

PhD project in ASTROPHYSICS

Title of the Project: Unveiling the origin of diffuse radio emission in galaxy clusters through MeerKAT and LOFAR observations

Supervisors: Dr. A. Botteon (INAF-IRA), Dr. M. Balboni (Università di Bologna & INAF-IASF Milano), Prof.ssa A. Bonafede (Università di Bologna & INAF-IRA), Dr.ssa R. Cassano (INAF-IRA)

Scientific Case:

Galaxy clusters are the most massive gravitationally bound structures in the Universe and form via a sequence of mergers of other clusters and groups across cosmic time. These processes generate turbulence and shocks in the intra-cluster medium (ICM), which release a large amount of energy that mainly enhances the cluster thermal bremsstrahlung emission in the X-rays, while a small fraction is channeled into the re-acceleration of relativistic particles. In the presence of μG magnetic fields, these particles produce non-thermal, Mpc-scale radio emission known as radio halos and relics ([van Weeren+2019](#)). A strong relation between thermal and non-thermal components in the ICM is therefore expected and can be investigated by combining radio and X-ray observations of clusters.

The details of the re-acceleration processes are not understood yet (e.g., [Brunetti & Jones 2014](#)). In the next years, the Square Kilometer Array (SKA) will provide a large amount of data that will enable detailed studies. At present, the SKA precursors and pathfinders (LOFAR 2.0 and MeerKAT) already have a great potential to pave the way in constraining particle acceleration mechanisms in the ICM. Surveys of the spatial distribution of radio spectral properties across halos and relics, as well as searches for steep-spectrum radio halos, would provide additional tests for the turbulent and shock re-acceleration models. To date, however, no systematic studies of spectral index distributions in diffuse cluster radio sources have been carried out.

Outline of the Project:

The PhD candidate will investigate the properties of the diffuse radio emission of [CHEX-MATE](#) galaxy clusters, employing recently acquired data from the most powerful radio telescopes currently operating on Earth: LOFAR and MeerKAT. The availability of X-ray data from XMM-Newton will enable to relate the properties of the non-thermal emission with that of the thermal gas. In particular, this project leverages the CHEX-MATE sample to investigate two fundamental aspects of cluster physics:

- Interplay between thermal and non-thermal components: the PhD student will study the relation between thermal and non-thermal emission in galaxy clusters by comparing both integrated and spatially resolved quantities derived from X-ray and radio observations (e.g., [Balboni+2024, 2025](#), [Botteon+2024](#), [van Weeren+2026](#)). Relations between surface brightness and synchrotron spectral index or ICM temperature can vary depending on the microphysical processes involved, and those variations are reflected in model predictions. Statistically determining whether such relations exist is crucial to constrain parameters of particle acceleration models.
- Systematic spectral analysis and statistical properties of the diffuse radio emission: by leveraging the high quality of LOFAR and MeerKAT radio observations, the PhD student will produce robust measurements of the spectral index of radio halos and relics in a large cluster sample, characterized by many newly discovered sources (e.g. [Balboni+2026](#)). Results will be interpreted in the context of current particle acceleration models in the ICM, investigating for example the relationship between the spectral index of the diffuse radio emission and the cluster mass, redshift, and dynamical state (e.g. [Cassano+2010, 2023](#)).

The PhD student will be part of the CHEX-MATE and LOFAR collaborations and will be involved in international working groups specialized in radio and X-ray observations of galaxy clusters. In particular, a close collaboration with the INAF-IASF cluster group in Milan is foreseen for the X-ray data reduction and interpretation. Travels to visit collaborators in Europe and a period abroad are also planned.