Extreme stars share unique properties that may provide a link to mysterious sources

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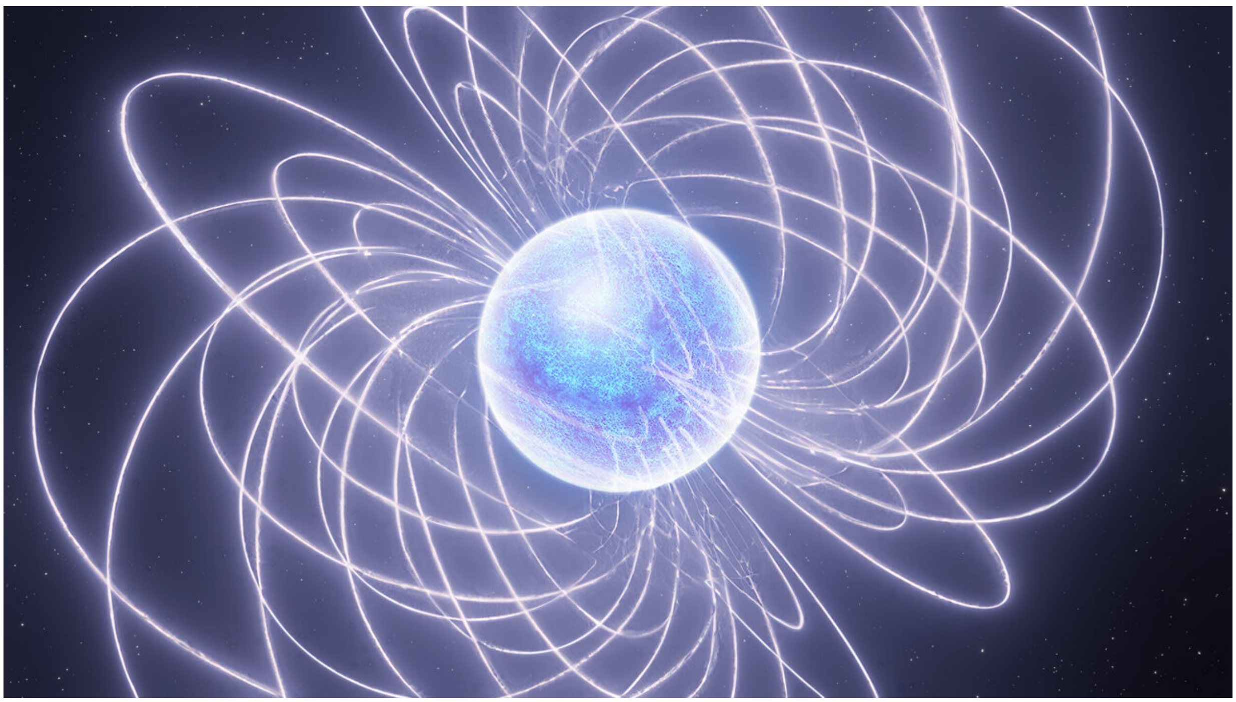

Artistic impression of a magnetar, where a neutron star emits radio light powered by the energy stored in the ultra-strong magnetic field, causing outburst which are among the most powerful events observed in the universe. Credit: Michael Kramer / MPIfR

An international research team led by Michael Kramer and Kuo Liu from the Max Planck Institute for Radio Astronomy in Bonn, Germany, have studied magnetars to uncover an underlying law that appears to apply universally to neutron stars.

This law gives insight into how these sources produce radio emission and it may provide a link to the mysterious flashes of radio light, fast radio bursts, that originate from the distant cosmos. Their study is published in *Nature Astronomy*.

Neutron stars are the collapsed cores of massive stars, concentrating up to twice the mass of the sun in a sphere of less than 25 km diameter. As a result, the matter there is the most densely packed matter in the observable universe, squeezing electrons and protons into neutrons, hence the name. More than 3,000 neutron stars can be observed as radio pulsars, when they emit a radio beam that is visible as a pulsating signal from Earth, when the rotating pulsar shines its light towards our telescopes.

The magnetic field of pulsars is already a thousand billion times stronger than the magnetic field of the Earth, but there is a small group of neutron stars that have magnetic fields even 1,000 times stronger still. These are the so-called magnetars. Of the about 30 magnetars known, six emit radio emission, at least occasionally. Extragalactic magnetars have been suggested to be the origin of fast radio bursts (FRBs).

To study this link, researchers from the Max Planck Institute for Radio Astronomy (MPIfR) with help from colleagues at the University of Manchester have inspected the individual pulses of magnetars in detail and have detected sub-structures. It turns out that a similar pulse structure was also seen in pulsars, the fast-rotating millisecond pulsars, and in other neutron star sources known as Rotating Radio Transients.

To their surprise, the researchers found that the timescale of magnetars and that of the other types of neutron stars all follow the same universal relationship, scaling exactly with the rotation period. The fact that a neutron star with a rotation period of less than a few milliseconds and one with a period of nearly 100 seconds behave like magnetars suggests that the intrinsic origin of the subpulse structure must be the same for all radio-loud neutron stars.

This reveals information about the plasma process responsible for the radio emission itself, and it offers a chance to interpret similar structures seen in FRBs as the result of a corresponding rotational period.

"When we set out to compare magnetar emission with that of FRBs, we expected similarities," says Michael Kramer, first author of the paper and Director at MPIfR. "What we didn't expect is that all radio-loud neutron stars share this universal scaling."

"We expect magnetars to be powered by magnetic field energy, while the others are powered by their rotational energy," says Kuo Liu. "Some are very old, some are very young, and yet all seem to follow this law."

Gregory Desvignes says, "We observed the magnetars with the 100-m radio telescope in Effelsberg and compared our result also to archival data, since magnetars do not emit radio emission all the time."

"Since magnetar radio emission is not always present, one needs to be flexible and react quickly, which is possible with telescopes like the one in Effelsberg," says Ramesh Karuppusamy.

For Ben Stappers, co-author of the study, the most exciting aspect of the result is the possible connection to FRBs. "If at least some FRBs originate from magnetars, the timescale of the substructure in the burst might then tell us the rotation period of the underlying magnetar source. If we find this periodicity in the data, this would be a milestone in explaining this type of FRB as radio sources."

"With this information, the search is on," says Kramer.

More information: Michael Kramer et al, Quasi-periodic sub-pulse structure as a unifying feature for radio-emitting neutron stars, *Nature Astronomy* (2023). DOI: 10.1038/s41550-023-02125-3

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