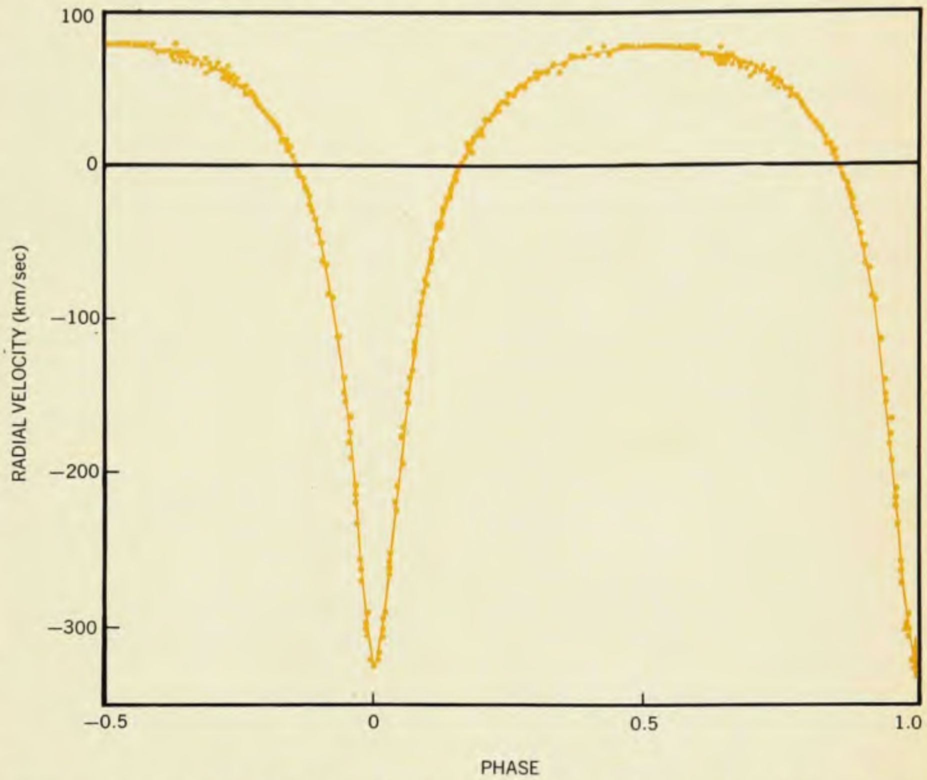
search & discovery

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.

Péter and B. Tamain.[2] They bombarded Bi^{209} with 525-MeV Kr^{84} ions and measured a cross section for quasifission events of 0.5 barns, or more than 60% of the total reaction cross section. Another surprising feature of their data was that the angular distribution was sharply peaked at an angle of about 95 deg in the center-of-mass system.

Similar results were subsequently obtained by a group working at the SuperHILAC at the Lawrence Berkeley Laboratory. This team used a 600-MeV Kr^{84} on a Bi^{209} target and found that the cross section for strongly damped collisions had increased to about 1.5 barns or 80% of the total reaction cross section.[3] They, too, measured a peak in the angular distribution; however, the peak was shifted to a center-of-mass angle of 58 deg. In both experiments this peak occurs at an angle near the grazing angle for the corresponding energy. The grazing angle is the angle of scattering of a projectile that barely hits the outside edge of the target nucleus. Such a projectile has the highest angular momentum.

The group that used the SuperHILAC consisted of Kevin L. Wolf and John P. Unik of Argonne, John R. Huizenga and John Birkelund of the University of Rochester, Victor E. Viola of the University of Maryland and Hartwig Freiesleben of the University of Marburg, Germany, and formerly of the University of Rochester.

Both experiments were correlation experiments in which two detectors on either side of the beam measure events that occur in coincidence. The Orsay group used three surface-barrier detectors. One was fixed at a laboratory angle of 55 deg, whereas the other two formed a pair with an angular width of 10 deg in the reaction plane. This pair is moved step by step to cover the full range of angular correlation of fragments in a few measurements. This arrangement of detectors does not allow measurement of the angular distribution of fragments in general; that would require rotating the first detector from 55 deg through all angles. However, the Orsay group measured the singles spectra—one in which they do not impose a coincidence requirement—over a wide angular range, and they assume that the mass of the krypton-like product does not change with angle. On the basis of their coincidence data at one angle, the Orsay group argues that this singles angular distribution is representative of the fragment with mass near that of the projectile.

The experiment at the SuperHILAC used a similar technique, but one detector was a large position-sensitive detector that subtended an angle of 26 deg in the reaction plane. The other was an angle-defining detector that had a 2 deg acceptance angle. With this arrangement, the angles and energies of both fragments could be measured with a high geometry factor, allowing mass-identification over the entire angular distribution. A significant mass-exchange was found to take place at backward angles. This group performed coincidence measurements at five angles and showed that the low-energy peak in each singles spectrum was due to the lighter mass fragment of the strongly damped collision process.

Theoretical explanations. The Argonne-Maryland-Rochester group attempts to account for the large cross section for the strongly damped process in terms of the delicate balance between the nuclear, Coulomb and centrifugal forces for interactions between heavy target nuclei and projectiles as heavy as krypton. Their examination of nuclear potentials for various values of the angular momentum l shows that only a limited number of l waves have potential wells at some radius from the target nucleus. Those waves that do not have potential wells are not likely to form a compound nucleus, and hence the fusion cross section is low.

The variation in the radial dependence of the interaction potentials for the various l waves may also provide a clue to the sharp peaking of the angular distributions. The conservative force driving the nuclei apart is much weaker for low-l waves and gives sticking times for these waves that are much longer than the higher-l waves. On the other hand, the low-l waves rotate more slowly through larger angles of rotation than the high-l waves, and the general result may be for all waves to be emitted at nearly the same angle.

The findings of both groups have an important impact on heavy-ion research, particularly on the production of transactinide elements by the reactions with heavy ions. Certainly, the new results dim the hopes for producing new elements by complete fusion reactions with projectiles as heavy as krypton; however, reactions with projectiles lighter than krypton may still be productive. —BGL

References

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Correcting for atmospheric distortion in telescopes

Optical astronomers are frequently hampered by atmospheric turbulence that distorts telescopic images by causing random phase shifts in the incoming light. These distortions often reduce the resolution of a telescope far below its diffraction limit. But the outlook may be brightened by new techniques now being developed to detect and correct for the phase error in real time. Until now most techniques to correct for atmospheric distortions have been post-detection compensation techniques: The effects of turbulence are extracted after the image data has been recorded. Three of the groups that are conducting major development efforts on real-time compensation described their work at a conference on Optical Propagation Through Turbulence that was sponsored by the Optical Society of America at the University of Colorado, 9–11 July. These three groups are from Hughes Research Laboratories, from Itek Corporation and from Lawrence Berkeley Laboratory[1] and the Institute for Advanced Studies.

The pre-detection compensation schemes all feature a component for detecting the errors introduced by turbulence, some active optical elements to correct for the errors and an on-line data processing system to calculate the desired response of the optical elements. All components must have extremely fast response times because the pattern of atmospheric disturbances changes typically every 20 msec. Beyond these general features lie interesting differences in approach.

At Itek, John Hardy, Julius Feinlieb and James Wyant use a shearing interferometer[2] to detect the phase errors in the wavefront arriving at the telescope aperture. The phase error introduced by turbulence changes over a region of roughly 10-cm square, so the interferometer essentially generates a wavefront map by measuring the phase error in each of these regions. The map is measured in about 1 msec, independent of the size of the telescope. The phase corrector is a monolithic piezoelectric mirror.[3] This solid slab is divided into regions, each driven electrically by a separate actuator. The measuring and data processing between the interferometer and the mirror are done in parallel.

The Itek group is the only group that has demonstrated its system in the laboratory. Working with thermal turbulence, they obtained a resolution close to the diffraction limit. Hardy told us that the Itek design is an add-on system that can be relatively small and has a high-frequency response.

Richard Muller and Andrew Buffington of LBL have developed an idea for a feedback system that continuously monitors and improves the image quality.[1] By contrast to the above two techniques, they do not directly measure the