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Gravity

Weighing the universe

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How scientists are trying to find where Einstein went wrong

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FAMILIAR as it may seem, gravity remains a mystery to modern physics. Despite several decades of trying, scientists have failed to fit Einstein's general theory of relativity, which describes how gravity holds big objects together, with the quantum mechanics he pioneered, which describes the tiny fundamental particles of which matter consists and the forces by which they interact. Recent discoveries have highlighted further problems.

Many physicists are therefore entertaining the idea that Einstein's ideas about gravity must be wrong or at least incomplete. Showing exactly how and where the great man erred is the task of the scientists who gathered at the “Rethinking Gravity” conference at the University of Arizona in Tucson this week.

One way to test general relativity is to examine ever more closely the assumptions on which it rests, such as the equivalence principle: that gravity accelerates all objects at the same rate, regardless of their mass or composition. This principle was famously demonstrated by Galileo Galilei some 400 years ago when he simultaneously dropped cannon and musket balls, and balls made of gold, silver and wood, from the Tower of Pisa. Each appeared to hit the ground at the same time.

A more precise test requires a taller tower. In effect, researchers are sending balls all the way to the moon and back. Tom Murphy, of the University of California, San Diego, and his colleagues fire laser beams from the deserts of New Mexico at reflectors placed on the moon by American and Russian spacecraft in the late 1960s and early 1970s. They use a telescope to capture the small fraction of the light that returns. Because the speed of light is known, they can calculate the distance between the Earth and the moon from the time taken for light to traverse it.

Great minds think alike

According to general relativity, because the Earth and the moon orbit the sun, they should "fall" towards it at the same rate, in the same way as Galileo's balls fell to the ground. By repeatedly measuring the distance between them, scientists can calculate the orbits of the Earth and the moon around the sun relative to each other.

If the equivalence principle were violated, the moon's orbit around the Earth would appear skewed, either towards or away from the sun. So far, Dr Murphy told the conference, these experiments have merely confirmed the equivalence principle to one part in 10 trillion. Dr Murphy and his colleagues hope that even more precise measurements could ultimately show general relativity to be only approximately correct. This would usher in a new revolution in physics.

Another aspect of Einstein's work to be tested is the existence of gravitational waves. General relativity views gravity not as a force but as a consequence of the curved geometry of space and time. Space-time, as it is known, has four dimensions: the three familiar spatial ones of length, breadth and height, and time. It can be distorted or curved by massive objects, such as stars. Temporary ripples in space-time—gravitational waves—are caused when such objects accelerate. They are weak, but if the accelerating object has enough mass it should be possible to spot them.

Scientists at several new ground-based observatories are hoping to do just that. The most sensitive of these, the Laser Interferometer Gravitational Wave Observatory, is based on two sites in Livingston, Louisiana, and Hanford, Washington. So far, it has seen nothing worthy of mention—but it has been running at both sites for less than a year. Even so, the American space agency, NASA, and the European Space Agency are collaborating on plans for the next step: the Laser Interferometer Space Antenna, which would be far more sensitive to gravitational waves. If they were detected, another of Einstein's predictions could be confirmed.

Further experiments are testing gravity in space. NASA has a spacecraft called Gravity Probe B that is examining a subtlety known as the Lense-Thirring effect that produces a small force as space-time is twisted by a spinning mass, such as a rotating planet. The probe orbits the Earth's poles; the Lense-Thirring effect is predicted to shift, little by little, the point on the equator crossed by the spacecraft. This may take several months to become noticeable; the results are due in the spring.

What is happening to space-time around a rotating object that is much more massive than the Earth—a black hole, say—should be more obvious. Some elegant and profound mathematics says that black holes can be described using just two numbers: their mass and their spin. Now astronomers want to know whether the maths is correct. Avery Broderick, of Harvard University, told the conference that studies of the supermassive black hole at the centre of the galaxy could be detailed enough to decide this. He thinks it may be possible to measure the spin using an intercontinental network of existing radio telescopes over the next five years.

Data from existing X-ray satellites that show images of gas whizzing about black holes at close to the speed of light hint that time slows as the gas plunges into the zone from which escape is impossible. NASA has proposed a mission, called Constellation-X, that would build on this work by providing detailed pictures of what happens to space-time at the edges of these gravitational chasms.

Then there are plans to examine the gravitational wave background, which would show what the universe looked like a fraction of a second after the Big Bang. The earliest images that cosmologists have found come from a couple of hundred thousand years after the birth of the universe. The pictures show that it was already lumpy; the denser areas went on to become galaxies, stars and planets. Knowing how this came about by looking even further back would allow cosmologists to decide which of their theories of the early universe were correct. This, in turn, would tell them more about the nature of gravity. Will Kinney, of Buffalo University, told the conference of future plans to detect the extremely faint gravitational waves still ringing in the heavens from the Big Bang.

More than 100 years after Einstein began the most recent revolution in physics, his ideas remain mostly correct. But physicists are convinced they are incomplete, and are determined to discover precisely where they fail.

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