Astronomers weigh 'recycled' millisecond pulsar

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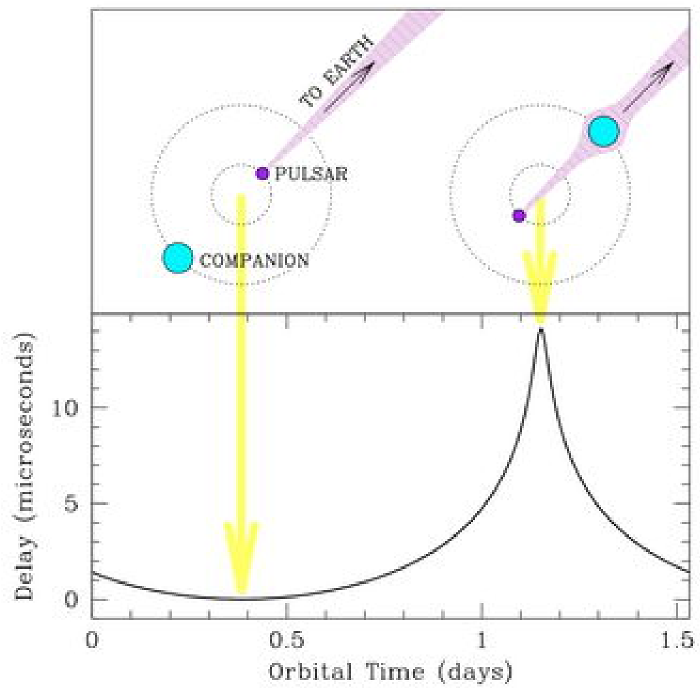

Shapiro delay in the pulsar PSRJ 1909-3744&acutes signal due to the gravitational field of its companion. In the top panel, diagrams show the configuration of the pulsar and its white dwarf companion in their orbits relative to the line of sight to the observer on the Earth at two key points in the orbit: when the pulsar is closest to the Earth (left, the point of minimum Shapiro delay) and when the pulsar is on the far side of its companion as viewed from Earth (right, the point of maximum Shapiro delay).

A team of U.S. and Australian astronomers is announcing today that they have, for the first time, precisely measured the mass of a millisecond pulsar -- a tiny, dead star spinning hundreds of times every second. This result is of special interest because it gives new insight into the production of millisecond pulsars and may shed light on the laws that govern nuclear matter.

Pulsars are truly extreme, with significantly more mass than the sun but so compact that they would fit inside the Washington, DC, beltway. These spinning neutron stars are produced when a massive star is destroyed by a supernova explosion at the end of its normal stellar life. As a pulsar spins, it emits beams of radio waves that sweep through space like a lighthouse beacon; astronomers use radio telescopes to observe the apparent blinking of the pulsar and precisely measure the time when its pulses arrive at the earth. A pulsar's spin slows at it ages, but If the pulsar is in a binary system with another star, it can accumulate gas shed by its companion star. This process of accretion, called "recycling," can accelerate the pulsar's spin to hundreds of rotations per second -- faster than a kitchen blender!

Using the 64-meter (210-foot) Parkes radio telescope in Parkes, Australia, the research team made very precise measurements of the pulses from a recently discovered millisecond pulsar called PSR J1909-3744, about 3700 light years away in the constellation Corona Australis. This pulsar spins every 2.9 milliseconds, or 340 times per second; the pulsar and its white dwarf companion star orbit their common center of gravity every 1.5 days. These observations were carried out at a frequency of 1.4 GHz, which provides a good compromise between the brightness of the pulsar and the deleterious effects of the interstellar medium.

By taking exact measurements of the arrival time of pulses from PSR J1909-3744 at regular intervals for nearly two years, and keeping count of every pulse of radio waves during this time (about 19 billion pulses), the astronomers precisely mapped out the pulsar's position on the sky and the shape of its orbit. They also noticed something unusual: when the pulsar is on the far side of its orbit, behind its white dwarf companion, its pulses arrive at the earth about 14 millionths of a second later than expected based on Newtonian mechanics. This effect, called Shapiro delay, is a consequence of Einstein's general theory of relativity; essentially, the light from the pulsar slows down when traveling through the companion star's gravitational field. When the pulses have to go past the companion on the way to the earth, they arrive late compared to when the companion is behind the pulsar. This is in addition to the much larger Roemer delay (3.8 seconds) arising simply because light from the pulsar has to travel further when it is on the far side of its orbit. Disentangling these two effects is only possible if the orbit is measured in incredible detail. The orbit of PSR J1909-3744 is the most circular known in the universe: the elliptical orbit is over one million kilometers across (about 1.5 times the size of the Moon's orbit around the Earth), but the major axis is larger than the minor axis by only 10 microns, a fraction of the thickness of a human hair.

By precisely measuring the size of the Shapiro delay and how it varies throughout the orbit, the astronomers ascertained the mass of the white dwarf companion and the angle that the pulsar's orbit makes with the sky. Combined with Kepler's laws of motion, this information allowed them to calculate the pulsar's mass: 1.44 times that of the sun. The uncertainty in this measurement, 0.02 solar masses, is about 5 times smaller than the uncertainty of the previous best measurement of a millisecond pulsar's mass. This improvement was possible because this particular pulsar is well suited to high-precision pulse arrival time measurements, because its orbit is oriented so that we view it almost exactly from its edge (maximizing the Shapiro delay), and because of the specialized instrumentation developed at the California Institute of Technology and the Swinburne University of Technology for these observations.

Before this result, only the masses of slower-spinning (non-millisecond) pulsars had been measured precisely. Mildly-recycled pulsars, spinning a few tens of times per second and thought to have accreted a relatively small amount of matter from a companion, are between 1.31 and 1.44 times the mass of the sun; reassuringly, none are more massive than PSR J1909-3744 which should have accreted more material from its companion. In only one case has the mass of a completely unrecycled pulsar, spinning once every several seconds, been measured at 1.25 solar masses. If this mass is typical, we can infer that a millisecond pulsar can be produced with the accretion of less than 0.2 solar masses from its companion. If this is the case, then the pulsar recycling process must be messy: more than half a solar mass must have been lost from the companion as a wind of ejected gas as it evolved from a normal main sequence star to a white dwarf.

Because neutron stars behave, in many respects, like giant atomic nuclei, measuring the physical properties of these exotic objects enhances our understanding of fundamental physics. This result is exciting because "we now have a more complete picture of how these exotic objects are formed, and how they relate to other types of neutron stars," says Dr. Jacoby, who is a National Research Council Postdoctoral Associate at NRL.

The work is being presented today at the American Astronomical Society meeting in Washington, DC, by Dr. Bryan A. Jacoby of the Naval Research Laboratory (NRL) in Washington, DC; Aidan W. Hotan of the University of Tasmania in Hobart, Australia; Professor Matthew Bailes of Swinburne University of Technology in Melbourne, Australia; Dr. Stephen M. Ord of the University of Sydney in Sydney, Australia; and Professor Shrinivas R. Kulkarni of the California Institute of Technology in Pasadena, CA.

Source: Naval Research Laboratory