RATT Postgraduate Scholarships and Research Projects For 2025

Closing date: 13 August 2024

RATT invites applicants for postgraduate scholarships commencing in 2025. We have a mix of science-oriented and techniques-oriented projects – some may fall into both categories, depending on scope. Note that a number of our projects are also eligible for funding via SARAO freestanding bursaries, these are marked by "(SARAO)" below, and the project text includes a link to a more detailed project description on the SARAO website. The funding levels and the application process are the same for all categories of funding:

1. Carefully read the NRF guidelines to make sure you are eligible for funding. Note that RATT and SARAO scholarships are only available to citizens of South Africa and SKA Africa partner countries.
2. (Applicants from partner countries: please check your equivalent SAQA NQF level. Rhodes normally requires NQF 8 for MSc applicants, and NQF 9 for PhD applicants, although exceptions may be motivated for if substantial additional research experience can be demonstrated.)
3. Make e-mail contact with the listed project supervisor(s) and obtain their approval. Please write an e-mail motivation (it may be informal) and include a detailed CV and all academic transcripts.
4. Once you have the approval, proceed to apply via the NRF Connect portal, **selecting "SARAO Doctoral" or "SARAO Masters" as the application category**.
5. E-mail your supervisor(s) with your application reference number.

The Rhodes internal closing date for applications is **13 August 2024**, but please allow yourself ample time for the application process.

Science-oriented projects

(MSc) A filament feeding the Virgo cluster
(MSc) HI morphologies in 3D: A machine learning approach
(PhD / MSc) (SARAO) Dynamical Detective: Probing the merger state of MERGHERS clusters
(PhD) (SARAO) Studying diffuse cluster emission evolution with MERGHERS
(PhD) (SARAO) Probing formation mechanisms of MGCLS radio halos
(PhD) (SARAO) Galaxy evolution and galaxy cluster dynamics in the GCAV sample explored with MeerKAT and JWST
(PhD) (SARAO) Observations of the Universe first (radio) light with HERA
(PhD/MSc) Peering through the Cosmic Dawn
(PhD/MSc) Observations of the Cosmic Dawn and the Epoch of Reionization with the Radio Experiment for the Analysis of Cosmic Hydrogen (REACH)
(PhD/MSc) Observations of the radio signature of Dark Matter
(MSc / PhD) Galaxy cluster stacking studies with SKAO Precursor telescopes
(MSc) (SARAO) How to mitigate errors in the observations of the closure phase power spectrum with HERA using fringe rate filters
(PhD / MSc) Spectropolarimetric studies of radio galaxies in MERGHERS fields
(MSc)(SARAO) Radio halo/mini-halo upper limits in MGCLS
(MSc)(SARAO) Multiband MeerKAT study of JWST SMACS0723
(MSc) Analysis of a sample of new Giant Radio Galaxies detected with MeerKAT
(MSc) Dying radio galaxies: what is so special about them?
(MSc) Ring-shaped radio sources

Techniques-oriented projects

(PhD) (SARAO) Wide-band polarimetric imaging and polarization selfcal with MeerKAT and VLA
(PhD) MeerKAT cinematography: the radiation belts of Jupiter in 4D
(PhD) A proposed design for baseline-dependent correlators using Farrow filters combined with the raised cosine
(MSc/PhD) Identifying PSF patterns around sources using deep learning techniques
(MSc) (SARAO) Dealing with pointing errors and heterogeneous MeerKAT+ dishes
(MSc) (SARAO) Designing an Active Integrated Antenna for the Rhodes University Transient Array Radio Telescope
(MSc) Improving Dask Scheduling for Radio Astronomy Algorithms
(MSc) Distributed low-rank approximation for baseline-dependent lossy compression
(MSc) Visual Interpretability and Explainability of Deep Learning Models for Radio Astronomical Source Classification and Detection Tasks

(MSc) A filament feeding the Virgo cluster

Supervisors: Dr Mpati Ramatsoku (m.ramatsoku@ru.ac.za)
Prof Pascale Jablonka (pascale.jablonka@epfl.ch)

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 manifests itself in a multitude of processes such as ram-pressure and tidal stripping, galaxy-galaxy encounters, and removal of the diffuse gas reservoir of galaxies. The dense galaxy clusters have been shown to have a deep impact on the gas phase of galaxies and in accelerating their evolution. However, it has also been found that filaments might already be pre-processing galaxies long before they get channelled towards the cluster centres. Fewer studies on understanding the true impact of filaments in galaxies exist, of note, an important question is whether they deplete or replenish galaxies' cold gas reservoirs.

In this project, the student will participate and partly lead the gas analyses of the Virgo III filament to be observed with MeerKAT. The proximity of this large-scale structure and exquisite MeerKAT data make a perfect laboratory with tools to examine the cold gas content and pre-processing in this environment.

(MSc) HI morphologies in 3D: A machine learning approach

Supervisors: Dr Mpati Ramatsoku (m.ramatsoku@ru.ac.za)
Dr James Dawson (james.d.astro@gmail.com)

Asymmetries in the spatial HI distribution of galaxies and kinematics are indicators of gas removal processes and accretion which are important in studies of the physics of galaxy formation and evolution. The vast amount of the publicly available MeerKAT data will contribute greatly to these efforts; however, this brings about new challenges. Among these, one of the most crucial is to develop objective and reliable methods to parametrise HI properties such as morphologies spatially and spectrally. Current parametric methods model the full HI data cube or integrated HI maps (moment 0) or velocity fields (moment 1 maps) using tools which fit 3D tilted-ring models, e.g.,TiRiFiC (Józsa et al. 2012) and 3D-Barolo (Di Teodoro & Fraternali, 2015). Other tools such as the Gipsy task rotcur (van der Hulst et al. 1992) obtain rotation curves by fitting velocity fields. Non-parametric techniques decompose integrated HI maps or determine indices adopted from optical characterisation (Holwerda et al. 2011) i.e., Asymmetry, Smoothness, Concentration, Gini, M20. Comparing asymmetry criteria used for these approaches with galaxy HI morphology from visual inspection found that on average only 25% of galaxies with asymmetries are correctly identified as such (Giese et al. 2016). A large number of galaxies have been (will be) detected by MeerKAT through large blind (or systematic) HI surveys (e.g., LADUMA, MIGHTEE, MGCLS). Modelling every galaxy and verifying visually will be time-consuming. This will be made more challenging by the limited resolution of most of the galaxies that will be (are) detected.

This project aims to explore machine learning (ML) approaches in combination with the above-mentioned tools, particularly to eliminate the visual inspection aspect of the HI morphology classification process.

(MSc / PhD) (SARAO MSc) Dynamical Detective: Probing the merger state of MERGHERS clusters

Supervisors: Dr Kenda Knowles (kendaknowles.astro@gmail.com)
Prof Matt Hilton (U. Witwatersrand)

Diffuse cluster radio emission comes in several forms - radio halos, radio relics, mini-halos - with each classification having a different proposed formation mechanism related to the dynamical state of the host cluster. Historically, cluster samples targeted for diffuse emission searches were restricted to low redshift, massive systems. The target selection criteria must be broadened in order to take a step forward in understanding the formation and evolution of diffuse cluster radio sources. The MERGHERS (Knowles et al., 2016, 2021a) programme consists of tiered MeerKAT observations of Sunyaev-Zel'dovich-selected galaxy clusters, with L-band and potentially UHF as well. The aim of MERGHERS is to perform statistical and evolution studies of diffuse cluster emission over wide redshift and mass ranges using a sample of ~200 clusters, with each tier serving as a well-selected subsample. Clusters are selected from the Atacama Cosmology Telescope's DR5 catalogue, which is blind to the cluster dynamical state. However, knowing the physical environment of a cluster is an important component in understanding the presence or lack of diffuse cluster emission, and investigating its evolution. The dynamical state of a system is also required to correctly classify any observed diffuse emission in the cluster region.

This project focuses on determining the dynamical state of the MERGHERS targets through the use of multiwavelength data (eROSITA/other X-ray imaging, optical density maps via DES photometry, available optical spectroscopy from SALT [PI: M. Hilton]). For systems with both imaging and spectroscopic information, the student will produce a model of the merger to study the diffuse radio emission connection in detail. The project is expected to produce a student-led paper on the dynamical state results of the targeted systems.

To date, 56 MERGHERS targets have been observed. All data will be processed and imaged before the start of this project. Archival X-ray imaging from Chandra or XMM-Newton exists for 60% of the clusters, with other data to be obtained through new proposals or collaboration with eROSITA. All MERGHERS targets to date lie within the footprint of the Dark Energy Survey which provides photometric data for optical density maps. Spectroscopic data from SALT has been applied for the MERGHERS targets with a diffuse emission detection (PI: M. Hilton) in order to probe the line of sight morphology. The student will initially focus on the MERGHERS targets with diffuse emission detections, and extend to all targets if time allows. Familiarity with Python programming is required. Familiarity with spectroscopic data reduction and X-ray data analysis is advantageous.

(PhD) (SARAO) Studying diffuse cluster emission evolution with MERGHERS

Supervisors: Dr Kenda Knowles (kendaknowles.astro@gmail.com)
Dr Virginia Cuciti (INAF Bologna)

Diffuse cluster radio emission comes in several forms - radio halos, radio relics, mini-halos - with each classification having a different proposed formation mechanism related to the dynamical state of the host cluster. Historically, cluster samples targeted for diffuse emission searches were restricted to low redshift, massive systems. The target selection criteria must be broadened in order to take a step forward in understanding the formation and evolution of diffuse cluster radio sources. The MERGHERS (Knowles et al., 2016,2021) programme consists of tiered L-band and UHF MeerKAT observations of Sunyaev-Zel'dovich-selected galaxy clusters. A key aim of MERGHERS is to perform statistical and evolution studies of diffuse cluster emission over wide redshift and mass ranges using a sample of ~200 clusters, with each tier serving as a well-selected subsample. Clusters are selected from the Atacama Cosmology Telescope's DR5 catalogue, which is blind to the cluster dynamical state.

The first two tiers of the MERGHERS project consist of 56 mid to high redshift clusters. By comparing the MERGHERS data with observed samples at lower redshift, we can begin to study the evolution of the occurrence rates of diffuse cluster emission and their scaling relations with cluster properties. Understanding the evolutionary properties, if any, of diffuse radio sources is critical for understanding how they are formed and evolve through cosmic time.

This project focuses on analysing existing MERGHERS data for extended diffuse cluster radio emission and using the results in conjunction with literature results from other SZ-selected surveys (e.g. Cuciti et al 2021) to study evolution in the sample statistical properties. The student will work closely with Dr Kenda Knowles and other members of the MERGHERS collaboration to reduce and analyse the radio images (processed images for all first tier targets are already available), identify faint extended emission, investigate in-band spectral indices, and extract the faint source properties. The student will mine the literature for compatible datasets and combine them with the MERGHERS sample to create well-defined sub-samples at different redshifts. Finally, the student will perform a statistical investigation of the (sub)samples, looking for evolution in mass or redshift. The project is expected to produce at least one publication on the results of the statistical analysis. Knowledge of Python programming and Unix platforms is required. Familiarity with continuum MeerKAT data reduction is advantageous.

(PhD) (SARAO) Probing formation mechanisms of MGCLS radio halos

Supervisors: Dr Kenda Knowles (kendaknowles.astro@gmail.com)
Dr Sinenhlanhla Sikhosana (UKZN)

Different radio halo formation scenarios predict different slopes in the point-to-point non-thermal vs thermal ICM correlations. We will use archival X-ray data to study the point to point correlation for MGCLS radio halos in order to constrain the formation mechanism at play in the different clusters, and compare the results with the multiwavelength view of the cluster mergers to determine if different formation models produce distinguishable merger characteristics. This project is expected to produce at least one publication. Link to the full project description here.

(PhD) (SARAO) Galaxy evolution and galaxy cluster dynamics in the GCAV sample explored with MeerKAT and JWST

Supervisors: Dr Tiziana Venturi (INAF, tventuri@ira.inaf.it)
Prof Oleg Smirnov (osmirnov@gmail.com)

This project aims to explore the overlap between the MeerKAT Galaxy Cluster Legacy Survey, JWST observations, and the Galaxy Clusters At Vircam (GCAV) survey. This will allow for a very detailed study of the radio galaxy population down to the transition regime between AGN and starburst in elliptical galaxies, and to very faint star formation emission in late-type objects. Combined with ancillary data already available, this will open a window on galaxy evolution over a large, and largely unexplored, diversity of cluster environments. See full project description.

(PhD) (SARAO) Observations of the Universe first (radio) light with HERA

Supervisors: Prof Gianni Bernardi (giannibernardi75@gmail.com)
Prof Oleg Smirnov (osmirnov@gmail.com)

The Hydrogen Epoch of Reionization Array (HERA) is currently under construction at the Karoo site, with the goal of observing the birth of the first stars and galaxies through the (still undetected) 21 cm line from the intergalactic neutral Hydrogen. The candidate will become part of the HERA collaboration, with the goal of producing the deepest, all-sky, HERA images to date. This goal will require the development of a direction-dependent imaging algorithm for transit arrays - like HERA. The images will be crucial to study the low frequency sky as well as foreground emission - crucial to reveal the faint 21 cm signal. See full project description.

(PhD/MSc) Peering through the Cosmic Dawn

Supervisors: Prof Gianni Bernardi (giannibernardi75@gmail.com)
Prof Oleg Smirnov (osmirnov@gmail.com)

Our current understanding of the cosmic evolution from the epoch of Hydrogen recombination (300000 years after the Big Bang) till the first billion years is very poorly known from an observational perspective, although it must have seen the growth of the initial density perturbations via gravitational attraction into the first stars and galaxies.

The 21-cm transition from neutral Hydrogen promises to be the best observational probe of such cosmic time and has driven the construction of the new generation of low frequency radio instruments. The Large aperture Experiment to detect the Dark Ages (LEDA) was built to attempt the detection of the sky-averaged 21-cm from the Cosmic Dawn at 15 < z < 36, before widespread reionization took place, in order to understand the formation of the first luminous structures in the Universe.

The Hydrogen Epoch of Reionization Array (HERA) is also an array that attempts to measure the 21 cm signal from the Cosmic Dawn at 10 < z < 25. It is currently under construction and its observations are already yielding the best upper limits on the 21 cm signal to date.

The candidate will have the chance to:

- work on the analysis of LEDA radiometric data, with the aim to calibrate them and extract the 21-cm signal;
- work on the analysis of LEDA interferometric data, with the goal of calibrating them and extracting the 21-cm power spectrum;
- work on the analysis of HERA interferometric data, with the goal of calibrating them and extracting the 21-cm power spectrum.

An ideal candidate will have a good background in physics and mathematics, the willingness to learn about advanced radio interferometry, statistics, signal processing techniques and cosmology, but, mostly, the desire to contribute to the 21-cm cosmology revolution.

(PhD/MSc) Observations of the Cosmic Dawn and the Epoch of Reionization with the Radio Experiment for the Analysis of Cosmic Hydrogen (REACH)

Supervisors: Prof Gianni Bernardi (giannibernardi75@gmail.com)
Prof Oleg Smirnov (osmirnov@gmail.com)

Note: under the NRF-Nuffic program, qualified South African candidates can also pursue this project as a joint 4-year PhD between RATT and the University of Groningen, Netherlands.

The study of cosmic reionization is one of the frontiers in modern cosmology and low frequency radio astronomy. Despite two decades of intense theoretical and observational studies, we only have a limited knowledge of how the first stars and galaxies formed (Cosmic Dawn) and when their intense star-formation driven UV radiation completely ionised the surrounding intergalactic medium (Epoch of Reionization, EoR). The 21 cm line emitted from the neutral Hydrogen in the InterGalactic Medium (IGM) is considered to be the best probe of the Cosmic Dawn and the Epoch of Reionization and has been the driver behind the construction of several low frequency radio interferometric arrays like HERA, LOFAR, MWA and PAPER. These arrays aim to measure the redshift evolution of the neutral Hydrogen spatial fluctuations and, ultimately, to image the redshift evolution of the IGM across cosmic time (e.g., like the SKA; Koopmans et al., 2015).

Observations carried out with individual dipoles offer an alternative to interferometric arrays: they measure the sky-averaged (global) 21 cm frequency spectrum and, therefore, aim to measure the redshift evolution of the IGM. Recently, the EDGES global signal experiment reported the first detection of the redshifted 21 cm line, a 550 mK-deep absorption trough centred at $z = 17.5$ (Bowman et al., 2018) that remains highly controversial. The IGM is essentially neutral and colder than the cosmic microwave background (CMB), i.e. it is expected to be observed in absorption against the CMB before widespread reionization (i.e., $z > 12$), . However, the most optimistic models predict an absorption profile that is ~250 mK bright, i.e. less than half of the EDGES result. The magnitude of the EDGES signal has been explained so far by invoking two exotic mechanisms:

- the presence of collisional dark matter in the early Universe. If dark matter was (at least partially) collisional, it would be colder than the IGM and would have cooled it further down via a collisional exchange;
- the presence of an extra background radiation, additional to the CMB, which increases the contrast against the gas temperature, enhancing the absorption profile.

Either explanation is unsatisfactory: the required fraction of collisional dark matter violates independent constraints from observations of CMB anisotropies and particle physics experiments, and the generation of an extra background requires ad hoc astrophysical assumptions on the nature of the high redshift sources. Most of the EoR community is awaiting for an independent confirmation (or disproof) of the EDGES results.

The Radio Experiment for the Analysis of Cosmic Hydrogen (REACH) is one of the very few global signal experiments that aims to measure the evolution of the 21 cm signal across the Cosmic Dawn and the Epoch of Reionization, therefore providing an independent assessment of the EDGES findings. It is a partnership between the University of Cambridge (co-PI: E. de Lera-Acedo) and Stellenbosch University (co-PI: D. de Villiers) that are working together to deploy a new large-bandwidth singole dipole in the Karoo reserve area in early 2020. The Karoo radio astronomy reserve is an extremely radio quiet environment that allows observations in the FM band (88-110 MHz) where the EDGES signal was discovered. REACH is designed to simultaneously measure the global 21 cm signal in the 50-200 MHz frequency range ($6 < z < 35$) and characterise the thermal and ionisation history of the IGM.

The candidate will be working on the scientific exploitation of REACH data, focusing on the following topics:

- Simulations of REACH observations with the aim to forecast cosmological parameters. In particular, the candidate will use the instrument models developed by the Cambridge and Stellenbosch groups in order to simulate realistic observations of the global 21 cm spectrum. Models of the 21 cm signal will be generated with existing publicly available codes but also using custom developed models that account for collisional dark matter (Fialkov et al., 2019). The candidate will add foreground models (e.g., following Bernardi, McQuinn & Greenhill, 2015) and use existing foreground separation methods to extract the 21 cm signal (e.g., following Bernardi et al., 2016). In this way the candidate will be able to forecast the detectability of cosmological parameters (e.g., mass of the first galaxies, star formation rate, X-ray heating efficiency) as well as the EDGES-like signal from actual REACH observations;
- Application of the developed simulation pipeline to actual REACH observations in order to place constraints on 21 cm parameters - essentially unconstrained till now - and to confirm

(or disproof) the EDGES result. The candidate will also have the opportunity to be involved in the analysis (e.g., flagging, calibration) of REACH data.

(PhD/MSc) Observations of the radio signature of Dark Matter

Supervisors: Prof Gianni Bernardi (giannibernardi75@gmail.com)
Prof Oleg Smirnov (osmirnov@gmail.com)

Most of the matter in our universe must be non-baryonic. Observations accumulated over the last few decades show that some form of dark matter is the invisible scaffolding that holds the visible universe together. The remarkable and indisputable evidence is still accompanied by an aura of mystery about the particle origin of dark matter. Two of the best-motivated possibilities are
WIMP or QCD axion dark matter. WIMP dark matter is expected to have a mass around the weak scale and weak couplings, as predicted, e.g., in the case of the neutralino in supersymmetry. The weak coupling implies that WIMP annihilations can inject electron/positron pairs with sizable yields. For typical WIMP masses in the GeV-TeV range and typical micro-Gauss magnetic fields of galaxies, they generate a synchrotron emission in the radio band. On the other hand, axion-like particles can decay into radio photons - depending upon the particle mass and the mass of the astrophysical object.
In this project the candidate would look for the radio signature of DM particles (other WIMP or axion-like) in a variety of astrophysical objects observed by MeerKAT. The candidate will search for radio emission in MeerKAT archive data of the local dwarf spheroidal galaxies, the Large Magellanic Cloud and galaxy clusters from the MeerKAT Galaxy Cluster Legacy Survey. Even in absence of a detection, the candidate will constrain the mass of DM through upper limits on their radio emission.

(MSc / PhD) Galaxy cluster stacking studies with SKAO Precursor telescopes

Supervisors: Dr Kenda Knowles (kendaknowles.astro@gmail.com)

There is currently a wealth of data being collected from SKAO precursor and pathfinder telescopes, covering a large sky area and hundreds of galaxy clusters. Diffuse cluster emission in high redshift and/or low mass clusters is expected to be faint, possibly too faint to detect on an individual basis. By using available galaxy cluster catalogues, this project aims to cross match cluster positions in the available radio data to perform stacking experiments to attempt to detect the lowest brightness extended sources within galaxy cluster environments. As a member of several radio collaborations with large volumes of radio data (MERGHERS, MALS, EMU, superMIGHTEE, LoTSS DR2) from telescopes like MeerKAT, ASKAP, LOFAR, and the uGMRT, the student will have the opportunity to work with a wide range of data and large research collaborations. Experience with Python scripting is required.

(MSc) (SARAO) How to mitigate errors in the observations of the closure phase power spectrum with HERA using fringe rate filters

Supervisors: Prof Gianni Bernardi (giannibernardi75@gmail.com)
Prof Oleg Smirnov (osmirnov@gmail.com)

The Hydrogen Epoch of Reionization Array (HERA) is currently in an advanced stage of construction at the Karoo site, with the goal of observing the birth of the first stars and galaxies through the (still undetected) 21 cm line from the intergalactic neutral Hydrogen. A recent technique to detect the 21 cm signal uses the interferometric closure phase, as they are more robust to calibration errors. The analysis of HERA observations only partially confirms this hypothesis, with some limitations due to systematic effects (Thyagarajan et al., 2020; Keller et al., 2023). The candidate will explore the use of fringe rate filters to mitigate systematic effects in HERA simulated observations of the closure phase power spectrum and, if successful, will apply them to actual HERA data. See full project description.

(PhD / MSc) Spectropolarimetric studies of radio galaxies in MERGHERS fields

Supervisors: Dr Kenda Knowles (kendaknowles.astro@gmail.com)

This project focuses on study the continuum intensity and polarisation properties of radio galaxies in the MERGHERS cluster fields. MERGHERS currently has 56 targets observed with MeerKAT and L and/or UHF band, with thousands of compact sources and hundreds of extended radio galaxies. By cross-matching with optical data from the Dark Energy Survey, and combing the information with the MeerKAT and other frequency radio data, this project can be scoped to the student's preferences and the level of the study (MSc or PhD), with some primary goal options being studies of complex spectral sources, or the connections between extended radio galaxy properties and their environment. The student would become a part of the MERGHERS collaboration and work with collaborators in the US, Italy, Germany, and the UK.

(MSc)(SARAO) Radio halo/mini-halo upper limits in MGCLS

Supervisors: Dr Kenda Knowles (kendaknowles.astro@gmail.com)
Dr Konstantinos Kolokythas (NWU)

The MeerKAT Galaxy Cluster Legacy Survey (MGCLS) consists of 115 galaxy clusters observed at L-band with the full MeerKAT array. In the sample, 41 of the targets host detectable cluster-scale diffuse radio emission in the form of either radio halos or radio mini-halos. In order to perform statistical analyses of the diffuse emission in MGCLS, radio halo upper limits need to be determined for those systems with no visible detection.

The aim of this project is to determine radio halo upper limits for non-detections in the MGCLS. The student will work with the supervisors and other MGCLS consortium members to create a (semi-)automated pipeline for upper limit determination, following the standard process which uses simulated halo injections. As upper limit determination can be a time-consuming process, the clusters to which the student applies their process will be prioritised according to the consortium needs. This project is readily upgradable to a PhD by measuring upper limits for the full sample, and performing statistical analyses on a well-selected sub-sample. At the Masters level, this ambitious project is likely to produce a journal publication. The student must be familiar with Python coding.

(MSc)(SARAO) Multiband MeerKAT study of JWST SMACS0723

Supervisors: Dr Kenda Knowles (kendaknowles.astro@gmail.com)

The James Webb Space Telescope (JWST) has recently released its first science images, enthralling to the astronomical community and public alike. Its first galaxy cluster observation is of SMACSJ0723.3−7327 (hereafter SMACSJ0723), a massive cluster at z=0.388. Gravitational lensing analyses of the JWST observation (Mahler et al. 2022, Pascale et al. 2022, Caminha et al. 2022) indicate the presence of significant past dynamical activity, with the intracluster light revealing extended features West and South-west of the brightest cluster galaxy (BCG). MUSE spectroscopy analysed by Mahler et al. shows no significant substructure along the line of sight, however there is a clear offset between the radial velocity of the BCG and that of the cluster centroid. Combined with Chandra imaging, the multiwavelength view of this system indicates traces of past/recent merger activity.

The newly obtained UHF and L band MeerKAT data for this system shows the presence of diffuse cluster emission, expected based on the past merger history, but a lot brighter than predicted by existing scaling relations, as well as a high density of radio galaxies. Coupled with high quality multiwavelength data from JWST, we will use the radio data to study the SMACJ0723 cluster environment, its non-thermal component, and its constituent galaxies in order to obtain a holistic understanding of the system. The almost contiguous frequency coverage between 550 MHz and 1.67 GHz provided by a joint L and UHF study will allow for a determination of the spectral index for even the faintest sources, as well as the spectral shape of the radio galaxies detected with a signal-to-noise > 10. Familiarity with Python is required. Familiarity with radio data processing is advantageous but not required.

(MSc) Analysis of a sample of new Giant Radio Galaxies detected with

MeerKAT

Supervisors: Dr Nadeem Oozeer, SARAO (nadeem@sarao.ac.za)

Radio galaxies show a wide variety of morphologies. However, in some sources, the evolution of the jets into the intergalactic medium (IGM) can extend to large linear sizes. One class of large linear size objects is the Giant Radio Galaxy (GRG). We have detected a series of new GRGs from the MeerKAT galaxy cluster survey (MERGHERS - Knowles et al., 2016, 2021a). The project will consist of carrying out a multi-wavelength analysis of the GRGs.

This project will involve:

- Understanding MeerKAT data pipeline reduction
- Carry out multi-wavelength analysis (Optical/IR and X-Ray)
- Using Machine Learning algorithms to extract and characterise radio sources

Familiarity with Linux and Python scripting is strongly recommended. Understanding machine learning algorithms will be an advantage.

(MSc) Dying radio galaxies: what is so special about them?

Supervisors: Dr Nadeem Oozeer, SARAO (nadeem@sarao.ac.za)

Dying radio galaxies represent a stage of the active galactic nuclei (AGN) evolution that is rare and unexplored. Determining the physics of such dying sources is essential for radio galaxy physics, the duty cycle of AGN activity, interactions with the surrounding environment and their usefulness as cosmological probes. The very high angular resolution, coupled with the relatively high sensitivity of the MeerKAT radio telescope, shows its strength to pick up low surface brightness features and isolate confusing sources. In a recent cluster survey, we have detected three potential dying radio galaxies. In this work, we propose to carry out a multi-wavelength analysis of these sources and mine the MeerKAT archive for more potential dying radio sources.

This project will involve:

- Understanding the physics behind dying radio galaxies.
- Mining of MeerKAT archival data to search for new dying radio sources.
- Carry out multi-wavelength analysis of the detected sources.

Familiarity with Linux and Python scripting is strongly recommended.

(MSc) Ring-shaped radio sources

Supervisor: Dr Nadeem Oozeer, SARAO (nadeem@sarao.ac.za)

An unexpected new class of radio-astronomical objects, consisting of a circular disk, which in some cases is limb-brightened, and sometimes contains a galaxy at its centre, have been detected in ASKAP and MeerKAT images. Named 'Odd Radio Circles', these objects do not seem to correspond to any known type of astronomical object. We have detected a few examples of such sources from meerKAT images. The proposed project will mine such types of radio sources, using machine learning algorithms (e.g. astronomaly), from the MeerKAT archival data and perform multi-wavelength analysis.

Familiarity with Linux and Python scripting is strongly recommended. Understanding machine learning algorithms will be an advantage.

(PhD) (SARAO) Wide-band polarimetric imaging and polarization selfcal with MeerKAT and VLA

Supervisor: Prof Oleg Smirnov (osmirnov@gmail.com)

MeerKAT is providing a rich trove of polarization information with every observation. A lot of this remains under-exploited due to the intricacies of polarization calibration, as well as the need to correct for the wide-field polarimetric leakage response of the primary beam. The technique of self-calibration has been around since the 1980s, but has not been adapted to the polarization problem despite some initial work by Hamaker in the context of the measurement equation. Recent results with MeerKAT demonstrate both the feasibility and the urgent need for pol self-cal, particularly in the context of wide-field imaging. This project aims to develop this technique, and to demonstrate its application on a number of science targets. See full project description.

(PhD) MeerKAT cinematography: the radiation belts of Jupiter in 4D

Supervisors: Prof O. Smirnov (osmirnov@gmail.com)
Dr Julien N. Girard (CEA-Saclay) (julien.girard@cea.fr)
Dr Landman Bester (SARAO) (lbester@ska.ac.za)

Jupiter's powerful magnetosphere, together with its 10h rotation period, produces a spectacular show of emission in the radio regime. At MeerKAT frequencies, this is mostly synchrotron radiation originating from relativistic electrons in the radiation belts.

As an interferometric imaging target, Jupiter is particularly challenging, as it is bright and strongly time-variable, and also moves with respect to the background radio sources. A number of MeerKAT observations covering, in each case, nearly a whole period of rotation are now available. Imaging these with the sensitivity and resolution that MeerKAT enables can make for spectacular images and movies of the rotating magnetosphere. However, traditional radio interferometric deconvolution techniques assume stationary and time-invariable sources.

The aim of this project is to develop multidimensional radio imaging techniques which take advantage of Jupiter's rotation to directly constrain a rotating 3D model (with frequency providing the fourth axis). Such techniques also have direct application to, and can be informed by, other imaging problems at the forefront of radio astronomy, in particular VLBI imaging of variable sources (the images of M87's black hole taken by the EHT being a prime example).

(PhD) A proposed design for baseline-dependent correlators using Farrow filters combined with the raised cosine

Supervisors: Prof Oleg Smirnov (osmirnov@gmail.com)
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Baseline-dependent averaging (BDA) is a potential uv-data compression scheme that could be adopted for next-generation radio telescopes such as MeerKAT and the future SKA. A large body of work has already been done regarding BDA applied to MeerKAT, VLA, EVN and LOFAR (e.g. Atemkeng et al., MNRAS 2016; C. Tasse et al., A&A, submitted; Atemkeng et al., MNRAS, in prep.). Currently, BDA can only be used post-correlation and not in real-time. The main aim of this work is to focus on a correlator design that implements BDA in real-time correlations.

This project will use finite impulse response filters (FIR) (e.g. the raised cosine) and Farrow filters to implement a low pass and decimation filters to design a possible correlator workflow for BDA. If a long baseline is down-sampled, then the decimation phase filters will consist of interpolating the signal by some factor and decimating with an offset by taking the baseline-dependent delay parameters into account: this is equivalent to decompression on these type of long baselines and this will preserve uv-bins resolution. If a short baseline is oversampled, then the decimation phase filters will resample the data according to the variable delays: this is equivalent to compression.

A naive implementation would be very inefficient given that most of the decimation filters' band will not contribute to the correlator output. An ideal FIR filter will be the one that uses as few samples as possible, has good alias rejection, and is computationally efficient. This motivates the use of Farrow filters for this project.

MeerKAT is already producing a large volume of data. The data rate of the future SKA will be several orders of magnitude higher and will increase even more for any SKA surveys that adopt multiple phase tracking (e.g. AVN). New data compression algorithms and storage systems are key techniques to handle these volumes of data. A large field of view (FOV) is essential for the SKA, and the current compression method i.e., averaging in the correlator suffers from limited FOV and compression factor due to decorrelation/smearing.

BDA has been shown (in post-correlation) to be a potential compression method: we need to investigate and design BDA in real-life correlator architectures.

(MSc/PhD) Identifying PSF patterns around sources using deep learning techniques

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New radio interferometers rely on very large volumes of data to be transferred between various parts of data processing over distances that are often several (tens of) kilometres. A typical example is the MeerKAT telescope. Its primary beam at the full-width half-maximum and at 1.4 GHz covers a field of view (FOV) across ~2.6 deg. At this frequency, and for about 15 s time and 0.84 MHz frequency bins resolution, sources are degraded towards the edges of the FOV. To retrieve the total FOV the data should be correlated using high time and spectral resolution, however, this leads to high data volume. Any radio interferometric data compression method that is based on averaging is detrimental to the image fidelity because the PSF is distorted and attenuated (smearing). Radio interferometric algorithm for source finding relies on the clean image. The clean image is produced by a deconvolution algorithm, which means that if the clean algorithm does not perform accurately then the source finding algorithm will fail. Clean algorithms are regarded as an iterative approach, where the brightest pixel value is found step by step and subtracted from the image until the loop reaches a given threshold. During each step, the brightest pixel is considered to be a source, which may not be the case, however, the brightest pixel could be an artefact or a ghost source that does not have the PSF structure. There have been efforts to detect sources and calibration artefacts in an automated fashion using machine learning methods (e.g., Aniyan et al, in prep.). This gives the potential for application of machine learning based methods for similar problems in the discussed context. Finding the PSF structure around an object in the dirty image is quite intuitive and was impossible in the past since the PSF is position-dependent and expensive to compute iteratively for each location in the dirty image where there is a brighter pixel. A framework to accurately compute these position-dependent PSFs with fewer computations is established in Atemkeng et al, in prep.

This work will use machine learning algorithms and the position-dependent algorithms to find the structure of a given position-dependent PSF at the location of a potential source (the source located at the brightest pixel in the dirty image). If the structure matches (for a given probabilistic trust) then the algorithm should classify this source as a true source that should be deconvolved, if not the source is an artefact that should not be included in the clean image/restored map.

(MSc) (SARAO) Dealing with pointing errors and heterogeneous MeerKAT+ dishes

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This project aims to develop and validate procedures for calibration and imaging of heterogeneous arrays (arrays composed of telescopes with different primary beam patterns), such as the upcoming MeerKAT+. Procedures for alleviating imaging artefacts caused by pointing errors within existing MeerKAT data will also be improved. See full project description.

(MSc) (SARAO) Designing an Active Integrated Antenna for the

Rhodes University Transient Array Radio Telescope

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The project involves designing and fabricating an active integrated antenna (AIA) for Transient Array Radio Telescope (TART). We need antennas that can be modified anytime to optimize the performance of TART. Computational software such as Altair FEKO will be used, as well as testing and characterization of the fabricated AIA by actual measurement. See full project description.

(MSc) Improving Dask Scheduling for Radio Astronomy Algorithms

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Dask is a Python Parallel Programming Framework for distributing Compute over multiple CPU Cores and Cluster Compute Nodes. Programs are constructed as Compute Graphs, establishing dependencies between tasks.

The Dask Distributed Scheduler heuristically assigns tasks to CPU Cores and Compute Nodes attempting a Depth-First Traversal of the Graph by favouring independent, parallel streams of execution. Connections between parallel streams of execution, often created by broadcasting different array dimensions against each other can interfere with this Depth-First Traversal leading to suboptimal scheduling patterns and OutOfMemory errors.

This work seeks to utilise a priori and other structural information in the Compute Graph in order to solve the above problems.

(MSc) Distributed low-rank approximation for baseline-dependent lossy compression

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Radio interferometric arrays consist of an assembly of radio antennas that are correlated in pairs to produce complex data values known as visibility or spatial frequency. This visibility data volume grows quadratically with the number of antennas, wide field of view (FoV), high spectral and temporal resolution. Processing and saving this volume of visibility data has become a challenge e.g. calibrating and translating the data to the image space via resampling and fast Fourier transform operations. The large volume of visibility data is an important problem to deal with in the context of calibration and deep wide-field imaging with current radio interferometric arrays such as MeerKAT (Jonas 2009), ASKAP (Johnston et al. 2008), NenuFAR (Zarka et al. 2015), LOFAR (van Haarlem et al. 2013) and future radio interferometers, including the Square Kilometre Array (SKA, Dewdney et al. (2009)). To resolve the morphological structure of compact sources, the SKA will sample very high spatial frequencies with long baselines. This high spatial frequency sampling will take the SKA to an unprecedented visibility data volume era; that will need more computation and improved data compression strategies. Long-term data archiving of calibrated products will be imperative, which then requires the implementation of new data compression algorithms. Data compression is imperative to provide an efficient benefit by reducing the costs involved in storing, processing and archiving data.

In practice, the visibility data are integrated and averaged over finite time and frequency intervals which introduces source smearing and decorrelation effects as opposed to high resolution time and frequency intervals. To limit smearing and decorrelation, the finite time and frequency are kept very small so that the phase term on long baselines is preserved. The effect of smearing attenuates and changes the morphological structure of sources at the edges of the FoV. Visibility data often require some sort of data archiving to be enforced for later use. Traditional averaging and/or BDA is applied before the data is archived. This poses many questions, as high spectral and temporal resolution is imperative for certain sciences (e.g. VLBI science, spectral line studies) and for calibration routines that take into account the variation of the primary beam (PB) and the effect of the ionosphere for example. Traditional averaging and/or BDA is accompanied by a decrease in the spectral and temporal resolution at least on the shorter baselines or BDA, therefore, have to be applied with care before archiving the data. This implies the need to investigate data compression techniques that can archive the visibility data with little to no decrease in spectral and temporal resolution compared to any existing averaging schemes. This work will implement a distributed version of the low-rank approximation as investigated in Atemkeng et al. (in prep). Visibility data has some natural basis consisting of row data. This information will be used to speed up the low-rank approximation compression via distributed algorithms.

(MSc) Visual Interpretability and Explainability of Deep Learning Models for Radio Astronomical Source Classification and Detection Tasks

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Deep Learning and pattern recognition techniques are increasingly gaining rapid adoption in astronomy for classification and detection tasks. However, while deep learning techniques have continued to provide state-of-the-art predictive performance, one of the primary challenges that stand to hinder this progress for astronomers is the opaque nature of the inference mechanism of these models. So, attribution has a vital role in building confidence for the predictions made by deep learning models to inform astronomy decisions. As an initial goal, this work plans to implement a novel attribution framework using adaptive path-based techniques. The results from this will solidify the trust of domain experts and will improve source detection and/or classifications outcomes by allowing astronomers to understand the input-prediction correlation, discover new objects, and reveal potential model biases. This result will open several research investigations.