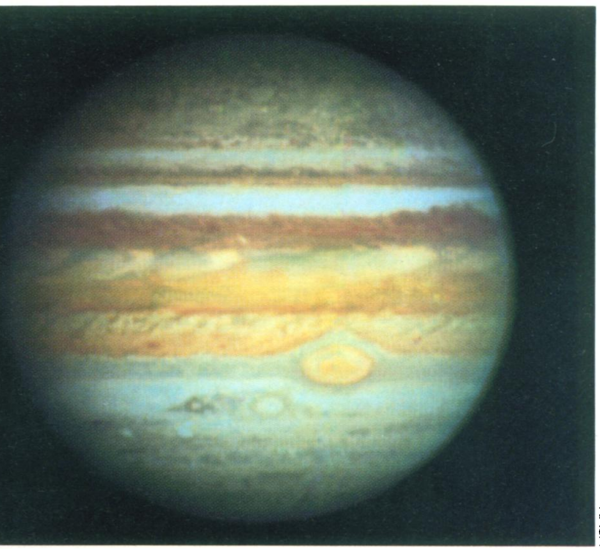
JUPITER'S MODEL S•P•O•T

By IVARS PETERSON



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An impending comet crash stirs up interest in Jupiter's atmosphere

Like an unblinking Cyclopean eye, Jupiter's Great Red Spot has stared back at astronomers for more than three centuries. Enthralled by this immense, enigmatic feature, researchers have spent untold hours trying to determine what it is.

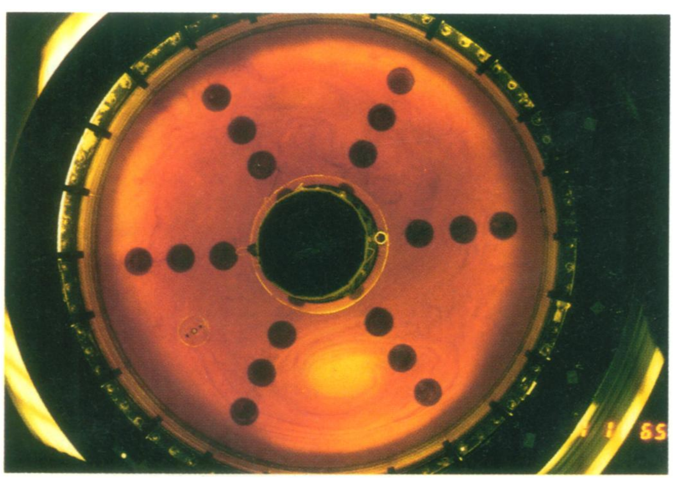
Step by halting step, they are beginning to unravel how a sprawling, shallow vortex — wider than Earth but no more than 100 kilometers deep — can persist for so long in a turbulent atmosphere.

Close-up images of the planet, obtained by the Voyager spacecraft in the 1970s, provided a detailed portrait of the complicated flows around and within the Great Red Spot. Earth-based observations supplied other details. More recently, the Hubble Space Telescope furnished new data, confirming the remarkable stability of the winds girdling Jupiter, including the westward and eastward flows between which the Great Red Spot slowly rolls.

Now, planetary scientists and fluid dynamicists keenly await the impending crash of a fragmented comet into the planet's atmosphere (see p.117). If they are strong enough to be observed, the ripples resulting from the impact may enable researchers to measure and calculate some of the key elements missing from a complete picture of how Jupiter's winds operate and how the Great Red Spot survives.

"The waves will tell us how Jupiter's atmosphere is set up," says astronomer Timothy E. Dowling of the Massachusetts Institute of Technology. "The only thing we need the comet to do is be big enough to make the waves big enough."

"It's like an interesting experiment," says Philip S. Marcus of the mechanical engineering department at the University of California, Berkeley. "You're going to be perturbing the atmosphere. The question is what measurements should you make to try to learn something."



Steven D. Meyers

Using a spinning, water-filled tank, researchers at the University of Texas at Austin showed that a large, stable vortex can form in the midst of turbulent flow, made visible by red dye. Dark circles are valves at the tank's bottom.

Vortices are common in nature, from the swirling funnel created as water drains out of a bathtub to the eddies and whirlpools that punctuate rivers racing across rough beds. Much larger vortices can form in Earth's atmosphere and oceans, and these features can strongly influence weather systems.

What makes the Great Red Spot unique as a vortex is its longevity and vast size. "It's amazing to see it on such a grand scale," says planetary scientist Andrew P. Ingersoll of the California Institute of Technology in Pasadena.

Jupiter's upper atmosphere consists largely of hydrogen and helium gas. The Great Red Spot resides in a thin layer that contains the visible tops of ammonia clouds. Above this level, the atmosphere is stable and acts as an impermeable lid, holding down underlying, upwelling, convecting gas.

Within the cloud-strewn layer, Jupiter's winds sweep around the planet in alternating bands, abruptly changing direction from one band to the next. Winds in the "belts" travel in the same direction as the planet's rotation, while those in the "zones" travel in the opposite direction.

Considerably thinner than it is long and wide, the Great Red Spot represents an enormous, spinning pancake of fluid wedged between two adjacent bands of opposing winds in Jupiter's southern hemisphere. This high-pressure storm circulates in the opposite direction to the planet's rotation.

But the spot doesn't spin as if it were a solid body. Its center remains relatively quiet, while most of its speed appears concentrated in a narrow ring of gas at its outer edge.

Although the Great Red Spot is by far the largest vortex on Jupiter, it is by no means the only one. Researchers have detected hundreds of vortices of various sizes, and they have witnessed a number of vortex births, deaths, and mergers.

"From the Voyager images, it is apparent that the vortices and their interactions are very turbulent," Marcus notes.

Researchers have a lengthy laundry list of questions they would like to answer about the Great Red Spot and other atmospheric vortices. For example, "How can something that's completely fluid hold itself together while being battered by turbulence all around?" Dowling asks.

If such spots were unstable, they would last only a few days, which is roughly how long it takes for fluid to complete a circuit of a vortex's outer edge. Moreover, without access to some kind of replenishing energy source, these vortices would run down in a matter of years.

Among other questions of interest to researchers: What determines the size, velocity, and number of vortices at a given latitude? Why do more vortices rotate in the opposite direction of the planet's rotation than in the same direction? How and why do vortices merge? Where does the energy required to keep the Great Red Spot and other vortices spinning so long come from?

Progress in answering these questions has been slow because researchers have data only on the one atmospheric layer made visible by the ammonia clouds. They must guess at what goes on underneath this layer to create the patterns seen.

"We don't know the atmosphere's vertical structure [that is, how its temperature and density vary with depth]," Dowling says.

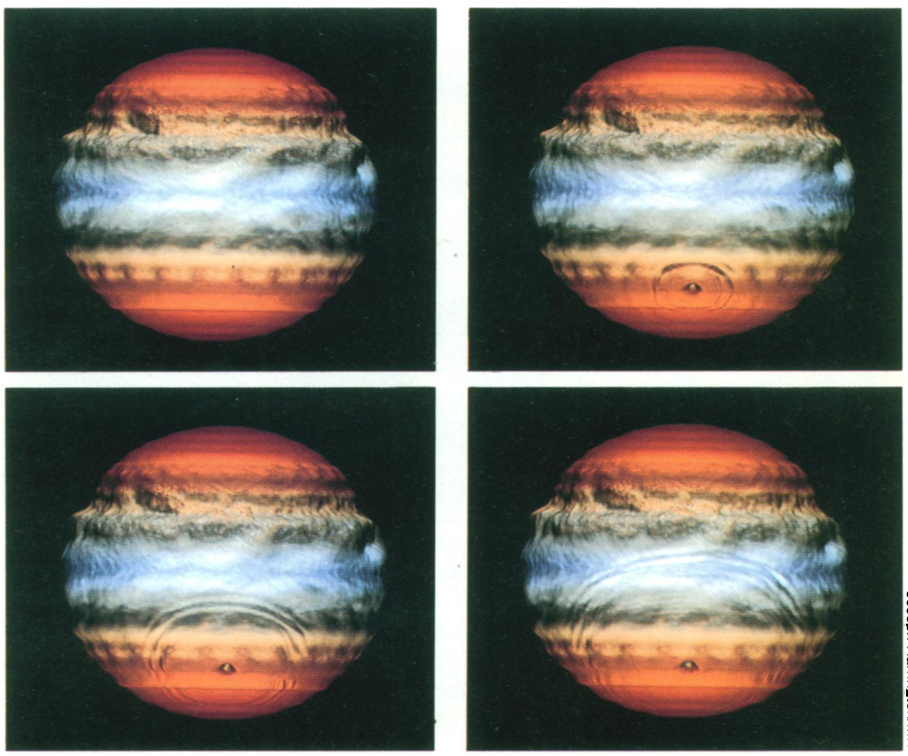
As a result, a variety of theories and models, based on different assumptions about what factors may be important in driving Jupiter's atmosphere at various levels, have emerged. Each has its strengths and weaknesses, and disputes among researchers concerning the relative merits of these models have turned acrimonious at times.

Some theorists postulate that these giant vortices function as deep hurricanes, extracting energy from the lower part of the atmosphere. Others argue that the spots draw energy from the winds between which the vortices sit. Still others favor the notion that these giant swirls survive on a diet of smaller eddies, which the giants simply engulf.

"The Voyager films show the Great Red Spot eating a small vortex every few days," Dowling says. "In fact, at any given time, there are 12 or 13 of these [small vortices] at the same latitude, coming in from the right, circling part way round the Red Spot, then merging with it."

Surprisingly, it's possible to concoct computer simulations based on any of these scenarios and end up with an isolated, long-lived, oval feature that looks like the Great Red Spot. Indeed, as numerous experiments and studies have shown, such features arise spontaneously under a variety of conditions (SN: 2/27/88, p.132; 11/13/93, p.308).

However, no model developed to date really fits all the data, Ingersoll says. But observations of the ripples from the impact of Comet Shoemaker-Levy 9 in July and additional data from the Jupiter-bound Galileo spacecraft may provide enough new information to rule out at least some theories.


Joseph Harrington/MIT

This computer simulation of Jupiter's atmosphere illustrates how surface waves generated by a comet impact spread outward day by day from the impact site.

In attempting to understand the Great Red Spot and other giant vortices, Marcus has chosen a somewhat different course than that taken by most other researchers. Instead of creating a general-circulation model that encompasses the entire atmosphere, he has focused on developing the simplest possible model that explains the Great Red Spot's chief characteristics and illuminates their relationship to other features, such as the winds.

Marcus describes his model in a lengthy article in the 1993 Annual Review of Astronomy and Astrophysics.

"If you look at Jupiter, you see all this turbulence, you see strong east-west winds, you see vortices, all made visible by the clouds," Marcus says. "My point of view is that everything — the clouds, the motions, the vortices — are confined to a very, very shallow layer. It all occurs at the same point in the atmosphere."

According to Marcus, rising plumes of gas — resulting from convection in Jupiter's atmosphere — smash into a stable atmospheric layer that acts as a lid. This forces the rising gas sideways. Combined with the planet's rapid rotation (1 Jovian day lasts 9.92 hours), these motions readily generate vortices and winds.

Marcus and his co-workers have demonstrated in computer simulations based on this model that a thin layer will develop circulation patterns closely resembling those on Jupiter. "You start with just a rotating planet, and it all comes out," Marcus says. "You get the nice [alternating] east-west bands. You get the vortices, and they sort of interact in the right way. And the clouds look right."

"It's a very coherent picture," he maintains.

This model, however, remains controversial. Other researchers contend, for example, that the wind pattern actually penetrates deep into the atmosphere.

Marcus has been talking with physicist Harry L. Swinney of the University of Texas at Austin about running some laboratory experiments to test his ideas. "To set up and do such experiments is always a slow process," Swinney notes. "But there are certainly a lot of issues [concerning the Great Red Spot and

Jupiter's atmosphere] that are not yet resolved."

Meanwhile, the comet is coming. Broken into at least 21 pieces, it will plunge into Jupiter's southern hemisphere, landing in a turbulent belt much farther south than the region in which the Great Red Spot swirls.

Compared to the scale of the planet, the impacts will be small. "The way I like to think about it is you're taking an apple and sticking 21 needles into it," says Mordecai-Mark Mac Low of the University of Chicago, who has been developing computer models of the comet impact. "Locally, each needle does significant damage, but the whole apple isn't really modified very much."

Nonetheless, the comet impacts may create ripples in the atmosphere. Not directly visible, these ripples will show up as tiny temperature differences of 0.5 kelvin or less between the waves' crests and troughs. Researchers may be able to observe these temperature fluctuations at infrared wavelengths, or they may see disruption of the planet's cloud patterns.

By measuring the speed of these surface waves, astronomers may be able to deduce numerical values for crucial characteristics of the atmosphere, especially at depths other than the layer in which the Great Red Spot resides.

The speed of the ripple will reveal details about the vertical structure of the atmosphere through which the wave propagates, Dowling says. "That will help settle a lot of disputes."

Dowling, Joseph Harrington, and their colleagues have developed a computer model to simulate what may happen to Jupiter's atmosphere after the comet hits. Their three-dimensional, general-circulation model starts with Jupiter's distinctive pattern of winds. As the atmosphere evolves in the simulation, turbulence and vortices develop at the boundaries where opposing winds brush past each other. The comet impact shows up as a ripple slightly distorting this pattern of bands and vortices.

Ingersoll and his co-workers are developing a somewhat different model to study how energy travels from the bottom to the top of Jupiter's atmosphere. Unlike Dowling's computer simulation, their model doesn't include the winds. "We assume it's a flat pond with ripples spreading out in perfect circles from the impact point," Ingersoll says.

Instead of looking at what these ripples do to visible features in the ammonia-cloud layer, Ingersoll's model focuses on how different layers within Jupiter's deep atmosphere may affect energy propagation. However, because no one knows how the atmosphere is layered, the researchers must postulate its structure, trying various sets of layers with different characteristics.

"The whole idea is to vary our assumptions and get a suite of models ready so that when the impact does occur, we can select one from our library and say, 'It's that one,'" Ingersoll says.

There exists the possibility that a comet fragment may generate enough of a splash to create a long-lasting vortex at the impact site. "The energy is there," Ingersoll says. "But it's a question of the efficiency with which this energy is dissipated in different ways."

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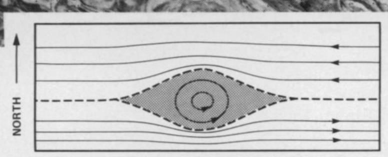

This mosaic of Voyager 1 images reveals the turbulence surrounding the Great Red Spot (top). This giant vortex appears at the boundary between strong winds traveling in opposite directions (bottom).

"The shock [of the comet] coming into the atmosphere drives a blast wave, and that blast wave loses its energy partly through heating the surrounding atmosphere and partly through moving it," Mac Low says.

For example, the energy may go into waves that radiate downward and get lost in the vastness of the planet's interior. It may dissipate horizontally as surface waves that ripple the atmosphere. It may propagate upward, where the waves turn into heat.

Dowling's model shows that if the energy goes largely into moving the atmosphere, a whirlpool forms at the impact site. This vortex may last a few days or several weeks. However, even though the total energy carried by the comet into Jupiter's atmosphere is comparable to the energy represented by the Great Red Spot, the model predicts that nothing on this scale will form.

"It'll be just a little thing," Mac Low says.

Whatever the outcome of the comet crash and the subsequent visit by the Galileo spacecraft, researchers are bound to learn more about Jupiter's atmosphere. And the new data may help resolve a variety of questions concerning not only Jupiter's winds and vortices but also wind and weather patterns on other planets, including Earth.

The solar system has 12 bodies with atmospheres: all of the planets except Mercury, three satellites (Io, Titan, and Triton), and the sun. "With the possible exception of the Earth, we don't have numerical models that [generate] the wind patterns observed," Dowling says.

For example, "Why would Jupiter and Saturn . . . have 12 jet streams instead of just a couple?" he asks. "No one has an answer to that."

Moreover, it's difficult to isolate the specific factors that make one planetary atmosphere different from another. "The Earth probably has the most unpredictable weather in the solar system," Ingersoll says. "Weather structures last for a shorter time on Earth than they do just about anywhere else. It's very hard to say why that's true."

At the same time, there are several types of phenomena in Earth's atmosphere and oceans that resemble the Great Red Spot, though they don't last nearly as long, Dowling says. Occasionally, for example, a high-pressure cell, called a blocking high, will form and station itself over North America or Russia. "It just sits there and diverts rainstorms from their normal patterns for months," he says.

In the ocean, pockets of salty water, extruded from the Mediterranean Sea into the less saline Atlantic, can survive virtually intact for years. Similarly, eddies may break off from the main flow of the Gulf Stream in the Atlantic to form long-lived, surprisingly robust circulating rings.

"We think that the . . . dynamics here [are] related to the same mechanism that holds the Great Red Spot together," Dowling contends.

The impending crash of a wayward comet into distant Jupiter has brought new attention to these and other issues that arise in attempts to understand the perplexing behavior of planetary atmospheres — at home and abroad. □