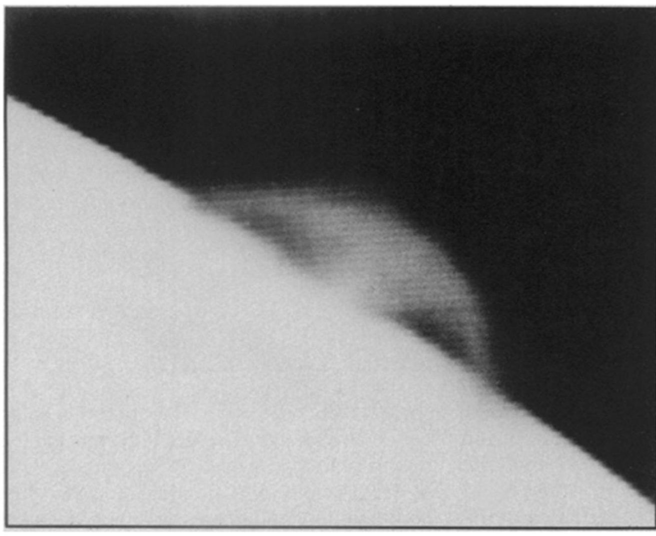
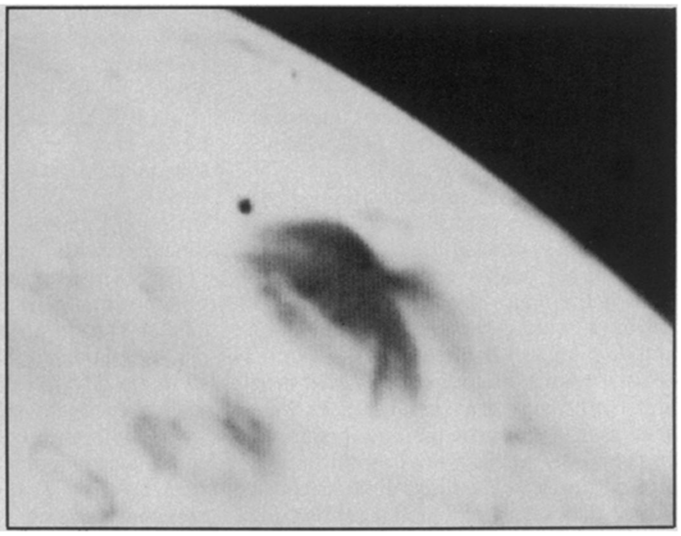
Voyager 1: Active Io, Jolting Jupiter





Huge volcanic plume of dust and gas (top) and dark streamers (right) reveal Io as the only other known active, rocky planetoid.

Since the earliest days of the Space Age, scientists have hoped that one of the spacecraft being sent out among the worlds would find another active planet besides the earth. The already complex consequences of the earth's evolution are further distorted by plate tectonics, drowned beneath oceans and eroded by weather and climate, making the picture of our geologic past a staggeringly difficult one to assemble. The moon turned out to be essentially dead, as did Mercury. There were higher hopes for Mars, but they have yet to be borne out. Radar studies of Venus indicate some surface shapes that may have resulted from tectonic processes in the past, but it is difficult to predict what it will take to see whether the haze-shrouded planet is still churning away. Little objects — the moons of Mars, most asteroids — probably don't have enough heat-producing radionuclides or enough mass (for gravitational heating) to have kept internal fires alight throughout the billions of years of the solar system's lifetime. The big, gassy planets — Jupiter, Saturn, Uranus and Neptune—hardly even count; either there are no solid worlds at all beneath the clouds, or their atmospheres are so thick that finding signs of internal upheavals may be all but impossible.

But the prize has been found. Some scientists have allowed that no other finding in planetary research short of extraterrestrial life would be so significant. And making it all the more dramatic is the fact that, if the early front-runner among explanations for the momentous find is correct, it could be the only other active hardrock world besides the earth now circling the sun.

Its name is Io. One is almost tempted to add "of course," since Io has acquired a reputation even from earth-based studies as perhaps the strangest planetary body yet to be examined. Neither Saturn's rings nor the controversial channels of Mars can compete as sheer exotica with Io's red-gold-and-then-some surface, its various atomic and ionized veils and tori, and the electrically conductive "flux tube" that connects it with Jupiter. But this latest contribution from the Voyager 1 spacecraft's data makes the 3,640-km satellite's other oddities seem almost pallid by comparison.

The discovery was made not by one of Voyager's scientists at all, but by Linda Morabito, who works on the project's "optical navigation" team, plotting spacecraft positions and planetary ephemerides by careful comparisons with the known positions of the stars. On March 9, she was looking at an image of Io's limb, or edge, that had been deliberately overexposed to bring out the stars and to make the limb crisply visible for measuring. While attempting to fit a precise mathematical curve along the limb (in order to locate the exact center of Io's disk), she noticed an odd, mushroom-shaped feature extending off the limb for several hundred kilometers. Consultation with other OpNav workers and with scientists on the imaging team soon led to the conclusion: The feature was a volcanic plume, a cloud of dust and gas being tossed far above the surface by a violent eruption that was taking place even as the spacecraft's camera took its picture. It was not just "signs of an eruption," or even a "geologically recent" one (which could refer to a hundred-million-year-old event in the solar system's vast lifetime), but an actual eruption in progress. And You Are There.

A hurried look at more Io close-ups revealed at least three more plumes as well as several "probables" and a few "possibles." The height of the plumes suggests that the material was spewed forth with velocities as high as a kilometer per second or even more (compared with Io's escape velocity of about 2.5 km per second). Some major eruptions from earth's Mount Etna have been calculated to have velocities of a mere 51 *meters* per second, which could make Io not only a still active world, but one far more so than the earth. In fact, says an imaging-team summary, Io appears to have "by far the most active surface in the solar system." Before the discovery was made, Voyager researchers had already asserted from Io's lack of impact craters that the surface could be less than 10 million years old. In fact it was changing even as Voyager 1 looked on, and is slightly different now than it was when the pictures were taken.

Nor are the plumes the only signs of Io's

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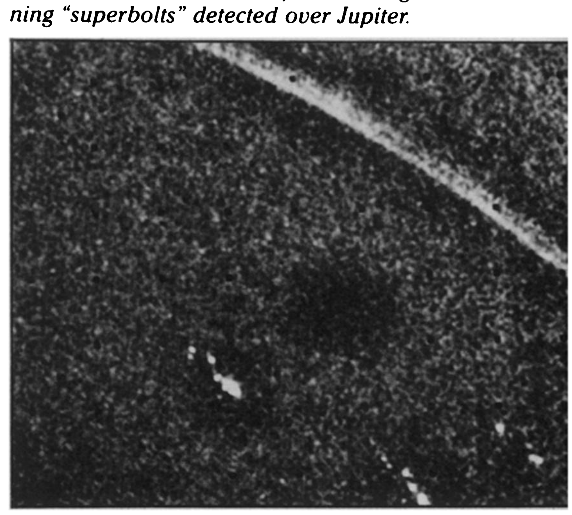
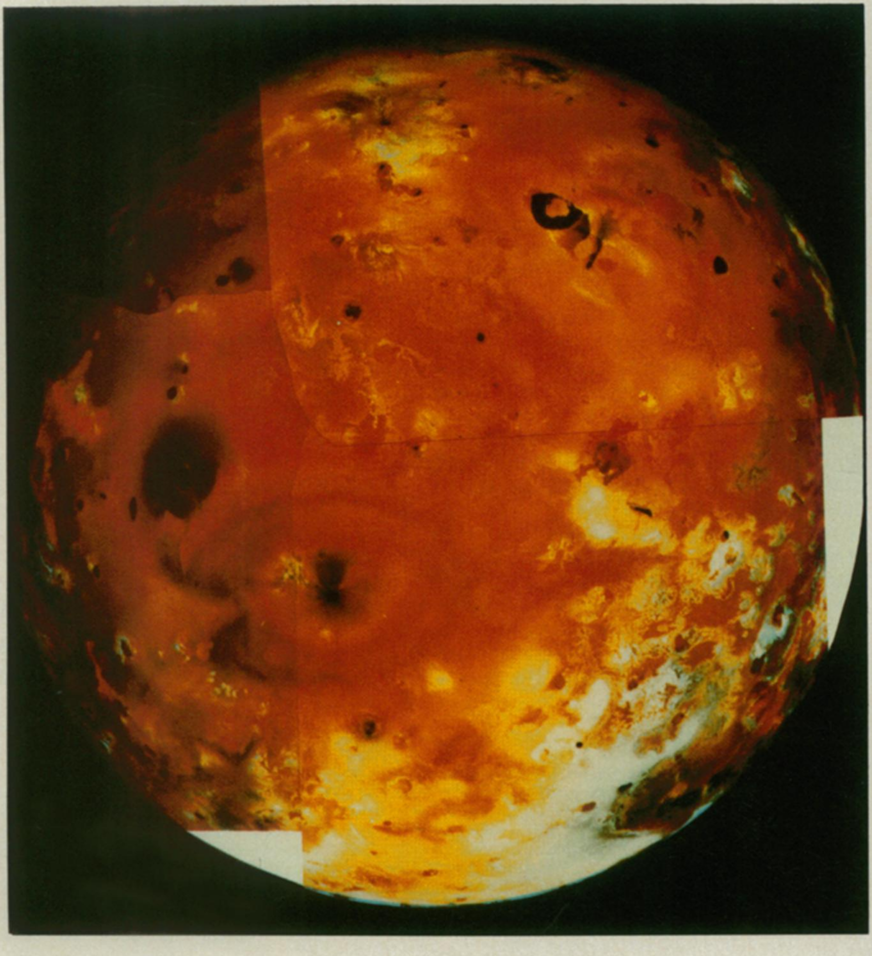
Vast northern aurora and probable lightning "superbolts" detected over Jupiter.



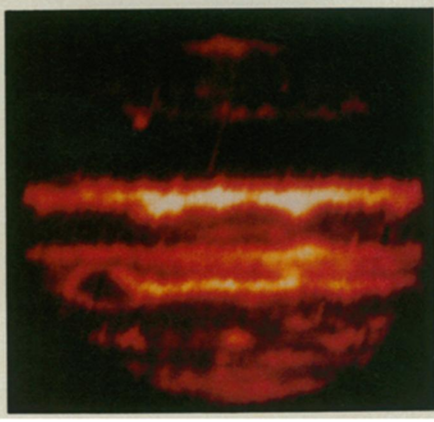
JUPITER & FAMILY

Photos: Voyager 1/NASA

Large brown oval (above), informally known as "the barge," may represent an opening in Jupiter's upper cloud deck through which the atmosphere's deeper chemistry can be seen; to the north, the North Temperate Current whips by at speeds of more than 400 kilometers per hour. Jupiter's spectacularly colored moon Io (below) shows diverse details including a ringlike area (below left of center) from which apparent volcanic emissions have been observed and a dark feature (upper right) tentatively identified as a "lava lake." Sequence of images at right shows the complex face of Jupiter as photographed by Voyager 1 (top), the more regularly banded planet seen by Pioneer 10 in 1973 (middle), and an earth-based infrared image—from the same date as the Voyager photo—indicating five-micron "hotspots" believed to represent differing altitudes in the clouds.



Pioneer 10



R. J. Terrile with 5-meter Hale telescope, Palomar Mtn.

... Jupiter

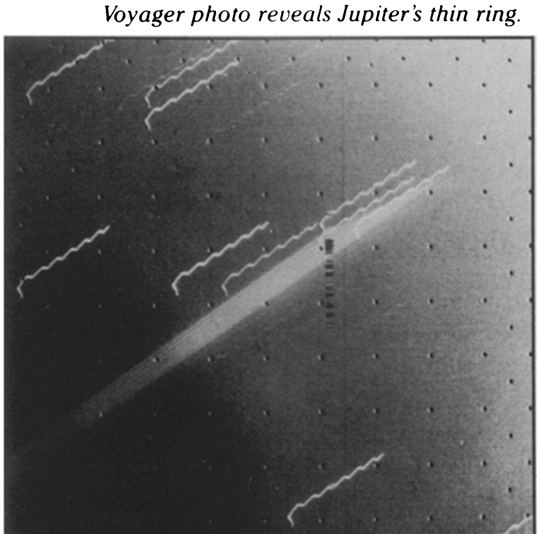
liveliness. Voyager 1's infrared sensor has detected what appear to be three molten "lava lakes," one of them the size of "the whole state of Hawaii." Team leader Rudolf A. Hanel of NASA's Goddard Space Flight Center calculates that the three regions are at temperatures between 100° and 200° F, compared to the −260° F of their non-volcanic surroundings.

It is possible, according to Torrence Johnson of JPL, that the eruptions may also contribute to Io's various hazes, as well as to the multi-element torus that circles Jupiter along Io's orbit. Sulfur has long been a suspected candidate as a major surface constituent on the satellite, and volcanic gases such as sulfur dioxide and hydrogen sulfide are light enough, Johnson says, that they could stay aloft long enough for various "escape mechanisms" to sweep them into the torus.

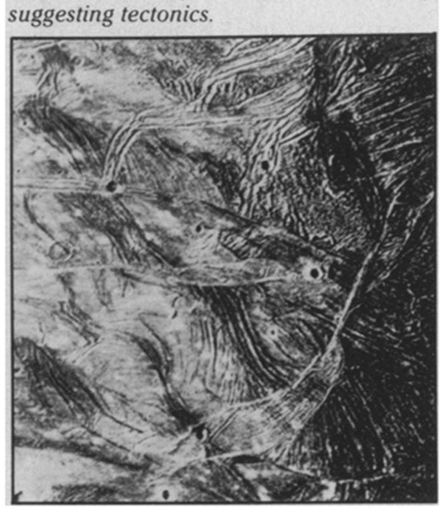
Another component believed to be driven into the surrounding space from Io is sodium, which shows as a golden veil around the satellite by reflected sunlight. The sodium emissions disappear when the atoms are ionized, and the average "lifetime to ionization" of an Io-spawned sodium atom, according to Johnson, is about 20 hours. That, he says, means roughly that if the sodium comes from the volcanoes (instead of being sputtered loose from the surface by charged particles riding in on Jupiter's magnetic field lines, as in past conjectures), the sodium cloud would disappear if the eruptions stopped for much longer than 20 hours— "and we've never seen it do that."

The composition and volume of the volcanic outpourings, along with the rate at which they re-cover Io's surface, may be calculable from other data. But even before the plumes were discovered, a mechanism was proposed that may be able to account for them. According to Stanton J. Peale of the University of California at Santa Barbara, along with Patrick P. Cassen and Ray T. Reynolds of NASA's Ames Research Center, Io may be "the most intensely heated terrestrial-type body in the solar system." The reason, they have reported (in the March 2 SCIENCE), is that Io is continually being stressed — and thus heated — by a gravitational tug-of-war between Jupiter itself and one or two of its other satellites, Europa and Ganymede. Io is gravitationally locked with the same face always turned toward Jupiter, producing a "tidal bulge" on that side. Europa and possibly Ganymede (to a lesser extent) perturb Io's motions just enough to keep its orbit slightly eccentric, so that Jupiter essentially pumps the tidal bulge in and out as Io passes nearer and farther away.

Voyager photo reveals Jupiter's thin ring.



Apparent fault shows 50-km lateral displacement in wide surface streak on Ganymede (above). Closer view of streaks (below) indicates myriad fault lines possibly suggesting tectonics.



None of the moons of Saturn are likely to be in such a state, Peale says, because the inner satellites are too small and the outer ones too far apart. The families of Uranus and Neptune also look negative, he says, and Pluto's tentatively identified single satellite would need a companion to make the tug-of-war work. Thus, unless some yet-unstudied solar-system object is still seething with its own inner fires, Io and earth may be the lone active worlds in the vicinity.

The phenomenon, of course, is far from understood, and the hypothesis of Peale's group was an advance speculation that is yet unconfirmed. How, for instance, asks assistant imaging team leader Laurence A. Soderblom of the U.S. Geological Survey, can Io's south polar region support what appear to be towering mountains if — as the Peale *et al.* hypothesis suggests — Io is molten nearly through and through? Voyager 2, due to pass by in early July, is being reprogramed to take a better look, and the Galileo Jupiter-orbiting mission (due to travel 1,000 km from Io in the mid-1980s) is also likely to have its priorities re-evaluated.

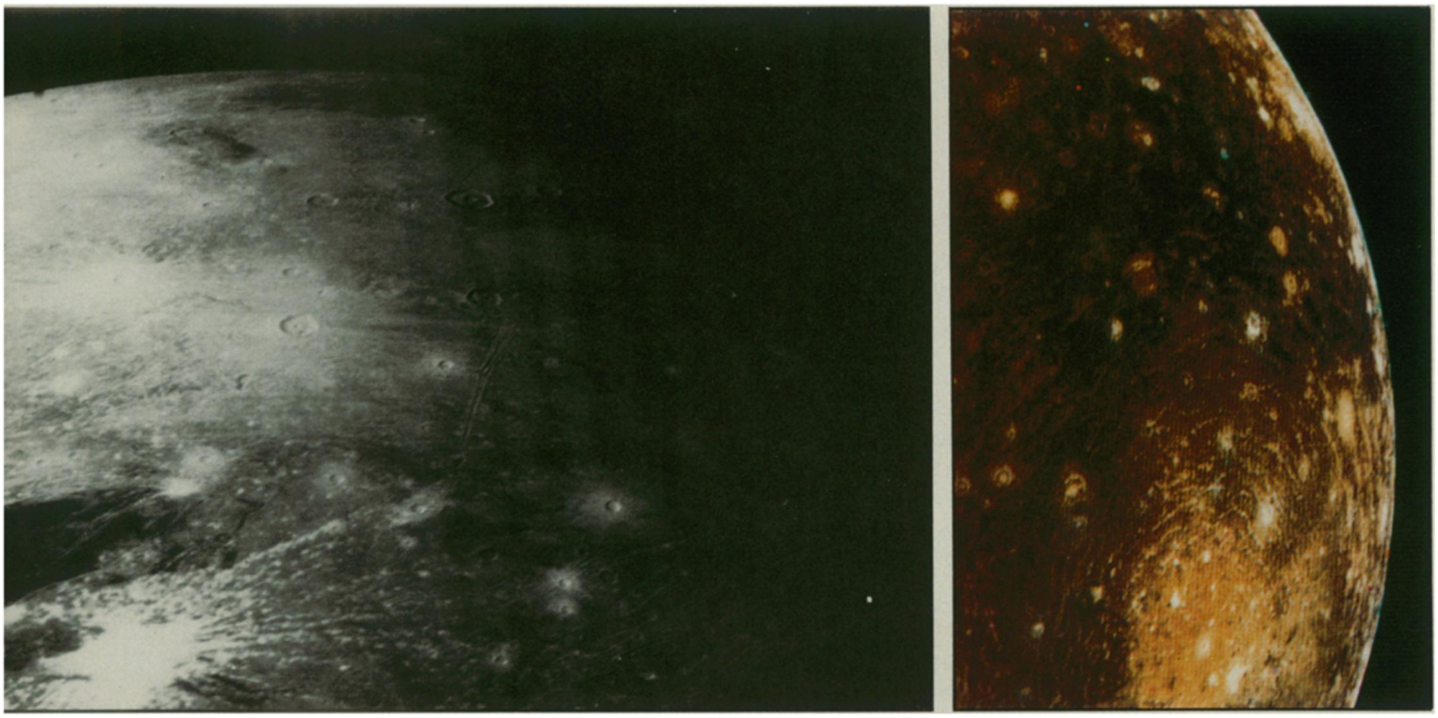
Yet despite the portent of the discovery — the chance to watch another world change — not all the excitement centers on Io. Recent observations of Jupiter itself have revealed the mighty world to have — appropriately — a supercharged electrical environment, replete with auroras larger than most whole planets and what appear to be lightning bolts as powerful as the biggest on earth.

In photos of the planet's night side, taken as the spacecraft was heading away toward Saturn, Allan Cook of the Smithsonian Astrophysical Observatory was seeking a variety of phenomena, including "fireballs" possibly produced by meteorites hitting the atmosphere. Instead, he found a vast, glowing arc over the planet— the first such photo showed a 30,000-km span of it — that reached as far north as 83°N. The image shows either a double exposure (Voyager has had some) or a double layer or auroras (also possible), but a later exposure showed a single clear arc, extending the auroral region down to at least 70°N and demonstrating (by its different viewing angle) that the aurora is really a more diffuse formation than a well-defined crescent.

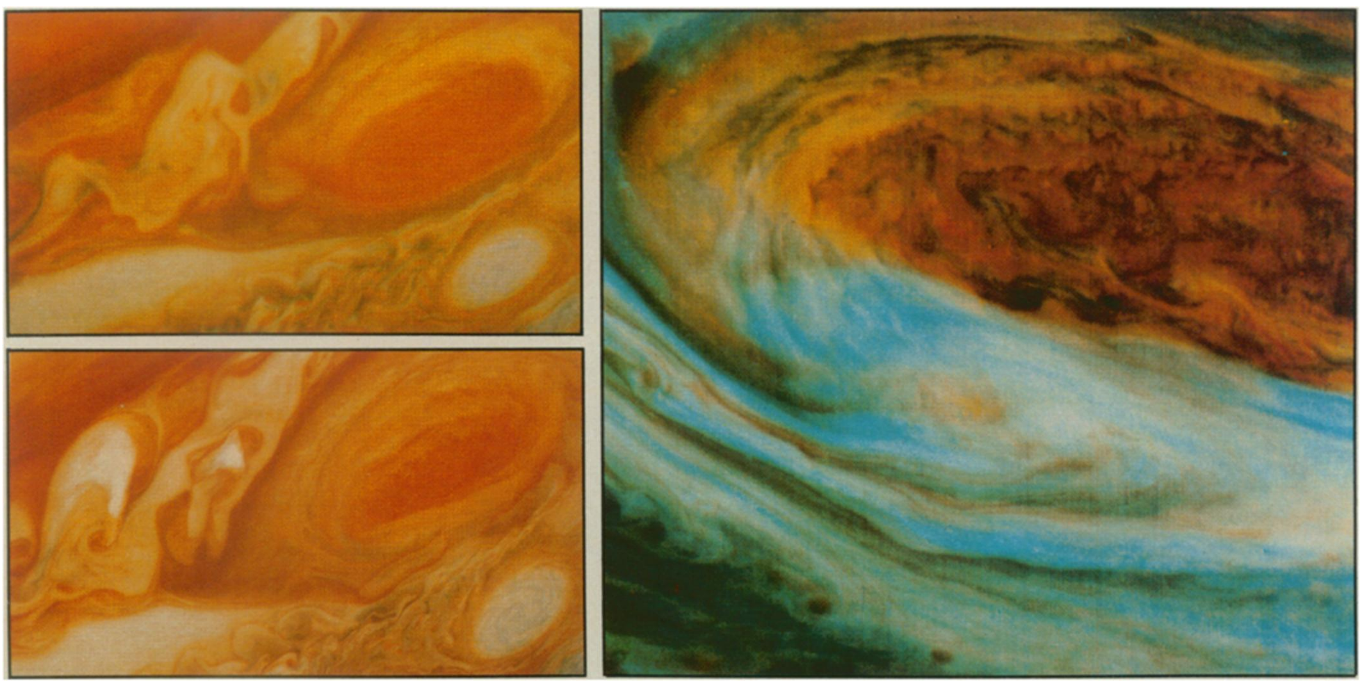
In some of the same photos, Cook found a multitude a bright flashes, apparently above the cloud tops, which the imaging team now believes to represent huge lightning bolts. Cook calculates that the electrical strength of the bolts is about 10 billion joules, which would mean that the only earthly lightning in the same league is the "superbolts" noted above the clouds in the tropics (and also visible from space to earth-orbiting satellites). The light output of the Jovian superbolts in Voyager 1's images, calculates Garry Hunt of University College, London, is about that of a second-magnitude star.

Earth-based observations are also continuing to help. At the University of Hawaii, E. E. Becklin and C. G. Wynn-Williams have used the 2.2-meter Mauna Kea telescope to successfully photograph the ring of Jupiter recently discovered from a single Voyager image. They estimate it to be about 11 magnitudes fainter than Saturn's rings as seen with the same equipment. Carl Pilcher and J. S. Morgan, also of U. of H., have meanwhile identified singly ionized oxygen in infrared spectra from the region of Io's torus.

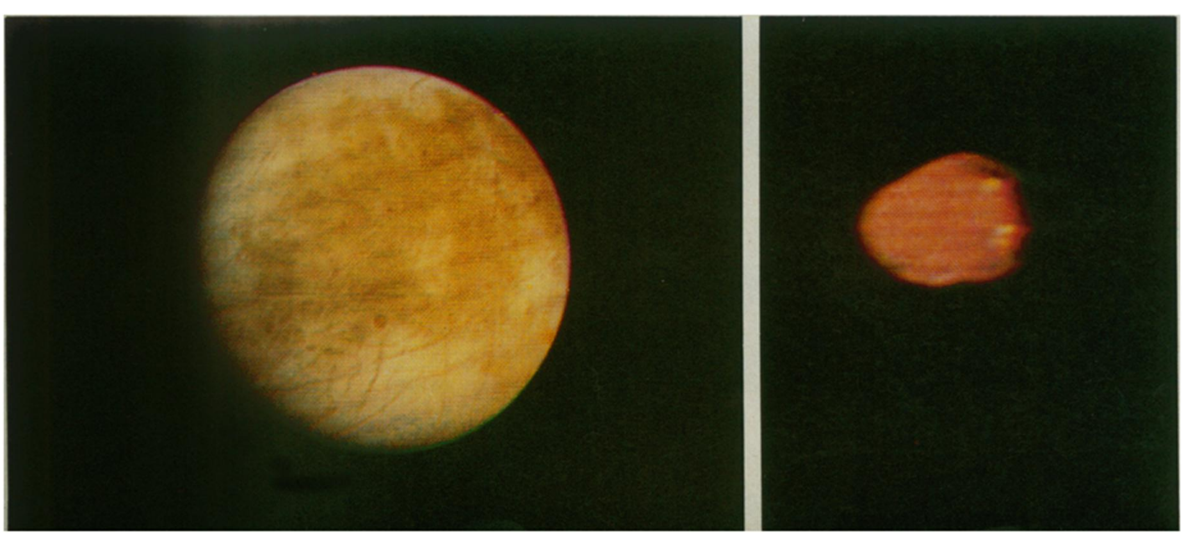
And the bulk of Voyager 1's data has barely been touched. □



Ganymede (left) shows rayed impact craters that may owe their brightness to near-surface ice exposed by the impacts. Callisto (right) reveals a 2,600-km basin whose concentric rings may be the preserved "ripples" formed by a huge impact in the ancient ice.



Red Spot at 4-day intervals shows marked changes in surrounding turbulence. Exaggerated color (right) reveals spot structure.



Europa (far left) shows linear features (though regular horizontal bands are an artifact of processing). Reddish little Amalthea is the most elongated planetary satellite yet measured.