Pulsars test Einstein

The universe is really a far more bizarre and exciting place than living in Aussie suburbia might lead you to believe. With the aid of modern astronomy we can now see far out into the cosmos, where some unusual objects make our planet, or even our entire solar system, seem very humdrum and plain.

Take neutron stars for instance: they result from the collapse of stars millions of kilometres in diameter, in the course of which a vast amount of matter is squeezed into a ball just 20 kilometres across and composed entirely of neutrons (subatomic particles about as massive as protons but with no electrical charge).

A neutron star has a mass similar to that of the original parent star, but as it is compressed into such a small volume its matter is incredibly dense, such that just a pinhead would weigh a million tonnes. Of course, these neutron stars are too small for us to see optically, but they do give off X-rays or radio waves that we can detect.

Equally strange were the radio signals that astronomers at Cambridge University in Britain picked up in 1967. So regular were these radio pulses — emanating from one precise spot in the sky and ticking as accurately as any electronic timepiece — that at first it was even considered that they could be artificial in origin and represent signals from another civilisation! But scientists quickly realised that the radio pulses originated from a rotating neutron star.

Like the lamp at the top of a giant lighthouse, the pulsar sweeps a beam of radio waves in our direction with each complete turn. (Most astronomers accept that the radio waves are emitted by electrons moving out from the star's magnetic poles along the lines of a very strong magnetic field. Thus, the pulses only originate from the two magnetic poles, which need not necessarily correspond with the poles of rotation.) What we detect is a regular series of radio pulses, their frequency related to the speed of rotation of the neutron star.

Binaries

Most of the early pulsars astronomers discovered spun round at somewhere between ten times a second and once every 4 seconds. They were also, as far as was known, single objects. But in 1974 astronomers found a spinning pulsar in orbit around another object, which was also probably a neutron star; the whole system was termed a binary pulsar. (To be precise, no object really orbits another; they both circle the common centre of gravity between them — but if one object is vastly more massive than the other, this point may well be located within it.)

Until recently, we knew of only nine of these binary pulsars — but then CSIRO radio-astronomer Dr Jon Ables and his colleagues, in collaboration with scientists at the University of Sydney and the University of Tasmania, discovered two more.

The new objects are not in our own galaxy, but in a globular cluster — a ball of about a million or so stars that is a type of small satellite to the galaxy. Astronomers know of many such clusters, and some are easy to observe by amateurs with small telescopes, binoculars, or even the naked eye. The globular cluster that is home to these two binary pulsars — called 47 Tucanae — can be seen unaided on a dark night, but is only visible from our southern latitudes. (Consult the diagram if you want to see the cluster yourself; of course you won't be able to spot any pulsars!) If you do glimpse 47 Tucanae, you are looking about 15 000 years into the past, because that's how long its light has taken to reach us.

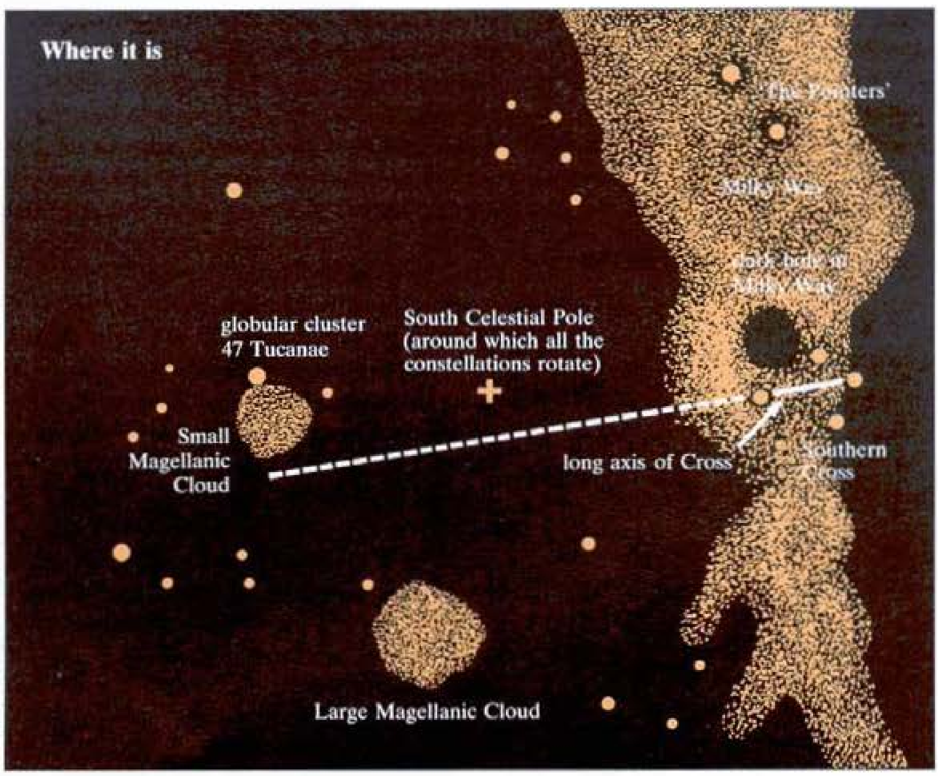
Also exciting about the two binary pulsars in 47 Tucanae is that in each one the rotating neutron star — the one whose radio waves come to us in pulses — is spinning more than usually fast — in the case of the faster of the two, a dizzy 232 times a second.

Theories

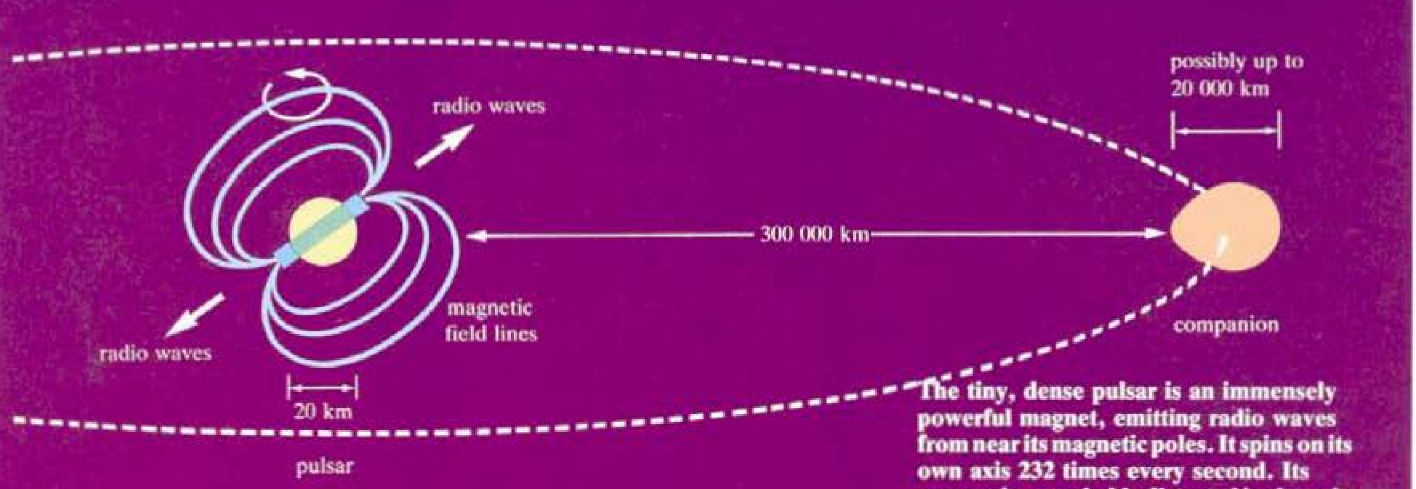
All these mind-boggling statistics show us that conditions elsewhere in the universe can be a lot more extreme in some respects than those in our local neighbourhood. And unusual or extreme conditions provide physicists with means of testing to the limit the truth of their theories, and how widely applicable they may be.

Few theories have had as much impact on as many areas of modern physics as those of Albert Einstein. He developed his revolutionary special and general theories of relativity near the beginning of the

The globular cluster that is home to the two binary pulsars is in the constellation of Tucana — the toucan — and is called 47 Tucanae or NGC 104. In the same constellation is the Small Magellanic Cloud, which is visible as a misty patch looking rather like a piece of the Milky Way that has broken off. You can find it by continuing an imaginary line that passes through the long axis of the Southern Cross.



An odd couple



The tiny, dense pulsar is an immensely powerful magnet, emitting radio waves from near its magnetic poles. It spins on its own axis 232 times every second. Its companion, probably distorted in shape by the intense gravity of the tiny pulsar, orbits it every 32 minutes.

century when the technology for testing most of their predictions was unavailable. Although some of each theory has been verified by various observations since, parts remain untested even now — more than 70 years later. On earth, or in our immediate vicinity, we still can't see some of the strange effects tne theories predict because the conditions are not sufficiently extreme.

One of the effects predicted by the general theory of relativity concerns rapidly orbiting bodies, and until quite recently the best example that we could study was Mercury, which, being the innermost planet, orbits the sun at the greatest speed. Einstein predicted that the elliptical orbit was itself slowly rotating, something that should not occur if Newton's theories of celestial mechanics applied.

To understand what is meant, remember that in an elliptical orbit, such as all the planets describe, there is a point where the orbiting body comes nearest to its primary, and one where it is furthest away.

In the case of a planet moving around the sun, the point of closest approach is called perihelion. You might expect this to occur at the same point along the orbit with each revolution, assuming nothing is acting to perturb either body.

But, in fact, the point of perihelion itself slowly rotates, in the case of Mercury by about 43 seconds of arc each century. (Sixty arc-seconds make 1 arc-minute and 60 arc-minutes add up to 1° of a circle.) This is a tiny amount, because Mercury is not really moving fast enough to provide the necessary extreme conditions for the effects of relativity to be readily apparent. Of course, such a small amount takes several years to observe, and as Mercury is in fact perturbed by the gravitational effect of the other planets, testing Einstein's prediction rigorously has always been difficult.

Extremely rapidly rotating binary pulsars provide a far more stringent means of checking the theory. One found by scientists in the United States in 1974 showed that the point of closest approach in the orbit of the satellite body — in the case where a star other than our sun is involved this is called periastron — moved by 4° every year (compare this with the figure for Mercury). In only a few decades the orbit itself would make a complete revolution.

One of the binary pulsars discovered by the CSIRO scientists and their colleagues beats even this. The companion to the pulsar orbits it unbelievably rapidly. Lying about 300 000 km away from the tiny pulsar — slightly less than the distance from the earth to the moon — the speedy companion covers in only 32 minutes nearly the same distance that the more sedate moon completes in 28 days. With the unbelievably rapid orbital period of 32 minutes relativistic effects have a large part to play, and the scientists have observed that periastron shifts about half a degree every day, which would be in order with the theory.

More predictions

Relativity predicts something else that the new binary pulsars may be able to test. The equations suggest that a body spinning very rapidly on its own axis, in orbit around another body, or with another body orbiting around it, will exhibit the grandly named gravito-magnetic effect.

Despite its name, this has very little to do with magnetism in the sense of the common or garden bar magnets that we all knew and loved as children. But it is connected with gravity, and, put simply, means that the plane of the orbit that the two bodies make around each other should slowly change.

Also, the axis of the spinning object (like the earth's north–south axis) will show a type of precession — that is, rather than pointing always in one direction, it will shift rather like a spinning top may wobble. These changes with time are called spin–orbit coupling and may well occur in our solar system, but are just too tiny to observe because our planets do not move quickly enough.

With the advent of the space age, physicists now believe they can perform an experiment to test for the presence of this effect — by placing a very fast-spinning sphere in a spacecraft in orbit around the earth, and looking for changes in the position of the axis of spin and other manifestations.

But this would cost a great deal, and the newly discovered binary pulsar may enable us to measure the effect far more cheaply. The CSIRO team and their collaborators are hoping to do just that, with results due in about a year. Your correspondent is reliably informed that if the gravito-magnetic effect is proved not to exist then the whole of the general theory of relativity would collapse.

Most scientists are confident that Einstein will be vindicated yet again. Theories of gravitation other than that proposed by the great man also predict some spin–orbit coupling in a similar situation, although to different degrees. So it will be important not only to observe the effect, but to measure it exactly. Our ideas of how the universe 'works' hang in the balance.

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