

# Ph.D. Report

(XXXV Cycle - II year)

**PROJECT TITLE: Cross-population radio galaxies as a test of the jet-accretion relationship**

**CANDIDATE: DUCCIO MACCONI**

**SUPERVISOR: Dr. Paola Grandi**

**CO-SUPERVISORS: Dr. Eleonora Torresi, Prof. Cristian Vignali, Dr. Andrea Comastri, Dr. Bia Boccardi**

## Research project

**Context:** In Radio Galaxies (RGs) the accretion disk and the jet form a symbiotic system: powerful/weak jets are ejected by nuclear regions hosting efficient/inefficient accretion disks, respectively (see e.g. Willott et al. 1999; Allen et al. 2006; Heckman & Best 2014, and references therein). Powerful RGs, classified as Fanaroff-Riley II (FRII) (Fanaroff & Riley 1974) on the basis of their radio morphology, and High-Excitation RGs (HERGs), on the basis of their optical spectra (Laing et al. 1994), are characterized by efficient accretion. On the contrary, low-power RGs, i.e. RGs classified as FRIs and Low-Excitation RGs (LERGs), own low accretion rates. However, there exists a class of RGs that does not fit into this picture, i.e. they are powerful FRII radio sources associated to low-accretion rates (LERGs). In FRII-LERGs, the one-to-one correspondence between accretion efficiency and jet power is apparently not valid anymore.

**Aims:** FRII-LERGs represent  $\approx 25\%$  of the 3CR catalog ( $z \leq 0.3$ ) with uniform radio and optical classification (Buttiglione et al. 2009, 2010), and  $\approx 90\%$  of the local ( $z \leq 0.15$ ) mJy FRII population (Capetti et al. 2017). Therefore, finding an explanation for the existence of powerful radio sources associated with low accretion rates is becoming of great importance, since they seem to break the known accretion/ejection scheme. The goal of my PhD project is to explore the jet-accretion link through a multi-wavelength and multi-scale analysis of FRII-LERGs, in order to shed light on their nature.

### Current status:

1. the main part of the work is to expand the 3CR sample of RGs analyzed in X-rays during my first year of PhD (Macconi et al. 2020) to disentangle between the proposed scenarios for FRII-LERGs: they could be evolved RGs (i.e. powerful in the past but currently inefficiently accreting) or their environment may have played a role in shaping their FRII morphology. I am currently working on the CoNFIG catalog built by Gendre et al. (2013). It allows us to expand the 3CR sample, going down in radio flux density by a factor  $\approx 100$  in the same redshift range. For each source in the CoNFIG sample, both optical and radio classifications are available. In addition, the sample contains significant pieces of information such as Mpc-scale environment (cluster richness) and host-galaxy properties (e.g. Star Formation Rate (SFR), stellar mass, velocity dispersion and various tracers of the stellar age). 58 sources, available in X-rays, have been analyzed. The preliminary results, based on the characterization of the radio, optical and X-ray properties of the different RG classes, seems to indicate that: i) the environment does not play a key role in shaping the RGs morphology; ii) the most promising scenario is the evolutive one: in the mJy regime, FRII-LERGs appear to be old system with lower accretion rate, weaker radio emission and older stellar population than FRII-HERGs (Macconi et al. in prep.);
2. the serendipitous discovery of an X-ray cavity in NGC 5141 (a FRI belonging to another sample under investigation from Sikora et al. 2013) has triggered a parallel study on the jet and environment interaction. The inferred total cavity power is only  $P_{cav} = E_{cav}/t_{cav} \approx 6 \times 10^{40}$  erg/s, the lowest one among the radio-filled systems. We show that NGC 5141's central AGN is able to heat the ISM and balance its cooling luminosity, confirming that the  $P_{cav} - L_{cool}$  relation, mainly tested on groups/clusters, works also for such a low-power system (Macconi et al. in prep.).

### Future objectives: The successive steps will be:

- to test a theoretical model on the 3CR and CONFIG data in order to strengthen the interpretation of the observational results. Garofalo et al. (2010) have developed a theoretical model able to explain the evolution of FRII and FRI RGs in terms of BH spin evolution. Given the initial conditions (e.g. BH mass, accretion mode, environment, prograde or retrograde accretion), the model predicts the jet power and provides evolutionary tracks of the nuclear/galactic properties. The comparison between observations and theoretical predictions will allow to improve our knowledge of the accretion-ejection link and, in particular, to explore the evolutive scenario for the FRII-LERGs class;
- to explore the disk/jet connection on pc-scales, exploiting X-rays and radio (cm- and mm-VLBI) data, respectively. The radio small scale analysis allows to study the present physical conditions of the jet in the black hole vicinity.

## REFERENCES:

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Macconi, D., Torresi, E., Grandi, P., Boccardi, B., & Vignali, C. 2020, MNRAS, 493, 4355  
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Willott, C. J., Rawlings, S., Blundell, K. M., & Lacy, M. 1999, MNRAS, 309, 1017

## Second year activities (01/11/2020-30/09//2021)

### Workshops, Conferences & Meetings

- **Seminar** held at the University of Würzburg. **Title:** *A JOURNEY THROUGH RADIO GALAXIES: FROM CENTRAL ENGINES TO RADIO LOBES* (05 November 2020)
- **Contributed Poster** at the Super Black Holes (SMBHs) Conference, Universidad de Concepción, Chile (7-11 December 2020, online)
- **Contributed Poster** at the Conference: *Extragalactic jets on all scales - launching, propagation, termination*, Heidelberg, Germany (14-18 June 2021, online)
- **Contributed talk** at the YAGN21–Young Astronomers on Galactic Nuclei 2021, Copenhagen, Denmark (1-3 September 2021)

### PhD Schools

- 22-26 March 2021 *6th LOFAR Data Processing School* **Organized by:** ASTRON, The Netherlands (online)
- 24-28 May 2021 *CHEMICAL ABUNDANCES IN GASEOUS NEBULAE: FROM THE MILKY WAY TO THE EARLY UNIVERSE* **Organized by:** Univap - Universidade do Vale do Paraíba, Brazil (online)
- 1-5 June 2021 *Summer School in Statistics for Astronomers XVI* **Organized by:** the Penn State, Center for Astrostatistics (online)

### Internal Courses

- *from 30 November to 2 December 2020* **Title:** The Interstellar Medium, **Organized by:** the Italian node of the European ALMA Regional Centrenetwork (INAF-Istituto di Radioastronomia) in collaboration with INAF-OAS and University of Bologna (online)
- *from 19 April to 23 April 2021* **Title:** Gamma Ray Bursts: from observations to physical properties, **Organized by:** Dott. Marcello Giroletti (INAF-IRA Bologna) (online)
- *from 5 May to 14 May 2021* **Title:** Writing, talking and presenting Science **Organized by:** Dott. Roberto Decarli (INAF-OAS Bologna)

## ISA Lectures

- 15 DECEMBER 2020, Bologna, Italy  
**Title:** *Translating texts which do not exist. Pseudo-originality, multistable figures, and Fortini's literary reception of Heine and Brecht*  
**Lecture by:** Irene Fantappiè, Institut für Romanische Philologie, Freie Universität Berlin, Germany.
- 9 FEBRUARY 2021, Bologna, Italy  
**Title:** *Nanoscale pharmacology and biochemistry using advanced fluorescence microscopies*  
**Lecture by:** Paolo Annibale, Max Delbrück Center for Molecular Medicine, Germany.
- 28 SEPTEMBER 2021, Bologna, Italy  
**Title:** *How the Brain Controls Pain*  
**Lecture by:** Mary Heinricher, Oregon Health and Science University, USA

## Research period abroad

- 19 October- 06 December 2020: Scholarship won for research activity at the Lehrstuhl für Astronomie, Universität Würzburg, **Supervisor** Prof. Matthias Kadler, **Project Title:** *Combined X-ray and radio (VLBI) analysis of two Gamma-ray emitting radio galaxies.*

## Competitive telescope/computer time allocations

- March 04 2021, Proposal for scientific observation at SubMillimeter Array (SMA), *Title:* "The Nature of the Thermal Equilibrium in NGC5141" - Rejected.

## Publications

- Boccardi B., Perucho M., Casadio C., Grandi P., **Macconi D.**, Torresi E., Pellegrini S., Krichbaum T. P., Kadler M., Giovannini G., Karamanavis V., Ricci L., Madika E., Bach U., Ros E., Giroletti M., Zensus J. A.; **2021, A&A...647A..67B**  
**Title:** *Jet collimation in NGC 315 and other nearby AGN*
- Grandi P., Torresi E., **Macconi D.**, Boccardi B., Capetti A.; **2021, ApJ...911...17G**  
**Title:** *Jet-Accretion System in the Nearby mJy Radio Galaxies*
- **Macconi D.** et al. in preparation  
**Title:** *Discovery of a radio-filled X-ray cavity within the interstellar medium of NGC 5141*