Section A: Overview of the Research Project

1. **Title of research project:**
   Difuse Radio Emission in the MeerKAT Cluster Legacy Survey

2. **Broad area of research:**
   Science

3. **Academic level of research project:**
   Masters

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. This is the aim of the MeerKAT Exploration of Relics, Giant Halos, and Extragalactic Radio Sources (MERGHERS) survey, led by UKZN. MeerKAT's Galaxy Cluster Legacy Survey has observed 110 galaxy clusters at L-band, heterogeneously selected via X-ray or radio selections, and contains 55 clusters from the Advance ACT sample used by MERGHERS. In this project we will study the diffuse emission population statistics and scaling relations within various homegenously selected sub-samples from the legacy datasets, specifically the Advanced ACT sub-sample, and attempt to identify potential biases in radio detections.

5. **Primary supervisor's details:**
   a. **Full name of primary supervisor:**
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6. **Co-supervisor's details:**
   a. **Full name of co-supervisor:**
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   b. **University where co-supervisor is employed:**
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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. The MeerKAT Galaxy Cluster Legacy Survey is a heterogenous sample of 110 clusters selected through X-ray or radio selections. Several homogeneously selected samples can be extracted from this survey and used for diffuse emisison scaling relation studies. In particular, 55 legacy clusters are in the AdvACT catalog being used by MERGHERS.

In this project, we will study the diffuse emission population statistics and scaling relations within various homegenously selected sub-samples from the legacy datasets, specifically the AdvACT sub-sample, and attempt to identify potential biases in radio detections. The results will be incorporated into the MERGHERS project and will help inform future sample selections.

2. Feasibility:

The MeerKAT Galaxy Cluster Legacy Survey data is available, with data products already produced to a certain degree.

An approximate timeline for the project:
- Year 1: identification of various sub-samples in the legacy data; development of the methods/skills required to analyse the legacy products and/or perform additional processing if necessary
- Year 2: work leading to a paper on the diffuse emission statistics of the AdvACT sub-sample, and one other homogeneously selected sub-sample for comparison.

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.