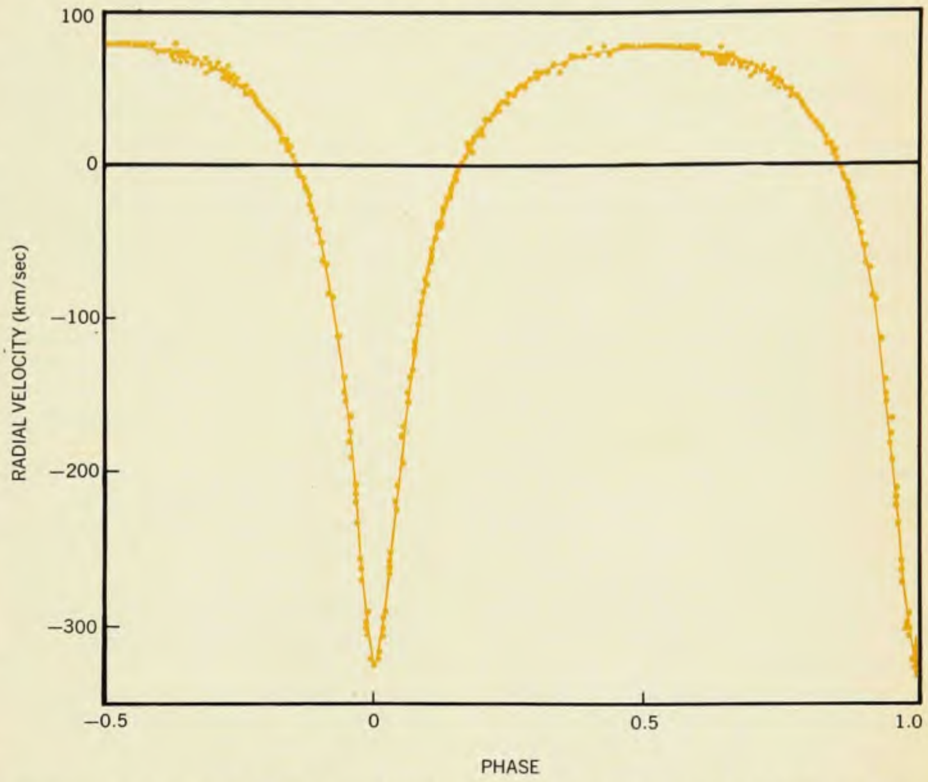
search & discovery

Pulsar in binary system may test fundamental theories

A pulsar in orbit about a second compact star would form a very convenient arrangement for studying gravitational interactions and learning the elusive details of the physics of neutron stars. So the announcement by Joseph Taylor and Russell Hulse of the University of Massachusetts, Amherst, that they have observed such a system has been greeted joyfully by general relativists and by astrophysicists who have been longing for a chance to test their models. Studying changes in the pulsar period as the rotating neutron star travels about its companion in a close, highly elliptical orbit should provide checks of time dilatation, precession and perihelion advance effects free of the complications that occur in the weaker gravitational fields of the solar system, perhaps settling the question of which theory of gravitation is the correct one. The changes in period may also yield more details of the structure of pulsars and perhaps even of the nature of the pulsed radiation.

Taylor and Hulse discovered the binary pulsar during a systematic search for new pulsars with the recently resurfaced radio dish at Arecibo, Puerto Rico. They used a multichannel receiver together with a small computer and achieved a sensitivity roughly twenty times better than that of previous pulsar surveys. The pulsar, PSR 1913+16, was first detected this past July and frustrated all attempts to measure its pulsation period (roughly 59 milliseconds) to within one microsecond: The period apparently changed by as much as 80×10^{-6} seconds from day to day and sometimes by as much as 8×10^{-6} seconds within five minutes, whereas the previously known maximum secular change for any pulsar was 10^{-5} sec per year. Then the astronomers realized that these apparent changes in period were actually a Doppler effect caused by the orbital motion of the pulsar about a companion, and by September they had plotted a velocity curve for the pulsar. To learn the orbital parameters, they measured the pulsar period directly during 200 separate five-minute intervals over ten days and found that it varied between 0.058697 sec and 0.059045 sec over a cycle of 0.3230 days (about eight hours).



Velocity curve for binary pulsar shows Doppler effect. Points are experimental data over parts of ten different orbital periods; curve is a theoretical calculation based on orbital parameters.

How did Taylor and Hulse realize that the companion must be compact—not a normal star? From their observations they determined the mass function ($[M_2 \sin i]^3/[M_1 + M_2]^2$, of the

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Heavy-ion projectiles produce a new kind of fission

Nuclear scientists studying the reactions induced by heavy ions have encountered an unexpected process that has been variously dubbed "quasifission," "deep inelastic transfer," "relaxed-peak process," "incomplete fusion" and "strongly damped collisions." In this process the reaction products have the kinetic energies typical of fission products, but their masses differ from what one would expect in fission: In the latter process, each of the reaction products has a mass roughly equal to one-half of the total mass of the compound nucleus (target plus projectile). In quasifission the two product nuclei have masses close to those of the target and projectile, individually.

In this new reaction process the compound nucleus is apparently not formed. The projectile loses kinetic energy as it approaches the target nucleus, remains in contact briefly, exchanging a few nucleons, and then is repelled away from the residual nucleus by the Coulomb forces.

Such events were first observed in small yield for reactions induced with argon projectiles,[1] but the big surprise was that they constitute a major fraction of the total reaction cross section for reactions induced by Kr^{84} ions at high energies. The first experiment to measure a large cross section with Kr^{84} ions was conducted at Orsay, France, by F. Hanappe, Marc Lefort, C. Ngô, J.

form negative ions directly by sputtering a solid target surface with heavy atoms. M. Müller and Günter Hortig (Heidelberg) had shown that coating the sputter surface with a monolayer of alkali metal ions (preferably cesium) greatly increased the yield of negative ions produced by sputtering with heavy ions, typically krypton. Although the mechanism is not understood, cesium does have the lowest ionization potential (2.8 eV) of any alkali metal.

In the present design, the function of the sputtering beam and the cesium coating are performed by cesium alone. Here cesium serves as sputterer as well as activator or electron donor. It is vaporized in a boiler at about 300 deg C, then passed through a hot (1100 deg C) tungsten sponge that ionizes about 99% of the atoms to Ce^+ ions. After being accelerated to 30 keV the atoms are aimed at the target, which is a hollow cone mounted on a rotatable copper wheel. The sputtered negative ions are extracted and accelerated to ground potential, then injected into the accelerator. (After their work, Middleton told us, they learned of the work of Victor Krohn,[2] who in 1962 had shown that sputtering with cesium ions is a highly efficient way to produce negative ions.)

The copper target wheel, which may be compared with a revolver chamber, can be rotated within minutes to change the conical target and resulting negative-ion beam. With other negative-ion sources, this process can take several hours. Inclusion of a gas inlet close to the sputter target allows an experimenter to generate ions that are not conveniently available from solids. Ammonia (NH_3) gas, for example, with a titanium cone results in the formation of NH^- and NH_2^- ions, which, for the purpose of forming a high-energy beam of nitrogen ions for nuclear physics studies, are as good as N^-.

Middleton tells us that the group at Penn is trying to develop a tritium ion source and is testing the idea with deuterium. He notes that normally tritium sources consume about 10–20 cm^3 of the gas per hour, whereas he hopes to get 500 hours of use from 100 cm^3 of tritium absorbed in a thin titanium target and avoid the hazards of handling tritium gas. —MSR

References

1. R. Middleton, C. T. Adams, Nucl. Instr. and Methods **118**, 329 (1974).
2. V. E. Krohn, J. Appl. Phys. **33**, 3523 (1962).

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system where M_1 and M_2 are the masses of the pulsar and its companion and i is the orbital inclination) to be 0.13 solar masses. By restricting M_1 to those values reasonable for a neutron star, they found that the ratio M_1/M_2 must be close to unit. For a very different ratio, the orbital inclination would have to be small, which is unlikely, given the large observed radial velocity, roughly 10^{-3} c (where c is the velocity of light). And, if the inclination is large, say 90 deg, a large companion would eclipse the pulsar at some point in the orbit. No eclipse is observed, so the companion must be both massive and small.

Should the second star turn out to be an observable pulsar or have measurable spectral lines of any sort, the binary masses could be found rather easily. But this situation is unlikely, even if the star is a pulsar: It may be a pulsar but not be beamed in our direction. Or, the radiation may be too weak to be observable from this distance, roughly five kiloparsecs. (If it were as strong as the known pulsar, it would have been detected during the original search.) But even if the companion is not directly observable, absolute timing of the pulses, probably possible to within 10^{-4} sec, is expected to reveal details not available from pulsars alone in space.

Tests of general relativity. As the pulsar orbits its companion, we can watch as the degree of penetration of the gravitational fields varies. Taylor and Hulse point out that changes of both v^2/c^2 and GM/c^2r (where v is the velocity of the pulsar, G the gravitational constant, and r the orbital radius) during the orbit are great enough to cause changes of several parts in 10^6 in the period. The time dilatation effect here would be observable as an apparent change in pulse rate. This experiment is the analog of the radar ranging studies done by Irwin Shapiro and his colleagues (Massachusetts Institute of Technology), without the interference of the solar corona. Accurate observation of the dilatation effect could distinguish between general relativity and scalar–tensor theories.

If the perihelion shift of the neutron-star orbit were observed it might also distinguish between general relativity and the other theories. Astronomers have noted a large perihelion shift of Mercury, but tests in the solar system are confused by the unknown effects of the Sun's oblateness. The highly elliptical form of the orbit also increases the perihelion effect.

A spin precession may also be observable. This effect would be the analog of an experiment planned by Francis Everitt, William Fairbank and their colleagues at Stanford University (based on the ideas of Leonard Schiff), in which a spinning quartz ball is placed in an orbiting satellite. General relativity predicts a gravitational coupling of the orbital and spin motion that would lead to a spin precession of a few arcsec per year. According to Remo Ruffini (Institute for Advanced Study, Princeton), a similar effect should be observable in the binary pulsar of the order of 0.6 deg per year; the result would be that within one year or so, the orientation of the pulsar beam will have changed.

Nature of pulsars. Spin precession is also one of the effects that would increase our understanding of the physics of neutron stars. Once the effect for the pulsar has been compared with that for the quartz gyroscope, we will have a test not only of general relativity but also of the geometry of the emission region of the pulsar. The satellite test would give quantitative results about gravitational effects so that changes in pulsar radiation intensity could be interpreted in terms of neutron-star structure. At present, the emission is believed to come from conical regions off the rotation axis.

The predictions of what we will learn about neutron stars from this binary are, of course, more speculative than the plans to test gravitational theories with more accurate versions of solar-system studies. As of now, all we know about collapsed objects has been learned from single pulsars themselves and from binary x-ray sources, or x-ray sources in combination with normal stars. The latter allow us to estimate the mass of collapsed objects.

Several years ago, the Soviet astrophysicist V. F. Schwartzman of the Shternberg Astronomical Institute, Moscow had argued that a pulsar could not exist in a binary with a normal star. But no one had yet observed pulsars in combination with any other star, although the existence of binary pulsars was not unexpected. Tom Gold (Cornell) suggests that the probability of forming such objects in pairs or discs may be higher than the probability of forming them singly. He postulates that a large proportion of supernova explosions may be "fizzlers": The supernova may be spinning too fast to collapse all the way and so the event "fizzles," and multiple semi-collapsed stars result, with less energy emission.

In a less speculative vein, Gold is looking forward to learning about the precessional periods of the pulsar—periods other than the main revolution period. For an object spinning at a given rate (known from the pulses) the precession is affected by the degree of flattening, and the degree of flattening is determined by the density. The question of magnetosphere interaction is also intriguing: If pulsar radiation comes from the magnetosphere of the star, one star rushing through the magnetosphere of another should cause magnetic-field disturbances observable as changes in pulse shape and in radiation polarization. —MSR □