Section A: Overview of the Research Project Proposal

1. Academic level of the research project:

Masters

2. Broad field of research:

Astrophysics

3. Title of the research project:

Star formation in a fat galaxy cluster: MeerKAT and SALT observations of El Gordo

4. Research project abstract/summary:

El Gordo is a massive merging galaxy cluster at z = 0.87, originally discovered using the Atacama Cosmology Telescope. It hosts radio relics, which trace the position of a shock wave that has passed through the cluster as a result of the merger. In this project we will test if the star formation rate in cluster member galaxies is enhanced in the vicinity of the merger shocks. We will do this using deep MeerKAT L-band continuum observations (obtained by SARAO), in combination with (proposed) SALT [OII] 3727 Å observations, and archival spectroscopic observations. The student will extract flux measurements for sources detected in the MeerKAT data, cross-match these with member galaxies identified from the optical data, and in turn infer their star formation rates. While this project is entirely self-contained, there is the potential to apply the techniques used here to a larger statistical cluster sample in the future.

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 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:

Clusters of galaxies are harsh environments in which star formation is suppressed and eventually shut off. A variety of processes may operate, including ram pressure stripping (Gunn & Gott 1972), harrassment (e.g., Moore et al. 1999), and strangulation (e.g., Peng et al. 2015). However, the dominant mode has not yet been identified. For some galaxies, the ram pressure on entering the cluster environment may also lead to enhanced star formation for a short time (e.g., Rasmussen et al. 2006).

The recently completed MeerKAT instrument has the potential to improve our understanding of star formation in clusters, by using deep radio continuum observations (unaffected by dust) to infer the star formation rate (e.g., Bell 2003). In this project, we will use the combination of MeerKAT and SALT data to study star formation in El Gordo, a massive merging cluster at z = 0.87 (Menanteau et al. 2012). The MeerKAT L-band data are sufficiently deep to detect galaxies with star formation rate 30 $M_\odot$/yr at 5σ at the redshift of El Gordo (RMS depth ~4 μJy; F. Camilo, private communication). However, optical data are needed to confirm that the MeerKAT sources are in fact cluster members. While we have collected extensive spectroscopic data on El Gordo, identifying 89 cluster members (Menanteau et al. 2012, Sifon et al. 2013), this existing data set is biased towards quiescent, red-sequence cluster members. Since [OII] 3727 Å emission is associated with star-forming cluster galaxies, we have submitted a SALT proposal to scan across the cluster in velocity space using the RSS instrument in Tunable Filter mode. We will then simply cross match the resulting SALT [OII] 3727 Å catalog with the MeerKAT source catalog, and estimate the SFRs for the MeerKAT sources from their radio continuum fluxes (e.g., Bell 2003, Schober et al. 2017).

Note that El Gordo is a special case: an almost equal mass cluster merger in the plane of the sky, in which radio relics have been detected (Linder et al. 2014). The relics trace the position of a shock wave that has passed through the cluster as a result of the merger. We hypothesize that the star formation rate will be enhanced in cluster galaxies trailing the shock front, as the passage of the shock may compress the gas within these galaxies, perhaps leading to a starburst. We would therefore expect to see a higher density of [OII] 3727 Å and/or MeerKAT continuum sources in

such positions within the cluster. Such an enhancement has been seen at lower redshift in a couple of clusters hosting radio relics (Stroe et al. 2014).

2. Feasibility:

As mentioned above, MeerKAT data reaching an RMS depth of ~4 μJy have already been obtained.

We have submitted a SALT proposal to observe El Gordo using the Tunable Filter mode that should be of sufficient depth to detect [OII] 3727 Å in star forming galaxies well below the minimum SFR that should be detectable in the MeerKAT observations. If successful, the SALT observations will take place before January 2019, and should be in hand by the time a student begins work on this project. While highly desirable, the SALT data are not absolutely crucial for the success of this project (e.g., we could use a statistical background subtraction based on only the MeerKAT source counts in / out of the cluster field, if we had to).

The student will work to produce radio continuum imaging of El Gordo, detect sources and extract flux estimates (and in turn SFR measurements) for sources in the cluster. They may also work to extract an [OII] 3727 Å catalog from the SALT observations for cross-matching with the MeerKAT source catalog (to identify sources that are cluster members). It is hoped that the student will lead a short, original research paper describing the results within 12-18 months of commencing the MSc.

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.

References: Bell, E. F., 2003, ApJ, 586, 794 ● Gunn, J. E., Gott, J. R., 1972, ApJ, 176, 1 ● Linder, R. R., et al., 2014, ApJ, 786, 49 ● Menanteau, F., et al., 2012, ApJ, 748, 7 ● Moore, B., et al., 1999, MNRAS, 304, 465 ● Peng, Y., et al., 2015, Nature, 521, 192 ● Rasmussen, J., et al., 2006, MNRAS, 370, 453 ● Schober, J., et al., 2017, MNRAS, 468, 946 ● Sifon, C., et al., 2013, ApJ, 772, 25 ● Stroe, A., et al., 2013, MNRAS, 438, 1377

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 and data analysis using Python (the student will learn these skills in doing the project).