Section A: Overview of the Research Project

1. **Title of research project:**
   First Tier Results of the MERGHERS Survey

2. Broad area of research:
   Science

3. Academic level of research project:
   Doctoral

4. Abstract of research project:

   To date approximately 80 galaxy clusters have been found that host Mpc-scale diffuse synchrotron emission. These steep spectrum, cluster-scale signals have been exclusively found in dynamically disturbed systems, indicating a strong link between their formation and the energetic processes disturbing the intracluster medium during cluster mergers. Observations of large X-ray and SZ-selected cluster samples have determined scaling relations between the radio emission and thermal properties of the host clusters. However, these samples have been restricted to high mass ($M_{500} > 6 \times 10^{14}$ Msol), low redshift ($z < 0.4$) systems where the emission is expected to be brightest. In order to better understand the formation of these diffuse structures and their link to cluster evolution and the hierarchical build-up of structures in the Universe, the discovery space must be expanded to higher redshift and lower mass. The MeerKAT Exploration of Relics, Giant Halos, and Extragalactic Radio Sources (MERGHERS) project is a proposed large-scale radio cluster follow-up to address this, by observing ~100-200 clusters over a wide range of mass and redshift. The first tier data for MERGHERS is expected to be in hand in 2021/22. With this data we will study the occurrence of diffuse emission in high-redshift systems and compare this to the theoretical predictions from current formation models.

5. Primary supervisor's details:

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Section B: Details of Research Project

1. Scientific Merit:

Galaxy clusters are dynamic environments, with the intracluster medium (ICM) showing evidence of both thermal and non-thermal processes. The latter have been studied through diffuse, faint, steep-spectrum synchrotron emission in the form of radio halos and relics (e.g., Brunetti & Jones 2014, IJMPD, 23, 1430007-98). Halos and relics are typically found in the most massive, merging clusters, shedding light on cluster magnetic fields and the physical processes occurring during these highly energetic events (e.g. van Weeren et al. 2019).

A strong dynamical link has been found with respect to the host cluster: the ~ Mpc-scale emission has exclusively been found in massive ($M_{500} > 4 \times 10^{14}$ Msol) clusters with X-ray and/or optical merger signatures (e.g., Cassano et al. 2013, ApJ, 771, 141). The power of the radio emission has been found to correlate with thermal host cluster properties, with non-detections lying an order of magnitude below the correlation (Cassano et al. 2013), as predicted by one of the leading formation theories (Brunetti & Jones 2014). However, ultra-steep sources are shown to populate the region between the correlation and upper limits, making the dichotomy less clear. Cluster selection also affects the relations: samples selected via their Sunyaev-Zel'dovich signal (SZ; Sunyaev & Zel'dovich 1972, Comm. on Astrophys. and Space Physics, 4, 173) show a higher detection rate than X-ray-selected samples (Cuciti et al. 2015, A&A, 580, A97), which may be due to the different timescales of boosting the SZ vs X-ray emission during mergers.

Although over a hundred clusters have been studied to date in terms of diffuse emission, they have been heterogeneously selected, with all homogeneous samples restricted to high mass clusters at low to medium redshift (Cuciti et al. 2015). Diffuse emission has been detected in a handful of higher redshift or lower mass systems (Lindner et al. 2014; Knowles et al. 2016), however these have mostly resulted from single-target programmes, and no larger statistical study has yet been observed.

With the increased sensitivity of available radio telescopes, the next step in advancing the understanding of diffuse emission and imposing stronger constraints on formation models is to expand the thus far limited discovery space by observing a homogeneously selected, statistical sample of clusters with broader redshift and mass ranges. This will allow for studies into the evolution of radio scaling relations with redshift, as well as an investigation into whether the current scaling relations hold at lower mass and higher redshift. Given the complex nature of its origin, expanding the discovery space will also invariably lead to discoveries of new types of diffuse emission as the physical environments being probed are different: higher redshift clusters are younger than those at lower redshift, based on the hierarchical view of structure formation (Sheth & Tormen 2002, MNRAS, 329, 61), and lower mass merging systems have a smaller turbulent energy pool than higher mass systems (Kravtsov & Borgani 2012, ARA&A, 50, 353). Extending statistical samples into these wider ranges will result in an improvement in the understanding of the lifecycle of diffuse cluster radio emission.

The MERGHERS (MeerKAT Exploration of Relics, Giant Halos, and Extragalactic Radio Sources; Knowles et al. 2017, POS, arXiv:1709.03318) project aims to be the first large-scale radio follow-up of ~ 100-200 clusters with extended selection ranges. MERGHERS will target a mass-selected AdvACT (Henderson et al. 2016, JLTP, 184, 772) sample of SZ-detected clusters which will be blind to the cluster dynamical state. As preparation for the MERGHERS project, we have obtained L-band MeerKAT observations of 20 AdvACT clusters which show indications of merger activity through multiwavelength data. Each cluster has a relatively short exposure time (1-2 hours). A

campaign to obtain the homogeneously selected first tier of MERGHERS clusters will be carried out in 2020 and 2021.

This project forms part of MERGHERS and will focus on the data reduction and analysis of the first tier data expected to be in hand by 2021/22. With this data we will study the occurrence of diffuse emission in high-redshift systems and compare this to the theoretical predictions from current formation models.

2. Feasibility:

As mentioned above, MeerKAT data for 20 AdvACT clusters is already in hand, with more observations expected in 2020. All of these clusters are new targets in diffuse emission studies and therefore have a high probability of producing new results.

At UKZN we have a pipeline in place for reducing MeerKAT data, and as such, the student should be able to start with the scientific analysis of the data in the first six months. An approximate timeline for the project:
- Year 1: development of the methods/skills required to reduce and analyse MeerKAT data
- Year 2: work leading to a paper on the diffuse emission occurrence rates in the first tier sample
- Year 3: work leading to a paper on an individual interesting detection, including X-ray/optical data

Students and postdocs based at UKZN have access to a High Performance Computing facility (https://www.acru.ukzn.ac.za/~hippo/) which has recently been upgraded with a PB of storage/processing space, and a 64 processor shared-memory machine with more than 700 GB of RAM.

3. SARAO research priority areas for 2021:

Science topics exploiting MeerKAT data projected to be available by 2021-22.

4. Student academic abilities / skills required:

None – processing and data analysis with various softwares will be learned during the project.
Understanding of interferometry is advantageous.