Taking the pulse of a neutron star for almost five decades finds nearly cyclic spin changes on long time-scales

September 15 2021, by Amar Deo Chandra

Figure 1: Schematic of Vela X-1 X-ray binary system. The dotted arrows show the stellar wind emanating from the supermassive companion star which is all pervading. Credit: Amar Deo Chandra

The X-ray binary system Vela X-1 consists of a neutron star (which contains as much mass as our sun (~10^{30} kg), but is very compact and has

a radius of ~10 km or so, about the size of a small city) and a supermassive star with a mass of ~23 times of our sun and that is ~34 times bigger in size than our sun. The stars orbit around their common center of mass. The neutron star rotates once every ~283 s and shines brightly in X-rays by accreting gas from the stellar wind emanating from the massive companion star. The captured gas falls in the strong gravitational potential of the neutron star and is funneled along its strong magnetic field, hitting its poles at high velocities, making them hot and generating thermal X-rays during the process. The magnetic axis and the rotation axis of the star are misaligned (like Earth), which generates X-ray pulses akin to a lighthouse beacon.

Exploring the rotation of Vela X-1 for ~46 years using X-ray space observatories since 1975, a team of Indian scientists has constructed the longest known spin period history of an X-ray pulsar. They found that the neutron star shows cyclic changes in spin period on long time scales of about 5.9 years, making Vela X-1 only the third known X-ray pulsar with such a long-term periodicity in spin changes. The pulsar also shows random spin period changes on shorter timescales, which is a hallmark of X-ray pulsars that accrete from the stellar wind from a companion star.

Slowing or speeding a bicycle requires external torque—braking to slow down, or pedaling harder to cycle faster. However, what causes intriguing slowing down or speeding up of a massive neutron star on both short (a few minutes to few days) and long time-scales (a few months to many years) has been a long-standing puzzle, and many attempts have been made to solve it to some extent in different X-ray binary systems. The scientists explore working of "astrophysical brakes" and "pedals" using theoretical models that could make Vela X-1 spin-up or spin-down on cyclic time scales of about 5.9 years. They suggest that the answer to this puzzle is probably blowing in the wind from the companion star! The companion star may itself undergo cyclic changes on time scales of

about 5.9 years during which the amount of gas lost from the star changes in a cyclic manner modulating those "astrophysical brakes" and "pedals."

Figure 2: Long-term spin history of Vela X-1 from 1975 February until 2021 June. The general trend of secular spin-down of the X-ray pulsar superposed on random episodes of spin-up and spin-down behaviour is discernible. The dashed curve shows the best fit polynomial to the spin evolution of Vela X-1. A careful look at the long-term pulse period evolution also suggests presence of 5.9 year cyclic trend in the long- term spin evolution of Vela X-1. The different markers indicate spin period measurements from 24 different X-ray space missions. Credit: Chandra et al. 2021

"This discovery opens a new paradigm of exploring spin changes on long time scales in other X-ray pulsars and attempts to understand the underlying phenomena which causes long-term nearly cyclic spin-changes in other X-ray pulsars," said Amar Deo Chandra, lead author on the new study.

Figure 3: An artist's conception of spin-up (left panel) and spin-down (right panel) scenario of a neutron star. When the external torque acts in the same sense (clockwise) as that of the rotation of the neutron star (clockwise) it causes the neutron star to rotate faster leading to spin-up of the neutron star (left panel). But if the external torque acts in the opposite sense (anti-clockwise) as that of the rotation of the neutron star then it acts like a "brake" and causes the neutron star to spin-down (right panel). Credit: Amar Deo Chandra

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More information: Amar Deo Chandra, Jayashree Roy, P. C. Agrawal, Manojendu Choudhury, Detection of nearly periodic spin period reversals in Vela X-1 on long time-scales: inkling of solar-like cycle in the donor star?arXiv:2108.07097v1 [astro-ph.HE], arxiv.org/abs/2108.07097

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Provided by Science X Dialog

Citation: Taking the pulse of a neutron star for almost five decades finds nearly cyclic spin changes on long time-scales (2021, September 15) retrieved 25 April 2024 from https://sciencex.com/news/2021-09-pulse-neutron-star-decades-cyclic.html

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