Cold Gas and black hole accretion in central galaxies: An HI Stacking Study with MeerKAT MIGHTEE

Research category: Science

Academic level: MSc

Institute: University of Cape Town (UCT)

Primary Supervisor: Dr Jacinta Delhaize (UCT); drjdelhaize@gmail.com

Co-Supervisors: Dr Narges Hatamkhani (SAAO); n.hatamkhani@gmail.com, Dr Moses Mogotsi; m.mogotsi@saao.nrf.ac.za

1. Project Description

Brightest Cluster Galaxies (BCGs) and Brightest Group Galaxies (BGGs) frequently host powerful radio-loud active galactic nuclei (AGN) whose mechanical feedback plays a key role in regulating gas cooling and heating within dense environments (McNamara & Nulsen 2007; Fabian 2012; Heckman & Best 2014). However, the role of cold atomic gas in fuelling AGN activity and sustaining black hole accretion in these massive central galaxies remains poorly understood. This project will investigate the neutral hydrogen (HI) content and accretion properties of central galaxies in the COSMOS field at $z < 0.3$ using publicly available MeerKAT MIGHTEE-HI data and spectral stacking techniques.

The radio-loud AGN sample, including HERG/LERG accretion-mode classifications, will be adopted from the published MIGHTEE Early Science catalogue of Whittam et al. (2022), based on MeerKAT L-band continuum observations. These systems will be cross-matched with established COSMOS group and cluster catalogues (e.g. Finoguenov et al. 2007, 2009) to identify BCGs and BGGs. Based on existing COSMOS catalogues, we expect a sample of approximately 100–200 central galaxies, with around 30–80 galaxies having secure spectroscopic redshifts suitable for HI stacking analyses.

Given that central galaxies in dense environments are expected to be HI-poor due to environmental processes such as ram-pressure stripping, tidal interactions, and AGN feedback, spectral stacking will be the primary analysis technique used to constrain the average HI content of the sample (Maddox et al. 2021; Healy 2021). HI masses or upper limits will be derived directly from the publicly released MIGHTEE-HI DR1 spectral-line cubes in the COSMOS field (Heywood et al. 2024). Individual HI masses will be measured where direct detections are possible, while stacking analyses will provide statistically robust average HI measurements for the broader sample. The stacking analysis will account for redshift alignment, continuum subtraction uncertainties, and varying noise properties across the data cubes. The inclusion of BGGs provides an important comparison sample in less extreme environments, enabling investigation of how the environment influences cold gas content and AGN accretion activity.

Secure spectroscopic redshifts will be obtained from publicly available COSMOS spectroscopy, including zCOSMOS and LEGA-C. Stellar velocity dispersions will be measured for a high-quality subsample using established spectral fitting tools such as pPXF. Approximately 20–50 galaxies are expected to have spectra suitable for robust velocity dispersion measurements. Optional SALT RSS spectroscopy may be pursued for a small subset of galaxies (≈5–10 objects), but the project is fully feasible without new observations.

Black hole masses will be estimated using the M–σ relation (McConnell & Ma 2013; Kormendy & Ho 2013), enabling calculation of Eddington-scaled accretion rates as proxies for black hole accretion activity. By linking average HI content to AGN accretion mode (HERG/LERG), radio power, environment, and Eddington-scaled accretion properties, this study will test whether cold gas availability is associated with enhanced black hole accretion in central galaxies and whether AGN mode influences the depletion of atomic gas.

2. Aims and Objectives

- Adopt the published MIGHTEE radio-loud AGN and HERG/LERG classifications (Whittam et al. 2022);
- Identify BCGs and BGGs using COSMOS group and cluster catalogues;
- Measure HI masses or upper limits directly from the publicly released MIGHTEE-HI DR1 spectral-line cubes in the COSMOS field (Heywood et al. 2024), using spectral stacking techniques where appropriate;
- Use publicly available spectroscopy (zCOSMOS, LEGA-C) to obtain secure redshifts and derive stellar velocity dispersions for a high-quality subsample using pPXF;
- Derive black hole masses and Eddington-scaled accretion rates;
- Analyse correlations between HI content, radio power, accretion mode, black hole accretion activity, and environment;
- Compare cluster-central and group-central galaxies to determine how the environment influences cold gas content and AGN activity.

Feasibility and Methodology

The core MSc project will focus on HI stacking using publicly available MeerKAT MIGHTEE-HI data cubes and COSMOS multiwavelength datasets. The project is therefore fully feasible without requiring new observations. Spectral stacking will provide statistically robust constraints on the average HI content even where individual detections are not possible. The use of secure spectroscopic redshifts minimises uncertainties in spectral alignment during stacking, although the sample may be biased toward brighter galaxies with existing spectroscopy.

Stellar velocity dispersions will only be measured for galaxies with sufficiently high-quality spectra, ensuring that the scope remains achievable within MSc timescales. SALT observations, if available, will be treated as an optional extension rather than a requirement for project completion.

Skills Development

The student will develop advanced skills in radio astronomy, spectral-line analysis, HI stacking techniques, optical spectral fitting using pPXF, multiwavelength catalogue cross-matching, statistical analysis, and scientific programming in Python. The project will also provide experience in handling large astronomical datasets and interpreting galaxy evolution processes in the context of AGN feedback and black hole accretion.

Project Timeline (24 Months)

Months 1–3: Literature review and sample definition

Months 4–6: Data acquisition and spectroscopic completeness assessment

Months 7–10: HI data extraction and spectral stacking

Months 11–14: Stellar velocity dispersion measurements using pPXF

Months 15–18: Correlation analysis between HI content, AGN properties, and environment

Months 19–24: Thesis writing, interpretation, and publication preparation

3. Potential Impact

This project will provide new empirical constraints on the relationship between cold gas reservoirs and black hole accretion activity in the most massive galaxies in the Universe. By combining MeerKAT HI observations with optional SALT spectroscopy, the study directly leverages South Africa's flagship astronomical facilities and contributes to SKA-era galaxy evolution science. The results have strong potential for publication and will provide advanced training in radio spectral-line analysis, multi-wavelength data integration, and optical spectroscopy.

4. Alignment with National Imperatives

NRF Broad Category: Environmental, Material, Physical and Technology; This project utilises South Africa's flagship facilities, MeerKAT and SALT.

National Priority: Transformation and Skills Development; The project contributes to postgraduate training in data-intensive astronomy and advanced observational techniques.

Grand Challenge: Astronomy; The study addresses fundamental questions in galaxy evolution and black hole accretion using national research infrastructure.

Sustainable Development Goal: Quality Education; Astronomy supports high-level STEM training and research capacity development.

5. National Infrastructure Platforms

SARAO / MeerKAT

Southern African Large Telescope (SALT)

Data Availability Declaration

I declare that this project can be performed using data sets that are already publicly available. Additionally, the proposed supervisors are members of the MIGHTEE team and may have advanced access to newer data releases, such as MIGHTEE-HI DR2, should these become available during the timeframe of this project.

I, Jacinta Delhaize, am the PI of the UHF-COSMOS data and declare that the data are available in a calibrated format that can be reprocessed by the student if that extension is pursued, although this component is optional and only if time permits.