Section A: Overview of the Research Project

1. Title of the research project:
Probing formation mechanisms of MGCLS radio halos

2. Broad area of research:
Science

3. Academic level of research project:
Doctoral

4. Abstract of research project:
Different radio halo formation scenarios predict different slopes in the point-to-point non-thermal vs thermal ICM correlations. We will use archival X-ray data to study the point to point correlation for MGCLS radio halos in order to constrain the formation mechanism at play in the different clusters, and compare the results with the multiwavelength view of the cluster mergers to determine if different formation models produce distinguishable merger characteristics. This project is expected to produce at least one publication.

5. Primary supervisor's details:
Dr Kenda Knowles, kendaknowles.astro@gmail.com, Rhodes University

6. Co-supervisor's details:
Dr Sinenhlanhla Sikhosana, University of KwaZulu-Natal

Section B: Details of Research Project

1. Scientific merit:

Low-frequency ($\lesssim$ GHz) radio observations of some galaxy clusters reveal large volumes of centralised synchrotron-emitting plasma that is not associated with individual cluster galaxies, and often trace the projected morphology of the X-ray emitting gas. These "radio halos" are linked to major merger activity in the cluster region (Brunetti & Jones 2014) and, as such, they provide insight into cosmic ray transport and particle (re)acceleration physics within the intracluster medium. The two main competing formation models for radio halos are the 'hadronic' (e.g., Dennison 1980) and 're-acceleration' (e.g., Pinzka, Oh & Pfrommer 2017) models, with most observations currently supporting the latter case. However, a key open question is with regards to the source of the pre-existing electron population required for both models. One way in which potential formation theories can be distinguished from the observations is through spatial and brightness correlations between the radio and thermal cluster signatures, for example X-ray emission or the Sunyaev-Zel'dovich (SZ) signal (e.g., Rajpurohit et al., 2021). These studies require high fidelity imaging of the radio emission and have therefore to date only been carried out on individual deeply-imaged systems.

The MeerKAT Galaxy Cluster Legacy Survey (MGCLS, Knowles et al. 2022) is a programme of long-track observations of 115 galaxy clusters with MeerKAT at L-band, with 62 of the targets hosting a radio halo. In this project, we will combine the high-quality MGCLS imaging with available X-ray and SZ imaging of the clusters to perform point-to-point correlations for the radio halos in the sample. These will be used to analyse the likely formation mechanisms in each cluster. This has been done for the Bullet cluster (Sikhosana et al. 2023) using reprocessed MGCLS data, and this project would be the first time such a study was carried out on a large sample of galaxy clusters.

When combined with multiwavelength information on the cluster dynamical state, obtained via X-ray imaging and optical density maps and/or spectroscopy where available, we can interrogate whether different merger scenarios produce distinguishable signatures in the spatial brightness correlations. We can also use the available high-quality data to determine the limits on radio and/or thermal imaging quality required to perform such studies, for example resolution or sensitivity constraints, to inform future studies of statistical cluster samples.

2. Feasibility:

All raw MGCLS data is available via the SARAO archive, with roughly 20% of the cluster visibilities in-hand at Rhodes University. Self-calibrated L-band images are publicly available for all fields. Of the 62 MGCLS clusters that host a radio halo, almost all have available SZ imaging from either ACT or SPT, and roughly 70% of the sample has X-ray imaging from one of the recent satellite programmes. The study will first focus on those radio halo host clusters with the necessary multiwavelength data whilst campaigns to complete the multiwavelength coverage are undertaken.

An estimate of the project timeline is as follows:

Months 1 – 3:	Literature review. Census of available multiwavelength data. Identification of a preferred MGCLS sub-sample.
Months 4 – 16:	Reprocessing of relevant MGCLS fields (if necessary) and preparation of halo images (e.g. source subtraction). Processing of X-ray data (if necessary) and preparation of X-ray imaging. Development of the point-to-point correlation code. Apply for missing X-ray data to complete the sample of 62 clusters.
Months 17 – 22:	Perform and analyse the point to point correlation of radio vs X-ray and radio vs SZ for the identified subsample. Prepare and submit a paper on interesting individual systems.
Months 23 – 31:	Interrogate the dynamical state of the studied clusters and investigate any connection with correlation results. Prepare and submit a paper on the sample findings.
Months 32 – 36:	Prepare and finalise doctoral thesis for submission.

3. SARAO research priority area:

This project exploits data projected to be available by 2025 from key existing radio astronomy instruments located in South Africa, specifically MeerKAT. This is a multi-wavelength project with a direct link to a MeerKAT programme.

4. Specific qualifications/abilities/skills/experience required:

Experience with Python and Unix environments is required. Experience with MeerKAT data processing is highly advantageous. Experience with X-ray imaging is advantageous.

Interested students to email the primary supervisor well in advance of application deadlines. Interviews will be undertaken no later than two weeks before internal application deadlines.