Putting relativity to the test: was Einstein right?

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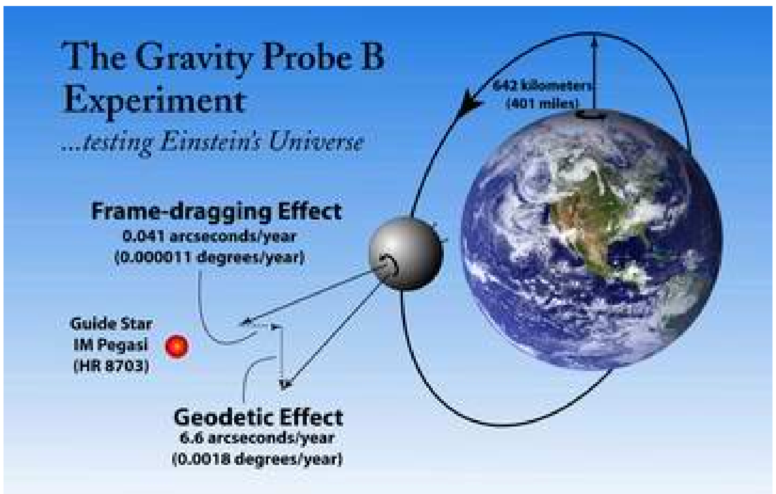


Almost 90 years after Einstein postulated his general theory of relativity — our current theory of gravity — scientists have finally finished collecting the data that will put this theory to an experimental test.

For the past 17 months, NASA's Gravity Probe-B (GP-B) satellite has been orbiting the Earth using four ultra-precise gyroscopes, about a million times better than the finest navigational gyroscopes, to generate the data required for this unprecedented test. As planned, the helium that cooled the experiment and powered its micro-thrusters has run out, ending the data-collection and final instrument calibration phase of the experiment. All the data—50 weeks' worth—has been downloaded from the spacecraft and relayed to computers in the GP-B Mission Operations Center at Stanford University, where GP-B scientists have begun the final painstaking task of data analysis and validation. Was Einstein correct? They won't know for another 15 months, when the analysis has been completed, but physicists around the world are eagerly awaiting the results.

"This has been a tremendous mission for all of us," said Stanford's Francis Everitt, GP-B's principal investigator. "Gravity Probe B presented many challenges along the way and the team rose magnificently to every occasion. With all the data now gathered, we are now proceeding very deliberately over the next 15 months to make sure that everything is checked and re-checked in as many ways as possible. NASA and Stanford can be proud of what has been achieved so far."

This year, physicists celebrate the 100th anniversary of Einstein's "miraculous year," in which he received his doctorate in physics from the University of Zurich and published four seminal papers, including the special theory of relativity and a paper on light that garnered him the Nobel Prize in 1921. But Einstein's crowning achievement came in 1916, with his publication of the general theory of relativity, in which he expanded the special theory of relativity to include the elusive concept of gravity. With general relativity, Einstein forever changed our Newtonian view of gravity as a force, postulating rather that space and time are inextricably woven into a four-dimensional fabric called spacetime, and that gravity is simply the warping and twisting of the fabric of spacetime by massive celestial bodies. Even though it has become one of the cornerstones of modern physics, general relativity has remained the least tested of Einstein's theories. The reason is, as Caltech physicist Kip Thorne once put it: "In the realm of black holes and the universe, the language of general relativity is spoken, and it is spoken loudly. But in our tiny solar system, the effects of general relativity are but whispers." And so, any measurements of the relativistic effects of gravity around Earth must be carried out with utmost precision. Over the past 90 years, various tests of the theory suggest that Einstein was on the right track. But, in most previous tests, the relativity signals had to be extracted from a significant level of background noise. The purpose of GP-B is to test Einstein's theory by carrying out the experiment in a pristine orbiting laboratory, thereby reducing background noise to insignificant levels and enabling the probe to examine general relativity in new ways.

Deceptively simple

Launched on April 20, 2004, from Vandenberg Air Force Base on the California coast, GP-B has been using four spherical gyroscopes to measure precisely two extraordinary effects predicted by Einstein's theory. One is the geodetic effect—the amount by which the Earth warps the local spacetime in which it resides. The other effect, called frame-dragging, is the amount by which the rotating Earth drags local spacetime around with it.

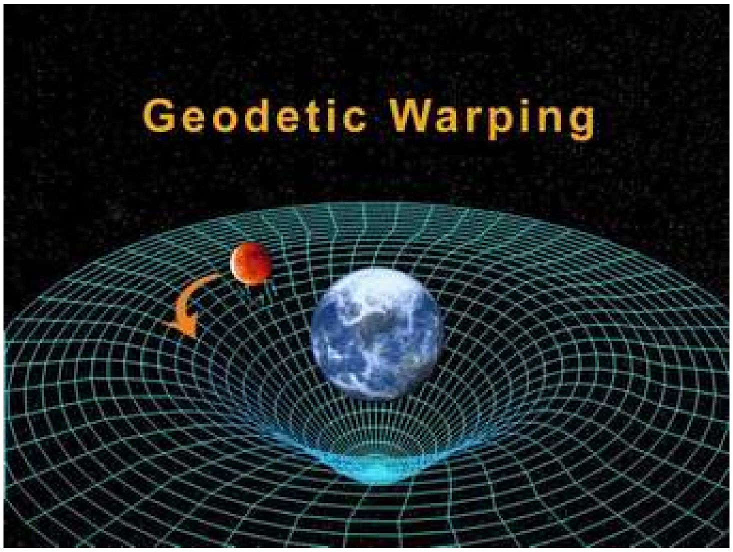
How does GP-B measure these effects? Conceptually, the experiment is simple: Place a gyroscope and a telescope in a satellite orbiting the Earth. (GP-B uses four gyroscopes for redundancy.) At the start of the experiment, align both the telescope and the spin axis of the gyroscope with a distant reference point—a guide star. Keep the telescope aligned with the guide star for a year as the spacecraft orbits the Earth more than 5,000 times. According to Einstein's theory, over the course of a year, the geodetic warping of Earth's local spacetime should cause the spin axis of the gyroscope to drift away from its initial guide star alignment by a minuscule angle of 6.6 arcseconds (0.0018 degrees). Likewise, the twisting of Earth's local spacetime should cause the spin axis to drift in a perpendicular direction by an even smaller angle of 0.041 arcseconds (0.000011 degrees), about the width of a human hair viewed from 10 miles away.

As the late Stanford physicist and GP-B co-founder William Fairbank once put it: "No mission could be simpler than Gravity Probe B. It's just a star, a telescope and a spinning sphere." However, it took the exceptional collaboration of Stanford, NASA, Lockheed Martin and a host of other physicists, engineers and space scientists almost 44 years to develop the ultra-precise gyroscopes and the other cutting-edge technology necessary to carry out this deceptively "simple" experiment. The ping-pong-ball-sized gyroscope rotors, for example, had to be so perfectly spherical and homogeneous that it took more than 10 years and a whole new set of manufacturing techniques to produce them. They're now listed in the Guinness Database of Records as the world's roundest objects. Similarly, it took two years to make the flawless roof prisms in the GP-B science telescope that tracks the guide star. Some scientists have mused about how Einstein, himself once a patent clerk, would have enjoyed reviewing these extraordinary technologies.

Stanford's Bradford Parkinson, GP-B's co-principal investigator and winner of the 2003 Draper Prize in Engineering, said: "Optimism was rampant [in 1960, when GP-B began]. We didn't have any idea how hard this was, and I would contend it was probably not until 30 years later that we brought [into existence] the technology to make perfect spheres, the coating technology, the readout technology, the cryogenic technology, the [telescope] pointing technology. Â… None of this was possible in 1960."

Running on empty

At launch, the Dewar, a giant Thermos bottle that comprises most of the body of the spacecraft, contained approximately 650 gallons of helium, cooled to a superfluid state just above absolute zero. The helium in the Dewar served two vital functions: First, it was the superfluid bath that kept the four gyroscopes at a superconductive temperature, required for the readout of their spin axes. Second, helium gas that constantly evaporated from the bath was reused as the propellant for the spacecraft's micro-thrusters to maintain both its proper orientation and roll rate in orbit and to keep it pointed at the guide star. When designing the Dewar, the team carefully calculated that 650 gallons of helium would be adequate to sustain the GP-B mission for at least 16 months, and that a Dewar large enough to hold that amount would just barely fit in the nose of the Boeing Delta II rocket that would launch the experiment. When the helium in the Dewar was depleted on Sept. 29, it had outlived the team's initial calculations by more than three weeks.



Mac Keiser, GP-B chief scientist who heads the data analysis team at Stanford, said: "Getting 50 weeks of data from the satellite has been particularly important—not only because it will allow us to reduce our statistical errors but also because the Earth has made almost a complete revolution around the sun. This complete cycle will allow us to take full advantage of one of our calibrating signals and eliminate potential sources of systematic error."

Next-to-last milestone

The completion of data collection marks the last milestone prior to announcing and publishing the results of this historic 44-year program. It is a time of both triumph and emotion for the GP-B team. Some team members have been working together on the program for more than 15 years. As the focus of the mission shifts from spacecraft operations to data analysis, it is time for many of the team's engineers and mission operations specialists to move on, and this naturally brings a note of sadness into the otherwise joyful spirit of accomplishment.

"It's a bit like sending your kid off to college," said GP-B Program Manager Gaylord Green. "Our operations team became a family accomplishing this mission, and after a good job the members will be departing to the next phase of their lives."

Added Tony Lyons, NASA's GP-B program manager from Marshall Space Flight Center in Huntsville, Ala.: "The completion of the GP-B mission is the culmination of years of hard work, training and preparation by the GP-B team. Every team member should feel proud of this accomplishment."

It will take the GP-B science team more than a year to complete the data analysis, followed by up to six months of preparing and submitting papers to major scientific journals detailing the experimental results. Following NASA protocols used for other missions with precise quantitative measurements, there will be no preliminary announcements of results nor any speculation about the data before a formal announcement and publication of results, expected early in 2007.

Source: Stanford University (by Bob Kahn)

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