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OF THE WEEK



RESEARCH NOTES



ARTICLES



DEPARTMENTS



**COVER:** This mosaic of Jupiter was assembled from six violet images taken by Voyager 1 at a distance of 6.5 million km (4 million miles) as it closed in on the planet and its surprisingly diverse satellites. See p. 147. (Photo: NASA)



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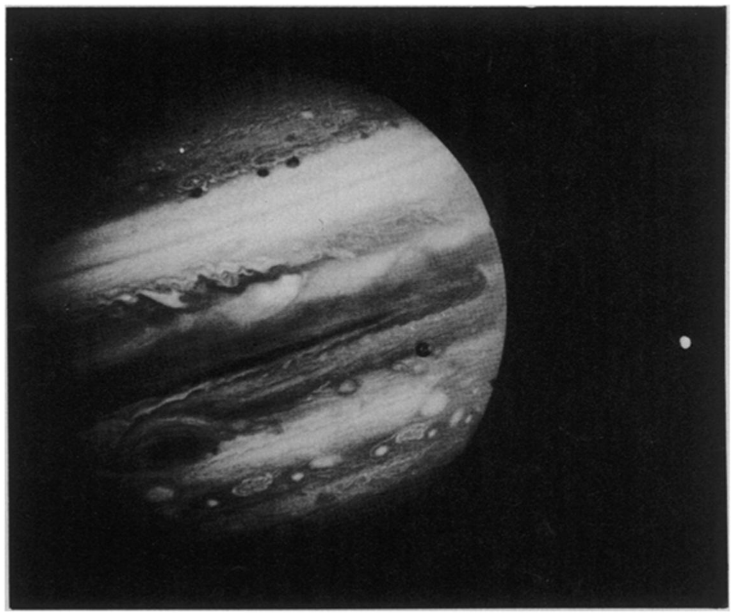
# Jupiter's World




*Jupiter, its Giant Red Spot and three of its four largest satellites visible in photo taken Feb. 5 by Voyager 1 from 28.4 million km (17.5 million miles).*

Jupiter is many things: It is a giant world, embodying within itself more than 70 percent of all the mass in the solar system that did not end up in the sun. It is the heart of what amounts in many ways to a miniature solar system in its own right, its major moons oddly filling the roles of the planets of a star. It is a mighty dynamo, generating a force that binds self and satellites in a unique electromagnetic realm that has itself been called "the largest structure in the solar system."

Together with its moons, Jupiter has also been the initial goal of the Voyager spacecraft, which this week climaxed its 18-month journey from earth by revealing new wonders of the huge world in all of its diverse aspects. In so doing, the craft had to undergo a trip through the planet's intense radiation belts and the 400,000-volt "flux tube" connecting Jupiter with its moon Io, providing data for the mission's more than 100 scientists.

The only other probes to visit the planet were Pioneer 10 and 11 in 1973 and 1974, which photographed a regularly banded world with an exotic but apparently well-controlled circulation system that wrapped it in seemingly stable bands of multicolored cloud. For centuries, earth-based observers have known that Jupiter's visible cloud top is a changeable place, but not even the Voyager researchers were prepared for what they found. "For the most part," says imaging-team leader Bradford Smith of the University of Arizona, "the existing atmospheric circulation models have all been shot to hell by Voyager." Jupiter, he says, is "far more complex in its motions that we have ever imagined."

Besides its stripes, Jupiter is famous for its Great Red Spot, large enough to hold several earths, and the Pioneers revealed a host of other light- and dark-colored spots apparently representing circulation cells of varying dimensions. Voyager 1 found all that and more — and in turmoil. Narrow bands have consolidated and widened, wide ones have come to pieces, and a major finding of the encounter has been that material is often transferred between bands, rather than sticking to isolated paths. In a group of "movies," patiently assembled from still photos, one of the many round spots circuiting the planet is seen to overtake another and roll around it several times before being ejected in another direction. Linear flows diverge, vortices reverse direction, and the tortuous currents and flows thrashing the Great Red Spot have been compared to a down-the-curl view of waves beating on the shore.

A major part of the mission's excitement, in fact, says Andrew Ingersoll of the California Institute of Technology, is that amid such rabid turbulence, some features have managed to survive for so long. The Great Red Spot, the prime example, has been known almost since telescopes were first turned toward the planet. On the other hand, three large, white ovals, says Smith, "are what is left of a wide, white belt that circled the planet in the 1930s." Lesser features have been seen to change in less than Jupiter's 10-hour period of rotation.

And yet, maintains Garry Hunt of Uni-

*The Giant Red Spot, one of several white ovals that once formed a white belt around the planet and complex turbulence patterns resembling curved sawteeth.*

versity College in London, it is important to realize that the strangeness of Jupiter can still be described within the perceptions of meteorology and other sciences that apply to the earth — Jupiter is not, says Hunt, the repository of a new physics. The Red Spot, for example, he says, is not unique, only bigger. One category of almost indescribably complex turbulence patterns between adjacent flows — something like highly curved sawteeth — turns out to have a remarkably close analog in classical, terrestrial fluid dynamics, when separated parallel flows reconverge behind an obstacle.

Still, striking reds, oranges, yellows, browns and even blues make Jupiter's convoluted patterns seem all the more fantastic. Turbulent interfaces analogous to jetstream interactions high in earth's atmosphere become twisted riots of color. They appear stranger still because the clashing hues often look sharp-edged down to resolutions as fine as 25 kilometers. A major goal of Voyager is to find out the nature and chemistry of the coloring agents — the Red Spot, for example, is now not red but orange-ochre, embellished in some views with white. Phosphene and other candidates have been suggested, but they have been far from certain.

Important to such questions is Voyager's infrared radiometer/spectrometer, capable of measuring the five-micron wavelengths that represent heat leaking out through the blues, browns and dark reds believed often to indicate "holes" into the atmosphere's depths where the chemistry may begin. Earth-based studies have identified five-micron "hotspots" through which at least three major cloud levels have been seen: a high, white stratum of frozen ammonia crystals, a brown middle layer and what may be the deepest "windows" of all, regions of oddly earthlike blue. The five-micron band is the key, says Richard J. Terrile of Jet Propulsion Laboratory in Pasadena (the Voyager control center), because it is not absorbed by overlying gases. Terrile has been studying Jupiter at five microns since 1973, "and every year," he says, "something's different." Five-micron source regions the size of the earth vary by 40°C in only four earth-days as they change altitude, he says, and there can be as much as 60 km between the highest such regions and the lowest at a given time.

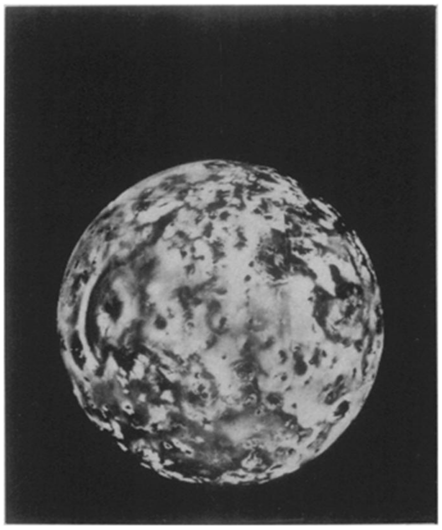
But Voyager 1 has had far more to see in Jupiter's vicinity than just the planet itself. The idea of a miniature solar system stems in large measure from the four moons known as the Galilean satellites — Io, Europa, Ganymede and Callisto, in order of increasing distance outward. Like the solar system, with four rocky planets near the sun and Jupiter and Saturn outboard, the Galilean satellites get lighter as they get farther from Jupiter. Ganymede and Callisto, in fact, are barely twice as dense as water, almost surely suggesting that about half their bulk is just that. The oddity is that those two objects, which ought to be ice-shiny to telescopic observations, are less reflective than either Io or Europa. However, the big four (all but Europa are bigger than earth's moon, and Ganymede is bigger even than Mercury) are anything but a matched set. And Voyager 1's sharp close-ups of them have produced as much if not more excitement than those of Jupiter itself.

Io is unquestionably the odd moon out. Constantly bombarded by charged particles trapped in Jupiter's prodigious magnetic field, it is wrapped in a faint, glowing veil of sodium atoms (intensely studied by Voyager), generates a torus of sulfur ions that encompasses its entire orbit, and has been linked in past studies with emissions of potassium and hydrogen. The magnetic field lines passing through Io apparently close a circuit through what may be electrically conductive salts on the satellite's surface, forming a "flux tube" estimated to carry a current of a million amperes at 400,000 volts. But Voyager has made Io more dramatic still. Infrared studies from earth revealed the presence of singly ionized sulfur around its orbit, but Voyager 1's ultraviolet spectrometer has produced spectra indicating temperatures so high as to imply a far richer presence of doubly ionized sulfur — perhaps 10 to 50 times as much as the lower-temperature species.

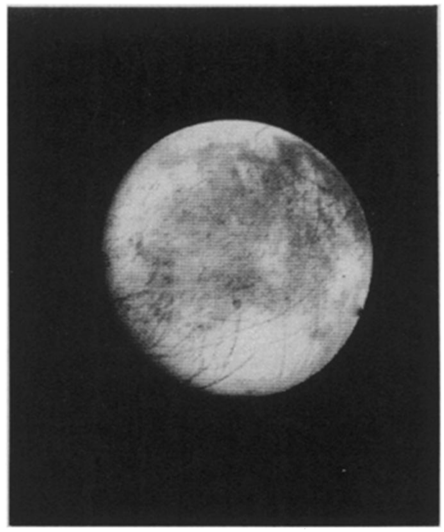
But it was Io's face, not its halo, that got the attention during a specially planned intensive study of the weird moon. Observations from earth had already indicated Io to be yellowish, with reddish polar regions. Evidence has suggested a possible surface of water-soluble, evaporite salts (whose deposition could have contributed to Io's being the only Galilean satellite with no water in its spectra), and early looks at Voyager 1's data seemed consistent with the possibility. A red and yellow surface, flashed with white and pocked with seemingly jet-black pits, everywhere exhibits a characteristic odd, smoothed-over appearance to angles, planes and contours that makes them almost seem to have been "sanded down." More important, although the surface shows a variety of large-scale relief such as possible hills, a strange circular feature some 1,500 km across, and etched-looking regions suggestive of the so-called "collapsed terrain" on Mars (tentatively attributed in that case to rapid melting of subsurface permafrost), Io seems to show an almost complete lack of craters. Judging from lunar studies of the number of craters that ought to have formed through time, says Laurence Soderblom of the U.S. Geological Survey, implies that Io's currently exposed surface may be startlingly young — possibly less than 10 million years. A priority task for Voyager's scientists and others will be to discover what process — salt migration, internal upheavals, charged-particle bombardment from Jupiter's magnetic field — could have done the job.

Whatever the answer, says Soderblom, the complexity of Io's surface features is "mind-boggling." As for the lack of water, the University of Hawaii's David Morrison commented early this week that Io might be seen as a sort of metaphor for a planet earth that had been similarly heated (such as by evolving so close to Jupiter).

An opposing metaphor might be in-

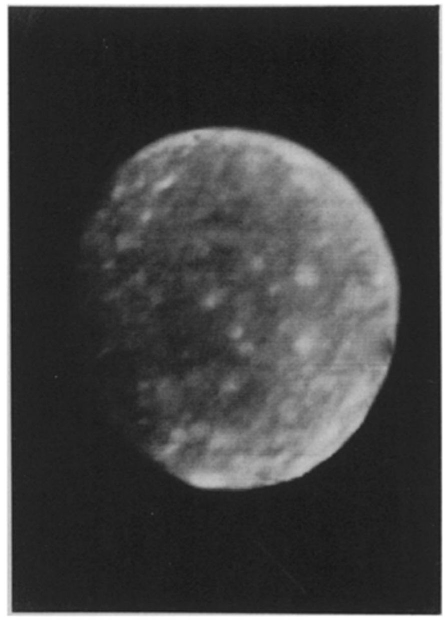


*Io: A red and yellow, craterless surface.*



*Europa: Orange-hued with long streaks.*

*Ganymede: A few craters and possibility of internal, earthlike heavings.*



*Callisto: Many craters and at least one large, basin-like feature.*

ferred from the appearance of the next moon out, Europa, which has an earthlike density but the high reflectivity that has suggested (in earth-based studies) an ice-rich surface — like a watery earth that had been frozen. The reasons for that are yet unclear, but Europa, a lightly orange-hued off-white and the least contrasty in appearance of the four satellites, has its own visible distinctions. Again there are few if any craters, or even bright spots, but there are numbers of vast, linear features — some of them 100 km wide and thousands of kilometers long and described in one early interpretation as being "on the scale of the grand canyons of Mars," though they may turn out to be mere surface streaks.

Next out is Ganymede, the inner of the two low-density iceworlds. And at last, there are some craters — more of them than in the Lunar Maria (which have been partially filled by basaltic flows), but without the shoulder-to-shoulder big ones that typify the older Lunar Highlands. "We don't even see the *scars* of the big ones," said Soderblom after an early look. Yet if they were simply erased by time, he believes, there ought to be traces of large craters in various stages of degradation. A surface or subsurface of ice, he says, also ought to leave at least some remnant. Another mystery?

What Ganymede does have, however, may be considerably more momentous — perhaps one of Voyager's major findings, if early speculations are correct. For scattered across the large moon's face are numerous linear features that, according to Soderblom, appear to be surface manifestations of transverse faulting, some of them representing hundreds of kilometers of movement. If so, he says, they would provide the first substantial evidence of an extraterrestrial body with symptoms of the same kinds of internal heavings that give rise to earth's tectonics.

The outermost of the Galilean satellites is Callisto, just a bit smaller and a bit less dense than Ganymede, and thus with perhaps a bit less rock at its center to contain heat-producing radionuclides. Perhaps Callisto cooled sooner, and got a little harder (being farther from Jupiter's own heat) — which might be why it seems to have as many as 10 times the number of craters as Ganymede. It seems to lack Ganymede's apparent fractures, but it does have at least one large, basin-like feature enclosed by concentric circular forms totaling a diameter of perhaps more than 1,500 km. Like Ganymede, however, it seems to have an unusually smooth limb, or edge, suggesting that its surface can't support much vertical relief — that it perhaps gives in to hydrostatic equilibrium instead of raising mountains.

Also on Voyager 1's satellite schedule was Amalthea, closest-in of Jupiter's moons (though not one of the Galilean satellites). So tiny that little is known about it and too far from the spacecraft's path for a clear photo, reddish Amalthea nonetheless garnered attention when images indicated it to be nearly twice as big in one dimension as in the other, which would make the most elongated moon yet measured in the solar system. The only known skinnier planetoids are a couple of asteroids — which Amalthea may once have been.

But there's more than moons around the huge planet. A bright streak in a single photo indicates what Smith describes as "a thin, flat ring of particles surrounding Jupiter," making it the third known ringed world in the solar system. Probably well under 30 km thick — it was seen edge-on — the apparent ring is at least 9,000 km wide, with its outer edge some 57,000 km from the planet. The probable small size of the ring particles (an early estimate was tens to hundreds of meters) poses dynamical problems for theorists studying the ring's survival through the eons, and the data are limited. But Voyager II will take a more deliberate look in July, and there may be signs of the ring's presence in micrometeroid and charged-particle data from Pioneers 10 and 11.

Jupiter's other role is as the producer of a huge magnetic field that extends millions of kilometers into space, encompassing all the Galilean satellites (and the presumed ring) and linking them far more intimately than the planet-moon families of, say, the earth or Mars. It relates to Io's flux tube and various emissions, as well as to Jupiter's own radio emissions and far flung electron bursts. Darrell Strobel of the U.S. Naval Research Laboratory has even hypothesized that oxygen from the Galilean satellites may be transported by the fields to Jupiter, forming carbon monoxide in the Jovian upper atmosphere — moons providing atmosphere to their host's planet. Perhaps it is reasonable to consider the field as a, or the, operative entity, with planet and satellites existing as nodes within it. □