From Low-frequency Pulsar Observations to Interstellar Holography

Research Field
Observational Pulsar Astronomy

Project Suitability
Honours
Masters
PhD

Project Supervisor
Ramesh Bhat
Ramesh.bhat@curtin.edu.au

Co-Supervisors
Willem van Straten (Auckland)
Mark Walker (Manley)

Pulsars make fabulous tools as probes of the interstellar medium (ISM) of our Galaxy. Their radiation is pulsed, spatially coherent and highly polarised – an ideal combination that enables their signals to carry imprints of the ionised, turbulent and magneto-ionic properties of the media through which they propagate. At low radio frequencies (i.e. longer wavelengths), these effects are significantly magnified as a result of their strong dependencies with the observing frequency.

Multipath propagation through the ISM gives rise to a wealth of observable phenomena, many of which can be meaningfully used to study the small-scale structures in the ISM. For decades, possible investigations were limited to the use of more traditional scattering and scintillation techniques, which are generally useful for a statistical characterisation of the ISM along the pulsar's sight line. Deflected parts of the radiation may also occasionally give rise to subtle features in the secondary spectra of pulsar scintillation (e.g. parabolic arcs; Figure 1), and these can be exploited to pinpoint the location of turbulent plasma or probe any anisotropy that may be present (e.g. Bhat et al. 2016, 2018). The physical origin of these arcs is an active area of research, with a multitude of recent interpretations involving hot stars or plasma sheets (Walker et al. 2017; Simard & Pen 2018; Gwinn 2019). Another notable development is the application of cyclic spectroscopy (Demorest 2011), and phase-retrieval algorithms that enable coherent de-scattering; i.e. simultaneous recovery of the pulsar's intrinsic signal and the ISM delay structure (Walker et al. 2013).

This project will capitalise on new instrumentation and capabilities that are now routinely available for pulsar observations with the Murchison Widefield Array (MWA), which enable signal reconstruction at a microsecond time resolution. Developing the related software instrumentation and signal processing techniques, and exploiting them for novel pulsar science will form the central theme of the project. This includes, for example, an accurate characterisation of the signal distortion caused by the ISM (important for high-precision timing applications such as pulsar timing arrays) and the holographic reconstruction of the interstellar microstructure at resolutions unattainable by other techniques. The project involves close collaboration with the University of Auckland and Manly Astrophysics.

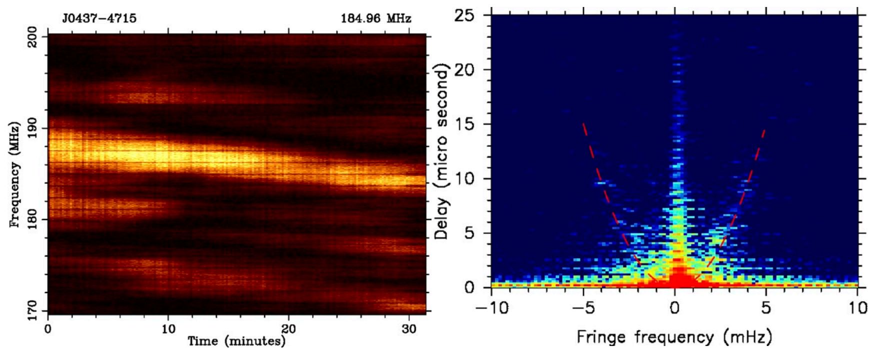

Fig 1: Dynamic scintillation spectrum of the millisecond pulsar J0437-4715 (left) and its secondary spectrum (right), from MWA observations (Bhat et al. 2018). Faint *parabolic arc-like* features arise from the deflected parts of pulsar's scattered radiation. The indicated delays (~microseconds) will be directly measurable using the new capabilities and the advanced techniques that will be realised through this project.