World's largest filled-aperture radio telescope finds missing link in evolution of spider pulsar system

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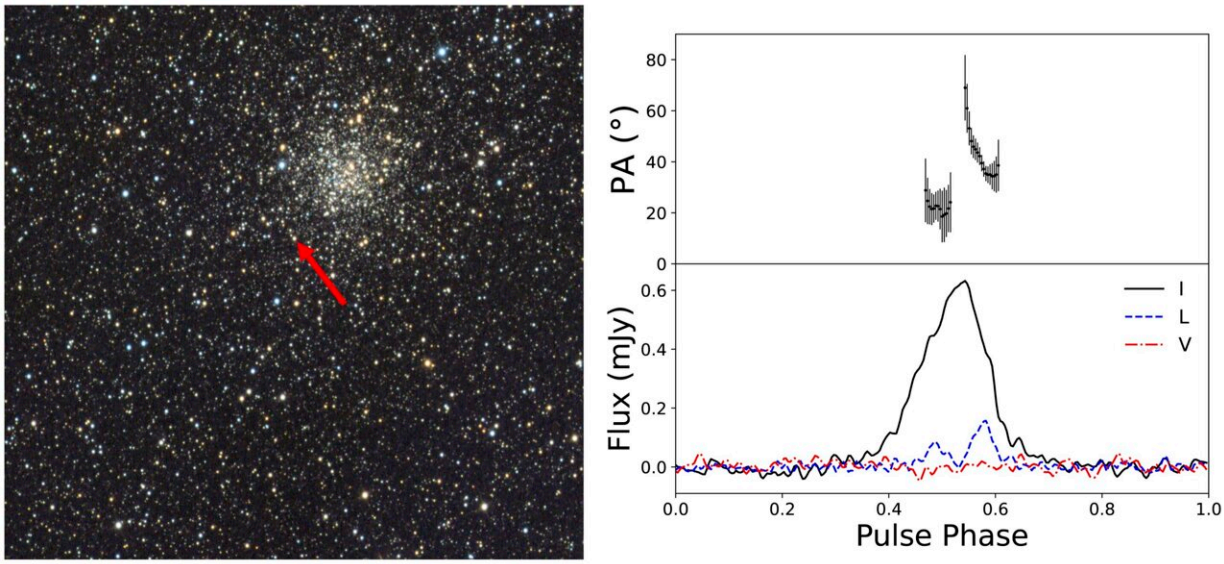
Picture of M71E (the pulsar binary on the right of the figure), FAST (bottom of the figure) and the globular cluster M71 (background). Credit: ScienceApe/CAS/NAOC

Researchers from the National Astronomical Observatories of the Chinese Academy of Sciences (NAOC) and their collaborators at home

and abroad have discovered a binary pulsar with a 53-minute orbital period using the Five-hundred-meter Aperture Spherical radio Telescope (FAST). The discovery of this binary system—named PSR J1953+1844 or M71E—fills the gap in the evolution of spider pulsar systems. The findings were published in *Nature* on June 20.

The first pulsar was discovered in 1967. As of now, about 3,000 of these fascinating objects, which rotate regularly and quickly like spinning tops in the sky, have been found.

Some pulsars are located in binary systems, orbiting with companion stars. If the two stars are close together, the pulsar will swallow material from the companion star to keep spinning. At the beginning, the companion star is heavy. But as the pulsar "eats" its companion star, the two stars get closer together and orbit each other with increasing speed. In contrast, as the star loses mass and gets lighter, the pulsar can't continue to plunder and thus pushes the companion star away. As a result, the pulsar's orbital speed slows down.

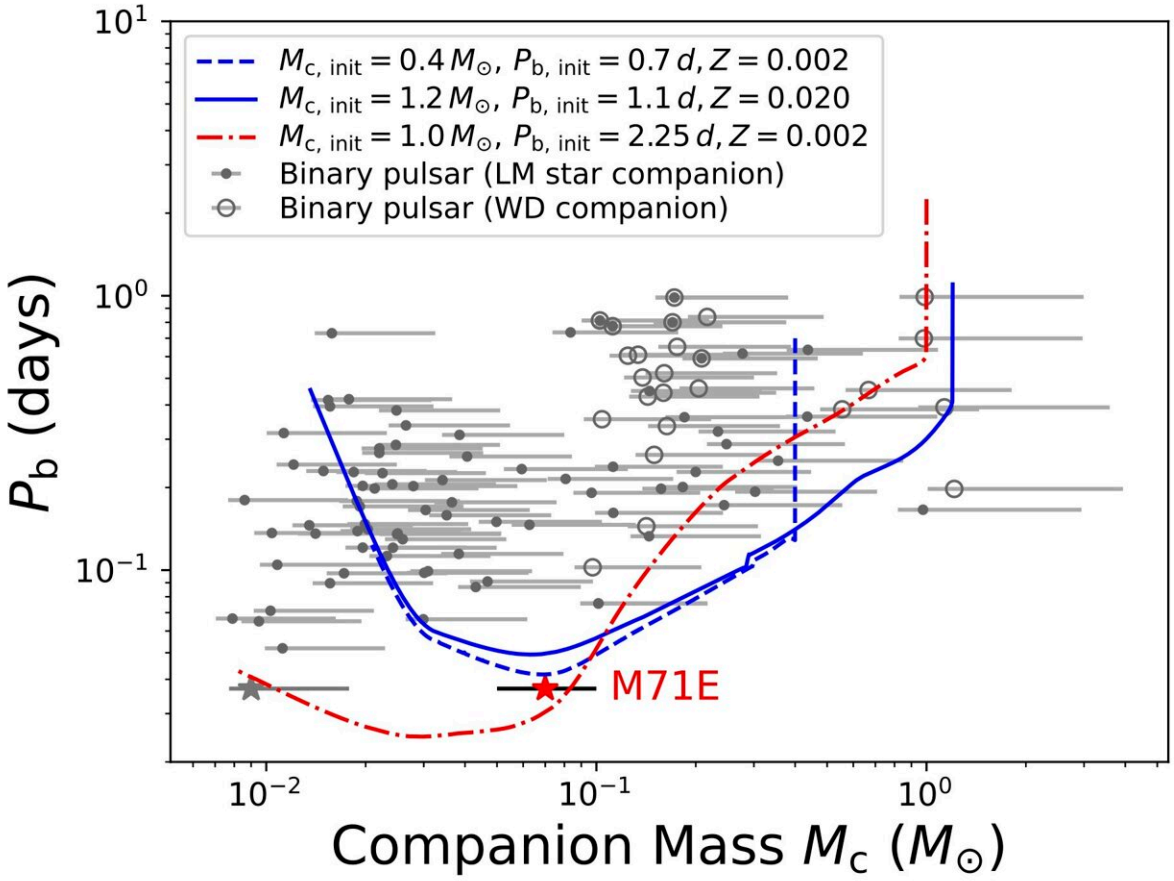


Left panel: The red arrow indicates the location of M71E next to the globular cluster M71; Right panel: The average pulse profile and polarization position angle of M71E based on FAST observations. Credit: NAOC

This behavior, which is reminiscent of female spiders eating male spiders, inspired astronomers to name the objects in these two stages after redback and black widow spiders, respectively. They are collectively known as spider pulsars.

The evolution from redback to black widow takes a long time, up to hundreds of millions of years. Previously, only binary pulsar systems in the redback and black widow states had been detected, with no intermediate states yet found. The reason is that the orbital period of the intermediate pulsar predicted by this theory would be very short and the distance between the two stars would be very close, thus posing challenges for observation. For this reason, the theory of the evolution of spider pulsar systems from redback to black widow had not been fully proved.

Now, however, the possibility of this evolutionary path has been confirmed by FAST, the world's largest and most sensitive radio telescope. The research team used long-term observation by FAST to detect a spider pulsar system whose orbital duration is the shortest ever discovered—only 53 minutes. Based on various indications during observation, the researchers determined that the system was in an intermediate state on the evolutionary path from redback to black widow , thus filling in the missing link in spider pulsar evolution theory.



The position of M71E on the orbital period-mass diagram of the companion star. Both the red and blue curves represent paths of theoretical simulations of binary star evolution. M71E is located at an intermediate state of evolution. Credit: Pan et al.

"The orbital of the binary is almost face-on—such a system is extremely rare. FAST found it in the vast sea of stars using its extremely high detection capabilities. This filled the gap in the evolution of spider pulsar systems and reflects [FAST's] unprecedented sensitivity," said Jiang Peng of NAOC, co-corresponding author of the study.

Nature reviewers described the result as a "very interesting pulsar binary

system. This discovery shortens the record for the shortest orbital period of a pulsar binary system by about 30%, indicating a new and unknown process in the evolution of spider pulsars."

More information: Z. Pan et al, A Binary Pulsar in a 53-minute Orbit, *Nature* (2023). DOI: 10.1038/s41586-023-06308-w

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