Jovian Weather: Like Earth's or a Star's?

Last year's Voyager flybys lent some support to the theories linking Jupiter's weather to Earth's, but with no data from beneath the cloud tops researchers still have most of the same questions

The stunning, sometimes chaotic, always colorful pictures of Jupiter returned last year by the Voyager spacecraft seem exotic even for another planet, but an explanation for their appearance may be surprisingly mundane. Jupiter's atmosphere might be responding, in its own gargantuan way, to the sun's heat and its own rotation, in much the way Earth's atmosphere does. Studies of the Voyager data support that possibility in some ways, but they do not rule out Jupiter's being more like a star, whose visible face reflects the inner turmoil of its hot interior.

Explanations for Jupiter's most prominent feature, the enigmatic Great Red Spot, have not fared as well. The most detailed theory, which relates this one-of-a-kind storm to a type of water wave that was first observed in the 19th century in a canal, appears to explain some details of its appearance but is contradicted by other details detected by the Voyager spacecraft. Researchers are anxiously awaiting their first glimpse through Voyager of details on Saturn, but they will see no red spot and possibly none of the smaller white ovals typical of Jupiter. At worst, they hope Saturn's heavy haze layer will not blot out their view entirely.

The idea that the circulation of Jupiter's visible atmosphere is simply a bigger, faster spinning version of Earth's had been elaborated on before the Voyager flybys by Gareth Williams of the Geophysical Fluid Dynamics Laboratory at Princeton. He modified a mathematical model of Earth's atmospheric circulation developed in the 1950's so that it reflected the likely conditions in Jupiter's atmosphere. Major adjustments included an increase in the model planet's radius from 6,400 to 72,000 kilometers and an increase in its rate of rotation until the day was only 10 hours long. The changes split each of Earth's jet streams, one of which meanders across the middle latitudes of each hemisphere, into several straight jets of zonal wind like those forming Jupiter's alternating light and dark bands. Jupiter's huge Coriolis effect is the main cause of the transformation, Williams says. It is stronger on the larger, faster spinning planet than on Earth, where it deflects ocean currents and gives highs and lows in the atmosphere their spinning motion.

If Jupiter's regular bands are jet streams produced according to Williams' model, they should be fed energy from the turbulent eddies, swirls, and streaks seen in the pictures, which is exactly what Voyager found. Common sense suggests that the organized always decays into the chaotic, like a wave breaking on the shore—churning foam does not pull itself together into a wave. But in Earth's and, it now appears, Jupiter's atmospheres something like that does happen. The small-scale, turbulent "weather" transfers energy to the more organized jet streams. A major difference between the two planets is that the transfer appears to be 100 times more efficient on Jupiter.

That kind of efficiency presents a problem, according to Andrew Ingersoll of the California Institute of Technology. Such a high rate of energy input to the jet streams should lead to relatively rapid variations in their patterns of circulation. But they remained rock-steady during the 120 days between the two Voyager encounters, and they have changed little during 80 years of Earth-based observation. The most likely explanation, Ingersoll believes, is that the deep interior of Jupiter, which Williams' model does not include, interacts with and steadies the visible circulation.

The deep interior of Jupiter is hard to ignore, in Ingersoll's view. On Earth, all the visible weather occurs within an altitude range of 10 to 12 kilometers. At the level of Jupiter's visible clouds, an equivalent range might be tens of kilometers thick, but the atmosphere extends downward about 1000 kilometers, where it gradually merges into an ocean of liquid hydrogen that is almost 70,000 kilometers deep. The flow of heat through these fluids toward the visible clouds, a trickle left over from the high temperatures of the planet's formation, equals the energy absorbed at the cloud tops from sunlight. The sun alone drives the jets in the Earth-like model. With the interior carrying such a large energy flow, Ingersoll says, the unseen portion of the planet probably plays a significant role in shaping the visible circulation.

According to at least one theory, proposed by Fritz Busse of Caltech, the Jovian interior could actually dominate the visible circulation, which would make Jupiter star-like rather than Earth-like. On Earth and in Williams' model of Jupiter, the patterns of clouds reflect the movements of the atmosphere as it carries heat, however circuitously, from the warmer equator toward the poles. On a star, fluid motion must carry heat from the hot interior toward the surface by convection. On the basis of his mathematical model of a rotating star, Busse suggests that, instead of carrying heat vertically to the surface, the convection would be twisted by the Coriolis effect into concentric cylinders centered about the star's axis of rotation. Where the cylinders intersect the surface, banded jets would form. The same could happen on Jupiter because of its rapid rotation and relatively large source of internal heat, Busse says.

The most curious aspect of the Earth-like/star-like argument is that the Earth-like model does work so well in spite of its obvious limitations, notes William Rossow of the Goddard Institute for Space Studies in New York. The uphill transfer of energy from eddies to jets cannot occur unless atmospheric motions are confined to a thin layer, as they are on Earth. No one knows if the motions in Jupiter's atmosphere are confined in that way, he says. In the Earth-like model it is also assumed that both the top and bottom of the atmosphere are solid, rigid boundaries. That presents some difficulties when studying the terrestrial atmosphere near the surface, but the results for Jupiter, which has no solid surfaces at all, may be misleading. The trick, Rossow says, may be to find a physical mechanism that allows the circulation of Jupiter to look like Earth's despite the lack of a solid surface. "That is the value of going to another planet," he says, "you have to stretch and pull and twist theories that are reasonably successful for Earth and see if they still work." If they do, he says, there is greater assurance that their success on Earth was not happenstance.

A theory that describes the spots or ovals of Jupiter, which jostle about among the jets, as distant relatives of a peculiar terrestrial water wave also re-

0036-8075/80/0912-1219$00.50/0

ceived some support, as well as new problems, from Voyager data. The most detailed theory of the ovals, worked out before the Voyager encounters by Tony Maxworthy and Larry Redekopp of the University of Southern California, describes them as solitary waves, a type of wave first noticed rolling down canals in the 19th century. They look peculiar because they are single wave crests with no other crest ahead or behind, as if a rock were dropped into a pond and only a single ripple emerged instead of a train of expanding crests and troughs. Such a wave is an isolated distortion of the water's surface acting against the force of gravity that depends on a delicate balance between its height and the depth of the canal. In an atmosphere, waves such as the meanders in Earth's jet streams are a distortion of the atmosphere's structure that acts against the tendency of the atmosphere to rotate with the solid Earth.

On Jupiter, solitary waves would respond to the same forces and be oval shaped. Telescopic observations of the long-lived ovals—the Great Red Spot and the smaller white ovals—had suggested that they do behave like solitary waves. In particular, their persistence over many decades, in contrast to the daily waxing and waning of terrestrial weather, seemed reasonable because solitary waves do not interact with each other. After investigators had a closer look through the eyes of the Voyager spacecraft, the ovals still resembled solitary waves in some ways, but they seemed much too rambunctious. As theory predicts, the center of the Great Red Spot is relatively calm and a narrow jet does circle it along its outer fringe. The trouble is that the ovals interact with each other and their surroundings too much. The Great Red Spot leaves a swirling wake half way around the planet. Smaller ovals rip each other apart or gobble each other up. And a sea of turbulent clouds buffets them all. Admitting that such behavior puts a strain on the solitary wave theory, Redekopp points out that solitary waves are a bit more durable than generally thought, especially if they are drawing energy from winds rubbing their edges, as the Great Red Spot may be doing.

Williams offers as an alternative the spots that appear in his computer model. They originate from temperature variations, just as highs and lows in the terrestrial atmosphere do, but they are a sort of disturbance that is too weak to survive except in the nearly frictionless Jovian atmosphere. Still, Williams cannot crank out anything that resembles the Great Red Spot itself, only the smaller ovals. Perhaps the Great Red Spot is an idiosyncrasy of the Jovian atmosphere, he says, whose unique balance of forces has not yet been duplicated in models. Or, it could be a localized storm of the sort that continues to frustrate modelers studying even the closely scrutinized storms of Earth.

More extensive analysis of the Voyager spacecraft data from Jupiter may lead researchers toward a consensus about the nature of ovals and the cause of the banding, but that is not assured. Without observations from below the visible cloud tops, only a weeding out of a few of the theories may be possible. Ingersoll likens the situation to that of oceanographers decades ago who could only watch the movement of surface waters and guess at what the water beneath might be doing. The Galileo mission in late 1985 will include probing beneath the clouds by remote sensing and, at a single point, by a plummeting instrument package. In the meantime, planetary meteorologists are looking forward to Voyager 1's encounter with Saturn on 12 November.

Although theoreticians have no good reason to expect Saturn to look much different from Jupiter, some types of features will probably be missing. Nothing like the Great Red Spot has ever been seen on Saturn. In addition, Reta Beebe of New Mexico State University at Las Cruces notes that less than a dozen well-documented features of any kind other than broad bands have been detected on Saturn during the many decades of ground-based observation. These isolated features resemble the vague, whitish, bright regions sometimes reported in Jupiter's equatorial region, but not the ovals. Unlike the present white ovals formed during the late 1940's on Jupiter, the largest feature on Saturn persisted only a few months. Beebe does expect to see turbulent mixing and shifting between the bands, even through the overlying haze. That is good news for those who need markers to track the winds for comparison with circulation models.

—Richard A. Kerr

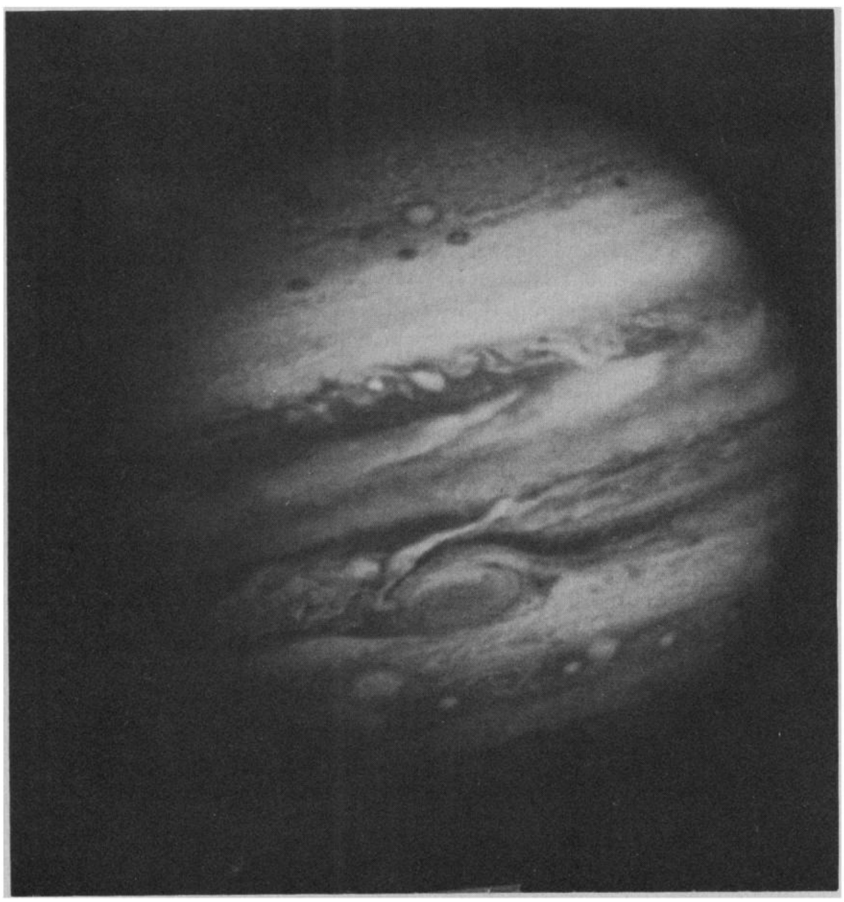

Photo of Jupiter taken in 1979 by Voyager 1 from a distance of 40 million kilometers. Although the appearance of the Great Red Spot (lower center of disk) generally conforms to that of a solitary atmospheric wave, the Great Red Spot's strong interaction with its surroundings, as evidenced by its turbulent wake to the left, argues against such an interpretation. Studies of many such photos have supported the idea that the strong zonal winds, seen as alternating light and dark bands, are driven in the same way as Earth's jet streams. Jupiter's satellite Ganymede is visible at the bottom of the picture. [Photo: NASA]