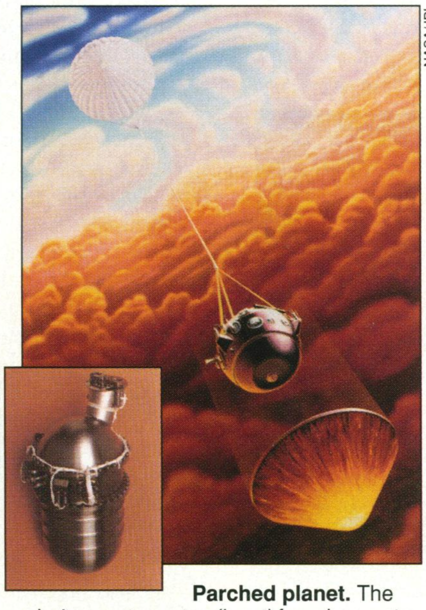
PLANETARY SCIENCE

Revised Galileo Data Leave Jupiter Mysteriously Dry

Jupiter's water has gone missing, and researchers are scrambling to understand where it might be—and why it vanished. Theories about the giant planet's formation had predicted that its atmosphere would be relatively rich in water, although researchers knew that the moisture would be secreted somewhere beneath a veiling cloak of ammonia clouds. But on 7 December the Galileo spacecraft's probe plunged more than 100 kilometers beneath the cloud tops—and found almost no water, as reported along with other probe findings on page 846 of this issue.

Preliminary evidence reported at a January press conference had hinted that Jupiter might be a bit drier than expected, but the early data were contradictory (*Science*, 2 February 1996, p. 593). Now careful calibration has given the scientists confidence in their data, and they conclude that Jupiter—or at least the part penetrated by the Galileo probe—has only 10% of its predicted water. That raises questions about the traditional theory of how Jupiter gained its rich mixture of methane and ammonia—namely from an icy bombardment of debris from space. The new evidence creates "a profound problem, a fascinating puzzle," says planetary physicist David Stevenson of the California Institute of Technology.


NASA/JPL

H. NIEMANN / GSFC

Parched planet. The probe's spectrometer *(inset)* found no water.

The new results may be puzzling, but at least they are secure, say Galileo probe scientists. Back in January, many investigators weren't sure they could trust data from the crucial instrument, the neutral mass spectrometer (NMS). What raised the doubts was a comparison between probe data and earlier measurements. Preliminary results from the probe showed both water and methane to be about as abundant in Jupiter as they are in the sun, reported Hasso Niemann of the Goddard Space Flight Center in Greenbelt, Maryland, principal investigator for the instrument. But Earth-based and Voyager observations had previously measured about twice as much methane.

The problem, Niemann now says, was a matter of instrument calibration. The raw data needed to be calibrated for the instrument's response to water, a calculation only hastily performed before the January press conference. Since then, a more thorough analysis showed that the effect of the calibration would be substantial, says Niemann. At the same time, work on the calibration of methane caused its abundance to jump to three times that of the sun, putting the methane values in line with previous observations—and boosting confidence in the NMS data.

With greater certainty came a surprise: The abundance of water had dropped to 20% of the solar value. And three other probe instruments had also failed to detect much water, such as the predicted water clouds or the high humidity that would accompany them. At first, researchers had thought those values might only be signs of local aridity, because the probe came down in a Jovian "desert"—a region of sinking air, like the atmosphere over Earth's great deserts, that might be expected to be dry. But preliminary analyses of probe radio signals transmitted through the Jovian atmosphere and picked up on Earth by the Very Large Array hint that water was also scarce thousands of kilometers from the probe entry site, says planetary meteorologist and probe project scientist Richard Young of Ames Research Center in Mountain View, California.

It's the abundance of other volatile compounds, like methane, in Jupiter's atmosphere that makes the scarcity of water such a mystery. The Earth-based observations that revealed Jupiter to be rich in methane had led planetary scientists to propose that carbon-rich, icy debris left over from the formation of the solar system pelted the new planet, raising the abundance of carbon to several times that seen in the sun (which is assumed to typify the solar system's starting material). But that way of finishing off the construction of Jupiter would have boosted the abundance of water too—and the Galileo observations directly contradict that notion.

The late, icy bombardment theory "was kind of made up to solve a problem with Jupiter," says cosmochemist and probe team member Tobias Owen of the University of Hawaii. Now "we're trying to sort this out in a way that makes sense with the other things we know, instead of inventing something that works just to solve this particular problem." But they've got their work cut out for them, says Thomas Donahue of the University of Michigan, a theorist on the NMS team. Other than the scarcity of water, the evidence for an icy bombardment is consistent, he notes: All of the elements that react to form volatile compounds appear to be overabundant in Jupiter, except for the oxygen in water. So he and others are trying to adjust the bombardment theory to explain the absence of water. "Unfortunately, there are about four possible explanations" for how and why the water vanished, he says, "and we're not in a position to pick one out yet."

One possible explanation would simply adjust the composition of the infalling planetesimals to match that seen on the planet—rich in carbon and other volatiles but poor in water. But although there are some carbonaceous asteroids that appear to be water-poor, such a composition is atypical, and having enough such debris in the early solar system to account for Jupiter's makeup "would be a stretch," says Donahue.

Another possibility is that the bombardment did bring in the expected water, but the part of Jupiter that the probe fell into is unusually dry after all. Young now wonders whether the whole equatorial region of Jupiter, where the probe entered, has been dried by some sort of atmospheric circulation that wrings the water out before sending the air equatorward. If so, the planet as a whole may be wetter than Galileo's data suggest.

One way to test this idea is by analyzing the Jovian abundance of ammonia, says Donahue, because ammonia and water should behave similarly. If both compounds are scarce, then it's likely that both are condensing out of the atmosphere before circulating to the probe site. The NMS measured ammonia, but unfortunately the numbers aren't out yet because the team is worried that ammonia cloud droplets became stuck in the instrument's sample inlet, skewing the measurements.

In Donahue's third and fourth possibilities, the missing water is sequestered deep inside the planet. If the bombardment of volatile-rich planetesimals took place early enough during the planet's formation, Owen and Daniel Gautier of the Paris Observatory proposed in 1989, water might have remained frozen on the planet's rocky core. The heat of impact would have boiled away more volatile materials, such as carbon monoxide, methane, and nitrogen gas, enriching the growing gaseous atmosphere.

The trick, Owen admits, is to build a core and add layers of volatiles without heating the growing planet to the point where the water is driven off as well.

In the fourth possibility, Jupiter started out with a water-enriched atmosphere but somehow withdrew its water deeper into the planet, beyond the probe's reach. That possibility intrigues Stevenson. "In this scenario, you imagine that in addition to water forming a cloud deck at some depth, something else happens at much, much higher pressures that is specific to water," he says. What that something might be is hard to say because laboratory experiments on Jovian materials at such megabar pressures have only recently become practical. Perhaps water is raining out of the upper parts of Jupiter despite fiery temperatures, as helium is, speculates Stevenson. Or, under extreme pressure in the depths of Jupiter, water might be forged into a metal that prefers the company of the metallic hydrogen of the deep interior.

"It's going to be difficult to choose between the [possibilities] except on plausibility grounds," says Donahue. "As usual, it seems we may have raised more questions than we answered."

–Richard A. Kerr

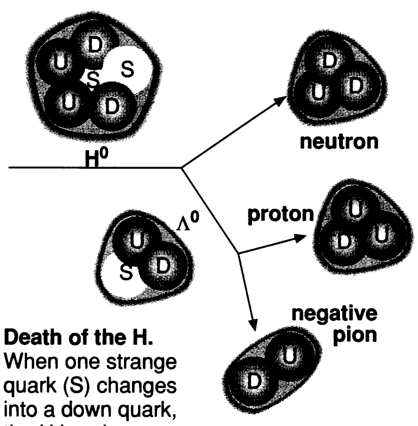
PHYSICS

A First Glimpse of Strange Matter?

Strange as the world of quantum physics might seem at times, to some theorists it is not nearly as strange as it might be. The problem is that all matter in the universe seems to be composed of just two of the six available kinds of quarks, the up and the down. Theoretical calculations suggest that mixing in a fair share of strange quarks, the next heaviest type, or "flavor," should yield another family of stable particles—strange matter—that might exist in such exotic crannies of the universe as the interiors of neutron stars. But every effort to create strange matter in accelerators on Earth has come up empty—until now, perhaps.

In the 29 April issue of *Physical Review Letters*, a team of physicists working at the Brookhaven National Laboratory reported that by sifting through a beam of neutral particles, they had recorded two possible sightings of the lightest form of strange matter, known as an H dibaryon—a package of six quarks, two of which are strange. Two events constitutes a signal so weak that it allows the physicists only to set an upper limit on how often these particles can be produced. "With 20 events you can learn something," says Princeton University physicist Alan Schwartz, who led the analysis. "With two, you're neither here nor there." Theorists, however, are tantalized, because they have been speculating about strange matter—and puzzling over its absence—for nearly 2 decades.

Theorist Bob Jaffe of the Massachusetts Institute of Technology, who proposed the H in 1977, explains that it is the offspring of quantum chromodynamics, the theory describing the strong force that binds quarks. Just as the electromagnetic force acts on particles carrying electrical charge, the strong force responds to a kind of "charge" known whimsically as color. Ordinary protons and neutrons, for instance, are bags of three up and down quarks stabilized mainly by their combinations of color. But theorists have realized that the strong force should have an even tighter grip on collections of quarks that include wide combinations of flavors as well as colors, says Jaffe. "This tendency cannot be fully realized among the usual states made of three quarks," Jaffe says, because of what he calls the "Chinese puzzle" of allowed and forbidden combinations of color, flavor, and other quantum-mechanical parameters. "But it can in a system of six quarks." In this sense the H—made of two up, two down, and two strange quarks—is the most stable quark combination imaginable.



Death of the H. When one strange quark (S) changes into a down quark, the H breaks up.

SOURCE: JAFFE

Even though the H would be a paragon of strong-force binding, it could still decay via so-called weak interactions, which would transform one of its strange quarks into a down quark. The H would then break up into a neutron and an unstable particle called the lambda, which has one up, one down, and one strange quark. But that process would take a relatively long time: a billionth of a second, long enough for it to be observed in an accelerator experiment. The trick would be to create showers of short-lived particles consisting of quarks—including strange quarks—and their antimatter counterparts. On rare occasions the right combination might come together to form an H.

Until recently, nothing has worked. But in 1992, Val Fitch, a Nobel laureate at Princeton, contacted the leaders of a Brookhaven experiment that had been set up to look for rare decays of particles known as kaons, suggesting an H search. By slamming protons into a copper target and then sweeping away the charged debris with magnets, Brookhaven's Alternating Gradient Synchrotron was producing the highest intensity beam of neutral particles anywhere in the world. Because H particles would themselves be neutral, Fitch argued, such a beam would be the natural place to look for them. And he pointed out that the kaon detector could do double duty, searching for decays that might signal the brief appearance of an H particle.

The Brookhaven administration was quick to approve the project, and Schwartz, Fitch, and their collaborators then spent a hectic 6 weeks setting up the experiment. In the spring and early summer of 1992, they took a month's worth of data, an episode University of California, Los Angeles (UCLA), physicist Bob Cousins, who was also involved, calls "just a blip in our lives tacked onto the kaon thing."

The analysis, however, was definitively less bliplike. The physicists looked for H's in two different ways: Fitch, Cousins, and two graduate students—Josh Klein at Princeton and Karl Ecklund at Stanford—followed Fitch's original idea, which was to look for H's that jumped into an excited state in the detector and broke up into two lambda particles. Schwartz and Brent Ware, a University of Texas graduate student, looked for H's that spontaneously decayed into a lambda and a neutron.

Fitch and his colleagues came up empty, but Schwartz and Ware were more successful. After spending 3 years on what everyone describes as an extraordinarily painstaking and conservative analysis, Schwartz and Ware were left with two candidates that had all the features expected of the decay of an H particle and no other natural explanation. "But we all know that with only two events," says Cousins, "there could be all kinds of unnatural explanations that aren't the H."

The next few years should help distinguish the strange from the unnatural. At Brookhaven, one experiment is already looking for other forms of strange matter besides the H, and another, which Cousins describes as "the definitive experiment," is currently under construction by a group from Berkeley, UCLA, and Brookhaven. The experiment, says Berkeley physicist and co-spokesperson Hank Crawford, should have 1000 times the sensitivity needed to settle the question. "We fully expect to find the H if it exists," says Crawford. "We'll nail it tight."

–Gary Taubes