will require some way to detect mass ejections directly. Ernest Hildner, director of the Space Environment Laboratory, raises one possibility: the radio-frequency twinkling, called interplanetary scintillation, that a mass of oncoming plasma would create. Like a dust cloud growing on the horizon, the twinkling would warn that a mass ejection is on the way. Other researchers speak of powerful radar that could clock the onrushing plasma like a traffic officer's radar gun. Still others, including Gosling, dream of a satellite that would trace out the same orbit as Earth, but offset by a quarter of a revolution, so it could watch the edge of the sun for mass ejections that are headed toward Earth.

Even those schemes won't yield foolproof warnings, however, until some remaining scientific issues are cleared up. Bruce Tsurutani of the Jet Propulsion Laboratory and Walter Gonzalez of the National Institute of Space Research in São Jose dos Campos, Brazil, have found that only about one mass ejection in six is accompanied by a southward magnetic field strong enough to cause a large storm. Just why is still not known. One factor may be how fast the mass ejection plows through the solar wind, compressing and intensifying the fields ahead of it. Large storms may also be favored by episodes of southward field on the sun or in the solar wind—and investigators are still unsure what causes those episodes, or how to predict them.

But another plan might give reliable—albeit very short-term—warnings even before those issues are resolved. The idea, as Hildner describes it, would be to recreate the success of ISEE-3 by stationing a monitor upwind of Earth at the L1 point. By recording both mass ejections and the accompanying magnetic fields, such a solar wind sensor "could give an hour's warning [of a magnetic storm] with almost 100% certainty," he says. "That way, you'd know when the dam had burst and the flood had started toward you." An hour may not sound like much time, but Hildner says it would be enough for utilities, satellite operators, and communications networks to prepare for magnetic havoc.

The Department of Energy and the Air Force are cheering NOAA on in its campaign for a solar wind monitor, Hildner says, and several private space companies are interested in launching and operating the probe and selling the data to NOAA. The worst magnetic storms of this solar maximum may have come and gone before any such warning system gets off the ground. But before the solar cycle peaks again, bringing a new season of magnetic storms, the deep space weather station may be on site.

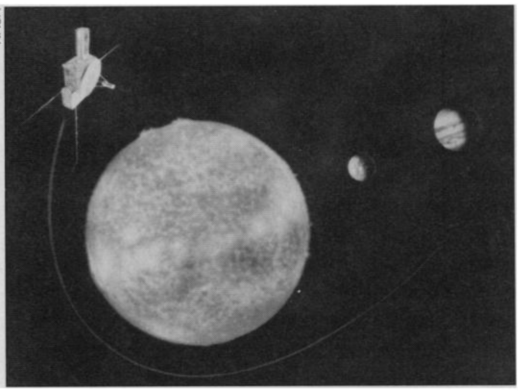
■ TIM APPENZELLER

Boom and Bust at Jupiter

When the Ulysses spacecraft swung by Jupiter early this month on its way to study the sun's polar regions, the U.S. and European scientists monitoring its transmissions got a big surprise. Since Jupiter was last visited, by the two Voyager spacecraft in 1979 and 1980, the planet's enveloping magnetosphere has swollen to twice its former size. Now scientists are wondering what periodically pumps up the magnetosphere—a teardrop-shaped region of ionized gas, or plasma, trapped by the planet's magnetic field. A likely candidate: the erupting volcanoes of the Jovian moon Io.

In retrospect, Ulysses scientists say, they might not have been so surprised by the size of the magnetosphere if they had taken full account of some earlier observations. The Voyager encounters had led them to predict that Ulysses would not reach the bow shock—where the plasma wind that streams out from the sun slams into the magnetosphere—until the spacecraft came within about 4 million kilometers of the planet. But the two Pioneer spacecraft, which visited Jupiter in 1973 and 1974, had sometimes encountered the bow shock at 8 million kilometers out, notes space physicist Edward Smith of the Jet Propulsion Laboratory, who is NASA's project scientist for Ulysses. And as it happened, that's just where Ulysses' bow shock crossing came.

The big question now is what is driving these changes in the size of Jupiter's magnetosphere. Part of the answer undoubtedly lies in changes in the solar wind, says Smith. The greater its speed and density, the more it will compress the leading edge of the teardrop magnetosphere toward the planet. When Ulysses approached Jupiter, Smith notes, the solar wind pressure was down, so an expanded magnetosphere might have been expected.


NASA

Farewell to Jupiter. *Ulysses reaches the sun.*

But Smith suspects the solar wind is not alone in shaping Jupiter's magnetosphere. And that's where Jupiter's satellite Io comes in, because it has a clear influence on the magnetospheric plasma. Orbiting 0.4 million kilometers from the planet, Io has active volcanoes that spew towering plumes of sulfur dioxide. Indeed, a ton of that sulfur dioxide escapes from the satellite's gravity every second to be dispersed as plasma throughout the Jovian magnetosphere. Like air blown into a balloon, the Io plasma could be inflating the magnetosphere, Smith says.

But too much added plasma could make the magnetosphere go bust. Load the magnetic field lines with Io plasma, as might happen at times of heightened volcanic activity, and they might collapse into a more compact arrangement, shrinking the magnetosphere. Io has been relatively quiet in the past year, but it was quite active a decade ago, when the Voyagers saw a shrunken magnetosphere.

The realization that Io may be inflating and collapsing the parent planet's magnetosphere wasn't the only surprise to emerge from Ulysses' brief Jupiter encounter. The Jovian magnetosphere has also changed in character since it was last studied. The smaller magnetosphere charted by Voyager had a simple configuration. What Ulysses found in the outer reaches of the swollen magnetosphere was quite different: an unruly jumble of changing fields and plasma flows. Deeper within the magnetosphere lay another striking change: The equatorial disk of dense plasma, which may be fed by Io, was far larger than it was before. Team member Andre Balogh of Imperial College, London, thinks that blobs of plasma flung off the edge of this disk may be contributing to the commotion in the outer magnetosphere.

Researchers don't know exactly how the tug of war between Io and the solar wind might be producing this Jekyll and Hyde magnetosphere. And because Ulysses will never return to Jupiter, magnetospheric researchers eager to learn more have to wait at least until 1995, when the Galileo probe will make its rendezvous with Jupiter. The wait will be even longer, of course, if JPL's engineers don't succeed in straightening out Galileo's crippled main antenna before then.

■ RICHARD A. KERR