Fast radio bursts: Research introduces a novel approach to characterize their behavior

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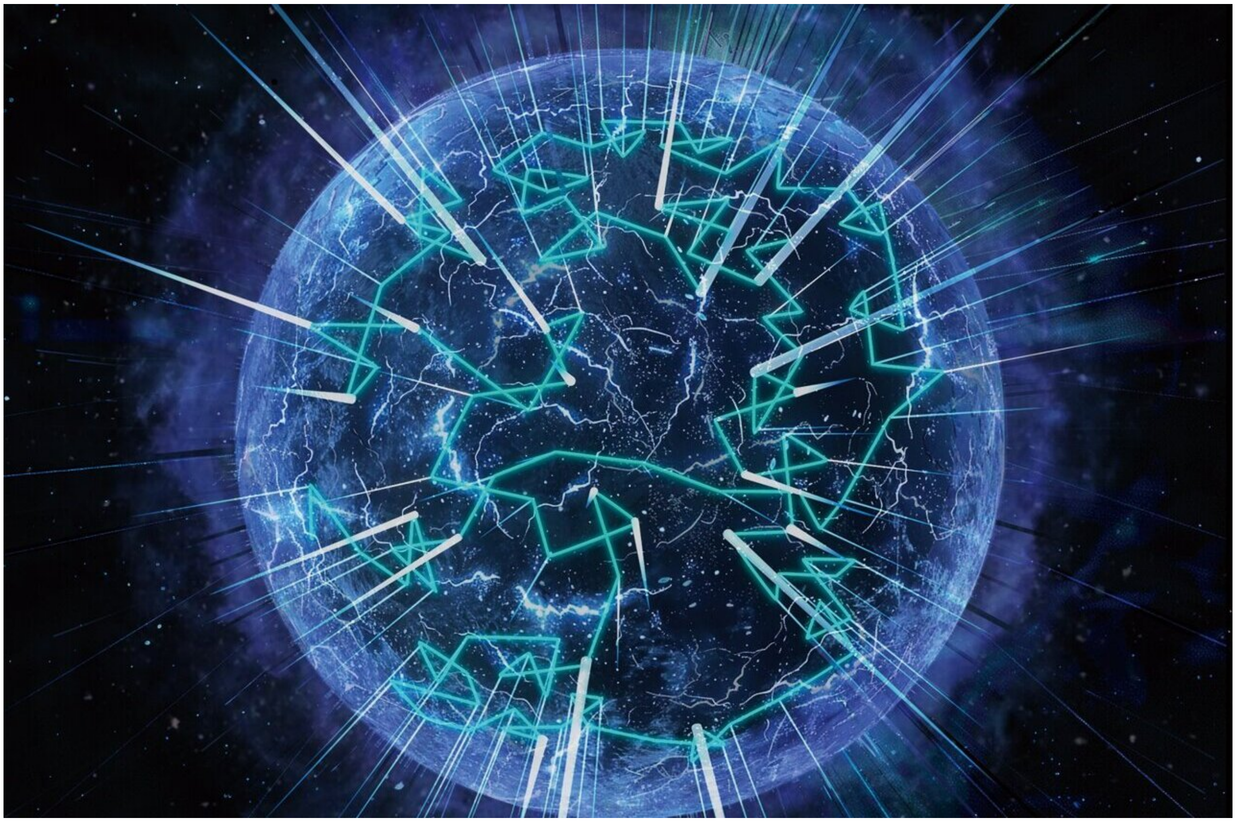


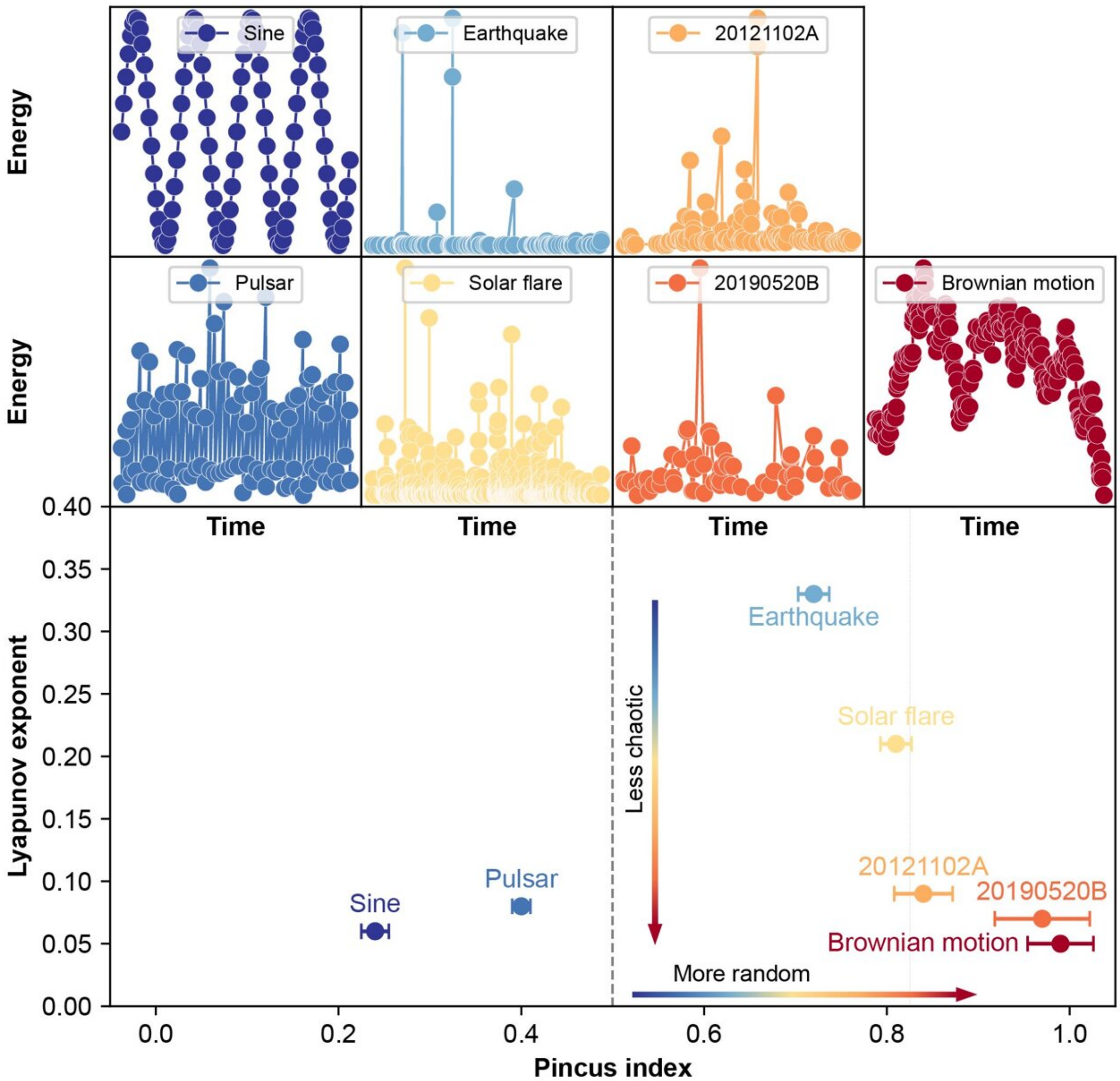
White fissures on the magnetar's surface symbolizing starquake activity, and conical spikes extending from the surface representing multiple bursts of FRBs. The spikes vary in size, mirroring the variability in burst energy. Green lines connecting the bursts indicate a random walk path, symbolizing the stochastic nature of fast radio burst activity. There's no direct link between the green zigzag lines and the starquake fissures, highlighting the distinction between the nature of FRBs and earthquakes. Credit: Science China Press

Fast radio bursts (FRBs) represent the most intense radio explosions in the universe. Since the first discovery in 2007, FRBs have garnered significant attention, culminating in the 2023 Shaw Prize in Astronomy. With yet unknown origin, these extreme cosmic bursts are among the most enigmatic phenomena in astronomy as well as physics.

Causality dictates that FRB sources should be smaller than c·dt in size, where c is the speed of light and dt is the duration of the events. For a typical 1 millisecond burst, this implies a region smaller than 300 kilometers, implying compact objects such as neutron stars or black holes to be the FRBs' engines.

Fast spin has been observed in most compact objects, giving rise to the expectation of periodicity in repeating FRBs' bursts. However, extensive searches for periodicity from millisecond to second scales have all failed, prompting a re-evaluation of FRB emission mechanisms.

A team led by Professor Di Li from the National Astronomical Observatories of the Chinese Academy of Sciences has introduced a novel approach to characterize the FRBs' behavior in the time-energy bivariate phase space. Quantifying the randomness and chaos using generalized "Pincus Index" and "Lyapunov Exponent," respectively, they manage to place FRBs in the context of other common physical events like pulsars, earthquakes and solar flares.



The top and middle panels present event series in the time-energy space of these sources. The color changes from blue to red, implying increased stochasticity. In the bottom panel, fast radio bursts congregate with Brownian motion toward highly random, yet less chaotic regions in the stochasticity-chaos phase space, which is distinct from earthquakes and solar flares, both of which are more chaotic but less random than FRBs. Credit: Science China Press

Both randomness and chaos cause unpredictability, but they are distinct. The unpredictability of a random sequence stays constant over time—picture rolling dice, the outcome of each roll bears no link to the previous one. In chaotic systems, unpredictability increases exponentially over time. For example, anyone can predict the weather in the coming seconds by looking up and around, but it is still challenging for mankind to accurately predict weather in the long term.

The team found FRBs to roam around the energy-time phase space, with a lower level of chaos but a higher degree of randomness than those of earthquakes and solar flares. The pronounced randomness of FRB emissions suggests a combination of multiple emission mechanisms or locations. This study establishes a new frame of quantifying FRBs and gets us closer to finally revealing the origin of these violent cosmic explosions.

The research is published in the journal *Science Bulletin*.

More information: Yong-Kun Zhang et al, The arrival time and energy of FRBs traverse the time-energy bivariate space like a Brownian motion, *Science Bulletin* (2024). DOI: 10.1016/j.scib.2024.02.010

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