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:

Quantifying AGN feedback processes in massive galaxy clusters with MeerKAT

4. Full names of supervisor and co-supervisor:

Supervisor: Prof. Matthew Hilton

Co-supervisor: Dr. Kenda Knowles

5. University where postgraduate student would be registered

University of KwaZulu-Natal

Section B: Full Research Project Proposal

1. Scientific merit:

It is now known that jets and winds from active galactic nuclei (AGN) influence their surrounding environments. `Feedback' by AGN regulates cooling of gas and subsequent star formation, and is a key ingredient in simulations of both galaxy clusters (e.g., Sijacki et al. 2007, Short et al. 2010) and galaxy formation (e.g., Bower et al. 2006, Croton et al. 2006). Its inclusion is essential for such models to reproduce observed X-ray scaling relations (e.g., between luminosity and temperature of the intracluster medium (ICM); e.g., Maughan et al. 2006, Pratt et al. 2009) and the evolution of the galaxy stellar mass function (e.g., Muzzin et al. 2013). However, the details of how feedback happens, and the evolution between different modes of feedback -- `quasar' and `radio' mode -- are highly uncertain. This uncertainty feeds into the cosmological constraints from clusters, as simulations have shown that mass-observable relations depend on the physics of AGN feedback (see, e.g, the discussion in Hasselfield et al. 2013).

In the case of clusters, it is well established that radio jets, triggered by radiatively inefficient, low levels of accretion onto supermassive black holes in brightest cluster galaxies (BCGs), carve out cavities in the ICM (e.g., McNamara et al. 2005, Gitti et al. 2007, Hlavacek-Larrondo et al. 2013); indeed, this is the main evidence we have for the influence of AGN activity on large scales. The AGN activity is mechanically coupled to the ICM, driving buoyant bubbles which act to redistribute energy from the AGN throughout the cluster. Quasar-mode feedback, on the other hand, is radiatively efficient, associated with high accretion rates, and thought to be responsible for the quenching of star formation in massive galaxies (e.g., Di Matteo et al. 2005, Croton et al. 2006, Bower et al. 2006). Evolution between quasar-mode and radio-mode is expected (e.g., Churazov et al. 2005), with the former including a highly obscured stage that keeps the quasar hidden from view in the optical (e.g., Hopkins et al. 2005).

In this project, we will conduct a census of radio AGN activity in the Advanced Atacama Cosmology Telescope (AdvACT) Sunyaev-Zel'dovich (SZ) effect selected galaxy cluster sample. The SZ effect is the inverse Compton scattering of cosmic microwave background (CMB) photons by the hot gas atmospheres of galaxy clusters, and allows the construction of effectively mass limited cluster samples independent of redshift. As well as providing a probe of cosmology by charting the growth of structure in the universe, the clean SZ selection simplifies the comparison of galaxy evolution studies in clusters with the results of cosmological simulations. **The aim of this project is to quantify the mode, strength, and evolution of AGN feedback processes in massive galaxy clusters over the past 7 billion years.**

The targets of this programme are drawn from the AdvACT SZ cluster survey. The preliminary AdvACT sample is constructed from observations obtained up to 2018 (the survey will continue up to 2021). We have already assembled a sample of 2600 optically confirmed clusters with redshifts, drawn from a survey area of approx. 15,000 square degrees, covering most of the Southern extragalactic sky. To put this into context: this sample is more than eight times larger than the ACTPol cluster sample (Hilton et al. 2018), and is in fact even larger than the total number of published SZ-selected clusters to date. We will use a subset of clusters that overlap with MeerKAT observations - both from our own targeted observations, and from overlap with the MeerKAT Absorption Line Survey (MALS; Gupta et al. 2016). Optical photometry (needed for measuring photometric redshifts and colours of the AGN host galaxies) will come from public Dark Energy Survey (DES) data, and DECaLS (http://legacysurvey.org). A subset of the brightest cluster members will have optical spectroscopy from BEAMS (https://acru.ukzn.ac.za/~beams), a SALT Large Science Project.

2. Feasibility:

We already have MeerKAT data in-hand on several AdvACT clusters (either targeted observations of our own, or MeerKAT commissioning observations of massive clusters that are in the AdvACT sample). We also expect to obtain serendipitous MeerKAT observations of several hundred clusters from MALS, a Key Science Project. All of these data will be sufficiently deep (typical RMS ~5 uJy/beam in L-band) to probe the cluster AGN population.

An approximate timeline for the project:

- Year 1: development of the methods / skills needed for extracting luminosity measurements of AGNs from MeerKAT data (in combination with optical spectroscopic/photometric redshifts)

- Year 2: work leading to a paper on constraints on the evolution of the number of radio AGNs in massive clusters, and constraints on their contribution to the feedback energy (cf. Gupta et al. 2019)

- Year 3: work leading to a paper on spectral ages of AGN radio lobes in the sample (from spectral index maps), as a function of redshift (to constrain the timing of radio-mode feedback)

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: Bower, R. G., et al., 2006, MNRAS, 370, 645; Churazov, E., et al., 2005, MNRAS, 363, L91; Croton, D. J., et al., 2006, MNRAS, 365, 11; Di Matteo, T., et al., 2005, Nature, 433, 604; Gitti, M., et al., 2007, ApJ, 660, 1118; Gupta, N., et al., 2016, Proceedings of MeerKAT Science: On the Pathway to the SKA (Stellenbosch, South Africa), 14; Gupta, N., et al., 2019, arXiv:1906.11388; Hasselfield, M., et al., 2013, JCAP, 07, 008; Hlavacek-Larrondo, J., et al., 2013, MNRAS, 431, 1638; Hilton, M., et al., 2018, ApJS, 235, 20; Hopkins, P. F., et al., 2005, ApJ, 625, L71; Knowles, K., et al., 2016, Proceedings of MeerKAT Science: On the Pathway to the SKA (Stellenbosch, South Africa), 30; Maughan, B. J., et al., 2006, MNRAS, 365, 509; McNamara, B. R., et al., 2005, Nature, 433, 45; Muzzin, A., et al., 2013, ApJ, 777, 18; Pratt, G. W., et al., 2009, A&A, 498, 361; Sijacki, D., et al., 2007, MNRAS, 380, 877; Short, C. J., et al., 2010, MNRAS, 408, 2213

3. SARAO priority areas:

Science topics that involve the exploitation of MeerKAT data projected to be available by 2020-2021.

4. Student academic abilities / skills required:

Nothing special - processing of MeerKAT data with CASA and other tools (e.g., killMS/DDFacet; PyBDSF) and data analysis with Python (the student will learn these skills in doing the project).