Project Title: Simulating Giant Radio Galaxies

Supervisors: *Dr Gourab Giri (Institute for Radio Astronomy, India), Dr Jacinta Delhaize (UCT)*

Level: *Honours*

Location: *UCT*

Background:

A small fraction of galaxies experience a remarkable event where their central supermassive black hole becomes active, ejecting superheated plasma at nearly the speed of light. Since their discovery, a fundamental question has been how far these jets can propagate through space. Observations have shown that their extent ranges from galactic scales to larger cosmic structures, such as galaxy groups, spanning hundreds of kiloparsecs. However, only about 5–8% of these jets extend to truly enormous distances, forming what are known as Giant Radio Galaxies (GRGs), which evolve on megaparsec scales—the largest single structures a galaxy can produce.

GRGs have been observed since the 1970s, yet their origins remain a subject of debate. Four primary formation scenarios have already been proposed, but statistical analyses have repeatedly challenged these models, highlighting the difficulty of explaining how these jets maintain their vast, straight propagation within their observable synchrotron lifespan. Recent discoveries using modern radio telescopes have further deepened the mystery, with massive GRGs stretching up to 5 and 7 Mpc. These findings suggest that multiple formation mechanisms may be at play. Given the rarity of jets exceeding 2 Mpc, such discoveries fuel scientific curiosity, as these AGN jets likely hold crucial clues to understanding the factors driving the extraordinary growth of GRGs.

Contemporary radio telescopes such as MeerKAT in South Africa, LOFAR in Europe, and uGMRT in India have begun uncovering GRGs with bent jets, exhibiting a variety of complex morphologies. Some display mirror-symmetric tails, while others show inversion-symmetric winged structures. Many exhibit abrupt bends, possibly caused by large-scale turbulent flows, disturbed shapes that may hint at kink instabilities, or even precessing motions.

For example, several GRGs have recently been discovered in high-sensitivity MeerKAT observations (Delhaize et al., 2021 and Charlton et al., 2025), which highlight the diversity in GRG morphologies and require tailored theoretical interpretations. For instance, "GRG1" exhibits a complex morphology suggesting a combination of jet precession and interactions with a turbulent ambient medium. Meanwhile, "GRG3" displays a pronounced asymmetry, with one jet arm significantly distorted while the other remains relatively straight.

Given this complexity, observational data alone is no longer sufficient to fully understand these sources. To try and understand the astrophysics underpinning these systems, Dr Gourab Giri has recently developed advanced magneto-hydrodynamical simulations of

GRGs using the PLUTO code (Giri et al 2025). These can be used to model how AGN and their large-scale environments interact to shape these extraordinary structures.

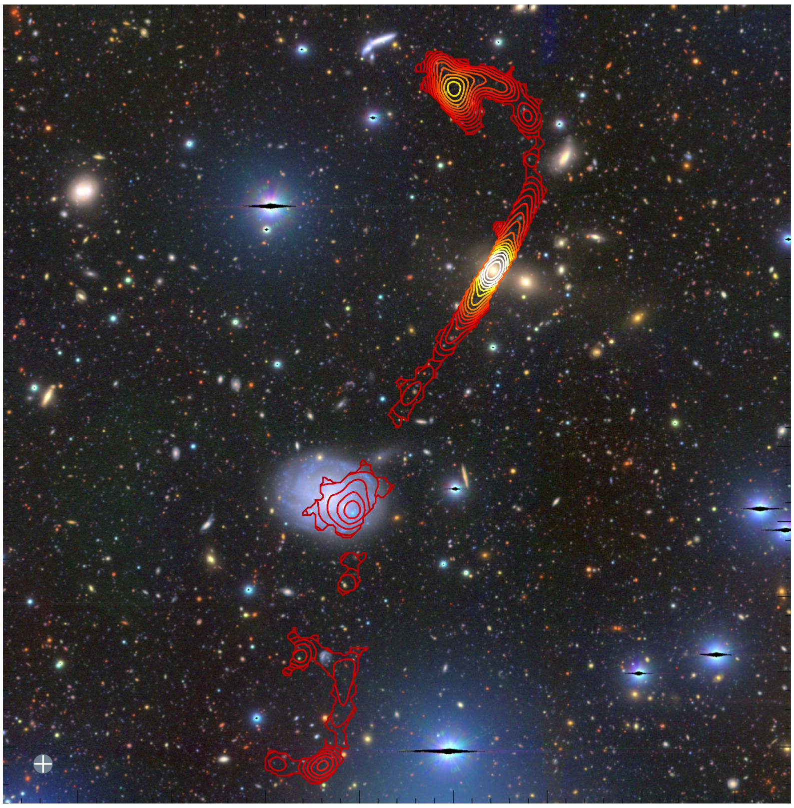

Image: "GRG3", nicknamed 'Inkathazo'. The radio light from the plasma jets, as seen by the MeerKAT telescope, are shown by the contours (white/yellow=brighter, red=fainter). The stars of the elliptical host galaxy, from which the plasma jets originate, can be seen in the middle of the white contours. The starlight from other surrounding galaxies can be seen in the background. The large spiral galaxy seen in the lower-left of centre is actually a much closer foreground galaxy which is unrelated to Inkathazo. Credit: K.K.L Charlton (UCT), MeerKAT, HSC, CARTA, IDIA.

Project outline:

We are excited to offer an opportunity for a highly motivated and capable Honours student to contribute to this GRG research, forming the foundation of a broader effort to understand these extraordinary cosmic structures.

The student will first familiarise themselves with the simulation code provided by Dr Giri and explore the extensive literature and gain an understanding of the physics of GRGs. They will then implement the PLUTO code on the ilifu supercluster. The student will alter the initial conditions and constraints of the code, based on their understanding of the underlying astrophysics, in an attempt to reconstruct the unusual shapes and features of GRGs observed in MeerKAT data by Dr Delhaize and her RADHIANCE research group. They will then interpret the results in an attempt to explain the astrophysics of the particular GRG systems.

Supervision:

The primary scientific supervision will be provided online by Dr Gourab Giri, who is currently based in India. The student will therefore need to be comfortable with virtual supervision and the associated complications such as time zone differences. For this reason, the student will need to be highly motivated and as independent as possible.

Local co-supervision will be provided by Dr Jacinta Delhaize in a support role. The student will be welcome and encouraged to join Dr Delhaize's fortnightly RADHIANCE research group meetings.

Recommended skills:

As this is quite a high-level project for Honours, the student should ideally have good foundational knowledge of extragalactic astronomy, basic python programming skills (or similar language), show strong initiative and be keen to rapidly develop research independence.

Contacts:

- Gourab Giri: gourab.giri@up.ac.za
- Jacinta Delhaize: drjdelhaize@gmail.com

Related reading:

- Giri et al., 2025: https://ui.adsabs.harvard.edu/abs/2025A%26A...693A..77G/abstract
- Charlton et al., 2025: https://ui.adsabs.harvard.edu/abs/2025MNRAS.537..272C/abstract
- Delhaize et al., 2021: https://ui.adsabs.harvard.edu/abs/2021MNRAS.501.3833D/abstract