Section A: Overview of the Research Project Proposal

1. Title of the research project:

The Gas Tails of the Fornax Cluster

2. Broad field of research:

Astrophysics

3. Academic level of the research project:

PhD

4. Research project abstract/summary:

The evolution of galaxies is mainly governed by their star formation activity. Cold and dense gas is fuel for star formation, therefore understanding how, and more importantly, where gas is accreted and depleted is among the fundamentals in evaluating galaxy evolution. Through observations, it is clear that the galaxy environment plays a crucial role in this process. The environmental effect on the gas component of galaxies occurs through a multitude of processes such as ram-pressure and tidal stripping, galaxy-galaxy encounters, and removal of the diffuse gas reservoir of galaxies. These processes leave clear imprints on the delicate and diffuse neutral atomic gas (HI) disks of galaxies, making HI an ideal tool to start studying and understanding the complex processes affecting star-formation and consequently galaxy evolution. In particular, efficient gas removal can be seen in the form of **HI tails** stripped away from the galaxy body and other lopsided HI distributions. In this project, the student will participate and partly lead the analysis of HI tails in the Fornax galaxy cluster as part of the MeerKAT Fornax Survey, which is one of the MeerKAT Large Projects. The proximity of this cluster and the exquisite sensitivity and resolution of the MeerKAT data make this a perfect galaxy environment to examine the physics behind the existence of the long HI tails.

5. Primary supervisor's details

a. Full name of the primary supervisor
Dr Mpati Ramatsoku
b. Primary supervisor's email address
m.ramatsoku@ru.ac.za
c. University where the primary supervisor is employed
Rhodes University

6. Co-supervisors' details

a. Full name of the research co-supervisor

Prof. Oleg Smirnov

b. Research co-supervisor's email address
o.smirnov@ru.ac.za
c. University where the co-supervisor is employed
Rhodes University/SARAO

Section B: Details of Research Project

1. Scientific merit

Galaxies can be schematically described as either star forming, predominantly with spiral late-type morphologies, or passive, predominantly with elliptical/lenticular early-type morphologies. The ongoing research is to understand the origin and working modes of the cessation of star formation activity in galaxies and to characterise their transition evolutionary phases from late- to early type. It is well established that the neutral atomic hydrogen (HI) gas in galaxies is one of the major drivers of star formation activity. Galaxies lose their HI and consequently transform from late- to early types (Poggianti+, 2001; Bravo-Alfaro+, 2000, Bravo-Alfaro+, 2009; Chung et al+, 2009; Gavazzi+, 2013; Jaffe+2015, Yoon+, 2017). This transition occurs through a myriad of processes that occur within the various environments of the cosmic web including, tidal stripping (Gnedin+, 2003), ram-pressure stripping (Gunn & Gott, 1972), thermal evaporation (Cowie+, 1977), encounters with other satellites (Moore+, 1996), and the removal of the diffuse gas reservoir of galaxies (Larson+ 1980). These effects are more pronounced in dense environments and a number of HI surveys have demonstrated that late-type galaxies have lower HI mass the closer they are to cluster centres.
However, to fully understand the details of these processes, sensitive and high resolution HI imaging is of paramount importance. Such observations allow low and faint HI column density to be detected which enables us to directly observe gas accretion from the large cosmic-web and gas removal from the outskirts of galaxy discs as they happen. Therefore, at high resolution and sensitivity, HI offers a unique opportunity to directly catch these processes in action because it is able to reveal stripped gas tails and truncated gas discs.

The aim of the student project is to study HI tails in the Fornax cluster. Thanks to MeerKAT high resolution and sensitive data has been obtained for this nearby cluster at 20 Mpc as part of the MeerKAT Fornax Survey (PI: Paolo Serra). The proximity of this system and the high concentration of galaxies make it uniquely suited for studies of galaxy evolution in dense environments.

The goal of the project is to study the physics governing gas removal from galaxies of different mass and type as a function of their position within the Fornax galaxy cluster. This will include but not limited to:

- understanding the balance between the tidal and hydrodynamical effects in the creation of the HI tails,
- studying the multi-resolution properties of the tails and their the star formation activity,
- investigating the effect of ram-pressure within the disc of galaxies,
- comparing the observed HI tails to state-of-the-art hydrodynamic simulations.

2. Feasibility and resources

The HI data required for this project have already been observed as part of the MeerKAT Large Science Program (LSP) for the MeerKAT Fornax Survey. Close to 75% of the data has been observed and fully processed and will be accessible to the student who starts their work in 2024. The PhD work will consist of getting acquainted with; the data reduction of the more incoming Fornax data, characterisations and analyses of the HI gas content in the galaxies to address main goals outlined in section 1. The PhD work also includes comparing the HI gas properties (within the context of the aforementioned main goals) with Illustris TNG (Nelson+19) high resolution hydrodynamical simulations of Fornax-like clusters, which the MeerKAT Fornax Survey team has already started working on.

The project has a wealth of ancillary data which is already available and will support this study. The MeerKAT Fornax field is fully covered by a deep optical imaging survey carried out with OmegaCAM on ESO VST. This data set provides the way to detect any low surface brightness counterpart to the extra planar HI. Additional VST imaging taken by our team further enables the study of the star formation properties of this low surface brightness HI through the comparison with Hα. The Fornax field also has a lot of publicly available ancillary data; Xray from Chandra and XMM-Newton, UV photometry from GALEX, Infrared from WISE and other gas phases such as CO from ALMA.
Rhodes University (RATT/RARG) and INAF-Cagliari (where part of the MeerKAT FOrnax Survey team is based and where the student is likely to spend some time during the the course of the Ph.D. project) have access to several high-performance computing facilities and sufficient storage, such that there are adequate resources to analyse the data for this project.

A plausible time-frame for the project is as follows:

Year 1: The student will start with a literature study in the first half of 2024 to understand the topic. They will use this time to become up to date with the latest scientific results on the subject and familiarise themselves with the scientific goals of the project, the scientific questions to be addressed in the dissertation, and the new results obtained by the MeerKAT Fornax Survey. During this time the student will also familiarise themselves with observational radio astronomy and interferometry (if necessary).

Year 2: The student will then analyse the distribution and detailed HI properties of the tails, and place them in the context of the Fornax cluster. This process will also include collecting and processing the complementary multi-wavelength data required to perform the necessary analyses and address the scientific questions, as outlined above. The work will be done in close partnership with a co-supervisor at the collaborating institution (e.g., INAF-Cagliari) where the student is expected to visit and work with the rest of the team.

Year 3: The student will finalise the results and write up their thesis. At the end of the PhD work, they will present their work at both institutions (Rhodes and INAF-Cagliari). A paper or two based on this PhD will form part of the work to be conducted in year 2 or will be expected to follow.

In all cases, the student will work in close collaboration with supervisors at Rhodes University and INAF-Cagliari. This project benefits from an international consortium which will offer the student an opportunity to interact closely with many faculty on the program and to give (remote) seminars on her/his work at the various institutions.

3. SARAO research priority areas

This project is addressing the following SARAO priority area;

- Topics exploiting data projected to be available by 2024-25 from key existing radio astronomy instruments located in South Africa: this is a MeerKAT project.

4. Student academic abilities/skills required

For this project, a candidate would require a Masters degree in astronomy, physics, engineering or a similar discipline. They need to have a working knowledge of scripting languages e.g., Python, Matlab etc, and if not present the candidate must be capable of becoming rapidly familiar with a scripting language of their choice. Some experience with observational radio astronomy, interferometry, analysis of radio astronomical data is desirable but not a requirement.

Supervisor's Signature:

Mpati Ramatsoku

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About me: Research interests: The formation and evolution of structure in the Universe and galaxy clusters; nature and evolution of galaxies; their interactions, structure and composition; the role of dust and gas in galaxies.

WORK EXPERIENCE

06/2019 – CURRENT – Makhanda, South Africa
RESEARCH FELLOW – RHODES UNIVERSITY

Research and development:
- Conducting research in radio astronomy and techniques.
- Testing and developing radio interferometric data reduction pipelines for MeerKAT and other instruments.

Supervision of students:
- Creating research projects for prospective graduate students.
- Supervision of graduate students at Rhodes University.

10/2017 – 05/2019 – Cagliari, Italy
POST-DOCTORAL RESEARCHER – ISTITUTO NAZIONALE DI ASTROFISICA (INAF) - CAGLIARI

Researcher:
- Conducting studies on how gas in cluster galaxies affected their star formation and consequently galaxy evolution in these kinds of environments.
- Defining radio data acquisition strategies, processing and analyses as part of the MeerKAT Fornax and GAs Stripping Phenomena Surveys.

EDUCATION AND TRAINING

01/2013 – 10/2017 – Landleven 12, Groningen, Netherlands
PHD IN ASTROPHYSICS – University of Groningen and University of Cape Town

https://www.rug.nl/research/kapteyn/?lang=en

STUDENT SUPERVISION

01/2020 – CURRENT
Bachelor (Honours) and Masters

Koketso Mophahlane - Rhodes University
Thesis Title: HI imaging of the Norma cluster with MeerKAT

PUBLICATIONS

Papers in refereed journals and conference proceedings

A total of ~ 40

First author papers :

Ramatsoku, M., Verheijen, M. A. W., Kraan-Korteweg, R. C., Jarrett, T. H., Said, K., & Schröder, A. C., *A near-infrared study of the obscured 3C129 galaxy cluster,* (2020), A&A, 644, A107.

Ramatsoku, M., Serra, P., Poggianti, B. M., Moretti, A., Gullieuszik, M., Bettoni, D., Deb, T., Franchetto, A., van Gorkom, J. H., Jaffé, Y., Tonnesen, S., Verheijen, M. A. W., Vulcani, B., Andati, L. A. L., de Blok, E., Józsa, G. I. G., Kamphuis, P., Kleiner, D., Maccagni, F. M., Makhathini, S., Molnár, D. C., Ramaila, A. J. T., Smirnov, O., & Thorat, K., *GASP. XXVI. HI gas in jellyfish galaxies The case of JO201 and JO206,* (2020), A&A, 640, A22.

Ramatsoku, M., Verheijen, M. A. W., Kraan-Korteweg, R. C., Józsa, G. I. G., Schröder, A. C., Jarrett, T. H., Elson, E. C., van Driel, W., de Blok, W. J. G., & Henning, P. A., *The WSRT ZoA Perseus-Pisces filament wide-field H I imaging survey - I. H I catalogue and atlas*, (2016), MNRAS, 460, 923. ... (truncated list)

Distinguished Prof Oleg M. Smirnov 1 January 2023

SKA Research Chair,
Centre for Radio Astronomy Techniques & Technologies (RATT), Rhodes University
Head: Radio Astronomy Research Group,
South African Radio Astronomy Observatory

Department of Physics and Electronics, Rhodes University
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Born in Moscow, Russia 10 May 1973
Nationality: Dutch

Professional Activities

2012-present: Rhodes University (Grahamstown, South Africa, http://www.ru.ac.za), Department of Physics and Electronics. SKA Research Chair in Radio Astronomy Techniques and Technologies.

2012-present: South African Radio Astronomy Observatory (Cape Town, http://ska.ac.za), Head: Radio Astronomy Research Group (RARG)

1999--2012: Netherlands Institute of Radio Astronomy (Dwingeloo, The Netherlands, http://www.astron.nl). Positions: post-doctoral researcher, scientific software developer, software architect, researcher.

1988--1999: Institute of Astronomy of the Russian Academy of Sciences (INASAN, Moscow, Russia, http://www.inasan.ru/). Positions: lab assistant, PhD student, researcher.

1994--1999: AGNET Systems (Moscow, Russia). Chief software engineer. Software development for air traffic control & air traffic information systems

Education

1995-1998 PhD Astronomy & Astrophysics
Institute of Astronomy of the Russian Academy Of Sciences, Moscow
Supervisor: Dr. N.N. Samus (Sternberg Astronomical Institute)
Thesis defended at the Astro Space Center, Lebedev Physics Institute, Moscow:
“CCD photometry of globular clusters”.

1990-1995 Mathematics
Mechanics and Mathematics Faculty, Moscow State University
Degree obtained in June 1995

Professional Achievements

Awarded an A-rating by the National Research Foundation (2022).

Research into radio interferometric calibration and imaging: Mathematical modelling of the measurement process (radio interferometry measurement equation); software and methods for radio astronomical calibration, imaging, and simulations, ionospheric modelling. Mathematical treatment of direction-dependent effects. Data compression techniques for radio interferometry. Bayesian techniques for estimating scientific parameters from radio observations. Radio imaging at extreme dynamic range.

Development of software systems for radio astronomy: Primary developer of the MeqTrees package (http://meqtrees.net) for implementing arbitrary measurement equations, calibration and simulation. Lead developer and/or contributor to various other current packages (CASA via AIPS++, pyxis, Montblanc).

Student supervision

MSc: J. Kenyon, C. Nunhokee (graduated 2015), L. Philip, B. Hugo (graduated 2016), L. Sebokolodi, U. Mbou Sob, T. Blecher (graduated 2017), A. Akoto-Danso (graduated 2018), S. Zitha, A. Ramailla (graduated 2019), L. Andati (graduated 2020), J. van Staden, C. Russeawon (graduated 2021), C. Ntsikelelo, P. Legodi (graduated 2021), R. Kincaid (graduated 2022), B. Welman, S. Manaka, K. Trehaeven (in progress)

PhD: H. Shukla (graduated 2014), A. Marcellin, S. Makhathini, I. Natarajan (graduated 2017), C. Nunhokee (graduated 2018), J. Kenyon, E. Bonnassieux (graduated 2019), T. Narh, K. Iheanetu, U. Mbou Sob (graduated 2020), G. Molenaar (graduated 2021), L. Sebokolodi (graduated 2022), L. Andati, I. D. Ramalla, A. Ramailla, B. Hugo (in progress)

Publications: 291 total, 10596 citations

Main publications 2015-present:

Sob, U.M.; Bester, H.L.; **Smirnov, O.M.**; Kenyon, J.S.; Grobler, T.L.; Radio interferometric calibration using a complex Student's t-distribution and Wirtinger derivatives; MNRAS 2020, 491, 1026

Kenyon, J.S.; **Smirnov, O.M.**; Grobler, T.L; Perkins, S.J.; CubiCal - Fast radio interferometric calibration suite exploiting complex optimisation; MNRAS 2018, 478, 2399

Dabbech, A.; Onose, A.; Abdulaziz, A.; Perley, R. A.; **Smirnov, O. M.**; Wiaux, Y.; Cygnus A super-resolved via convex optimization from VLA data; MNRAS 2018, 467, 2853

Grobler, T.LL, Bernardi, G., Kenyon, J.S., Parsons, A.R., **Smirnov, O.M.**; Redundant interferometric calibration as a complex optimization problem; MNRAS 2018, accepted

Atemkeng, M.; **Smirnov, O.**; Tasse, C.; Foster, G.; Keimpema, A.; Paragi, Z.; Jonas, J.; Baseline-dependent sampling and windowing for radio interferometry: data compression, field-of-interest shaping and outer field suppression; MNRAS 2018, 477, 4511

Smirnov, O. M., Tasse, C. 2015, "Radio interferometric gain calibration as a complex optimization problem", MNRAS, 449, 2668