Fundamental physics

To catch a gravitational wave

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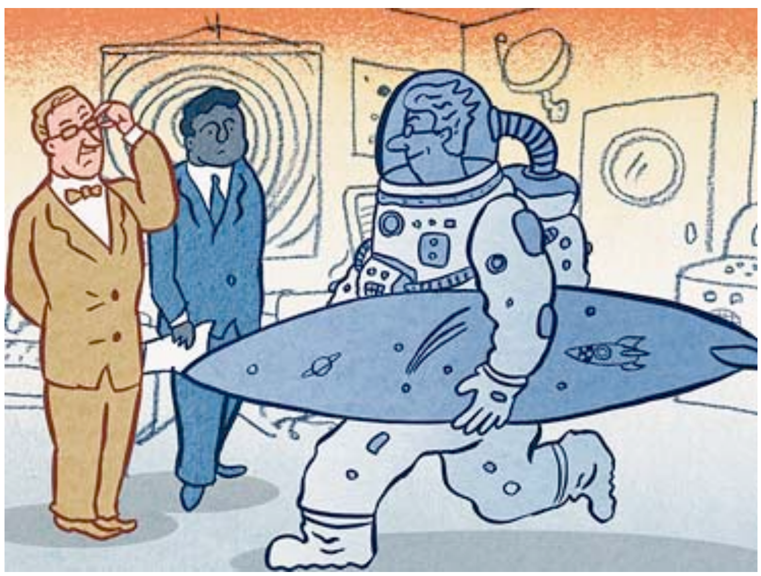
Physicists hope to find a new astronomy and test some wacky ideas



SCIENTISTS trying to detect gravitational waves—ripples in the fabric of space-time—are a reticent lot. Understandably so: in the late 1960s Joseph Weber, a pioneer of the field, declared that he had found them when he had not, and mouths have been kept firmly shut ever since. Nearly 40 years on, researchers around the world are still straining to see gravitational waves, so far without success. This week scientists met to discuss plans for a more sensitive detector that could be built in space.

Gravitational waves were predicted by Einstein's general theory of relativity in 1916. This theory 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.

Space-time can be distorted or curved by the presence of massive objects, such as stars. Temporary ripples in space-time are caused when such objects accelerate. The ripples are gravitational waves. They are very weak but, if the accelerating object has enough mass, it should be possible to spot them. The waves that emanate from the collision of two black holes should be detectable. So should echoes from the Big Bang with which the universe is believed to have begun. And whereas microwaves, radio waves and light—all forms of electromagnetic radiation—are easily absorbed by dust and gas, leaving much of the universe hidden, gravitational waves penetrate anything in their path. Finding them could thus offer astronomers new tools for studying the universe.

Setting traps

Today's attempts to detect gravitational waves use instruments called interferometers. These exploit the fact that gravitational waves should cause space to stretch in one direction and shrink in the dimension at right angles to it. The instruments consist of two tubes arranged in an L-shape. A laser beam is split and one half is sent down each tube, bouncing off a mirror at the end. The two parts are arranged so that when they return to the beam-splitter, the peaks of one wave are in step with the troughs of the other. They therefore cancel each other out, leaving darkness. A passing gravitational wave would stretch one tube and shrink the other, disturbing the neat alignment of peaks and troughs, and creating light.

A couple of interferometer-based experiments are under way. Others are due to start within a year. The information they yield will be combined and analysed by scientists involved in all the experiments. For a gravitational wave to be unambiguously identified, it must be detected by more than one instrument.

The biggest experiment, with arms up to four kilometres (about two and a half miles) long, is called the Laser Interferometer Gravitational Wave Observatory, or LIGO. It has been collecting data for the past seven months. It has three machines, one near Livingston, Louisiana, and two at Hanford in Washington state. A smaller, German-British experiment called GEO600 (because the interferometer arms are 600 metres long) started taking scientifically useful data in Hanover last month. These will be joined by Virgo, a collaboration between Italian and French researchers with three-kilometre arms, which is being built near Pisa. Another interferometer with arms of the same length is under construction at Kamioka in Japan.

Unfortunately, a passing gravitational wave will make only a tiny change in the distance the laser beams have to travel. Even if experimenters bounce the beams to and fro to increase the effective length of an interferometer's arms to more than 100 kilometres, the expected difference in length between the two beams' paths still amounts to less than a hundred-millionth of the diameter of a hydrogen atom.

Scientists are trying ever more clever ways to sense this change: new materials have allowed GEO600's mirrors to be better isolated from the world outside, making it as sensitive as the longer-armed LIGO. The interferometer in Japan is being built underground and will be kept at extremely low temperatures to minimise stray vibrations. There are also plans to refine existing experiments.

Ultimately, however, the answer may be to conduct the experiments in space. There, the length of the arms could be truly enormous. In fact, they would not even have to be built; the devices at their ends are all that would be needed. The American space agency, NASA, and the European Space Agency are collaborating on plans for an experiment in space in which the contraptions that would be used instead of mirrors would be 5m kilometres apart. At a meeting at the Goddard Space Flight Centre in Maryland this week, scientists outlined what this could achieve.

The putative device—called the Laser Interferometer Space Antenna, or LISA—would not merely detect gravitational waves; it could identify their sources precisely, in the same way that an optical telescope identifies pricks of light as stars. Any object of sufficient mass, no matter how exotic, could be studied in detail.

For example, neutron stars—the extraordinarily dense remnants of stars that have exploded as supernovae—often have nearby partners that orbit one another. Strong gravitational waves are thought to be produced by the collision of two neutron stars. Indeed, in 1974 Russell Hulse and Joseph Taylor recorded an indirect sighting when they showed that a pair of stars spiralling towards each other was radiating energy in the form of gravitational waves at exactly the rate predicted by Einstein. That won them a Nobel prize. However, LISA would be able to see gravitational waves directly, and from them identify the prevalence and whereabouts of pairs of neutron stars in the universe.

The coalescence of two black holes would create even stronger gravitational waves, but physicists believe that there are fewer black holes than neutron stars, so such events would be rarer. With LISA, they would be able to find out whether all this is true. Other envisaged sources are supernovae and rapidly rotating isolated neutron stars. The early universe is also thought to have produced a background of gravitational waves from quantum fluctuations. Again, LISA would be able to examine such phenomena.

Fundamental tests

Indeed, LISA could do more. It could allow scientists to examine the validity of string theory, which says that there are more than four dimensions to space-time and that the extra dimensions are hidden. String theory has come under fire because its predictions have so far proved untestable. The normal version has it that these dimensions are curled up in strings that are smaller than the known elementary particles. However, in some versions strings form very long “superstrings” that stretch across the universe. These superstrings form loops and vibrate, radiating gravitational waves; they can also crack like whips, sending bursts of gravitational waves towards Earth. “Seeing direct evidence of strings would be as important as discovering that the world is made of atoms,” claims Craig Hogan, an astronomer at the University of Washington, who is a member of the international science team for LISA.

Whether gravitational wave scientists will have to stay tight-lipped for long remains to be seen. Back in August 2004, Ladbrokes, a British bookmaker, offered odds of 500 to one against gravitational waves being detected by 2010. After taking a flurry of bets, it slashed the odds to 100 to one and then two to one in just a few weeks before closing the book. The bookies must be hoping that gravitational-wave scientists find no reason to end the reticence of the past four decades.