Details of the research project

Section A: Overview of the research project

1. **Project Title:** Multi-wavelength studies of the radio pulsar population of the Large Magellanic Cloud
2. **Broad area of research:** Science
3. **Academic level**: PhD
4. **Abstract:** This PhD aims to explore the radio pulsar population of the Large Magellanic through beamformed MeerKAT observations undertaken as part of the TRAPUM survey. Target selection will be based on existing datasets across wavebands ranging from radio to X-ray. The student will perform pulsar searches on the MeerKAT data, potentially also uncovering fast radio bursts and double neutron star systems, and contextualise their results in terms of the population of radio pulsars and related objects in the Magellanic Clouds.
5. **Primary supervisor details:**
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6. **Co-supervisor details:**
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Section B: Details of Research Project

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1. Scientific Merit

The vast majority of radio pulsars have been detected within our Milky Way, and a handful are known in the Milky Way's nearest satellite galaxies — the Magellanic Clouds. With the improved sensitivities of radio telescopes like MeerKAT, combined with the computational power of engines like APSUSE (used as part of TRAPUM), rigorous searches for populations of radio pulsars outside of the Milky Way have become feasible. The scientific objective of this PhD project is to explore the radio pulsar population of the Large Magellanic Cloud (LMC) through the TRAPUM large survey project on MeerKAT, and use MeerLICHT optical data and the MeerKAT imaging surveys of the LMC along with population models to explore the radio pulsar population of the LMC.

The Large Magellanic Cloud (LMC) is our closest satellite galaxy, providing a unique environment to study entire stellar populations outside of the Milky Way. It's close enough that individual stars can be resolved, but far enough away that distance uncertainties do not constrain the pulsar luminosity function. The LMC has also been the subject of numerous multiwavelength surveys that produced a wealth of information and large archival datasets. These can provide vital supporting information to characterise the pulsars this survey will discover.

The detection of gravitational waves from merging neutron stars and the likelihood that at least some Fast Radio Bursts (FRBs) originate from neutron stars has highlighted the value in understanding the neutron star population in galaxies other than the Milky Way. We know that the LMC has a significantly different metallicity to the Milky Way and it is also known to have a high proportion of high mass X-ray binaries (HMXBs) — likely progenitors of double neutron star (DNS) systems. So, there is the possibility of finding a DNS or putting limits on the population in the LMC. We can then compare this to the growing knowledge from the merging population seen in gravitational waves. We can also compare and contrast with the results of the ongoing search for pulsars in the SMC (e.g. Titus et al 2019), which appears to have a higher, per unit mass, rate of HXMBs (Shtkovesk_. With star formation episodes as recent as 6 Myr ago, there is the possibility

that there might be a population of young magnetars located in the LMC. Young magnetars are thought to be linked to the sources of at least some of the FRBs and so detecting a young magnetar that is emitting in the radio and studying its emission, spin properties and environment could provide vital information for confirming or refuting the link to the source of FRBs.

Alongside its exceptional sensitivity, an advantage of MeerKAT is that we can get good localisation of the new pulsars we find from the discovery and confirmation observations, this allows for rapid follow up across the electromagnetic spectrum. This would include associations with supernova remnants, optical counterparts to binary systems and possibly high energy emission.

The previous radio pulsar surveys (Crawford, Manchester, Ridley) of the LMC discovered only 23 pulsars over the last 30 years. In order to characterise the LMC radio pulsar population more radio pulsars have to be discovered. Due to the large distance (50 kpc) to the LMC, current telescopes, such as Parkes, have worked at the limit of the requisite sensitivity for detection. Finally with MeerKAT, we have access to a much more sensitive telescope to search for new pulsars (probably an order of magnitude increase in number of pulsars).

This project will primarily focus on characterising the radio pulsar population of the LMC by searching TRAPUM data for new pulsars. Upon the discovery of new pulsars, the MeerKAT Magellanic Cloud Legacy Survey data can also be utilised to determine the spectral indices, and polarisation. In addition to the MeerKAT data, follow-up multiwavelength campaigns can be launched to further characterise any intriguing sources or to identify possible companions. With this population of radio pulsars, it will be instructive to understand how the LMC environment plays a role in formation and evolution of neutron stars in binaries. This can be achieved through populations synthesis models, which can account for environmental factors like star formation, metallicity effects and properties intrinsic to neutrons, e.g. magnetic fields, mass etc. Such population models have already been run for the Small Magellanic Cloud (Titus et al. 2020) and comparison between these galaxies will help us understand how the local environment plays a role in the evolution of massive stars and their remnants.

Crawford et al. 2001, ApJ 553, 367
Manchester et al. 2006, ApJ 649, 235
Ridley et al. 2013, MNRAS 433, 138
Shtykovskiy & Gilfanov 2005, A&A 431, 597
Titus et al. 2019, MNRAS 487, 4332
Titus et al. 2020, MNRAS 494, 500

2. Feasibility

The primary objective is to search the TRAPUM data for new radio pulsars. The TRAPUM survey of the SMC commenced late 2020, and will provide the template for the observing and processing strategies for the LMC observations. We are planning that the majority of the LMC observations will take place in 2022 matching ideally the proposed student's timeline. The student will be provided with the necessary support and training (local & international) to master various pulsar searching routines and concepts. Expected duration: 1 year.

In the last couple of years there has been a revolution in our understanding of the radio properties of sources within the Magellanic Clouds through observations with both the MeerKAT and ASKAP telescopes. We propose to use data from the MeerKAT Magellanic Cloud Legacy Survey, along with information from ASKAP, and X-ray surveys of the clouds to identify likely host locations for pulsars. As part of the TRAPUM Large Survey Proposal observations we will then target these regions with highly sensitive coherent beams formed using at least the inner 40 dishes of the MeerKAT telescope. This gives the optimum combination of sensitivity and field of view. The approximately 400 coherent beams we can form with the TRAPUM beamformer (FBFUSE) will allow us to effectively target the vast majority of these regions in observations each approximately 2 hours in duration. This will gives us a sensitivity that is a factor of 5-8 (depending on the exact

sky position and pulsar parameters) times better than the previous surveys for radio pulsars with the Parkes telescope.

All computational resources will be provided by the TRAPUM consortium and processing takes place on the TRAPUM cluster (APSUSE) in as close as possible to real time after the observations have taken place.
Highly optimised pipelines have already been developed which the student will be able to utilise to discover the new sources.

3. SARAO science priority

Science — MeerKAT — multi wavelength — pulsars — stellar populations

The project described above is based on MeerKAT data that will be accumulated through the TRAPUM large programme. The specific observations undertaken will be determined through a multiwavelength approach: using existing imaging radio data, X-ray imaging and narrow and wide band optical imaging (e.g. through MeerLICHT) to determine positions for pulsar searching. Thus there is a strong multiwavelength component. The project also has the potential to use the MeerKAT data towards a more coherent understanding of the population of radio pulsars, and hence the pathways of massive star evolution, in the Magellanic Clouds.

4. Skills required

Some programming experience in Python will be useful, however all skills will be taught during the course of the project.