Astronomers measure the heartbeat of spinning stars

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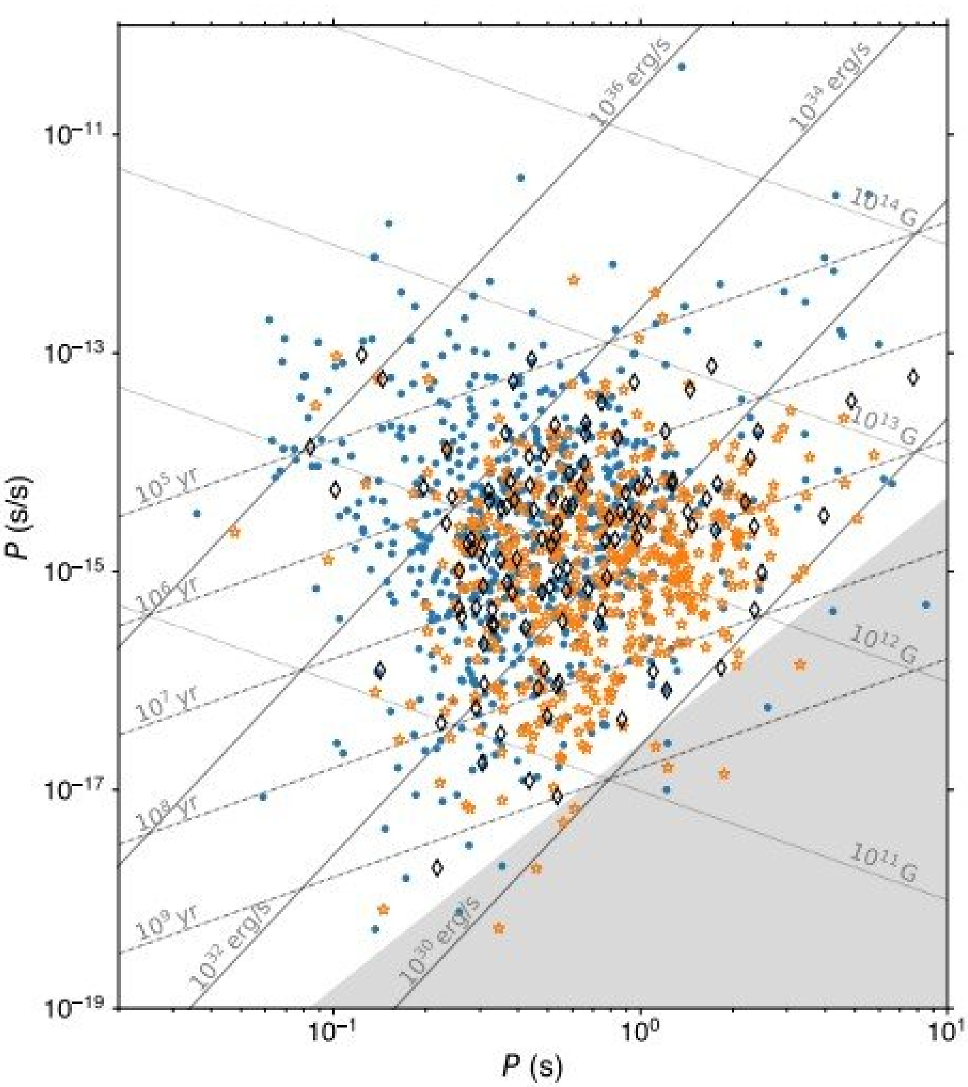

?-?¤ diagram showing pulsars with detected drifting subpulses with stars, ?$_3$-only pulsars with diamonds, and the other pulsars in the sample with the dots. Credit: *arXiv*: https://arxiv.org/abs/2301.04067

An international team of scientist have used the MeerKAT radio telescope to observe the pulsing heartbeat of the universe as neutron stars are born and form swirling lightning storms which last for millions of years.

Radio pulsars are spinning neutron stars from which we can observe flashes of radio waves in the manner of light pulses from a lighthouse. With masses of about one and a half times the mass of the sun, and sizes of only about 25 km, neutron stars are the densest stars known. They rotate extremely fast, typically once every thousandth of a second to once every ten seconds, only gradually slowing down as they age.

Now, a team of collaborative astronomers have published the largest pulsar survey ever in the *Monthly Notices of the Royal Astronomical Society*.

Neutron stars are also the strongest magnets in the universe, on average a million times stronger than the strongest magnet on Earth. Such extreme properties present an opportunity to test the laws of physics with exceptionally high accuracy. Even 60 years after their discovery, fundamental questions about the nature of these exotic objects remain.

No two pulsars are the same, and headway in these exciting areas of physics requires sensitive observations of as many pulsars as possible. The "Thousand Pulsar Array" (TPA) project is an international collaboration aimed at pursuing these aims by exploiting the unprecedented sensitivity of the MeerKAT radio telescope. This consists of 64 antennas in the Karoo desert in South Africa, and is a stepping stone towards the Square Kilometer Array, in which the U.K. has leadership.

The findings are published in two parts, one of which is led by researchers at The University of Manchester, which details the findings of the study of over one million individual flashes recorded. The sequence of flashes can be visualized as a train of pulses.

Dr. Patrick Weltevrede of The University of Manchester said, "Observing a pulsar is like checking the pulse of a pulsar, revealing the particularities of its 'heartbeat.' Each individual pulse is different in shape and strength."

For some pulsars ordered patterns of diagonal stripes appear when visualized. Dr. Xiaoxi Song, Ph.D. student at The University of Manchester explains, "The superb quality of the TPA data and our sophisticated analysis allowed us to reveal these patterns for many pulsars for the first time. These patterns can be explained by the lightning storms swirling around the star. The findings point to something fundamental about how pulsars operate."

After the pulsar is born, the lightning storms swirl around the star fast and chaotically. After a few million years, the lightning storms settle down and the patterns become slower and steadier. This turns out to be the opposite of what models predict. Eventually, after a few billion years the lightning will stop altogether, and pulsars will no longer be detectable.

The MeerKAT team recently received the prestigious Group Award of the Royal Astronomical Society, and the TPA project has now reached an extraordinary milestone: detailed observations of more than 1,200 pulsars, representing more than a third of the known pulsars.

In accompanying work, led by researchers at the University of Oxford, the statistical properties of the pulse shapes are presented. Dr. Bettina Posselt explains, "We find that the most important property governing the radio emission of a pulsar is its so-called spin-down power. It quantifies the energy set free by a neutron star each second as its rotation slows down. Some of this spin-down power is used to produce the observed radio waves."

Models predict that the ionized gas surrounding the star continuously discharges in what can be compared to lightning storms, producing the radio pulses. The new data indicate that the spin-down power influences how high above the neutron star surface the radio emission takes place and how much energy the charged particles are endowed with. Since there is evidence that the spin-down power decreases with age, and the 1,200 pulsars exhibit large variety in spin-down power, the TPA data are ideal to study the aging of neutron stars.

The new data shows that even pulsars with the least spin-down power emit intense radio emission and can be detected up to large distances. This result suggests there may be a larger population of pulsars yet to be discovered than previously expected.

The TPA data from both projects are now publicly available. They enable the international community to pursue further studies both on the properties of these pulsars and those of the intervening interstellar space.

More information: Xiaoxi Song et al, The Thousand-Pulsar-Array programme on MeerKAT—VIII. The subpulse modulation of 1198 pulsars, *Monthly Notices of the Royal Astronomical Society* (2023). DOI: 10.1093/mnras/stad135. On *arXiv*: arxiv.org/abs/2301.04067

Bettina Posselt et al, The Thousand-Pulsar-Array program on MeerKAT—IX. The time-averaged properties of the observed pulsar population, *Monthly Notices of the Royal Astronomical Society* (2023). DOI: 10.1093/mnras/stac3383. On *arXiv*: arxiv.org/abs/2211.11849

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