Einstein’s theory of gravity confirmed by NASA probe

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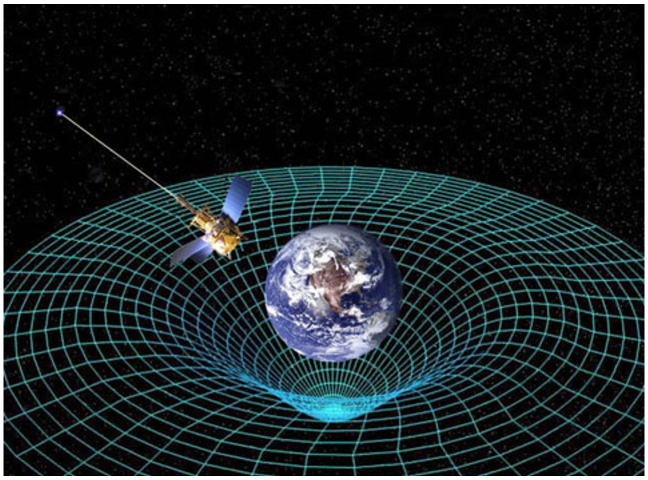

NASA has just announced that Einstein’s theory of gravity, also known as the General Theory of Relativity, has been verified in two ways by its Gravity Probe-B (GP-B) with astonishing accuracy [1]. The experiment was begun in 2004 when a satellite containing four specially developed gyroscopes was put into orbit around the earth, passing over the North and South poles.

GP-B measures two predictions of Einstein’s theory known as the geodetic effect and the frame dragging effect. The geodetic effect is the amount that space and time is “warped” by the gravitational mass of the Earth, well known in non-technical explanations of the theory. The frame-dragging effect is less well known, though it was predicted by the Austrian physicists Josef Lens and Hans Thirring in 1918 only two years after Einstein first published his General Theory. This effect results in local space and time being pulled by the rotation of the Earth.

The frame dragging effect is analogous to the way in which a rotating electric charge produces magnetism and is sometimes referred to as the “gravitomagnetic effect” and is even regarded as producing a new force of nature, the gravimagnetic force.

As the leading scientist of the GP-B team, Francis Everitt of Stanford University, graphically explained, “Imagine the Earth as if it were immersed in honey. As the planet rotates, the honey around it would swirl, and it’s the same with space and time.”

The gyroscopes in GP-B are attached to a telescope that is pointed at a distant star, so that if space and time were unaffected by the Earth they would remain spinning in the same direction. Instead Einstein’s theory predicts they tilt by a very tiny amount because of the Earth’s gravity. The measurement of this tilt in GP-B is compared with the theoretical predictions of Einstein’s theory.

Previously the geodetic effect had been measured by studying the trajectory of the Earth-Moon system as it orbits the Sun and had been found to verify General Relativity with about 1 percent accuracy. The GP-B results just announced are a hundred times more accurate at 0.01 percent.

The frame dragging effect is so small that it has never previously been directly measured. The accuracy of the GP-B measurement differs by 4.9 percent from Einstein’s prediction.

If this accuracy does not seem exceptional, it must be emphasised that the experiment depends on measuring angles through which the gyroscopes tilt to 1.8-thousandths of a degree for the geodetic effect and 11-millionths of a degree for the frame dragging effect—the latter is equivalent to measuring the thickness of a human hair viewed from a quarter of a mile away.

Although the experiment proper was begun in 2004, the project was first started by NASA in 1963 and is one of the longest running in their history. The idea of using gyroscopes to test relativity was first put forward by physicists in 1959-60.

Over the intervening four decades a dozen or more remarkable technological innovations were made in order to carry out the experiment to such a high level of accuracy.

The gyroscopes themselves are made of pure quartz in a perfectly spherical shape. They are the roundest objects ever manufactured. To give some indication of just how smooth they are, imagine that they were magnified to the size of the Earth. The biggest hills or valleys on their surface would then be at most eight feet (2.4 meters) tall or deep.

They are designed to have virtually no drift from their spin axis so that they are 10 million times more accurate than the best Earth-based gyroscopes used in military aircraft and nuclear submarines.

The sensors measuring the direction of each gyroscope’s axis relies on the quartz surface being coated with a thin film of superconducting metal, niobium, that generates a magnetic field as it spins. Such superconductivity—an electric current flowing indefinitely with no resistance—takes place at a temperature of 1.8 degrees Centigrade above absolute zero. To achieve this effect the GP-B spacecraft was built around a 650-gallon thermos bottle, filled with liquid helium that must remain at these low temperatures throughout its mission. In itself, this is a remarkable feat of engineering.

A superconducting niobium pickup loop surrounds the gyroscope in which an electric current will flow if the gyroscope moves off its axis by an extremely tiny amount. The current is then measured by a special device called a SQUID (Superconducting Quantum Interference Device) magnetometer. These magnetometers measure changes in magnetic fields as small as 1-ten-trillionth (1/10,000,000,000,000) of the Earth's magnetic field, enabling the phenomenally tiny tilt of the gyroscopes to be measured.

A number of other techniques developed in GP-B have been applied in other NASA projects such as the Cosmic Background Explorer (COBE) mission. It measured the background radiation in the universe, and provided supporting evidence for the Big Bang Theory of the origins of the Universe. The techniques will be used in many other areas of science and technology.

As Everitt succinctly put it, "The decades of technological innovation behind the mission will have a lasting legacy on Earth and in space."

What is the significance of confirming Einstein's General Theory? Surely it has already been accepted and needs no further confirmation. The significance of the GP-B experiment is that it has confirmed important aspects of the theory to such a high level of accuracy.

This has both a scientific and a more general philosophical significance. Einstein's theory is based on the conception that space and time are neither God-given, as Isaac Newton had believed, nor built into the human mind, as the philosopher Immanuel Kant maintained. Einstein based himself on the materialist conception that space and time are fundamental properties of matter. His theory of General Relativity shows that local space-time is determined by the distribution of matter, both locally (as with GP-B and the Earth) and, to a very tiny extent, even by the matter throughout the Universe. That materialist conception of space and time is richly confirmed by the GP-B project and other theories of space and time that are based on more subjectivist conceptions that have been disproved.

From a scientific point of view the GP-B experiment is important in that the high degree of accuracy it has achieved will allow scientists to test the limits of Einstein's theory. They will be able to devise future experiments that determine within what "tolerances" the theory holds true.

As GP-B physicist John Mester notes in the Stanford University GP-B overview, "General relativity is our current theory of gravitation, and it has wide-ranging implications for our understanding of the structure of the cosmos. At present, Einstein's theory of gravitation lies outside the other three forces of nature (the strong force, the weak force and the electromagnetic force), which are explained within a unified framework called "The Standard Model." Attempts to unify all four forces of nature have eluded physicists from Einstein to the current day. Testing theories to high precision will help define their range of validity or reveal where these theories break down."

A deeper understanding of Einstein's theory will have immense practical relevance to the development of technology. Already the theory of General Relativity plays a vital part in the Global Positioning System (GPS) that millions of people use in their personal lives, whether hiking in the hills or driving, and that has an essential role in modern industrial production and distribution. The GPS system can give an absolute position on the surface of the Earth to within 10 metres and is now widely used for navigation in trucks, planes and ships. Its accuracy depends on an application of the General Theory of Relativity.

The 24 satellites on which GPS depends must keep time to an accuracy of 20-30 nanoseconds (1 nanosecond = 1 billionth of a second). General Relativity predicts that clocks on satellites run slightly faster (45 microseconds a day, 1 microsecond = 1 millionth of a second) than clocks on Earth. Time on the satellites must be corrected by this tiny amount or errors in GPS positioning would rapidly build up at the rate of up to 10 kilometres a day.

The GP-B project tells us something significant about science as a whole. There is a widespread belief that science develops purely on the basis of individual genius. This distorted conception of scientific development was reinforced by the work of the sociologist Thomas Kuhn, who argued that science underwent periodic paradigmatic shifts as a result of the work of outstanding individuals who happen to develop new theories. What the GP-B project demonstrates is that science is a social endeavour and develops in close relationship with technological advances. The work of individual geniuses like Einstein, and their contribution is undoubtedly essential, depends on an entire scientific culture with which they are trained and against which they test their ideas. The creation of scientific culture is the work of generations and not brilliant but isolated insights or solitary experimental results.

The GP-B project is an expression of the work of hundreds of scientists who have been involved in the conflicts and debate over 50 years to arrive at our current understanding of relativity. As Einstein did before them, they have depended on developments in technology, and their work in turn provides the basis for further developments in technology as our understanding of the Universe deepens. A complex relationship exists between scientific advances, technological developments and the theoretical or philosophical understanding of matter. Trotsky addressed this question in C*ulture and Socialism*: [2]

"'Does culture drive technology, or technology culture?'—asks one of the notes lying before me. This is the wrong way to pose the question. Technology cannot be counter-posed to culture, for it is culture's mainspring. Without technology there is no culture. The growth of technology drives culture forward. But the science and general culture which rise up on the basis of technology give a powerful impulse to the growth of technology. Here there is a dialectical interaction."

The GP-B project is an embodiment of this principle.

Notes:

1. http://www.nasa.gov/mission_pages/gpb/ [back]
2. Leon Trotsky, Culture and Socialism, 1927 [back]