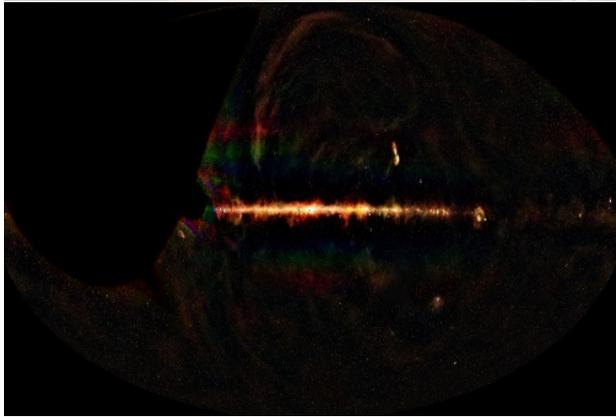
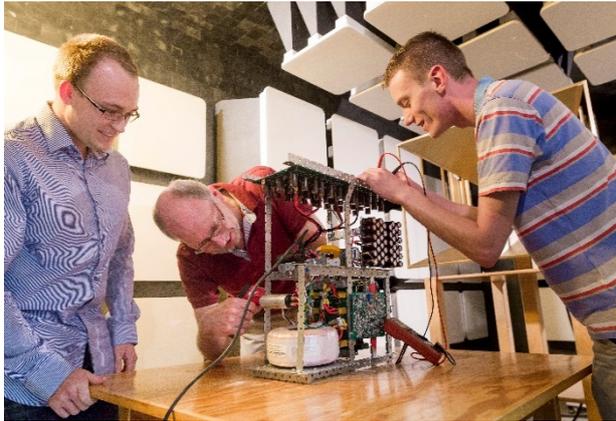




Curtin University



CURTIN INSTITUTE OF RADIO ASTRONOMY

POST-GRADUATE  
RESEARCH PROJECTS

For Applicants Commencing Studies in 2017/18



# CURTIN INSTITUTE OF RADIO ASTRONOMY

## Postgraduate Research Projects for commencement in 2017/18

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# CURTIN INSTITUTE OF RADIO ASTRONOMY

Curtin's Institute of Radio Astronomy (CIRA) offers relevant, practical and forward-thinking postgraduate research ready to advance your career in astronomy, space science, technology, physics and/or engineering. CIRA is led by world-renowned experts in radio astronomy. Our students join a lively and deeply engaged group working with national (Australian) and international partners. We are heavily involved with the Murchison Widefield Array (MWA) radio telescope, SKA pre-construction design and development work and are a major partner in both the International Centre for Radio Astronomy Research (ICRAR) and ARC Centre of Excellence for All-Sky Astrophysics 3D (CAASTRO3D).

This booklet showcases our current set of higher degree research projects suitable for commencement during 2017 & 2018. These projects cover a range of aspects of modern astronomy including observational astronomy, analytical astronomy and radio astronomy engineering. Students will gain vital skills as part of their study with us including analysing huge datasets (often multi-wavelength), working in teams and collaborations as well as communicating their results, both written (paper publication) and via presentations at major conferences. Depending on the focus of the student's project, their research may include opportunities to develop skills with telescope proposals and observing at Australian and international facilities and supercomputing experience. Many of our projects are designed to develop expertise ready for the next era of radio astronomy, most notably the Square Kilometre Array (SKA).

We welcome enquiries from well-qualified applicants to develop research proposals as part of their formal application to study at Curtin University. To be eligible to apply you must have a strong background in physics, ICT or electrical engineering, good communication skills (including excellent English language, both written and spoken) and be ambitious to complete a first-rate higher degree at our Institute.

More information about CIRA can be found at <http://astronomy.curtin.edu.au> and all potential applicants to Curtin University should consult <http://futurestudents.curtin.edu.au/postgraduates/> for details on admission, funding and course details.

We look forward to hearing from you!



Professor Steven Tingay

CIRA Executive Director

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## A Census of Radio Galaxy Components via Measurements of Interplanetary Scintillation

The infalling of matter into the central supermassive black hole in a massive galaxy causes the nuclear region to become extremely luminous, an object known as an Active Galactic Nucleus or AGN. The jets from AGNs transport matter outwards. Where these jets meet the intergalactic medium, bright spots called hot-spots are formed and are seen as part of radio galaxy lobes. At high radio frequencies (>1GHz), the brightness of hotspots decreases with increasing frequency, but at low radio frequencies (~100MHz) the behaviour is poorly understood, since only a small number of objects have been studied in detail. Until now, a large study of hotspots at low frequencies has not been technically feasible due to the challenges of achieving sufficiently high angular resolution to separate the hotspot and lobe emissions. The Murchison Widefield Array (MWA), operated by the Curtin Institute of Radio Astronomy, is a low-frequency radio interferometer unparalleled in its wide field of view and its imaging fidelity, making it an excellent instrument to study powerful radio galaxies at low radio frequencies. Although a remarkably flexible instrument, its angular resolution does not exceed 1 arcminute.

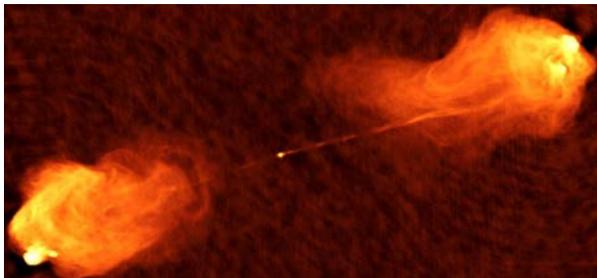


Figure 1: Powerful radio galaxy Cygnus A with AGN core (centre), jets and hotspots on lobes. Such detailed images at low frequencies are currently not possible due to angular resolution limitations. (Image courtesy of NRAO/AUI).

### Research Field

Radio Astronomy

### Project Suitability

PhD

Masters

Honours

### Project Supervisor

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### Co-Supervisors

Dr John Morgan

Dr Jean-Pierre Macquart



Figure 2: 3C33 as it appears in TGSS, a low frequency survey. There appears to be a hotspot in the Southern lobe, but the resolution is not sufficient to separate lobe and hotspot emission

However, we have shown that we can use this instrument to probe the sub-arcsecond properties of sources via the phenomenon of Interplanetary Scintillation (IPS). Sources which have compact components will change rapidly in brightness (on timescales of ~1s) due to turbulence in the interplanetary medium. Applying this well-studied technique to the wide field of view of the MWA allows us to identify compact components in thousands of objects. Using this information, combined with complementary catalogues, the presence of secondary compact components (hot spots) and their brightness can be inferred. This will allow us to perform a survey of radio galaxies, identifying hotspots, and use the resulting information to understand their relationship with their host radio galaxies.

The powerful technique of IPS on wide field-of-view is an important new development, and its full implications in the era of the Square Kilometre Array are not yet fully appreciated. There is therefore a unique opportunity for a student to contribute to the development of a technique which can directly inform SKA design studies, and ultimately be leveraged to perform new science with the SKA. The project would require a student with an interest in confronting technical challenges in order to perform novel science. Experience in radio astronomy or big data computation would be beneficial. The project can be tailored to suit the individual candidate's interests, whether they be in Radio Galaxies, SKA science, or high-performance computing.

## A Semi-Empirical Foreground Model for the EoR

The study of the Epoch of Reionisation (EoR) is one of the primary goals of large low-frequency radio telescopes, such as Western Australia’s Murchison Widefield Array (MWA) and the future Square Kilometre Array. The principal challenge in these studies are the overwhelming foreground sources of noise, including the emission from every galaxy in the known Universe. While a number of promising approaches have been proposed to mitigate these obscuring sources, they typically require high-fidelity statistical models of the foreground population. This project will explore a semi-empirical technique based on Halo Occupation Distributions (HODs) or Conditional Luminosity Functions (CLFs) to provide intuitive and quick estimates of the statistical properties of the extra-galactic foregrounds. The work will be constrained both observationally by the MWA GLEAM survey, and also by semi-analytic simulations.

### Research Field

Radio Astronomy

### Project Suitability

Masters

PhD

### Project Supervisor

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### Co-Supervisors

Dr Cathryn Trott

Prof. Chris Power (UWA)

Dr. Claudia Lagos (UWA)

This project may be part of the ARC Centre of Excellence for All-Sky Astrophysics in 3D (CAASTRO-3D) EoR program, with potential for scholarship funding.

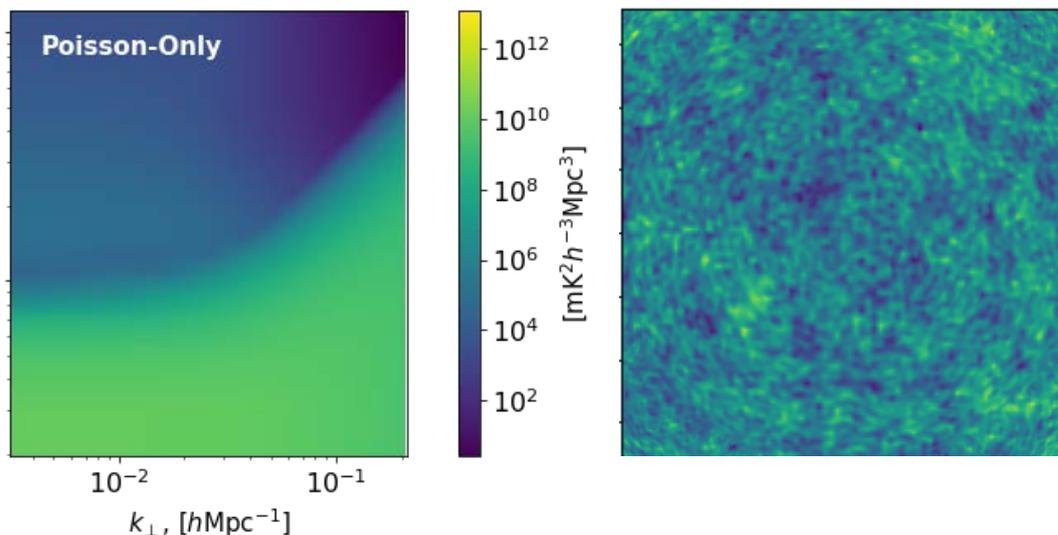


Figure: (left) 2D power spectrum of source brightness for a very simple source model. (right) Sky brightness distribution for a simple model including source clustering.

## Advanced Calibration and Imaging with the MWA

The Murchison Widefield Array (MWA) is a low frequency (80 — 300 MHz) radio telescope operating in Western Australia and the only SKA\_Low precursor telescope. Its design has many small antennas rather than fewer larger antennas as is typical for radio telescopes working at higher frequencies.

Forming high-fidelity images with the MWA can be challenging. The issues include: the very wide field of view of the MWA, the large data volume due to having many antennas, the corrupting effect of the ionosphere, the unusual reception pattern of the antennas (they are fixed on the ground), among others. Processing MWA data can often violate assumptions inherent in conventional radio astronomy data processing software. More accurate techniques are available but often come at a huge computational cost. Because of this, supercomputers are required to process large quantities of MWA data.

This project aims to investigate and develop novel techniques in radio astronomy data processing to improve the performance and/or fidelity of calibration and imaging algorithms, with a focus on MWA and future SKA\_Low data. The application of these techniques has the potential to impact the Epoch of Reionisation (EoR) and GLEAM survey science programs of the MWA, which have each collected several PB of raw data. These techniques will be vital for exploiting the full potential of the new long baselines of the MWA, installed in 2017.

This project is suited to a student with a strong interest in the fundamentals of radio astronomy and a solid background in computer science, maths and/or physics.

### Research Field

Radio Astronomy

### Project Suitability

Masters

PhD

### Project Supervisor

Dr Natasha Hurley-Walker

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### Co-Supervisors

Dr André Offringa (ASTRON)

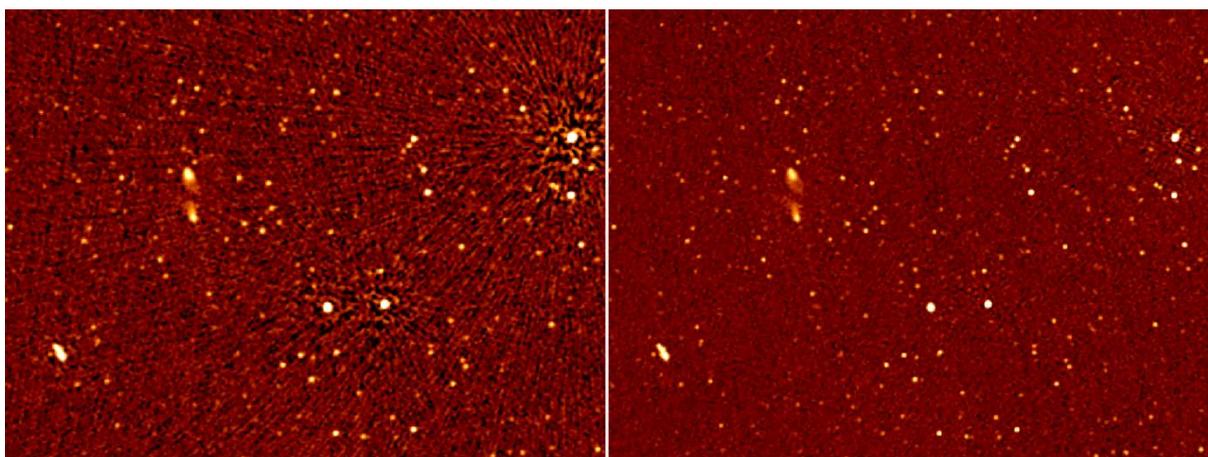


Figure: Example MWA data before (left) and after (right) improved calibration

## An Effective Cross-matching Framework for Catalogues and Images

‘Stacking’ is a common task in astronomy that consists of combining images of the sky to gain an increased signal to noise. This technique can be very powerful, however it requires that the individual images are aligned correctly. At optical wavelengths, and high radio frequencies, this alignment process can be relatively easily achieved by applying a single shift/rotate to each of the images. However at low radio frequencies the ionosphere can cause lens-like distortions on scales smaller than the image. This effect combined with the often-complicated structures of radio sources at low radio frequencies means that a single shift/rotate is no longer able to align the pixels in the image to produce a properly stacked image.

Another common task in astronomy consists of stacking catalogues together in order to extract a light curve (flux vs time plot) for each source. The process of associating sources between different catalogues typically relies on a nearest-neighbour type matching scheme and thus requires catalogues to be aligned in order to reduce false matches. The process of aligning catalogues is the same as for images.

The Murchison Widefield Array (MWA) routinely makes observations that are adversely affected by the Earth’s ionosphere. This means that the images and catalogues that are produced can be distorted and difficult to compare with data from other telescopes, and even with other MWA observations in different ionospheric conditions.

Ultimately, the problem at hand is that of matching features within datasets. Whilst there are many domain-specific solutions, there is no general framework under which cross-matching can be achieved in the event of many-to-many matches. The aim of this project is to develop such a framework within which cross matching can be achieved in the general case where many-to-one and many-to-many matches are present. It is envisioned that the framework will be largely algorithmic, and presented as a set of software.

When complete, this project will be able to demonstrate a method by which: 1. Radio images can be stacked together to increase sensitivity, even in the presence of ionospheric distortions, and 2. Catalogues of radio sources can be combined

### Research Field

Radio Astronomy

Ionosphere

Machine learning

### Project Suitability

PhD

Masters

### Project Supervisor

Dr John Morgan

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### Co-Supervisors

Dr Paul Hancock

Dr Rajan Chhetri

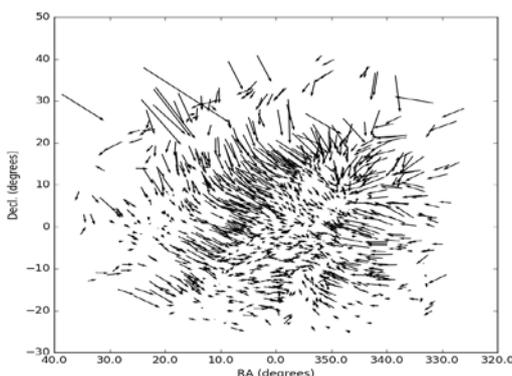


Figure: Offsets between observed positions of radio sources and their nearest crossmatch in a catalogue. The hole near RA=345, Dec=30 is due to the offsets being too large to successfully crossmatch. In some areas nearby sources have wildly discrepant offsets, which may indicate that the crossmatch is false.

## Application of Spatial filtering RFI Mitigation Techniques to MWA and SKA1-Low

Radio Frequency Interference (RFI) has been highlighted as one of the most significant threats to the new radio telescopes such as the Square Kilometre Array, due to the great sensitivity of these new instruments. The SKA core sites in both Western Australia and the South African Karoo are inherently radio quiet, but there are a variety of RFI sources (terrestrial, airborne and in orbit) with which the SKA must contend.

Spatial filtering of RFI leverages covariance matrices (usually already available in an interferometric array) to provide methods to identify and suppress unwanted RFI sources. However, these methods require further simulation work for specific telescopes, as well as testing on real systems, and the MWA and SKA1-Low prototypes will provide a suitable test platform. The example below shows an application of such an algorithm to a measurement made with LOFAR, indicating the promise of such methods.

This project is especially suited to a student with a strong interest in the fundamentals of radio astronomy and a solid background in electronic engineering. It would also be suitable for students with computer science, maths and/or physics backgrounds.

### Research Field

Electrical Engineering  
Radio Astronomy

### Project Suitability

Masters  
PhD

### Project Supervisor

Prof David Davidson  
No Curtin e-mail yet

### Co-Supervisors

A/Prof Randall Wayth

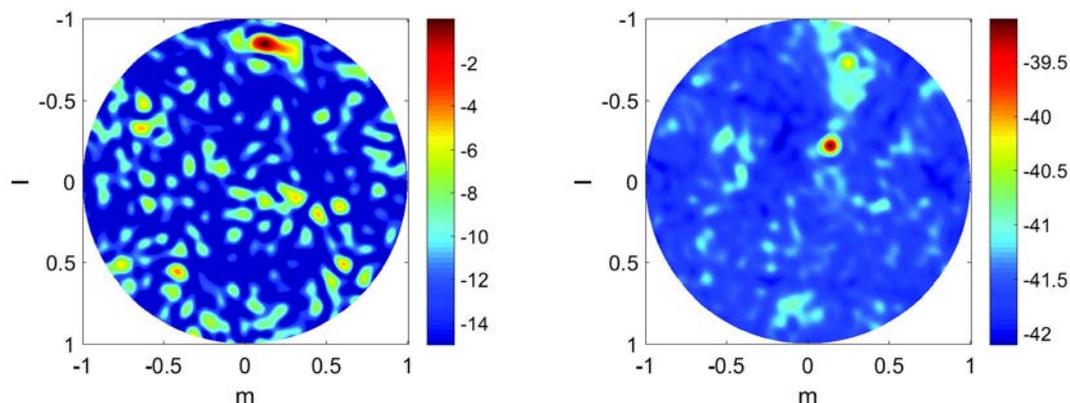


Figure: (left) A sky map with an RFI source visible at upper right. [Steeb et al, 2016 RFI] (right) The map with the RFI source removed using a spatial filtering method [Ibid]

## Black Holes in the Weak Accretion Regime

When black holes accrete matter they release large amounts of energy into their large-scale environments, such that black holes appear to play a prominent role in the processes that control galaxy formation. The vast majority of black holes accrete at very low-accretion rates, if they accrete any matter at all. In this low-accretion regime, we expect the inner regions of their accretion disks to be replaced by a geometrically thick, radiatively inefficient accretion flow (RIAF); also, such weakly accreting black holes nearly always launch steady jets of material moving away from the black hole at relativistic speeds, which can deposit kinetic energy into the nearby environment.

For this project, the student will work with multiwavelength datasets to better understand the physics of weakly accreting black holes and their jets, particularly aiming to learn how much energy is channeled into jets, and also if the observed radiation is emitted predominantly by the inflow or the outflow. The student will compare the smallest accreting black holes (~10 Solar mass black holes found in X-ray binary systems) to some of the largest supermassive black holes (nearly 1 billion Solar masses).

X-ray binaries: the student will combine observations from radio facilities (in Australia, South Africa, and the United States) and from X-ray satellites, to study weak accretion.

Supermassive black holes: the student will focus on BL Lac objects, which are weakly accreting supermassive black holes with a jet pointed toward the Earth. The student will use BL Lacs to investigate weak accretion by focusing on the properties of their broad emission line regions and their dusty tori, via optical spectroscopy and infrared observations.

This will be a multi-wavelength project, with the student expected to gain observing experience in the radio, optical, and X-ray wavebands.

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### Research Field

Accretion Physics

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### Project Suitability

PhD

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### Project Supervisor

Dr Richard Plotkin

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### Co-Supervisors

A/Prof James Miller-Jones

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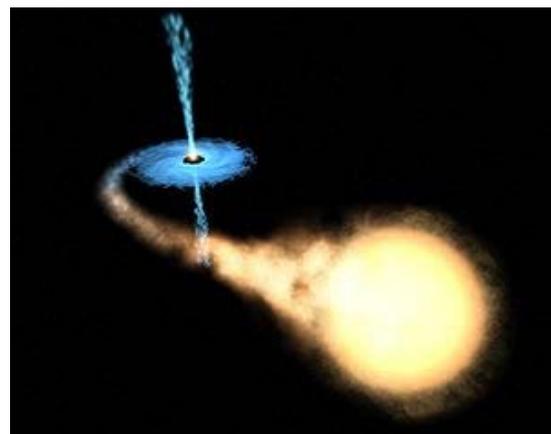


Figure: (Left) artist's impression of a black hole X-ray binary, which is fed by an accretion disk (blue) supplied by material from the outer layers of a companion star (yellow). Credit: ESA/NASA. (Right): an illustration of the unification model for radio-loud active galactic nuclei. Credit: Urry & Padovani 1995, *PASP*, 107, 803.

## Calibration and imaging for SKA1-Low: station modelling

SKA1-low is the low-frequency instrument of the Square Kilometre Array (SKA) project. It covers the band 50-350 MHz, and is to be built in Australia. SKA1-low is expected to consist of around 130 000 individual antennas, spread between around 500 stations. These stations will have an irregular distribution of antennas. Most of the stations will be located at the core of Murchison Radio-astronomy Observatory (MRO).

SKA1-low will draw on expertise acquired from the precursors and pathfinders, in particular MWA and LOFAR, but there are significant new considerations to include in the calibration and imaging for this instrument. (Calibration and imaging aim to include models of instrumental effects, to permit these to be removed from the images formed, thus improving image quality). These include the effects of primary beam variations between elements and mutual coupling, both of which the irregular distribution suppresses, but does not entirely remove.

The aim of this project is to develop and incorporate representative SKA1-low station models into a modern calibration and imaging framework incorporating direction-dependent effects (i.e. 3rd generation calibration). It will leverage various test deployments, including the Aperture Array Verification Systems currently being rolled out on the MRO.

This project is suited to a student with a strong interest in the fundamentals of radio astronomy and a solid background in electronic engineering, computer science, maths and/or physics; it is on the interface between science and engineering.

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**Research Field**

Radio Astronomy (Instrument Calibration)

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**Project Suitability**

Masters  
PhD

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**Project Supervisor**

Prof David Davidson  
No Curtin e-mail yet

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**Co-Supervisors**

A/Prof Randall Wayth  
Dr Cathryn Trott/Dr Adrian Sutinjo (TBD)

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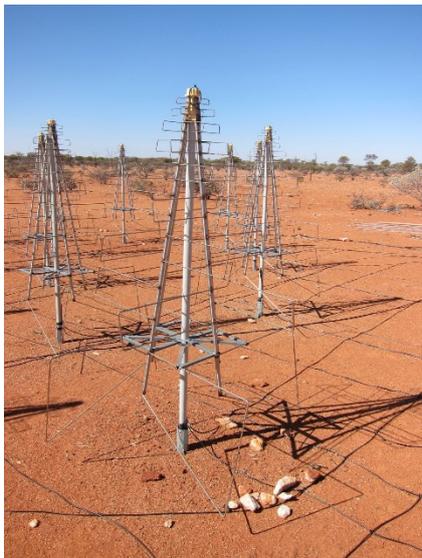


Figure: The AAVS 0.5 prototype at the Murchison Radio-astronomy Observatory

## Characterising the ionosphere over the Murchison Radio astronomy Observatory

The Murchison Widefield Array (MWA) is a ground-breaking low-frequency radio telescope conducting novel observations of the southern sky. One of the principal science projects from the MWA is the GaLactic and Extra-galactic All-sky MWA (GLEAM; Wayth 2015) survey which tackles numerous scientific goals by imaging the entire southern sky. This survey was conducted from July 2013 to June 2015 and collected 600 TBs of data. The first public data release from GLEAM is a catalogue of over 300,000 radio sources (Hurley-Walker et al. 2016).

Low-frequency radio observations (<400 MHz) present unique challenges; principal among these is the effects of the ionosphere, a layer of the upper atmosphere which is weakly ionised (~1% of particles), caused by UV and soft X-ray emission from the Sun. As a radio wave passes through this plasma it is refracted, and causes radio sources to appear to move from their true positions. Changes in solar emissions and the Earth's magnetosphere cause these apparent positions to fluctuate on time-scales of a few minutes or less, sometimes due to traveling waves and other structures within the ionosphere. The magnitude of these offsets is inversely proportional to the frequency squared: the effect is much more severe at lower frequencies.

The MWA can create wide, high-fidelity “snapshot” images on short timescales (<2 minutes) and correct for the positional offsets with reference to higher frequency, higher resolution surveys, or the first GLEAM catalogue, using hundreds of reference sources to correct the distortion across the field-of-view. For the two years of GLEAM data collected, these measurable distortions can be used to completely characterise the ionosphere over the MRO, giving insight into how the ionosphere responds to changing solar activity, the temperature shocks from sunset and sunrise, and even time of year and changing magnetic field behaviour. The student will perform this analysis and use the results to write at least one scientific paper.

The MWA doubled the maximum separation of its antennas in 2017, so this analysis may feed into designing calibration methods for the extended array. The student will be able to work with experts in the field of radio astronomy to develop methods and apply them as the extended MWA comes online. This work, as well as the ionospheric characterisation, will have an impact on the calibration of the low-frequency component of the Square Kilometre Array, which will be built on the same site as the MWA.

This project would suit a student with good organisational skills, critical thinking and analysis skills. Programming skills, particularly in python, would be very useful.

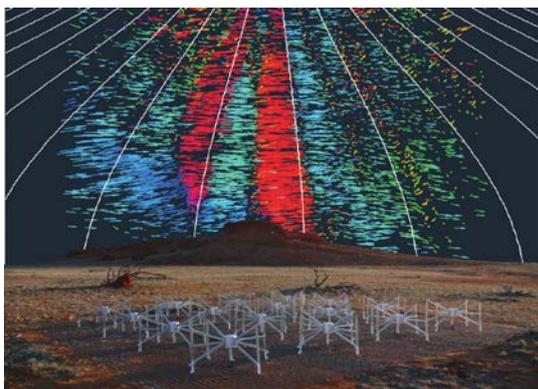


Figure: *The effect of the ionosphere on the sources seen by the MWA during a particularly extreme event. Each arrow represents the shift in position of a source; colours indicate directions. Earth's magnetic field lines are shown as white lines.*

### Research Field

Radio Astronomy

### Project Suitability

PhD

Masters

### Project Supervisor

Dr John Morgan

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### Co-Supervisors

Dr Natasha Hurley-Walker

Dr Chris Jordan

Dr Nick Seymour

## Combining GLEAM and ATLBS to discover the history of active galactic nuclei

The Murchison Widefield Array (MWA) is a low frequency (80 — 300 MHz) radio telescope operating in Western Australia and the only SKA\_Low precursor telescope. One of the largest science programs for the MWA is the GaLactic and Extragalactic All-sky MWA (GLEAM) survey, which has surveyed the entire visible sky for two years since the MWA commenced operations.

Given the steep negative power-law spectra of synchrotron emission from radio galaxies, the low operational frequencies of the MWA are well-suited to detect and image relic lobes and hence past activity associated with active galactic nuclei. This project would use the GLEAM survey data in conjunction with higher-resolution imaging to construct a more complete picture of the activity history of AGN.

The exquisitely imaged and characterised sky region covered by the 1.4 GHz Australia Telescope Low Brightness Survey (ATLBS; Subrahmanyan et al. 2010; Saripalli et al, 2012) will be used for this exercise. In addition to the well-imaged and well-characterized information in the radio, the survey region also has available deep optical imaging and spectral data. Combining structural information from the high-resolution images of ATLBS radio sources with the well-separated low-frequency data from the GLEAM survey would render an effective method not only for discovering past activity phases of radio galaxies but also activity history as a function of source type. This project would suit an organised student interested in astrophysics and radio astronomy.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Honours

Third Year

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**Project Supervisor**

Dr Natasha Hurley-Walker

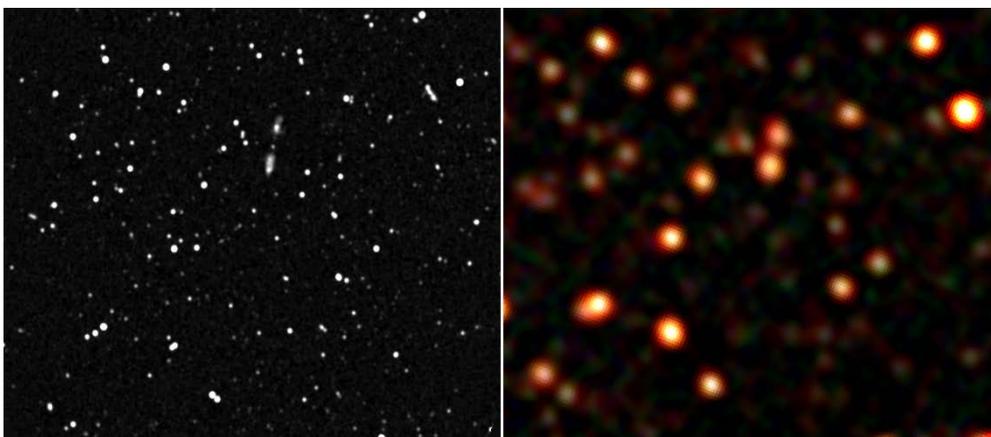
[nhw@icrar.org](mailto:nhw@icrar.org)

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**Co-Supervisors**

Dr Lakshmi Saripalli

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The ATLBS (left) and GLEAM (right) views of four square degrees of the radio sky. Combining the high resolution ATLBS data with the spectral “radio colour” of GLEAM will uncover the history of the AGN in the field.

## Cooperative Sensor Networks for the Detection of Ultra-High Energy Cosmic Rays

The Square Kilometre Array (SKA) will be the biggest astronomy infrastructure on the planet, when built over the next decade. Curtin University owns and operates the only functional SKA precursor, the Murchison Widefield Array (MWA). The MWA is located at a radio quiet location in the Shire of Murchison (future location for the SKA) and operates in the 80–300 MHz range.

A telescope similar to the MWA in the Northern Hemisphere (LOFAR) has pioneered the field of astroparticle detection using low frequency radio telescopes and arrays of particle detectors. However, LOFAR has several drawbacks: 1) not on a radio quiet site, like the MWA; 2) relatively sparse distribution of antennas on the ground; 3) has technical difficulties achieving a high duty cycle of observations and cannot utilise frequencies above 100 MHz.

The MWA covers the Southern Hemisphere and is located in a radio quiet location. This allows the better detection of the nanosecond timescale pulses of radio emission caused by high-energy particles colliding with the Earth's upper atmosphere. The distribution of MWA antennas on the ground is well-suited to detecting this emission.

The aim of this work is to prototype the development of cooperative sensor arrays for particle detection, establishing it as the most precise technique for studying high-energy cosmic rays. The MWA will form a sensor network sensitive to radio emission caused by the collision of the high energy particle with the Earth's atmosphere and map the distribution of the radio emission at ground level. The second sensor network will be a particle detector that detects the particle shower from the same collision. The two sensor networks, in cooperation, can provide information on the energies and directions of the particles, and the composition of the ensemble of particles detected.

This work will make a significant contribution to both particle- and astrophysics by studying cosmic rays at energies at 10<sup>17</sup> eV and higher. It is not known whether they originate from within or outside our own galaxy; knowing their characteristics is vital for understanding both the objects that might produce them, such as exploding stars or supermassive black holes, and our galaxy itself. Furthermore, these energies exceed those achieved in terrestrial particle accelerators such as the Large Hadron Collider, providing insights into how the universe works at a fundamental level.

The radio measurements enabled by this work have the potential for more precise measurements of cosmic rays at these energies than have ever previously been possible. This makes it possible to identify whether the cosmic rays are protons, helium nuclei, or heavier species, which provides information about the nature of their sources and the astrophysical environments through which they propagate. As the radio signature also depends on which physics model is correct, these measurements can discriminate between different theoretical extrapolations from particle-accelerator measurements.

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**Research Field**

High Energy Astrophysics,  
Particle Physics

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**Project Suitability**

PhD (Scholarship Incl.)

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**Project Supervisor**

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Dr Justin Bray (University of  
Manchester, UK).

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## Cubesat Beacon and Receiver System for Faraday Rotation Measurement

Faraday Rotation (FR) is the rotation of the plane of polarization of a linearly polarized electromagnetic (EM) wave as it travels through a medium under the influence of magnetic field. In radio astronomy, we are interested in measuring FR as it facilitates study of magnetic fields. The amount of FR is proportional to the square of the wavelength of observation. Hence, a low frequency radio telescope such as the Murchison Widefield Array or the Low-Frequency Square Kilometre Array (SKA-Low), operating at ~50 to 350 MHz is highly sensitive to FR. This is both good and not good. It is good because it is sensitive to FR. It is not good because for an earthbound telescope, we measure an FR which is a combination of the desired quantity from space plus the FR due to the earth's ionosphere.

The purpose of the Cubesat beacon is to measure the FR of the ionosphere such that it may be subtracted from the observation using the MWA or the SKA-Low to recover the desired FR originating from celestial bodies. We propose to do this using a small satellite (Cubesat) transmitting linearly polarized waves at three frequencies. There are three major components to this system: the Cubesat beacon, the ground receiving station, and the signal processing. The design of the Cubesat and ground receiving station is an engineering project suitable for one PhD (and one MPhil) in electrical/electronics/communications engineering. The signal processing and related software is suitable as a PhD topic in radio astronomy, applied physics or engineering. The goal of the project is a functioning proof-of-concept prototype to be demonstrated in a laboratory environment.

### Research Field

Radio Astronomy/Engineering

### Project Suitability

PhD

MPhil

### Project Supervisor

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### Co-Supervisors

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Dr. John Kennewell

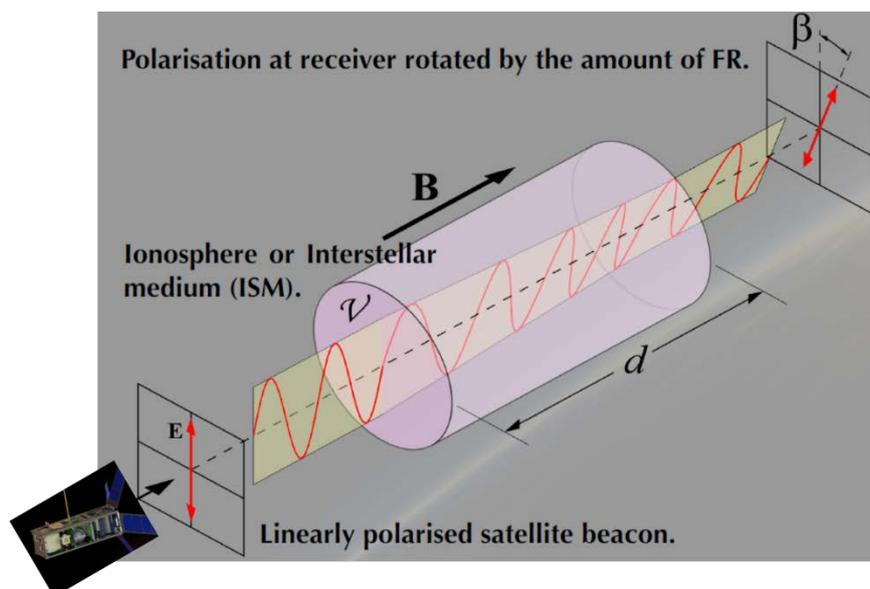


Figure: An illustration of a satellite beacon transmitting a linearly polarized wave to measure Faraday Rotation. Taken from a presentation in AstroSats2016 given by Drs. D. Heme, J. Kennewell, and Prof. M. Lynch.

## Do Powerful Millisecond-Bursts from Across the Universe Repeat?

They are bursts of radio waves from space that are over in a blink of an eye. They are variously attributed by hard-nosed and self-respecting physicists to everything from microwave ovens, to the accidental transmissions of extraterrestrials making their first baby steps in interstellar exploration. The remarkable properties of these Fast Radio Bursts (FRBs) have so enthralled astronomers that, in the decade since their discovery with the Parkes radio telescope, more theories have been advanced to explain them than new bursts have been detected.

FRBs are remarkable because they are outrageously bright yet appear extremely distant. As far as astronomers can tell, they come from a long way away - half way across the observable Universe or more! Because of that, whatever makes FRBs must be pretty special - unlike anything astronomers have ever seen.

Only a handful of FRBs are still known. Recently, however, the Australian SKA Pathfinder began looking for FRBs, and is now rapidly increasing the sample of known events.

In this project you will work with other members of the Commensal Real-Time ASKAP Fast Transients (CRAFT) team to examine the properties of FRBs and help understand what causes them. Specifically, you will delve into a statistical analysis of the CRAFT data to determine whether the FRBs detected by ASKAP are one-off cataclysmic events, or whether some of the bursts repeat with time. You will expand existing techniques to search for FRB events in the datastream, and find the means to search the data to much lower sensitivities than have been attempted previously. The scope exists to broaden this project into a PhD if one or more repeating FRBs are detected in the CRAFT data

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### Research Field

Radio Astronomy

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### Project Suitability

Honours

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### Project Supervisor

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### Co-Supervisors

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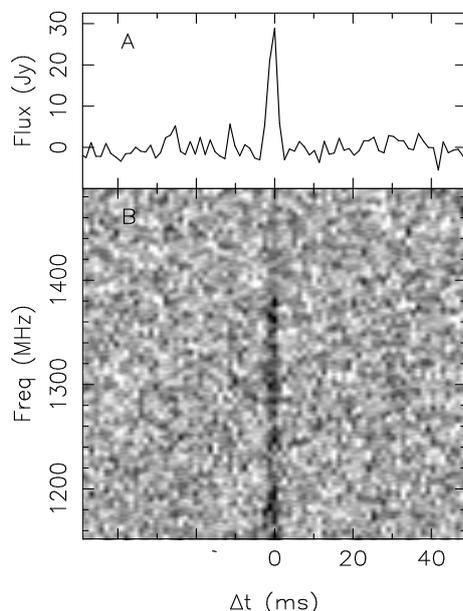


Figure: *FRB 170107*, the first Fast Radio Burst detected by ASKAP. To date, two more bursts have subsequently been found by CRAFT, with a projected detection rate of one burst every 1.5 days of observing time.

## Epoch of Reionisation Angular Power Spectrum with the Murchison Widefield Array

The Murchison Widefield Array (MWA) Epoch of Reionisation (EoR) experiment consists of the observation of ~1000 hours of data from two fields in the sky. These data are being processed to a spherical power spectrum, in order to attempt a detection of the weak signal from neutral hydrogen 0.5-1 billion years after the Big Bang. The spatial structure and evolution of the 21cm signal encodes a wealth of information about structure formation in the Universe, and helps us to understand which ionising sources are responsible for transitioning the Universe from the Dark Ages to the luminous cosmos observed today (first stars, bright or faint galaxies, black holes). The signal is extremely weak, and is embedded in noise and very bright contaminating foreground radio sources (galaxies, our Galaxy, free-free diffuse emission). Combined with a complicated instrument model, the EoR experiment is highly challenging.

### Research Field

Radio Astronomy  
Curtin Institute for Computation

### Project Suitability

Masters  
PhD

### Project Supervisor

Dr Cathryn Trott  
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### Co-Supervisors

Dr Steven Murray

The current MWA dataset suffers from missing frequency channels, which complicate the transformation to a spherical power spectrum. Also, the treatment of foreground sources is an ongoing research topic. By computing the angular power spectrum, where frequency information is treated separately, the foregrounds have a different signature, and the missing channels can be removed cleanly from the analysis. This project will use existing MWA EoR data to develop an optimal angular power spectrum algorithm and apply it to current data, in an attempt to provide the first detection of the EoR signal.

This project may be part of the ARC Centre of Excellence for All-Sky Astrophysics in 3D (CAASTRO-3D) EoR program, with potential for scholarship funding.

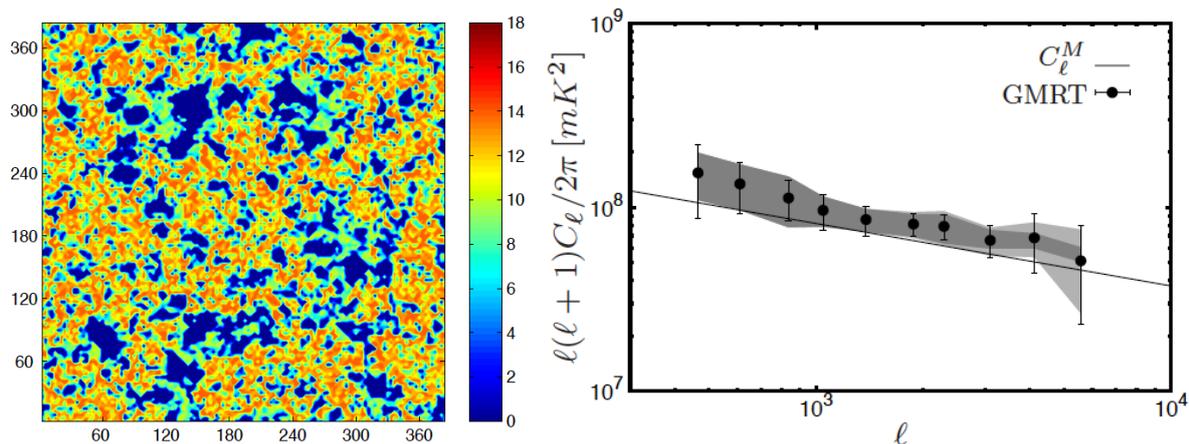


Figure: (left) Example simulated field of hydrogen brightness temperature fluctuations (Fialkov et al. 2014). (right) simulated angular power spectrum (Choudhuri et al. 2014).

## Exploring the Epoch of Reionisation using the Light Cone Effect

The statistical study of the Epoch of Reionisation (EoR) involves computing the power spectrum (variance) of the signal as a function of spatial wavenumber ( $k$ , measured in inverse megaparsec). The angular scales are obtained by Fourier Transform of radio astronomy images, or equivalently, we may directly use the visibilities (raw data) measured by an interferometer. The line-of-sight scales are computed by obtaining data in individual frequency channels, mapping those channels to cosmological distances, and then taking the Fourier Transform across frequency. This procedure assumes that the information within the observation volume (field-of-view times depth) is statistically equivalent. However, the 21cm cosmological signal of the EoR evolves with redshift, and taking Fourier Transforms over large redshift ranges dilutes and biases the signal.

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### Research Field

Radio Astronomy  
Curtin Institute for Computation

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### Project Suitability

Masters  
PhD

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### Project Supervisor

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### Co-Supervisors

Dr Steven Murray

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In Trott (2016, MNRAS 1310, <http://adsabs.harvard.edu/doi/10.1093/mnras/stw1310>), we proposed using wavelets to perform wide bandwidth analysis, but with localised properties. This project takes those initial explorations and applies the methods to existing Murchison Widefield Array data. We aim to study the impact of foreground contamination in the wavelet space, and refine our wavelet methods based on optimising signal relative to noise and contamination.

This project may be part of the ARC Centre of Excellence for All-Sky Astrophysics in 3D (CAASTRO-3D) EoR program, with potential for scholarship funding.

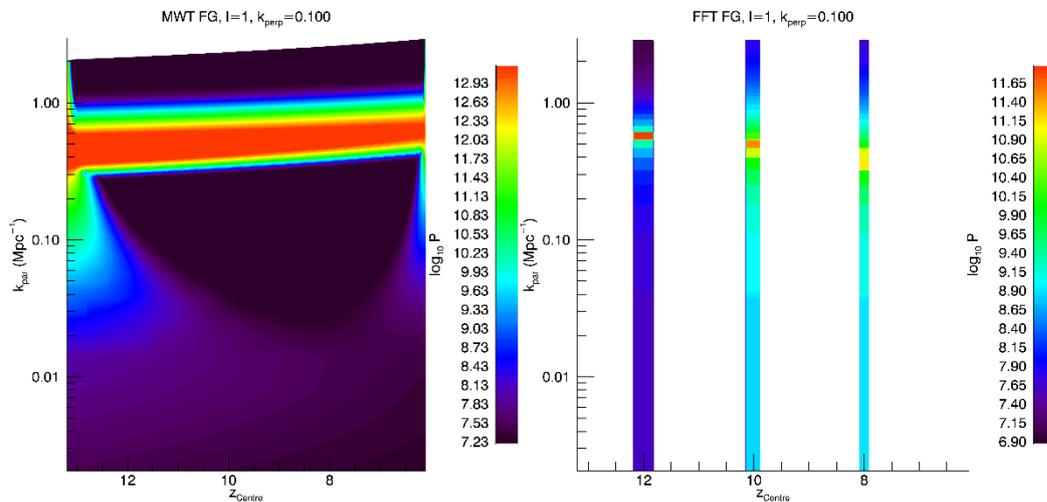


Figure: Simulated EoR power spectrum using a wavelet basis (left) versus the traditional Fourier basis (right). From Trott (2016).

## Fast follow-up of Gamma-Ray Bursts with the Murchison Widefield Array

Gamma-Ray Bursts occur either when a massive star undergoes core collapse or two neutron stars merge. In either case there is a short period in which a huge amount of material is accreted onto a newly formed black hole, and a very powerful jet of gamma-rays is squirted out into space. For a small fraction of these events the jet is aimed toward the Earth where it can be detected by gamma-ray satellites such as Fermi and Swift. These space missions then send immediate alerts to a network on the ground, allowing telescopes such as the Murchison Widefield Array (MWA) to rapidly begin observing the event.

The MWA is a low frequency (80-300 MHz) radio telescope operating in Western Australia and the only operational Square Kilometre Array (SKA)-Low precursor telescope. The MWA is an entirely electronically steered instrument, meaning that it can 'slew' to any part of the sky nearly instantaneously. The MWA also has an extremely large field of view. The large field of view and fast slew time means that the MWA is uniquely placed to provide the fastest follow-up radio observations of transient (explosive or outbursting) events, including GRBs.

For the last 3 years the MWA has been automatically responding to GRBs detected by the Fermi and Swift satellites, obtaining over 700 observations within 30 minutes of the explosion. These observations are being processed, and even more are being taken all the time. An automated pipeline is in place to download and process all these data and make the required images.

In this project you will analyse radio images to look for signs of prompt GRB radio emission - something that has never been seen before at radio frequencies. This project will help build your programming and time management skills, and will allow you to work on the Pawsey supercomputers.

### Research Field

Radio Transients

### Project Suitability

Honours or 3rd year

### Project Supervisor

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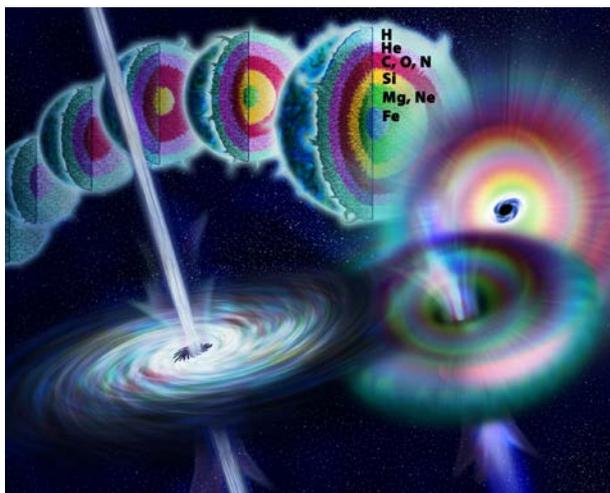


Figure: A massive star undergoing core-collapse to produce a brief jet of gamma-rays. As the jet breaks through the material left by the dying star there is a flash of radiation detectable at radio wavelengths. This radio flash is yet to be detected (credit: wikipedia).

## Finding Pulsars with a Next-generation Low-frequency Radio Telescope

Pulsars – rapidly-rotating, highly-magnetized neutron stars – make nature’s premier laboratories for advancing fundamental physics and astrophysics, with applications including testing strong-field gravity and probing physics at nuclear densities. More than 2500 pulsars are now known, and a vast majority of them were found in major sky surveys using large single-dish telescopes such as Parkes. Historically, pulsar surveys are proven to be highly rewarding, with a multitude of science enabled by the discoveries of exotic objects and specialised targets; e.g. relativistic binaries, millisecond pulsars and magnetars. Not so surprisingly, fundamental physics with pulsars is a headline science theme for the Square Kilometre Array (SKA), and conducting a full census of the Galactic pulsar population is among its key science drivers.

### Research Field

Observational Pulsar Astronomy

### Project Suitability

Honours

Masters

PhD

### Project Supervisor

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### Co-Supervisors

Steven Tremblay

Stephen Ord (CASS)

Finding pulsars with SKA precursor and pathfinder telescopes however pose numerous major challenges. The computational costs associated with beamforming and signal processing are prohibitive, besides the complexity associated in achieving the full potential in terms of exploiting their field of view or sensitivity. The Murchison Widefield Array (MWA) – a low-frequency (80-300 MHz) telescope in Western Australia, and the Precursor for SKA-LOW (i.e. the low-frequency component of the SKA) – has been no exception. Fortunately, with a major upgrade planned to expand the MWA, it will soon become possible to conduct sensitive pulsar searches with an efficiency that is ~2-3 orders magnitude better than that possible with any other currently operational facilities around the world.

This project will involve undertaking a large sky survey for pulsars with the MWA. Besides serving as an important SKA-demonstrator survey, it will also be the first major low-frequency southern sky pulsar survey since the 1990s. The project will involve developing new software and instrumentation, including efficient beam-forming techniques for pixelising the field of view, and localising pulsar discoveries rapidly using smart beam-forming and imaging techniques. Given the MWA’s unique access to the southern sky we expect a number of exciting discoveries, and consequently there is a lot of potential for high impact science.

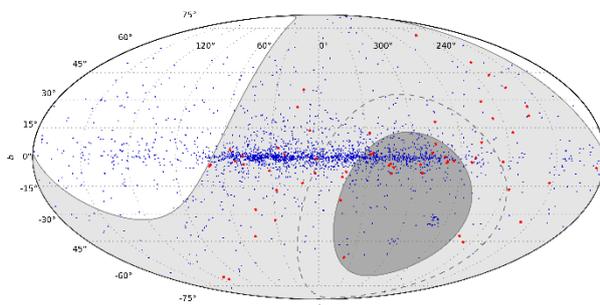


Figure: *The sky coverage provided by the MWA is shown as light and dark grey regions; blue dots represent the known pulsar population and red stars indicate the pulsars successfully detected in a census project which is effectively a shallow survey for detectable pulsar population with the MWA. The dark shaded region in the far southern sky is uniquely accessible to the MWA at low radio frequencies.*

**Funding:** This PhD project can attract a stipend of ~\$26k per annum with a discretionary travel budget of \$5k principally for international travel.

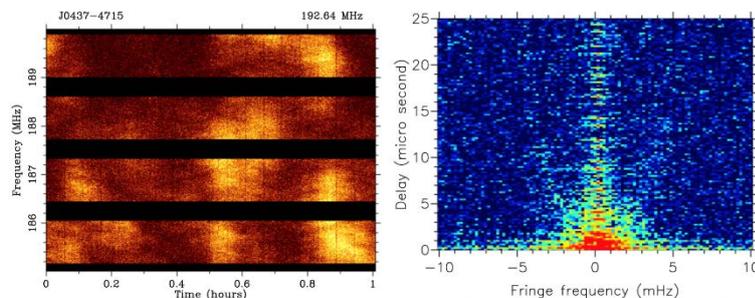
## From Low-frequency Pulsar Observations to Interstellar Holography

Pulsars make fabulous tools as probes of the interstellar medium (ISM) of our Galaxy. Their radiation is pulsed, spatially coherent and highly polarised – a combination which 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 magnified as a result of strong dependencies of these effects with the observing frequency.

Multipath propagation through the ISM gives rise to a rich variety of observable effects, many of which can be meaningfully used to probe the smallest structures in interstellar turbulence. 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), and these can be exploited to pinpoint the location of turbulent plasma or probe any anisotropy that is present. A particularly exciting development has been the application of novel techniques such as 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 signal delay structure of the ISM (Walker et al. 2013).

This project will capitalise on new instrumentation and capabilities that are now on the horizon for pulsar observations with the Murchison Widefield Array (MWA) and its sister facility, the Engineering Development Array (EDA). It will soon be possible to access fine time resolution (~microseconds) pulsar data with the future high time resolution capabilities of the MWA, and even finer time resolution (~nanoseconds) with the EDA. Development of the related instrumentation and signal processing and exploiting them for first science applications will form the central theme of the project. Potential new science include accurate characterisation of signal distortion due to the ISM and holographic reconstruction of the interstellar microstructure. The project will involve close collaboration with Univ. of Auckland (NZ) and Manly Astrophysics.

Figure: *Dynamic scintillation spectrum of the millisecond pulsar J0437-4715 (left) and its secondary spectrum (right), from MWA observations (Bhat et al. 2016). Faint parabolic arc-like features arise from deflected parts of pulsar's scattered radiation. Future capabilities at the MWA and EDA will provide very high time resolution pulsar data to enable detailed characterisations of the ISM effects.*



**Funding:** This PhD project can attract a stipend of ~\$26k per annum with a discretionary travel budget of \$5k principally for international travel.

### Research Field

Observational Pulsar Astronomy

### Project Suitability

Honours

Masters

PhD

### Project Supervisor

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### Co-Supervisors

Willem van Straten (Auckland)

Steven Tremblay

## Galaxy Evolution of the Powerful Radio-Quiet AGN Population

Galaxy evolution is intimately related to supermassive black hole (SMBH) activity. Numerous studies have tried to identify the symbiotic relation of these two physical processes across the history of the Universe. Indeed, while SMBHs appear to be ubiquitous in galaxies, only ~1% present signs of activity (seen in optical, infrared or X-rays). Even worse, only ~10% of these active SMBHs present radio emission associated with relativistic jets. Despite their limited appearance, these jets appear to play a crucial role in shaping galaxies by providing an efficient mechanism to redistribute energy in the galaxy halo. In order to build a more consistent picture, an evolutionary scheme of SMBH was hypothesised from the study of local stellar masses black holes and invoking the scale invariance hypothesis. If SMBHs are indeed going through different phases (referred as the duty cycle) this could explain naturally the large variety of observational classifications of AGN. However, while physical processes related to galaxy evolution are better constrained, the origin of this duty cycle for SMBH is still poorly understood. How long does it last? What are the characteristics of each phase? How are they triggered?

A first step of our understanding comes from powerful high redshift radio galaxies (HzRG; radio-loud and obscured AGN), a population which has been studied carefully for more than ten years and are now relatively well understood. However, the mystery of the origin of their radio emission is a question still to be answered. Is this morphological difference originating from the galaxy environment, the SMBH, the accretion disc properties, or from the galaxy itself? In order to tackle these questions, we aim to build matched samples of radio-quiet AGN, corresponding at different stages of evolution and compare it with this existing, well-studied sample of radio galaxies.

For this project, we will use a multi-wavelength approach combining observations and modelling already used on HzRGs to estimate the properties of each of the components and allow a direct comparison between samples to unveil possible deviation indicating the origin of the different phases of this AGN duty cycle. This project will be in collaboration with a team spread between Australia, Europe and USA.

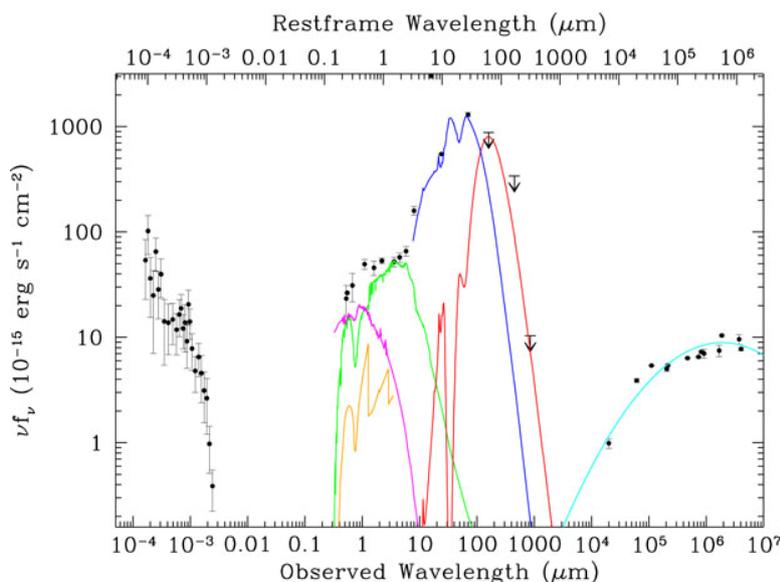


Figure: *typical spectral energy distribution of a powerful radio galaxy (4C 23.56,  $z=2.16$ ). The plot represents the distribution of energy depending of wavelength of the different galaxy/AGN components. Black: X-rays from the AGN; Yellow: nebular continuum from AGN photo-ionisation; Pink: scattered optical AGN from the accretion disc; Green: stellar emission; Blue: hot dust from AGN torus; Red: cold dust mainly from star formation; Cyan: radio emission from lobes. Source Miley & De Breuck 2008*

### Research Field

Radio Astronomy

### Project Suitability

PhD

### Project Supervisor

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### Co-Supervisors

Dr Nick Seymour

## GLEAM-X: Exploring the Universe in Radio Colour

The Murchison Widefield Array (MWA) is a low frequency (80 — 300 MHz) radio telescope operating in Western Australia and the only SKA\_Low precursor telescope. One of the largest science programs for the MWA is the GaLactic and Extragalactic All-sky MWA (GLEAM) survey, which has surveyed the entire visible sky for two years since the MWA commenced operations.

A large part of the 0.5 PB of GLEAM data has been published as an extragalactic source catalogue (see figure), and work is ongoing to publish deeper fields of some areas, and the Galactic Plane. Pilot observations of GLEAM-X have commenced, using the newly-upgraded MWA, which now has double the resolution, allowing images 10x deeper to be created, potentially revealing millions of new radio sources over the next few years.

Combining the datasets will create the most sensitive survey output from the MWA ever. As well as generating images and catalogues that are widely useful, the student will also undertake a focussed research project of his/her choice that utilises the data. This could include (but is not limited to): transient/variable radio sources, scintillation, the ionosphere, and many different radio galaxy population studies. The project is well suited to a student with strong computing skills, an interest in gaining a deep understanding of radio astronomy calibration and imaging, and an interest in a science area that can be addressed by data from the GLEAM survey.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Honours

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Joint CSC PhD

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**Project Supervisor**

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**Co-Supervisors**

Dr Tom Franzen

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Dr Nick Seymour

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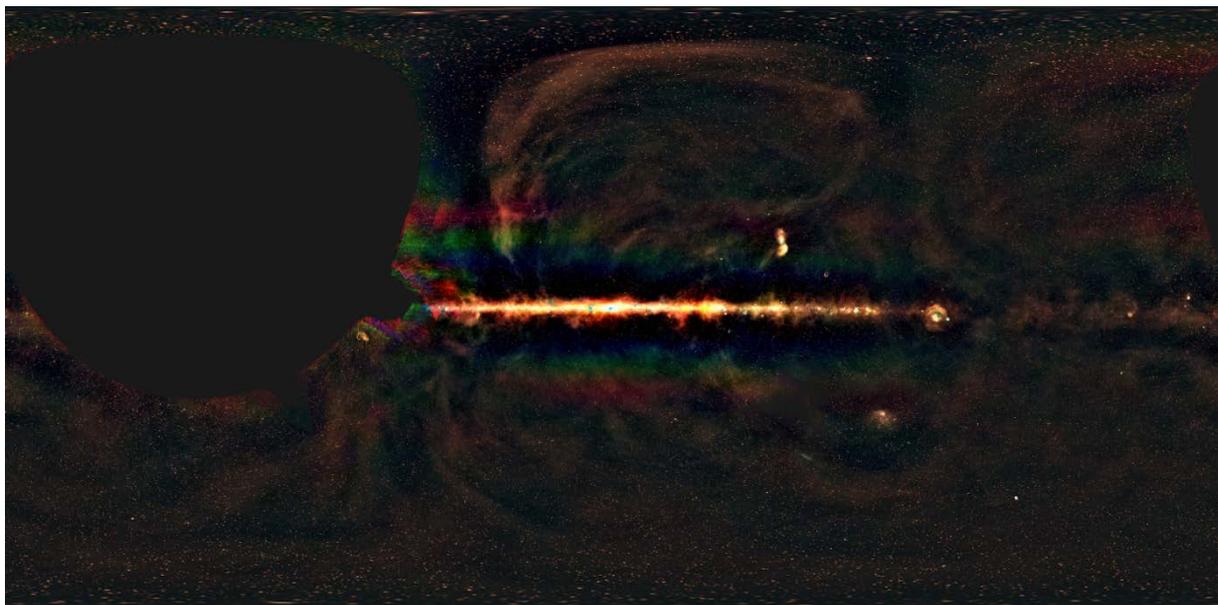


Figure: The first year of GLEAM observations, covering the whole Southern Sky. This is the first radio colour view of our universe: find out more via this TED talk: [goo.gl/LT6I0R](https://www.ted.com/talks/natasha_hurley-walker_the_first_radio_colour_view_of_our_universe) .

## HI absorption in high-z radio galaxies

Before the very first galaxies formed, the Universe was a sea of hydrogen and helium, gently cooling and collapsing. When the first galaxies formed, they ionised the surrounding gas, turning it from an opaque absorbing cloud into the transparent, ionised plasma we see today: this time is called the Epoch of Reionisation.

This change will have occurred at different rates in different locations in the Universe. When we look at high-redshift galaxies which emit in the radio spectrum, any neutral hydrogen along the line-of-sight will absorb the characteristic HI line at that redshift. For the highest-redshift galaxies, this HI line is shifted from 1.4GHz down to ~150MHz. This is within the frequency range of the Murchison Widefield Array, a radio telescope operated by Curtin University and based in the Murchison Radio Observatory.

This project aims to detect HI absorption in high-redshift radio galaxies using the MWA. As this is a spectral line experiment, it requires a unique data processing pipeline and careful control of calibration and systematics. There are several candidate radio galaxies on which first studies could be made, and once a pipeline is developed and detections made, the project can expand to include other high-z candidates currently being identified from the GaLactic and Extragalactic All-sky MWA (GLEAM) survey. There are thousands of hours of data already taken on several fields which would be suitable for this search. This project is designed to synergise with the project “How Does the Cosmic Microwave Background Impact the First Radio Galaxies?” which is designed to search for the first black holes.

**Research Field**

Radio Astronomy

**Project Suitability**

Masters

PhD

**Project Supervisor**

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**Co-Supervisors**

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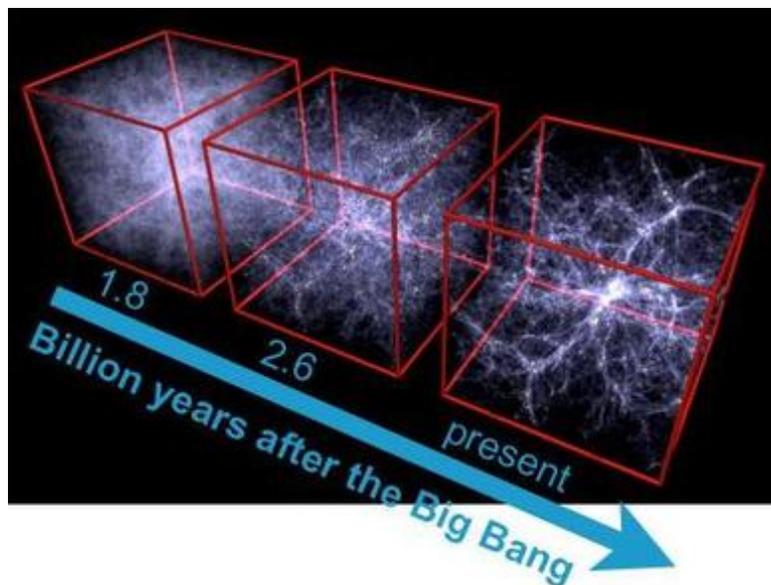


Figure: the Universe ionises due to the first stars, transforming from a sea of opaque hydrogen into the complex structures we see today.

## How Does the Cosmic Microwave Background Impact the First Radio Galaxies?

Supermassive black holes at the centres of galaxies produce powerful relativistic jets of electrons which can be observed at radio wavelengths across cosmic time due to their high luminosity. Current studies have not found luminous radio sources earlier than 1.6 billion years after the Big Bang although there is evidence for fully formed super-massive black holes at 1.2 billion years after the Big Bang. Where are all the radio sources in the early Universe?

A current popular theory is that the relativistic electrons interact with the Cosmic Microwave Background (CMB) and lose energy (thus suppressing radio emission). The energy is not lost though with the CMB photons being up-scattered to very high energies, typically in the X-ray regime but possibly lower frequencies too.

This project will investigate this effect by modelling it on current known high redshift radio galaxies and making predictions about how to best detect the up-scattered photons. The student will then use the wide range of observational facilities available to Australian astronomers to observe this emission. The model will be further tested on large area radio surveys such with the Murchison Widefield Array and the Australian Square Kilometre Array Pathfinder and with the next generation all-sky X-ray survey with eROSITA. This project may also include predictions on the up-scattering of CMB photons for the very first super-massive black holes.

### Research Field

Radio Astronomy

### Project Suitability

PhD

Honours

### Project Supervisor

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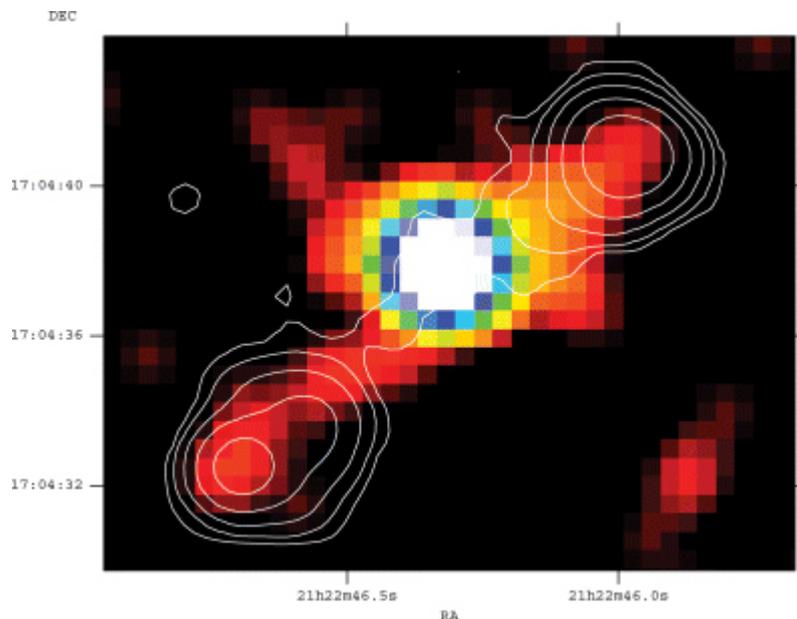


Figure: radio contours overlaid on X-ray emission from the radio galaxy 3C 432 at  $z=1.785$  when the Universe was just 4 billion years old (Erlund et al. 2006). X-ray emission is seen from the radio lobes thought to be due to up-scattering of the CMB.

## Identifying Optical Counterparts of Radio Sources Using Citizen Science

The Murchison Widefield Array (MWA) is a low-frequency (80-300 MHz) radio telescope operating in Western Australia and the only SKA\_Low precursor telescope. One of the largest science programs for the MWA is the GaLactic and Extragalactic All-sky MWA (GLEAM) survey, which has surveyed the entire visible sky for two years since the MWA commenced operations. GLEAM has collected vast quantities of data. A large part of the first year of this data has been published as an extragalactic source catalogue. These data have relatively low resolution, about 1/30th of a degree; optical data has about 1000x better resolution, so there is some difficulty in identifying exactly which galaxy is emitting radio waves.

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**Research Field**

Astronomy

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**Project Suitability**

Honours

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**Project Supervisor**

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**Co-Supervisors**

Dr Sarah White  
 Dr Nick Seymour

---

TAIPAN is a multi-object spectroscopic galaxy survey starting in late 2017 that will cover the whole southern sky and will obtain spectra for over one million galaxies in the local Universe ( $z < 0.3$ ) over 4 years. This will be the most comprehensive spectroscopic survey of the southern hemisphere ever undertaken. The Taipan galaxy survey will use the refurbished 1.2m UK Schmidt Telescope at Siding Spring Observatory with the new TAIPAN instrument which includes an innovative starbugs optical fibre positioner and a purpose-built spectrograph.

Matching radio sources to optical counterparts is key to understanding the radio population. Optical observations can provide redshifts and reveal crucial properties of the host galaxy, e.g. stellar mass and star formation rate. One useful route is to use higher-resolution, higher-frequency radio catalogues to “bootstrap” from the low-frequency, low-resolution image, up to a better cross-match, but there is still a 100-fold difference in resolution between the optical and the radio. The Radio Galaxy Zoo project (<https://radio.galaxyzoo.org/>) aims to bridge the gap between infrared and radio observations. We would like to expand this approach to connect the recently-completed GLEAM survey, and the upcoming TAIPAN survey.

The project would involve building on existing cross-matching tools to automate the bootstrap as much as possible, and then working with experienced astronomers to figure out the true matches more difficult cases. Then, these skills need to be transferred to a web-based tutorial in the Radio Galaxy Zoo framework, teaching citizens how to perform the cross-match themselves. Finally, the GLEAM and TAIPAN datasets would be rolled out in the framework, and the project opened to the world to test out.

This project would suit a student interested in outreach and citizen science, with good problem-solving skills. Programming experience would be helpful.

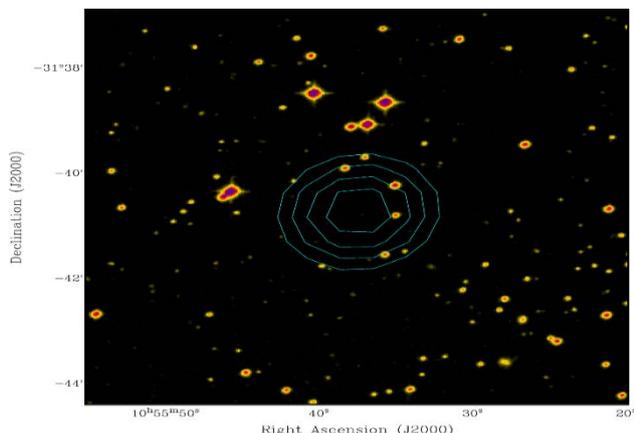


Figure: Radio contours (cyan) from GLEAM overlaid on an optical Digital Sky Survey Image (yellow on black). Which is the host galaxy for the radio emission.

## Implementing a Space Debris Detection and Tracking System Using Next Generation Radio Telescopes, Advanced Data Processing, and Data Analytics

The Square Kilometre Array (SKA) will be the biggest astronomy infrastructure on the planet, when built over the next decade. Curtin University owns and operates the only functional SKA precursor, the Murchison Widefield Array (MWA). The MWA is located at a radio quiet location in the Shire of Murchison (future location for the SKA) and operates in the 80–300 MHz range.

The MWA has the ideal characteristics for passive radar detection and monitoring of space debris in the FM broadcast band: wide field of view on the sky; low levels of local interference; and high sensitivity at FM broadcast frequencies (88 – 108 MHz). FM signals broadcast from Earth form a network of non-cooperative transmitters that illuminate elements of space debris in Earth-orbit. The FM signals reflected from the space debris can be received by the MWA, allowing the debris to be detected, imaged and located on the sky, and tracked over time to determine orbits. This technique has been demonstrated and published already (Tingay et al. 2013; Palmer et al. 2017, in press).

Space debris are now a critical risk to hundreds of billions of dollars worth of active assets in Earth orbit (satellites and human space-flight) and the problem of monitoring and ultimately removing space debris from orbit is now a significant commercial and government activity. This project will uniquely exploit the frequency coverage of many Australian radio telescopes such as the ATCA, and the Curtin-operated telescopes MWA, EDA and AAVS1 (or some such summary statement).

The aim of this work is to extend the proof-of-concept analyses in the use of the MWA for passive radar detection and tracking of space debris, in order to develop operational systems that may be of interest to government agencies and commercial entities.

The increasing population of space debris (estimated at more than 500,000 at sizes greater than 1 cm) are now a major threat to space borne assets such as communications and Earth-sending satellites, as well as human space flight (the ISS performs a handful of evasive manoeuvres per year to avoid space debris). The \$US340 billion/year space industry is increasingly focused on new ways to detect, monitor, and track space debris, to eliminate risks to these assets.

Passive radar with the MWA is a novel technique using a unique facility and has been shown to work in proof-of-concept demonstrations. The MWA wide field of view means that multiple elements of space debris can be monitored simultaneously and its rapid response capability means that major break-up events (such as the collision between a defunct Russian satellite and an active Iridium satellite in 2009) can potentially be rapidly characterized.

The Southern Hemisphere and Western Australian location is also strategic and would make such capability unique. Passive radar with the MWA could be a valuable addition to the hierarchy of Australian and international efforts in the area of Space Situational Awareness (SSA).

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**Research Field**

Transients,  
Space Situational Awareness

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**Project Suitability**

PhD (Scholarship Incl.)

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**Project Supervisor**

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**Co-Supervisors**

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Defence Pty Ltd)  
Dr Greg Madsen (Lockheed  
Martin)

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## Machine Learning Techniques in Radio Astronomy

The next generation of radio telescopes will greatly expand the number of radio sources we know by several orders of magnitude. Even with increased computing power and algorithms it will not be possible to classify them all, hence new techniques must be found. The burgeoning field of Machine Learning provides powerful and novel tools to use in identifying radio sources including kth Nearest Neighbour and Self-Organised Map amongst others.

These methods will be expanded and developed to tackle several problems in the radio surveys including:

Identification: cross-matching a radio source with surveys at other wavelengths, which is a key requirement to understanding the radio source.

Classification: determining whether the radio source is powered by star formation or black hole activity including automatically classifying the radio morphology.

Distance estimation: usually distances are determined from spectroscopy, which is expensive in terms of telescope time, but this project will also refine methods to obtain statistical distance estimates from more limited data.

This project will be at the fusion of astronomical observations and modern computing problems requiring a student with interest in both aspects.

This project will develop tools to be tested on and used for the Evolutionary Map of the Universe (EMU <http://emu-survey.org/>) on the Australian Telescope Square Kilometre Array Pathfinder. This survey is expected to find around 70million radio sources including most of the star forming galaxies in the Universe and the first black holes. EMU is an international project with over 200 members from around the world.

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**Research Field**

Radio Astronomy

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**Project Suitability**

PhD

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Honours

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**Project Supervisor**

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**Co-Supervisors**

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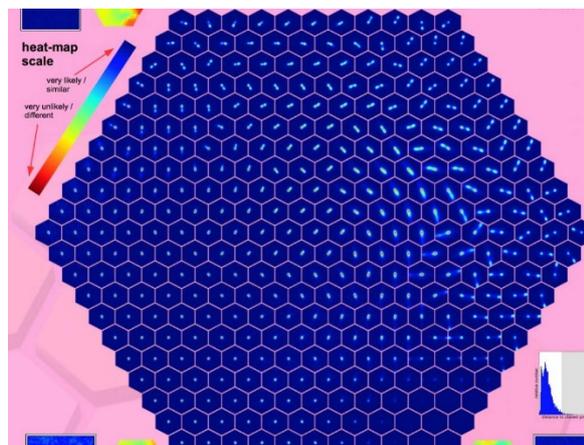


Figure: *Example of a Self-Organised Map used to classify radio sources by their morphology (Polsterer et al. 2014).*

## Noise Measurement, Modelling and Low-Noise System Design for Low-Frequency Radio Astronomy

Instrumental noise plays an important role in radio astronomy. We often hear that a low frequency radio telescope such as the Murchison Widefield Array (MWA) or the Low-Frequency Square Kilometre Array (SKA-Low), operating at ~50 to 350 MHz, are mostly dominated by noise originating from the sky. This suggests that instrumental noise is less important than in the gigahertz range. Although this is nominally true, significant effort and care are needed to ensure that the interaction between the low-frequency radio astronomy antenna and the low-noise amplifier (LNA) indeed results in a sky-noise dominated system. The reason for this is that low-frequency radio astronomy antennas tend to be highly mismatched to the nominal operating impedance of the (LNA), particularly at the low end of the frequency range.

### Research Field

Radio Astronomy/Engineering

### Project Suitability

PhD

MPhil

### Project Supervisor

Dr Adrian Sutinjo

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Although noise interaction between the antenna and LNA is well understood in theory, extraction of the relevant noise parameters typically requires a highly specialized and expensive instrument (impedance tuner). Furthermore, an impedance tuner for the low hundreds of MHz is prohibitively large. Hence the initial objective for this project is to devise a low-cost but reliable alternative for noise extraction in the SKA-Low frequency range. The second stage of the project involves modelling and optimization of the LNA for lowest instrumental noise in the SKA-Low frequency range. This is an engineering project suitable for one PhD/MPhil in electrical/electronics/communications engineering.



Figure: A replica of the Murchison Widefield Array (MWA) under measurement at Curtin Institute of Radio Astronomy.

## Observing Radio Jets from the Most Luminous Extragalactic Black Holes Discovered by eROSITA

Some black holes can be accreting material at such high rates that they approach, and sometimes supersede, the Eddington limit, which is the brightest X-ray luminosity predicted by accretion physics theory. These X-ray outbursts can last for months, with additional flaring activity on hour to day timescales. The X-ray emission is known to be coupled to the radio emission produced by relativistic jets launched in response to the in-falling matter (accretion disc), known as jet-disc coupling, and it applies across the whole black hole mass range, from stellar to supermassive. Such sources include tidal disruption events (TDEs), which are rare, flaring events resulting from the tidal disruption (ripping apart) of a star that strays too close to the event horizon of a supermassive black hole at the centre of a galaxy. TDEs are one of a few types of accretion events that allow astronomers to study the jet-disc coupling of supermassive black holes on human timescales, enabling us to compare their behaviour to stellar-mass black holes. On smaller scales, transient ultraluminous X-ray sources (ULXs) are stellar mass black holes (or possibly neutron stars) that pull large amounts of material off a companion star, resulting in outbursts that reach super-Eddington X-ray luminosities. While we regularly observe stellar-mass X-ray binaries outbursting within the Milky Way, only a handful reach the regime where they would appear as a transient ULX for an extragalactic observer.

Given the rarity of super-Eddington accreting black holes, our understanding of the associated physics is not complete. However, with the launch of the eROSITA X-ray survey mission at the beginning of 2018, we will be offered a unique opportunity to efficiently identify super-Eddington accreting X-ray transients across half of the sky. This PhD project involves collaborating with the eROSITA transient team, including members based in Germany and the UK. The aim will be to study jet-disc coupling in the super-Eddington regime through performing radio and optical follow-up observations of eROSITA-detected TDEs and transient ULXs, using the Australia Telescope Compact Array (ATCA) and the Anglo-Australia Telescope (AAT).

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### Research Field

Accretion physics

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### Project Suitability

PhD

Honours (as appropriate)

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### Project Supervisor

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### Co-Supervisors

A/Prof James Miller-Jones

Dr Paul Hancock

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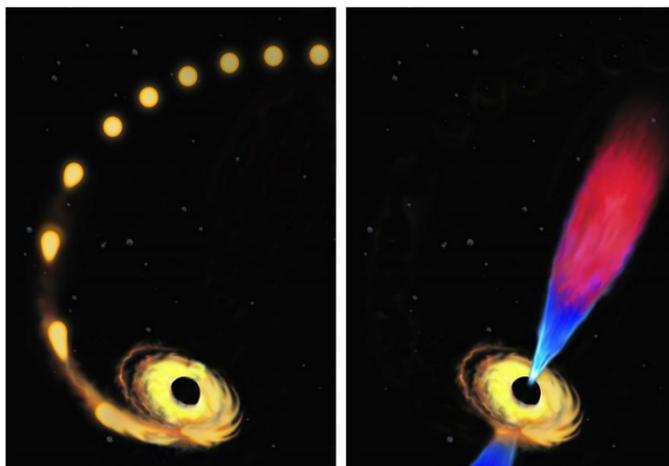


Figure 1: *The launch of a radio jet following the tidal disruption of a star that strayed too close to a supermassive black hole event horizon (credit: Amadeo Bachar).*

## Opening a Window on the Ionised Interstellar Medium of Nearby Galaxies

The ionised Interstellar Medium (ISM) is an important component of our Galaxy, comprising as much as 50% by volume and 80% by mass of the total ISM. It traces many astrophysical processes, and yet, due to the difficulty of observing it directly (compared with the neutral component, which can be studied via the 21 cm line) it is poorly understood. Very Long Baseline Interferometry (VLBI) observations allow the turbulence in the ionised ISM to be probed along lines of sight by measuring the “scatter broadening” of intrinsically compact sources. However, there are great difficulties in determining the distribution of the ionised ISM from our position well within the plane: only within 1kpc of the Solar System can complex structure be mapped, allowing correlation with other astrophysical phenomena.

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**Research Field**

High-resolution Radio -  
Astronomy, turbulence

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**Project Suitability**

Master, PhD

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**Project Supervisor**

Dr John Morgan  
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**Co-Supervisors**

Dr Jean-Pierre Macquart

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Applying this technique to other galaxies could produce significantly improved results since even a small inclination to the line of sight separates the components of the ISM, greatly increasing the observable information. A pilot study of M31 undertaken a few of years ago showed very promising results, with strong evidence of the detection of the ionised ISM of a nearby galaxy for the first time. Much deeper VLBI observations of M31 have now been undertaken and await analysis.

Beyond the main goal measuring the ISM of M31 there are further secondary goals that might be achieved with these data. The first is HI absorption towards the brighter background sources, one of which lies right on a neutral filament in the M31 galaxy. The second is determining accurately the brightness M31\* across at least 3 epochs in 2012, when it is thought to be much dimmer than expected. Third, the possibility of detecting compact sources that are hosted within M31, such as X-ray binaries.

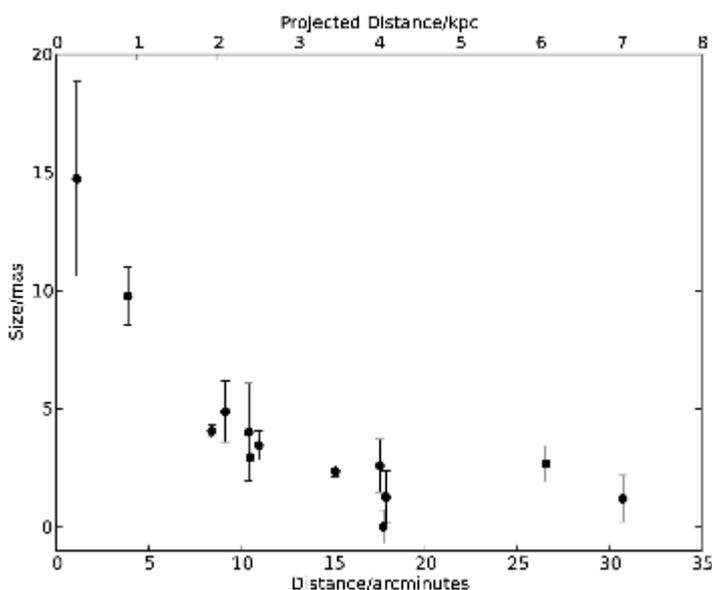


Figure: *The angular size of sources (assumed to be intrinsically compact sources seen through the M31 galaxy as a function of angular distance from the core of M31. Those nearest to the centre appear to be larger. This is thought to be due to “scatter broadening” of the sources by the turbulent ISM of M31.*

## Probing cosmic explosions and unveiling extreme astrophysics using rapid-response radio telescopes

The radio Universe is an extremely dynamic place. Flaring and explosive (also known as “transient”) radio emission can be produced by hungry black holes launching powerful radio jets, from the interaction of material ejected from exploding stars (known as supernovae and long-duration gamma-ray bursts), and even in the form of bright radio flares from our smallest solar neighbours. Short-duration gamma-ray bursts (SGRBs), which result from the merger of two dense neutron stars and therefore thought to be a subclass of gravitational wave events detectable with Advanced LIGO (aLIGO), can also produce radio emission. Studying the radio emission produced by transient sources provides vital insights into shock physics and particle acceleration, magnetic field strengths, and the structure of the surrounding interstellar medium. However, one complication is that transient radio emission can be very short-lived (seconds to hours) so it is imperative radio telescopes begin observing these objects before any rapid flaring activity fades away forever. This PhD project involves the use of a new and innovative rapid-response observing mode on the Australia Telescope Compact Array (ATCA), which will probe the earliest radio properties of high-energy (X-ray/gamma-ray) transients detected with NASA’s Swift satellite. The rapid-response observing system on ATCA responds to Swift-detected transients and automatically repoints the telescope, allowing it to begin observing the event within minutes of its detection.

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**Research Field**

Transient radio astronomy

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**Project Suitability**

PhD

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**Project Supervisor**

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**Co-Supervisors**

A/Prof James Miller-Jones

Dr Paul Hancock

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ATCA is currently collecting rapid-response observations on Swift-detected SGRBs and superflares from nearby flaring stars (with future plans to expand the project to include other transients). These data will be used to characterise the timescales and brightness of SGRB radio flares, which will provide vital insight into the radio properties of gravitation wave events, and thus the radio signatures to search for within the large positional uncertainties provided by aLIGO. The emission mechanisms capable of generating giant radio flares associated with the high-energy superflares from flare stars, which are 10,000 times more powerful than those from our Sun, will also be investigated. As the project develops, it is planned that similar experiments will also be conducted with the Murchison Widefield Array (MWA) and the Australian Square Kilometre Array Pathfinder (ASKAP). These rapid-response programs will act as a test-bed for transient observing strategies with the Square Kilometre Array (SKA).

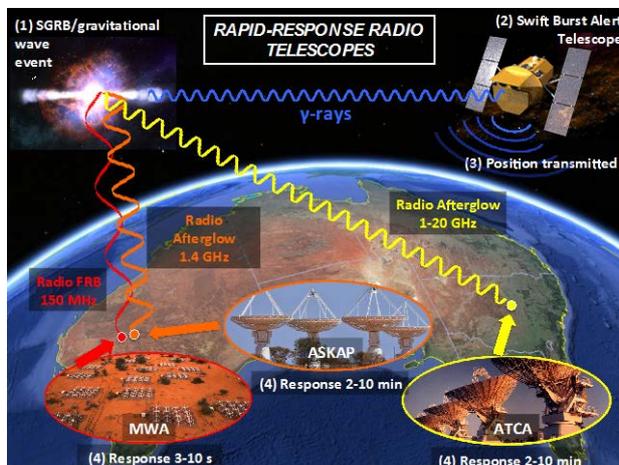


Figure 1: Flow diagram depicting the rapid-response observing system required for detecting prompt radio emission from SGRBs. Following a SGRB (1), Swift will detect the event (2) and then transmit its position down to Earth (3). This positional information will then be received by MWA and ATCA (with future plans for ASKAP), resulting in radio observations of the event with response times within minutes of the burst’s detection (4).

## Probing the Environment of the Most Massive Proto-cluster

Clusters are the most massive bound structures in the Universe and are a unique place to study galaxy formation. Around half of the stellar mass of the Universe is produced in clusters or their proto-cluster ancestors. Tracing proto-clusters in the distant Universe is difficult as traditional techniques become much less effective. However, the most powerful radio sources are unique beacons of the earliest over-densities which form proto-clusters. Using radio surveys we have discovered many high redshift proto-clusters associated with powerful radio galaxies.

Many of these high redshift radio galaxies are extremely polarised with unusual polarisation properties. As the radio emission is large,  $>100,000$  parsec in the case of the Spiderweb galaxy below, it is not clear how sources so big can have such unusual radio properties. One prevailing argument is that it is partly due to the intra-cluster medium, the dense environment within the gravitational well of the cluster, but between the galaxies.

This project would utilize a wealth of archival radio observations on these well studied sources as well as low-frequency radio observations from the Murchison Widefield Array (run by Curtin and located in Western Australia). The student would need to develop a good understanding of radio astronomy and the astrophysics of powerful radio sources and clusters in the early Universe.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Honours

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PhD (potentially)

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**Project Supervisor**

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**Co-Supervisors**

Dr Craig Anderson (CASS)

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Dr Guillaume Drouart

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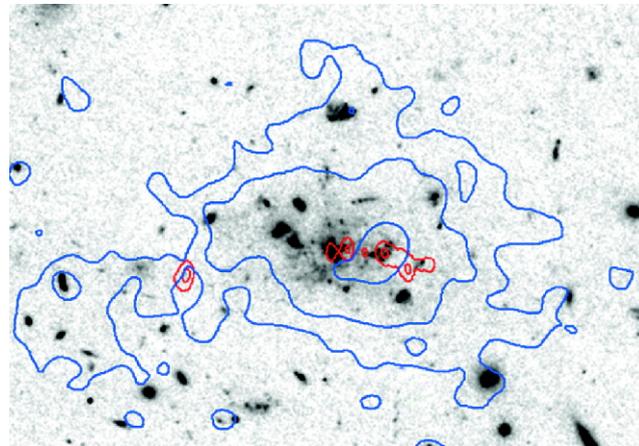


Figure: The Spiderweb galaxy (aka PKS1138-262) so called as this *Hubble Space Telescope* image gives it the appearance of flies being caught in its gravitational web. This proto-cluster is forming at just 3.5 billion years after the Big Bang and was discovered via its powerful radio emission (seen from the red contours). This project aims to use polarised radio observations to probe the intra-cluster medium in this system and possibly others. Picture credit: George Miley

## Radio Morphology Evolution of Radio Sources at Low Frequency

Radio emission is a powerful proxy to study the impact of active supermassive black holes residing in the centre of massive galaxies. The Fanaroff-Riley classification, established in 1974, separates radio-loud active galactic nuclei (AGN) in two categories: sources either presenting a flaring double-jet (FRI, see Figure, left) or a collimated double-jet ending with two clearly identified hot-spots (point of jet injection in the intergalactic medium, FR II, see Figure, right). The origin of these two morphologies is not yet fully understood (galaxy environment, black hole and/or accretion properties), but they present a dependence on luminosity, where FRI galaxies are on average weaker than their FR II counterparts. Yet this radio emission is thought to be an extremely efficient way to redistribute energy in the galaxy and its vicinity, a process which is essential in galaxy evolution simulations to reproduce observations.

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**Research Field**  
Radio Astronomy

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**Project Suitability**  
Honours

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**Project Supervisor**  
Dr Guillaume Drouart  
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**Co-Supervisors**  
Dr Nick Seymour

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We propose in this project to identify and classify radio sources of different sizes and luminosities, making use of newly available low-frequency surveys such as GLEAM and TGSS. These two new all-sky surveys present observations at a common frequency of 150MHz each with a unique --- but complementary --- advantage, the resolution aspect for TGSS (25'' vs 3' for GLEAM) and the frequency coverage for GLEAM (70-230MHz vs 150MHz for TGSS). While TGSS is essential to measure size of the source, GLEAM provides the unique spectral index information, enabling characterisation of the radio emission. By characterising the fraction, the nature and size of sources presenting multiple components at higher resolution, we aim to develop new criteria to characterise radio source in the size/spectral/luminosity plane.

This project is a part of a broader project looking to make use of radio morphology to look at radio sources in a cosmological context, making use of their size as a prior to estimate their redshift (in collaboration with researchers in France and Tasmania).

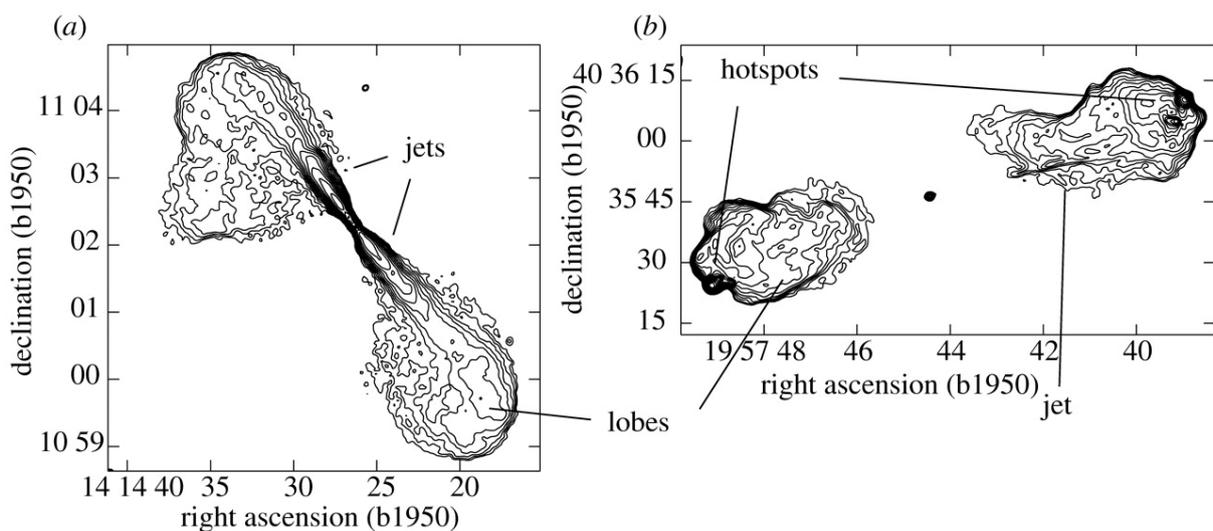


Figure: Example of the FRI-FR II morphology dichotomy as seen in radio. Images are taken at 1.4GHz, FRI on the left and FR II on the right.

## Radio Recombination Lines with the MWA

Radio recombination lines (RRL) are produced when atoms cascade into a series of successively lower ionisation states. In particular, the RRLs found at low frequencies are highly sensitive probes of the environment where the atoms are found, making them useful diagnostics of temperature, density and pressure.

RRLs at low frequencies were first discovered in 1980 and have since been discovered at frequencies from 14 to 1420MHz. However, the region between 100 — 200MHz is not well studied. Early studies suggest that somewhere between 100 and 200MHz the RRLs transition from emission lines to absorption lines. Recent constraints from studies by LOFAR have suggested that this transition may be around 130MHz.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Honours

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**Project Supervisor**

Dr Natasha Hurley-Walker

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**Co-Supervisors**

Chenoa Tremblay

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This project will utilize data cubes generated and published by Tremblay et al (MNRAS submitted) as part of a spectral line survey with the Murchison Widefield Array (MWA) to search for RRLs, with a particular focus on carbon recombination lines from 103 to 133MHz.

In 2017 the MWA received upgrades to increase its resolution, so new data taken in this mode may also be used to search for lines, adopting existing spectral line pipelines. This project is suited to a student with a strong grounding in astrophysics and a good understanding or willingness to learn statistics so that these sensitive measurements may be made in a robust and quantitative way.



Figure: The Orion Nebula in optical light (left) and radio (right), the latter as observed by the MWA GLEAM survey. This project would involve using the fine frequency resolution of the MWA to search for radio recombination lines in star-forming regions like Orion.

## Rapid Follow-ups of Fast Radio Bursts with the MWA

In 2013, the Parkes team conducting a large sky survey for pulsars, announced the discovery of an exciting and new class of transient sources – Fast Radio Bursts (FRBs; Thornton et al. 2013). These bursts are thought to originate from cosmological distances, and they provide potential new probes for cosmology: e.g, measuring the baryonic content and the magnetic field of the Intergalactic Medium.

The physics governing the origin of these energetic bursts remains unknown, notwithstanding a continuing flurry of theoretical ideas including exotic possibilities involving compact objects, dark matter and even cosmic strings. As with other high-energy phenomena, such as gamma-ray bursts, localization and follow-up at multiple wavelengths holds the key to uncovering their origin and physics.

Follow-up investigations of FRBs pose major technical challenges given their extremely short (~milliseconds) time durations. The Australian SKA Pathfinder (ASKAP) telescope is a highly promising instrument for FRB hunting (Bannister et al. 2017), and will soon start detecting them in real-time. With its astonishingly huge field-of-view (~300-1000 deg<sup>2</sup>) and electronic steering capability the Murchison Widefield Array (MWA) is an ideal instrument for conducting rapid follow-ups of FRBs. Low-frequency detections are crucial not just for characterizing their spectral and scattering characteristics, but also for excluding certain classes of progenitor models.

This PhD project will focus on maturing a capability currently under development at the MWA to receive and respond to the trigger alerts from premier facilities such as ASKAP and Parkes. This will enable some unique science relating to FRB emission, as well as their propagation and progenitor models. This will go a long way in advancing our understanding of these mysterious sources.

### Research Field

Time-domain Astronomy

### Project Suitability

Honours

Masters

PhD

### Project Supervisor

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### Co-Supervisors

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Dr Ryan Shannon

A/Prof Randall Wayth

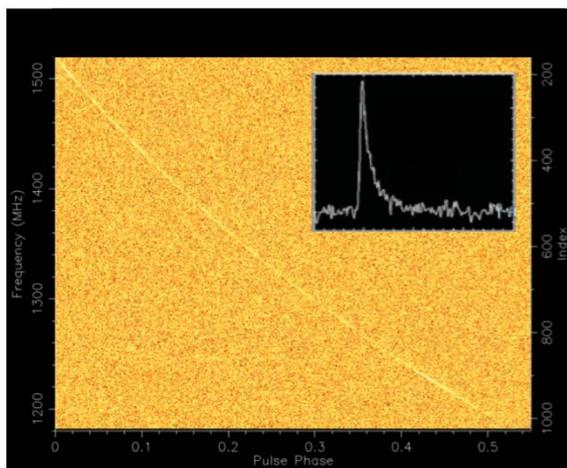


Figure: *FRB 110220 – one of the brightest FRBs discovered in the Parkes high time resolution Universe survey (Thornton et al. 2013). The burst's dispersion measure of  $945 \text{ pc cm}^{-3}$  results in an arrival time spread of approximately 1100 milliseconds across the 400 MHz observing band of Parkes survey observations. The burst would have arrived at the MWA 185 MHz band approximately 112 seconds after its time of detection at Parkes. The inset shows the shape of the pulse, where an exponential tail resulting from multi-path scattering through the intergalactic medium is clearly visible, and follows the expectations based on a Kolmogorov-type turbulence.*

**Funding:** This PhD project can attract a stipend of at least ~\$26k per annum plus \$5k per annum travel support.

## Real-time Signal Processing and High Time Resolution Science with the MWA and EDA Radio Telescopes

The Murchison Widefield Array (MWA) radio telescope operates in the remote Murchison shire of Western Australia. A key feature of the MWA is its very large field of view (approximately 25 degrees, or 50 full moons across), which enables the MWA to view many astronomical sources simultaneously.

In order to undertake astrophysical studies that require high time resolution (typically much finer than 1 second), the MWA presently records raw data for short observations then processes the data later using a slow, offline technique. The aim of this project is to combine the capabilities of a new MWA backend signal processing system with a dedicated 100 Gbps link from site to develop a real-time high time resolution capability for the MWA, and to use it for a range of potential astrophysics studies from pulsars and powerful magnetars, through to enigmatic “Fast Radio Bursts” and even (if the student is interested) the Search For Extra-Terrestrial Intelligence.

The very broad field-of-view of the MWA combined with a real-time signal processing system will transform the capabilities of the MWA for high time resolution science and allow large-scale commensal science programs, whereby observing time for a primary science program is re-used for secondary programs. This capability will change the amount of time observed for high time resolution projects from the tens of hours to the thousands of hours per year.

This project would suit a student with an interest in physics/astrophysics and a strong background in computer science and/or software engineering. The project will require the implementation of computationally intensive signal processing algorithms on cutting-edge hardware such as graphics processing units (GPUs) or Xeon Phi co-processors.

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**Research Field**

Radio Astronomy/Engineering

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**Project Suitability**

PhD

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**Project Supervisor**

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---

**Co-Supervisors**

Dr Ramesh Bhat

Dr Ryan Shannon

---



*Figure: The Engineering Development Array (EDA) radio telescope is operated by the Curtin Institute of Radio Astronomy*

## Searching for Optical Transients with the Desert Fireball Network

The Desert Fireball Network (DFN, [fireballsintthesky.com.au](http://fireballsintthesky.com.au)) is a project that aims to detect bright meteors (fireballs) as they fall through the sky, and to retrieve the meteorites that they may drop. The DFN group have deployed cameras all over the southern and western parts of Australia as part of their work. As part of a collaboration between the Murchison Widefield Array (MWA) and the DFN group, a camera has been installed near Wooleen Station that is part of the DFN network, but is specially built for astronomy observations. We call this the astrocam!

### Research Field

Transients and Variability

### Project Suitability

PhD

Honours

### Project Supervisors

Dr Paul Hancock

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The astrocam has a very wide field of view ( $100 \times 80^\circ$ ), can detect stars as faint as 10th magnitude, and has a fully automatic observing schedule. We have developed a calibration method that will allow us to extract science quality images from the astrocam data. We are now in the nice position of having a large amount of excellent data that needs to be mined for science results.

The first part of the project is to use the astrocam images to produce light curves for all the known variable stars above 10th magnitude. With the all-night, all-year observations, and generally favourable weather conditions, this will be the most detailed and largest study of its kind.

The second part of the project is to search for variable stars and transient events that are yet unknown. This includes searching for transient events such: cataclysmic variables, novae, and supernovae. With a sensitivity limit of approximately 10th magnitude it will also be possible to find new variable stars, which have gone unnoticed by the more sensitive but narrow surveys carried out on large telescopes.

In this project you will learn about the life cycle of stars. You will also gain experience handling large amounts of data in an automated way and will have access to supercomputing facilities such as the Pawsey Supercomputing Centre.



Figure: (left) The astrocam that has collected all the data for this project. It is co-located with a normal DFN camera. (right) The constellation of Orion as seen by the astrocam.

## Searching for the Most Massive Clusters Around Radio Galaxies

Clusters are the most massive bound structures in the Universe and are a unique place to study galaxy formation. Around half of the stellar mass of the Universe is produced in clusters or their proto-cluster ancestors. Tracing proto-clusters in the distant Universe is difficult as traditional techniques become much less effective. However, the most powerful radio sources are unique beacons of the earliest over-densities which form proto-clusters.

This project will investigate the feasibility of searching for massive clusters in the distant Universe around radio sources found with both the Murchison Widefield Array (MWA) and the Australian Square Kilometre Array Pathfinder (ASKAP). This project will use the publically available mid-infrared survey from the WISE mission to search for over-densities of galaxies around a given radio source.

This project will refine this technique on known distant clusters before extending it to discover new clusters, pushing back the epoch at which they are known and furthering our understanding of galaxy evolution. If this method proves successful this project could be expanded into a PhD utilising follow-up observations of these new proto-clusters.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Honours

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PhD (potentially)

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**Project Supervisor**

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**Co-Supervisors**

Dr Guillaume Drouart

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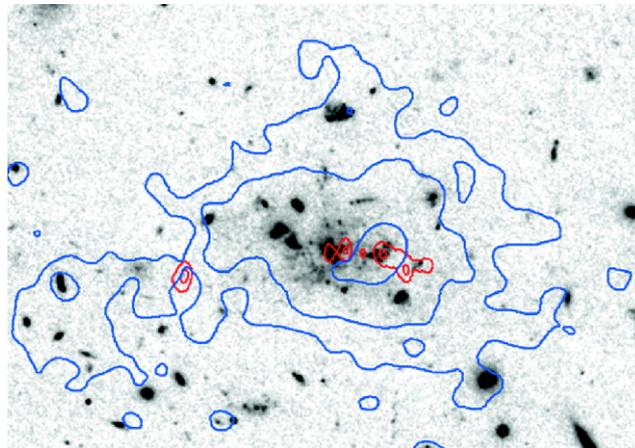


Figure: The Spiderweb galaxy (aka PKS1138-262) so called as this *Hubble Space Telescope* image gives it the appearance of flies being caught in its gravitational web. This proto-cluster is forming at just 3.5 billion years after the Big Bang and was discovered via its powerful radio emission (seen from the red contours). This project aims to develop a technique to find more such clusters in the early Universe. Picture credit: George Miley

## Searching for transients and variables in the GaLactic and Extragalactic All-Sky MWA (GLEAM) survey

The Murchison Widefield Array (MWA) is a low frequency (80-300 MHz) radio telescope operating in Western Australia and the only SKA\_Low precursor telescope. One of the largest science programs for the MWA is the GaLactic and Extragalactic All-sky MWA (GLEAM) survey, which has surveyed the entire visible sky for two years since the MWA commenced operations.

GLEAM has collected vast quantities of data. A large part of the first year of this data has been published as an extragalactic source catalogue. However, to produce this catalogue, all of the data was averaged together in time. The original data in full time resolution still remains to be investigated: hidden in these images are possible transient events, such as: flaring M-dwarf stars, reflective space junk, and potentially other undiscovered sources. There are also many astrophysical reasons for sources to change in brightness with time, such as scintillation from intervening plasma, and the flaring and dimming of distant black holes.

The project involves careful re-analysis of the original GLEAM data, using the combined catalogue as a reliable reference source. The student will search for objects which do not appear in the combined catalogue (transients), and identify their nature. There is also the potential to monitor the brightness of sources over time (variables). With approximately 7million source measurements to search and correlate, organisation and clear thinking are crucial skills.

This project would suit a student with good programming skills who is willing to learn more and search a large dataset for potentially interesting events.

### Research Field

Transients and Variables

### Project Suitability

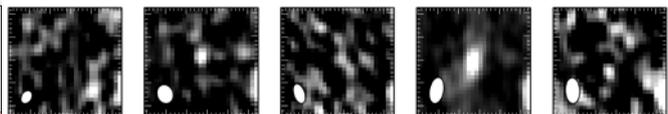
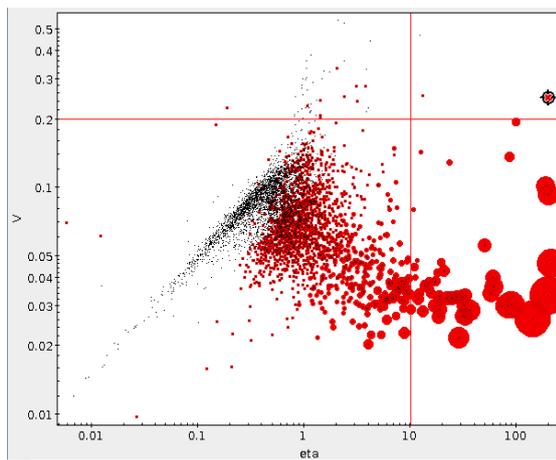
Honours

### Project Supervisor

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### Co-Supervisors

Dr Paul Hancock



**Above:** An example set of images, demonstrating a variable source. The source is detected only in the 2nd and 4th images.

**Left:** The degree (V) and significance (eta) of variability for a subset of sources that will be used in this work.

## “The A-Team”: Low-frequency Observations of the Brightest Radio Galaxies in the Southern Sky

The Murchison Widefield Array (MWA) is a low frequency (80 — 300 MHz) radio telescope operating in Western Australia; its location in the southern hemisphere gives it an excellent view of the Galactic Plane, and several bright radio galaxies: Hercules A, Fornax A, Virgo A, Hydra A, Centaurus A, and Pictor A: colloquially and collectively called “The A-Team”.

These radio galaxies are some of the closest and brightest objects visible with the telescope, but are so bright that they are often removed or “peeled” from observations without being well-characterised, in order to reveal fainter sources. However, these objects are interesting, because they are powerful, bright, and close enough that even with the MWA, relatively fine details can be observed. At low frequencies, this can give insights into the nature of the jets emitting from the central black hole; for instance, it is suspected that the jets of Pictor A become partially synchrotron self-absorbed, causing the spectrum to flatten at low frequencies.

This project aims to use the best observations from many hundreds of hours of observations of these very bright sources to completely characterise them over the entire MWA band, as well as new high-resolution observations from the extended MWA and the GMRT to explore their complex morphologies at low frequencies. The resulting sky models will be extremely useful for calibration and peeling for the rest of the international MWA team, and also for future work with the Square Kilometer Array. Insights into the astrophysics of the individual sources may well result in papers in refereed journals.

This project is suited to a student with a strong grounding in astrophysics and a willingness to learn various software data reduction packages in order to create the best images possible.

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### Research Field

Radio Astronomy

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### Project Suitability

Honours (as appropriate)

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### Project Supervisor

Dr Natasha Hurley-Walker

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### Co-Supervisors

Dr Sarah White

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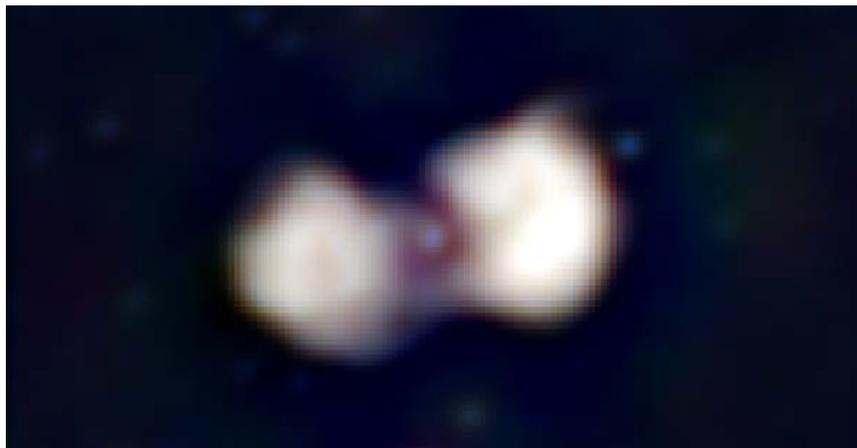


Figure: Fornax A, as seen in radio “colours” via the GLEAM survey; red = 72 — 103 MHz; green = 103 — 134 MHz; blue = 139 — 170MHz; the lobes have a different spectral behaviour to the central core.

## The explosive outbursts of black holes

The release of gravitational potential energy as matter falls onto a compact object such as a black hole powers the most energetic phenomena in the Universe, allowing us to study higher energies and stronger gravitational fields than could ever be reproduced in a laboratory here on Earth.

As matter falls onto a black hole, its angular momentum causes it to form a rotating accretion disc around the central object. Depending on the accretion rate, the inner radius of the disc can extend down to the innermost stable circular orbit of the black hole, or it can be truncated further out, with the inner regions containing a more vertically-extended, hot flow. However, matter does not only flow inwards. Some fraction of the infalling material can be diverted outwards in relativistically-moving, oppositely directed, bipolar jets, or in slower, more massive, equatorial winds. The different geometries of the inflow appear to be associated with these different types of outflow. With multiwavelength observations, we can probe all these different components of the system; jets, winds and accretion flow. On occasion, the accretion rate onto the central black hole increases by several orders of magnitude, changing both the inflow geometry and the nature of the outflows, and causing a dramatic increase in the amount of light emitted at all wavelengths.

We believe that the same physics governs the behaviour of these stellar-mass compact objects as governs their more massive analogues in the supermassive black holes seen at the centres of galaxies (Active Galactic Nuclei; AGN). However, since stellar-mass objects evolve on much faster timescales (days and weeks rather than millennia), they act as unique probes of the physics governing the accretion and outflow around black holes. We can study the explosive outbursts of these systems as they evolve in real time, providing new insights into their radiative and kinetic feedback that has an impact on cosmological scales

In this project, you will work as part of a large international team conducting multi-wavelength observational studies of the explosive outbursts of black hole X-ray binary systems, aiming to understand how these powerful events evolve, and in particular the connection between the changing conditions in the inflow and the launching of relativistic jets. Via comparative studies between black holes and their less massive analogues, the neutron star and white dwarf systems, you will probe the effect of the depth of the gravitational potential well, the stellar surface, and the stellar magnetic field, on the jet launching process.

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### Research Field

Accretion Physics

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### Project Suitability

PhD

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### Project Supervisor

Dr James Miller-Jones

james.miller-

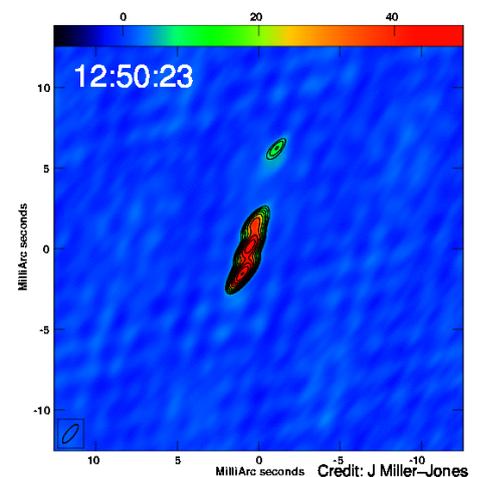
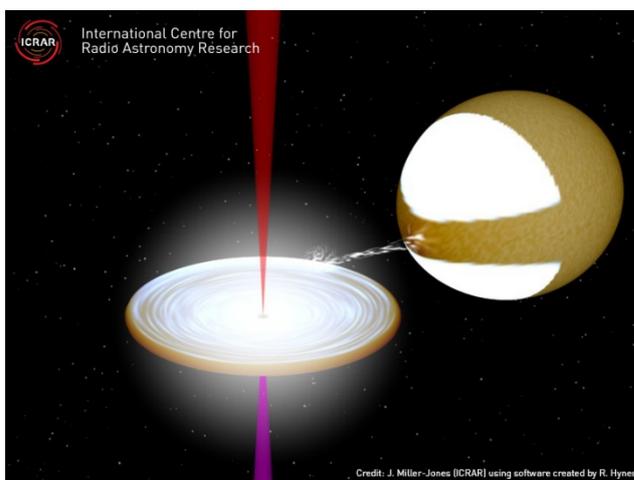
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### Co-Supervisors

Dr Richard Plotkin

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Left: A schematic of a black hole accreting matter from a donor star via an accretion disk. Relativistic jets (shown in red and purple, as observed in right panel) are launched from the inner regions of the accretion flow.

## Tracing the Evolution of Supermassive Black Holes Across Cosmic Time

At the centre of every galaxy is thought to lie a supermassive black hole. While these black holes are billions of times more massive than the sun, they are still less than 1% of the mass of their host galaxy. Yet they are thought to play a key role in galaxy evolution across cosmic time affecting the star formation in their host and environment. Radio surveys are uniquely capable of tracing the evolution of these black holes and in particular the kinetic power they inject via relativistic jets into their immediate environments.

This survey will combine a suite of radio data from state-of-the-art radio observatories with one of the largest multi-wavelength surveys: GALaxy and Mass Assembly (GAMA - [gama-survey.org](http://gama-survey.org)) survey. The combination of the different radio surveys will provide a unique probe of the black hole jet activity. The radio data will include:

- The Murchison Widefield Array (MWA) GLEAM survey (see below) covering 70-230 MHz
- The Australian Square Kilometre Array Pathfinder (ASKAP) EMU survey covering 0.7-1.8GHz
- The Australian Telescope Compact Array GLASS survey covering 5.5-9.5 GHz

This position will involve learning how to reduce and analyse radio data from one or more of these surveys, as well as combining and modelling the radio data. Then when the radio data is combined with GAMA, the host galaxies of the supermassive black holes can be determined as well as the evolution of the whole population be determined.

This project is suited to a student with a strong interest in learning about radio astronomy and combining it with multi-wavelength data. A solid background in physics.

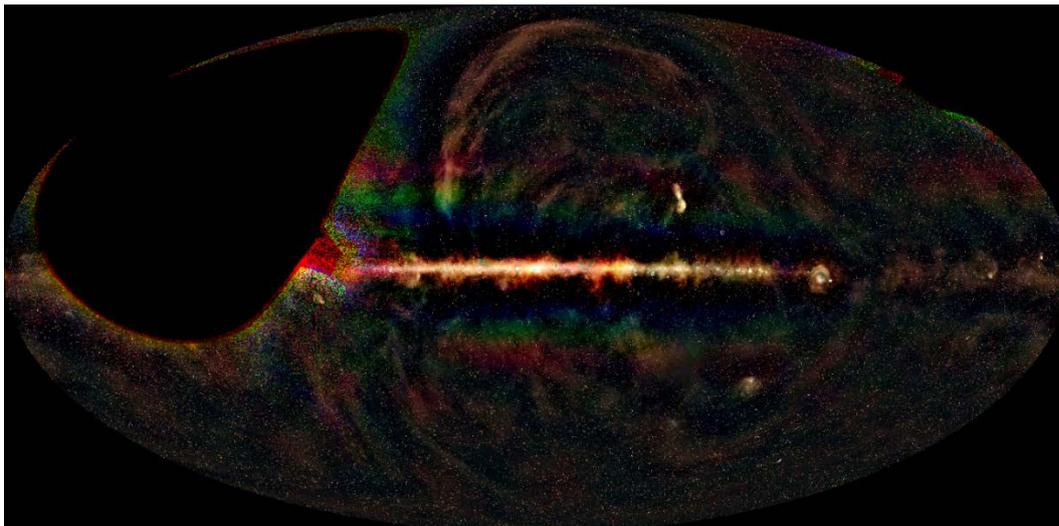


Figure: the MWA GaLactic and Extra-gALactic MWA (GLEAM) survey, a major component of this project to be used to trace the evolution of super-massive black holes across cosmic time.

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**Research Field**

Radio Astronomy

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**Project Suitability**

PhD

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Honours

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**Project Supervisor**

Dr Nick Seymour

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**Co-Supervisors**

Dr Minh Huynh (CASS)

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Dr Guillaume Drouart

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## Weighing Proto-clusters in the Early Universe

Clusters are the most massive bound structures in the Universe and are a unique place to study galaxy formation. Around half of the stellar mass of the Universe is produced in clusters or their proto-cluster ancestors. Tracing proto-clusters in the distant Universe is difficult as traditional techniques become much less effective. However, the most powerful radio sources are unique beacons of the earliest over-densities which form proto-clusters. Using radio surveys, we have discovered many high redshift proto-clusters associated with powerful radio galaxies.

This project aims to ‘weigh’ the proto-clusters and possibly determine the distribution of hot intra-cluster medium via the Sunyaev-Zel’dovich (SZ) effect. The SZ effect causes a distortion in the Cosmic Microwave Background (CMB) due to the hot thermal electrons in the cluster gravitational potential well scattering the CMB photons. The strength of this effect is directly proportional to the mass of hot intra-cluster medium, which dominates the non-dark matter mass of clusters, hence providing a more robust measure of their total mass.

This project will take advantage of deep high frequency radio observations from both the Australian Telescope Compact Array and the Atacama Large Millimetre Array to search for this effect. Detections of the SZ effect in the distant Universe is rare. Much of this data is in hand from projects with other scientific goals, so the goal of this project would be to determine the feasibility of this technique with the data we have on sources like the Spiderweb (below). If successful we would apply for further time to follow-up other prime high redshift proto-clusters.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Honours

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PhD (potentially)

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**Project Supervisor**

Dr Nick Seymour

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**Co-Supervisors**

Dr Guillaume Drouart

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Dr Bjorn Emonts (CAB)

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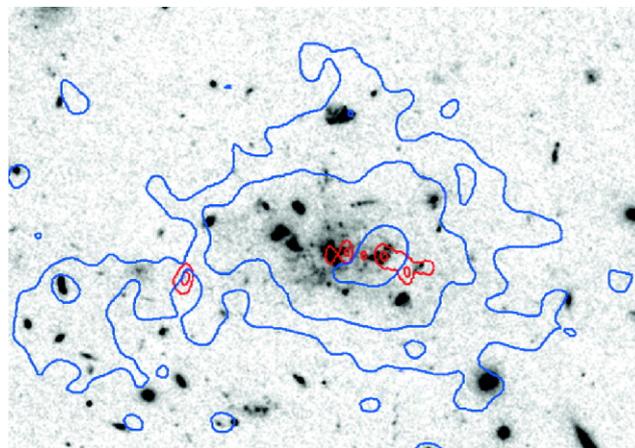


Figure: The Spiderweb galaxy (aka PKS1138-262) so called as this *Hubble Space Telescope* image gives it the appearance of flies being caught in its gravitational web. This proto-cluster is forming at just 3.5 billion years after the Big Bang and was discovered via its powerful radio emission (seen from the red contours). This project aims to use high frequency radio observations to ‘weigh’ proto-clusters like the Spiderweb. Picture credit: George Miley

## X-ray Ionised Nebulae in Metal Poor Dwarf Galaxies

Radiation from the first baryonic structures in the Universe ionised the intergalactic medium, ending the so-called Dark Ages and beginning the Epoch of Reionisation. Some of our best analogues to the first stellar populations in the early Universe come in the form of very local star-forming dwarf galaxies with low metal abundances.

Intriguingly, some nearby metal-poor galaxies are observed to display hard emission in the extreme ultraviolet waveband, which is revealed by the presence of nebulae composed of doubly ionised helium. The hard continuum responsible for doubly ionising helium is traditionally attributed to emission from certain stellar populations, particularly Wolf-Rayet stars, and/or rapidly rotating stars; however, there is some uncertainty on the level to which some of these populations can exist in low-metallicity galaxies, particularly Wolf-Rayet stars.

Alternatively, some of the hard ionising continuum could be provided by accreting black holes or neutron stars, which can emit radiation across nearly the entire electromagnetic spectrum, including in the hard ultraviolet waveband. Intriguingly, in recent years there have been indications that metal-poor dwarf galaxies contain an excess of luminous X-ray point sources that could be explained as rapidly accreting stellar mass black holes or neutron stars; there is also a growing population of accreting supermassive black holes being discovered near the centres of dwarf galaxies.

In this project, the student will use observations from the Chandra and XMM-Newton X-ray satellites to explore if ultraviolet and X-ray photons from accreting compact objects could be responsible for a portion of the hard ultraviolet continuum that is doubly ionising helium in some metal-poor dwarf galaxies. The student's results will have implications on the degree to which X-rays from accreting compact objects might contribute to cosmic reionisation in the early Universe.

The dwarf galaxy Holmberg II (located ~11 million light years from the Earth) contains a bright X-ray source named "X-1", likely a rapidly accreting compact object. The image to the right was taken by the Hubble Space Telescope, and it shows the location of doubly ionised helium in Holmberg II which appears to be photoionised by the bright X-ray source (the blue contours show radio emission, which is coincident with the X-ray source and reveals a potential jet-like structure). In this project, the PhD student will search for similar X-ray ionised nebulae in other nearby, metal-poor dwarf galaxies.

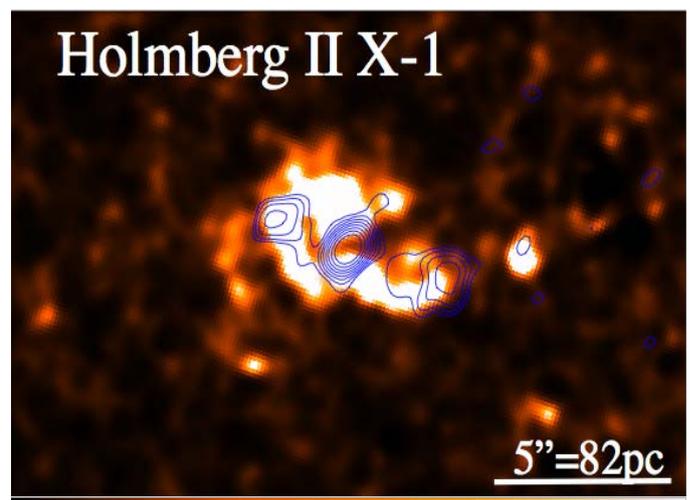


Image credit: Cseh et al. 2014, MNRAS, 439, L1.

### Research Field

Accretion Physics

### Project Suitability

PhD

### Project Supervisor

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### Co-Supervisors

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