The X-ray cavity system and radio mini-halo in the galaxy cluster RBS 797

Alberto Doria[1], Myriam Gitti[2,3], Stefano Ettori[2], Fabrizio Brighenti[1]

[1] Dipartimento di Astronomia, University of Bologna - Italy
[2] Astronomical Observatory of Bologna, INAF - Italy
[3] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA - USA

ABSTRACT

We present a study of the cavity system in the galaxy cluster RBS 797 based on Chandra and VLA data. The Chandra data confirm the presence of a cool core and indicate an higher metallicity along the cavity directions. This could be due to the AGN outburst, which lifts cool metal-rich gas from the center along the lobes orientations, as seen in other systems. We found indications of cool cavity rims surrounding the cavities. Likely, the 1.4 GHz radio emission, expanding, have displaced the gas compressing it into bright cool arms. Finally we show that the large scale radio emission detected with our VLA observations may be classified as a radio mini-halo powered by the cooling flow (cf), as it nicely follows the trend P_{radio} vs. P_{cf} predicted by the re-acceleration model.

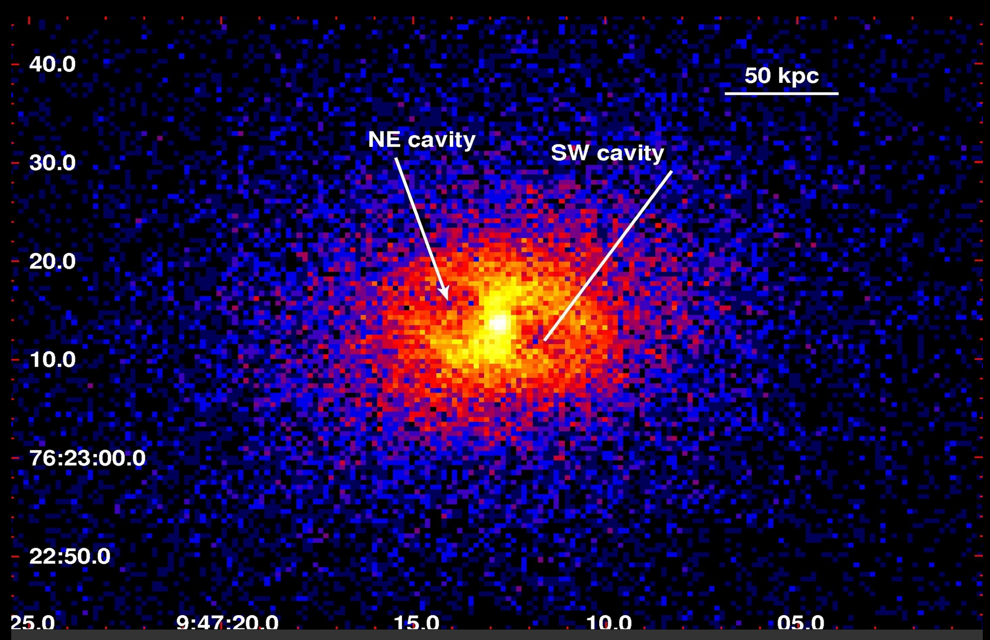

Fig. 1: ACIS-S3 raw image of the central region of RBS 797 in the 0.5-7.0 keV energy band. The cavity system extends along the northeast-southwest (NE-SW) direction.

INTRODUCTION

Imaging spectroscopy obtained with the new generation of X-ray telescopes shows that the spectra of galaxy clusters do not present the evidence of any cooler phase of the cooling flow gas below an intermediate temperature (~1-2 keV). Many possible explanation to these observations have been proposed (e.g., Peterson and Fabian, 2006 for a review) but the most accredited scenario is the non gravitational heating by a central AGN in the galaxy cluster (McNamara and Nulsen, 2007 and references therein).

The central AGNs of galaxy clusters drive strong jet outflows which interacts with the hot plasma of the ICM inflating bubble-like non-thermal lobes. These lobes displace the ICM, creating X-ray photon-deficient holes that for this reason are generally called cavities. Such peculiar features can heat the cluster gas in various ways, moreover the bubbles contain also relativistic particles and magnetic fields, hence making possible to be observed in the radio band.

We present the analysis of new, deep *Chandra* X-ray data and new VLA radio observations of RBS 797 to investigate the ICM physical properties and study its interaction with the radio source. RSB 797, whose central cluster galaxy is located at RA (J2000): 09h 47m 12s .5, Dec (J2000): 76° 23′ 14″.0, is at a redshift z = 0.35. With H_0 = 70 km s^{-1} Mpc^{-1}, and $\Omega_M = 1 - \Omega_\Lambda = 0.3$, the luminosity distance is 1858 Mpc and 1 arcsec corresponds to 4.8 kpc. The radio spectral index α is defined such as $S_\nu \propto \nu^\alpha$.

X-RAY DATA ANALYSIS

RBS 797 (z = 0.35) was observed by *Chandra* ACIS-I on October 20th 2000 (ObsID 2202) and by ACIS-S on July 9th 2007 (ObsID 7902). The final exposure time after cleaning is ~49.6 ks.

Chandra ACIS-S and ACIS-I data were both used for temperature and metallicity profiles extraction and for the deprojection analysis. A study of temperature and abundance variations has given indication of higher temperatures and metallicities along the cavity directions rather than in the unperturbed regions.
The cooling core analysis enabled us to estimate the central cooling time (t_{cool} = 7.72 × 10^8 yr) and then to estimate the cooling radius of RBS 797 as r_{cool} ~ 180 kpc.
Finally, the X-ray luminosity within the cooling radius is $L_{X,cool}$ = 1.7 × 10^{45} erg s^{-1}.

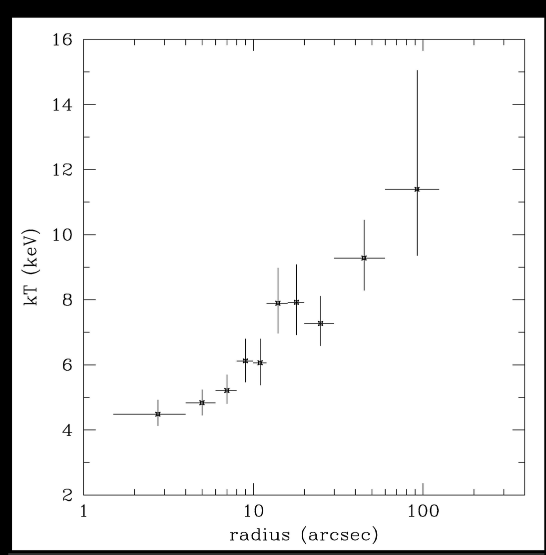

Fig. 2: Azimuthal temperature profile estimated by ACIS-S3 and ACIS-I3 data in the energy range 0.5-7.0 keV. The first 1.5 arcseconds, containing the central AGN, were excluded. Errors are at 90% of confidence level.

From ACIS-S data it has been possible to estimate the surface brightness profile of the undisturbed cluster and along the cavities directions.

The azimuthally-averaged radial surface brightness profile in the 0.5-2.0 keV energy band shows a strong excess in the center with respect to the β-model.

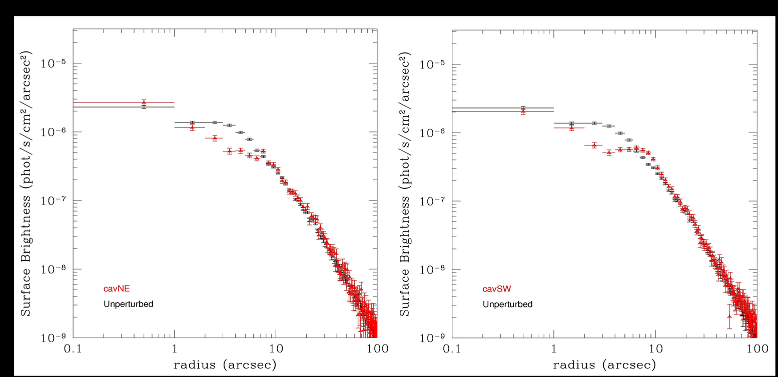

Fig. 3: Background subtracted, azimuthally-averaged 0.5-2.0 keV radial surface brightness profiles of the unperturbed cluster compared with NE (left *panel*) and SW (*right panel*) surface brightness profiles.

Red triangles indicate the surface brightness profile along the cavities directions, while black crosses show the profile of the undisturbed cluster. Errorbars indicate uncertainties at 1σ confidence.

There is a clear drop of the surface brightness profile in the cavitiy regions.

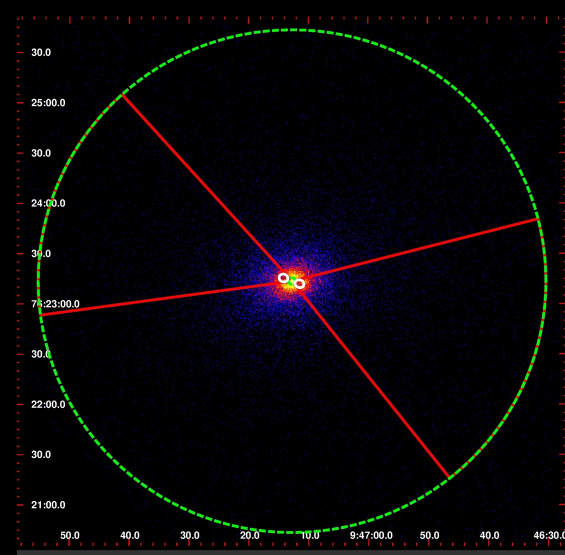

Fig. 4: Raw ACIS-S3 image in the 0.5-2.0 keV energy interval. Surface brightness profiles were obtained excluding the two inner white elliptical regions containing the cavities and their surrounding rims.

Annuli of 1″ were considered from 2″ up to 150″ as indicated from the two dashed green circles.

The red lines delimit the two sectors considered for the surface brightness extraction along the cavity directions.

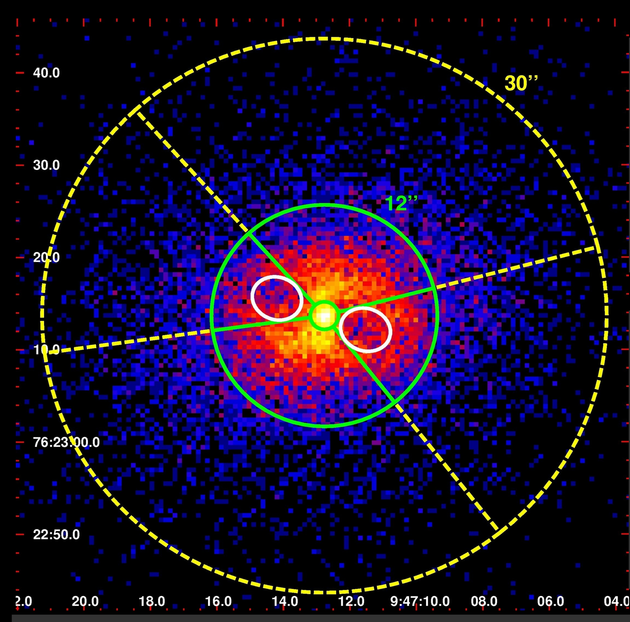

Fig. 5: Raw image of RBS 797 in the 0.5-7.0 keV energy range. The white ellipses are the cavities.

The four sectors are tangent to the cavities and divide the cluster in two unperturbed regions and two cavity regions.

Metallicity variations: in the 1".5-30" yellow annulus the abundance of heavy elements is higher (1σ errors) in the NE-SW direction reather than in the umperturbed regions:

$$Z_{CAV} = 0.55^{+0.10}_{-0.10} Z_{sun} \qquad Z_{UND} = 0.38^{+0.04}_{-0.04} Z_{sun}$$

Temperature variations: considering together the NE and SW cavity regions and the two unperturbed N and S regions, we found higher temperature values (1σ errors) along the cavity directions (green annulus, 1".5-12"):

$$kT_{CAV} = 5.89^{+0.43}_{-0.43} keV \qquad kT_{UND} = 5.20^{+0.14}_{-0.14} keV$$

ENERGETICS AND RIMS

The comparison between the X-ray luminosity of the ICM within the cooling radius and the cavity power provides an estimate of the balance between energy losses by X-ray emission and the cavity heating.

Table 1: Cavity energetics

	Cavity NE	Cavity SW
a (kpc)	12.82	12.96
b (kpc)	11.04	10.99
R (kpc)	25.78	22.18
V (cm^3)	2.08 × 10^{68}	2.10 × 10^{68}
p (erg cm^{-3})	4.47 × 10^{-10}	4.47 × 10^{-10}
kT (keV)	4.6	4.60
pV (erg)	9.29 × 10^{58}	9.38 × 10^{58}
E_{cav} (erg)	3.72 × 10^{59}	3.75 × 10^{59}
t_{buoy} (s)	1.64 × 10^{15}	1.13 × 10^{15}
P_{cav} (erg s^{-1})	2.27× 10^{44}	3.32× 10^{44}

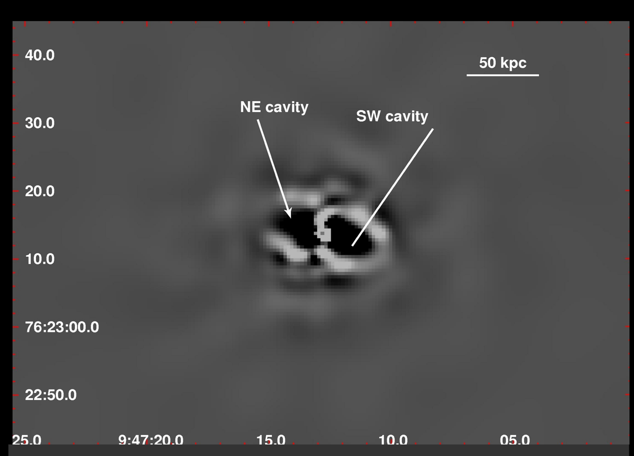

Fig. 6: Unsharp masked image in the 0.5-7.0 keV energy range, obtained by subtracting a smoothed image with S/N=10 from a smoothed image with S/N=3. Very bright rims surround deep X-ray-deficient lobes.

Comparison between the temperature of the cavities (white contours) and the temperature of the surrounding rims (green regions).

There is an indication of cool rims compared with the cavity system, supported also by the analysis of the hardness ratios:

$$kT_{rims} = 4.73^{+0.15}_{-0.14} keV$$

$$kT_{CAV} = 5.34^{+0.76}_{-0.50} keV$$

The 1.4 GHz emission with its expansion could have spread and pushed away the gas that previuosly was in the X-ray lobes, finally compressing it into bright cool rims.

RADIO MINI-HALO

Radio data were obtained in three configurations of the *Very Large Array* (*VLA*). The analysis of several frequencies and resolutions allowed us to distinguish different features at various scales. From previous *VLA* observations it has been possible to estimate the radio power of the central radio source as $P_{1.4GHz}$ = 1.1 × 10^{25} W Hz^{-1} (Gitti et al., 2006).

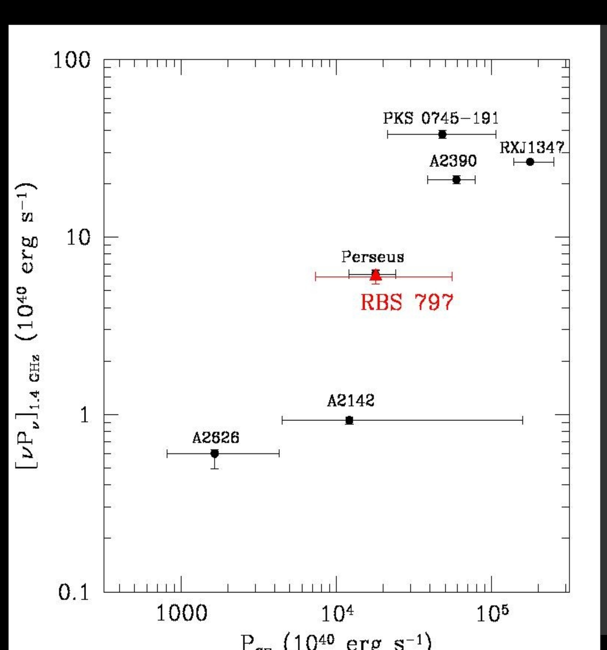

Fig. 8: Cooling flow power, calculated as P_{CF} = MkT/μmp, plotted versus the integrated radio power at 1.4 GHz. The other black objects plotted with RBS 797 (red triangle) are galaxy clusters whose diffuse radio emission size is comparable to the cooling radius.

This trend shows how at bigger radio powers correspond bigger cooling flow powers.

$$P_{cf} = 6.80 \times 10^{44} ergs^{-1}$$

$$[\nu P_\nu]_{1.4GHz} = 5.97 \times 10^{40} ergs^{-1}$$

Gitti et al. (2002) developed a model of particle acceleration by magneto-hydrodinamics turbulence, finding that the diffuse synchrotron emission of the radio mini-halos may be due to the re-acceleration of relativistic electrons via Fermi-like processes in the ICM. Mini-halos are then triggered by turbulences in the core of cf clusters: the magnetic field in cluster of galaxies is amplified by compression due to the cooling flow.
Utilizing both *Chandra* and *VLA* data we compared the power of the cooling flow with the integrated radio power at 1.4 GHz.

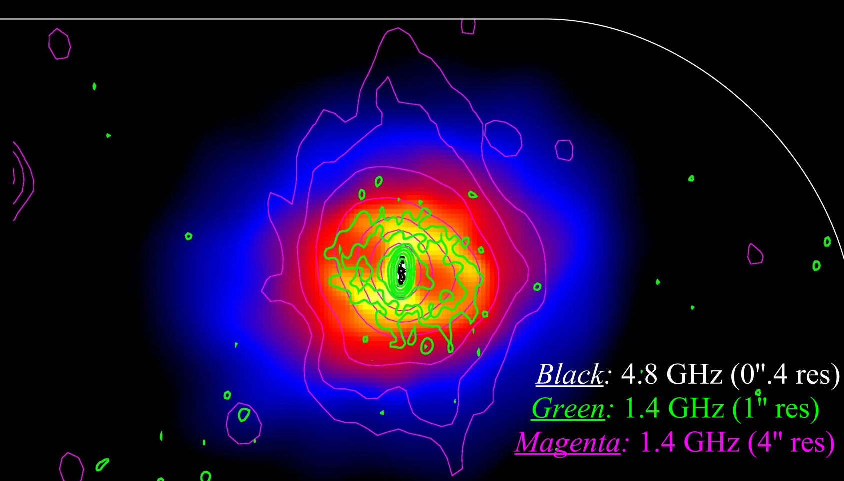

Fig. 7: Radio emission of RBS 797 detected by *VLA* in three different configurations, overlayed on the X-ray vignetting-corrected smoothed image with S/N=3.

Black contours: 4.8 GHz (resolution of 0″.4) emission, due to the inner jets of the central radio source.

Green contours: 1.4 GHz (resolution of 1″) emission which fills the cavities and denotes the AGN/ICM interaction.

Magenta contours: the amorphous large-scale 1.4 GHz (resolution of 4″) radio emission which indicates thepresence of a radio mini-halo due to the re-acceleration of particles.

REFERENCES

- M. Gitti, G. Brunetti, and G. Setti. *Modeling the interaction between ICM and relativistic plasma in cooling flows: The case of the Perseus cluster.* A&A, 386:456–463, May 2002. doi: 10.1051/0004-361:20020284.
- M. Gitti, L. Feretti, and S. Schindler. *Multifrequency VLA radio observations of the X-ray cavity cluster of galaxies RBS797: evidence of differently oriented jets.* A&A, 448:853–860, Mar. 2006. doi: 10.1051/0004-6361:20053998.
- B. R. McNamara and P. E. J. Nulsen. *Heating Hot Atmospheres with Active Galactic Nuclei.* Annu. Rev. Astron. Astrophys., 45:117–175, Sept. 2007. doi: 10.1146/annurev.astro.45.051806.110625.
- J. R. Peterson and A. C. Fabian. *X-ray spectroscopy of cooling clusters.* Phys. Rep., 427:1–39, Apr. 2006. doi: 10.1016/j.physrep.2005.12.007.

Structures in Clusters and Groups of Galaxies in the Chandra Era Workshop, July 12-14 2011, Boston, MA - USA