Resolving Pico-arcsecond Structures in Relativistic Plasmas Around Pulsars

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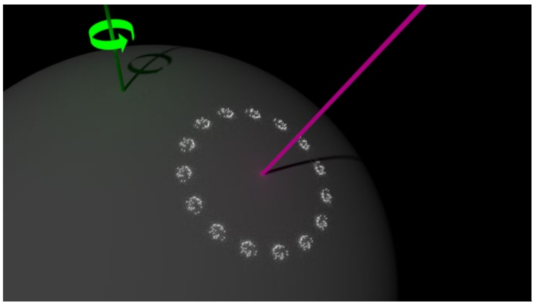
Description:
Pulsars, or neutron stars, are exquisite laboratories for studying extreme, high-energy physics. Their super strong gravitational and magnetic fields cannot be replicated on Earth, making the environment of pulsars the only places in the universe in which ultra-relativistic plasmas can be studied. Pulsars emit highly coherent beams of radio waves which are detected as a series of pulses as the neutron star rotates and the beam sweeps by the Earth. The physics that underlie the emission mechanism is not well understood and is one of the most celebrated unsolved problems in modern astrophysics.

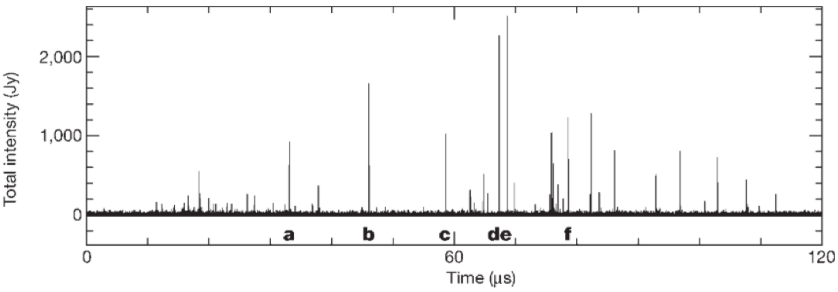
Because neutron stars are so small (~25 km in diameter) and distant (thousands of light years), they cannot be resolved by conventional imaging techniques. However, thanks to the pulsars' rotation, pulse-by-pulse variations in the observed time series contain information about the spatial structure and dynamics of the emitting relativistic plasma.

Pulsar signals are known to exhibit structure on a wide range of timescales, ranging from milliseconds and microseconds and down to nanoseconds (Hankins 1971, Cordes 1981, Hankins et al. 2003), with the finest time structures corresponding to physical structures on the order of metres! Owing to the technical challenges of obtaining high-quality, ultra-high-time resolution recordings of pulsars, the smallest timescales (microsecond and nanosecond) are rarely studied in detail.

However, recent advances in instrumentation and software have now made microsecond resolution possible for the Murchison Widefield Array (MWA), Australia's premier pathfinder telescope for the upcoming Square Kilometer Array (SKA). As a well-established instrument for pulsar studies, the MWA is uniquely positioned to become a leader in ultra-high time resolution studies of the pulsar emission mechanism.

This project will exploit the MWA's new high-time resolution capabilities to study several bright pulsars in the southern sky, whose micro-pulses (microsecond structures) have not previously been studied. The primary focus will be to uncover the physics that govern the dynamics of the relativistic plasma by mapping out the locations of the emitting blobs as they change over time. The frequency structure of micro-pulses will also be studied over the whole frequency band of the MWA (~80 to 300 MHz), yielding further insights into the underlying plasma physics as well as enabling unprecedented studies of the dispersive properties of the interstellar medium through which the micro-pulses propagate.





Left: A cartoon diagram showing a pulsar's polar cap, depicting a carousel arrangement of sparks made up of individual microbursts. *Right:* A time series showing "nanoshots" in a giant pulse from the Crab pulsar. These structures reveal the presence of emitting regions on the order of metres (from Hankins et al. 2003).