Proposal for SARAO-funded Postgraduate Research in 2022

Section A: Overview of the Research Project

1. Title of the research project:

    Identifying high-redshift radio-galaxies in the G4Jy Sample

2. Broad area of research: Science

3. Academic level of research project: Doctoral

4. Abstract of research project:

The GLEAM 4-Jy (G4Jy) Sample is a compilation of 1,863 of the brightest, extragalactic radio-sources in the southern sky, the vast majority of which are active galactic nuclei (AGN) with powerful radio-jets. Whilst being easy to detect in the radio, a subset of these sources has faint mid-infrared emission, which suggests that they are at high redshift. To confirm whether this is the case, we will first consult near-infrared (specifically, *K*-band) images, since these are deeper than the mid-infrared images already used for visual inspection. The radio morphology and host galaxy may also need be refined, using a combination of the VLA Sky Survey (VLASS) and the Rapid ASKAP Continuum Survey (RACS), as existing radio images are of too low spatial resolution (25 to 45-arcsec). Based on this dataset, we will then be able to gather new and existing redshift information, which is necessary for determining their *intrinsic* properties (such as radio luminosity). Alongside this, G4Jy sources have already been observed as part of a multi-semester spectroscopic campaign (PI: White) on the Southern African Large Telescope (SALT). Even though such 'radio-loud' AGN 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 over cosmic time. They are also useful for studying neutral hydrogen along the line-of-sight, and have been confirmed to exist out to just after the end of the Epoch of Reionisation. Furthermore, being the brightest radio-sources in the southern sky makes this a legacy sample that can be used for many studies with the Square Kilometre Array (SKA) and its precursor/pathfinder telescopes.

5. Primary supervisor's details:

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6. Research supervisor's details:

    a. Full name: Dr Sarah White
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    c. University: Rhodes University

Section B: Details of Research Project

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. For these ‘radio galaxies’, it is still unclear whether the overall effect of the jets 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). In order to investigate how the properties of such sources vary as a function of redshift and/or environment, White et al. (2020a, 2020b) have created a sample that is over 10 times larger than 3CRR (consisting of 1,863 radio sources). This new sample, of the brightest sources across the southern sky, is known as the GLEAM 4-Jy (G4Jy) Sample (https://arxiv.org/abs/2004.13125, https://arxiv.org/abs/2004.13025). These are also selected at low radio-frequencies, but using the Murchison Widefield Array, which is the low-frequency precursor telescope for the 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 AGN with their jet axis close to the line-of-sight.

There is much interest in finding radio galaxies at high redshift ($z > 1$), including for investigating the interplay of star formation and black-hole accretion, since both processes peak at $z \sim 2$ (Madau & Dickinson 2014). They are also useful probes of the intergalactic medium in the early Universe, allowing neutral hydrogen to be detected along the line-of-sight to such sources (Carilli et al. 2002). One way to search for high-redshift radio galaxies is via their steep spectral-shape, since radio emission moves to lower frequencies as it ages. By targeting such sources for optical spectroscopy, powerful radio-galaxies have been confirmed to exist out to $z = 5.84$ (Bañados et al. 2018) – i.e., just after the end of the Epoch of Reionisation. Another route is to spectroscopically confirm the redshifts for infrared-faint radio sources (IFRSs; Norris et al. 2006, Zinn et al., 2011), which (as the name implies) have host galaxies that are too faint (i.e. too far away) to be detected in the mid-infrared (the usual tracer for warm dust in the system). This has proven effective for analysing large datasets (Collier et al. 2014, Orenstein et al. 2019) – with redshifts ranging from 2.0 to 4.4 (Orenstein et al. 2019; https://ui.adsabs.harvard.edu/abs/2019MNRAS.484.1021O/abstract) – and is the approach we are applying to the G4Jy Sample.

Careful visual inspection and thorough checks against the literature have allowed White et al. (2020a, 2020b) to identify the host galaxy for 86% of the G4Jy Sample, but the faint/confused mid-infrared emission for 126 sources prompts closer inspection. The primary aim of this project is to use *K*-band images, VLASS (Dec > -40 deg), and RACS (Dec < -40 deg) radio images to better determine the host-galaxy position and the morphology of the radio emission. Using these refined positions, we can then gather existing optical spectroscopy and new follow-up observations on SALT, for obtaining redshifts. This is necessary for calculating the intrinsic properties of the G4Jy sources, as current work is limited to the observed frame. As such, we will be able to compare the properties of high-redshift G4Jy sources with those of G4Jy sources belonging to the local Universe. There will also be the opportunity to propose follow-up observations using MeerKAT (~6-arcsec resolution) for sources where there is ambiguity regarding the host galaxy in the new radio-on-*K*-band overlays.

2. Feasibility:

The student will spend the first year splitting their time between:

a) Reassessing the (lack of) host-galaxy identifications, using *K*-band images that are deeper than the mid-infrared data available. Combined with checks against the literature, and new radio images from VLASS and RACS, the refined positions will lead to an updated version of the G4Jy catalogue. The student will then establish which sources already have redshifts in the literature, and have the opportunity to apply for follow-up spectroscopy using the Southern African Large Telescope, allowing them to calculate new, additional redshifts for G4Jy sources.

b) Obtaining experience in data reduction by reducing SALT spectra that is already in-hand. This is a large spectroscopic campaign where we expect at least 200 sources to have been observed by the start of 2022. (It will continue through 2022, with an estimated end date of 31st October 2022.) Using this dataset the student will determine redshifts and classify the G4Jy sources into high-excitation radio galaxies (HERGs) and low-excitation radio galaxies (LERGs). Whilst these subsets are expected to occupy different host-galaxy populations, the 3CRR sample is too small to also investigate this as a function of redshift.

The student's second year will then determine how the infrared-faint radio sources compare with previous work, noting that our low-frequency selection leads to a sample that is unbiased with respect to jet-axis orientation. Depending on progress, and the outcome of any additional proposals, the student would also be in a good position to use this complete sample of AGN to test the findings of Thomas et al. (2020; https://ui.adsabs.harvard.edu/abs/2020arXiv201011225T/abstract), which were obtained through the Simba simulations (Davé et al. 2019).

The final six months of the three-year project are allocated for the student to write up their research, with one to two papers expected to result from their work.

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

This project plans to use SALT data already obtained for the G4Jy Sample, these being the brightest radio-sources in the southern sky and so a valuable reference for future work with the SKA. 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 ~ 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. As such, the G4Jy Sample is an excellent springboard for projects that would benefit from the 6-arcsec resolution and sensitivity provided by MeerKAT. This would 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).

Identifying radio galaxies at high redshifts will also be of interest to those studying the Epoch of Reionisation (EoR) and the intergalactic medium, as they can be used as background sources for probing neutral gas along the line-of-sight. Furthermore, 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. Following up these bright sources with MeerKAT we would also reveal which G4Jy sources remain compact (i.e. unresolved) at 6-arcsec resolution. These bright targets could be used as excellent wideband calibrators for MeerKAT down to Dec = -84 deg, and characterising their polarisation properties means that they could also be used as polarisation calibrators in the future.

4. Student requirements:

To complete this PhD within 3 years, the student is expected to have completed a Masters on a galaxy-evolution topic or a Masters that focused on astronomy pipeline-development. Previous programming experience is necessary, with good knowledge of Python and statistical methods being highly desirable. If interested in this project, the student should contact *both* supervisors as soon as possible, so that the most-suitable candidate can be identified/confirmed two weeks (tbc) ahead of the university's *internal deadline*. For reference, in 2020 the University of Pretoria had set 13th July as the internal deadline for an external (NRF) deadline of 14th August.

Section C: Signatures

1. Primary supervisor: Dr. Kshitij Thorat ( ) Date: 23rd February 2021

2. Research supervisor: Dr Sarah White Date: 23/2/2021