

# CURTIN INSTITUTE OF RADIO ASTRONOMY

## POST-GRADUATE RESEARCH PROJECTS

For Applicants Commencing Studies in 2016/17

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## Postgraduate Research Projects for commencement in 2016/17

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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 (CAASTRO).

This booklet showcases our current set of higher degree research projects suitable for commencement during 2016 & 2017. 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 Carole Jackson  
CIRA Co-Director, Science



Professor Peter Hall  
CIRA Co-Director, Engineering

# 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.

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.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

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PhD

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**Project Supervisor**

Dr Natasha Hurley-Walker,  
nhw@icrar.org

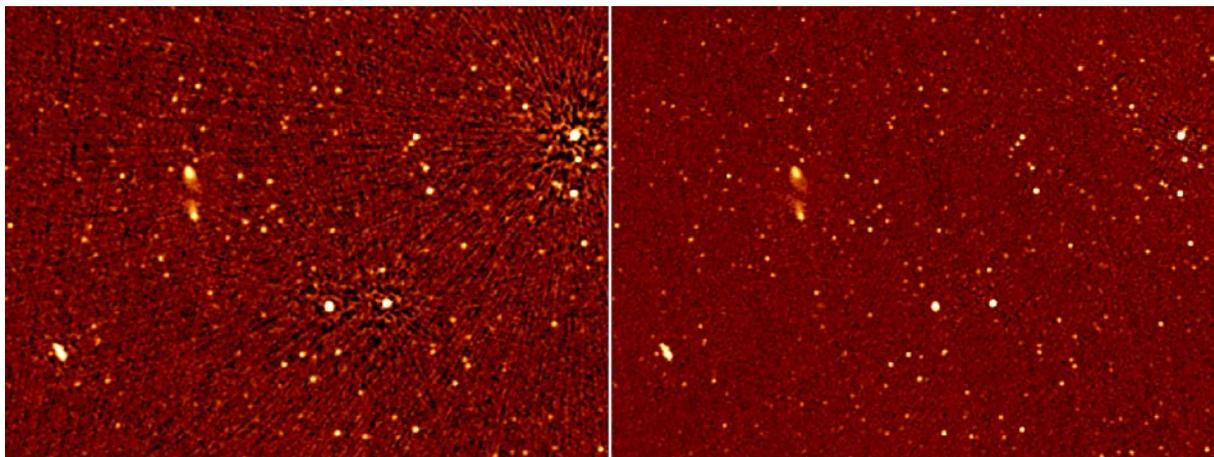
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**Co-Supervisors**

Dr Randall Wayth

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

# Advanced Techniques for RFI Removal in the MWA and SKA\_Low

The MWA is a low frequency radio telescope operating between 80 and 300 MHz in at the Murchison Radio-astronomy Observatory (MRO) in Western Australia and is the only precursor telescope to the SKA\_Low. Although the MRO is extremely radio quiet, in particular in the FM radio and TV bands where the telescope operates, residual low levels of radio-frequency interference (RFI) have the potential to affect very sensitive experiments, like the Epoch of Reionisation (EoR) key science program.

This project aims to characterise the source of residual low-level RFI in MWA data and to design, build and deploy dedicated monitoring equipment that can be used to identify and subtract this RFI from MWA data.

This project would suit a student with an electrical engineering background with good computing skills and an interest in signal processing.

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**Research Field**

Radio Astronomy Interference Mitigation

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**Project Suitability**

Masters

PhD

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**Project Supervisor**

Dr Randall Wayth

[r.wayth@curtin.edu.au](mailto:r.wayth@curtin.edu.au)

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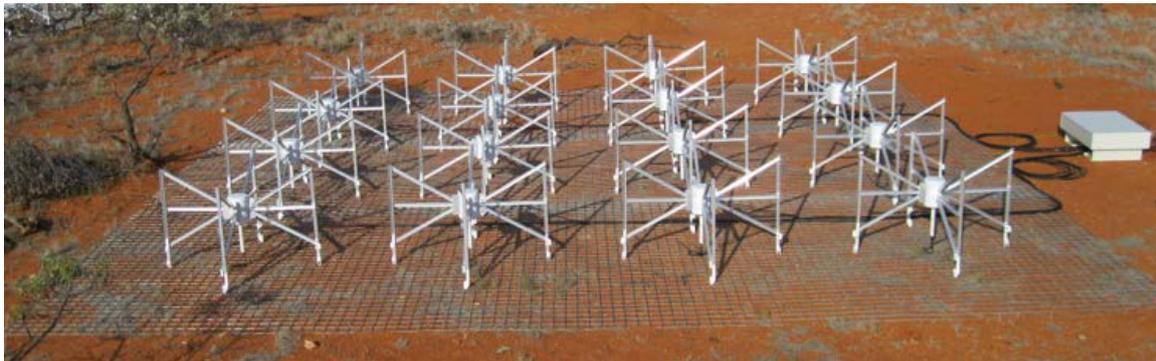


Figure 1: An MWA antenna 'tile'

# Black hole natal kicks: using space velocities to constrain how black holes form

Black holes and neutron stars form from the deaths of the most massive stars. While neutron stars and some black holes are believed to form in supernova explosions, black holes can also form by direct collapse of the most massive stars, with no ejection of matter. While conservation of momentum during a supernova explosion will impart a velocity kick to a newly-formed black hole, those black holes that form via direct collapse should not receive a substantial kick. However, our knowledge of the distribution of black hole kicks is currently very limited.

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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

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james.miller-

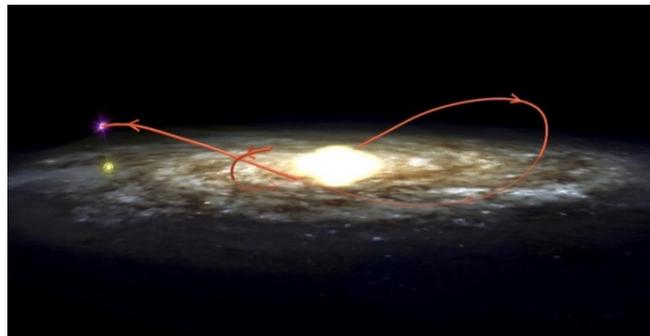
jones@curtin.edu.au

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The Laser Interferometer Gravitational Wave Observatory (LIGO) recently announced the detection of gravitational waves from the merger of two black holes with masses approximately thirty times that of the Sun. The distribution of black hole natal kicks is a key ingredient in determining the expected rates of such merger events, since large kicks will tend to unbind a primordial binary system that could go on to merge, or, in the case of dynamical formation in a globular cluster, would eject a black hole from the weak gravitational potential of the cluster before it has a chance to acquire a companion.

One of the few available probes of black hole kicks is via measurement of the proper motions of known black hole systems in our Galaxy. Black holes or neutron stars accreting matter from a less-evolved donor star emit steady, collimated outflows known as jets. These radio-emitting jets can be detected with Very Long Baseline Interferometry, combining the signals detected by radio telescopes spread over thousands of kilometres to achieve extremely high angular resolution. By using this technique to provide precise measurements of the positions of black hole systems over time, we can determine the proper motion of the system across the sky. Combined with measurements of the line-of-sight space velocity from optical or infrared spectroscopy, as well as the distance to the source, we can determine the full three-dimensional space velocity of a black hole system. This can be traced back through the Galactic gravitational potential to determine possible birthplaces in the Galactic disc, and hence to constrain the natal kick required to launch the black hole into its current orbit.

In this project, you will use VLBI arrays in Australia, Europe and the USA to conduct astrometric studies of X-ray binary systems, aiming to probe the formation mechanisms of black holes, constraining their natal kicks, and comparing the kicks received by black holes with those imparted to neutron stars at birth, to provide a better understanding of the black hole formation process.



Trajectory of the black hole X-ray binary system XTE J1118+480 through the Galaxy. Image credit: I. Rodrigues and I.F. Mirabel, NRAO/AUI/NSF.

# Characterisation of RF-Over-Fibre Solution for Low-Frequency Aperture Arrays

The Square Kilometre Array (SKA) is an international project to build radio telescope with a combination of unprecedented sensitivity, resolution, and field of view (FoV) covering the frequency range from 50 MHz up to 10 GHz. SKA telescope is divided into several frequency bands, the lowest is known as SKA\_LOW (50-350 MHz) and will be built in Australia. SKA\_LOW is expected to consist of hundreds of stations with hundreds of antenna elements in each. Most of the stations will be located at the core of SKA\_LOW at the Murchison Radio-astronomy Observatory (MRO), within an area of 50 km radius.

As a precursor to SKA\_LOW, a low frequency aperture array (LFAA) verification system 1 (AAVS1), envisaged as a small subset of the SKA\_LOW, will be constructed at the MRO. The purpose of AAVS1 is to verify various critical design parameters of SKA\_LOW using an on-site engineering prototype. Initial efforts in this area have resulted in the construction and characterisation of an experimental array of 16 antennas co-located with the Murchison Widefield Array (MWA).

RF-over-fibre (RFoF) technology is a leading candidate solution for transporting radio frequency (RF) signal from the LFAA front-end, where analogue radio signal is transmitted from the antennas to the central processing facility via fibre optic (FO) cables, as opposed to coaxial cables. The SKA\_LOW aims to perform highly sensitive observations. Consequently, impairments accrued in the signal transport chain components such as the RFoF need to be well understood and characterized.

As an example, stability of RFoF modules and the fibre optic cables over time and temperature is a critical in obtaining correct radio astronomy data. Characterisation of parameters such as gain and phase variations due to the thermal exposure of the RFoF modules and FO cable has been performed in the lab and at the MRO. In addition, we expect to further understand of the impact of these parameters to radio telescope calibration and observation. The scope of this project is to further analyse existing field results, develop understanding of RFoF parameters which are relevant to radio astronomy, and devise measurement strategies for characterisation of those parameters.

This project will be associated closely with the work in the low frequency aperture array work for SKA project within the Aperture Array Design Consortium (AADC), in which ICRAR/Curtin is a major player. The student is expected have some exposure to and/or is willing to acquire backgrounds in RF system analysis, radio astronomy techniques, optical communication, and laboratory measurements. Some field trips to the MRO are to be expected. This project is suitable for an engineering or applied physics student with a career outlook in radio astronomy, telecommunications and/or applied physics.



Figure 1: Laboratory measurements of RFoF links.

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**Research Field**

Electrical Engineering  
Radio Astronomy

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**Project Suitability**

Masters  
PhD

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**Project Supervisor**

Dr Adrian Sutinjo  
adrian.sutinjo@curtin.edu.au

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**Co-Supervisors**

Dr Budi Juswardy

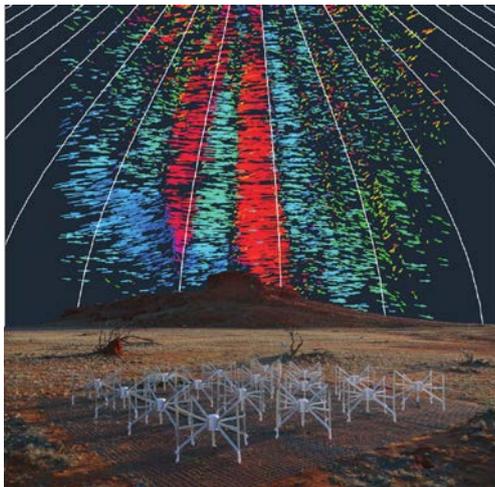
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# Characterising the ionosphere over the Murchison Radio astronomy Observatory

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 (submitted)).

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 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.

The MWA will double 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.

**Research Field**  
Radio Astronomy

**Project Suitability**  
Masters  
PhD

**Project Supervisor**  
Dr John Morgan  
John.morgan@curtin.edu.au

**Co-Supervisors**  
Dr Nick Seymour  
Dr Natasha Hurley-Walker

# Constraining Jet Activity in Radio Galaxies Using New MWA Data

Present astrophysical theories hold that all sufficiently large galaxies host supermassive black holes at their centres. For reasons not entirely understood, these supermassive black holes sometimes spew out jets of energetic particles. In the most powerful radio galaxies, the period of jet activity is rather short (less than  $\sim 10^8$  years) compared with the lifetime of the parent galaxy ( $\sim 10^{10}$  years). The jets produce enormous lobes of radio emission which expand over time. These lobes are one of the two major components of a typical radio galaxy, the other being its active galactic nucleus (AGN). The figure on the bottom left shows a radio image of the radio galaxy 3C348 superimposed on an optical image.

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**Research Field**

Radio Astronomy

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**Project Suitability**

PhD

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**Project Supervisor**

Dr Tom Franzen

[thomas.franzen@curtin.edu.au](mailto:thomas.franzen@curtin.edu.au)

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**Co-Supervisors**

Prof Carole Jackson

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There is a growing body of evidence that AGN activity can involve multiple episodes. The most striking examples of recurrent AGN activity in radio galaxies are the double-double or triple-double radio sources which contain two or three pairs of distinct lobes on opposite sides of the host galaxy. The figure on the bottom right shows an example of a double-double radio galaxy imaged by the Giant Metrewave Radio Telescope (GMRT) in India. Although the typical duty cycle of AGN activity (the relative lengths of the radio- active and radio quiescent phases) is relatively well constrained in distant, powerful radio galaxies, this is not the case in more nearby, low-luminosity radio galaxies. A key question is therefore how the typical duty cycle varies with radio luminosity and cosmic epoch.

This project will use radio data spanning several orders of magnitude in frequency, including the new 70-230 MHz GLEAM survey, to identify sources which are 'restarted' radio galaxies, showing signs of AGN activity at high frequency together with lobe activity at low frequency, and will combine this with optical data to determine their prevalence as a function of radio luminosity and redshift. This will provide important new information about the lifetimes and duty cycles of radio galaxies. The PhD student will have the opportunity to conduct follow-up observations using radio and optical telescopes in Australia.

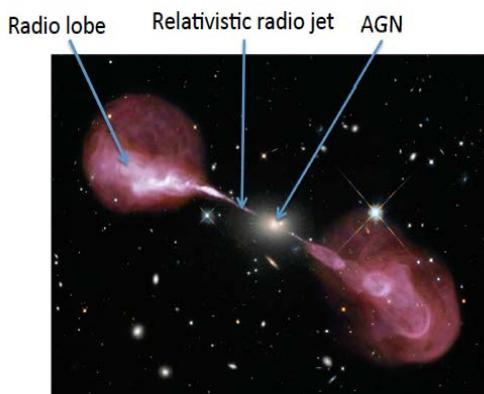


Figure 1: False colour image of radio galaxy 3C348: Optical in white/yellow, radio in red.

Credit: NASA, ESA, S. Baum, C. O'Dea, R. Perley, W. Cotton and the Hubble Heritage Team.

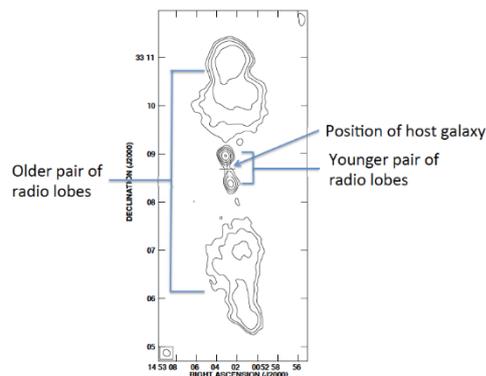


Figure 2: Image of the double-double radio galaxy J1453+3308 at 334 MHz reproduced from Konar et al. (2006). Two pairs of lobes appear on either side of the host galaxy; the age of the outer lobes is  $\sim 50$  Myr and that of the inner lobes is  $\sim 2$  Myr. The physical size of the radio galaxy is  $\sim 1.3$  Mpc.

# Constraining the Foreground signal to the Epoch of Reionisation due to Discrete Extragalactic Sources

The primary science goal of the MWA is to perform statistical detection (power spectrum) of the Epoch of Reionisation (EoR) using the redshifted 21cm line of neutral hydrogen to probe changing conditions within the intergalactic medium. A major challenge for EoR detection is the presence of bright extragalactic radio galaxies contaminating the Early Universe signal. This project will build a statistical model for the impact of unresolved populations of AGN and star forming galaxies, on EoR science. In particular, it will use existing understanding of these source populations, their clustering on the sky, and spectral properties, to correctly incorporate them into the data analysis. This work will build on current, simplistic models of foreground contaminants.

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**Research Field**  
 Epoch of Reionisation; Radio Sky Populations

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**Project Suitability**  
 Masters  
 PhD

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**Project Supervisor**  
 Dr Cathryn Trott  
[cathryn.trott@curtin.edu.au](mailto:cathryn.trott@curtin.edu.au)

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**Co-Supervisors**  
 Prof Carole Jackson

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Students with good mathematical and statistical skills, and an interest in extragalactic populations of galaxies, would be well-suited to this project.

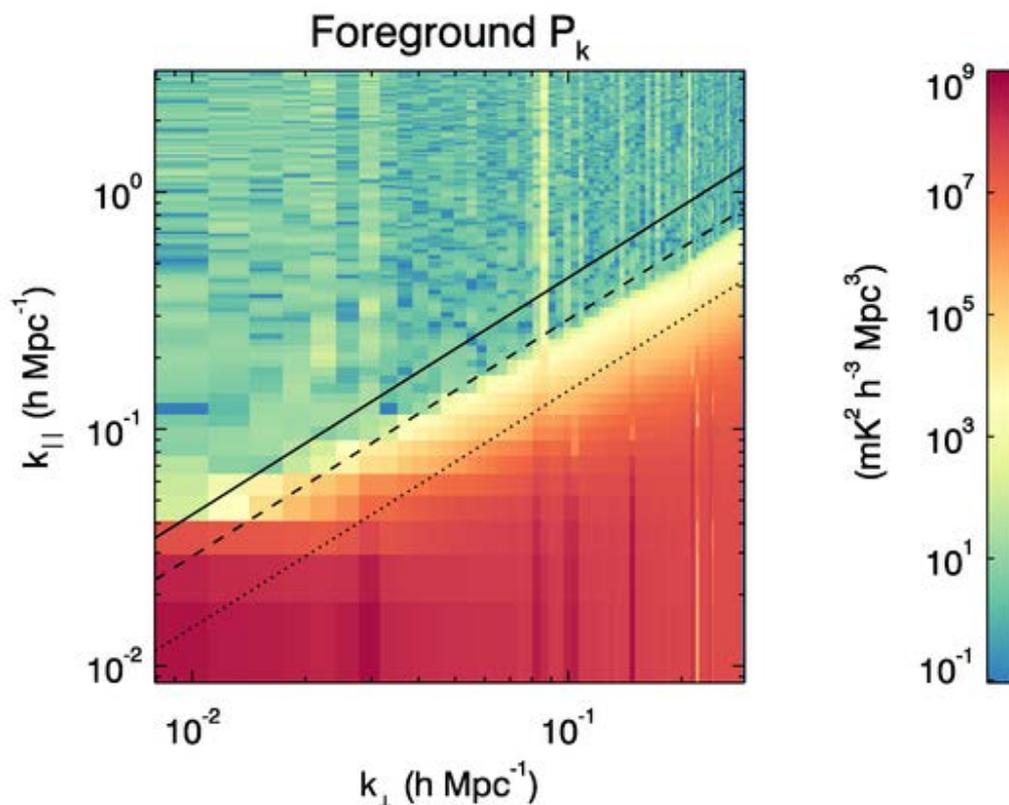


Figure 1: Simple model for structure of extragalactic radio galaxies in the Epoch of Reionisation power spectrum.

# Detecting nanohertz-frequency gravitational waves with current and future radio telescopes.

Gravitational-wave astronomy is revolutionizing the way we look at the Universe. Because they can be produced in places either invisible or hidden from conventional (electromagnetic) observations, gravitational waves are invaluable probes of the astrophysics of the most extreme environments. One potential way to search for gravitational waves is through observations of ultra-stable millisecond pulsars, rapidly rotating neutron stars that beam radio emission out of their magnetic poles. The most likely source of these long-wavelength gravitational waves is from binary supermassive black hole binaries: orbiting pairs of the **most massive black holes** in the Universe, embedded in the centre of the largest galaxies, that have so far **eluded both electromagnetic and gravitational-wave detection**.

**Research Field**  
Radio Astronomy

**Project Suitability**  
Masters  
PhD

**Project Supervisor**  
Dr Ryan Shannon  
Ryan.Shannon@curtin.edu.au

**Co-Supervisors**  
Dr George Hobbs (CSIRO)

As part of this project, you will join the Parkes Pulsar Timing Array (PPTA) collaboration (<http://www.atnf.csiro.au/research/pulsar/ppta/>), which leads the world in nanohertz-frequency gravitational wave science. Your contributions will lead to improved methods for observing pulsars and searching for gravitational waves and accelerating nanohertz-frequency gravitational wave detection. Your contributions to the PPTA project could include:

- Commissioning new instruments and developing wide band pulsar-timing methods for use at the Parkes Radio Telescope and the Murchison Widefield Array.
- Producing the most sensitive data sets for nanohertz-frequency gravitational waves.
- Searching for gravitational waves in PPTA and International data sets.
- Developing strategies for incorporating new telescopes (such as FAST and MeerKAT) into pulsar timing arrays.

Specific contributions will depend on your interests. Through this project you will gain experience with computation and signal processing while doing cutting-edge astrophysics. You will gain experience working in a large group and collaborate with a global network of astronomers working with the world's largest radio telescopes.

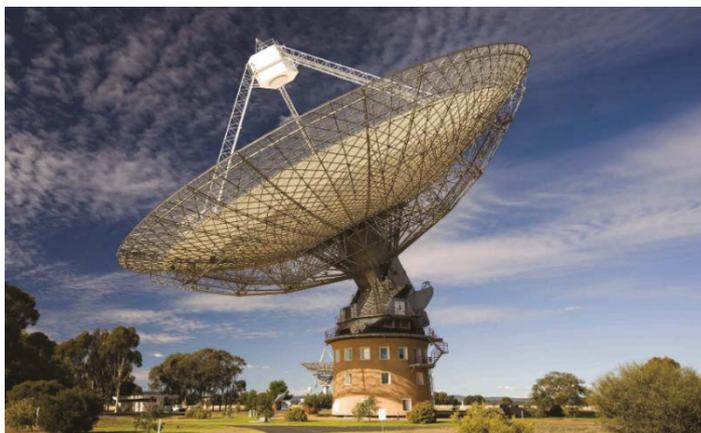


Image Credit: CSIRO

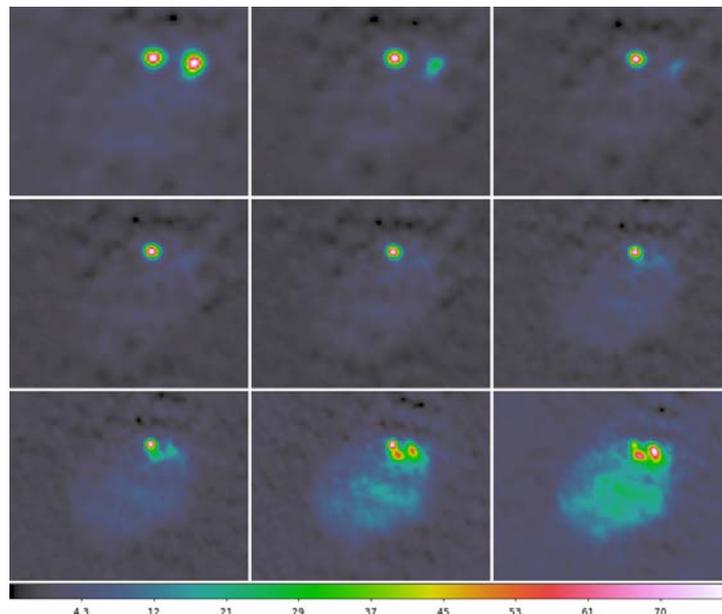
# Examining the Sun with the Murchison Widefield Array

The Sun displays a wide range of activity in the metric ( $\lambda \approx 1\text{m}$ ) range. Radio bursts were first classified in the 1950s (here in Australia) and even at that time their links to space weather in the vicinity of Earth were identified. Until the mid-1980s Australia led the world in solar imaging with the Solar Radio Heliograph at Culgoora (now the home of the Australia Telescope Compact Array). From that time until recently, no major instruments capable of imaging the Sun at metric wavelengths were commissioned. However study of the Sun at other wavelengths, as well as theoretical advances continues apace, while our reliance on technology which is vulnerable to extreme space weather has only increased.

<b>Research Field</b>
Solar Radio Astronomy
<b>Project Suitability</b>
Masters
PhD (including 2-year CSC)
<b>Project Supervisor</b>
Dr John Morgan
John.morgan@curtin.edu.au

With renewed interest in the Radio Astronomy at low-frequencies, a whole slew of new instruments capable of imaging the Sun have been built. The MWA has a number of features that make it a good choice for solar imaging. First, it has unrivalled instantaneous imaging fidelity due to its large number of interferometer elements (128). Secondly it is adaptable, with a flexible frequency setup, and a new capability to image at almost arbitrary time resolution.

A MWA archive contains ~1 petabyte(!) of solar data which would be an absolute treasure trove for a PhD student. A number of projects could be considered, depending on the interests and abilities of the student. Possibilities include imaging of emission from Coronal Mass Ejections, polarimetric or high time resolution studies, and use of novel algorithms to seek out interesting phenomena in the vast MWA solar data archive.



**Figure 2: The Sun imaged with the MWA at frequencies ranging from 100-200MHz. The solar disk is visible at higher frequencies, and a number of discrete sources with evolving time and frequency structure are visible.**

# Excising the Foreground from MWA Epoch of Reionisation Observations

The MWA is a low frequency radio telescope operating between 80 and 300 MHz in Western Australia. One of the key science goals for the MWA is to measure the faint diffuse signal from neutral hydrogen in the early universe – the Epoch of Reionisation (EoR). Measuring the properties of the EoR is currently the greatest goal in observational cosmology. The expected radio signals from the hydrogen, however, are much fainter than those from our Galaxy, hence making a robust measurement challenging. The diffuse polarised radio emission from our Galaxy is generated by the interstellar plasma and magnetic fields.

**Research Field**  
 Epoch of Reionisation

**Project Suitability**  
 PhD

**Project Supervisor**  
 Dr Randall Wayth  
 r.wayth@curtin.edu.au

**Co-Supervisors**  
 Dr Cathryn Trott

The expected signal from the EoR evolves with cosmic time as shown in the Figure below. The fluctuations have many angular size scales, which are comparable to the size scales of the diffuse polarised emission. This project aims to understand, quantify and remove the effects of diffuse polarised radio emission on the EoR power spectrum measurement of the MWA. The project will involve understanding how the telescope’s response to polarised radio emission couples to the measurement of the EoR and how imperfect subtraction and/or calibration of the polarisation signal will affect the EoR measurements. This project will be essential to the ultimate EoR power spectrum measurement made by the MWA.

This project suits a student with a strong physics and mathematics background, good computing skills and an interest in physics of the early Universe. As an SKA\_Low precursor, the results of this MWA project are directly applicable to the future EoR key science program of the SKA.

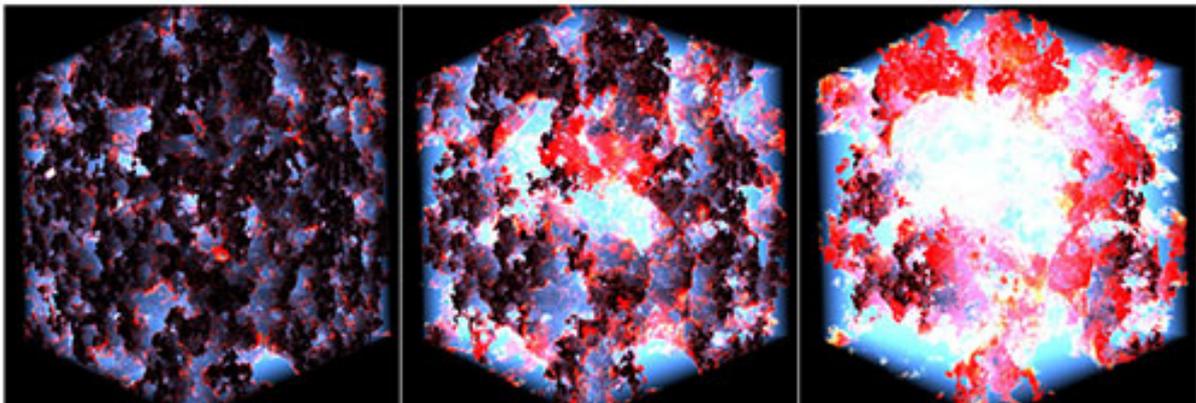


Figure 3: A simulation of the opacity of the universe changing with time (time increasing to the right) during the EoR.

# Exploring the Use of Redundant Baselines for Calibrating Radio Interferometers

Redundant baselines in radio interferometry are those that instantaneously sample the same Fourier mode. For Epoch of Reionisation science, they allow for the most rapid reduction in thermal noise with time, by allowing for coherent combination of the measured visibilities. They also have the advantage of allowing sky- and beam-independent gain calibration of the telescope, and the PAPER array uses redundancy to identify systematic errors in their data. Beyond these applications, redundancy has the ability to provide information about the telescope, by studying the systematic biases measured from nominally-redundant baselines. These tools may become useful for next-generation radio telescopes, such as the extended MWA and SKA-Low, where complicated primary beams make precision science a challenge.

<b>Research Field</b>
Instrument Calibration
<b>Project Suitability</b>
Honours
Masters
PhD
<b>Project Supervisor</b>
Dr Cathryn Trott
cathryn.trott@curtin.edu.au

This project will take existing work with redundant baselines as a basis to develop novel tools for understanding the instrument through measurements of redundant visibilities. It will be highly mathematical, and will develop mathematical models for the expected biases from different instrumental effects. The work can then be applied to future instruments to assess their impact.

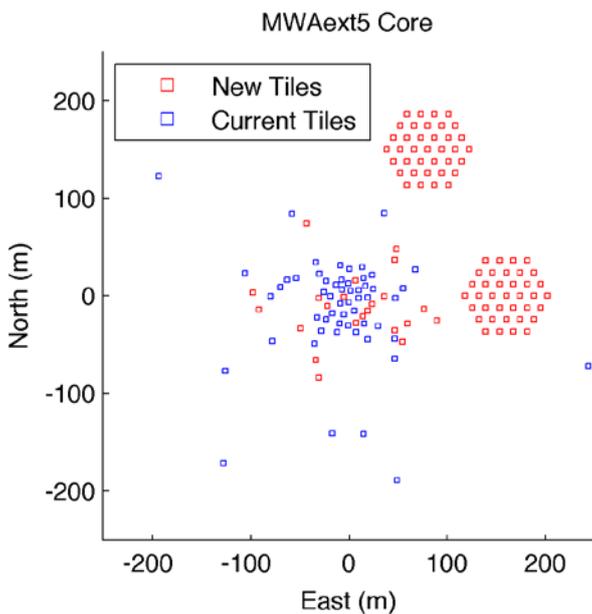


Figure 1: The proposed layout for an extended MWA including two patches of tiles set out in hexagons.

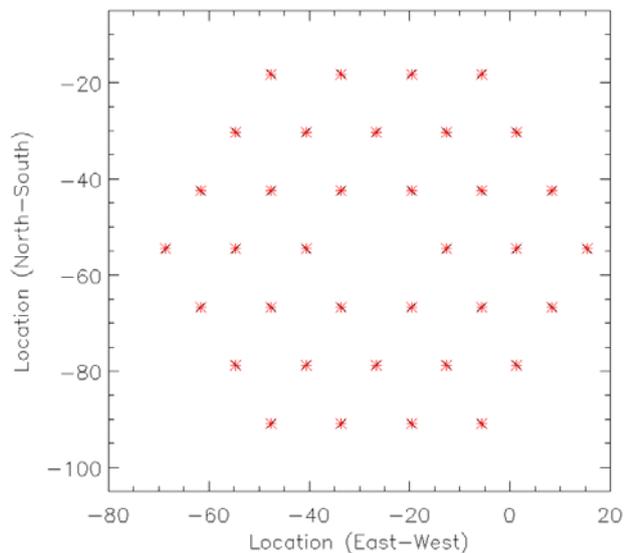


Figure 2: The detail of the tile configuration in one hexagon showing the regular spacing.

# Finding the Most Massive Clusters with the Murchison Widefield Array

Clusters of galaxies are the most massive bound structures in the Universe lying at the crossroads of the large scale structure. In the nearby Universe they dominated by giant elliptical galaxies with very low star formation rates, but in past they must have been forming stars at a prodigious rate. However, finding young proto-clusters in the distant Universe is difficult as typical search methods (e.g. X-ray emission from hot gas, Sunyaev–Zel'dovich, SZ, effect) become much less sensitive. High redshift radio galaxies are known to lie in over-dense, proto-cluster environments and be beacons to pockets of extreme star formation. This is because the radio galaxy is powered by a massive and rapidly growing black hole and scaling relations suggest that this will be in the most massive host galaxy and dark matter halo. This project will take advantage of a new all sky low frequency radio survey with the Murchison Widefield Array (MWA) and combine it with NASA's mid-infrared *WISE* mission to find and characterise new distance proto-clusters in particular looking for the most massive ones.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

PhD

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**Project Supervisor**

Dr Nick Seymour

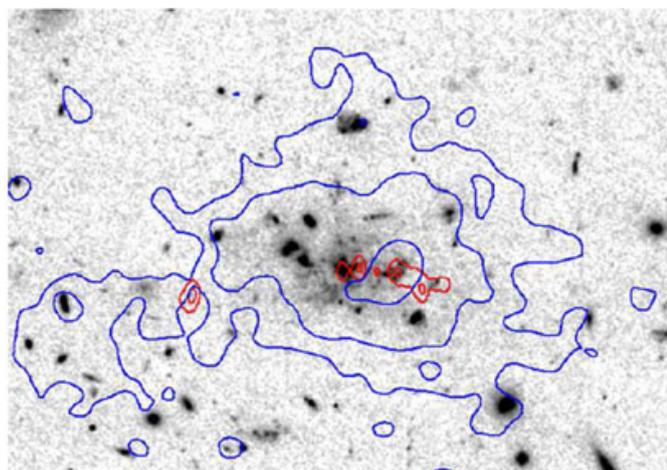
nick.seymour@curtin.edu.au

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This project will comprise three parts:

- (i) Calibrating how well the *WISE* survey traces known clusters found in X-ray, millimetre (via the SZ effect) and radio surveys as a function of mass and redshift. Then the *WISE* data can be used to investigate the build-up of the red sequence statistically. For the radio-loud sample the potential dependence on radio jet orientation and size of the over-density of proto-cluster members can be investigated
- (ii) Using this technique to search for new high redshift clusters around MWA sources. Once the best candidates are chosen, they can be followed-up with deep optical and near-infrared imaging and spectroscopy in order to confirm their redshift and nature.
- (iii) Using the Australian Telescope Compact Array to observe high redshift (above redshift=1) proto-clusters at high frequencies to measure their mass distribution via the SZ effect. This technique has only been applied to lower redshift clusters to date, but can provide unique insights in the dark matter content of clusters.

The [Spiderweb Galaxy](#). Deep Hubble image of the core of the [MRC 1138-262](#) protocluster at  $z = 2.2$  obtained with the Advanced Camera for Surveys. ([Miley et al., 2006](#)). Superimposed on the *HST* image are contours of  $\text{Ly}\alpha$  (blue) obtained with ESO's very Large Telescope (VLT), delineating the gaseous nebula and radio 8GHz contours (red) obtained with NRAO's VLA, delineating the non-thermal radio emission.

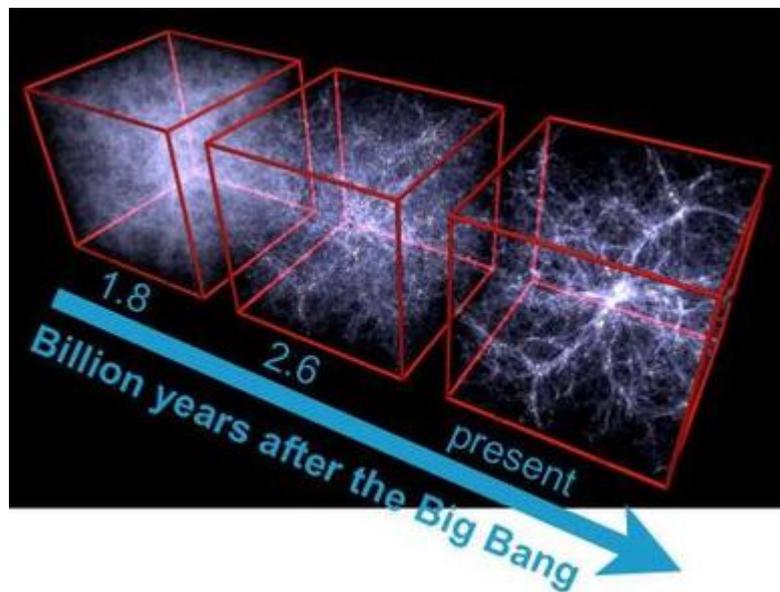


## HI absorption in high-z radio galaxies

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 “The First Black Holes with MWA”.



The Universe ionises, transforming from a sea of opaque hydrogen into the complex structures we see today.

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**Research Field**  
Spectral Radio Astronomy

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**Project Suitability**  
Masters  
PhD

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**Project Supervisor**  
Dr Natasha Hurley-Walker  
nhw@icrar.org

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**Co-Supervisors**  
Dr Nick Seymour

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# High-Resolution Astrometric Observations of X-Ray Binaries

By combining the signals from antennas spread across the globe, Very Long Baseline Interferometry (VLBI) provides the highest resolution images available to astronomers, resolving structures on angular scales of less than on milliarcsecond - as small as a person on the Moon. This high angular resolution also enables the measurement of extremely precise positions for astronomical sources. By tracking the position of an astronomical radio source over time, we can measure not only how fast it is moving across the sky (its proper motion), but also the apparent annual wobble imposed by the Earth's motion around the Sun (its parallax).

**Research Field**  
 Accretion Physics

**Project Suitability**  
 PhD

**Project Supervisor**  
 Dr James Miller-Jones  
 james.miller-jones@curtin.edu.au

Matter falling onto a dense compact object, such as a neutron star or a black hole can (under certain conditions) be diverted outwards into fast-moving, collimated, oppositely-directed jets of matter. These jets produce radio emission, which can be detected by VLBI arrays. Unless the rate of mass infall is very high, these jets appear as unresolved, point-like sources, and can be used as ideal astrometric probes, enabling the measurement of the proper motion and parallax of stellar-mass black holes and neutron star systems (X-ray binaries) within our own Milky Way Galaxy.

Black holes and neutron stars form from the deaths of the most massive stars. While neutron stars and some black holes are believed to form in supernova explosions, black holes can also form by direct collapse of a large gas cloud. By measuring the proper motion of a system, we can place constraints on the velocity kick imparted to the black hole when it was formed, and hence on the formation mechanism. By measuring the parallax of a source, we can obtain an accurate, model-independent distance, enabling us to convert observable quantities such as measured flux into physical quantities such as luminosity. Finally, for binary systems in wide orbits, we can trace the orbital motion of the radio-emitting source, enabling us to measure the masses of the sources and the inclination angle of the binary.

In this project, you will use VLBI arrays in Australia, Europe and the USA to conduct astrometric studies of X-ray binary systems, aiming to probe the black hole formation mechanism, probe the relativistic jets from compact objects, determine accurate source distances, and investigate orbital motion where possible.

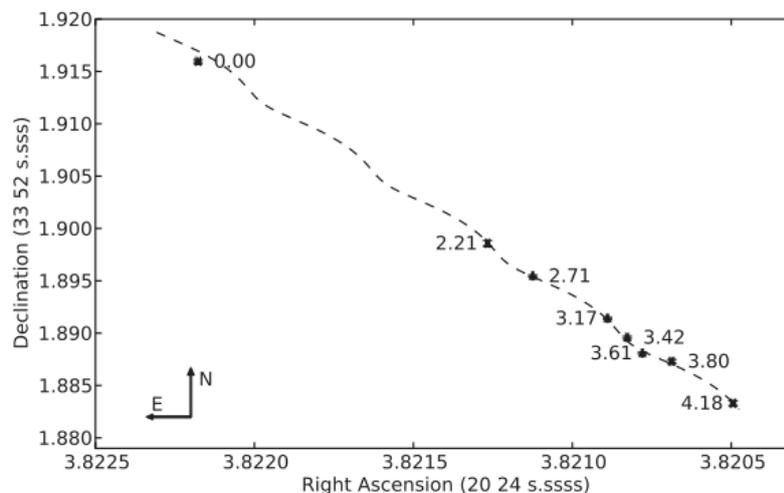


Figure 1: Motion of the black hole X-ray binary V404 Cygni over time (times indicated in years since the first observation). Note the parallax wobble superimposed on the linear motion (from Miller-Jones 2014).

# 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**

Masters

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**Project Supervisor**

Dr Natasha Hurley-Walker

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nhw@icrar.org

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**Co-Supervisors**

Dr Nick Seymour

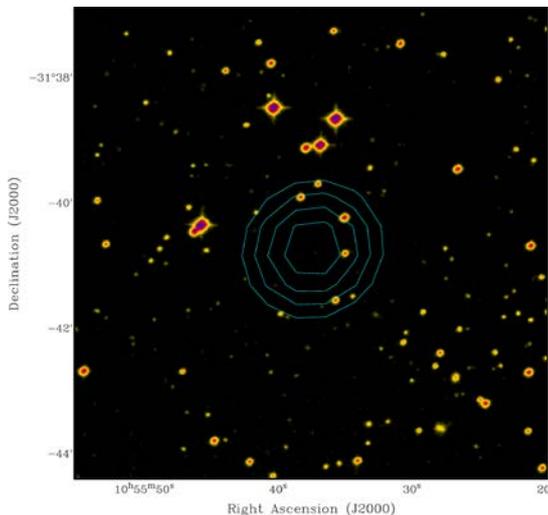
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TAIPAN is a multi-object spectroscopic galaxy survey starting in late 2016 that will cover the whole southern sky and will obtain spectra for over 1 million galaxies in the local Universe ( $z < 0.3$ ) over 4 years. This will be the most comprehensive 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.



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?

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

## Imaging the radio sky with the 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 over half a petabyte of data. A large part of the first year of this data has been published as an extragalactic source catalogue. However the second year of this dataset remains to be fully processed. This project will process the remaining GLEAM data and incorporate it into existing processed data along with making necessary improvements and innovations in the processing pipeline.

The resulting multi-year dataset will be the most sensitive survey output from the MWA yet. 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 radio source 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.

### Research Field

Radio Astronomy

### Project Suitability

PhD

### Project Supervisor

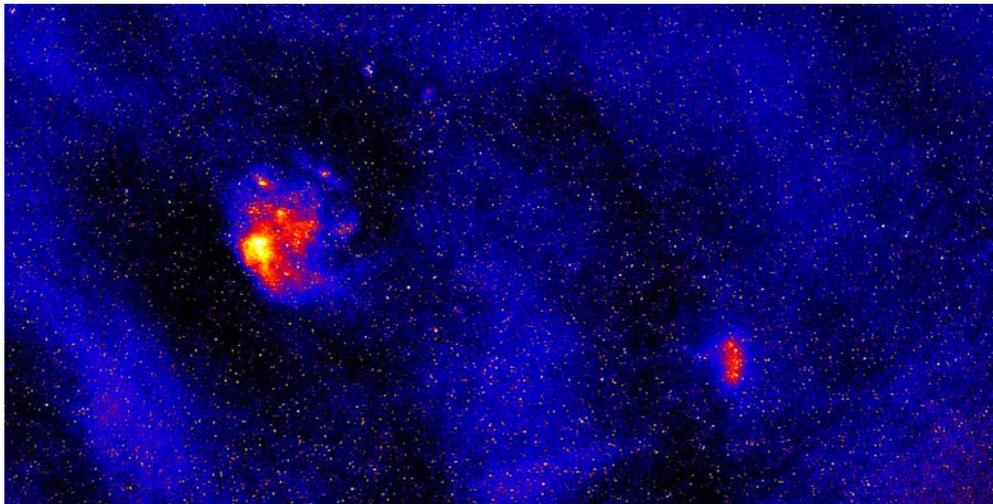
Dr Natasha Hurley-Walker

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

### Co-Supervisors

Dr Randall Wayth

Dr Thomas Franzen



An MWA radio image of the Large and Small Magellanic Clouds, the closest galaxies to the Milky Way.

# Inferring Compact Source Morphology Via Measurements of Interplanetary Scintillation

The Murchison Widefield Array (MWA) is a low-frequency radio interferometer unparalleled in its wide field of view and its imaging fidelity. Although a remarkably flexible instrument, its resolution does not exceed 1 arcminute. Determining source size and morphology on much smaller scales (~1 arcsecond or less) can be a very useful addition to the excellent spectral and arcminute-scale information that the MWA provides us with.

One way to learn about source morphology on arcsecond scales is via Interplanetary Scintillation (IPS). Sources which have compact components will change rapidly in brightness (on timescales of 0.1s-10s) due to turbulence in the interplanetary medium.

In many ways the MWA is extremely well-suited to this work. Its wide field of view means that IPS can be measured for a very large number of sources in a single observation. Its excellent imaging fidelity means that the scintillation signatures of difference sources can reliably be separated from one another. However a great deal of work remains to be done to realise the full potential of the instrument. The project would require a student with an interest in the technical details of interferometry. Experience in radio astronomy or big data computation would be beneficial. It could be tailored to suit interests in heliospheric physics and/or understanding compact radio sources. A wide-field image spanning 75x30 degrees. The Sun is on the left. To the right, many point-like sources can be picked out. Many of these will vary in brightness on timescales of 0.1-10s due to Interplanetary Scintillation.

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### Research Field

Low-frequency  
Radio Astronomy

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### Project Suitability

Honours  
Masters

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### Project Supervisor

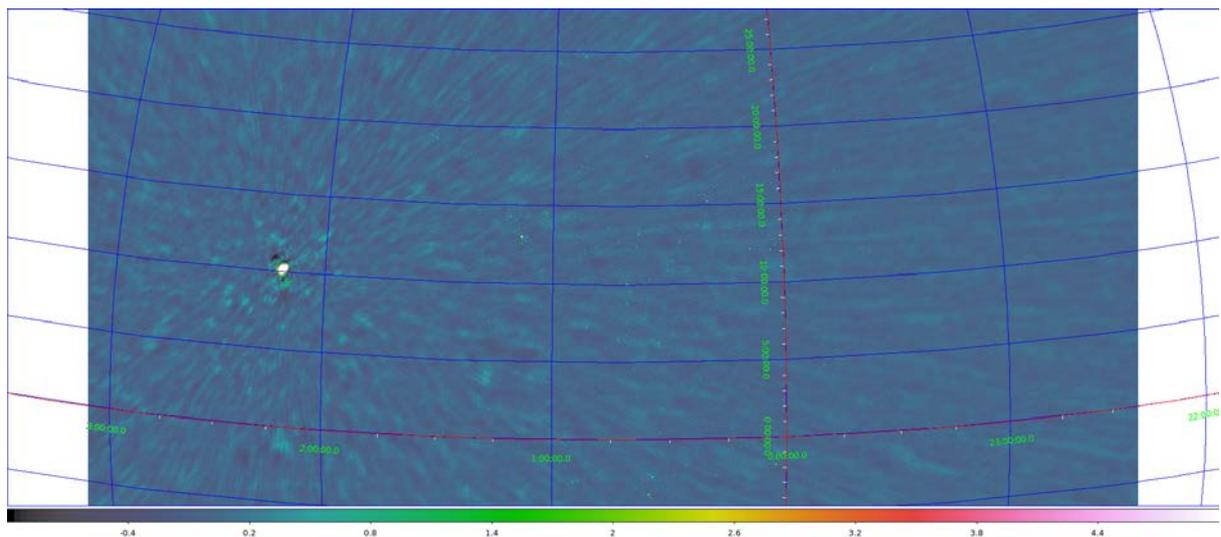
Dr John Morgan  
[John.morgan@icrar.org](mailto:John.morgan@icrar.org)

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### Co-Supervisors

Dr Jean-Pierre Macquart

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# Instrumental Calibration of Low-Frequency Aperture Array in the Southern Hemisphere

The Square Kilometre Array (SKA) is an international project to build radio telescope with a combination of unprecedented sensitivity, resolution, and field of view (FoV) covering the frequency range from 50 MHz up to 10 GHz. SKA telescope is divided into several frequency bands, the lowest is known as SKA\_LOW (50-350 MHz) and will be built in Australia. SKA\_LOW is expected to consist of hundreds of stations with hundreds of antenna elements in each. Most of the stations will be located at the core of SKA\_LOW at the Murchison Radio-astronomy Observatory (MRO), within an area of 50 km radius.

As a precursor to SKA\_LOW, a low frequency aperture array verification system 1 (AAVS1), envisaged as a small subset of the SKA\_LOW, will be constructed at the MRO. The purpose of AAVS1 is to verify various critical design parameters of SKA\_LOW using an on-site engineering prototype. Initial efforts in this area have resulted in the construction and characterization of an experimental array of 16 antennas co-located with the Murchison Widefield Array (MWA).

The radio signal received by AAVS1 and SKA\_LOW antennas is expected to be transported via Radio-on-Fiber (RFoF) links which allow low-loss long-distance transmission to a digital beamformer. Proper beamforming requires that correct weights be applied to each input. This requires the removal of the effects of the insertion of various RFoF link lengths between the beamformer and the antennas. We refer to this process as instrumental calibration.

Instrumental calibration in the Northern Hemisphere is aided by the presence of two bright and compact radio astronomical sources, CasA and CygA. However, those sources are not easily accessible in the Southern sky. The Southern sky has to contend with many less bright sources and the dominant Galactic noise. The aim of this project is to chart an instrumental calibration strategy for low frequency aperture array for the Southern sky. The AAVS1 in conjunction with the MWA will be used as an experimental test bed for this purpose. Successful outcome of this project is expected to be a major contribution to the SKA\_LOW.

This project will be associated closely with the work in the low frequency aperture array work for SKA project within the Aperture Array Design Consortium (AADC), in which ICRAR/Curtin is a major player. The student is expected have some exposure to and/or is willing to acquire backgrounds in phased array antennas, radio astronomy techniques, electromagnetic (EM) modelling and measurements and signal processing. Some field trips to the MRO are to be expected. This project is suitable for an engineering or applied physics student with a career outlook in radio astronomy, telecommunications and/or applied physics.

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**Research Field**

Electrical Engineering  
Radio Astronomy

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**Project Suitability**

Masters  
PhD

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**Project Supervisor**

Dr Adrian Sutinjo  
adrian.sutinjo@curtin.edu.au

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**Co-Supervisors**

Dr Randall Wayth

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Figure 1: Fully deployed AAVS1 at the MRO

# Interstellar Scintillation as a Probe of Invisible Gas in the Milky Way

The interstellar medium (ISM) is a diffuse gas that permeates our entire galaxy. The ISM is extremely important in astrophysics because it acts as an intermediary between events that happen on stellar scales and those that we see on galactic scales. Stars are born from and will return to the ISM over their million- to billion-year life cycles. One of the main components of the ISM is the warm ionized medium (WIM) - an ionized gas at a temperature of 8,000K, which makes up as much as 50% of the ISM. All of the light that travels to us from outside our Galaxy must travel through the WIM, which will cause changes in the light that we see. The WIM can change the polarization state of light through Faraday rotation, and will bend light rays to cause focusing and defocusing events like scintillation. This (Interstellar) scintillation (ISS) is similar to what you see at night when you see a bright star twinkling, however at radio frequencies the twinkling is less intense and a lot slower. By identifying extragalactic radio sources that are exhibiting scintillation, we can determine how the WIM is changing along that particular line of sight. These changes are due to turbulent motions in the WIM, and have been measured before. So far we are only able to determine the average global properties of the WIM because our lines of sight are spaced far apart.

Curtin University operates the Murchison Widefield Array (MWA) which is a low frequency radio array, and a precursor to the SKA. The MWA telescope has a very large field of view (>600deg<sup>2</sup>) and is able to create sensitive images in just a few minutes. This speed and field of view mean that it will be easy to image many thousands of extragalactic radio sources in a few minutes, and to do so on a weekly basis. With such a large population of sources to draw from, we will be able to identify ISS in thousands of radio sources. We will then use these sources to understand not just the global properties of the WIM, but how these properties change throughout the Galaxy. This will be the first time that such a map will be made and it will greatly increase our ability to understand the ISM and the vital role it plays in the evolution of both stars and our Galaxy.

This project will study the WIM by looking for scintillation in extragalactic radio sources that are observed with the MWA. We currently have an observing program in place that will observe a large section of the sky on a weekly basis, as well as a data reduction pipeline that will automate most of the processing stages. You will work with an international team of astronomers help identify scintillating sources within the large data sets that will be produced. You will learn many of the skills vital to modern astronomy including: processing and visualizing very large data sets, working on super-computing facilities, working effectively within a collaboration, and communicating results in written and oral form on a national and international level.

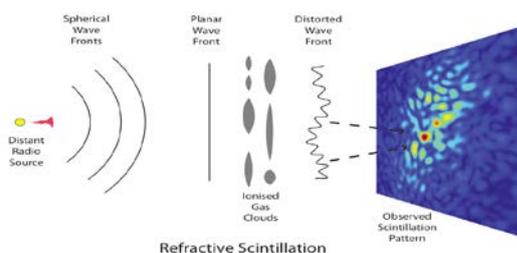


Figure 1: Refractive scintillation occurs when radio wave from a distant source (left) pass through an lumpy ionised gas cloud (middle). The gas clouds distort the wave front and cause a distorted view of the object (right). As the gas clouds move with respect to the distant source, the scintillation pattern changes, making it appear that the background radio source is changing in brightness. This scintillation effect can be used to determine the properties of the otherwise invisible gas clouds.

## Research Field

Radio Astronomy, Astrophysics

## Project Suitability

Honours

Masters

PhD

## Project Supervisor

Dr Paul Hancock

paul.hancock@curtin.edu.au

## Co-Supervisors

Dr Natasha Hurley-Walker

Dr Andrew Walsh

## Investigating the Nature of the Faint Radio Galaxy Population at 20 GHz

This project will explore the nature of the faint extragalactic radio source population selected at 20 GHz, using observations made with the Australia Telescope Compact Array (ATCA). Early radio surveys were conducted at low frequencies due to the technology available at the time, e.g. the 3C survey at 178 MHz. With advances in technology and the need for higher resolution surveys, studies moved to higher frequencies. As a result, source counts, particularly at 1.4 GHz, are well determined to flux densities below 0.1 mJy. The faint population at higher frequencies (tens of GHz), however, has been much less widely studied due to the increased time required to survey an area of sky to an equivalent depth at these frequencies.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

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**Project Supervisor**

Dr Tom Franzen

[thomas.franzen@curtin.edu.au](mailto:thomas.franzen@curtin.edu.au)

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**Co-Supervisors**

Prof Carole Jackson

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High-frequency surveys have the potential to shed light on possible new classes of sources. They also provide further insights into the physics of sources detected in lower frequency surveys, for example giving information on the break frequencies marking the transition from optically thick to optically thin regimes, and on any high-frequency steepening due to electron ageing.

In 2009, the ATCA was used to carry out a very deep survey of a small patch of the radio sky at 20 GHz (Franzen et al. 2014), detecting a total of 85 extragalactic radio sources. This project will use optical and infrared data to study these sources in more detail. This will help us learn more about the energetic events which are associated with massive black holes at the centres of galaxies.

# Machine Learning Techniques to Obtain Redshifts for the Square Kilometre Array

Obtaining distances, as derived from redshifts, to galaxies is a key prerequisite to studying the evolution of starforming galaxies and the hosts of powerful supermassive black holes across cosmic time. Typically an optical spectrum for each galaxy is required, but this requires a considerable amount of valuable time on 8m-class telescopes. Over the past decade, techniques of estimating the redshifts of large numbers of galaxies from broadband optical and infra-red photometry have been developed. However, such analyses are typically designed for optically selected galaxies and require a large number of photometric bands to be accurate. Radio surveys from the Murchison Widefield Array (MWA: 70-300MHz) and the Australian Square Kilometre Array Pathfinder (ASKAP: 700-1800MHz) will find tens of millions of extra-galactic radio sources many of which will not have decent coverage from optical telescopes.

**Research Field**  
Radio Astronomy

**Project Suitability**  
Masters  
PhD

**Project Supervisor**  
Dr Nick Seymour  
nick.seymour@curtin.edu.au

**Co-Supervisors**  
Dr Rob Sharp (ANU)

This project will examine a series of machine learning methods to obtain redshifts based on limited information including kth Nearest Neighbour and Self-Organised Map amongst others. These will be tested against a growing catalogue of known redshifts of radio sources in particular those obtained from the OzDES project (<http://www.mso.anu.edu.au/ozdes/>). Hence, this project will also be actively involved in a major observational programme on the Anglo-Australian Telescope along with reduction and classification of optical spectra.

Once these methods are well calibrated then even sources with large uncertainties on their distances can be used among the millions of radio sources from MWA and ASKAP to constrain the evolution of the star forming and black hole radio populations. This work will be of key importance in the preparation for deep surveys with the Square Kilometre Array.

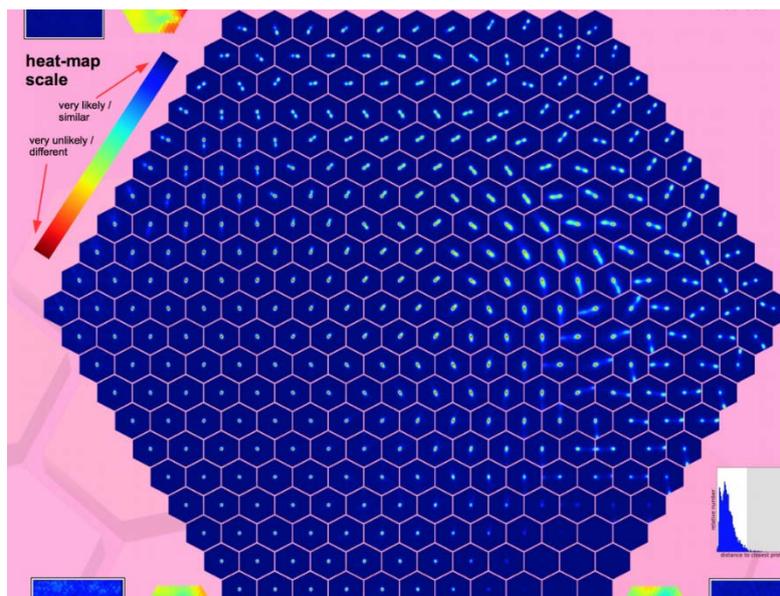


Figure 1: Example of a Self-Organised Map used to classify radio sources by their morphology (Polsterer et al. 2014).

# Measuring Primordial Element Abundances Across Cosmic Time

The majority of light elements were produced in the first 20 minutes after the Big Bang via nucleosynthesis. In particular, the Helium  $^4\text{He}$  isotope (comprising ~25% by mass) and trace amounts of Deuterium, D, an isotope of hydrogen (with an extra proton in its nucleus, i.e.  $^2\text{H}$ ). The relative abundances of these elements is important as amount of  $^4\text{He}$  is insensitive to the initial conditions of during nucleosynthesis, whereas D is only marginally stable and easy to destroy at this early time. This project will involve tracing these elements, as well as Hydrogen, using their hyperfine (spin-flip) transitions which are observable at radio wavelengths. The 21cm hyperfine transition line of hydrogen is well-studied, but the other two transitions (92cm for D and 3.5cm for  $^4\text{He}$ ) are not.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

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PhD

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**Project Supervisor**

Dr Nick Seymour

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nick.seymour@curtin.edu.au

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**Co-Supervisors**

Dr Natasha Hurley-Walker

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This project will comprise three parts:

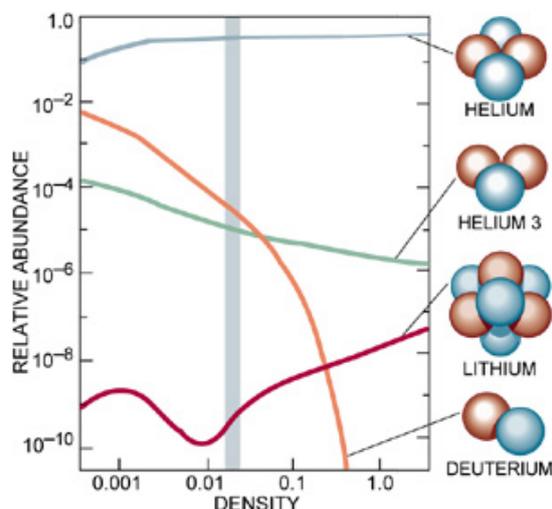
(i) Measuring absorption of these lines towards the Galactic centre using the Australian Telescope Compact Array (ATCA) and the Advanced Aperture Verification System (AAVS). Comparison with the strength of the Hydrogen absorption will reveal relative abundances within the Milky Way.

(ii) Search for absorption of these lines at moderate to high redshift with ATCA and the Murchison Widefield Array (MWA) in radio sources which have already demonstrated large absorption by neutral hydrogen. This will reveal their relative abundances at those redshifts. This will also involve the search for new Hydrogen absorption with the AAVS.

(iii) Helium reionised later than Hydrogen, ~12 billion years ago rather than ~13 billion years ago, as more energy is required to release the electrons. Absorption due to neutral Helium should therefore be observable at lower redshift ranges. Several powerful radio sources are already known at these redshifts which make them great candidates for detecting Helium absorption. Helium was mostly reionised by powerful accreting black holes so luminous radio galaxies are the obvious place to look.

This project will uniquely exploit the frequency coverage of many Australian radio telescopes such as the ATCA, and the Curtin-operated telescopes MWA and AAVS1.

Dependence of elemental abundance on the matter density of the Universe (credit Martin White, Berkeley)



## Modelling the Radio Continuum Universe for the Square Kilometre Array

A key science goal of the Square Kilometre Array (SKA) is to make deep continuum images of the radio Universe in order to trace the history of star formation and black holes across cosmic time. Due to its sensitivity, field of view and the fact that radio emission is not obscured by dust the SKA will make the most accurate measurement of the history of galaxy and black hole growth. To date the extensive modelling of the radio continuum Universe has been based on phenomenological extrapolation of how known radio populations behave with little consideration of the underlying physics or connections to other wavelengths. This project would aim to address these issues by using the state of the art mock galaxy simulations (e.g. the Theoretical Astrophysical Observatory) and radio emission simulations to estimate radio luminosities from star formation and black holes across cosmic time.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

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PhD

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**Project Supervisor**

Dr Nick Seymour

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[nick.seymour@curtin.edu.au](mailto:nick.seymour@curtin.edu.au)

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**Co-Supervisors**

Dr Stas Shabala (UTas)

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This project would cover three key areas:

- (i) Refinement and understanding of the physics producing radio emission from star forming galaxies and black holes in order to simulate what different surveys would measure.
- (ii) Comparison with different surveys, in particular those from the Murchison Widefield Array (MWA: 70-300MHz) and the Australian Square Kilometre Array Pathfinder (ASKAP: 700-1800MHz)
- (iii) Simulate how well the SKA will be able to measure galaxy and black hole evolution in order to guide the planning of the SKA Key Science Projects. This is vital step, yet to be undertaken by the community in planning for the SKA.

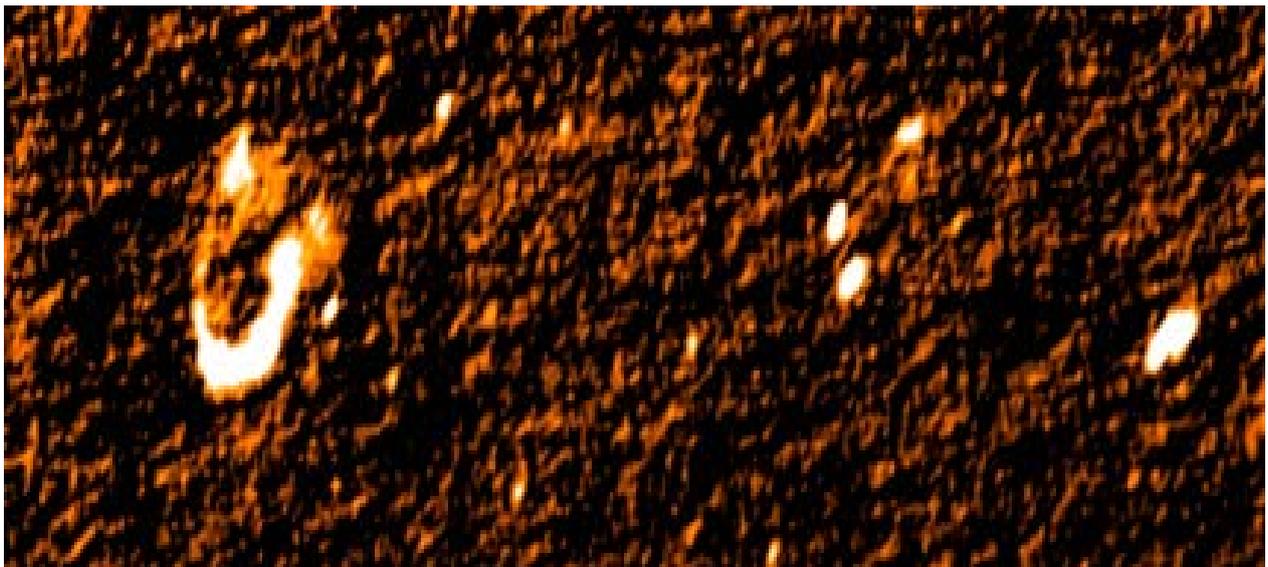


Figure 1: A close up of a deep radio survey with the Australia Telescope Compact Array showing the diversity of radio sources.

# New Insights to the Hosts of Radio Galaxies to $z \sim 0.3$ : Clues to the Triggers of AGN Activity and Feedback

A relatively small fraction of all galaxies are classical ‘radio loud’ galaxies – a class of Active Galaxies – at any particular epoch. The onset of AGN activity could be a single or recurrent phase of otherwise fairly ‘normal’ galaxy lifecycles. Understanding the conditions, environment and hosts of the powerful radio-loud galaxies is not well determined; moreover there are a number of apparent sub-classes (populations) of these radio-loud galaxies (compact, peaked, head-tail, etc) that complicate any simple analyses.

To investigate populations of radio galaxies we need multi-wavelength data, most obviously to obtain distance and spectral information. Intensive and absorbing follow-up of small radio-selected samples has resulted in some very significant complete samples. However, understanding the populations in detail is challenging – not least because bright radio sources can be embedded in distant and often otherwise quiescent galaxies.

Across the whole electromagnetic spectrum the quality and quantity of survey data has progressed with increasingly powerful instrumentation. Notably the quality of radio survey data has blossomed in the past decade. The MWA is currently surveying the southern sky at 70 – 230 MHz (GLEAM) and will provide a catalogue of extragalactic sources unbiased by beaming effects which often plague interpretation of radio data above  $\sim 1$  GHz. Combining GLEAM data with that from other radio surveys such as NVSS and SUMSS provides sufficient resolution to confidently cross-match with other wavelength data.

In this research we will use spectroscopic, photometric and a wide range of multi-wavelength data to investigate the hosts of powerful, relatively local ( $z < 0.3$ ) galaxies. The multi-wavelength data will be obtained primarily from the 5 regions of the GAMA database (<http://www.gama-survey.org> and Driver et al (2009) <http://arxiv.org/abs/1009.0614>) with possible follow-up observations of selected objects or classes to secure the conclusions of this research. Data from the MWA Galactic & Extragalactic all-sky survey (GLEAM) survey will be cross-matched with to select a complete sample of powerful radio galaxies. Using the well-calibrated GAMA data we will then investigate whether there are any physical differences between the low and high-excitation radio galaxies, including their host types, star formation rates, abundances and environment.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

PhD

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**Project Supervisor**

Prof Carole Jackson

[carole.jackson@curtin.edu.au](mailto:carole.jackson@curtin.edu.au)

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**Co-Supervisors**

Prof Simon Driver (UWA)

Dr Nick Seymour

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## 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**

Low-frequency  
Radio Astronomy

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**Project Suitability**

Honours  
Masters  
PhD

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**Project Supervisor**

Dr John Morgan  
[John.morgan@icrar.org](mailto:John.morgan@icrar.org)

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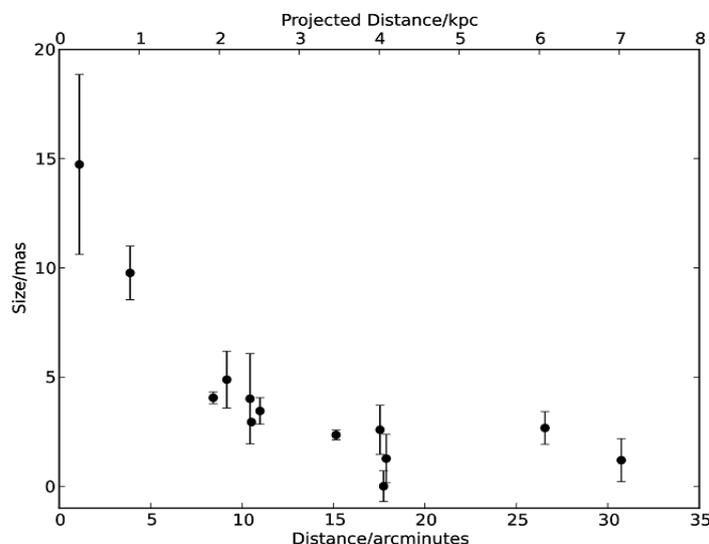
**Co-Supervisors**

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 couple 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.



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.

# Path-Loss Investigation for Low-Frequency Antenna Arrays

The Square-Kilometre Array (SKA) is an international project to build a radio telescope with unprecedented sensitivity, resolution, and field of view, covering the frequency range between 50 MHz and 20 GHz. The SKA will be divided in several frequency bands, the lowest is known as SKA\_LOW (50 MHz-350 MHz) and will be built across Australia and New Zealand. SKA\_LOW is expected to consist of hundreds of stations, with hundreds of antenna elements in each station. Most of the stations will be located within 50 km of the core of SKA\_LOW at the Murchison Radio-astronomy Observatory (MRO).

To achieve its ground-breaking science goals, electromagnetic interference (EMI) from SKA's own hardware must be tightly controlled. Specifications for electromagnetic radiation from any devices installed at the MRO must be developed based on correct threshold levels that cause interference with radio astronomy observations, and accurate values for the path-loss between sources and antenna elements.

The most critical EMI scenario for SKA\_LOW is emission in the frequency range 50 - 350 MHz from sources close to the ground, in a distance of less than 1 km. Reliable propagation models for such a scenario are currently not available, and must be developed and tested.

Analytical considerations and computer simulations will be important tools for this project. It is also expected that all results are substantiated by measurements on site at the MRO. The low frequency aperture array verification system 1 (AAVS1) is constructed as a precursor to SKA\_LOW to verify various design parameters, and can also be used as a test platform for EMI characteristics.

The scope of this project is to develop and test propagation models relevant for SKA\_LOW, and to investigate whether commonly used threshold levels of ITU Recommendation 769 (Protection criteria used for radio astronomical measurements) need to be revised for this special case.

The student is expected to have some exposure to and/or is willing to acquire backgrounds in antenna arrays, radio astronomy techniques, electromagnetic modelling and measurements, and signal processing. Some field trips to the MRO are to be expected. This project is suitable for an engineering or applied physics student with a career outlook in radio astronomy, telecommunications, or general system level electromagnetic compatibility.



Figure 1: SKA\_Low antennas installed at the MRO for trial purposes.

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**Research Field**

Electrical Engineering  
Electromagnetic Propagation

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**Project Suitability**

Masters  
PhD

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**Project Supervisor**

Dr Franz Schlagenhauer  
f.schlagenhauer@curtin.edu.au

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**Co-Supervisors**

Dr Adrian Sutinjo

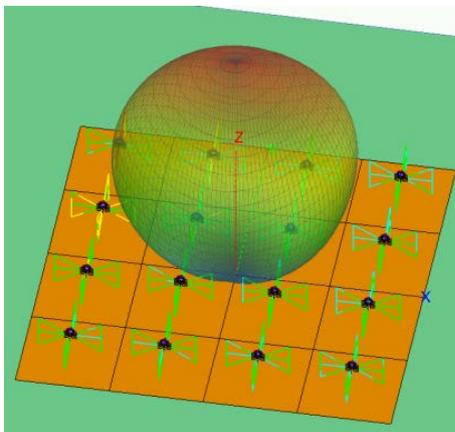
# Polarimetric Beam Modelling for Low-Frequency Aperture Arrays

The Square Kilometre Array (SKA) is an international project to build radio telescope with a combination of unprecedented sensitivity, resolution, and field of view (FoV) covering the frequency range from 50 MHz up to 10 GHz. SKA telescope is divided into several frequency bands, the lowest is known as SKA\_LOW (50-350 MHz) and will be built across Australia and New Zealand. SKA\_LOW is expected to consist of hundreds of stations with hundreds of antenna elements in each. Most of the stations will be located at the core of SKA\_LOW at the Murchison Radio-astronomy Observatory (MRO), within an area of 50 km radius.

As a precursor to SKA\_LOW, a low frequency aperture array verification system 1 (AAVS1), envisaged as a small subset of the SKA\_LOW, will be constructed at the MRO. The purpose of AAVS1 is to verify various critical design parameters of SKA\_LOW using an on-site engineering prototype. Initial efforts in this area have resulted in the construction and characterization of an experimental array of 16 antennas co-located with the Murchison Widefield Array (MWA).

In radio astronomy, polarimetry is the measurement of the state of polarization of astronomical sources. The ability to detect the state of polarization of radio astronomical sources is of great interest as a large amount of astrophysical information is encoded in it. However, radio astronomical instruments themselves are imperfect; they add “instrumental polarization” to the sources in question. Hence, it is critical that the polarization performance and calibration of the LFAA be well understood. ICRAR/Curtin has begun an in-depth investigation into the instrumental polarization of the MWA. Various models with varying levels of complexity are being compared and evaluated. The scope of this project is to refine, implement and test the polarimetric model of the MWA “tile” (an array of 4x4 antennas) to achieve an accurate but computationally efficient and flexible model. This model will be used to facilitate characterization of AAVS through interferometric measurements with the MWA.

This project will be associated closely with the work in the low frequency aperture array work for SKA project within the Aperture Array Design Consortium (AADC), in which ICRAR/Curtin is a major player. The student is expected have some exposure to and/or is willing to acquire backgrounds in phased array antennas, radio astronomy techniques, electromagnetic (EM) modelling and laboratory measurements and signal processing. Some field trips to the MRO are to be expected. This project is suitable for an engineering or applied physics student with a career outlook in radio astronomy, telecommunications and/or applied physics.




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**Research Field**

Electrical Engineering  
Radio Astronomy

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**Project Suitability**

Masters  
PhD

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**Project Supervisor**

Dr Adrian Sutinjo  
adrian.sutinjo@curtin.edu.au

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**Co-Supervisors**

Dr Randall Wayth

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# Powerful Radio Galaxies and Quasars

The Murchison Widefield Array (MWA) is a new radio telescope in Western Australia operating between 70 and 240 MHz – a waveband relatively unexplored until the recent advent of the MWA and its northern hemisphere counterpart, LOFAR.

To investigate populations of radio galaxies and quasars we need complete samples. Obtaining these relies on multi-wavelength data, most obviously to obtain distance and spectral information. Intensive and absorbing follow-up of small samples of radio-selected objects has resulted in some very significant complete samples but the *number of sources* in each remains statistically tiny. However, identifying any complete sample is challenging – not least because bright radio sources can be embedded in distant and otherwise quiescent galaxies.

Across the whole electromagnetic spectrum the quality and quantity of survey data has progressed with increasingly powerful instrumentation. Not least, the quality of radio survey data has blossomed in the past decade or so, with surveys such as NVSS and SUMSS providing all-sky coverage around 1 GHz, with sufficient resolution to confidently cross-match with other wavelength data. When coupled with other (particularly high resolution) radio-, IR- and optical data the resultant *radio-selected* source samples provide significant new data to untangle the physical nature of radio galaxies and quasars.

This project will start with the sample of the brightest MWA sources and seek to identify the most powerful radio sources selected at low radio frequencies; this sample will provide new insights into these extreme sources unbiased by relativistic beaming effects and obscuration.

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

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PhD

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**Project Supervisor**

Prof Carole Jackson

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carole.jackson@curtin.edu.au

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**Co-Supervisors**

Prof Jasper Wall (UBC)

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Dr Nick Seymour

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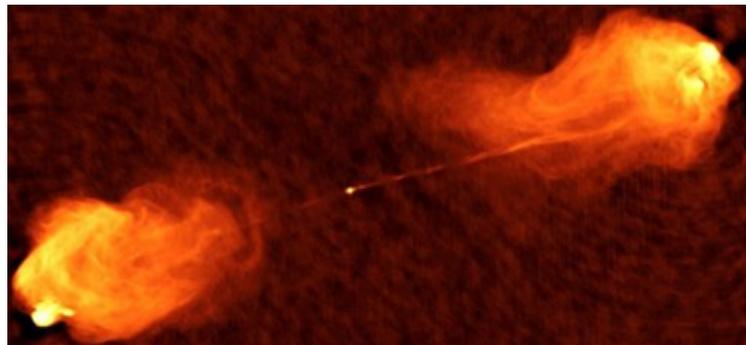
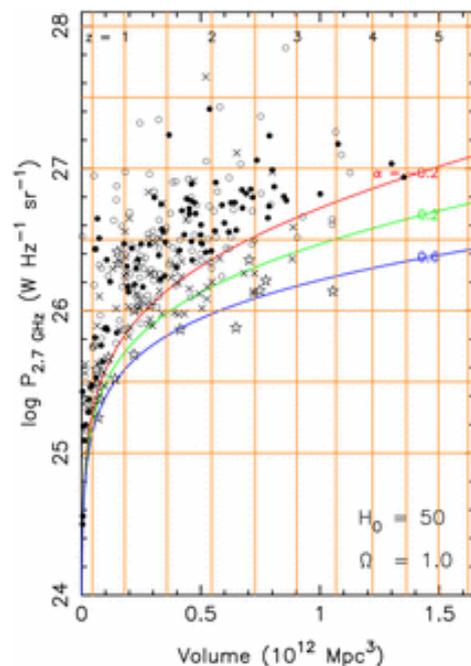


Figure 1: Cygnus A – a powerful radio galaxy at  $z=0.06$  discovered by Grote Reber in 1939.

Figure 2: from Wall et al (2005) the luminosity – volume plane for a complete set of powerful, flat-spectrum quasars selected at 2.7 GHz.

# Radio transients in the Galactic Plane: Exploring the low-frequency properties of X-ray binaries with the MWA

The process of accretion, whereby matter falls onto a compact object such as a black hole, is responsible for powering the most energetic phenomena in our Universe. The energetic radiation and powerful jets liberated by accretion onto supermassive black holes at the centres of radio galaxies are responsible for triggering or shutting off star formation, regulating the evolution of their host galaxies, and possibly even reionising the Universe. However, due to the long timescales on which such systems evolve, we cannot investigate how these processes of accretion, ejection and feedback proceed in individual supermassive black holes.

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**Research Field**

Radio Astronomy

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**Project Suitability**

PhD

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**Project Supervisor**

Dr James Miller-Jones

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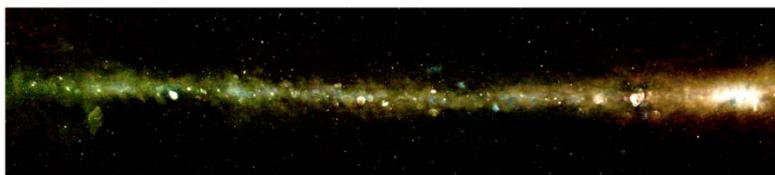
james.miller-  
jones@curtin.edu.au

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Since processes close to a black hole are governed by strong gravity, the physics should be very similar regardless of the black hole mass. We can therefore gain important insights into the physics of accretion and jet production by studying smaller black holes and neutron stars in our own Galaxy, with masses just a few times that of the Sun. If these stellar-mass compact objects accrete matter from a less-evolved donor star, the accreted mass builds up in a disc surrounding the central object until instabilities cause that mass to fall inwards, liberating gravitational energy, which powers a bright outburst in which the system increases in luminosity by several orders of magnitude, right across the electromagnetic spectrum. These outbursts lead to the ejection of powerful jets that can be studied at radio frequencies.

The Murchison Widefield Array (MWA) is a new, low-frequency radio telescope in Western Australia, which is operated by Curtin University as one of the precursor facilities to the Square Kilometre Array (SKA). The wide fields of view provided by the MWA enable us to efficiently survey the entire visible Galactic Plane and Galactic Bulge, where the majority of black hole and neutron star systems are located. The sensitivity of the MWA will allow us to detect outbursts of black hole or neutron star X-ray binaries anywhere in this region, determining how much kinetic energy is channelled into the jets in these outbursts, and allowing us to quantify their feedback effect on the surrounding environment. Over the past three years we have conducted fortnightly monitoring of the visible Galactic Plane and Bulge regions, and have been developing the software pipelines required to analyse the data in this technically challenging region of the sky.

In this project, you will use this Galactic Plane monitoring data to investigate the outbursts of known X-ray binary systems and search for new Galactic radio transients. You will refine the existing pipelines and implement them on the powerful facilities available at the nearby Pawsey supercomputing centre. You will also test new techniques for transient detection, helping to inform the observing strategies for more sensitive monitoring campaigns with both the newly-upgraded MWA, and eventually the SKA.



Mosaicked MWA image of a section of the Galactic Plane, made at three different frequencies. The Galactic Centre is on the right, and the Plane is filled with supernova remnants. Image credit: David Kaplan and Steve Croft.

# 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). Given their extremely large dispersion measures, these bursts are thought to originate from cosmological distances, of the order of several Giga-parsecs. They represent potential new probes for measuring the baryonic content and the magnetic field of the Intergalactic Medium. The physics governing the origin of these energetic bursts is currently unknown, although a large flurry of theoretical ideas have now been postulated including some exotic possibilities involving compact objects, dark matter and even cosmic strings. As with high-energy phenomena such as gamma-ray bursts, effective localization and follow-ups with other instruments and at multiple wavelengths hold the key to uncover their origin and underlying physics.

## Research Field

Time-domain Astronomy

## Project Suitability

Honours

Masters

PhD

## Project Supervisor

Dr Ramesh Bhat

ramesh.bhat@curtin.edu.au

## Co-Supervisors

Dr Steven Tremblay

Dr Stephen Ord (CASS)

Dr Chris Flynn (Swinburne)

Follow-up investigations of FRBs pose significant technical challenges given their short (~ milliseconds) time durations, thus necessitating real-time processing and rapid communication of alerts. With both the Parkes and Molonglo telescopes achieved the capability for real-time detection (Petroff et al. 2015; Caleb et al. 2016), it is now possible to undertake their effective follow-ups with low-frequency telescopes. The Murchison Widefield Array (MWA), a low-frequency radio telescope located in Western Australia with a large field-of-view (~300 – 600 deg<sup>2</sup>) and electronic steering capability, makes an ideal instrument for rapid follow-ups of FRBs that will be detected by Parkes and Molonglo. This is crucial for characterizing their spectral and scattering characteristics, thereby helping uncover as-yet unknown emission process.

This PhD project will focus on developing a capability for the MWA to receive and respond to the trigger alerts from premier Australian facilities such as Parkes and Molonglo. The MWA will also provide a much better localization than that is possible with either Parkes or Molonglo. The project will involve close collaboration with CSIRO Astronomy and Space Science (CASS) and Swinburne Centre for Astrophysics.

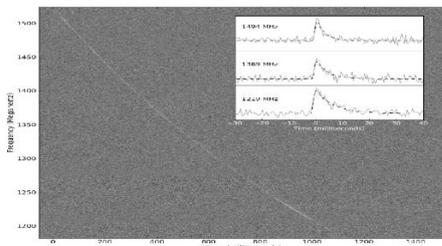


Figure 1: Detection plot of FRB 110220 from Thornton et al. (2013). The burst's dispersion measure of 945 pc cm<sup>-3</sup> results in an arrival time spread of approximately 1100 ms across the 400 MHz observing band of Parkes survey observations. The inset shows the shape of the pulse in the top, middle and lowest of 13 sub-bands that span the 400 MHz band, where an exponential-like tail resulting from multi-path scattering is clearly visible and follows the expectation from Kolmogorov-type turbulence.

## Searching for fast transients with the Australian Square Kilometre Array Pathfinder

Fast radio bursts are an enigmatic population of transient astronomical events. While only about around 20 of these bright millisecond-duration radio bursts have so far been discovered, all evidence suggests that they are coming from cosmological distances. The bursts are exciting because they both represent a **brand-new and unprecedentedly bright** class object and also promise to be **unique probes of the cosmology** of our Universe. This project will utilize the wide field of view of the Australia Square Kilometre Array Pathfinder (ASKAP) to rapidly increase the population of the bursts and identify hosts, emission mechanisms and explanations for the bursts. As part of the ASKAP-CRAFT team, your research could include:

**Research Field**

Radio Astronomy

**Project Suitability**

Masters

PhD

**Project Supervisor**

Dr Ryan Shannon

[Ryan.Shannon@curtin.edu.au](mailto:Ryan.Shannon@curtin.edu.au)

**Co-Supervisors**

Dr Keith Bannister (CSIRO)

- Developing methods and data analysis pipelines to detect bursts in real time.
- Developing methods to pinpoint the location of a burst with an interferometer.
- Studying the demographics of the burst population.
- Coordinating multi-wavelength campaigns to identify hosts and counterparts to the bursts.
- Searching for galactic analogues to FRBs through a galactic plane single pulse survey.

Specific contributions will depend on your interests. Through this project you will gain experience with computation and signal processing while doing cutting-edge astrophysics.



Image Credit: Alex Cherney

# 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.

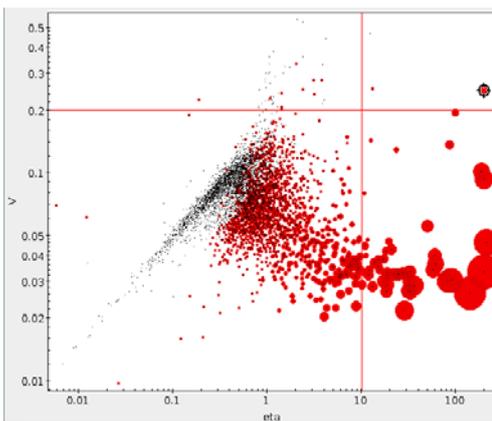
The project involves careful re-analysis of the original GLEAM data, using the combined catalogue as a reliable reference source. The student will search for objects which do not appear in the combined catalogue (transients), and identify their nature. There is also the potential to monitor the brightness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

**Research Field**  
 Transients and Variables

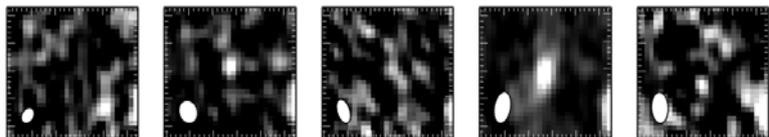
**Project Suitability**  
 Honours

**Project Supervisor**  
 Dr Natasha Hurley-Walker  
 nhw@icrar.org

**Co-Supervisors**  
 Dr Paul Hancock



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.



**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 Astrochemistry of the Star Forming Region G305

Astrochemistry is the study of the formation and evolution of molecules, ions and radicals in space through the natural processes normally associated with the formation of stars. In interstellar space, only the simplest molecules can exist. But buried deep inside a dark cloud of gas and dust, and gently heated by a nearby newly born star, atoms and simple molecules can undergo reactions to form ever-more complicated molecules. The Holy Grail for astrochemists around the world is to find evidence for naturally occurring amino acids in interstellar space. Amino acids are some of the building blocks for life, so their detection in space will help us understand how life can naturally begin. Glycine is the simplest amino acid and thus the most likely to be detected first, but despite over 30 years of searches has yet to be seen.

Astrochemistry can also be used to help us understand sites of star formation within our Galaxy. The complexity of molecules available can be used as a simple chemical clock to tell us how evolved one region may be. In this project, the focus will be on the star forming region G305, which shows multiple stages of star formation, from the earliest pre-stellar cores to well-developed stars on the main sequence and about to emerge from their natal dust shells.

G305 provides a unique environment to study all these stages in one place, which simplifies observations and allows us to study the interactions between the various sites. However, given the Southern declination of this region, not much work has been done on it. Some early work identified what might be the earliest stage of high mass star formation known (G305SW), showing unusual chemistry. This project will focus on G305SW and its surroundings.

This project will involve utilising telescopes such as the Australia Telescope Compact Array, the MWA, Parkes and ALMA. Both low and high resolution spectral line imaging will be needed to understand the chemistry of G305. This project is designed to align with planning for the SKA and will help place the student appropriately to continue research in future SKA radio astronomy.



Figure 1: An infrared image of the G305 star forming region, showing dense gas and dust, traced by extended green emission. These are the sites that harbour the next generation of star formation.

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**Research Field**

Galactic Astronomy

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**Project Suitability**

PhD

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**Project Supervisor**

Dr Andrew Walsh

[andrew.walsh@curtin.edu.au](mailto:andrew.walsh@curtin.edu.au)

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# The Evolution of the Radio Source Population

Radio surveys are superb tracers of both star formation and black hole growth across cosmic time. Unlike many other wavelengths radio emission is impervious to obscuration by dust. The upcoming generation of radio surveys will provide new insights into the evolution of both populations.

This project will comprise three parts:

(i) Constraining the evolution of radio sources in the ATLAS survey field by cross-matching with the optical DES survey. This will exploit optical spectroscopy from Anglo-Australian Telescope and involve further observing on the AAT. This project will involve classifying radio sources based on their optical spectra, as well as using the spectra in this field to train photometric redshifts for the radio sources without optical spectra.

(ii) Measure the star formation rate and radio black hole activity as a function of both stellar mass and redshift using early data from the Australian Square Kilometre Array Pathfinder in the GAMA survey fields. To obtain radio emission for all galaxies in the sample, techniques looking at the distribution of sub-threshold radio fluxes will be used as well as direct radio detections. This work may be extended to higher redshifts using the deeper data of the COSMOS survey field.

(iii) To determine a baseline for the evolution of the low frequency radio source population this project will cross-match the MWA all-sky catalogue with the up-coming all sky spectroscopic survey TAIPAN. This project will involve statistical techniques to reliably match the low-resolution radio data with the higher resolution optical data.

This project will uniquely exploit the large area surveys from MWA and ASKAP and pave the way for future studies with the Square Kilometre Array

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**Research Field**

Radio Astronomy

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**Project Suitability**

Masters

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PhD

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**Project Supervisor**

Dr Nick Seymour

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nick.seymour@curtin.edu.au

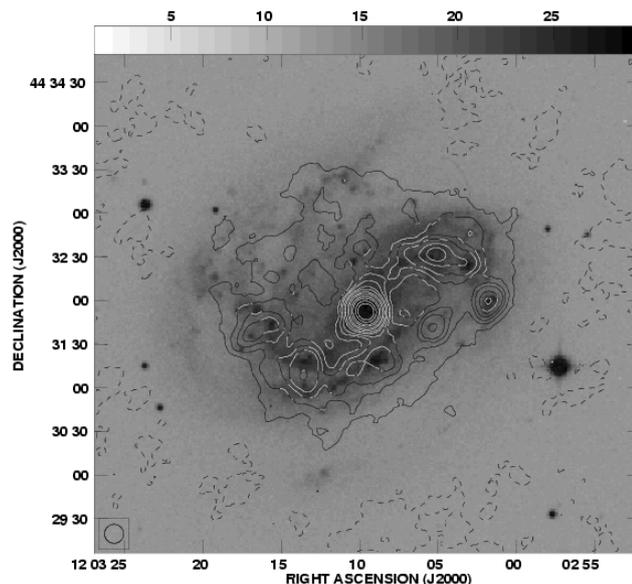
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**Co-Supervisors**

A/Prof Andrew Hopkins (AAO)

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Radio contours overlaid on a grey-scale optical image of NGC4051 demonstrating how radio emission can trace the star formation in the spiral arms and, in this exception case, black hole accretion at the centre of this galaxy.



## 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 multi-wavelength 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

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james.miller-jones@curtin.edu.au

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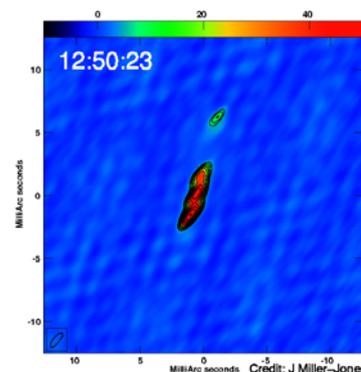
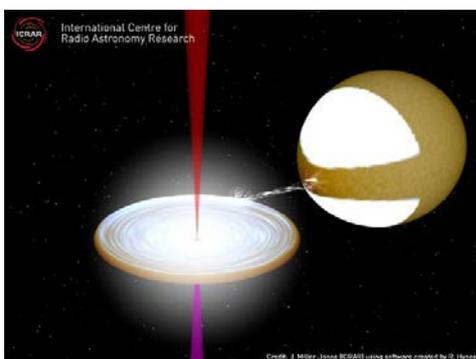


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**Co-Supervisors**

Dr Roberto Soria

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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.

# The First Black Holes with Murchison Widefield Array

How did the first super-massive black holes form and grow?

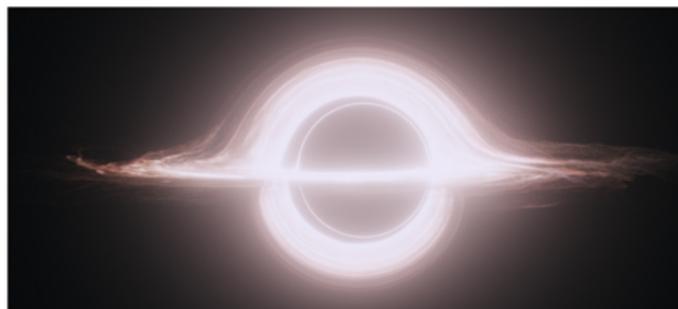
There is growing evidence that some of the very first black holes formed very early in the Universe (within the first billion after the Big Bang) and may have been active during the Epoch of Reionisation when all the neutral hydrogen was reionised. How they grow so big, in such a short period, is not yet understood. During active phases, accreting black holes are the most luminous objects in the Universe often producing powerful jets of out-flowing material. These jets produce synchrotron radiation visible at radio wavelengths which far out-shine the host galaxy. Hence, radio surveys are a key tool in finding super-massive black holes in the early Universe.

This project will comprise three parts:

- (i) Studying the broadband radio properties of known powerful black holes at high redshift in order to characterise their typical jet emission at these redshifts and to examine the role of jets in their evolution. This part will involve observing, reducing and modelling radio data from facilities such as the Very Large Array and the Australian Telescope Compact Array.
- (ii) Using the all-sky radio surveys from the low-frequency Murchison Widefield Array (MWA: 70-300MHz) and the Australian Square Kilometre Array Pathfinder (ASKAP: 700-1800MHz) to search for the earliest black holes. This part of the project will involve combining data from these two radio telescopes to select candidate sources in the early Universe.
- (iii) Follow-up of candidate early black holes with powerful optical and infrared telescopes such as the Very Large Telescope and the Atacama Large Millimetre Array. Such observations shall be used to weigh the primordial black hole, study its host galaxy and environment.

This project will uniquely exploit the large area surveys from the complementary MWA and ASKAP and pave the way for future studies with the Square Kilometre Array

Accurate simulated view of an accretion disk around a black hole as developed for the film Interstellar (James et al. 2015)




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### Research Field

Radio Astronomy

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### Project Suitability

Masters

PhD

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### Project Supervisor

Dr Nick Seymour

[nick.seymour@curtin.edu.au](mailto:nick.seymour@curtin.edu.au)

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### Co-Supervisors

Dr Jose Afonso

(IA, Lisbon University)

Dr Natasha Hurley-Walker

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# The relativistic jets of Cygnus X-1: the first confirmed black hole

While the concept of what we now call a black hole was first proposed by John Michell in 1783, it was not until Einstein developed his general theory of relativity in 1915 that we understood how light is affected by strong gravitational fields. The theory underlying these exotic objects was developed over the next fifty years, and in 1972, the first strong candidate for a black hole was discovered in the binary star system Cygnus X-1. This system consists of a massive star in a 5.6-day orbit with a dense central object. The release of gravitational energy as mass is transferred from the star to its compact counterpart causes the emission of strong X-ray radiation from close to the compact object, which was detected by early X-ray satellites.

We now know Cygnus X-1 to comprise a black hole of 15 solar masses, in orbit with a supergiant companion of 19 solar masses. Gas is transferred via a focussed wind from the companion star to an accretion disc around the black hole, causing powerful radio-emitting jets to be launched. By observing across the electromagnetic spectrum, we can probe the physical properties of the accretion flow, the jets, and the coupling between them. Since the processes of accretion and jet ejection are universal, seen from young stellar objects right up to supermassive black holes, new insights gained from studying a system such as Cygnus X-1 have broad implications across many areas of astrophysics.

In mid-2016, a large international team is conducting an intensive observational campaign to observe Cygnus X-1 over an entire 5.6-day binary orbit. The resulting legacy data set will allow us to conduct a wide range of studies, providing an unprecedented insight into the accretion and jet ejection processes in this system. Key science goals include measuring the temperature profile of the accretion disc, determining the structure of the stellar wind, measuring the speed and structure of the relativistic jets, and verifying the masses of the two components.

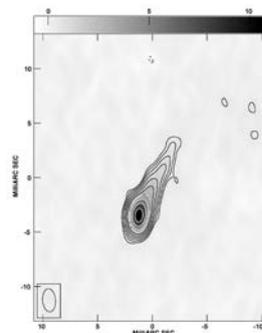
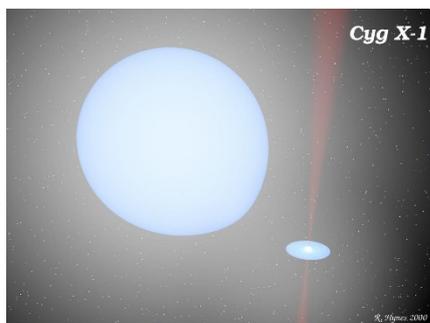
In this project, you will join this large international team, using radio telescopes spread across the globe, from the USA to Japan, Korea, and across Europe, to conduct time-resolved imaging and photometric studies of the relativistic jets in Cygnus X-1. You will investigate the speed and structure of the jets, determine how they are affected by the stellar wind of the companion, and how variations in the X-ray emitting regions of the accretion flow are manifested as they propagate outwards in the jets.

**Research Field**  
 Accretion Physics

**Project Suitability**  
 PhD

**Project Supervisor**  
 Dr James Miller-Jones  
 james.miller-jones@curtin.edu.au

**Co-Supervisors**  
 Dr Roberto Soria  
 Dr Richard Plotkin



Left: Schematic of Cygnus X-1. The black hole accretes gas from the wind of the massive donor star, generating X-rays from the accretion disc and launching relativistic radio jets (as seen in right panel).

## “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. 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 Kilometre Array. Insights into the astrophysics of the individual sources may well result in several letters in refereed journals.

This project is suited to a student with a strong grounding in astrophysics and a willing 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

Masters

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### Project Supervisor

Dr Natasha Hurley-Walker,  
nhw@icrar.org

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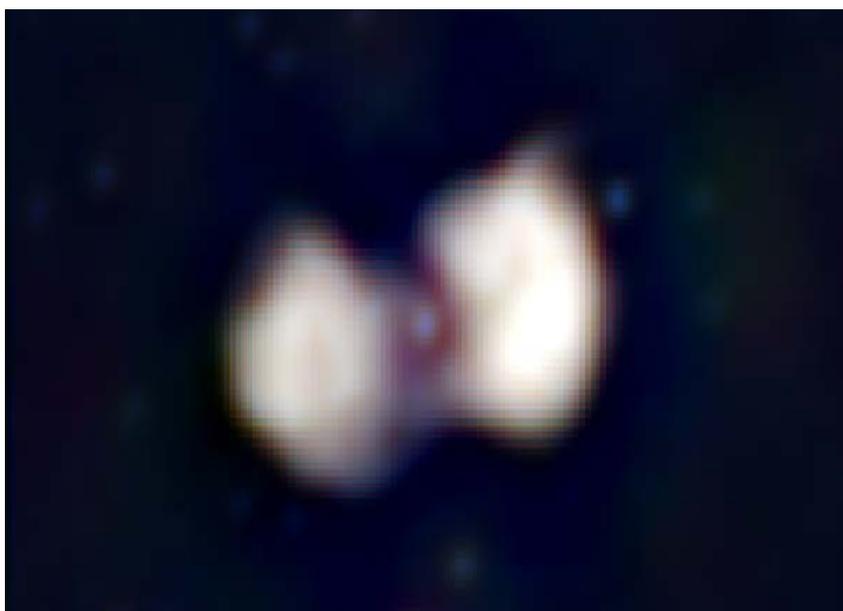


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### Co-Supervisors

Dr Pietro Procopio  
(University of Melbourne)

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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.

# ThunderKAT: hunting explosive radio transients with MeerKAT

Nearly all explosive astrophysical events are associated with transient radio emission, as particles are accelerated to relativistic speeds by the injection of energy from a powerful central engine. Detecting and characterising this radio emission, and following up newly-detected events with telescopes across the electromagnetic spectrum, can elucidate the nature of the engine powering the events, enabling us to probe physics in regimes of energy, gravitational and magnetic fields that can never be reached here on Earth. Such extreme events are often powered by gas falling onto a central compact object such as a black hole or neutron star, allowing us to better understand these exotic objects and the feedback they provide to their surroundings.

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**Research Field**

Radio Astronomy, transients

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**Project Suitability**

PhD

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**Project Supervisor**

Dr James Miller-Jones

james.miller-jones@curtin.edu.au

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Transient radio emission is one of the key science goals for the new generation of radio telescopes that are currently under construction, culminating in the completion of the Square Kilometre Array (SKA) over the next decade. Pathfinder and Precursor instruments for the SKA have been coming online over the past few years, and 2016 will see the beginning of early science operations for MeerKAT, the South African SKA Precursor facility, which will eventually comprise 64 dishes operating at radio frequencies around 1.5 GHz. Until the completion of the SKA, MeerKAT will be the most sensitive radio telescope in the world at these frequencies, opening up new parameter space for the study of transient radio sources, from faint, quiescent accreting black holes in our own Galaxy to higher-luminosity outbursts in distant galaxies.

ThunderKAT (The Hunt for Dynamic and Explosive Radio Transients with MeerKAT) is one of 10 approved Key Science Projects for MeerKAT, with several hundred hours of observing time awarded per year to study transient radio sources. The first data will be taken in late 2016, with transient science expected to feature prominently among the early MeerKAT targets.

In this project, you will work on MeerKAT observations of new radio transients, focusing primarily on relativistic accretion and jet ejection, via the study of X-ray binary outbursts within our own Galaxy, or ultraluminous X-ray sources in nearby galaxies. As well as breaking new scientific ground, the early observations will also be used to understand the system and help commission the telescope, and to develop imaging and analysis pipelines. The science goals will be extended to fainter sources over time, as more antennas come online and the sensitivity and imaging fidelity of the instrument improves.



The MeerKAT radio telescope. Image credit: SKA South Africa.

# Tracking Interstellar Space Weather toward Timing-array Millisecond Pulsars

With recent LIGO discovery of gravitational wave signals produced by the merger of a black-hole pair, a new window is opened for the study of the Universe – the Gravitational-wave astronomy. An array of extremely stable pulsars distributed over the sky, i.e. a pulsar timing array (PTA), is sensitive to gravitational wave signals of much longer wavelengths (i.e. very low frequencies). Pulsar timing-array experiments thus enable science that is highly complementary to the ground- and space-based detectors such as LIGO (operational) and LISA (planned).

Pulsar timing array experiments exploit the clock-like stability of fast-spinning (millisecond) pulsars for the detection of gravitational waves in the nanohertz frequency range. This incredibly challenging goal involves developing an in-depth understanding of a variety of systematics in pulsar timing data, arising from the instrumentation, the pulsar emission process and the effects of the interstellar medium (ISM), as well as developing suitable methods to accurately correct for them.

Among the most prominent systematics in long-term pulsar timing data are the effects caused by the ISM on pulsar signals, including dispersion, scattering and scintillation. These are difficult to characterize well at timing frequencies (typically above 1 GHz), but are better discernible (and hence measurable) at low radio frequencies, given their steep scaling with frequency. Observing timing array pulsars with the MWA thus offers great advantages for accurate characterization of important ISM effects.

This PhD project will focus on the effective use of MWA to support the Parkes pulsar timing array (PPTA) project – currently the world leader in high-precision timing efforts around the world. The MWA's large field-of-view (~600 sq.deg. at 200 MHz) can be exploited to observe multiple pulsars in a single pointing. The project will involve developing optimal strategies for observing PTA pulsars with the MWA, and the related data analysis and interpretation for ISM effects, assessment of their impact on timing precision, and developing methods to correct for them in pulsar timing data. Aside from its significance for the PPTA project, low-frequency observations of millisecond pulsars will be interesting in their own right. The project will involve close collaboration with CSIRO Astronomy and Space Science (CASS).

## **Research Field**

Observational Pulsar Astronomy

## **Project Suitability**

PhD

Honours

Masters

## **Project Supervisor**

Dr Ramesh Bhat

ramesh.bhat@curtin.edu.au

## **Co-Supervisors**

Dr Ryan Shannon

Dr Steven Tremblay

Dr George Hobbs (CASS)

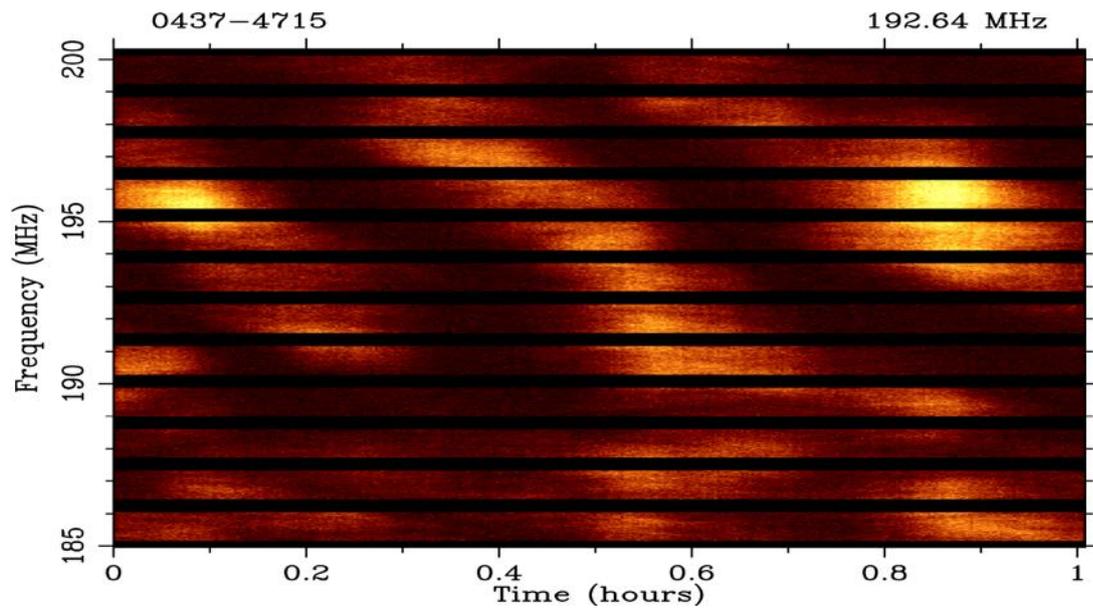


Figure 1: Dynamic spectrum of pulse intensity from MWA observations of the timing-array millisecond pulsar J0437-4715 (Bhat et al. 2016). The modulations and patterns seen in pulse intensity arise from multipath propagation of pulsar signals through the intervening interstellar medium (ISM). The MWA's 80-300 MHz operating frequency range is well suited for detailed characterisations of such propagation phenomena in the ISM toward all Parkes timing-array pulsars.

# Using N-Body and Semi-Analytic Simulations to Model the Integrated Foreground Signal to the Epoch of Reionisation

The primary science goal of the MWA is to perform statistical detection (power spectrum) of the Epoch of Reionisation (EoR) using the redshifted 21cm line of neutral hydrogen to probe changing conditions within the intergalactic medium. A major challenge for EoR detection is the presence of bright extragalactic radio galaxies contaminating the Early Universe signal. This project will build a statistical model for these contaminating signals, using the outputs of N-body and semi-numeric simulations. These simulations couple the reionisation source population at high redshift, to the sources of radio contamination at lower redshift (AGN, star forming galaxies), providing a self-consistent model of signal and contaminants. The candidate will explore the range of models derived from these self-consistent models, and compute constraints on high redshift structures given observations at lower redshifts.

**Research Field**  
 Epoch of Reionisation; Radio Sky Populations; Simulations

**Project Suitability**  
 Masters  
 PhD

**Project Supervisor**  
 Dr Cathryn Trott  
 cathryn.trott@curtin.edu.au

**Co-Supervisors**  
 Prof Chris Power (UWA)  
 Prof Carole Jackson

Students with good mathematical and statistical skills, and an interest in extragalactic galaxy populations, would be well-suited to this project.

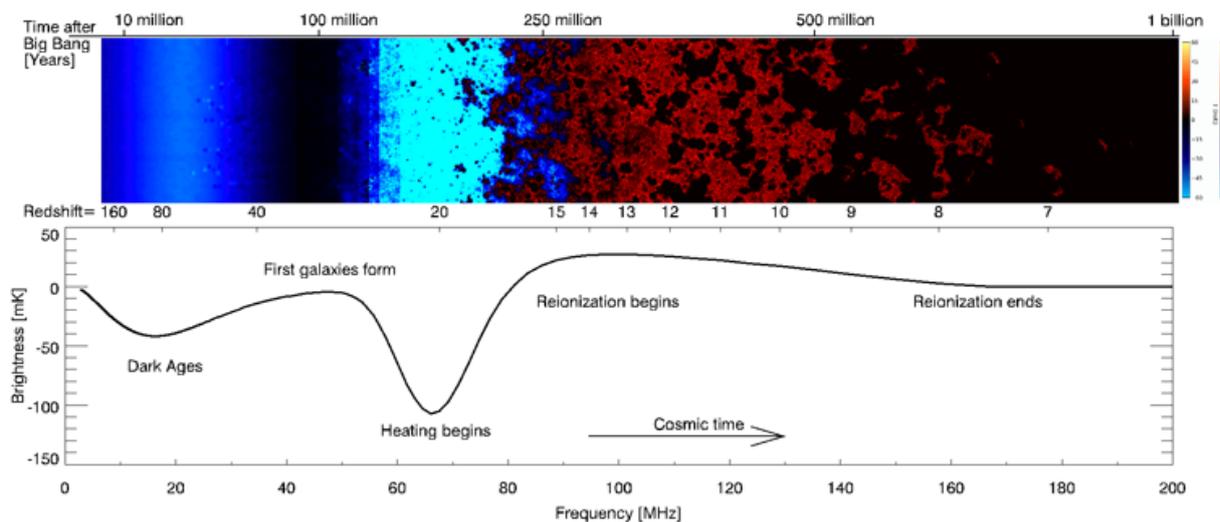


Figure 1: Model for the evolution of neutral hydrogen brightness temperature as a function of redshift, and pictorial representation of the reionisation of the Universe (Pritchard & Loeb 2008).

# Weighing the Universe Using Fast Radio Bursts and Probing its Evolution through Intergalactic Turbulence

The dynamics of the Universe in which we live — from the motions and clustering of galaxies to the very expansion of the Universe itself — is dominated by the gravitational influence of dark matter (26%) and the pressure exerted by dark energy (70%). The measured influence due to ordinary baryonic matter, the stuff of which people, planets and stars are made, is a paltry 4%. However, over the past decade, astronomers have come to the embarrassing realisation that there are serious problems in even accounting for this baryonic material, the only component of the Universe whose identity is known. Censuses of the baryons in the present-day Universe can account for no more than a third of the inferred amount.

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**Research Field**


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Astrophysical Transients and Cosmology

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**Project Suitability**


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PhD

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**Project Supervisor**


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Dr Jean-Pierre Macquart

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[j.macquart@curtin.edu.au](mailto:j.macquart@curtin.edu.au)

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**Co-Supervisors**


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Dr Cathryn Trott

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Where are these baryons? Cosmological simulations indicate that they most likely reside not in galaxies or stars, but in an extremely tenuous Intergalactic Medium (IGM) (Cen & Ostriker 1999). The IGM, believed to be 99.999% ionized, is extremely difficult to detect. It is undetectable in absorption lines. Emission lines of hydrogen, the most common species present in the Universe, are present but because the IGM is so diffuse, with a maximum likely number density of only  $\sim 10^{-7} \text{cm}^{-3}$ , these lines are almost impossible to detect. Other heavier elements, present in trace abundances, produce even weaker emission and absorption lines.

There is, however, an entirely different way to probe the IGM. A newly-discovered type of radio transient, *Fast Radio Bursts* (FRBs), emits radiation that is subject to scattering by small-scale density perturbations in the IGM. FRBs are extremely bright millisecond-duration events (see Figure 1 below) whose radiation emanates from bursts at cosmological distances, up to several Gpc away! The IGM alters FRB radiation by smearing their bright flashes in time, so that the pulse width increases at longer wavelengths. Furthermore, the radiation also arrives later at low frequencies, a fact that we can use to directly measure the total column of electrons that the radiation has propagated through in the IGM. The enormous prospects for using FRBs as precision cosmological tools are explained in a number of articles, including a popular review (<https://www.sciencenews.org/article/searching-distant-signals>) and a detailed scientific article (Macquart et al. 2015, <http://arxiv.org/abs/1501.07535>).

## Outline

In this project you will use advanced analytic skills to use FRBs to weigh the baryonic matter in our Universe and to determine its structure on cosmic scales. You will interpret observations of FRB dispersion and scattering properties to construct a model for the cosmic web of structure and physical conditions of the baryonic component of the IGM (see Figure 2 below).

You will directly address two of the most pressing fundamental problems in modern astrophysics and cosmology. You will determine both (i) the location of the missing baryons in our Universe and (ii) directly measure the effect of *feedback* in galaxy formation. Most dark matter in the Universe is found within massive galaxy halos, but most baryonic matter is outside this scale ( $\sim 100 \text{kpc}$ ). Since baryonic matter is more sensitive than dark matter to star formation and AGN feedback in galaxies, the baryon distribution is very sensitive to the way in which astrophysical processes distribute this matter in a

process known as feedback. The location of these missing baryons thus reveals how the feedback operates. The distribution of dispersion measures is sensitive to the locations of these baryons, and can determine whether they lie within the virial radius of galaxy halos, or whether they lie further out in an intra-halo medium.

For those more theoretically inclined, the project can be extended to include cosmological simulations of the distribution of baryonic matter near galaxies to directly determine the predictions of various galaxy feedback scenarios.

This project is ideally suited to someone who enjoys answering the big questions about our Cosmos. You will be at the forefront of cosmological and astronomical research involving the rapidly-developing field of FRBs.

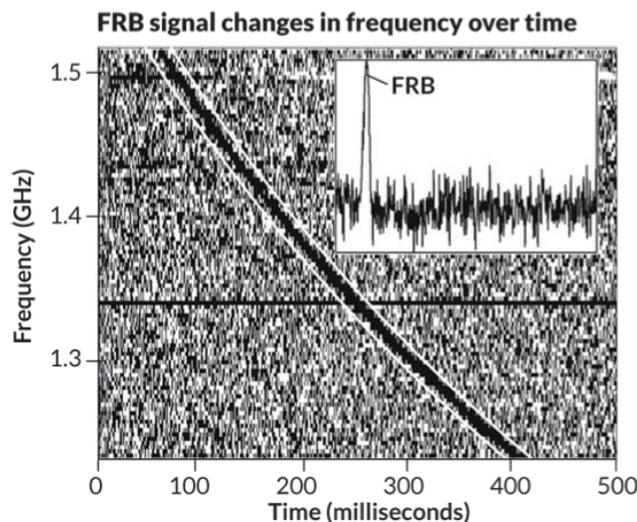


Figure 1: Intergalactic plasma slows down low-frequency radio waves more than higher frequencies, so they arrive at the telescope later. The figure above also shows that the pulse width increases to lower frequencies, demonstrating that the pulse is subject to scattering by turbulence in the Intergalactic Medium. (Credit: Duncan Lorimer et al.).

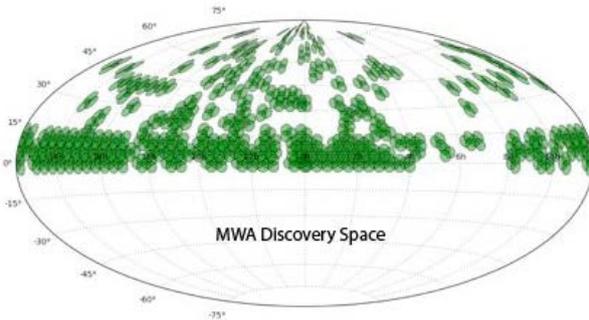


Figure 2: Numerical cosmological simulations trace the gravitational influence of dark matter in the Universe very well, but a key uncertain element in these simulations is the distribution of the baryonic matter. Where do the baryons reside? (Credit: Klaus Dolag).

# Wide-field Low Frequency Surveys for Pulsars and Radio Transients with the MWA

Radio pulsars are rapidly-rotating, highly-magnetized neutron stars. With more than 2500 now known, observations of pulsars allow the study of a range of astrophysical phenomena, from strong-field gravity and gravitational waves to interstellar scattering and the equation of state of dense matter.

The Murchison Widefield Array (MWA), a low-frequency (80-300 MHz) radio telescope recently constructed in Western Australia, provides a wide range of opportunities to perform pulsar observations and surveys. With an extremely wide field of view (30 degrees across at 150 MHz), the MWA will be an excellent facility for detecting transient radio emission. There is a counterpart survey being performed in the northern hemisphere by the LOFAR telescope. The MWA has a unique view of the southern hemisphere and therefore has the opportunity to open a new discovery space (see Figure). There are also opportunities within this research area for software engineers in developing efficient search and candidate excision procedures.



only beginning to become feasible due to the large computational requirements. There is considerable opportunity for high impact contributions to be made in this field.

## Research Field

Observational Pulsar Astronomy

## Project Suitability

Honours

Masters

PhD

## Project Supervisor

Dr Ramesh Bhat

Ramesh.bhat@curtin.edu.au

## Co-Supervisors

Dr Stephen Ord (CASS)

Dr Steven Tremblay

We will be running survey observations for radio pulsars throughout the MWA Operations phase. This program is highly compute intensive and offers projects in areas as diverse as data mining and pattern recognition as well as astronomy and astrophysics. The MWA will be especially sensitive to the poorly understood population of intermittent pulsars, and survey programs with interferometers are

### Admissions criteria

To gain entry to our Higher Degree program, you would be expected to have the equivalent of an Australian Masters or Bachelor's degree with first or upper-second class Honours. Full details of the admissions criteria can be found at <http://research.curtin.edu.au/postgraduate-research/future-research-students/>

### Funding

We welcome both domestic and international students to study with us at Curtin, although funding possibilities will depend on your citizenship status.

- **Australian and New Zealand citizens and Australian permanent residents** can apply for an Australian Postgraduate Award (APA) or a Curtin University Postgraduate Studentship (CUPS). These merit-based scholarships provide relocation funds and a living allowance. They are competitive, and applications close on 31 October 2016.
- **International students** can apply for an International Postgraduate Research Scholarship. These merit-based scholarships provide tuition fees, a living allowance, and basic health cover. They are competitive, and applications close on 31 August 2016.

Details of all scholarships currently offered can be found at <http://research.curtin.edu.au/postgraduate-research/postgraduate-research-scholarships/>