Triple millisecond pulsar laboratory challenges theory

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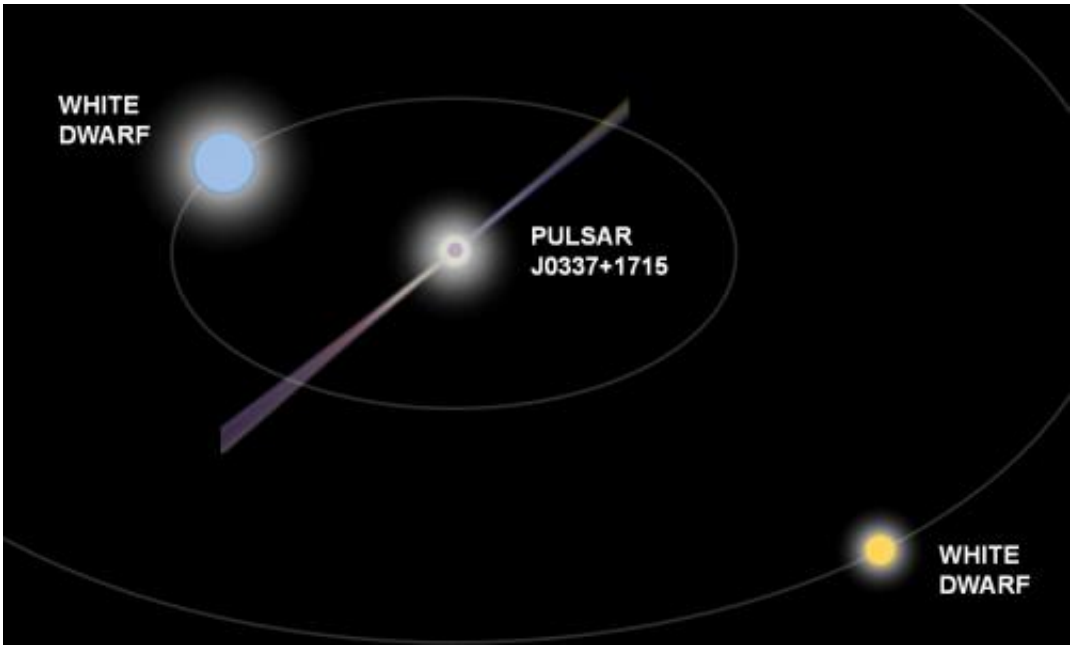

An illustration of the triple millisecond pulsar with its two white dwarf companions. According to the new model, this remarkable system has survived three phases of mass transfer and a supernova explosion, and yet it remained dynamically stable. Credit: Thomas Tauris.

(Phys.org) —Millisecond pulsars are old neutron stars, which rotate several hundred times per second. They are often found in binary systems and their existence can be explained by mass transfer from a companion star. The recent discovery of a millisecond pulsar orbited by two white dwarfs (Ransom et al., 2014) comes as a surprise and

challenges current theories of their formation. The astrophysicists Ed van den Heuvel of the University of Amsterdam and Thomas Tauris from Bonn have developed a semi-analytical model which can resolve the intriguing formation of this unique triple system.

Using stellar evolution calculations and triple system stability analysis, Tauris and Van den Heuvel present a theoretical model, which brings new insight to our knowledge of stellar interactions in multiple star systems. In addition, their study can help explain the increasing number of peculiar binary millisecond pulsars, which may also require a triple system origin. One of the key results obtained from their investigation is that the observed parameters reflect that both white dwarfs were indeed produced in the present system. The results are published online in The *Astrophysical Journal Letters* on January 6, 2014.

Pulsars are rapidly spinning magnetized neutron stars, which are among the most extreme celestial bodies known. They contain as much matter as four-hundred-thousand (400,000) Earths, compressed inside a sphere of only 20 kilometers diameter—about the size of a large city. In the volume of a raindrop they contain as much matter as the seven billion people on Earth put together. Pulsars are the remnants of violent supernova explosions of stars heavier than eight times the Sun. The fastest rotating neutron stars are known as millisecond pulsars, which rotate more than a hundred times per second. Thanks to their gigantic gravity the enormous rotational centrifugal forces do not rip them apart. They are thought to have obtained their high rotation rates by capturing rapidly rotating masses of gas from a normal Sun-like companion star in a binary system. Today we know of about 200 such pulsars, which spin with periods between 1.4 and 10 milliseconds. These are located both in the galactic disk and in globular clusters.

Since the first binary pulsar was discovered 40 years ago, theoretical astrophysicists have investigated mass transfer between stars and other

binary interactions in order to explain their origin. A surprising new discovery has now revealed a millisecond pulsar in a triple system with two white dwarf companions, posing a unique challenge to stellar physicists to explain its formation. Like neutron stars, white dwarfs are burned-out very compact ('degenerate') stars, though not as compact as a neutron star. They typically have about the same size as Earth but are some hundred thousand times heavier. They are remnants of stars like our Sun.

"This is a truly remarkable system with three degenerate objects. It has survived three phases of mass transfer and a supernova explosion, and yet it remained dynamically stable," says Thomas Tauris, first author of the present study. "Pulsars have previously been found with planets and in recent years a number of peculiar binary pulsars were discovered which seem to require a triple system origin. But this new millisecond pulsar is the first to be detected with two white dwarfs." During the last 6 months, the theoretical astrophysicists Thomas Tauris and Ed van den Heuvel have developed a semi-analytical model to explain its existence. One of the key results obtained from their investigation is that the observed parameters reflect that both white dwarfs were indeed produced in the present system.

Triple systems often become dynamically unstable during their evolution and a major challenge was to find a solution that remained dynamically stable throughout the entire evolution, including the stage of the supernova explosion. "An interesting result of our new investigation is that the system evolved through a common envelope stage where the progenitors of both white dwarfs were dragged into the envelope of the massive star when this star became a red giant. Frictional forces then caused these two stars to spiral inwards, causing their orbits to become much narrower, thereby enabling survival of the subsequent explosion of the giant," says Ed van den Heuvel. "Actually, we can apply several tests

of stellar evolution with this new system and also make predictions about its space velocity which can be measured within a few years," concludes Thomas Tauris. "This will allow us to further constrain the mass of the exploding star."

The new triple millisecond pulsar J0337+1715 was discovered recently by a joint American-European collaboration led by Scott Ransom from the National Radio Astronomy Observatory (USA). Participants from the Netherlands in this collaboration are Dr. Jason Hessels of the Netherlands Institute for Radio Astronomy (ASTRON) and the University of Amsterdam, and Dr. Anne Archibald of ASTRON. Ransom, Archibald and Hessels are part of the international team of researchers that reports their findings today. The team also includes ASTRON's Adam Deller, who led observations that precisely determined the position of the pulsar on the sky, as well as Vlad Kondratiev and Joeri van Leeuwen who performed part of the GBT pulsar survey.

J0337+1715 is located in the constellation of Taurus at a distance of about four thousand light-years.

More information: "Formation of the Galactic Millisecond Pulsar Triple System PSR J0337+1715—a Neutron Star with Two Orbiting White Dwarfs," T. M. Tauris & E. P. J. van den Heuvel, 2014, *Astrophysical Journal Letters*, scheduled for online publication on 6 January 2014.

A millisecond pulsar in a stellar triple system, Ransom et al., *Nature*, 5 January 2014, dx.doi.org/10.1038/nature12917

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