Nobel Prize in Physics 1993

Russell A. Hulse **Joseph H. Taylor Jr.**

The Nobel Prize in Physics 1993 was awarded jointly to Russell A. Hulse and Joseph H. Taylor Jr. *"for the discovery of a new type of pulsar, a discovery that has opened up new possibilities for the study of gravitation"*

Information about winners:

Russell A. Hulse and **Joseph H. Taylor, Jr**,

Both of Princeton University, New Jersey, USA

RESEARCH INFORMATION:

Gravity investigated with a binary pulsar

The discovery rewarded with this year's Nobel Prize in Physics was made in 1974 by **Russell A. Hulse** and **Joseph H. Taylor, Jr** using the 300-m radiotelescope at Arecibo, Puerto Rico, West Indies. Taylor, then Professor at the University of Massachusetts, Amherst, and his research student Hulse were searching systematically for pulsars - a kind of rapidly rotating cosmic beacon with a mass somewhat greater than that of the sun and a radius of about ten kilometres. (A human being on the surface of a pulsar would weigh some hundred thousand million times more than on Earth.) The pulsar's "beacon light" is often within the radio wave region.

The first pulsar was discovered in 1967 at the radioastronomy laboratory in Cambridge, England (Nobel Prize 1974 to Antony Hewish). What was new about the Hulse-Taylor pulsar was that, from the behaviour of the beacon signal, it could be deduced that it was accompanied by an approximately equally heavy companion at a distance corresponding to only a few times the distance of the moon from the earth. The behaviour of this astronomical system deviates greatly from what can be calculated for a pair of heavenly bodies using Newton's theory. Here a new, revolutionary "space laboratory" has been obtained for testing Einstein's general theory of relativity and alternative theories of gravity. So far, Einstein's theory has passed the tests with flying colours. Of particular interest has been the possibility of verifying with great precision the theory's prediction that the system should lose energy by emitting gravitational waves in about the same way that a system of moving electrical charges emits electromagnetic waves.

The significance of the discovery of the binary pulsar

The discovery of the first binary pulsar is primarily of great significance for astrophysics and gravitational physics. Gravity is the oldest known natural force, the one we are most aware of in daily life. At the same time it is in one sense the force that is hardest to study since it is so much weaker than the other three natural forces: the electromagnetic force and the strong and the weak nuclear forces. The development of technology and science since the second World War with rockets, satellites, space voyages, radioastronomy, radar technology and the precise measurement of time using atomic clocks has led to a renaissance of the study of this earliest-known natural force. The discovery of the binary pulsar represents an important milestone in this historical development.

Relativity theory and gravitational physics

According to Albert Einstein's general theory of relativity, gravity is caused by changes in the geometry of space and time: space-time curves near masses. Einstein presented his theory in 1915 and became a world celebrity when in 1919 the English astrophysicist Arthur Eddington announced that one of the predictions of the theory, the deflection of starlight passing near the surface of the sun - "the light is drawn towards the sun" - had been verified during solar eclipse expeditions. This deflection of light. together with a small general-relativity contribution to the perihelion motion of ercury (a slow rotation of Mercury's elliptical orbit round the sun), was for several decades the only, partly rather uncertain, support for Einstein's theory.

For a long time the theory of relativity was considered aesthetically very beautiful and satisfying, probably correct, but of little practical significance to physics except in applications in cosmology, the study of the origin, development and structure of the universe.

Attitudes to the general theory of relativity changed, however, during the 1960s when both experimental and theoretical developments made gravitational physics a topical part of physics. New opportunities for precise experiments, based on satellite and radar technology, opened up. In particular, the research of the Americans R. Dicke and I. Shapiro contributed to this. Dicke performed precision experiments in which the sun's gravitational field on the earth was used for verifying what is termed the equivalence principle, the identity between gravitational and inertial mass - one of the basic principles of the general theory of relativity (and also of several alternative gravitation theories). Important contributions were also Shapiro's theoretical prediction and experimental verification, using radar echoes from Mercury, of a new consequence of the general theory of relativity - a time-delay effect for electromagnetic signals passing through gravitational fields.

All these experiments, however, were confined to our solar system with its very weak gravitational fields and consequently small deviations, hard,to measure, from the Newtonian theory of gravity. Hence it was possible to test the general theory of relativity and other theories only in the first post-Newtonian approximation.

The discovery of the binary pulsar

Hulse's and Taylor's discovery in 1974 of the first binary pulsar, called PSR 1913 + 16 (PSR stands for pulsar, and 1913 + 16 specifies the pulsar's position in the sky) thus brought about a revolution in the field. We have here two very small astronomical bodies, each with a radius of some ten kilometres but with a mass comparable with that of the sun, and at a short distance from each other, only several times the moon's distance from the earth. Here the deviations from Newton's gravitational physics are large. As an example may be mentioned that the periastron shift, the rotation of the elliptical orbit that the pulsar (according to Kepler's first law from the beginning of the 17th century) follows in this system, is 4 degrees per year. The corresponding relativistic shift for the most favourable example in our solar system, the above-mentioned perihelion motion of Mercury, is 43 seconds of arc per century (this is less than a tenth of the very much larger contributions to the perihelion motion caused by perturbations from other planets, chiefly Venus and Jupiter). The difference in size between the shifts is partly due to the orbital speed in the binary pulsar, which is almost five times greater than Mercury's, and partly due to the pulsar performing about 250 times more orbits a year than Mercury. The orbiting time of the binary pulsar is less than eight hours, which can be compared with the one month our moon takes to orbit the earth.

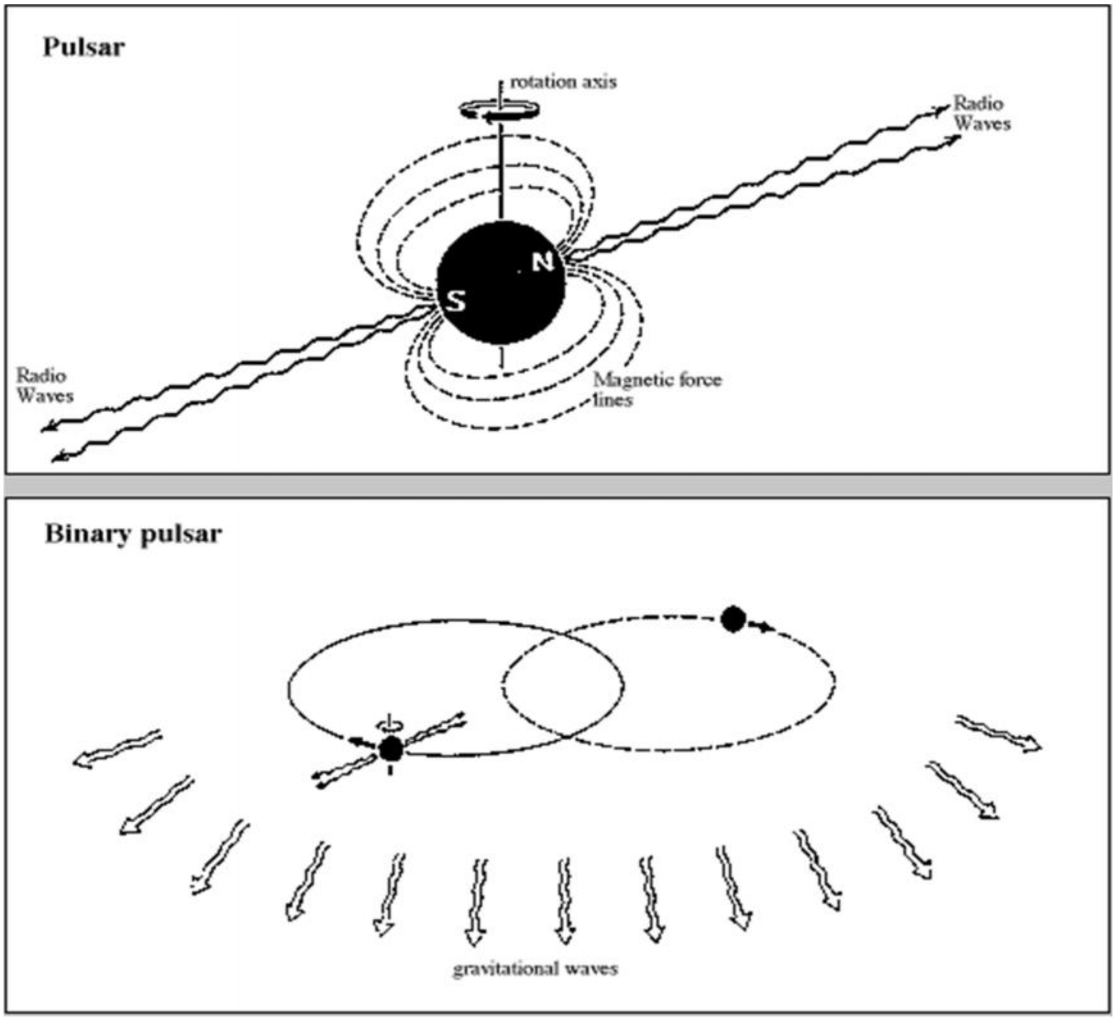
A very important property of the new pulsar is that its pulse period, the time between two beacon sweeps (0.05903 see) has proved to be extremely stable, as opposed to what applies to many other pulsars. The pulsar's pulse period increases by less than 5% during 1 million years. This means that the pulsar can be used as a clock which for precision can compete with the best atomic clocks, This is a very useful feature when studying the characteristics of the system.

The very stable pulse period is in fact a mean of the pulse period observed on earth over the time of one orbit of the pulsar system. The observed period actually varies by several tens of microseconds, i.e. by an amount that is much greater than the variation in the mean value. This is a Doppler effect, and led to the conclusion that the observed pulsar moves in a periodic orbit, meaning that it must have a companion. As the pulsar approaches the earth, the pulses reach the earth more frequently; as it recedes they arrive less frequently. From the variation in pulse period, conclusions can be drawn about the pulsar's speed in its orbit and other important features of the system.

Demonstration of gravitational waves

A very important observation was made when the system had been followed for some years. This followed theoretical predictions made shortly after the original discovery of the pulsar. It was found that the orbit period is declining: the two astronomical bodies are rotating faster and faster about each other in an increasingly tight orbit. The change is very small. It corresponds to a reduction of the orbit period by about 75 millionths of a second per year, but, through observation over sufficient time, it is nevertheless fully measurable. This change was presumed to occur because the system is emitting energy in the form of gravitational waves in accordance with what Einstein in 1916 predicted should happen to masses moving relatively to each other. According to the latest data, the theoretically calculated value from the relativity theory agrees to within about one half of a percent with the observed value. The first report of this effect was made by Taylor and co-workers at the end of 1978, four years after the discovery of the binary pulsar was reported.

The good agreement between the observed value and the theoretically calculated value of the orbital path can be seen as an indirect proof of the existence of gravitational waves. We will probably have to wait until next century for a direct demonstration of their existence. Many long-term projects have been started for making direct observations of gravitational waves impinging upon the earth. The radiation emitted by the binary pulsar is too weak to be observed on the earth with existing techniques. However, perhaps the violent perturbations of matter that take place when the two astronomical bodies in a binary star (or a binary pulsar) approach each other so closely that they fall into each other may give rise to gravitational waves that could be observed here. It is also hoped to be able to observe many other violent events in the universe. Gravitational wave astronomy is the latest, as yet unproven, branch of observational astronomy, where neutrino astronomy is the most direct predecessor. Gravitational wave astronomy would then be the first observational technique for which the basic principle was first tested in an astrophysical context. All earlier observational techniques in astronomy have been based on physical phenomena which first became known in a terrestrial connection.



The radio waves from a pulsar are emitted in two bunches which sweep across space at the same rate as the pulsar rotates (upper figure). From a binary pulsar, gravitational waves are also emitted (lower figure).

For more details please visit:

http://www.nobelprize.org/nobel_prizes/physics/laureates/1993/press.html