Section A: Overview of the Research Project Proposal

1. Academic level of the research project:

Doctoral

2. Broad field of research:

Astrophysics

3. Title of the research project:

Measuring the magnetic field strength of serendipitous galaxy clusters in MALS target fields

4. Research project abstract/summary:

The MeerKAT Absorption Line Survey (MALS) will observe ~1000 fields along quasar sight lines. We will use the overlap between MALS and the 14,000 square degrees surveyed by the Advanced Atacama Cosmology Telescope (AdvACT) to measure the average magnetic field strength of a sample of massive galaxy clusters at intermediate redshift ($z \sim 0.5$) from Faraday rotation measurements. This will be the first such measurement in clusters at this redshift, and allow us to estimate the contribution of magnetic fields to the energy budget of the intracluster medium. At the time of writing, the minimum sample size that we expect for this work is ~60 sight lines distributed across a sample of 186 Sunyaev-Zel'dovich selected clusters (we expect the sample size to grow as the AdvACT maps become deeper). This is already competitive with studies to date. If possible, we will expand the investigation to study how the magnetic field strength varies with cluster mass and/or redshift.

Section B: Supervisor(s) Details

1. Primary supervisor's details

a. Title and full name:

Dr Matthew James Hilton

b. Name of the South African university at which the primary supervisor is based:

University of KwaZulu-Natal

c. Email address and/or contact telephone number:

hiltonm@ukzn.ac.za / 031 260 2233

d. Supervision of postgraduate students

i. Doctoral Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-supervisor (if relevant)
Kenda Knowles	South African	02/2013	02/2016	Observational Probes of Merging Galaxy Clusters	K. Moodley (main supervisor)
Susan Wilson	South African	02/2013	08/2017 (note: internal examiner took 6 months to respond after submission; Susan worked as a teacher full time during write up)	Evolution of Galaxy Cluster Scaling Relations Over Half a Hubble Time	N. Oozeer
Sinenhlanhla Precious Sikhosana	South African	02/2017	02/2020	Diffuse Radio Emission in ACTPol Clusters	K. Moodley (main supervisor) K. Knowles

ii. Masters Students

Name of student	Nationality	Date started Masters Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-supervisor (if relevant)
Brian M. Kirk	USA	08/2013	06/2014	Southern African Large Telescope Observations of Sunyaev-Zel'dovich Effect Selected Clusters from the Atacama Cosmology Telescope	Catherine Cress (UWC)
Nhlakanipho Kwazi Mthembu	South African	02/2014	09/2016	Dynamical Mass Estimates of Sunayev-Zel'dovich Effect Selected Clusters in the Millennium Gas Simulations	
Zahra Essack	South African	02/2017	01/2018	Searching for Exoplanets Using the Transit Method	

2. Co-supervisor 1 details

a. Title and full name:

Dr Neeraj Gupta

b. Name of institution:

Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India

c. Email address and/or contact telephone number:

ngupta@iucaa.in / +91 20 25604227

d. Supervision of postgraduate students

To be added

3. Co-supervisor 2 details

a. Title and full name:

Dr Kenda Knowles

b. Name of institution:

University of KwaZulu-Natal

c. Email address and/or contact telephone number:

kendaknowles.astro@gmail.com

d. Supervision of postgraduate students

i. Doctoral Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-supervisor (if relevant)
Sinenhlanhla Precious Sikhosana	South African	02/2017	02/2020	Diffuse Radio Emission in ACTPol Clusters	K. Moodley (main supervisor) M. Hilton

Section C: Full Research Project Proposal

1. Scientific merit:

Galaxy clusters are the most massive collapsed objects in the Universe. They contain "atmospheres" of hot (~10^7 K) plasma (the intracluster medium: ICM), and in principle large-scale cosmological hydrodynamical simulations should be able to reproduce their observed properties, provided that we have sufficient understanding of the astrophysical processes that shape their evolution. The thermal properties of the ICM (the gas density, pressure, and temperature) have been studied for decades using X-ray and Sunyaev-Zel'dovich (SZ) effect observations. However, non-thermal emission in clusters - shaped by the effect of large-scale magnetic fields - is not yet well understood. The sensitivity of new facilities such as MeerKAT provides us with an opportunity to rectify this.

In this project, we propose to use serendipitous polarization observations of clusters with MeerKAT (obtained as part of the MeerKAT Absorption Line Survey - MALS; Gupta et al. 2016) to measure the magnetic field strength of a sample of massive clusters using Faraday rotation measurements (RM). This technique relies upon the presence of polarized sources behind clusters along our line of sight: the position angle of linearly polarized emission from background sources changes as a function of wavelength as it passes through the ICM, and the size of the change is dependent upon both the electron density and the magnetic field strength (e.g., Clarke et al. 2001).

To date, there have been relatively few measurements of cluster magnetic field strength. Kim et al. (1990) used measurements along several sight lines through the Coma cluster to infer its magnetic field strength. Studies of more distant clusters have been limited by the number of polarized sources along cluster sight lines, and instead measure the average rotation measure within some characteristic radius (typically R_{500}) for a cluster sample. For example, Böhringer et al. (2016) measured a typical magnetic field strength of 2-6 μG from RM observations along 92 sight lines through clusters in the all-sky CLASSIX X-ray cluster catalog (typical redshift ~ 0.1).

In this project, we propose to measure the average magnetic field strength in a sample of massive SZ-selected galaxy clusters discovered by the Advanced Atacama Cosmology Telescope (AdvACT). AdvACT has surveyed ~14,000 square degrees of the southern sky, and to date has assembled a sample of more than 1500 galaxy clusters reaching to z = 2 (Hilton et al. in prep.; using observations obtained to 2016; AdvACT will continue observations until 2021). The size of the SZ effect is independent of redshift, and leads to an effectively mass-limited cluster sample with a clean, well-understood selection function.

Given the large field of view of MeerKAT, we ultimately expect several hundred AdvACT clusters to fall within the MALS footprint (Gupta et al. 2016). At the time of writing, there are already 186 confirmed clusters that will fall within the MALS target fields (and this number will grow with time as the AdvACT survey gets deeper). We will use this sample to make a first measurement of the magnetic field strength in massive clusters at z ~ 0.5 (the median redshift of our sample). If possible, we will extend this study to look for trends in the magnetic field strength with cluster mass and redshift (e.g., Böhringer et al. 2016 found evidence that the magnetic field strength is higher in more massive clusters).

2. Feasibility:

The polarization data needed for this project will be gathered as part of MALS, a MeerKAT Key Science Project.

As noted above, currently there are *at least* 186 confirmed clusters (with mass measurements and redshifts) in the AdvACT catalog that will be found within MALS target fields. We will use the SZ measurements to infer the electron density along the line of sight (needed to infer the magnetic field strength from the RM data) using a model for the cluster emission, informed by X-ray observations.

The main limitation in the accuracy of measurements of cluster magnetic field strengths is the number of background polarized sources available. The nominal MALS RMS flux limit is ~5 μJy/beam, and so MALS will easily detect 5 mJy sources in intensity at high significance. If these sources are polarized at the 1% level, then we expect to find ~49 polarized sources per square degree with polarization flux ~0.05 mJy (according to the number counts given in Table 1 of Stil et al. 2014). A typical cluster with R_{500} ~ 1 Mpc at z = 0.5 covers ~0.0065 deg^2 on the sky, and so for this nominal sample of 186 clusters, we would expect to obtain RM measurements along ~60 sight lines. This is not as many as Böhringer et al. (2016) but: (1) the redshift of the sample is much higher, and so this would be a new measurement; (2) we expect the sample to grow with time as the AdvACT maps get deeper.

It may also be possible to perform a similar project using MIGHTEE data, if available (this would be deeper, but much smaller area; the Supervisor is a Co-I on MIGHTEE also).

An approximate timeline for the project:

- Year 1: development of the methods / skills needed for performing RM measurements on MALS data

- Year 2: work leading to a paper based on an initial sample (whatever is available depending on the progress of the MALS observations), setting out the methods used on MeerKAT data

- Year 3: work leading to a paper examining mass/redshift trends, with a larger sample

By the end of the project, the student will be well equipped to lead investigations on this topic into the SKA era.

Students and postdocs based at UKZN have access to a High Performance Computing facility (https://www.acru.ukzn.ac.za/~hippo/) and a 64 processor shared-memory machine with more than 700 GB of RAM. The proposed supervisor has a CPRR grant (2018-2020) and UKZN funds that can be used to purchase more equipment (e.g., disk space) as needed. In addition, IUCAA is currently commissioning a cluster (VROOM) dedicated to MALS data processing, and developing a MeerKAT data processing pipeline (ARTIP; https://github.com/RTIP/artip).

References: Böhringer, H., et al., 2016, A&A, 596, A22 ● Clarke, T. E., et al., 2001, ApJ, 547, L111 ● Gupta, N., et al., 2016, Proceedings of Science (arXiv:1708.07371) ● Kim, K-T., et al., 1990, ApJ, 355, 29 ● Stil, J. M., et al., 2014, ApJ, 787, 99

3. SARAO priority areas:

Science topics that involve the exploitation of MeerKAT data projected to be available by 2019-2020.

4. Student academic abilities / skills required:

Nothing special - processing of MeerKAT data with CASA/related pipelines and data analysis with Python (the student will learn these skills in doing the project).