Section A: Overview of the Research Project Proposal

1. Title: **Observations of high redshift galaxy clusters with MeerKAT**
2. Broad field of research: **Science**
3. Academic level of research project: **Masters**
4. Abstract: Almost two decades of observations of radio emission in galaxy clusters have proven the existence of relativistic particles and magnetic fields that generate Mpc-scale synchrotron emission in the form of radio halos. In the current scenario, radio halos are generated through re–acceleration of relativistic electrons by turbulence generated by cluster mergers. Although this theoretical framework has received increasingly supporting observational evidence over the last ten years, observations of statistically complete samples are needed in order to fundamentally test model predictions, in particular at high redshift. In this project the candidate will analyze MeerKAT observations of three high redshift ($z > 0.4$) galaxy clusters, in order to study their radio properties and test the prediction of radio halo formation models.
5. Primary supervisor: **Prof Oleg Smirnov,** o.smirnov@ru.ac.za, Rhodes University
6. Research supervisor: **Dr Gianni Bernardi,** INAF-IRA (Italy) & Rhodes University

Section B: Details of Research Project

1. Scientific merit: Galaxy clusters are the largest gravitationally bound systems and are believed to be formed via mergers of smaller systems. They have masses of the order of 10^{14}–10^{15} $M_\odot$, with 15−20% in the form of a hot (10^8 K) gas that pervades the cluster volume, emitting X–rays via the Bremsstrahlung mechanism and mm-wave radiation via the Sunyaev–Zeldovich (SZ) effect. The presence of a non–thermal (i.e. relativistic particles and magnetic fields) component emitting synchrotron radiation has been revealed by a variety of radio observations over the last two decades. In particular, there are four different sources of radio emission found in galaxy clusters:

- discrete radio sources associated with cluster galaxies;
- radio halos (RHs): Mpc–scale diffuse radio sources with steep spectrum and low surface brightness that are found in the central regions of a number of merging clusters;
- mini halos: central, diffuse radio sources extending over ~ 100 kpc scales, typical of dynamically relaxed systems;
- radio relics: diffuse radio sources with elongated morphology, significantly polarized, mostly located at the outskirts of a small number of merging clusters.

RHs are particularly interesting sources, as they are connected with the formation and evolution of galaxy clusters. The particle lifetime due to radiative losses is much shorter than the RH crossing time (e.g., Jaffe 1997), therefore a re–acceleration mechanism is required to explain the presence of Mpc–size structures in galaxy clusters. Theoretical efforts over the last two decades have provided a scenario for the formation of RHs based on the in–situ re–acceleration of relativistic particles due to merger–driven turbulence (e.g., see Brunetti & Jones, 2014, for a review). Radio observations of large samples of clusters carried out over the last ten years have established two key properties:

- RHs are not ubiquitous, but are found only in the 20−30% of clusters that are X–ray luminous;
- RHs are connected to the cluster dynamical state, being found only in merging clusters but not in relaxed systems (e.g., Cassano et al., 2010). This behaviour appears as a bimodal distribution between the 1.4 GHz RH power $P_{1.4}$ and the X–ray luminosity L_X, where clusters with a RH follow the $P_{1.4}$–L_X correlation and clusters without a RH are significantly below such correlation (e.g., Brunetti et al., 2009);

With the advent of Sunyaev-Zeldovich cluster surveys, RHs could be directly linked to the cluster mass and their bimodality has been confirmed in the $P_{1.4}$–M^{1}_{500} plane too, with RH clusters following the correlation, whereas clusters without RHs appear well below the correlation. In addition, it has been proven that the fraction of clusters with RH is larger in surveys of mass–selected clusters, being ~ 50% for clusters with $M_{500} > 6\times10^{14} M_\odot$.

These observational results support the current scenario for the formation of giant RHs whose history depends on the interplay between the galaxy cluster merging rate throughout the cosmic epochs and the process of particle acceleration.

In order to provide a more stringent test of the RH formation models, we need to observe the evolution of their fraction with cosmic time. In this project, the candidate will take a first step forward towards observations of a statistically complete sample of high redshift clusters that will allow to test the turbulence re-acceleration model at high redshift.

2. Feasibility: This project is a standard project - in terms of methodology. Three clusters at z > 0.4 have been recently observed with the MeerKAT telescope: PSZ2G277.76-51.74 ($M_{500} \sim 8\times10^{14} M_\odot$, z = 0.44), PSZ2G254.08-58.45 ($M_{500} \sim 9\times10^{14} M_\odot$, z = 0.46) and PSZ2G255.60-46.18 ($M_{500} \sim 8\times10^{14} M_\odot$, z = 0.42). These clusters are expected to host RHs because of their mass and disturbed dynamical status. All the targets have high quality X-ray observations.
The candidate will reduce the MeerKAT observations for the three clusters and produce high quality images at a range of angular resolutions in order to study the radio properties of the cluster population and in particular, to look for diffuse emission in the forms of haloes and relics.

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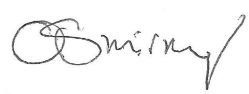
[1] *M_{500} is the total cluster mass within the radius R_{500}, defined as the radius corresponding to a total density contrast $500\rho_c(z)$, where $\rho_c(z)$ is the critical density of the Universe at the cluster redshift.*

The presence/absence of RHs will be interpreted in the light of the turbulent re-acceleration model expectations at high redshift. The candidate will be well placed to publish a first author paper at the end of the project.
Storage and computing resources for this project will be made available at the Radio Astronomy Techniques & Technologies (RATT) Centre at Rhodes University.

3. Link to SARAO research priority areas for 2021: This is a science project that uses MeerKAT data.

4. **Qualifications, academic abilities, skills and/or experience that a student should have in order to successfully deliver on the objectives of the research proposed:**
Familiarity with interferometry and physics of radiative processes would be advantageous but not required.

Supervisor



Oleg Smirnov 7 February 2020