SARAO Application for Supervisors to Propose Research Projects

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Short abstract:

We have used Open Time on MeerKAT to observe 140 of the brightest, extragalactic radio-sources in the southern sky (PI: White), belonging to the GLEAM 4-Jy Sample. The vast majority of these are active galaxies with powerful radio-jets, but despite being easy to detect in the radio, the poor resolution of previous data has prevented host-galaxy identification for these sources. We will now be able to carry out this crucial step, allowing the radio information to be combined with multi-wavelength data. This includes redshifts from optical/near-infrared observations, which are necessary for determining the *intrinsic* properties of these active galaxies. Even though such sources have been studied for over 50 years, we are yet to understand exactly how radio jets are launched, and their overall impact on the surrounding host galaxy. Furthermore, being the brightest radio-sources in the southern sky makes them obvious candidates for future studies with the Square Kilometre Array and its precursor/pathfinder telescopes.

Section A: Overview of the Research Project Proposal

1. Academic level of research project: Masters

2. Broad field of research: Astronomy/Astrophysics

3. Title of the research project:

Studying the brightest radio sources in the southern sky

4. Supervisors: Dr Sphesihle Makhathini, Dr Sarah White

5. University for student registration: Rhodes University

Section B: Research Project Proposal

1. Scientific merit:

A galaxy is described as being 'active' when material is accreting onto the supermassive black-hole at the centre, producing a large amount of emission over a wide wavelength range. In some cases, this output includes powerful radio-jets, which are believed to have a significant impact on the host galaxy. However, it is still unclear whether their overall effect is to *promote* star formation in the host galaxy (by triggering the collapse of molecular clouds) or to *suppress* it (through the expulsion of gas from the system). Furthermore, the mechanism behind jet production is still not well understood, nor is how these sources evolve with redshift. This is because detailed studies tend to be limited to 173 'radio loud' active galaxies that compose the revised Third Cambridge Catalogue of Radio Sources [3CRR; Laing et al, (1983) -- https://ui.adsabs.harvard.edu/abs/1983MNRAS.204..151L/abstract]. In order to investigate how the properties of such sources vary as a function of redshift and/or environment, we have created a sample that is over 10 times larger than 3CRR (consisting of 1,863 radio sources). These are also selected at low radio-frequencies, but using the Murchison Widefield Array, which is the low-frequency precursor telescope for the Square Kilometre Array (SKA). Doing so allows us to avoid the orientation bias caused by 'Doppler boosting'. This is a phenomenon that is inherent in higher-frequency radio surveys, and leads to a greater-than-expected fraction of active galaxies with their jet axis close to the line-of-sight.

Our new sample, of the brightest sources across the southern sky, is known as the GLEAM 4-Jy (G4Jy) Sample [White et al. (2018) -- https://arxiv.org/abs/1810.01226], and was constructed using the GaLactic and Extragalactic All-sky MWA (GLEAM) Survey. Careful visual inspection and thorough checks against the literature have allowed us to identify the host galaxy for 86% of the sample, but the limited (25 to 45-arcsec) resolution of existing radio images – along with there being multiple candidate host-galaxies -- prompted follow-up with MeerKAT for 140 of the remaining sources (PI: White). The primary aim of this project is to use these new images (of 5-arcsec resolution) to identify the galaxy hosting the radio emission. This is a crucial step, after which we can combine radio data with information at other wavelengths, and so investigate the intrinsic properties of these powerful radio-galaxies for the first time. Furthermore, cross-identification for the sample needs to be *complete* if we are to determine reliable and robust statistics as to the production and impact of radio jets. In addition, the MWA data provides excellent constraints of the radio spectrum, with initial analysis demonstrating that several G4Jy sources have significant spectral curvature. This is important to characterise/quantify, as we typically assume a power-law description of the radio emission when extrapolating flux densities from one frequency to another.

2. Feasibility:

This project will exploit in-hand radio data from Open Time on MeerKAT (PI: White), and multi-wavelength data that is already available over the southern sky. This includes mid-infrared images, as these allow us to reliably cross-identify the galaxy that is hosting the radio emission. The student will complete this through visual inspection and checks against the literature, with the new positions leading to an updated version of the G4Jy catalogue (White et al., under review). They will then be able to cross-match the new identifications with existing redshifts in order to study the intrinsic properties of these bright radio-sources, the vast majority of which are 'radio loud' active galaxies. For example, determining the radio luminosity is necessary for estimating the power of the radio jets, subject to the density of the surrounding medium. The work described so far should take up to 10 months, and if the student started in January 2020, they should have results ready for presentation at the 2020 SARAO Postgraduate Scholarship Conference. The next 10 months will concern combining the MWA (72 to 231 MHz) and MeerKAT (1.3 GHz) data with existing measurements at higher radio-frequencies (5, 8 and 20 GHz), obtained using the Australia Telescope Compact Array. Doing so will allow us to characterise the shape of the radio spectrum, with different types of curvature indicating the presence of: blazars (where we are looking down the axis of the radio jet), sources with a large reservoir of neutral gas (which fuels both black-hole accretion and star formation), and re-started radio-galaxies (where the radio jets appear to have 'switched on' a second time). There will also be the opportunity to obtain follow-up optical spectroscopy using the Southern African Large Telescope, allowing the student to determine new, additional redshifts for G4Jy sources. The final four months of the two-year project are allocated for the student to write up their research, with at least one paper also expected to result from their work.

3. Links of the project to one or more of the SARAO research priority areas:

This project will use radio data obtained earlier this year (PI: White), during the first round of Open Time on MeerKAT. The main research area driving this project is galaxy evolution, and specifically how star formation and black-hole accretion evolve in/over extragalactic sources detected out to high redshift ($z \sim 4$). Unlike optical observations, radio data are unaffected by dust obscuration along the line-of-sight, and so allow us to obtain a complete census of the different types of star-forming galaxy and active galaxy that exist. This project is concerned with active galaxies that are 'radio loud', which are easily-detected but poorly-studied over the southern sky due to the quality or coverage of existing data. It is thanks to the 5-arcsec resolution and sensitivity provided by MeerKAT that we will be able to reveal the complex morphology of these bright radio-sources for the first time, and possibly differentiate the radio core from the radio lobes (which dominate the radio emission at low frequencies). Studying their spectral behaviour over a wide frequency range will also be of interest to those wishing to detect the epoch of reionisation (EoR) using HERA. This is because these bright radio-sources contribute to contaminating emission in the foreground of the EoR signal, and so need to be well-modelled in order to be accurately subtracted.

4. Student requirements:

For this work, the student is expected to have an undergraduate background in physics and/or astronomy, preferably with a good understanding of statistical methods. Previous programming experience is necessary, with knowledge of Python being highly desirable.