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COVER: Europa, one of Jupiter's four major satellites, shows a tangle of streaks probably representing cracks in the icy crust, though vertical relief on the smooth object's surface may be as low as tens to hundreds of meters, perhaps because of the effect on the ice of heating due to tidal dissipation. Photo by the Voyager 2 spacecraft. For story and more photos, see story beginning on p. 35. (Photo: Jet Propulsion Laboratory)

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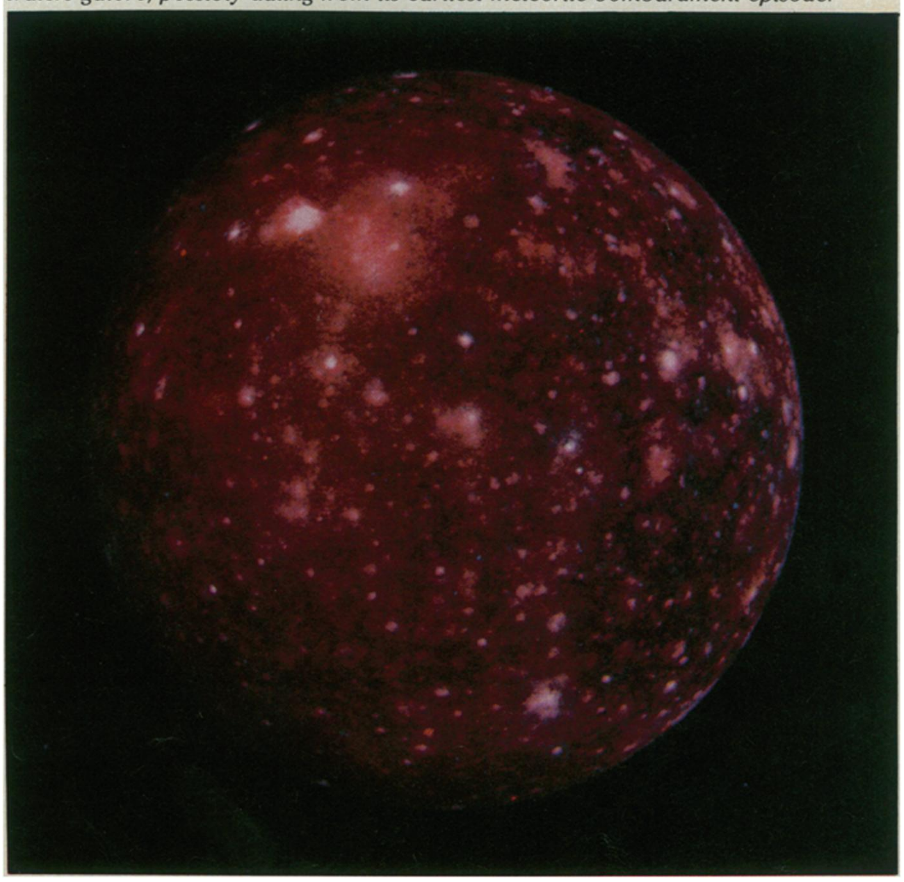
SCIENCE NEWS OF THE WEEK

The Worlds of Jupiter

Photos: Voyager 2/JPL

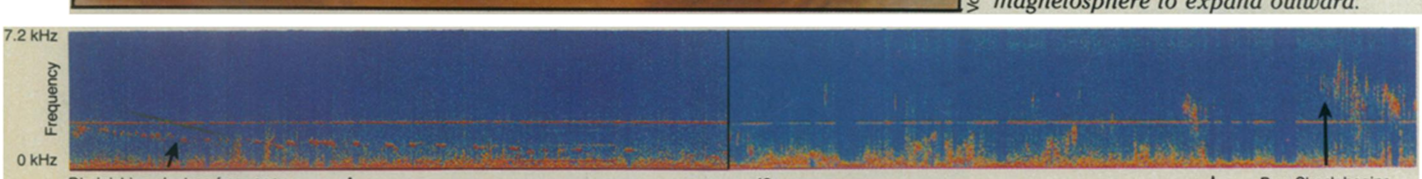
Ganymede (above) suggests a complex evolution with a long cratering history, a huge, ancient basin and possibly tectonic faulting. Callisto (false color image, below) shows craters galore, possibly dating from its earliest meteorite bombardment episode.

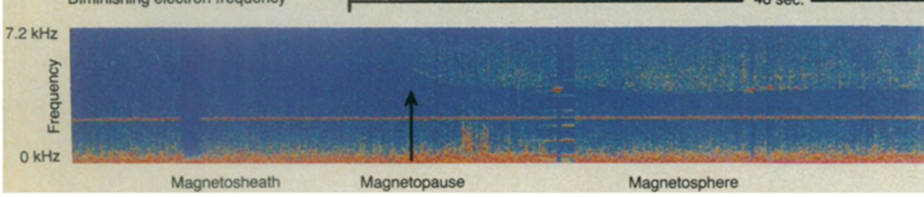


Voyager 1 & 2/JPL

Voyager 2 photo/Data: A. F. Cook II/Graphics: John R. Ellis

New views of Jupiter: Photos of the planet by Voyager 1 (top) and 2 (second from top) have been computer-combined into cylindrical projections, then shifted so that their longitude scales are aligned. Besides showing substantial cloud-pattern changes in the four months between photos, the images illustrate that the Great Red Spot, longest-lived major feature in the Jovian clouds, is not fixed but drifts around the planet. Other computer processing created the Voyager 1 north-polar stereographic projection at left, on which the Smithsonian Institution's Allan Cook has noted that subsequently detected lightning (locations circled) has seemed to occur at or near latitudes associated with strong, westward-blowing winds. Such winds, he says, are in turn often associated with regions of presumably convective upwelling, suggesting a link between upwelling and Jovian lightning, whereas pressure fronts, a key factor on earth, are probably only a "minor contributor" on Jupiter. Plasma-wave data (below) show changing frequency spectrum (vertical axis) versus time (horizontal axis) as Voyager 2 entered Jupiter's magnetic field. Diminishing electron frequency (left portion of upper graph) suggests decreasing solar-wind pressure, allowing the shock wave, or bow shock, around the Jovian magnetosphere to expand outward.





Further in, the spacecraft passed from the compressed region (magnetosheath) that exists behind the bow shock through the boundary (magnetopause) that separates it from the central part of the field.

F.L. Scarf, W.S. Kurth, D. A. Gurnett, P. Jepson

Voyager 2: The visible and the invisible

"Some months ago," says Laurence A. Soderblom of the U.S. Geological Survey, "we thought we had some idea of what planets were like." Then came the two Voyager spacecraft missions to Jupiter and its major satellites, providing a host of dramatic new findings from which Soderblom and his scientist-colleagues "discovered how narrow our vision really was." Much of the excitement came from the exotic moons, which turned out to be radically different not only from one another, but from virtually every other body yet studied in the solar system. Jupiter itself had already been visited on two previous occasions — by the Pioneer 10 and 11 spacecraft in 1973 and 1974, which gave only fleeting glances at the satellites. Yet with Voyager 2's data barely out of the computers and Voyager 1's only four months older, the giant planet is already revealing new secrets — and sometimes in subtle ways.

A key question, for example, has long been that of the driving force behind the famous Great Red Spot, a huge feature in the Jovian cloud tops, big enough to contain more than a dozen earths. Spacecraft photos had confirmed it to be a circulation pattern, but scientists were unsure whether it was drawing its substance from its rim or pulling it up from the depths of Jupiter's atmosphere, as indicated by whether material in the spot was spiralling into or out from its center. The answer would bear significantly on understanding of the chemistry of the atmosphere's brilliant colorations, as well as on the role of the deep atmosphere in the complex cloud motions of which earthly observers (and spacecraft) have seen only the tops. The search for "divergence" — the expected outward movement atop a rising convective cell — is painstaking and lengthy from even such sharp photos as Voyager's, but last week, Garry Hunt of University College London suggested that a preliminary answer has been found: A pattern of wind speeds and directions at different altitudes in the spot, calculated from infrared temperature measurements, has revealed signs of divergence even though they have not yet been identified in the images. The amount is small, according to Hunt, but that need merely mean that the process is relatively slow. On Jupiter's vast scale, even a little such motion could represent the upwelling of huge quantities of material.

Whatever their source, however, the nature of the coloring agents remains elusive. The planet is mostly hydrogen with a bit of helium, in a ratio close to that of the sun. (If earth had enough hydrogen, compared to the silicon in its rocks, to equal the sun's hydrogen:silicon ratio, says Andrew Ingersoll of California Institute of Technology, our planet would have the mass of Saturn.) The colors come from comparatively tiny traces of other molecules — "dirt on the skin of the orange," says one Voyager researcher — that may be interacting in complex ways. The Voyagers have detected some such "pollutants" (largely confirming, though with greater precision, earth-based measurements), but their working chemistry has yet to be unraveled. Hypotheses include organic polymers for the yellows, browns and oranges; large phosphorus molecules (P_4) for the Red Spot's red; ammonium hydrosulfide for white and monosulfide for yellow; and more. The problem is made tougher by the fact that, at different temperatures, some elements such as sulfur have different molecular structures — and different colors. Voyager data should help, but the best aid will be an actual dive into the Jovian atmosphere by a probe from the Galileo mission in the mid-1980s.

Many of Jupiter's most spectacular features, however, are not brightly colored at all; in fact, they are invisible. The planet's gigantic magnetic field, which has been called "the largest structure in the solar system," encompasses all of the Galilean satellites, produces seething radiation belts and other effects, and accelerates some particles perhaps as far as the sun.

Outside the field's sunward side is a shock wave, or bow shock, formed where the field abruptly stops the incoming solar wind and diverts it sharply around the planet while still millions of kilometers away. The Pioneer 10 and 11 spacecraft discovered, however, that the bow shock varies greatly — and rapidly — in its distance from Jupiter, which surprised scientists until they concluded that this was probably due to variations in the solar wind's pressure. Jupiter-bound spacecraft have thus crossed the bow shock on multiple occasions as it moved in and out, and plasma-wave detectors aboard the Voyagers have now apparently spotted the titanic shoving contest actually in progress. The sensors have recorded the radio emissions of sun-bound electrons from Jupiter outside the bow shock as their radio frequencies dropped, suggesting a decrease in solar-wind pressure that ought to let the bow shock expand outward. Sure enough, it followed close behind.

Another Jovian spectacular exists just inside the edge of the field (the magnetopause), where Voyager 1's low-energy charged-particle instrument detected what S. M. Krimigis of Johns Hopkins University calls "the highest temperature in the solar system" — 300 million to 400 million degrees, considerably hotter, he says, than any part of even the sun itself. Passing through the region some 5.6 million kilometers from Jupiter, the spacecraft was not consumed because, says Krimigis, the super-hot particles are so sparsely distributed — about 200 ions per cubic foot. (In fact, says a colleague, much of the region inside the magnetosphere includes "the solar system's best vacuum," far emptier than most of interplanetary space, since the bow shock keeps out particles from the solar wind, while Jupiter's own magnetically trapped particles are largely confined to a flattened disk.)

The field's mixture of trapped particles also changes rapidly in short periods of time. Voyager 2, for example, detected only about a tenth as many high-speed carbon and sulfur ions as did Voyager 1 only four months before, but a much higher carbon-to-oxygen ratio.

One major product of the field is the region of brilliant auroras discovered around the planet by Voyager 1 and further studied by its successor; yet this, too, is a fickle thing, since the auroras seem to have been virtually absent during the Pioneer 10 and 11 visits a few years before. For now, they are bright indeed. On earth, says Voyager project scientist Edward C. Stone of Caltech, an aurora with a brightness of 1,000 Rayleighs is just at the threshold of visibility; 40,000-Rayleigh auroras are clearly visible, but common enough to appear nightly in some places, and 100,000-Rayleigh auroras show up about once a month. The Jovian variety, he says, have been measured at 60,000 Rayleighs *in the ultraviolet,* which means that they are more energetic still.

One likely source of the charged particles that make Jupiter's auroras visible, Voyager data suggest, is the planet's bizarre satellite Io, from whose surface material is variously sputtered, ejected and/or otherwise cast forth into a huge torus that extends around Io's orbit. Ultraviolet scans of the ring-shaped auroral region around the Jovian north pole indicate that it is located at the latitude of the magnetic field lines that connect Jupiter with the torus. This suggests, says Stone, that the torus somehow causes a flow of energetic electrons along those field lines, producing the auroral effects seen by the Voyagers. (About three tons of material per second is kicked into the torus from Io's surface, estimates George L. Siscoe of UCLA, most of which is carried around and lost down Jupiter's magnetic tail. Over Io's lifetime, a colleague calculates, this would have reduced the satellite's total mass by about 0.3 percent).

Io's numerous exotic features — including active volcanoes, sulfurous chemistry and fast-changing, multicolored surface — have made some researchers yearn for a spacecraft that could be sent to land there. Within the bounds of present, reasonable technology, however, it is again Jupiter's magnetic field that controls the show, by bathing Io in the constant, intense radiation of trapped, charged particles that could be lethal to electronic equipment. Even far from Io (and farther from Jupiter than was Voyager 1), Voyager 2 suffered some radiation effects, albeit apparently temporary ones. □