Stellar astrophysics explains the behavior of fast rotating neutron stars in binary systems

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This is an artist's impression of an accreting X-ray millisecond pulsar. The flowing material from the companion star forms a disk around the neutron star which is truncated at the edge of the pulsar magnetosphere. Credit: NASA / Goddard Space Flight Center / Dana Berry

Pulsars are among the most exotic celestial bodies known. They have diameters of about 20 kilometres, but at the same time roughly the mass of our sun. A sugar-cube sized piece of its ultra-compact matter on the Earth would weigh hundreds of millions of tons. A sub-class of them, known as millisecond pulsars, spin up to several hundred times per second around their own axes. Previous studies reached the paradoxical conclusion that some millisecond pulsars are older than the universe itself.

The astrophysicist Thomas Tauris from the Max Planck Institute for Radio Astronomy and the Argelander Institute for Astronomy in Bonn could resolve this paradox by computer simulations. Through numerical calculations on the base of stellar evolution and accretion torques, he demonstrated that millisecond pulsars loose about half of their rotational energy during the final stages of the mass-transfer process before the pulsar turns on its radio beam. This result is in agreement with current observations and the findings also explain why radio millisecond pulsars appear to be much older than the white dwarf remnants of their companion stars - and perhaps why no sub-millisecond radio pulsars exist at all. The results are reported in the February 03 issue of the journal *Science*.

Millisecond pulsars are strongly magnetized, old neutron stars in binary systems which have been spun up to high rotational frequencies by accumulating mass and angular momentum from a companion star. Today we know of about 200 such pulsars with spin periods between 1.4-10 milliseconds. These are located in both the Galactic Disk and in Globular Clusters.

Since the first millisecond pulsar was detected in 1982, it has remained a challenge for theorists to explain their spin periods, magnetic fields and ages. For example, there is the "turn-off" problem, i.e. what happens to the spin of the pulsar when the donor star terminates its mass-transfer process?

"We have now, for the first time, combined detailed numerical stellar evolution models with calculations of the braking torque acting on the spinning pulsar", says Thomas Tauris, the author of the present study. "The result is that the millisecond pulsars loose about half of their rotational energy in the so-called Roche-lobe decoupling phase." This phase describes the termination of the mass transfer in the binary system. Hence, radio-emitting millisecond pulsars should spin slightly slower than their progenitors, X-ray emitting millisecond pulsars which are still accreting material from their donor star. This is exactly what the observational data seem to suggest. Furthermore, these new findings help explain why some millisecond pulsars appear to have characteristic ages exceeding the age of the Universe and perhaps why no sub-millisecond radio pulsars exist.

The key feature of the new results is that it has now been demonstrated how the spinning pulsar is able to break out of its so-called equilibrium spin. At this epoch the mass-transfer rate decreases which causes the magnetospheric radius of the pulsar to expand and thereby expell the collapsing matter like a propeller. This causes the pulsar to loose additional rotational energy and thus slow down its spin rate.

"Actually, without a solution to the "turn-off" problem we would expect pulsars to even slow down to spin periods of 50-100 milliseconds during the Roche-lobe decoupling phase", concludes Thomas Tauris. "That would be in clear contradiction with observational evidence for the existence of millisecond pulsars."

This work has profited from a recent effort to bridge the Stellar Physics group at the Argelander Institute for Astronomy at University of Bonn (led by Norbert Langer) with the Fundamental Physics in Radio Astronomy group at the Max Planck Institute for Radio Astronomy (led by Michael Kramer). The stellar evolution models used for this work were made using state-of-the-art code developed by Norbert Langer. A significant part of the observational data was supplied by the pulsar group. Michael Kramer and his colleagues use the 100 metre Effelsberg Radio Telescope to participate in several ongoing searches and discoveries of millisecond pulsars.

More information: Spin-Down of Radio Millisecond Pulsars at Genesis, T. M. Tauris, 2012, *Science*, February 03, 2012.

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