander and Michael Kaiser of Goddard Space Flight Center, Greenbelt, Maryland, discovered a new type of radio emission from Jupiter's magnetosphere. And the source region seems to circle the planet 3 to 5 percent slower than the planet spins. Kaiser and Alexander think that the signal comes from the outer edge of Io's doughnut-shaped cloud. They conclude that the plasma that is producing the radio waves in this region is not quite keeping up with the planet's rotation—in agreement with Bridge's measurements of the flow velocity in the same area.

Krimigis's data indicate that the Jovian merry-go-round does not go on forever. On the nightside of Jupiter, between 9 million and 10 million kilometers from the planet, "the plasma can't hang on anymore—it streams off away from Jupiter." This flow, which Krimigis dubs the magnetospheric wind, may resemble the solar wind, a flow of particles away from the sun. By studying in detail the Jovian magnetospheric wind, Krimigis hopes to understand the physics that drives it and, by analogy, the solar wind and the winds emanating from many other stars.

While the two Voyagers and the two Pioneer spacecraft that preceded them have revealed much about the Jovian magnetosphere, many of the new findings are surprises or cannot be fathomed completely with available data. Scientists eagerly await the Galileo spacecraft, "may it fly," to test their speculations about how material from Io's volcanoes is distributed into the magnetosphere and to resolve the corotation controversy. Galileo is supposed to orbit Jupiter after it is launched in the mid-1980's by the problem-plagued Space Shuttle.

—BEVERLY KARPLUS HARTLINE

# Gene Transfer Given a New Twist

***The demonstration that genes introduced into bone marrow cells work in living mice is the most recent development in a series of advances in gene transfer.***

Molecular biology has seen so many surprises in the past few years that the unexpected is becoming commonplace. Still, reports on television and in the newspapers that a "revolutionary" method of gene transfer had been discovered surprised many people, among them a number of scientists who are themselves studying methods of gene transfer between cells.

The reports described experiments in which a group of investigators* at the University of California at Los Angeles (UCLA) successfully introduced new genes into mouse cells and showed that the genes appeared to work when the cells were put back into living mice. Now this, in outline, is just what genetic engineering is all about.

Investigators have long sought a practical method of introducing new, functional genes into living organisms because such a technique might permit gene replacement therapy—a true cure for diseases, sickle-cell anemia, for example, which are caused by a single defective gene. And so the UCLA results were newsworthy.

Some news reports overstated their import, however, possibly aided by a press release from the university that hailed the techniques as "revolutionary," a word that subsequently appeared in the headline of a Washington *Post* story on the new developments. A more circumspect description was given by one researcher, who requested that he not be identified. "It is a nice experiment," he said, "but a logical extension of previous research." In other words, it fell something short of revolutionary.

In fact, investigators have been transferring genes between mammalian cells for years by a variety of techniques. Some of the earlier methods used cell fusion to produce hybrids bearing whole chromosomes or chromosome pieces from both cell types. More recently, investigators, with the aid of recombinant DNA technology, have devised more specific procedures for introducing individual genes into cells. During the past year and a half, for example, three groups of investigators reported the introduction of a globin gene from one animal species into cells from another. (Globin is the protein portion of the hemoglobin molecule.) In at least two of these cases, the transferred gene expressed itself in the synthesis of the appropriate globin protein.

The UCLA achievements grew out of this previous gene transfer work. According to Martin Cline, leader of the research group reporting the results, "We used established techniques for transferring the genes, but took them one step further—to an in vivo system."

In one series of experiments, described in the 3 April issue of *Nature*, the investigators induced resistance to the drug methotrexate in bone marrow cells by incubating them with DNA prepared from a line of methotrexate-resistant mouse cells. Methotrexate, which is used for cancer chemotherapy, kills cancer cells by inhibiting the enzyme dihydrofolate reductase (DHFR) and thus preventing the synthesis of the essential chemical folic acid.

Cancer cells may become resistant to methotrexate (or other cancer drugs, for that matter), in which case they are no longer killed by the drug, at least in concentrations that are tolerated by the rest of the body. Work from the laboratory of Robert Schimke, who is also at UCLA, has shown that methotrexate resistance is sometimes caused by amplification of the DHFR gene. Resistant cells, having many more copies of the gene than nonresistant ones, produce so much of the enzyme that they can live even in the presence of the drug.

The Cline group prepared DNA from methotrexate-resistant mouse cells having many extra copies of the DHFR gene. For the DNA preparation and subsequent gene transfer, they used meth-

*Martin Cline, Howard Stang, Karen Mercola, L. Morse, R. Ruprecht, Jeffrey Browne, and Winston Salser.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