South African Radio Astronomy Observatory

Research Project Proposals for Masters and Doctoral Research in 2019

1. All research project proposals must be submitted by a primary supervisor (see the definition of a primary supervisor in Section 1 of the Application Guide). In the case where the primary supervisor is not the research supervisor, the details of the co-supervisor, who will be responsible for supervising the research, must also be provided (as requested below).

2. Please provide the information requested below, in the order requested, and please use the same numbering, and "headings", as below.

3. As requested in the online application form, upload the research project proposal as a PDF document.

Information Required

Section A: Overview of the Research Project Proposal

1. Academic level of research project: Masters

2. Broad field of research: Astrophysics

3. Title of the research project: *Studying giant pulses in eclipsing binaries of Southerly millisecond pulsars using MeerKAT.*

4. Research project abstract/summary (max 250 words)

Project Abstract

Millisecond pulsars (MSPs) are rapidly spinning neutron stars that emit beams of radio emission from its magnetic poles. With the correct alignment, these radio beams will cross our line of sight periodically as the pulsar spins around its own axis. Sensitive radio telescopes, such as MeerKAT, can pick up pulses from MSPs and measure their time of arrival (TOAs) at the telescope with incredible precision.

Of the several hundred MSPs discovered to date, the majority of them are found in binary systems, orbiting a companion such as a main sequence star, a white dwarf or even another pulsar. Such binary systems can appear as eclipsing systems from our vantage point: as the pulsar moves behind its companion its emission disappears.

Recently it was found that the radiation of MSPs are greatly amplified by the stellar winds of their companions as they enter and leave the eclipse. Until now the Southern hemisphere has not had a telescope sensitive enough to detect these flux changes. Commissioning the MeerKAT telescope changes this. For the first time there is a telescope with enough sensitivity to detect giant pulses from the eclipsing

pulsars in the Southern hemisphere.

This MSc project will use data from the MeerTIME MSP census to search for giant pulses in eclipsing pulsar systems. We will learn whether all eclipses amplify pulsar emission or not. In systems where the pulsar emission is amplified, the atmosphere of the companion star will acts as a lens allowing us to probe the magnetosphere and emission mechanisms of these MSPs in more detail.

Team Information

Our partners at Swinburne University of Technology developed the pulsar processor for the MeerKAT telescope and have created a "search mode" that can create high time resolution data for giant pulse detection. Professor Bailes leads the MeerTime collaboration (http://www.meertime.org).

Professor Karastergiou is an expert on the pulsar emission mechanism and can help in the interpretation of the data. Dr. Marisa Geyer is a South African pulsar astronomer working in the MeerKAT Commissioning team at SARAO with experience in pulsar data analysis and the MeerKAT telescope operations.

Section B: Supervisor(s) Details

1. Primary supervisor's details

a. Title and full name: Dr. Aris Karastergiou

b. Name of South African or SKA Partner Country university at which the primary supervisor is a permanent academic staff member:

University of Western Cape/ Rhodes University

c. Email address and/or contact telephone number (please note that in the event this project is approved, these contact details will be made available to students awarded SARAO postgraduate bursaries)

aris.karastergiou@physics.ox.ac.uk

d. Supervision of postgraduate students – please provide the details of all the previous and current postgraduate students supervised. Please provide the information in table format, as shown below.

i. Doctoral Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)

Lucy Oswald	UK	October 2017	September 2020	Polarized radio emission from pulsars	
Marisa Geyer	South African	October 2014	December 2017	Pulsar Scattering and the Ionized Interstellar Medium	
Elmarie van Heerden	South African	October 2014	December 2017	Data Challenges in Pulsar Searches	Prof Steve Roberts
Paul Brook	UK	October 2011	May 2015	Variability in Radio Pulsars	

ii. Masters Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Isabella Rammala	South African	January 2016	July 2018	The dispersion measure in broadband data from radio pulsars	Prof Oleg Smirnov Dr Griffin Foster

2. Co-supervisor / Research Supervisor's details

a. Title and full name: Prof. Matthew Bailes

b. Name of the university/institute, at which the co-supervisor/research supervisor is a permanent academic/research staff member: Swinburne University of Technology and the the Director of ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav)

c. Email address and/or contact telephone number (please note that in the event this project is approved, these contact details will be made available to students awarded SARAO postgraduate bursaries)

mbailes@swin.edu.au, +61 414 324 677

d. Supervision of postgraduate students – please provide the details of all the previous and current postgraduate students supervised. Please provide the information in table format, as shown below.

Professor Bailes has supervised over 25 PhD and Masters students, 22 of which have completed their studies. These include Ben Stappers (Manchester pulsar group leader), Duncan Lorimer (WVU group leader), Willem van Straten (AUT pulsar group leader), Thomas Tauris (Bonn), Aidan Hotan (CSIRO staff), Joris Verbiest (Bielefeld University), Sarah Burke-Spolaor (WVU Faculty), Adam Deller (Swinburne faculty), Emily Petroff (Veni Fellow), Stefan Oslowski (Laureate Postdoctoral Fellowship, Swinburne)

i. Doctoral Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Emily Petroff	USA	16-08-2012	17-02-2016	The Transient Radio Sky Observed with the Parkes Radio Telescope	Van Straten
Stefan Oslowski	Polish	17-02-2009	16-05-2013	The Highest Precision Pulsar timing	Van Straten

Benjamin Barsdell	Australian	08-12-2008	05-12-2012	Advanced Architectures for Astrophysical Supercomputing	Chris Fluke
Lina Levin	Swedish	02-10-2008	15-11-2012	A Search for Radio Pulsars: from Millisecond Pulsars to Magnetars	
Sarah Burke-Spolaor	USA	26-03-2007	14-04-2011	Supermassive Black Hole Binaries and Transient Radio Events: Studies in Pulsar Astronomy	
Heather Ford	Canadian	22-10-2004	22-07-2010	The HI Cloud Population in the Lower Halo of the Milky Way.	
Paul Kiel	Australian	21-03-2005	16-07-2009	Populating the Galaxy with Pulsars	
Joris Verbiest	Belgian	11-07-2005	27-05-2009	Long-Term Timing of Millisecond Pulsars and Gravitational Wave Detection	

Emil Lenc	Australian	19-05-2004	05-02-2009	Studies of Radio Galaxies and Starburst Galaxies using Wide-field, High Spatial Resolution Radio Imaging	Steven Tingay (99% of supervision)
Adam Deller	Australian	02-02-2005	22-01-2009	Precision VLBI astrometry: Instrumentation, algorithms and pulsar parallax determination	Steven Tingay
Haydon Knight	New Zealand	07-01-2002	23-08-2007	Pulsar Applications of Baseband Recording	Dick Manchester
Aidan Hotan	Australian	25-02-2002	18-05-2006	High-Precision Observations of Relativistic Binary and Millisecond Pulsars	Dick Manchester
Willem Van Straten	Canadian	01-02-1998	07-08-2003	High Precision Timing and Polarimetry of PSR J0437-4715	
Russell Edwards	Australian	05-01-1998	18-10-2001	Pulsar Searching	

ii. Masters Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Duncan Lorimer	British	1991	1993	Pulsar Statistics	Andrew Lyne
Craig West	Australian	1999	2003	Software Correlators for Radio Astronomy	Steven Tingay

3. Additional South African Co-supervisor details

a. Title and full name: Dr. Marisa Geyer

b. Name of the university/institute, at which the co-supervisor/research supervisor is a permanent academic/research staff member: Square Kilometre Array SA / SARAO

c. Email address and/or contact telephone number (please note that in the event this project is approved, these contact details will be made available to students awarded SARAO postgraduate bursaries)

mgeyer@ska.ac.za

d. Supervision of postgraduate students – please provide the details of all the previous and current postgraduate students supervised. Please provide the information in table format, as shown below.

I have not formally supervised any students. During my studies at Stellenbosch University I acted as chief study mentor of my residence and have tutored in both mathematics and physics at first and second year level. At Oxford University (where I completed my DPhil in Dec 2017) I was a demonstrator in the computational physics lab. Being a co-supervisor to this project, and working with the student as well as Prof. Bailes and Dr. Karastergiou, will enable me to develop my supervision skills and allow me to contribute to the development of the young South African pulsar community in the future even more.

Section C: Full Research Project Proposal

Maximum of three A4 pages, written for a professional who is not necessarily an expert in the relevant subfield

1. Scientific merit: describe the objectives of the research project, placing them in the context of the current key questions and understanding of the field.

It is arguable that no other astrophysical object addresses so many diverse areas of physics and astrophysics as radio pulsars. The science derived from radio pulsar observations almost always stems from the pulsar timing methodology that uses the pulsar's inherent stability to deduce remarkable facts about the pulsar's environment, their orbital companions, gravitational forces and even internal composition.

Historical highlights include:

- Nobel prizes for their discovery (1974) and the confirmation of General Relativity (GR) (1993),
- Discovery of the first extra-solar planetary system (Wolszczan & Frail 1992, Nature 345, 145),
- New tests of GR with the double pulsar (Kramer et al. 2006, Science 314, 97),
- Astonishing clock precision that enables the search for a gravitational wave background (van Straten et al. 2001, Nature 412, 158),
- Swarms of millisecond pulsars in the cores of globular clusters (Manchester et al. 1991, Nature 352, 219; Ransom et al. 2005, Science 307, 892),
- The fastest spinning pulsar (Hessels et al. 2006, Science 311, 1901),
- Discovery of the radio-emitting magnetars, (Camilo et al. 2006, Nature 442, 892),
- Discovery of the Rotating Radio Transients (RRATs; McLaughlin et al. 2006, Nature 349, 817),

and

- Evidence for a high-mass neutron star (Champion et al. 2008, Science 320, 1309).

The MeerKAT telescope has the opportunity to become the dominant radio pulsar timing instrument in the world with its ideal combination of geographical location, high gain, large bandwidths, digital beamforming, low system temperature and rapid slew rates. Indeed, if one was to design the ideal pulsar timing instrument from scratch, the system would closely resemble MeerKAT.

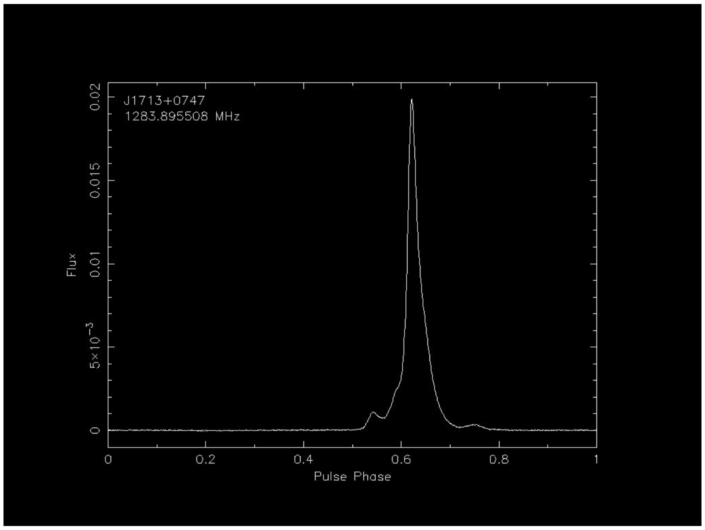
Our team has recently been involved in commissioning the MeerKAT as a pulsar telescope and the early results have been extremely exciting. Almost all pulsar science is signal-to-noise ratio or sensitivity limited, and this is why MeerKAT is so appealing.

A pulsar telescope has a sensitivity that is defined by its collecting area, the receiver temperature and observable bandwidth. The signal-to-noise ratio *SNR*, is given by

$$SNR = \frac{S\,G\,\sqrt{B\,N\,t}}{Trec + Tsky}\ \sqrt{\left(\frac{P-w}{w}\right)}$$

Where *S* is the radio flux of the pulsar, *G* is the gain of the telescope in K/Jy, T_{rec} and T_{sky} are the effective temperatures of the radio receiver and sky background respectively, *B* is the bandwidth of the telescope, *N* is the number of polarisations and *t* is the integration time. *P* and *w* are the pulsar's period and width.

Until now the largest radio telescope in the southern hemisphere has been the Parkes 64m telescope in Australia. By comparison the MeerKAT has 8 to 10 times the sensitivity, which opens up many new areas of pulsar science. Because the SNR scales as the square root of the integration time, a minute with MeerKAT is worth a whole hour on the Parkes telescope!



PSR J1713+0747 is a southerly MSP in a binary with a White Dwarf. This recent observation of this pulsar by MeerKAT using 56 antennas, shows the folded pulse profile obtained in a 30 minute observation. The pulse has a whopping SNR value of almost 2000.

MeerTime has assembled a strong team to develop the necessary instrumentation to tackle high-profile science from several major classes of pulsar. MeerTime concentrates on three major classes of pulsar:

• Millisecond Pulsars (for the direct detection of gravitational waves)

• Binary Pulsars (for testing theories of gravitation, the origin and evolution of neutron stars, and pulsar masses)

• Globular Cluster Pulsars (for testing cluster dynamics and evolution, and measuring pulsar masses)

Fortunately, in all of these systems a subset of the population belong to the so-called "binary eclipsing pulsars", pulsars where the ablated material from the pulsar's companion cause us to lose sight of the radio emission for minutes to hours. These eclipses have recently been of great interest, as Main et al. (Nature 557, 522) discovered that one of the eclipsing pulsars (B1957+20) causes very large amplification of the radio emission from the pulsar as it enters eclipse.

Remarkably one can then use these naturally-occurring plasma lenses to study the emission region of the millisecond pulsars themselves using planetary-sized lenses to differentiate the emission regions of the pulsar on 10s of km length-scales. The amplification in B1957+20 is up to a factor of 70-80. When combined with MeerKAT's improvement in sensitivity over the Parkes telescope (another factor of 7-10) this means that we have the opportunity to search for giant pulses up to about a factor of 1000 greater than can normally be seen from the Parkes telescope away from the eclipsing region.

2. Feasibility: outline the methods that will be used to achieve the objectives. Provide details on the availability of required data / access to required equipment / availability of research facilities and other resources required. Include any relevant expected intermediate milestones and associated timeframes towards attaining the overall objectives of the project.

In this Masters project, the student will first use the MeerTime pulsar "census" planned for the pulsar timing array and relativistic binary pulsar projects to establish what the typical mean signal-to-noise ratios are for the Southern MSP population. They will then use the binary ephemerides to plan when the MeerKAT will be able to observe these pulsars entering eclipse, perform 5-10 minute observations of all these pulsars as they enter eclipse, and search for giant pulses in the data.

This will establish if magnification is ubiquitous in the MSP population, and for those sources that have giant pulses use them to study the magnetospheres of millisecond pulsars using these naturally-occurring lenses. This may require additional observations of the pulsars where giants are discovered.

Dr Geyer will work with the student on a day-day basis initially on data reduction and use of the MeerKAT telescope, and later on the emission of the MSPs. Professor Bailes (leader of the MeerTime project) will help facilitate the observations into the MeerTime schedules, and host the student for an intensive 8-week visit to Australia as an Ozgrav visitor (accommodation and living expenses to be provided by www.ozgrav.org) to learn how to perform giant pulse searching from baseband data. Professor Karastergiou is an expert on pulsar emission and will work on the interpretation of the results.

The data will be initially calibrated using observations from Ter5A that is known to emit giant pulses with data taken from the MeerTime globular cluster program.

To start, pulsar timing data will be made available to the MSc student to familiarise themselves with both the MeerKAT telescope (sensitivity, bandwidth etc.) as well as to practise reducing and analysing pulsar data. This includes learning how to use established pulsar software suites and computing accurate time of arrival (ToA) measurements from the data. Familiarity with MeerKAT pulsar data will therefore be an straightforward initial objective.

Thereafter, science quality data of Southerly eclipsing MSPs will be provided via the MeerTIME programme observing on MeerKAT. An intermediate goal will be analysing data from an eclipsing binary pulsar system, and writing python scripts to pick out the brightest (giant) single pulses within a given dataset.

In the final leg of this project the student will interpret the analysed datasets, and aim to draw conclusions and ask scientifically meaningful questions. This analysis will include investigating whether correlations exist between the cadence of giant pulse emission and the orbital phase. That is, are there more giant pulses as the pulsar enters into the eclipse? Or are the giant pulses distributed randomly throughout the orbital phase? Obtaining a basic model of the relevant process will be one of the project's main objectives.

3. Link the proposed project to at least one SARAO research priority areas (refer to Annexure 1 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).

As described in the research statement above, this project will directly contribute to radio pulsar research and therefore addresses priority number one of the Annexure, namely

1. Radio Pulsar and Fast-Transient science, instrumentation and data analysis (including real-time RFI detection).

4. If relevant, describe any particular qualifications, academic abilities, skills and/or experience that a student should have in order to successfully deliver on the objectives of the research proposed.

This project will require high levels of analytical skills as well and computer programming skills. Students should have an undergraduate degree and/or honors degree in Physics, Mathematics, Astronomy, Engineering or Computer Science.

Students with a keen interests in systematic data analysis, data reduction and script writing are suited to the project. Students that apply are expected to show keen scientific interest in the world of astronomy at large, and are expected to develop a more detailed understanding of radio astronomy and particularly pulsar astronomy over the course of this project.

Section D: Signatures

1. Signature of the primary supervisor, with date

Dated: 30 Aug 2018

2. Signature of the co-supervisor/research supervisor, with date

Dated: 30 Aug 2018

3. Signature of the additional co-supervisor/research supervisor, with date

Dated: 30 Aug 2018