INAF3

INAF-IRA Projects available

Project code	Main supervisor	Title of the project
Botteon1	Botteon	Magnetic fields and particle acceleration on the largest scales
Botteon2	Botteon	Tales of tails: unraveling the tumultuous evolution of tailed radio galaxies in cluster of galaxies
Gheller1	Gheller	A new vision of particle acceleration in the intrascluster medium

PhD project in ASTROPHYSICS

Title of the Project: Magnetic fields and particle acceleration on the largest scales

Supervisor INAF-IRA: Dr. Andrea Botteon
Supervisor UniBo: Prof.ssa Annalisa Bonafede

Scientific Case:

LOFAR and MeerKAT are the most important pathfinder and precursor of the SKA. Thanks to their unprecedented sensitivity and capability to recover extended diffuse radio emission, they have opened a new parameter space in the study of non-thermal phenomena in galaxy clusters and large-scale structure, with implications on our understanding of the particle acceleration mechanisms on Mpc-scales, magnetogenesis, and the formation and evolution of galaxy clusters themselves.

Outline of the Project:

Recently, LOFAR and MeerKAT carried out very sensitive observations of numerous galaxy clusters. In particular, LOFAR performed the deepest observations to date on two local galaxy clusters: Abell 2255 and Coma. Shallower observations of these systems have already revealed the presence of very large-scale emission coming from the cluster outskirts and possibly from the cosmic web (Figure). The PhD candidate will use these deep radio observations to investigate the properties of the newly discovered features and of the cluster magnetic fields on very large scales. LOFAR is a unique instruments to detect low magnetic fields in low density environments, hence the deep field data are unique to explore the magnetic field properties in the uncharted territory of far cluster outskirts. On the other hand, MeerKAT observations are now enabling the detection of several polarized sources in the direction of galaxy clusters that can be used as Faraday rotation probes to study the intra-cluster medium magnetic field. The PhD candidate will thus work also on a selected sample of clusters observed with MeerKAT to constrain the magnetic field properties inside, outside, and in-between galaxy clusters. The origin of cosmic magnetism is one of the big unaddressed questions in astrophysics, and probing the magnetization of the large-scale structure constitutes a fundamental test for the models of magnetogenesis, allowing to discriminate between primordial and astrophysical scenarios. The results obtained during this PhD will thus represent an important step in this direction. Data will be used in combination with numerical simulations and theoretical models to determine the properties of magnetic fields, the allowed scenarios for cosmic magneto genesis, and the particle-acceleration mechanisms.
The PhD student will be part of the LOFAR collaboration and have access to the most recent analysis technique. The PhD student will also be involved in international working groups, and travels to visit collaborators in the Netherlands and Germany are planned.

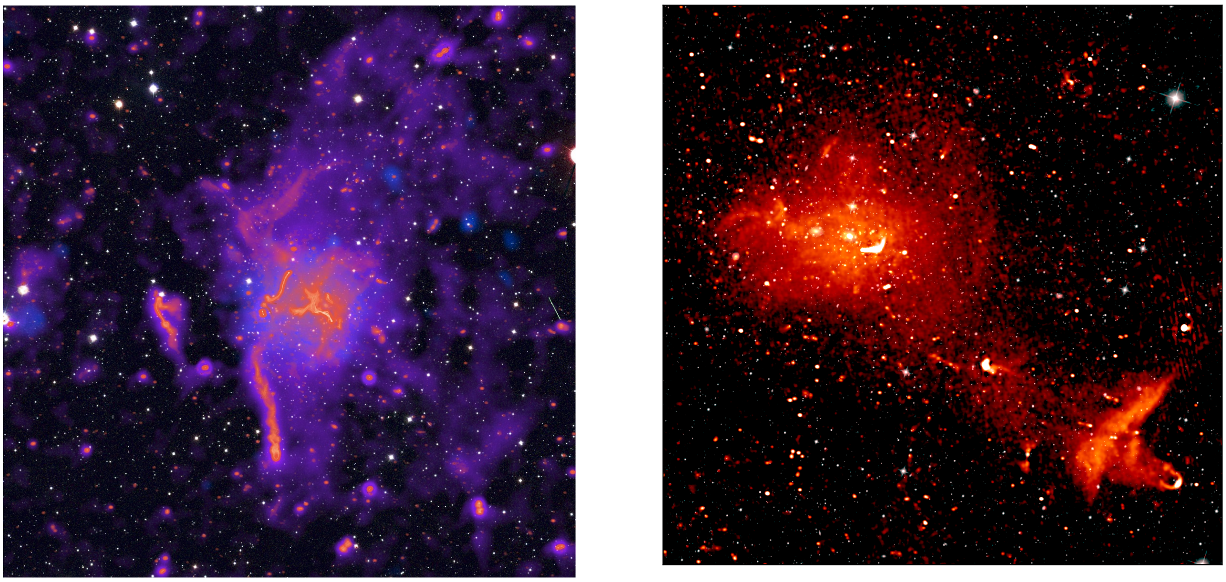


Figure: LOFAR images of Abell 2255 based on 72h integration (left) and Coma Cluster based on 8h integration (right). Diffuse radio emission (in reddish/purplish color) spans projected scales of 3-5 Mpc. From Botteon et al. (2022) and Bonafede et al. (2022).

PhD project in ASTROPHYSICS

Title of the Project: Tales of tails: unraveling the tumultuous evolution of tailed radio galaxies in cluster of galaxies

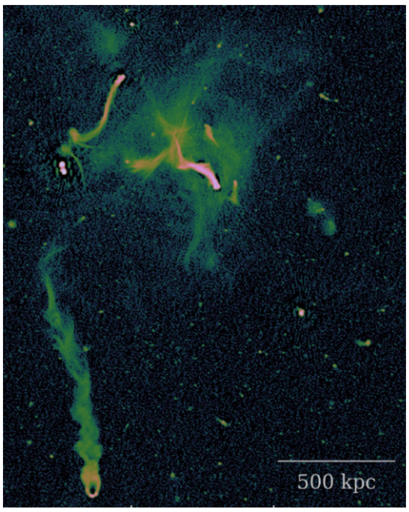
Supervisors INAF-IRA: Dr. Andrea Botteon, Dr. Gianfranco Brunetti
Supervisor UniBo: Prof. Daniele Dallacasa

Scientific Case:
New generations of radio telescopes, precursors and pathfinders of the SKA, are reveling that head-tail radio galaxies in galaxy clusters (i) often exhibit longer extensions than what expected by the radiative lifetime of relativistic electrons, (ii) may feature regions of surface brightness and spectral index flattening (contrary to the gradual steepening expected by particle aging), and (iii) frequently display filaments and disturbed morphology, especially at their terminal ends, where the tail structure "breaks". These properties suggest a non-trivial ongoing interplay between the non-thermal components in tails and the surrounding thermal gas, leading to processes that can sustain particles lifetime for periods of time and distances longer than usually expected.

Outline of the Project:
The PhD candidate candidate will work on multi-frequency observations performed with state-of-the-art instruments of nearby galaxy clusters hosting prominent head-tail radio galaxies. Data to be explored include the deep LOFAR, uGMRT, and JVLA observations available on A2255, A2256, and 3C129 (Figure). The candidate will utilize the sensitive and wide frequency range covered by these observations to constrain the spectral properties of the tails. These results will be combined with numerical simulations and theoretical models to determine the properties of magnetic fields and particle-acceleration mechanisms.

Part of the PhD project will also involve the statistical analysis of a large sample of tailed radio galaxies from the LOFAR and ASKAP surveys (LoTSS, LoLSS, EMU). The student will investigate the occurrence and properties of tailed sources in relation to the environment. As matter accretion in clusters occurs along cosmic filaments, the candidate will search for a correlation between the presence of tailed sources and the large-scale structure. This is crucial for understanding both the evolution of radio galaxies and the seeding of cosmic ray electrons in cosmic filaments, which are important scientific drivers for SKA.

The PhD student will be part of the LOFAR and EMU teams and have access to the most recent analysis technique. The PhD student will also be involved in international working groups, and travels to visit collaborators in Europe are planned.



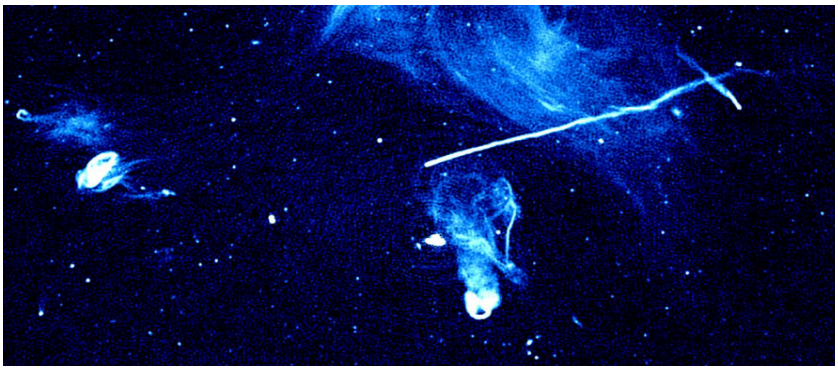


Figure: LOFAR image of Abell 2255 (left) and uGMRT image of Abell 2256 (right) showing numerous prominent tailed radio galaxies with complex morphologies. From Botteon et al. (2022) and Rajpurohit et al. (2022).

PhD Project in Astrophysics

Title: A new vision of particle acceleration in the intracluster medium

Supervisors INAF-IRA: Dr. Claudio Gheller, Dr. Gianfranco Brunetti

Supervisor UniBO: Prof. Franco Vazza

Summary:

The existence of large-scale diffuse radio emissions from galaxy clusters and filaments volume filling magnetic fields and of stochastic processes which channel a fraction of the gas kinetic energy into the acceleration of relativistic particles (Brunetti+Jones 2014 for review). The most recent discoveries allowed by low frequency radio observations, especially with LOFAR, have further opened a window into these mechanisms operating in novel regimes, never explored so far.

High resolution numerical simulations represent an ideal tool to couple the state-of-the-art in the theoretical modelling of such processes with the complex evolution of the cosmic structures in which major mergers or the continuous accretion of matter onto clusters of galaxies frequently generate shocks and stir turbulent motions on scales of Megaparsec.

However, in order to match the quality of the data provided by current and upcoming radio surveys, cosmological simulations software has to be extended and improved, introducing innovative algorithms and numerical approaches to describe cosmic ray astrophysics and to exploit the most powerful HPC systems.

In this project, the PhD candidate will work at the design and implementation of new algorithms describing relativistic processes (like injection of relativistic electrons from shocks, radio jets and galactic activity), capable to run on cutting-edge supercomputers, effectively exploiting GPUs and efficiently scaling on thousands of computing nodes in order to study the observable properties of state-of-the-art models of the relativistic particle content of our Universe.

Throughout the PhD programme, the candidate will have the chance to work extensively on cutting-edge supercomputing systems at INAF and CINECA. The candidate will also design, test, and run new large cosmological simulations exploiting the developed algorithms and will have the chance to explore uncharted theoretical territory, by testing the outcome of numerical predictions of particle acceleration scenarios against the latest observational results produced by the new generation of radio surveys.