

**Francesco Ubertosi**

PhD Cycle: XXXVI

Tutor: Prof. M. Gitti (DIFA), Prof. F. Brighenti (DIFA)

## **Studying AGN feeding and feedback in cool core galaxy clusters**

Multi-wavelength observations of galaxy clusters have allowed, in the last two decades, to investigate the low cooling and star formation rates in their cores. Surface brightness depressions (i.e., *X-ray cavities*) and weak shocks in the intracluster medium (ICM) have been observed to spatially correlate with radio lobes of the central active galactic nucleus (AGN). This has led to theorize that energy injection through mechanical feedback from the AGN might prevent over-cooling of the gas. However, the details of the heating-cooling regulation mechanism are far from being properly understood. First of all, it is unclear whether short phases of over-cooling and over-heating alternate each other. In this context, the uncertainties are most obvious when comparing the Phoenix and RBS 797 galaxy clusters, which are nearly identical in cool core properties. However, the star formation rate of Phoenix is two orders of magnitude higher than in RBS 797. This difference might be due to Phoenix currently being in an over-cooling phase, while RBS 797 might be experiencing strong heating (McDonald et al., 2018). Second of all, it is unclear what is the impact of cold ICM bulk motions (i.e., *sloshing*) on the mechanisms that regulate feeding and feedback of the AGN. The investigation of galaxy clusters in which the central radio galaxy, and its related X-ray cavities, are embedded in a highly turbulent medium is crucial to solve the above issues.

The main aim of my PhD is to examine in detail how AGN feeding and feedback in cool core clusters are coupled with the ICM. To fulfill this task, my PhD is focused in the first place on a new *Chandra* Large Program observation of RBS 797 (PI Gitti, 420 ks) awarded in Cycle 21, in order to investigate the whole cooling cycle in this cluster and search for footprints of enhanced heating. Currently, the reasons behind the dramatic quenching of star formation in RBS 797 are not known. The central radio source has inflated multiple pairs of perpendicular radio lobes (Gitti et al., 2006, 2013), however in archival *Chandra* data only one pair of X-ray cavities was found (Schindler et al., 2001). Additionally, there are hints of surface brightness discontinuities in the ICM, which have been interpreted as putative weak shocks (La Bella et al. in prep., for which I am co-author). The deep *Chandra* observation is best suited to determine the connection between the multiple radio lobes and the state of the ICM. During my first year I have reduced and analyzed the new *Chandra* data of RBS 797. Our first aim was to understand how the different radio orientations of the central AGN are coupled with the surrounding ICM. Thanks to our detailed study of the cluster core, we confirmed the presence of an additional cavity pair connected to the north-south extension of the AGN, located at the same distance from the center of the previously known east-west cavities. The discovery of the four perpendicular, equidistant X-ray cavities is in line with the hypothesis that RBS 797 is experiencing an over-heating phase. The results of this study have been submitted to ApJ Letters (Ubertosi et al., submitted on 27/09/2021), less than a year since when the *Chandra* observations were completed (Dec. 2020, the data are still proprietary).

Measuring the age of the cavities from X-ray data has revealed that we are observing nearly coeval outbursts, that possibly hint at the presence of binary active black holes in the radio core. However, in order to strengthen this claim, we need to measure the spectral properties of the radio plasma filling the cavities, thus determining the radiative age of the synchrotron emitting particles. Therefore, we asked for JVLA 3 GHz, 6 GHz and 10 GHz observations (JVLA/2021-06-170, 7.2 hours, PI Ubertosi). If accepted, the proposed observations will be carried out next spring, and data will be reduced in 2022. During the second year of the PhD we will finalize the whole cool core analysis, in order to build a complete picture of feedback in RBS 797. Our early results suggest the presence of at least two series of nested weak shocks propagating through the cluster, which further hint at repeated episodes of energy injection in the ICM (Ubertosi et al., in prep.). Additionally, we will start a collaboration with Prof. A. Bonafede and Dr. M. Giroletti to image the radio core at high resolution using LOFAR international stations (PI Bonafede) and multifrequency VLBI data (PI Gitti).

To address the open questions on feedback, during this year I have also analyzed *Chandra* observations of three galaxy clusters (A795, A2495, ZwCl0235) that show radio-filled X-ray cavities and evidences of sloshing. For A795, we carried on the collaboration with Dr. E. Torresi and Dr. P. Grandi (started during my Master thesis), aimed at studying the feedback properties of small sized radio galaxies in clusters. We completed and published the pilot study of the sloshing cluster A795, that hosts a radio compact AGN (Ubertosi et al. 2021). We have proposed for follow-up JVLA 1-2 GHz observations of A795 to improve our view of the central radio galaxy (JVLA/2021-06-171, 5 hours, PI Ubertosi). For A2495, we are analyzing a new *Chandra* observation (PI Gitti, 120 ks) to test whether the generation of multiple cavities is regulated by the cold gas oscillation timescale (Master thesis of L. Rosignoli, for which I am co-supervisor). For ZwCl0235, we found indications of metal uplift by radio lobe inflation and extended sloshing of low entropy gas, which contribute to the enrichment of the ICM at large distances from the cluster center (Ubertosi et al., in prep.).

## WORKSHOPS, CONFERENCES & MEETINGS

- 8-10 February 2021 – *CHEX-MATE Workshop: review of the status and multi-wavelength projects* (international, online meeting).
- 8-11 March 2021 – *A new window on the radio emission from galaxies, clusters and cosmic web: Current status and new perspectives* (international, online meeting).  
**Lightning Talk: “The curious case of the galaxy cluster Abell 795”;**
- 10-14 May 2021 Torun – *6<sup>th</sup> Workshop on Compact Steep Spectrum and GHz-Peaked Spectrum radio sources* (online meeting).  
**Talk: “The central FR0 in the sloshing cluster Abell 795”;**
- 14-18 June 2021 – *Extragalactic jets on all scales: launching, propagation, termination* (international, online meeting).  
**Poster: “Are jets of FR0s able to excavate cavities in the ICM?”;**
- 17-26 August 2021 – *Chandra Data Workshop: Novel Methods in Computing and Statistics for X-ray Astronomy* (international, online meeting).  
**Lightning Talk: “The deepest Chandra view of RBS 797: unprecedented evidence for two pairs of equidistant X-ray cavities”;**

### *Recurrent meetings:*

Internal Weekly PhD seminars.

Joint Astrophysical Colloquia.

Quid Ultra? Frontiers and controversies in Astrophysics.

Hypathia Colloquia – Early career Astronomer Series at ESO.

## PHD SCHOOLS

- 22-26 March 2021 Dwingeloo, Netherlands – *6<sup>th</sup> Lofar Data School* (international, online).

## INTERNAL COURSES

- 30 November – 2 December 2020 Bologna, Italy – *The Interstellar Medium*;
- 5<sup>th</sup> February 2021 Bologna, Italy – *How to give a scientific presentation*;
- 19 - 23 April 2021 Bologna, Italy – *Gamma Ray Bursts: from observations to physical properties*;
- 5 - 14 May 2021 Bologna, Italy – *Writing, talking and presenting Science*;
- 11<sup>th</sup> June 2021 Bologna, Italy – *How to write a scientific paper*;

## ISA LECTURES

- 26<sup>th</sup> January 2021 Bologna, Italy – *RNA: Biological Functions and Therapeutic Potential*.  
Lecture by Dr. Marco Marcia
- 6<sup>th</sup> July 2021 Bologna, Italy – *How positive pedagogy can address mental health and wellbeing of students?* Lecture by Dr. Priyank Shukla

## RESEARCH PERIOD ABROAD

Research period at the Harvard-Smithsonian Center for Astrophysics (Boston), in preparation for summer 2022.

## COMPETITIVE TELESCOPE/COMPUTER TIME ALLOCATIONS

- REQUESTED (results expected for November 2021) 7.2 hours at JVLA, proposal 2021-06-171, PI F. Ubertosi: *Are the perpendicular outbursts in RBS 797 hiding a dual AGN? A new JVLA perspective.*
- REQUESTED (results expected for November 2021) 5.0 hours at JVLA, proposal 2021-06-170, PI F. Ubertosi: *Is a FRO radio galaxy able to excavate X-ray cavities in the ICM? The case of Abell 795.*

## OTHER RELEVANT ACTIVITIES

- November 2020 – in progress: Co-supervisor of master thesis, student: Luca Rosignoli, University of Bologna. Title (subject to changes): *Detailed analysis of a deep Chandra observation of the galaxy cluster Abell 2495;*
- August 2021: Referee activity for proceeding articles (review of two manuscripts) from the *Compact Steep Spectrum & Ghz-Peaked Spectrum Workshop.*

## PUBLICATIONS

### PUBLISHED IN REFEREED JOURNALS

- *A Chandra study of Abell 795 – a sloshing cluster with a FRO radio galaxy at its center*, **Ubertosi, F.**, Gitti, M., Torresi, E., Brighenti, F., & Grandi, P. (2021), Monthly Notices of the Royal Astronomical Society, 503(3), 4627-4645.

### SUBMITTED TO REFEREED JOURNALS

- *The deepest Chandra view of RBS 797: unprecedented evidence for two pairs of equidistant X-ray cavities*, **Ubertosi, F.**, Gitti, M., Brighenti, F., Brunetti, G., McDonald, M., Nulsen, P., McNamara, B., Randall, S., Forman, W., Donahue, M., Ignesti, A., Gaspari, M., Etori, S., Feretti, L., Blanton, E., Jones, C. & Calzadilla, M. (submitted on 27/09/2021 to the Astrophysical Journal Letters).

### IN PREPARATION

- *The deepest Chandra view of RBS 797: the most quenched cool core cluster*, **Ubertosi, F.**, Gitti, M., Brighenti, F., Brunetti, G., McDonald, M., Nulsen, P., McNamara, B., Randall, S., Forman, W., Donahue, M., Ignesti, A., Gaspari, M., Etori, S., Feretti, L., Blanton, E. & Jones-Forman, C. (in preparation for the Astrophysical Journal).
- *AGN feedback, metal uplift and sloshing in ZwCl0235*, **Ubertosi, F.**, Gitti, M., Brighenti, F., et al. (in preparation for Astronomy & Astrophysics).
- *First evidence of a shock in a mini-halo cluster: implication from new LOFAR data*, La Bella, N., et al., including Ubertosi, F. (in preparation for Astronomy and Astrophysics).
- *Star formation rates of the most extreme cool core clusters*, Calzadilla, M., et al., including Ubertosi, F. (in preparation for the Astrophysical Journal).

### PROCEEDINGS

- *The central FRO in the sloshing cluster Abell 795: indications of mechanical feedback from Chandra data*, **Ubertosi, F.**, Gitti, M., Torresi, E., Brighenti, F., & Grandi, P. (submitted to Astronomische Nachrichten on 30/07/2021; referee report arrived, only minor comments).