Dynamical State of BEAMS SZ-Selected Galaxy Clusters Hosting Radio AGN

Level of the project: Honours
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Background and Motivation

Brightest cluster galaxies (BCGs) are the most massive galaxies in the Universe and typically reside near the centres of galaxy clusters. Many BCGs host radio-loud active galactic nuclei (AGN) that inject mechanical energy into the intracluster medium through relativistic jets. This feedback plays a crucial role in regulating the heating–cooling balance of hot gas in cluster cores and preventing runaway cooling flows (McNamara & Nulsen, 2007; Fabian, 2012; Voit, 2015).

AGN activity is commonly divided into two modes: a radiatively efficient "quasar mode" and a radiatively inefficient "radio mode" (Hardcastle, 2007; Heckman & Best, 2014). BCG AGN are typically found in the radio mode, where low-Eddington-ratio accretion powers jets that heat the surrounding intracluster medium. These systems are generally classified as low-excitation radio galaxies (LERGs) (Best & Heckman, 2012; Sabater, 2019).

Despite progress in understanding AGN feedback in clusters, it remains unclear whether radio-mode AGN activity is linked to the dynamical state of the host cluster. In particular, radio AGN may be preferentially associated with relaxed cool-core clusters, where cooling gas can fuel the central black hole, or with dynamically disturbed systems undergoing mergers or accretion (Hlavacek-Larrondo, 2012; McDonald, 2016; Voit, 2015).

The dynamical state of clusters can be probed using several observational indicators, including the spatial distribution of cluster galaxies, the positional offset between the BCG and the cluster centre, and the luminosity hierarchy among the brightest cluster galaxies (Lin & Mohr, 2004; Skibba, 2011; Lauer, 2014; Jones, 2003; Smith, 2010). This project will investigate these indicators in SZ-selected clusters hosting radio-loud BCGs.

Project Aim

The aim of this project is to investigate the dynamical state of SZ-selected galaxy clusters whose BCGs host radio AGN. By analysing the spatial distribution of cluster galaxies and the position of the BCG relative to the cluster centre, the project will explore whether radio AGN activity is associated with particular cluster dynamical states.

Where possible, the results will also be compared with a control sample of clusters without radio-detected BCGs, matched in redshift and cluster mass, to determine whether clusters hosting radio AGN exhibit systematically different structural properties.

Data

The project will use clusters drawn from the BCG Evolution with ACT, MeerKAT, and SALT (BEAMS) programme, which studies BCGs in Sunyaev–Zel'dovich (SZ) selected clusters identified by the Advanced Atacama Cosmology Telescope (AdvACT) survey (Hilton, 2021). The BEAMS programme provides a statistically representative sample of massive clusters over the redshift range $0.3 < z < 0.8$.

The Honours project will focus on a subsample of 25 clusters whose BCGs are detected in the Rapid ASKAP Continuum Survey (RACS) (Hale, 2021). Optical galaxy catalogues with photometric redshifts are available for each cluster and will be used to identify likely cluster member galaxies.

If feasible, a matched control sample of clusters without radio-detected BCGs will also be selected from the same BEAMS parent sample.

Methodology

For each cluster, the student will:

1. **Cluster Member Selection**

   Identify likely cluster member galaxies using photometric redshifts around a defined range of the cluster redshift.

2. **Galaxy Density Mapping**

   Construct two-dimensional galaxy density maps using kernel density estimation. Density contours will be used to visualise the cluster morphology and identify possible substructures, such as elongated structures or multiple density peaks that may indicate ongoing mergers.

3. **BCG Offset Measurement**

   Measure the positional offset between the BCG and the SZ centroid of the cluster, converting the angular separation into a projected physical distance. Large offsets may indicate dynamically disturbed clusters, while small offsets are typically associated with relaxed systems.

4. **Magnitude Gap**

   Measure the magnitude difference between the BCG and the second-brightest cluster galaxy (Δm_{12}). Large magnitude gaps are often associated with dynamically mature or relaxed systems, while small gaps may indicate recent mergers or ongoing cluster assembly.

5. **Comparison with a Control Sample**

   If time permits, the same measurements will be performed for a matched control sample of clusters without radio-detected BCGs to investigate whether clusters hosting radio AGN differ systematically in their dynamical properties.

Expected Outcomes

The project will produce catalogues of likely cluster member galaxies, galaxy density maps, measurements of BCG positional offsets, and magnitude gap estimates for each cluster. These measurements will be used to assess the dynamical state of the clusters and explore possible links between cluster structure and radio AGN activity in BCGs.

If a control sample is included, the analysis will also provide an initial comparison between clusters with and without radio-loud BCGs.

Skills and Tools

The student will gain experience in astronomical data analysis using Python and commonly used scientific packages such as `Astropy`, `NumPy`, `SciPy`, and `Matplotlib`. The project will also introduce techniques for galaxy cluster analysis, including photometric redshift selection, spatial density estimation, and cluster morphology diagnostics.

Scientific Impact

Understanding how the dynamical state of galaxy clusters influences AGN activity is important for understanding feedback processes in massive halos. By characterising the internal structure of SZ-selected clusters hosting radio AGN, and comparing them to clusters without radio activity, this project will contribute to ongoing studies of AGN feedback and galaxy evolution in dense environments.

References

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