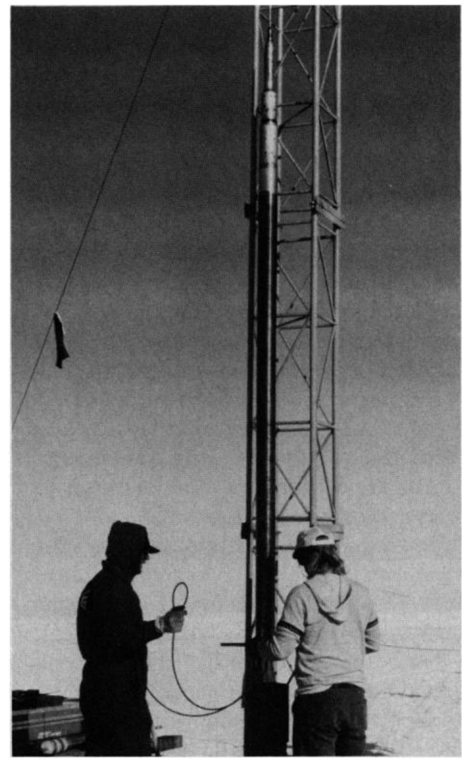
Was Newton Wrong?

Scientists disagree over the implications of recent experiments that indicate gravity may not behave exactly as predicted by Isaac Newton. Some say there may be an extra component to gravity



Researchers watch *gravity meter lowered into the Greenland borehole.*

NEWTON'S LAW OF GRAVITY, which celebrated its 300th birthday last year, may be starting to show its age. Several recent gravitational measurements have deviated from predictions based on Newton's law, and now researchers who lowered a gravity meter down a mile-deep hole in a Greenland ice sheet say their observations also disagree with theoretical calculations. The researchers say that this experiment, one of the most accurate tests to date of Newton's law, indicates gravity may not behave exactly as Newton thought.

"We're saying something pretty big, something you don't say everyday in physics," said Mark Ander, a physicist at Los Alamos National Laboratory in New Mexico who reported the results. "We're saying we appear to have the cleanest evidence to date of something that cannot be explained by Newtonian gravity."

Other physicists remain unconvinced, however. The key issue, they say, is not the accuracy of the experiment itself, which apparently was done very carefully, but rather whether the experiment's measurements actually disagree with the predictions of Newton's law. Since the mass density of the earth varies in a complicated way, it is hard to calculate exactly what Newton's law predicts for the strength of the earth's gravity at different points, and thus it is hard to tell whether experimental results agree with theoretical predictions.

The possible disagreement between experiment and theory has been touted by the press as evidence for a fifth force in addition to the accepted four—gravity, electromagnetism, the strong force, and the weak force. The experimental team, however, makes no claims about the theoretical implications of its data, but says only that the data disagree with what Newtonian gravity predicts. Further, other physicists familiar with the work say that even if the deviations from Newtonian gravity are real, they probably indicate the presence of a previously undetected component of gravity rather than an entirely new force. As Los Alamos theoretical physicist Richard Hughes noted, if the effects exist they are of about the same strength as Newtonian gravity, which would seem to imply they are a part of the gravitational force. The four known forces all differ greatly in strength and are quite unlikely to be confused with one another. "If it looks like gravity, it's probably gravity," Hughes said.

In the past few years, several research groups have found discrepancies between measured and calculated gravitational effects. Some experiments found discrepancies in how gravitational force varies with distance, while others have seen gravity dependent on quantities besides mass, such as baryon number or isospin. But none of the results convinced the general physics community that Newton was wrong.

So last year a group of researchers from Los Alamos, Scripps Institution of Oceanography, the University of California at San Diego, the University of Texas at Dallas, and other institutions trekked to Greenland to make an extremely sensitive test of gravity's variation over distance. They lowered a gravity meter down a 5478-foot-deep borehole in the ice and took gravitational measurements at various depths. Instead of measuring the gravitational field directly, the researchers measured the gravitational gradient—how the gravitational field changes from one point to another. The measurements, the researchers said, were done very accurately and reproducibly.

After the measurements came the hard part: comparing the measurements to theoretical predictions. This comparison is the key step in the experiment and the one on which the conclusions stand or fall, a point which is usually glossed over in popular accounts of this type of experiment. In principle, calculating the expected gravitational field—or gravitational gradient—is a straightforward process. For a perfect sphere composed of matter that is perfectly homogeneous (that is, is evenly distributed), the calculation can be done by a high school physics student. But the earth is not a perfect sphere and is far from homogeneous, and this causes difficulties.

The major problem is that differences in the density of matter near the borehole lead to variations in the gravitational field. For example, a lode of dense ore, such as iron ore, would have a stronger pull than the rocks surrounding it. Although such gravitational variations are small, so would be the discrepancies the researchers were looking for. For the researchers to recognize departures from the predictions of Newton's law, they first must know to great accuracy exactly what those predictions are.

That is the major reason the researchers went to the Greenland ice sheet, a spot unlikely to be confused with a vacation resort area. They went because gravitational calculations on an ice sheet are much simpler than any other spot on land, the ice sheet being relatively flat and homogeneous and its density being known quite accurately. The calculations were much more complicated and prone to error, for example, in an earlier experiment that was done in a mine shaft, where the density of the surrounding rock varied greatly from place to place.

To calculate what Newton's law predicts for the gravity down the borehole, the researchers measured the surface gravity at 20 points within 20 kilometers of the hole, as well as at various depths inside the hole. Using these measurements to calculate contributions to gravity due to local effects and a model of the earth's large-scale gravitational field for global effects, the researchers calculated what gravity should be inside the hole, according to Newton's law.

After finishing these calculations, the researchers found their measurements differed from what theory predicted. Newton's constant, G, which gives the strength of the gravitational interaction between different masses, was measured to be from 1.7 to 3.9% smaller in the borehole than it is in laboratory experiments.

Hughes at Los Alamos, who was not a part of the Greenland team but who is familiar with their data, said the team's result can be interpreted as implying there is a medium-range attractive force acting in addition to the normal Newtonian gravity (whose range is infinite). The presence of such a medium-range force would make G seem larger in the laboratory than in the borehole because laboratory measurements look at objects less than a meter apart, and a medium-range force would make a proportionately larger contribution at this range than at the scale of hundreds or thousands of meters. Although calculations are not complete, the range of the extra component to gravity is probably between 10 meters and several kilometers, Hughes said.

Some physicists, however, question whether the borehole measurements can be interpreted as evidence for an extra component of gravity. Their objections center on whether the calculations of the Newtonian gravity down the borehole are accurate enough to pick out anomalies as small as those found in Greenland.

"It's our belief we haven't seen enough evidence from existing experiments for a new force," said Ken Schatten of NASA's Goddard Space Flight Center. Schatten, with Ben Chao and Dave Rubincam of Goddard, has examined how density anomalies in the earth can affect the planet's gravitational field. They have found, Schatten said, that anomalies at medium and long distances can cause up to a 1% variation in the measurement of G. "These gravitational anomalies must be taken into account," he said, or else an experiment might mistake the anomalies for an extra force.

Carlos Aiken of the University of Texas at Dallas, a member of the Greenland team, replied that his group took into account every possible gravitational anomaly they could think of and still could not explain the data in terms of Newtonian gravity. "We allowed for things that almost verged on the absurd, geologically," he said.

Aiken acknowledged that the results must be examined closely, for they indicate a major revision in the understanding of gravity. "It makes us all real nervous," he said, speaking of the team's claim to have seen an additional gravitational force. "We go over and over the data, saying there's got to be something we're missing."

The next stop is Antarctica, where the ice is thicker and the underlying ground easier to account for in gravitational calculations, so a much more accurate measure of discrepancies is possible. That experiment, though, is probably 2 years away. Meanwhile, the debate on whether Newton was wrong is likely to continue. ■ ROBERT POOL

Secrets of an Unremarkable Star

With the kind of serendipity that almost seems routine in astronomy, an international team of researchers has stumbled upon a sun-like star that shows striking evidence for a nonstellar companion—a "planet" that paradoxically combines a mass at least ten times that of Jupiter with an orbital radius as small as Mercury's.

"People didn't really expect this," says team leader David W. Latham of the Smithsonian Astrophysical Observatory, who presented the findings at the recent meeting of the International Astronomical Union in Baltimore.* Given that Jupiter, Saturn, and the other giant planets of our own solar system are all quite far from the sun, "there was quite a prejudice against getting a giant planet this close." Nonetheless, he says, despite a variety of recent hints pointing to the existence of other planetary systems—infinitesimal wobbles in a star's motion across the sky, for example, or an anomalous glow of infrared that presumably arises from a disk of preplanetary gas and dust—"this is the first good orbital solution for a single body the size of a giant planet."

The star in question, designated HD 114762, is a yellowish, medium-sized, and apparently unremarkable star lying some 90 light years from Earth, where it is just a little too dim to be seen with the naked eye. Its spectrum shows that it has about one-tenth the sun's abundance of heavy metals, which presumably means that it is about 5 billion to 10 billion years older than the sun. (Low-metal stars are thought to be among the oldest in the galaxy.) But other than that, it is almost identical to the sun.

Ironically, says Latham, it was the very blandness of HD 114762 that led his group† to study it in the first place. Their original intention was (and is) to carry out a systematic search for substellar companions by checking hundreds of stars and looking for subtle, periodic shifts in their spectra. Such an effect would presumably arise from Doppler shifts in the star's spectral lines as it was being tugged back and forth by the gravity of an unseen companion. As a first step in this program, however, the astronomers had to refine the catalog of standard, constant-velocity stars that they use to calibrate their Doppler shifts on any given observing run. Starting in 1981, Latham and the Smithsonian's Robert Stefanik accordingly began taking spectrum after painstaking spectrum, eventually focusing on nine candidate standards.

Thus the serendipity: as time went on, it became increasingly apparent that one of the candidate stars, HD 114762, was precisely the opposite of what the astronomers had expected. Instead of being a paragon of stability, its spectra showed periodic variations in Doppler shift with a magnitude of about 500 meters per second. The signal was a noisy one, to be sure. But through the use of mathematical techniques developed by team member Tsevi Mazeh of the University of Tel Aviv, the data yielded a periodicity of 84 days. Assuming that the signal was real, this would give the companion an orbital radius roughly equal to that of Mercury, which orbits our own sun once every 88 days.

For an independent check of the findings, Latham then contacted the Geneva Observatory's Michel Mayor, who was also leading an effort to recalibrate the standard stars. The result, he says: "A different group, a different instrument [the Haute Provence Observatory in southern France], and the same orbit."

As time goes on, says Latham, the measurements accumulate and the statistics improve. He and his colleagues now have data for 30 cycles of the companion's orbit. Unfortunately, he says, "What we *don't* know is the inclination of the orbit." Thus the uncertainty about the companion's mass. If we are seeing the orbit edge on, then the companion is at least ten times the mass of Jupiter. But if we are seeing the orbit almost face on, the companion could be nearly as massive as a small star itself.

"That's why you can't argue anything with one example," says Latham. "You need a survey so you can get good statistics and see how frequently you get low-mass companions." Indeed, preliminary results from the surveys conducted by his own group have already turned up some additional candidates for low-mass companions.

■ M. MITCHELL WALDROP

*The 20th General Assembly of the International Astronomical Union, 2 to 11 August 1988, Baltimore, Maryland.

† David W. Latham, Robert Stefanik, Richard McCrosky, and Robert Davis of the Smithsonian Astrophysical Observatory and Tsevi Mazeh of the University of Tel Aviv.