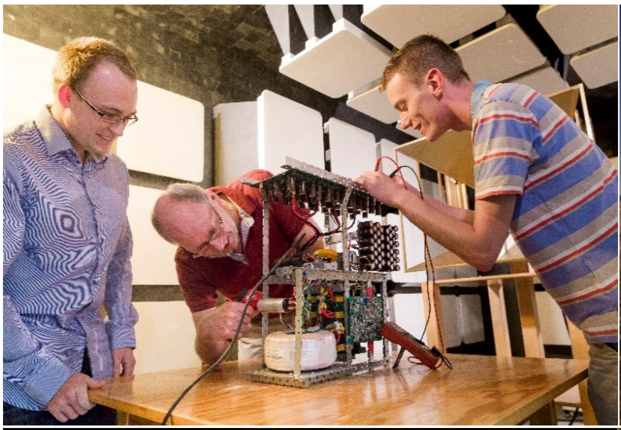

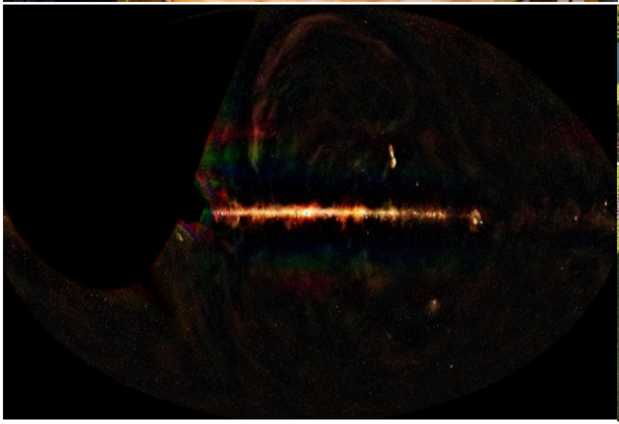

CURTIN INSTITUTE OF RADIO ASTRONOMY

POST-GRADUATE RESEARCH PROJECTS

For Applicants Commencing Studies in 2018/19

CURTIN INSTITUTE OF RADIO ASTRONOMY

Postgraduate Research Projects for commencement in 2018/19

CURTIN INSTITUTE OF RADIO ASTRONOMY

Curtin's Institute of Radio Astronomy (CIRA) offers relevant, practical, and forward-thinking postgraduate research training to advance your career in astronomy, space science, technology, physics, or engineering (in particular combinations of these disciplines).

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 deeply 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 Astrophysics in 3D (ASTRO-3D). With a large number of collaborators and partners across Australia and internationally, we offer our students an international research experience.

This booklet highlights our current set of higher degree research projects suitable for commencement during 2018 & 2019. These projects cover a range of aspects of modern astronomy including observational astronomy, analytical astronomy, and radio astronomy engineering. Students will gain vital skills as part of their study with us including analysing huge datasets (often multi-wavelength), working in teams and collaborations, as well as communicating their results, both written (paper publication) and via presentations at major conferences. Depending on the focus of the student's project, their research may include opportunities to develop skills with telescope proposals and observing at Australian and international facilities and supercomputing experience. Many of our projects are designed to develop expertise ready for the next era of radio astronomy, most notably the Square Kilometre Array (SKA).

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

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

We look forward to hearing from you!

Professor Steven Tingay

CIRA Executive Director

All queries: AppPhD_CIRA@curtin.edu.au

A Census of Young Black Holes via Measurements of Interplanetary Scintillation

Research Field	
Radio Astronomy	

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
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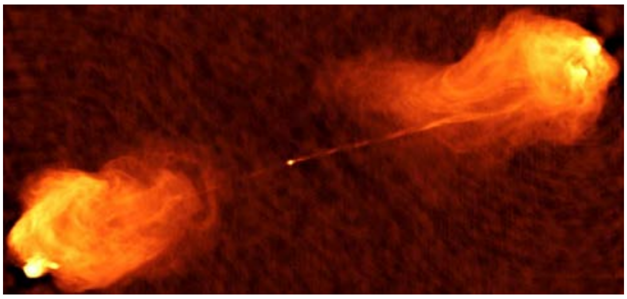
Co-Supervisors
Dr John Morgan
Dr Jean-Pierre Macquart

The infalling of matter into the central supermassive black hole in a massive galaxy causes the nuclear region to become extremely luminous, an object known as an Active Galactic Nucleus (AGN). The jets from AGNs transport matter outwards, terminating as bright spots called hot-spots, seen as part of radio galaxy lobes. At radio frequencies >1GHz, the brightness of hotspots decreases with increasing frequency, but at low radio frequencies (~100MHz) the behaviour is poorly understood, since only a handful of objects have been studied in detail. A large study of hotspots at low frequencies has not been technically feasible due to the challenges of achieving sufficiently high angular resolution to separate the hotspot and lobe emissions.

The Murchison Widefield Array (MWA), operated by the Curtin Institute of Radio Astronomy, is a low-frequency radio interferometer unparalleled in its wide field of view and its imaging fidelity, making it an excellent instrument to study powerful radio galaxies. Although a remarkably flexible instrument, its angular resolution does not exceed 1 arcminute.



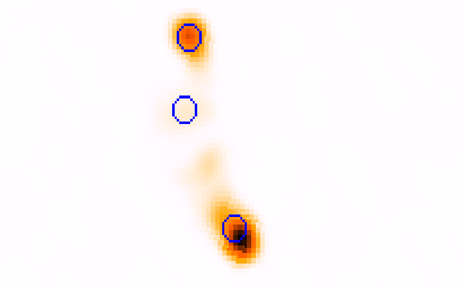


Figure 1 *(Above): Powerful radio galaxy Cygnus A with AGN core (centre), jets and hotspots on lobes. Such detailed images at low frequencies are currently not possible due to angular resolution limitations.* Figure 2 *(Right): 3C33 as it appears in a low frequency survey (TGSS), indicating a presence of hotspot in the Southern lobe, but the resolution is not sufficient to separate lobe and hotspot emission.*

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

The powerful technique of IPS on wide field-of-view is an important new development, and its full implications in the era of the Square Kilometre Array are not yet fully appreciated. There is therefore a unique opportunity for a student to contribute to the development of a technique which can directly inform SKA design studies and leverage it to perform new science with the SKA.

The project would require a student with an interest in confronting technical challenges in order to perform novel science. Experience in radio astronomy or big data computation would be beneficial. The project can be tailored to suit the individual candidate's interests, whether they be in Radio Galaxies, SKA science, or high-performance computing.

Advanced Calibration and Imaging with the MWA

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
Dr Natasha Hurley-Walker
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Co-Supervisors
Dr André Offringa (ASTRON)

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

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

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

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

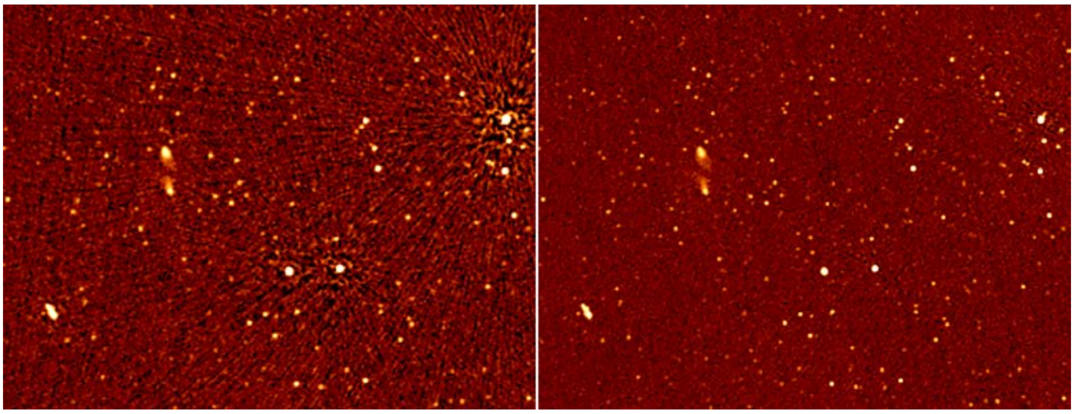

Figure: *Example MWA data before (left) and after (right) improved calibration*

An effective cross-matching framework for catalogues and images

Research Field
Radio Astronomy/ Astroinformatics

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
Dr Paul Hancock
Dr Rajan Chhetri

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

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

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

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

When complete, this project will be able to demonstrate a method by which:

1. Radio images can be stacked together to increase sensitivity, even in the presence of ionospheric distortions, and
2. Catalogues of radio sources can be combined.

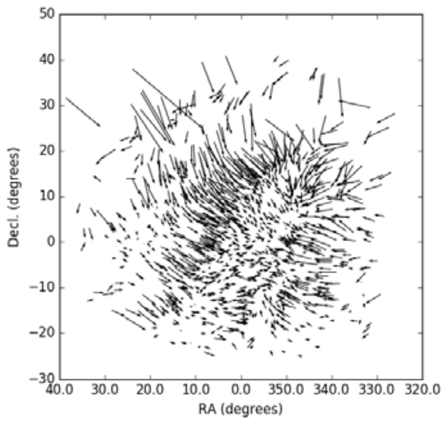

Figure*: Offsets between observed positions of radio sources and their nearest crossmatch in a catalogue. The hole near RA=345, Dec=30 is due to the offsets being too large to successfully crossmatch. In some areas nearby sources have wildly discrepant offsets, which may indicate that the crossmatch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

Application of spatial filtering RFI mitigation techniques to MWA and SKA1-Low

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

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

Research Field

Electrical Engineering
Radio Astronomy

Project Suitability

Masters
PhD

Project Supervisor

Prof David Davidson
david.davidson@curtin.edu.au

Co-Supervisors

Dr Greg Hellbourg

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

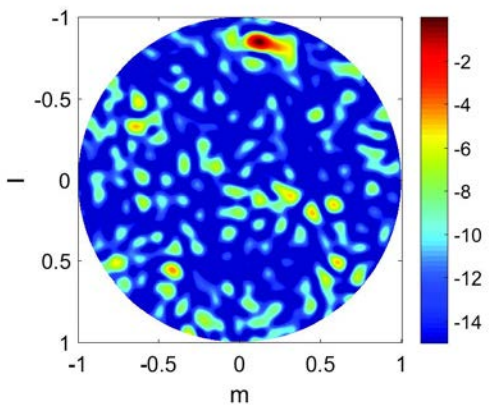

Figure 1*: A sky map with an RFI source visible at upper right. [Steeb et al, 2016 RFI]*

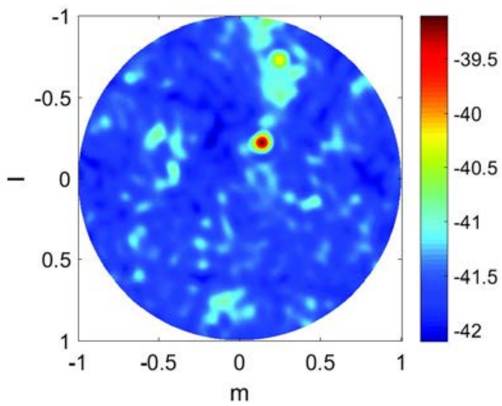

Figure 2*: The map with the RFI source removed using a spatial filtering method [Ibid]*

Calibration and imaging for SKA1-Low: station modelling

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

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

Research Field

Radio Astronomy (Instrument Calibration)

Project Suitability

Masters

PhD

Project Supervisor

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Co-Supervisors

A/Prof Randall Wayth

A/Prof Cathryn Trott

Dr Adrian Sutinjo (TBD)

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

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

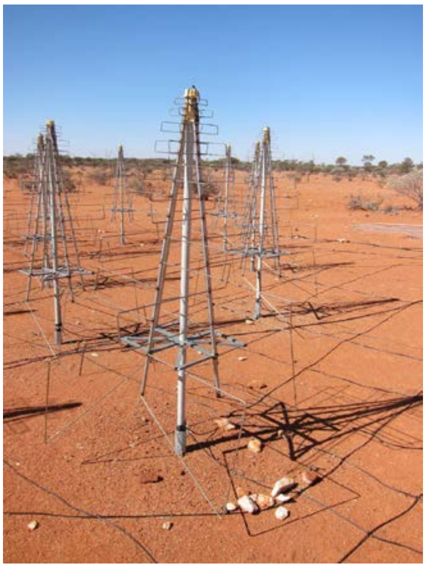

Figure 3: *The AAVS 0.5 prototype*

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).

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
Dr Natasha Hurley-Walker
Dr Chris Jordan

Low-frequency radio observations (<400 MHz) present unique challenges; principal among these is the effects of the ionosphere, an upper layer of the atmosphere which is weakly ionised (~1% of particles), caused by UV/X-ray emission from the Sun. As a radio wave passes through this plasma it is refracted, causing 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, 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 2 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.

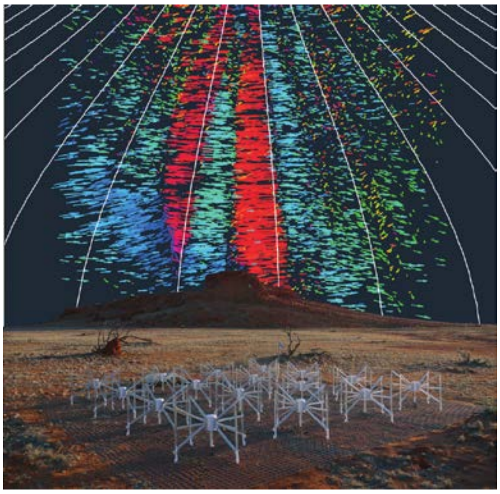

Figure: *The effect of the ionosphere on the sources seen by the MWA during a particularly extreme event. Each arrow represents the shift in position of a source; colours indicate directions. Earth's magnetic field lines are shown as white lines.*

The MWA doubled the maximum separation of its antennas in 2017, so this analysis may feed into designing calibration methods for the extended array. The student will be able to work with experts in the field of radio astronomy to develop methods and apply them as the extended MWA data is analysed. 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.

Chasing Fast Spinning Pulsars with the First SKA Precursor

Research Field	
Observational Pulsar Astronomy	
Project Suitability	
PhD	
Honours	
Project Supervisor	
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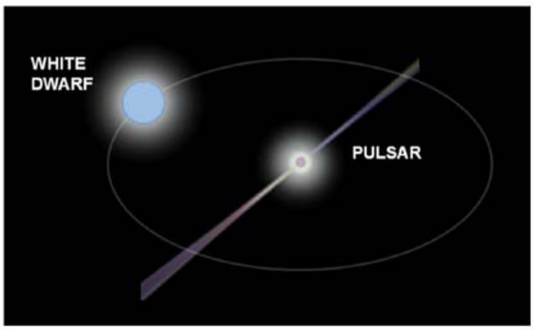
Co-Supervisors	
Dr Steven Tremblay	
Dr George Hobbs (CASS)	

Pulsars are proven laboratories for advancing fundamental physics; those with spin periods of the order of a few to several milliseconds – the so-called *millisecond* pulsars – are particularly promising for a wide variety of science. Their clock-like stability can be exploited for applications ranging from detecting gravitational waves to probing the state of ultra-dense matter. As such, doing *fundamental physics with pulsars* is a headline science theme for the Square Kilometre Array (SKA) telescope, e.g. making a direct detection of nanoHertz gravitational waves is a key science driver for the Phase 1 SKA.

Pulsars are generally brighter at radio frequencies below 300 MHz, in which Australia's Murchison Widefield Array (MWA) operates. The MWA is an official Precursor for SKA-Low, i.e. the low-frequency component of the SKA. However, finding fast-spinning pulsars at low frequencies poses several major challenges. In particular, traditional approaches involving tiling large areas of the sky and searching through thousands of pencil beams become computationally prohibitive. The large field-of-view and interferometric advantages of the MWA, along with its unique capability to record high-time resolution data from large parts of the skies at once, bring some exciting prospects to circumvent these formidable challenges.

This project will leverage a number of recent advances uniquely applicable to low-frequency wide-field interferometric arrays like the MWA. For example, implementing the hybrid approach of semi-coherent de-dispersion (Bassa et al. 2017) to process high-time resolution voltage time series data from the MWA will enable achieving optimal detection sensitivity to short-period pulsars. Furthermore, image-based techniques can be employed for efficient identification of promising pulsar candidates. These strategies will help accelerate the process of discovery and confirmation of pulsars, their rapid sky localisation and detailed characterisation. A demonstrable success in this area will bolster the prospects of SKA-Low to emerge as an efficient pulsar discovery machine.



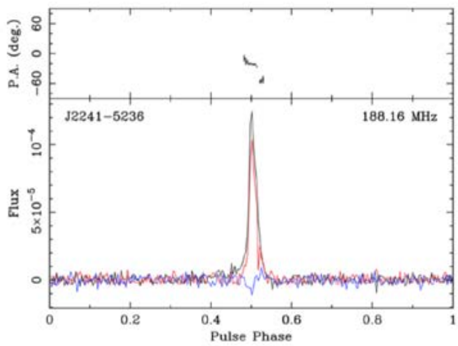


Figure (above): An artist's impression of a fast-spinning (millisecond) radio-emitting pulsar, in binary orbit with a white-dwarf companion star. Figure (Right): *MWA detection of a pulsar that spins at a rate of 456 times per second.*

Determining the Origin of the Most Massive Clusters

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
Dr Guillaume Drouart

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 are dominated by massive 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 surveys, Sunyaev-Zel'dovich effect) become much less sensitive. High redshift radio galaxies are known to lie in over-dense, proto-cluster environments and to be beacons regions of extreme star formation. This is due to the radio galaxy being powered by a massive and rapidly growing black hole. Scaling relations then suggest that this black hole will be in the most massive dark matter halo. This project will take advantage of low-frequency radio surveys with the Murchison Widefield Array (MWA) and combine it with NASA's mid-infrared *WISE* mission to find and characterise new distant, massive proto-clusters.

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. 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.

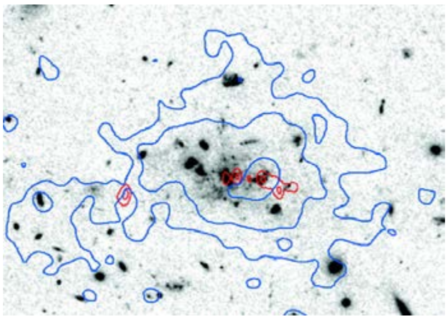

Figure: *The Spiderweb Galaxy. Deep Hubble image of the core of the MRC 1138-262 protocluster at z = 2.2 obtained with the Advanced Camera for Surveys.(Miley et al., 2006). Superimposed on the HST image are contours of Lyα (blue) obtained with ESO's very Large Telescope (VLT), delineating the gaseous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

Dying Radio Galaxies

Active galactic nuclei (AGN) are galaxies which host a supermassive black hole which is accreting matter and expelling jets along its magnetic axis. These highly ionised and fast-moving jets cause powerful synchrotron radiation to be emitted into space; radio astronomers can detect the AGN by seeing these jets extending from the host galaxy.

The life cycles of AGN are poorly understood; in particular it is not clear what happens when the jet emission process shuts down: why does this happen? How quickly do the radio jets fade? Why do some galaxies restart activity? Do different kinds of galaxies host more or less activity? What about earlier in time in the Universe? In order to answer these questions, we need to find a larger number of radio galaxies in the dying phase than the handful that are currently known.

Research Field	
Radio Astronomy	
Project Suitability	
PhD	
Honours	
Project Supervisor	
Dr Natasha Hurley-Walker	
nhw@icrar.org	
Co-Supervisors	
Prof Melanie Johnston-Hollitt	

The difficulty in finding these galaxies is that the radio emission at high frequencies fades faster than that at low, their overall brightness is low, and they also tend to be very diffuse and extended. Fortunately, the GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey is sensitive to these objects, and has the potential to find hundreds if not thousands of dying radio galaxies, finding the missing piece of the AGN population puzzle.

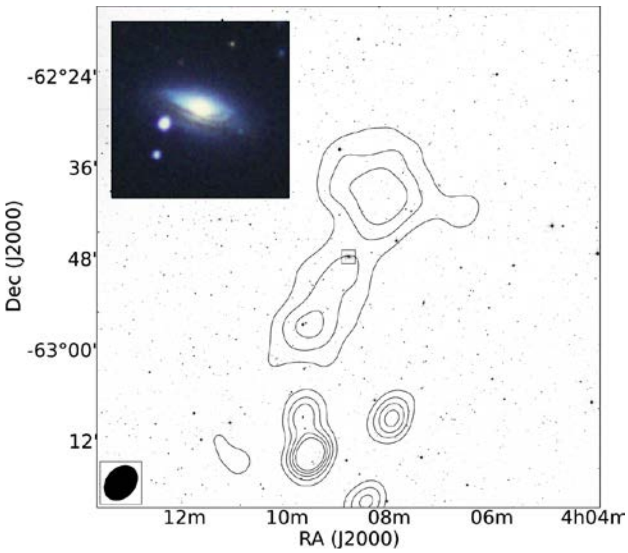

Figure: *An unexpected discovery of fading radio jets around the galaxy NGC1534, using early MWA observations; see [Hurley-Walker et al. 2015](#).*

The work will involve searching the GLEAM images for dying radio jets and cross matching them with infrared and optical images in order to identify the host galaxies, which will allow us to answer some of the big questions above.

This work would suit a student with good organisational skills and an interest in astrophysics and/or radio astronomy. Depending on the level of degree, the project can be as short as simply detecting new objects or as long as a large population study, with potentially many resulting publications. Programming, particularly python, will be useful.

Evaluating MWA operational performance using UAVs and electromagnetic simulation

Research Field
Engineering

Project Suitability
MSc/PhD

Project Supervisor
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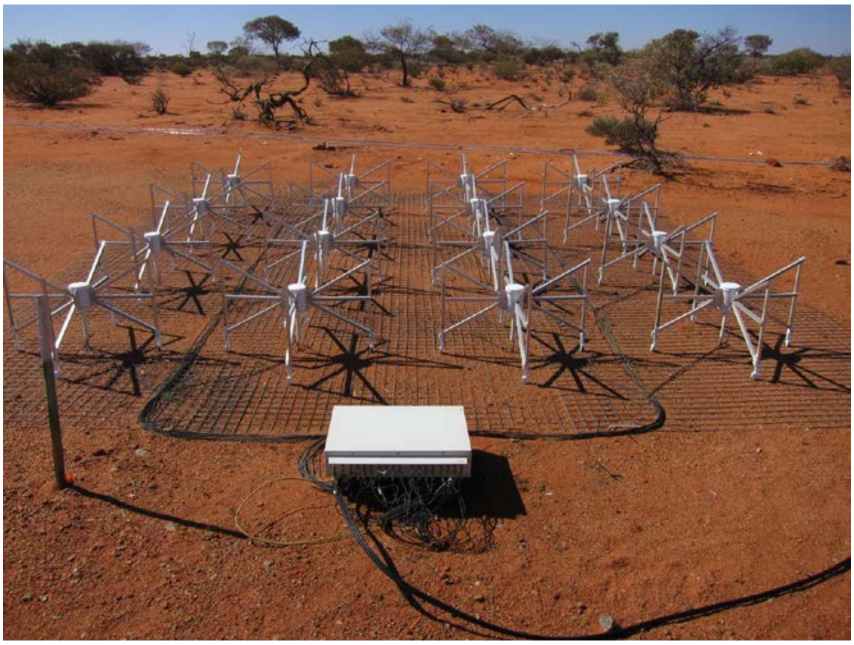
Co-Supervisors
To be advised

The Murchison Widefield Array has been operational on the Western Australian SKA site since 2013 (see photo below of a 16 antenna tile). The system is potentially vulnerable to damage by the elements, as well as wildlife. A recently proposed method to evaluate the current status of the system using UAVs and photometry requires engineering simulations to establish acceptable degradation of the antennas from the viewpoint of electrical performance.

The aim of this project is to establish a body of knowledge regarding the conditions (deformation of the antennas, etc) under which the system will still perform well, and link this to data which can be captured by UAVs. This may include the use of sophisticated techniques from optimisation theory such as surrogate modelling. Methods developed here will be applicable to a broad range of outdoor antenna applications in challenging environments, including communication, defence and space.



Evolution of the Radio Population Across Cosmic Time

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
Dr Minh Huynh (UWA)

Radio surveys are powerful tools for tracing the evolution of star forming galaxies and their central super-massive black holes across cosmic time. The radio luminosity of a galaxy is a measure of either its star formation rate or the power of the jets from the super-massive black hole. This project will utilise data from the plethora of cutting edge radio surveys conducted by Australian based facilities such as the Murchison Widefield Array, the Australian Square Kilometre Array Pathfinder and the Australian Telescope Compact Array. The radio sources from these surveys will then be cross-matched with multi-wavelength surveys such as the Galaxy and Mass Assembly (GAMA) survey in order to identify their host galaxy.

This project will include:

(i) processing and conducting some of the radio observations in these surveys, and becoming an expert in radio interferometry,

(ii) cross-matching with GAMA to identify the host galaxies of these radio sources and determine the redshift and nature the of these sources,

(iii) calculate the global evolution of star forming galaxies and black hole jet activity as a function of look back time,

(iv) use these observations to constrain models of galaxy and black hole evolution.

This project will uniquely exploit the broad frequency coverage of Australian radio telescopes and pave the way for deeper radio surveys with the Square Kilometre Array.

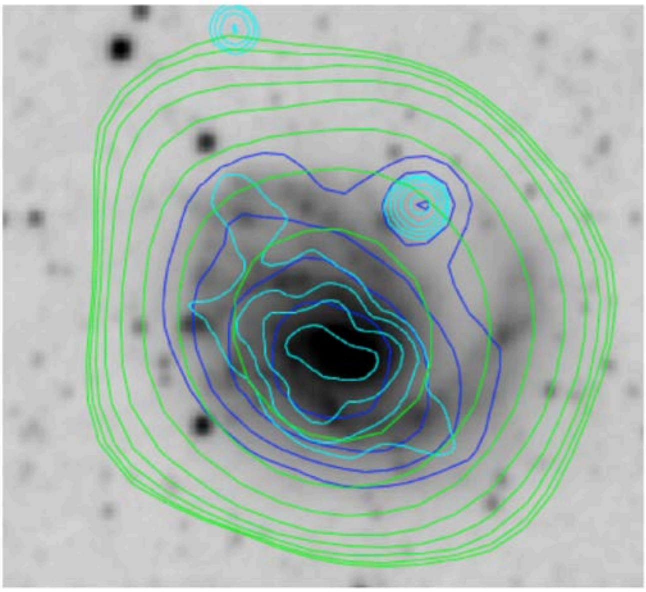

Figure: *Greyscale optical image of the galaxy Messier 99 overlaid with radio surveys of different frequencies and resolution. The radio emission is arising from the star formation in its spiral arms.*

Curtin University

Exploring the early Universe with the MWA and the Moon

Research Field

Radio Astronomy

Project Suitability

PhD

Honours

Project Supervisor

Dr Benjamin McKinley

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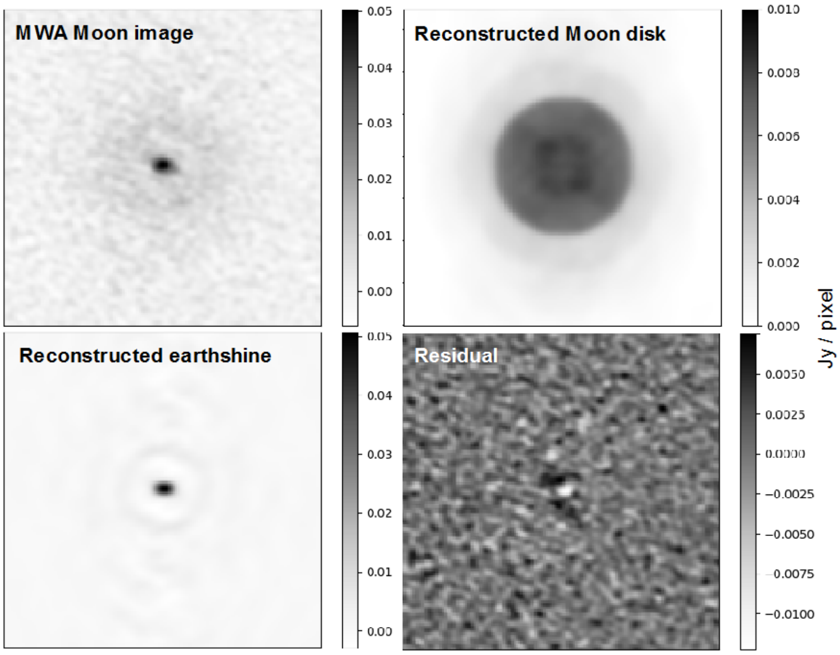
Co-Supervisor

A/Prof Cathryn Trott

Little is known observationally about the period in the early Universe between when the first stars formed and when the Universe was completely ionised by radiation from stars, galaxies and active black holes. Our group here at the Curtin Institute of Radio Astronomy is attempting to learn about this epoch by observing the 21-cm radiation emitted by neutral hydrogen, which has been redshifted by the expansion of the Universe to metre wavelengths. To achieve this we use the Murchison Widefield Array (MWA) telescope - an interferometer consisting of 256 antenna tiles, tuned to low radio frequencies (including both the FM radio and digital TV bands), situated in the West Australian outback, about 800 km north of Perth.

Early on, the Universe is mostly made up of neutral hydrogen. When the first stars and galaxies form, they create bubbles of ionised gas as their radiation dislodges the electrons from the surrounding hydrogen atoms. Without their electron, the hydrogen atoms do not emit 21-cm radiation, hence the bubbles of ionised gas create a detectable signature in the radio emission that reaches earth billions of years later. The MWA is ideally suited to an experiment to detect the spatial fluctuations in this redshifted 21-cm signal, however, because it is blind to the mean signal across the sky (a property of interferometers), it cannot detect the bright, average 21-cm signal that many other experiments around the world are targeting.

This is where the Moon comes in. The Moon can be considered a black-body of known temperature and can therefore be used as a reference to measure the average sky temperature! By measuring the signal from the Moon, we can recover the average redshifted 21-cm signal and compare this to computer simulations of the early Universe. However, there are many challenges involved in the experiment, which you can help to solve. Depending upon your interests and skills the project could be tailored to include: interferometric calibration and imaging, computer modelling of reflected terrestrial transmissions (earthshine), separation of earthshine from the Moon's thermal emission (as in the figure to the left), modelling and removal of Galactic foregrounds and extraction of the faint cosmological signal from multiple epochs of observations. There are a lot of data already collected and waiting to be processed and many opportunities to both learn the intricacies of radio astronomy and to try new ideas and make ground-breaking discoveries!



Exploring the separation of foregrounds and early Universe signal with the bispectrum estimator

Research Field
Radio Astronomy

Project Suitability
Honours

Project Supervisor
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Co-Supervisors
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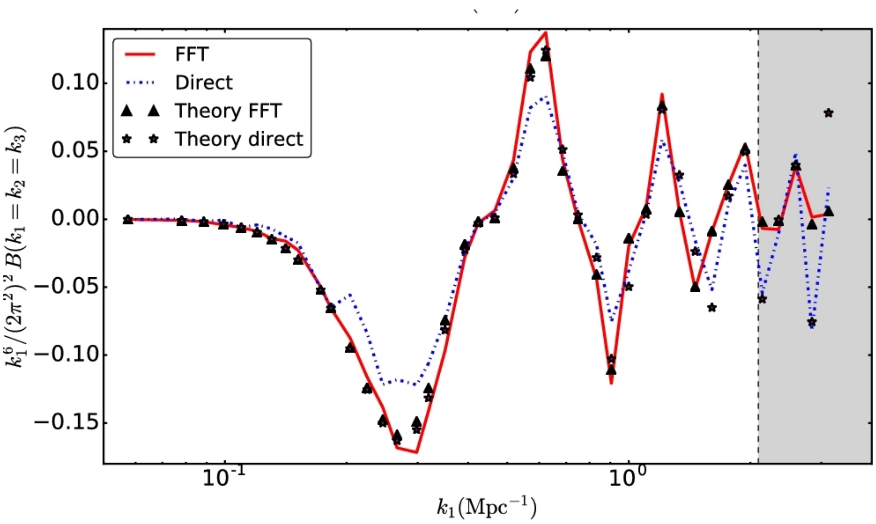
Dr Catherine Watkinson (ICL)

The emission line signal from neutral hydrogen in the first billion years of the Universe traces the formation and growth of structure, and the birth, lives and deaths of the first stars. This weak radio astronomical signal can be detected with low-frequency radio telescopes, such as the Curtin-operated Murchison Widefield Array (MWA), but it is obscured by the bright and ubiquitous foreground star-forming galaxies and quasars, and diffuse synchrotron emission from our own Galaxy. The bispectrum (triple product) extracts information about the level of non-Gaussianity in data. This project will understand the response of the MWA to the bispectrum estimator, and explore how it can be used to extract foreground contaminants.

The bispectrum is a tool that can be used to extract information about the non-linear growth of structure in the Universe, as traced by the 21cm neutral hydrogen emission line. It can also be used to extract non-Gaussian foreground contamination from the weak signal. The bispectrum has a different signature in radio astronomy data than the typically-used power spectrum estimator. This project will explore the structure of this signature for the MWA and other telescopes, and use this to understand its ability to separate signal and foregrounds.

This project would suit a student with a good grounding in statistical techniques, and who has an interest in statistics, data processing, the early Universe, and computing. This work has potential implications for future telescopes, such as the Square Kilometre Array (SKA).

The figure below shows an example of a bispectrum for the non-linear growth of structure in the Universe (taken from Watkinson et al. 2017, MNRAS, 472, 2). The noise level on each of these measurements is dictated by the design of the telescope observing it. This project will understand the noise properties of the MWA for bispectrum estimators.



From Low-frequency Pulsar Observations to Interstellar Holography

Research Field

Observational Pulsar Astronomy

Project Suitability

Honours

Masters

PhD

Project Supervisor

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Co-Supervisors

Dr Willem van Straten (AUT)

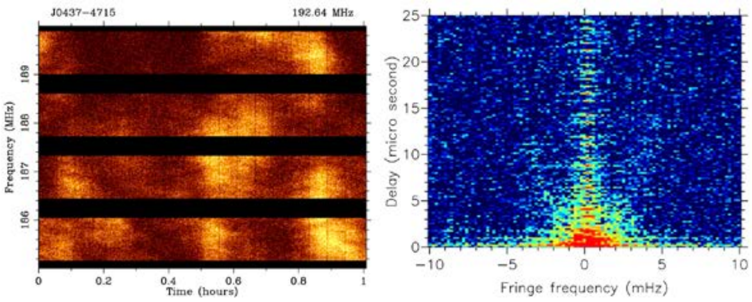
Dr Steven Tremblay

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

Multipath propagation through the ISM gives rise to a rich variety of observable effects, many of which can be meaningfully used to study the smallest structures in interstellar turbulence. For decades, possible investigations were limited to the use of more traditional scattering and scintillation techniques, which are generally useful for a statistical characterisation of the ISM along the pulsar's sight line. Deflected parts of the radiation may also occasionally give rise to subtle features in the secondary spectra of pulsar scintillation (e.g. parabolic arcs), and these can be exploited to pinpoint the location of turbulent plasma or probe any anisotropy that is present. A particularly exciting development has been the application of novel techniques such as cyclic spectroscopy (Demorest 2011), and phase-retrieval algorithms that enable coherent de-scattering; i.e. simultaneous recovery of the pulsar's intrinsic signal and the signal delay structure of the ISM (Walker et al. 2013).

This project will capitalise on new instrumentation and capabilities that are being developed for pulsar observations with the Murchison Widefield Array (MWA), which enable signal reconstruction at a very high time resolution of the order of microseconds. Its sister facility, the Engineering Development Array (EDA), can provide even finer time resolution (~nanoseconds), however it is primarily suited for bright pulsars. Development of the related instrumentation and signal processing, and exploiting them for novel science will form the central theme of the project. Potential topics include accurate characterisation of signal distortion caused by the ISM (important for high-precision timing applications) and holographic reconstruction of the interstellar microstructure (at resolutions unattainable by any other techniques). The project will involve close collaboration with the Univ. of Auckland (NZ) and Manly Astrophysics.

Figure: *Dynamic scintillation spectrum of the millisecond pulsar J0437-4715 (left panel) and its secondary spectrum (right panel), from MWA observations at a frequency of 192 MHz (Bhat et al. 2016). Faint parabolic arc-like features arise from the deflected parts of pulsar's scattered radiation. The indicated delays (~a few microseconds) will be directly measurable using the new capabilities and the advanced techniques that will be realised through this project*



GLEAM-X: Exploring the Universe in Radio Colour

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

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

Research Field
Radio Astronomy
Project Suitability
PhD
Project Supervisor
Dr Natasha Hurley-Walker
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Co-Supervisors
To be advised

Combining the datasets will create the most sensitive survey output from the MWA ever. As well as generating images and catalogues that are widely useful, the student will also undertake a **focussed research project** that utilises the data. This could include (but is not limited to): transient/variable radio sources, scintillation, the ionosphere, and continuum studies on objects such as radio galaxies, galaxy clusters, supernova remnants, and pulsars. 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 survey.

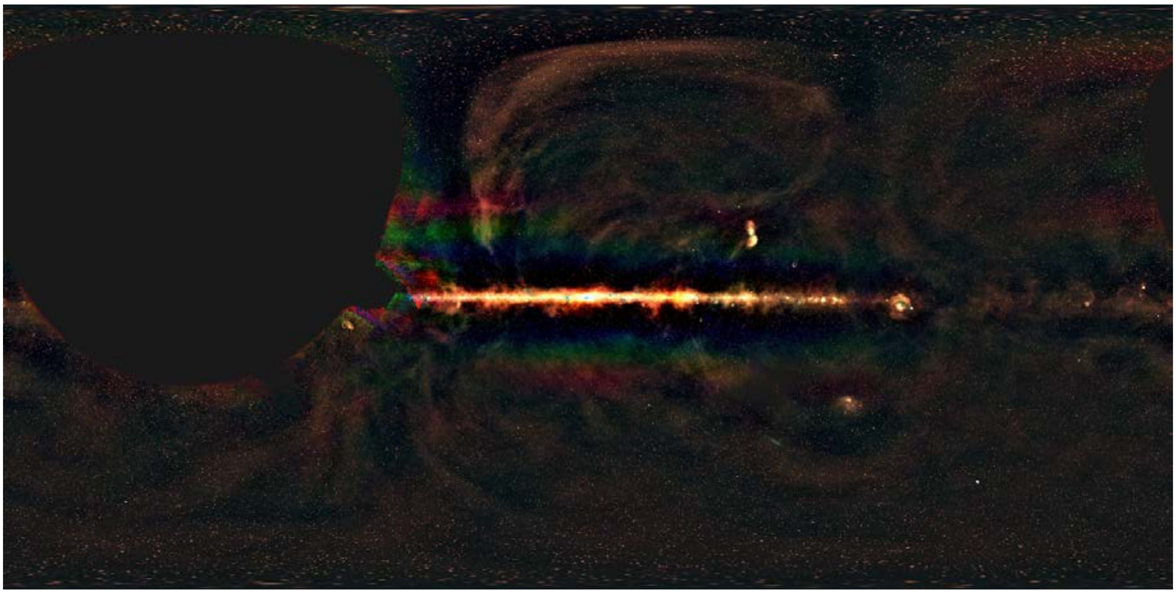

Figure: *The first year of GLEAM observations, covering the whole Southern Sky. This is the first radio colour view of our universe: find out more via this TED talk: http://bit.ly/nhwted*

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.

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
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Dr James Allison (Oxford)
Dr Nick Seymour

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".

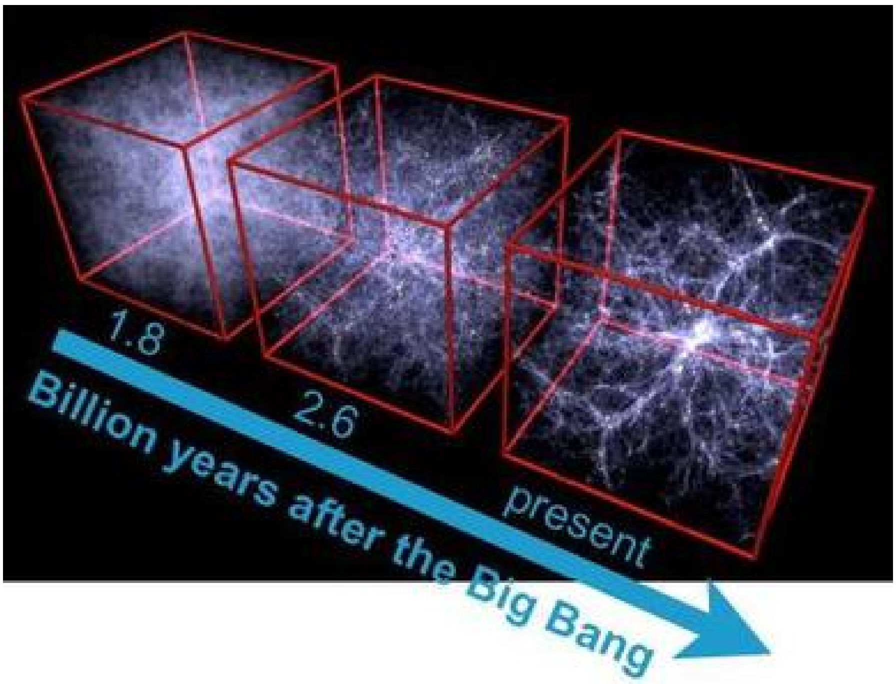

Figure: *The Universe ionises, transforming from a sea of opaque hydrogen into the complex structures we see today.*

Identifying optical counterparts of radio sources using citizen science

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
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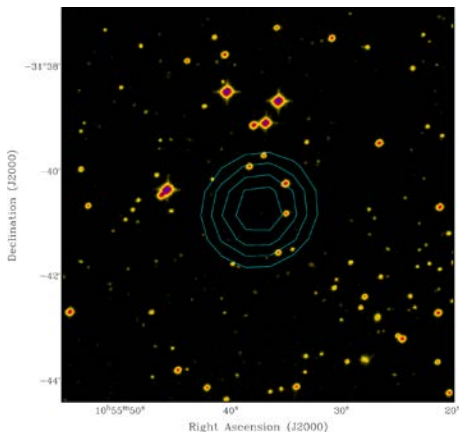
Dr Nick Seymour

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.

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

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



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

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

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

In-situ Measurements of MWA antenna beam shapes

Research Field
Radio Astronomy/Engineering

Project Suitability
PhD
Honours (as appropriate)

Project Supervisor
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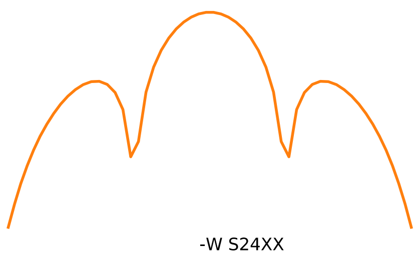
Co-Supervisors
A/Prof Randall Wayth
Dr Jack Line

The Murchison Widefield Array (MWA) telescope is one of the next generation of radio interferometers that utilises a large number of relatively simple, low-cost antenna elements and shifts the complexity of the telescope into the digital processing and computing stages. This design philosophy allows the telescope to have high sensitivity and good image quality at a greatly reduced cost compared to traditional radio telescopes. The MWA is a precursor to the planned Square Kilometre Array (SKA) telescope, which will be the largest radio telescope ever constructed, and is located on the future site of the SKA at the Murchison Radio-astronomy Observatory in Western Australia. The Curtin Institute for Radio astronomy is heavily evolved in both the MWA and the SKA projects in terms of both engineering and science and our team is working at the forefront of radio-astronomy technological and computational development.

The design philosophy of the MWA and its ambitious scientific goals mean that it is essential to know how the instrument itself affects the signals being measured, so that these effects can be accounted for in the data processing. For example, when an image is made of the sky, it has imprinted on it the sensitivity pattern of the antennas. To recover the true sky we must divide this antenna response out. But how do we know the response of the antennas? Computer modelling and simulations have been used to construct detailed models of the antenna response patterns, which vary with observing frequency, and for the MWA can be quite complex. Verifying that these models are correct, however, is not a trivial task. Additionally, we know that each low-cost antenna is not perfect in construction and that there are likely to be variations in response from antenna to antenna. It is therefore critical that we be able to measure the antenna response (also known as beam pattern) across the sky.

This project aims to measure the MWA antenna beam patterns in order to verify that the models we are currently using in our scientific analyses of the data are correct, and to determine the level of variability between antennas due to their imperfect construction and state of maintenance. We have recently had some success in measuring a small number of antenna beam shapes using ORBCOMM satellites and small handheld spectrum analysers, deployed at the MWA telescope during a series of week-long site visits. An all-sky beam map and a slice comparing the measurements to a beam model are shown in the figure above. In this project we aim to increase the number of antennas that have been measured, develop improved software and methods for analysing the data and investigate new methods of data collection - possibly including the use of drones. This is an ideal project for a motivated self-starter who enjoys hands-on engineering, software development and data analysis.



KM3NeT: studying neutrinos in the ocean depths

KM3NeT is a cubic kilometre experiment being constructed at the bottom of Mediterranean Sea. It is designed to detect neutrinos – almost massless subatomic particles – using the flashes of light they give off when they interact. By detecting them, KM3NeT will study the origin of the highest-energy particles in nature – cosmic rays – and resolve a long-standing question of particle physics, the neutrino mass hierarchy.

Research Field
Multimessenegr astrophysics

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
Prof Steven Tingay
Dr Gemma Anderson

The Curtin Institute of Radio Astronomy is collaborating with the European consortium constructing KM3NeT. Neutrino telescopes primarily look downwards, through the Earth – and so KM3NeT sees the same sky as in Australia. Our aim to identiy the astrophysical events producing the neutrinos KM3NeT detects, be they hypernovae, accreting black holes, neutron star mergers, or something as-yet unknown. Several projects are available in 'multimessenger astronomy', using astronomical expertise to study proposed cosmic ray/neutrino sources, and understand how to use KM3NeT to search for them. The predecessor of KM3NeT, ANTARES, has been operating for ten years, and its data are available for developing analysis methods to be used with KM3NeT.

The key aims of the project will be:

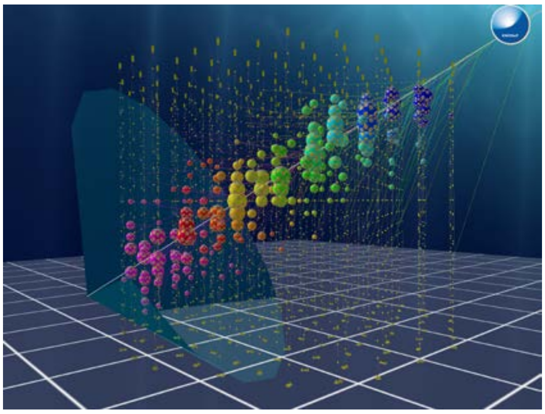
(i) Understand how KM3NeT detects neutrinos, and how to reconstruct their properties

(ii) Develop tests of neutrino production in astrophysical sources

(iii) Apply these searches to first data from KM3NeT phase 1, and archival data from ANTARES

Projects targeting particle physics, such as searches for supersymmetry and charm-meson decay, are also available.

Successful applicants will be expected to travel to Europe to attend collaboration meetings, and be willing to spend a one-month exchange at collaborating institutes (e.g. in Italy, Spain, Netherlands, France, and/or Germany), as appropriate to the project. They should also be prepared to collaborate with expert astronomers from radio, optical, and other backgrounds, as required for astrophysical modelling.



Simulation of a neutrino event in KM3NeT. The neutrino interacts to produce a muon (thick beige line) which travels through KM3NeT, producing Cherenkov light (thin coloured lines; cone indicates shock front). This light is detected by KM3NeT optical modules (circles). The time (blue: early, red: late) and magnitude (size of circles) of the photon signature can be used to reconstruct the original neutrino's energy and direction.

Lunar surface roughness

Research Field
Particle physics/radio astronomy

Project Suitability
PhD
Honours (as appropriate)

Project Supervisor
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Co-Supervisors
Prof Jaime Alvarez-Muniz (University of Santiago de Compostela, Spain)

Cosmic rays are the highest-energy particles in nature, impacting the Earth with energies more than a million times higher than can be achieved with the Large Hadron Collider. Yet we don't know where they come from. This is because cosmic magnetic fields deflect cosmic ray trajectories during propagation. As cosmic ray energy increases, this deflection may become small enough to trace cosmic rays back to their origin – but the highest-energy particles are very rare, arriving at a rate of one per square kilometre per century.

How to detect enough of these 'ultra-high' energy cosmic rays? The 'lunar technique' is a method for solving this problem. When a cosmic ray interacts, it gives off a burst of radio-wave radiation, lasting a few nanoseconds. By pointing a ground-based radio-telescope at the Moon, cosmic rays hitting the lunar surface might be detected. Preliminary calculations suggest that the newest generation of radio telescopes might be sensitive enough to detect cosmic ray interaction on the Moon, and discover their origin. However – these calculations ignore the effects of the rough lunar surface. Solving this problem will be the aim of the project.

Aims of project:

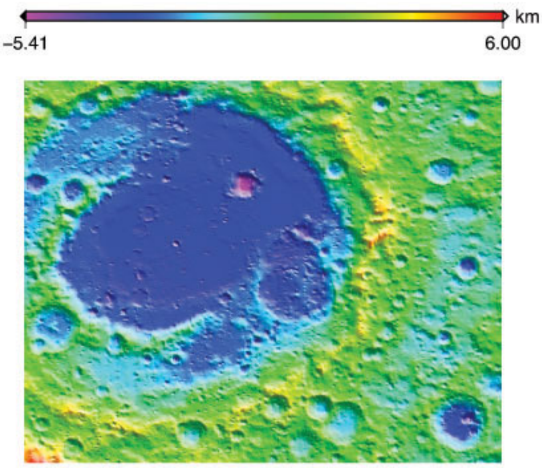
(i) Model the rough lunar surface.

(ii) Apply surface-transmission equations to model radio emission from cosmic ray cascades.

(iii) Determine whether current radio telescopes can observe these signals – and then go and discover them!

The results of this investigation will inform proposed lunar missions such as LORD (Russia), and potential ground-based radio observations with the Parkes, Effelsburg, and FAST radio telescopes (Australia, Germany, China respectively). An honours project would target aims (i) and (ii), while a PhD student may have the opportunity of participating in observations, extending their results to experiments searching for neutrinos underneath the Antarctic ice, and potentially visiting international collaborators such as Prof Jaime Alvarez-Muniz in Spain.

Figure (Right): *Example measurement of the lunar surface by the Lunar Reconnaissance Orbiter (using laser rangefinding). Data such as this will inform models of the lunar surface.*
Figure (Below): *Bootprint of an astronaut on an Apollo mission. Data such as this will not be used to inform models of the lunar surface.*



Mapping sky brightness temperature at low radio-frequencies (50-300 MHz) using the Engineering Development Array

Research Field
Radio Astronomy/Engineering

Project Suitability
PhD
Honours (as appropriate)

Project Supervisor
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Co-Supervisors
A/Prof Randall Wayth

To fully exploit the scientific capabilities of the Murchison Widefield Array (MWA), and the upcoming Square Kilometre Array (SKA), astronomers need an accurate model of the large-scale structure of the low-frequency sky. Current models[1] are largely based on the monochromatic 408-MHz observations made by Haslam et al. in 1981. This project aims to dramatically improve the sky model by mapping the brightness temperature of the sky across a wide bandwidth of 50 to 300 MHz, using the Engineering Development Array (EDA; Wayth et al. 2017).

The EDA is a SKA station consisting of 256 bow-tie dipoles (identical to those used by the MWA). The EDA has a narrow primary beam of the order of a few degrees, complementary to the original observations by Haslam et al. This should enable brightness temperature mapping with reasonable accuracy, with potential to improve the resolution by utilising oversampling techniques. The calibration of the EDA data has already been proven using observations of bright radio sources such as Hydra A and 3C444.

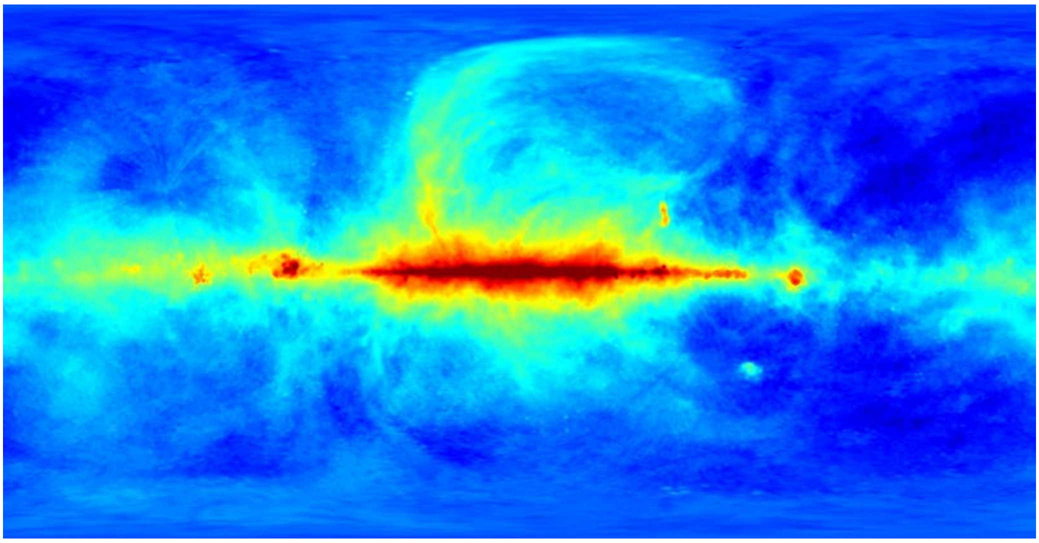

Figure 1: *Haslam 408 MHz Map (Haslam, et al., 1982)*

Figure 2 : *Engineering Development Array (EDA) at the Murchison Radio-astronomy Observatory*

[1] de Oliveira-Costa et al. 2017; http://space.mit.edu/home/angelica/gsm/

Mapping the magnetic field of white dwarfs

Research Field	
Stellar Astrophysics	
Project Suitability	
PhD	
Honours (as appropriate)	
Project Supervisor	
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Co-Supervisors	
A/Prof James Miller-Jones	

White dwarfs represent the final stage of stellar evolution for the majority of stars and they provide one the most sensitive probes into the history of stellar formation in the Milky Way due to their predictable cooling rates. A significant fraction of these stellar remnants harbours a magnetic field ranging from a few 100 G up to several 100 MG and it can affect the evolution and atmosphere structure of the white dwarf, as well processes such as accretion flows. The origin of magnetic fields in white dwarf stars remains unknown. Currently two leading theories have been proposed to explain the presence of magnetic fields in white dwarfs. The first is the fossil field origin, which means that the white dwarf has inherited the magnetic field from its progenitor, which is usually assumed to be a magnetic peculiar A and B star (Ap and Bp star). However, this scenario fails to explain the paucity of magnetic white dwarfs in close but non-interacting orbit with low-mass main-sequence stars. This leaves magnetic cataclysmic variables without direct progenitors, and as a result, a second origin was proposed. In this second scenario, a magnetic field is created within binary systems, either during a common envelope phase or in the merger of two white dwarfs. The two theories predict different magnetic field structures and rotational velocities. A study of the strength of the magnetic field, its surface structure and whether it is correlated with the white dwarf mass and/or cooling age will provide clues to the origin of the magnetic field. To understand the origin of magnetic fields and the role it plays in white dwarf atmospheres and evolution, we must first know the field strength and structure.

The European Southern Observatory (ESO) operates several 4m to 8m optical telescopes in the Chilean Atacama Desert which provides the best observing conditions on Earth. These telescopes are equipped with state of the art instruments covering a vast range of the electromagnetic spectrum from the near ultraviolet and optical to the infrared. Therefore, ESO provides the ideal tools that are needed to carry out detailed studies of white dwarf stars.

The aim of this project will be to study the magnetic field structure of white dwarfs known to show variability in photometry, spectroscopy or spectropolarimetry. You will calculate magnetic model spectra and develop fitting programmes to find a unique solution to the field structure through mapping the magnetic field on the surface of the white dwarf. The model spectra will be compared to photometric, spectroscopic and spectropolarimetric data. Since Australia has access to 8m class telescopes of the ESO and its vast range of instruments, this project will primarily use data obtained with ESO.

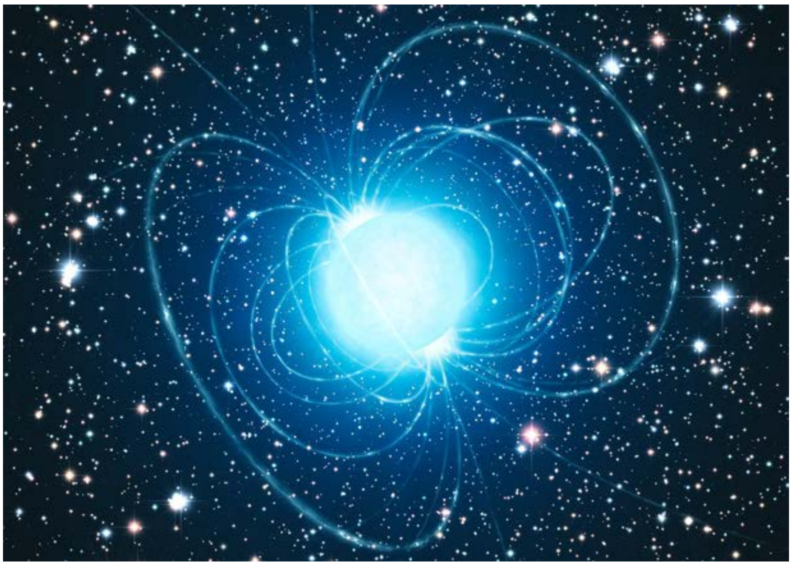

Figure 1: Artist's impression of stellar magnetic field lines (Credit: ESO/L. Calçada)

Measurement of brightness temperature of the Moon using the Engineering Development Array

The brightness temperature of the Moon (T_{moon}) is not well known at low radio-frequencies (<300 MHz). Such a measurement would provide a valuable input into the lunar occultation technique of the global Epoch of Reionisation (EoR) measurement. The lunar occultation method of the global EoR measurement has been developed for Murchison Wide-field Array (MWA; http://adsabs.harvard.edu/abs/2013AJ....145...23M) and LOFAR (http://adsabs.harvard.edu/abs/2015MNRAS.450.2291V). However, T_{moon} is a relatively poorly constrained parameter in the modelling.

Research Field
Radio Astronomy/Engineering

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
Dr Ben McKinley

The goal of this project is to test the feasibility of measuring the brightness temperature of the Moon using the Engineering Development Array (EDA; http://adsabs.harvard.edu/abs/2017PASA...34...34W). The EDA is a Square Kilometre Array (SKA) station consisting of 256 bow-tie dipoles (same as used by the MWA). The EDA with its very narrow primary beam (of the order of a few degrees) should enable brightness temperature mapping of the Moon with a reasonable accuracy (oversampling techniques might be necessary to improve the resolution). The calibration of the EDA data has already been tested by observations of bright calibrators (HydA or 3C444).

Figure: *Engineering Development Array (EDA) at the Murchison Radio-astronomy Observatory*

Measurement of Self-Generated Emissions from Radio Astronomy Instrumentation

In radio astronomy, we are interested in very feint extra-terrestrial signals. Radio interference from terrestrial sources or earthbound objects such as radio broadcast and satellite transmissions are inevitable no matter how remote the location of the radio observatory. The sources of these types of interference are outside the control of the instrumentation designers. Relevant mitigation strategy typically involves removal or avoidance of the undesired signal in post-processing

Research Field
Radio Astronomy/Engineering

Project Suitability
PhD
MPhil/Honours (as appropriate)

Project Supervisor
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Co-Supervisors
Prof David Davidson
A/Prof Randall Wayth
Dr Budi Juswardy

A related problem, which is within the control of the instrumentation designer, is that of *self-generated* emissions from the instrument in question. To minimize this type of interference, the designer must employ sound component selection as well as proper grounding, shielding and signal routing methodologies. The success of such designs must be ascertained by measurement, which leads to the first important question, namely: Which type and how much self-generated emissions is too much? A closely related question is: Which type and how much self-generated emission is measurable?

The aim of this project is to approach both questions leading to sensible emissions limit coupled with practicable, replicable, time-efficient and cost-effective measurement method. The resulting procedure will be tested in the laboratory and verified with Curtin-operated telescopes such as the Murchison Wiedfield Array and SKA Aperture Array Verification System (AAVS) 1.

Curtin University

Measurement of the Murchison Widefield Array (MWA) receiver temperature using sky observations, sky model and MWA primary beam model

Receiver temperature of a radio telescope (MWA bow-tie dipole in particular) can be measured in the laboratory. However, such measurements are complicated, have to take multiple factors into account and, therefore, require some form of verification. Fortunately, receiver temperature of a radio telescope can also be derived from the sky observations, model of the sky at low-radio frequencies of interest and model of the telescope's primary beam.

Ideally, it requires 24 hours of sky observations with the telescope in drift-scan mode (pointing at zenith with the sky passing overhead). Then, total power as a function of time in the sky observations (see the image below) is compared with the total power predicted by simulations (sky model convolved with the telescope primary beam) and gain and receiver temperature of the telescope can be measured by least-square fitting.

Research Field
Radio Astronomy/Engineering

Project Suitability
Honours

Project Supervisor
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Co-Supervisors
Dr Adrian Sutinjo
Mr Daniel Ung

A new laboratory method has recently been developed at CIRA by Dr. Adrian Sutinjo and his team. The method was successfully tested on the Engineering Development Array (EDA; http://adsabs.harvard.edu/abs/2017PASA...34...34W) and the receiver temperature obtained from the laboratory method agrees very well with receiver temperature derived from sky observations.

The aim of this project is to perform similar receiver temperature measurement of an MWA tile (4x4 array of MWA bow-tie dipoles) and compare the results with the predictions based on laboratory measurements and electromagnetic simulations of the mutual coupling between the bow-tie dipoles within an MWA tile.

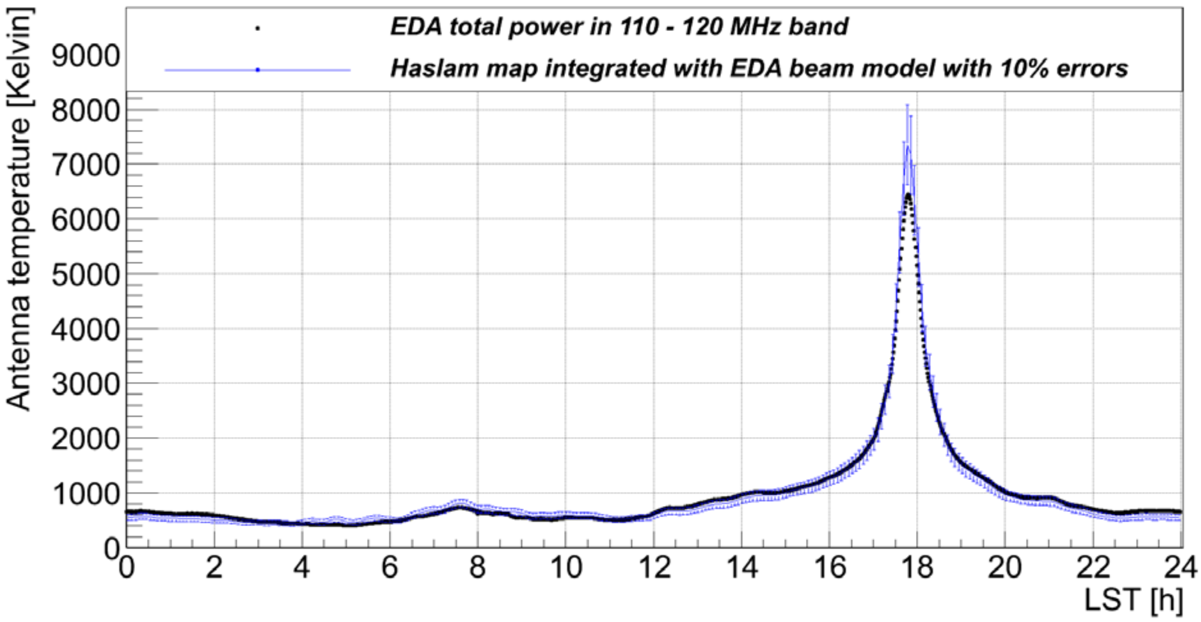

Figure 1: *Total power in the 110-120 MHz band as a function of local sidereal time (LST) observed with the EDA pointed at zenith The black data points are the EDA data (gain and receiver temperature were fitted in the entire 0-24 h LST range) and the blue curve with 10% error bars are the EDA beam model data integrated with the sky model (HASLAM map at 408 MHz scaled down to lower frequencies using a spectral index of -2.55).*

Metamaterials for radio astronomy engineering

Metamaterials are artificially engineered materials with electrical and magnetic properties not occurring in nature at radio frequencies – examples include "double negative" materials, with negative permittivity and permeability. These have been used in the theoretical development of transformation optics for electromagnetic cloaking, which has been demonstrated experimentally for some special geometries.

The aim of this project is to investigate the use of metamaterials for realizing new concepts in antenna elements for low-frequency radio telescopes, such as SKA-Low and other concepts. One line of investigation will focus on dense, regular arrays where strong mutual coupling complicates the design of wideband antenna arrays.

Research Field

Engineering

Project Suitability

PhD

Project Supervisor

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Co-Supervisors

Dr Adrian Sutinjo

The application of metamaterials is an important topic in contemporary antenna engineering in general and this project overlaps strongly with many other applications of antennas in telecommunications, defence etc.

Multi-messenger astrophysics: neutrinos, fast radio bursts, and gravitational waves, oh my!

Research Field	
Multimessenegr astrophysics	
Project Suitability	
Honours	
Project Supervisor	
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Co-Supervisors	
Dr Clancy James	
A/Prof Linqing Weng (UWA)	

'Multimessenger' astrophysics aims to extend astronomy beyond photons and study the universe using all four fundamental forces. The gravitational wave observatories LIGO and VIRGO measure the strain on space-time produced by the mergers of black holes and neutron stars. The ANTARES neutrino telescope studies particles which have traversed the entire Earth, and are thought to trace the origin of the highest-energy particles in nature, cosmic rays – wherever that may be. The Australian Square Kilometre Array Pathfinder, ASKAP, is surveying the universe for the shortest and most powerful bursts of radio waves known, and has detected an unprecedented number of these 'fast radio bursts'. Combining observations from these diverse instruments could allow the most complete picture to date of the high-energy universe.

Several possible investigations are available. One involves using the known location of fast radio bursts detected by ASKAP to improve the sensitivity of gravitational wave detection. Another involves the hypothesis that neutron stars may be sources of neutrinos, and will look for periodicity in the arrival times of ANTARES neutrinos. The key aims of such projects will be:

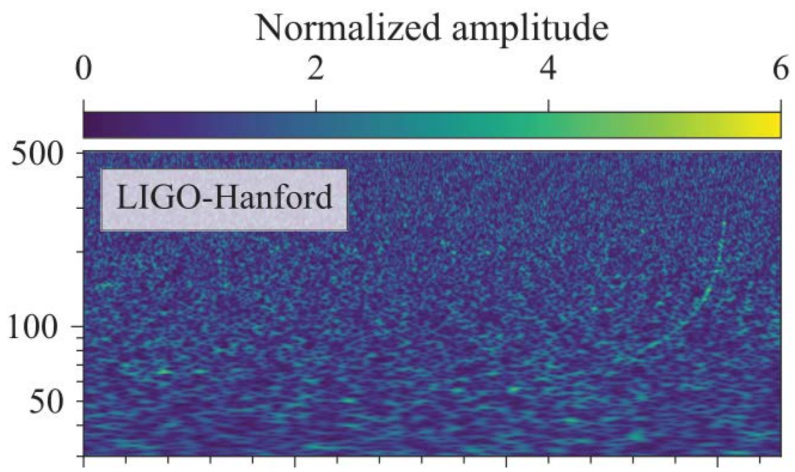
(i) Understand data from diverse experiments.

(ii) Develop a testable hypothesis of astrophysical processes.

(iii) Analyse data to determine if these high-energy phenomena are related.

The overall goal is to prepare a new generation of scientists able to take advantage of the next-generation of experiments probing the multi-messenger universe, such as Advanced LIGO, the KM3NeT neutrino telescope, and the Square Kilometre Array.

Figure: *Detection of GW170817, a neutron star-neutron star binary merger event, showing the evolution of gravitational wave frequency (y) with time (x). Could these events be the progenitors of fast radio bursts? Credit: LIGO Scientific Collaboration and VIRGO Collaboration.*



Opening a window on the ionised interstellar medium of nearby galaxies

Research Field	
Radio Astronomy	
Project Suitability	
PhD	
Honours	
Project Supervisor	
Dr John Morgan	
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Co-Supervisors	
Dr Jean-Pierre Macquart	

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.

Applying this technique to other galaxies could produce significantly improved results since even a small inclination to the line of sight separates the components of the ISM, greatly increasing the observable information. A pilot study of M31 undertaken a few of years ago showed very promising results, with strong evidence of the detection of the ionoised 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.

With future instruments, such as the SKA participating in observations, the number of lines of sight probing a galaxy such as M31 would be enormous. Planning for such observations could also form part of the project if the student is interested.

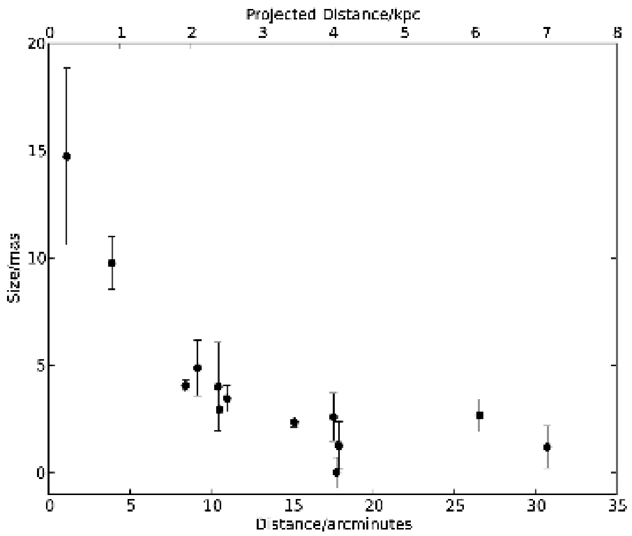

Figure: *The angular size of sources (assumed to be intrinsically compact sources seen through the M31 galaxy as a function of angular distance from the core of M31. Those nearest to the centre appear to be larger. This is thought to be due to "scatter broadening" of the sources by the turbulent ISM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

Particle physics beyond the LHC: what can the SKA say?

Research Field	
Particle physics/radio astronomy	
Project Suitability	
PhD	
Honours (as appropriate)	
Project Supervisor	
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Co-Supervisors	
Dr Maria-Vittoria Garzelli (DESY, Hamburg, Germany)	

Cosmic rays are the highest-energy particles in nature, impacting the Earth with energies more than a million times higher than can be achieved with the Large Hadron Collider. As such, they hold the key to particle physics processes that cannot be studied in a laboratory.

When a cosmic ray interacts, it leads to a cascade of billions of secondary particles, which in turn emits a burst of radio waves lasting less than a microsecond – yet this burst holds unique information on the primary cosmic ray's properties. And the world's most sensitive radio telescope, the Square Kilometre Array (SKA), will soon begin construction here in Western Australia.

The High Energy Cosmic Particles Focus Group is an international collaboration aiming to use the SKA to study both the origin of cosmic rays, and high-energy particle physics processes. It is therefore vital to understand exactly what the SKA could tell us about the standard model of particle physics – and beyond.

Aims of project:

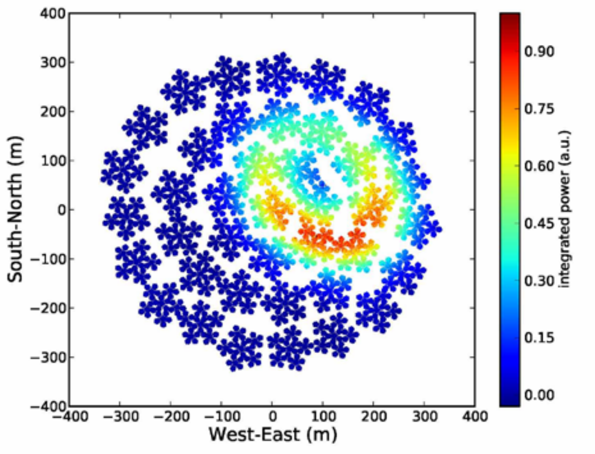
(i) Model high-energy particle physics interactions

(ii) Determine the effects on cosmic ray signals

(iii) Determine how SKA data can be used to probe high-energy particle physics processes

This project will use a particle physics simulation package, CORSIKA, and its radio extension, CoREAS, to simulate high-energy particle physics cascades, the associated radio emission, and its detection by the SKA. An honours project would progress through aims (i) and (ii) only, while a PhD student would be expected to collaborate with the Institute for Theoretical Physics in Hamburg, Germany, and present their results at an international conference.

Figure: *Simulation of the radio signal generated by a cosmic ray as seen by the core of the Square Kilometre Array, generated under standard physical assumptions. But what will deviations from this expectation tell us about physics at the highest energies? This project will tell us the answer.*



Powerful Black Holes Accreting at Extreme Rates

The release of gravitational energy as mass is suddenly dumped onto a black hole powers some of the most explosive phenomena in the Universe. This is the most extreme example of a universal process called accretion, which is responsible for the growth of all astrophysical systems, from stars to galaxies. In this project, the student will seek to understand how black holes transform the material they consume into powerful outflows, and quantify how much energy these jets can carry away. You will study the most powerful black holes to probe how this process works at its most extreme limit known as the Eddington limit, selecting the most short-lived, explosive events to unveil how the process proceeds in real time. These include stellar-mass black holes rapidly consuming material torn off a binary companion star, known as transient ultraluminous X-ray sources (ULXs), and supermassive black holes tearing apart unlucky stars that wander too close, known as tidal disruption events (TDEs).

Research Field
Accreting Physics/Radio Astronomy

Project Suitability
PhD

Project Supervisor
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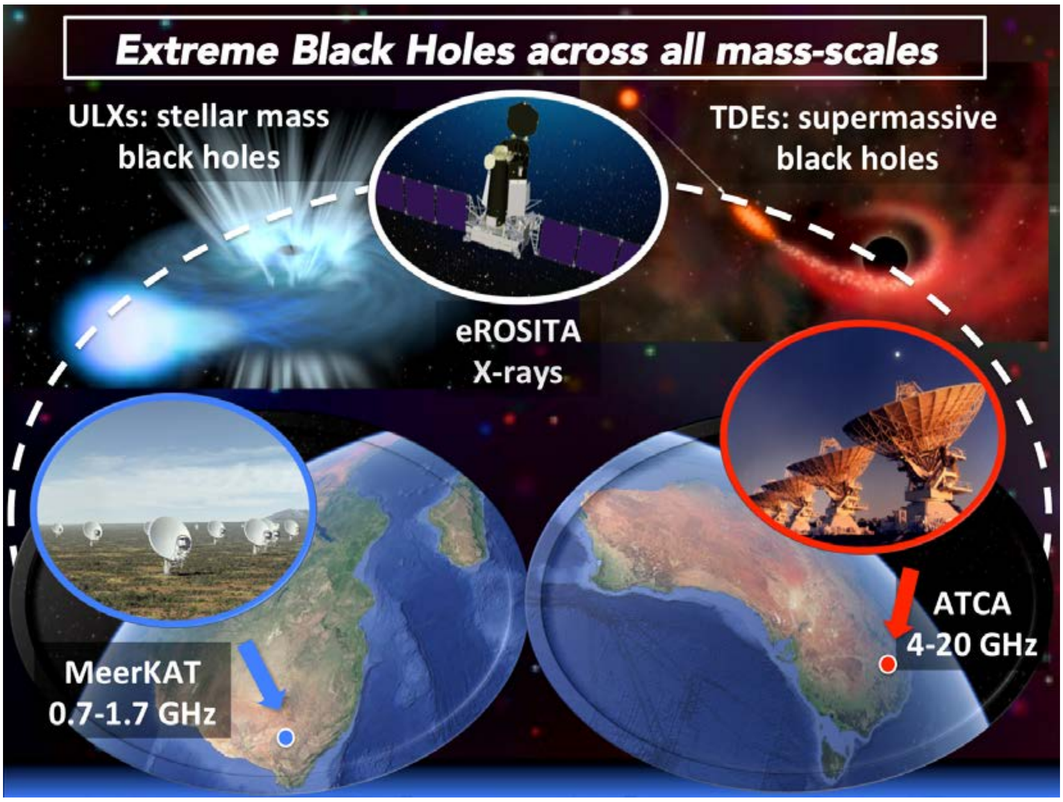
Co-Supervisors
A/Prof James Miller-Jones

The unrivalled capabilities of the new X-ray telescope eROSITA, which is due to be launched in March 2019, will discover thousands of transient ultraluminous X-ray sources and tidal disruption events. The PhD student will be expected to perform and analyse follow-up radio observations of these rapidly-evolving systems using advanced radio telescopes including the Australian Telescope Compact Array (ATCA), the South African Square Kilometre Array (SKA) pathfinder telescope MeerKAT, and the SKA low frequency precursor the Murchison Widefield Array (MWA; based in Western Australia). Such observations will probe the powerful jets that are launched by these rapidly accreting black holes, allowing for real-time exploration of the connection between the infalling matter and the launching of jets in some of the most extreme environments known in the Universe.



Radio Recombination Lines with the MWA

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

Research Field
Radio Astronomy

Project Suitability
Honours

Project Supervisor
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Co-Supervisors
Ms Chenoa Tremblay

RRLs at low frequencies were first discovered in 1980 and have since been discovered at frequencies from 10 to 1420MHz. However, the region between 100 — 200MHz is not well studied. Early studies suggest that somewhere between 100 and 200MHz the RRLs transition from emission lines to absorption lines. Recent constraints from studies by LOFAR have suggested that this transition may be around 130MHz, but it is highly dependent on the environment in which they are detected.

This project will utilize data cubes generated as part of a spectral line survey with the Murchison Widefield Array (MWA) to search for RRLs, with a particular focus on carbon recombination lines, which are detectable at low radio frequencies as the signal is boosted by collisional excitation.

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

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

Rapid Follow-ups of Fast Radio Bursts with the MWA

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

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

Research Field
Time-domain Astronomy

Project Suitability
Honours
Masters
PhD

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Co-Supervisors
Dr Steven Tremblay
Dr Marcin Sokolowski
Dr Ryan Shannon (Swinburne)

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

This PhD project will focus the scientific exploitation of a major co-observing program under way at the MWA and maturing a capability currently under development to receive and respond to the trigger alerts from premier facilities such as ASKAP. This will enable some unique science relating to FRB emission, as well as their propagation and progenitor models, which will contribute to advancing our understanding of these mysterious sources.

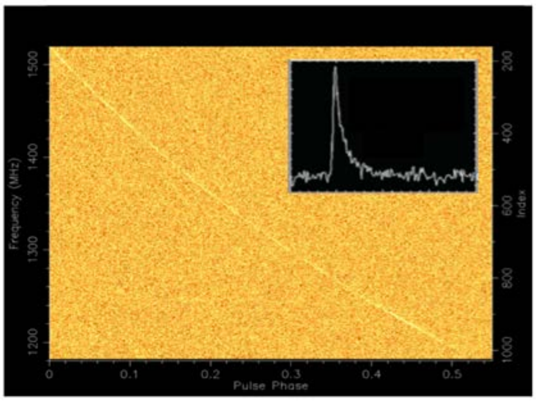

Figure*: FRB 110220 – one of the brightest FRBs discovered in the Parkes high time resolution Universe survey (Thornton et al. 2013). The burst's dispersion measure of 945 pc cm^{-3} results in an arrival time spread of approximately 1100 milliseconds across the 400 MHz observing band of Parkes survey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

Searching for Primordial Black Holes as Dark Matter

Research Field	
Radio Astronomy	
Project Suitability	
PhD	
Honours	
Project Supervisor	
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Co-Supervisors	
Dr Paul Hancock	

Free floating intermediate mass black holes (many tens of solar masses) are prime candidates for the unknown `dark matter' which makes up most of the mass of the Universe. They are cold (slow-moving) and would be very hard to spot in the halo of our galaxy. One method to detect them would be via gravitational lensing of distance extra-galactic sources when they pass close to their line of sight. These events would be rare but distinguished by their symmetric variability over time as the black hole reaches and then passes its closet separation to the the back-ground source. They would also affect all frequencies equally as lensing does not depend on frequency unlike most intrinsic variability. The Murchison Widefield Array telescope provides us with a great opportunity to discover these symmetrically achromatic variable (SAV) events due to its wide field of view, regular observations of calibrator sources and wide frequency coverage.

The aims of project this project are:

(i) produce images of all archive observations around calibrator sources and search for any transient sources,

(ii) select SAV events, model them, and estimate implications for dark matter,

(iii) follow-up on-going SAV events with high resolution radio, millimetre and optical observations to observe the distortion of the background source and estimate mass of lensing source,

(iv) use this large data set to provide an archive of calibration solutions and assess the health of the array over time.

This project will provide novel constraints (or determination) on the nature of dark matter and by providing an archive of calibration solutions it will be of great benefit to the wider astronomical community using MWA data.

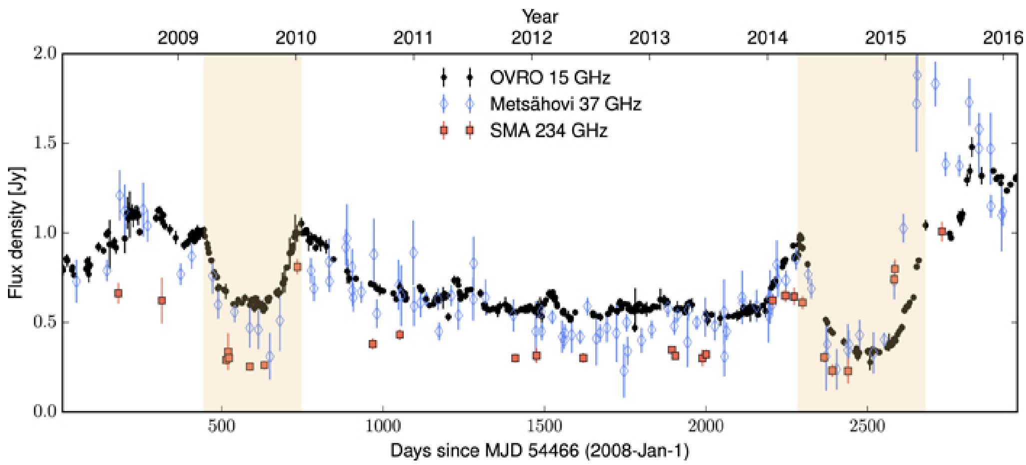

Figure: *Examples of SAV events from Vedantham et al. (2017) potentially caused by free floating black holes in the halo of the Milky Way.*

Searching for the First Black Holes with the MWA

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 grew 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.

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
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Co-Supervisors
Dr Guillaume Drouart
Dr Natasha Hurley-Walker

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 and to examine the role of jets in their evolution. This will involve observing, reducing and modelling radio data from 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.

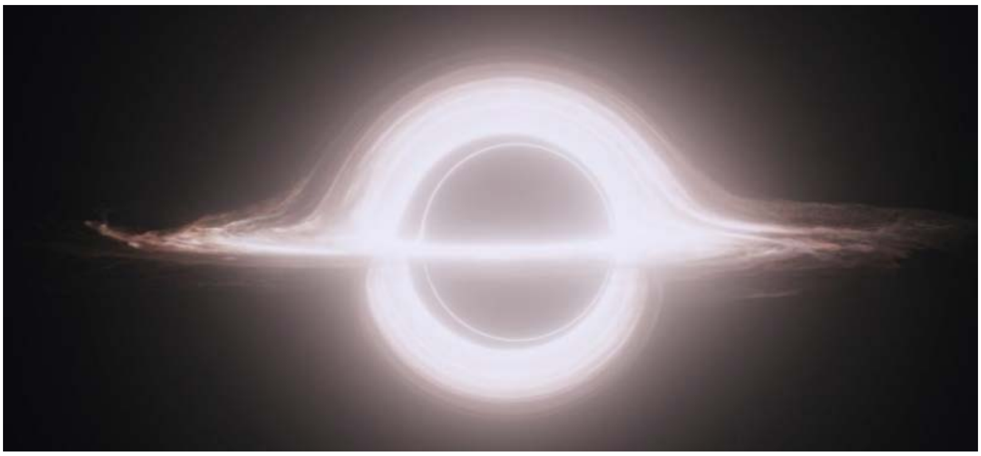

Figure: *Model of the distortion of an accretion disk by a black hole as used in the film Interstellar (James et al. 2015).*

Curtin University

Separating foreground galaxies from cosmological hydrogen using a Kernel Density Estimator

Research Field
Radio Astronomy

Project Suitability
PhD

Project Supervisor
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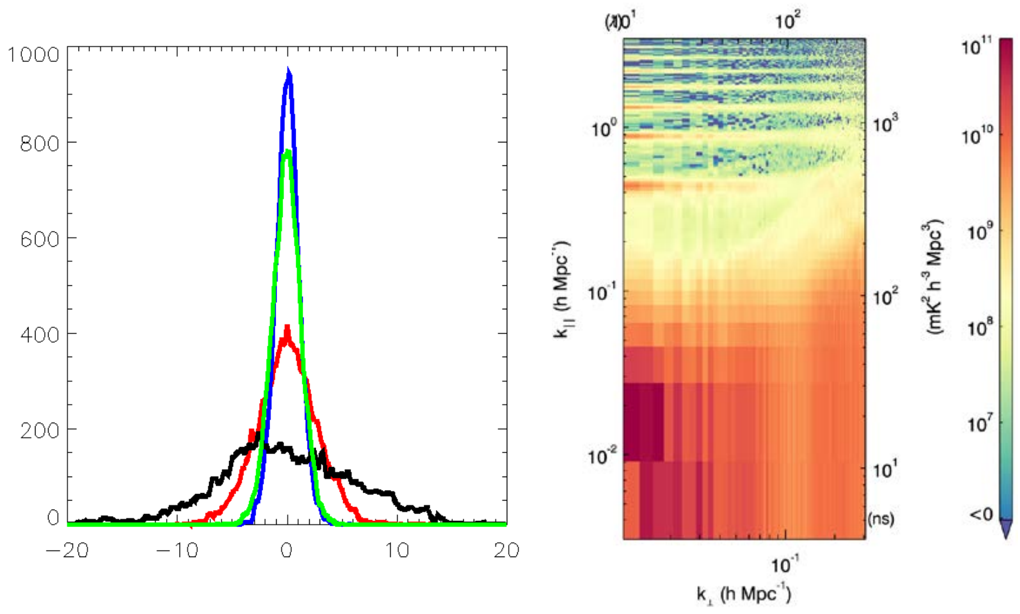
Co-Supervisors
Dr Steven Murray

The emission line signal from neutral hydrogen in the first billion years of the Universe traces the formation and growth of structure, and the birth, lives and deaths of the first stars. This weak radio astronomical signal can be detected with low-frequency radio telescopes, such as the Curtin-operated Murchison Widefield Array (MWA), but it is obscured by the bright and ubiquitous foreground star-forming galaxies and quasars, and diffuse synchrotron emission from our own Galaxy. This project will use a novel technique, called a Kernel Density Estimator, to try to separate the cosmological signal from the foreground contaminants.

A Kernel Density Estimator uses data to predict the underlying statistical properties governing those data. Because we expect the foreground contamination and cosmological hydrogen signal to behave differently, we can use such a technique to try to remove the primary contamination in our data. After development of a framework for separating such signals, the student will apply these to the many hours of data acquired with the MWA, in an attempt to produce the best limits on the first billion years of the Universe. This project would suit a student with a good grounding in statistical techniques, and who has an interest in statistics, data processing, the early Universe, and computing. This work has potential implications for future telescopes, such as the Square Kilometre Array (SKA).

This project will form part of the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D), a seven-year national Centre to explore the evolution of the Universe. There is the potential for scholarship funding for this project for a highly-achieving student.

The diagrams below are examples of the application of a Kernel Density Estimator to MWA data: (left) estimates of different spatial modes; (right) power spectrum of cosmological emission extracted from estimator.



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

Research Field
Radio Astronomy

Project Suitability
Honours

Project Supervisor
Dr Natasha Hurley-Walker
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Co-Supervisors
Dr Benjamin McKinley

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

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

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

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

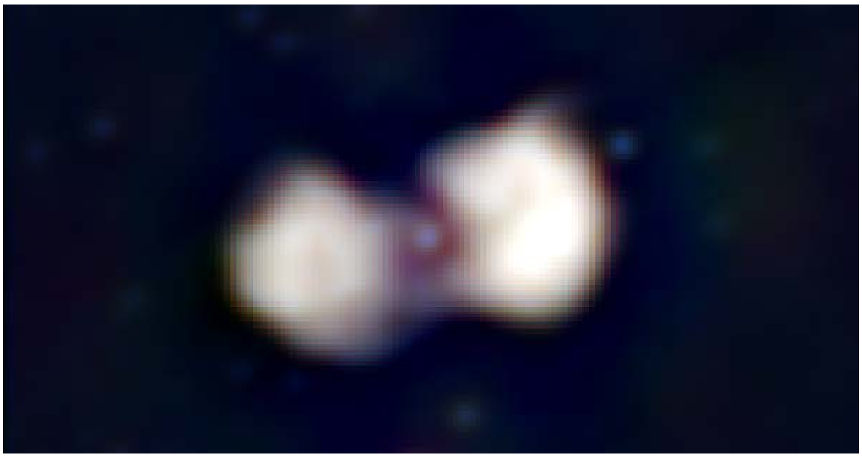

Figure: *Fornax A, as seen in radio “colours” via the GLEAM survey; red = 72 — 103 MHz; green = 103 — 134 MHz; blue= 139 — 170MHz; the lobes have a different spectral behaviour to the central core.*

The Evolution of Black Holes Across Cosmic Time

The formation and evolution of the super-massive black holes which reside in the centres of most galaxies remains one of the principle mysteries of astrophysics. We know that they evolve via two processes: merging (along with their host galaxies) and accretion. Their merging history would have to be consistent with models and observations of galaxy evolution, as well as future gravitational wave results (e.g. from LISA). Their accretion history can be constrained by X-ray and mid-IR surveys (for high accretion rates) and by radio surveys probing the relativistic jets emitted at low accretions rates. Hence it is possible to determine how the distribution of black holes masses evolves from the present day to the early Universe.

Research Field
Radio Astronomy

Project Suitability
PhD
Honours

Project Supervisor
Dr Nick Seymour
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Co-Supervisors
Dr Minh Huynh (UWA)

This project aims to:

(i) develop models to relate accretion rates and states of the accretion disk with observables such as X-ray, mid-IR and radio surveys. In particular, this work would focus on using multi-frequency radio surveys (e.g. the Murchison Widefield Array) to constrain the power of radio jets and therefore the accretion related to the radio emission. This work would also build upon our knowledge of galactic black holes,

(ii) use these models to determine the backward evolution of the black hole mass function consistent with observables,

(iii) examine the processes which could lead to the rapid formation of black holes in the early Universe and the effect they have on their environment,

(iv) make predictions of observables from accreting black holes at high redshift taking into account factors such as inverse Compton scattering of the CMB by relativistic electrons from the radio jets.

This project will uniquely exploit the broad frequency coverage of many Australian radio telescopes such to constraint the evolution of super-massive black holes across cosmic time.

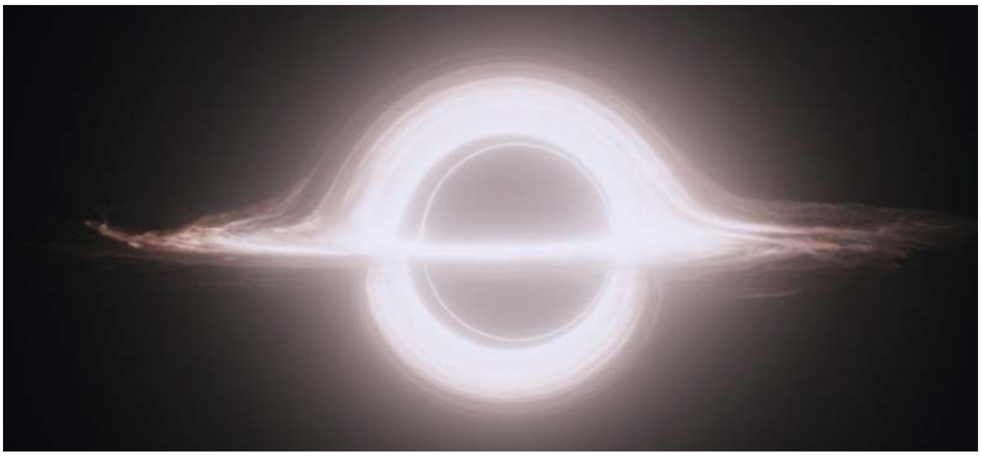

Figure: *Model of the distortion of an accretion disk by a black hole as used in the film Interstellar (James et al. 2015).*