The study of extended radio galaxies in MERGHERS fields

Banele Mthembu, Supervised by Dr. Kenda Knowles and Dr. Precious Sikhosana

University of KwaZulu-Natal (Westville Campus), School of Mathematics, Statistics, and Computer Science

Abstract

- **Catalogue Extended Radio Galaxies:** Make a complete list of large radio galaxies in the 21 cluster field using the first tier of MERGHERS data
- **Analyze Environmental Impact:** Investigate the relationship between radio galaxy morphology and their local environment, differentiating between cluster and field sources.
- **Study Spectral Properties:** Produce in-band spectral index maps and use multi-frequency data to understand the spectral characteristics of these galaxies.

Introduction

- Extended radio galaxies are generally categorized into two groups, FRI and FRII, according to the Fanaroff and Riley classification scheme [1],
- and their more morphologically complex counterparts (NATs, WATs, BTs, X-shaped, etc) [2], can help understand their specific role and how their local environment affects their properties, and vice versa.
- The MERGHERS survey is carrying out targeted observations of galaxy clusters using MeerKAT's L-bands.
- The wide-field images contain many instances of extended radio galaxies, across all morphologies.
- This project aims to catalogue and study the extended radio galaxies in the 21 cluster fields from the first tier of MERGHERS data in conjunction with available multiwavelength data.
- This project will investigate the statistics of the radio galaxies and their relationship to their environment (field versus cluster),
- study the spectral properties of the sources by producing in-band spectral index maps, or other frequency data where available, and
- investigates the environmental impact on sources with non-classical morphologies.

The complex visibility equation is defined as:

$$V = |V|e^{j\phi_\nu} = \int_{4\pi} A_N(\sigma) I(\sigma) e^{-j2\pi\frac{\vec{B}\cdot\vec{S}}{\lambda}} d\Omega \tag{1}$$

Where $A_N(\sigma)$ is the geometric mean of the beam pattern of the two antennas, $I(\sigma)$ is the source intensity observed from the distance of the antennas. $\vec{B}$ is the baseline vector, $\vec{S}$ is the unit vector in the direction of the source in the sky[3]

$$\tau = \frac{\vec{B}\cdot\vec{S}}{c} = \frac{B \times sin(H) \times cos(\theta)}{c} \tag{2}$$

Where τ is the geometric delay, c is the speed of light in the vacuum, H is the hour angle in degrees, and θ is the phase angle. Together H and θ define the coordinate of our source.

$$\phi_\nu = \frac{2\pi}{\lambda}\vec{B}\cdot\vec{S} = \frac{2\pi}{\lambda} \times B \times sin(H) \times cos(\theta) \tag{3}$$

Where ϕ_ν is the phase term. Now the visibility in terms of the phase will be given by:

$$V = \int_{4\pi} A_N(\sigma) I(\sigma) e^{-j\phi_\nu} d\Omega \tag{4}$$

To include the pointing error the phase equation has to consider the phase delay denoted by $\Delta\phi$. Now the new phase delay equation will be

$$\phi_\nu = \frac{2\pi}{\lambda} \times B \times sin(H) \times cos(\theta) + \Delta\phi \tag{5}$$

The real and complex visibility will be expressed as

$$V_{real} = |V| cos(\phi_\nu + \Delta\phi) \tag{6}$$

$$V_{imag} = -|V| sin(\phi_\nu + \Delta\phi) \tag{7}$$

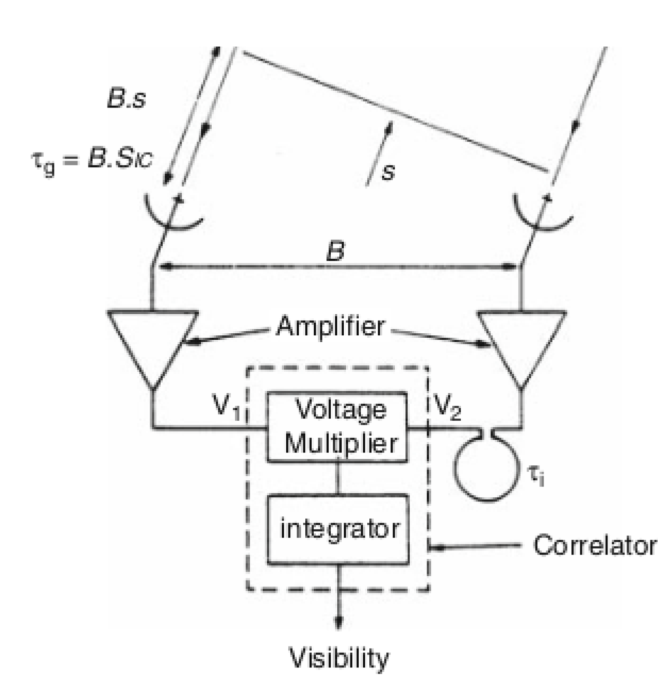

Figure 1:The 2-element interferometer

Methodology

Source Detection and Catalog Generation

- Applied PyBDSF (Python Blob Detection and Source Finder) [4] to the convolved MeerKAT FITS image to a catalog.
- **Set specific parameters for detection sensitivity:** `thresh_pix` and `thresh_isl` were adjusted to optimize detection of extended sources.
- Generated a catalog including parameters like `RA`, `Dec`, `integrated flux`, and source morphology (`S_Code` column where `M` indicates sources that fit multiple Gaussian which can be extended radio galaxies).
- **Filtering for Extended Radio Galaxies** : Isolated extended sources (`S_Code = M`) from the PyBDSF-generated catalog, then created a DS9 regions file of these sources. These regions were overlaid on our image viewed in DS9 to confirm the classification of extended radio galaxies.

Cross-Matching with Other Surveys

- Used tools like TOPCAT, and Python code to cross-match the MeerKAT catalog with other radio (e.g., RACS, SUMSS) and optical surveys (e.g., DECaLS).
- Employed a specified cross-matching radius (e.g., 5 or 10 arcsec) for consistency in source identification.

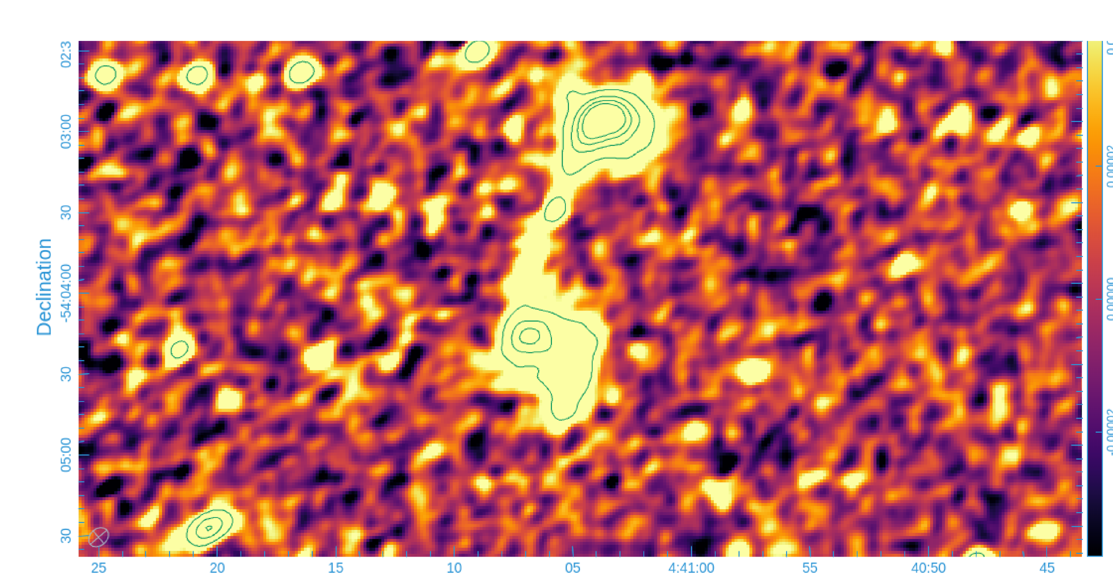

Figure 2:One of the extended radio galaxy detected by PyBDSF with contours overlayed. The contour levels detects the emission at 3σ, 6σ, 12σ, and 16σ. The rms noise level of the full image is 19.6 $\mu Jy/beam$. The colour units for this image are in $Jy/beam$.

On going/Future Work

1. Performing an astrometric check of the cross-matched MeerKAT data with other surveys such as RACS, SUMSS, and GLEAM.
2. Determining whether the detected extended radio galaxies (ERGs) are located in a field or cluster environment.
3. Generating spectral index maps of the detected radio galaxies (RGs).
4. Identifying potential host galaxies by cross-matching the MeerKAT data with the DECaLS survey.
5. Comparing the analysis of our results with existing literature and incorporating the findings into the thesis write-up.

References

[1] B. L. Fanaroff and J. M. Riley. The Morphology of Extragalactic Radio Sources of High and Low Luminosity. *Monthly Notices of the Royal Astronomical Society*, 167, 1974.

[2] AK Aniyan and Kshitij Thorat. Classifying radio galaxies with the convolutional neural network. *The Astrophysical Journal Supplement Series*, 230, 2017.

[3] A Richard Thompson, James M Moran, and George W Swenson. *Interferometry and synthesis in radio astronomy.* Springer Nature, 2017.

[4] Niruj Mohan and David Rafferty. Pybdsf: Python blob detection and source finder. *Astrophysics Source Code Library*, 2015.

Contact Information

- Email: mphomthembu53@gmail.com
- Phone: +27 76 255 6500