Resolving Pico-arcsecond Structures in Relativistic Plasmas Around Pulsars

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 environments 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 stars rotate and the beams sweep 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.

Research Field
Pulsar Astrophysics

Project Suitability
PhD
Masters

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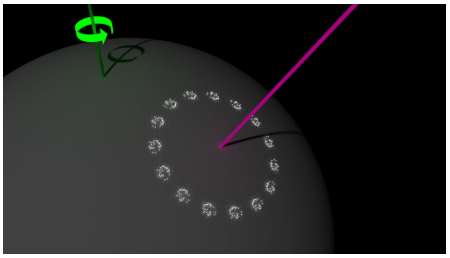
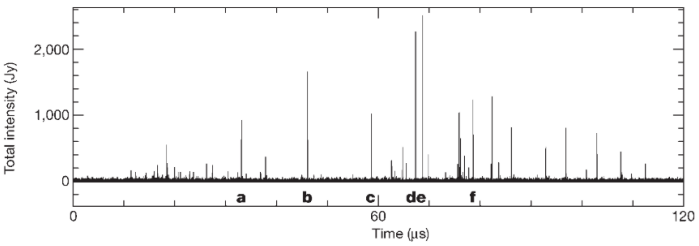
Co-Supervisors
To be advised

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 their rotation, pulse-to-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, from milliseconds and microseconds down to nanoseconds (cf. 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 (~microseconds to nanoseconds) are rarely studied in detail. However, recent advances in instrumentation and software have now made this possible with the Murchison Widefield Array (MWA), Australia's premier pathfinder telescope for the Square Kilometer Array (SKA) project. As a well-established instrument for pulsar studies, the MWA is uniquely positioned to become a leader in ultra-high time resolution studies of 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 micropulses (i.e. microsecond structures) have not previously been observed. The primary focus will be to uncover the physics that governs the dynamics of the relativistic plasma by mapping out the locations of the emitting blobs as they change over time. The frequency structure of “micropulses” will be studied over the full 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 these 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).