



Radio halos in galaxy clusters: The interesting case of Abell 2142

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Abstract. We present GMRT deep observations at 610 MHz and 325 MHz of the galaxy cluster Abell 2142, where a giant radio halo of extremely low surface brightness has been recently detected at 1.4 GHz with the Green Bank Radio Telescope (GBT). Comparison with a re-analysis of archival 1.4 GHz VLA data show that the spectrum of the radio halo is very steep between 325 MHz and 1.4 GHz. A 2142 is not a major merger, at odds with the very unrelaxed dynamical state of the galaxy clusters hosting giant radio halos. A new cold front, located at about 1 Mpc from the cluster centre, has been recently found with *XMM-Newton* observations, suggesting that the cluster is characterised by gas sloshing motion at all scales, following an off-axis minor merger. We propose that either the sloshing itself or the turbulence induced by the minor merger may be at the origin of the giant radio halo.

Keywords : galaxies: clusters: general – galaxies: clusters: individual: A 2141 – radio continuum: general

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1. Introduction

Radio halos are the most spectacular non-thermal effects of galaxy cluster mergers. They are diffuse synchrotron radio sources, permeating the whole cluster volume, characterized by steep spectra (α steeper than ~ 1.2 , for $S \propto \nu^{-\alpha}$) and extremely low surface brightness ($\leq \mu\text{Jy/arcsec}^2$). Radio halos are not ubiquitous in galaxy clusters (e.g. Venturi et al. 2008; Kale et al. 2013) and growing observational evidence shows that $\sim 30\%$ – 40% of massive clusters ($M \geq 10^{15} M_{\text{Sun}}$) experiencing major merger events host one (Cassano et al. 2010, 2013).

The current favourite theoretical scenario to account for the origin and rarity of radio halos is the turbulent re-acceleration model (Brunetti et al. 2001). Following this model, merger-induced turbulence re-accelerates in-situ relativistic electrons up to the energy required to produce synchrotron radiation at GHz frequencies. Predictions based on this model, such as for instance the existence of radio halos with ultrasteep spectrum (i.e. $\alpha > 1.5$) due to less energetic events and/or less massive clusters, have been confirmed observationally by the discovery of the “ultrasteep” spectrum radio halo in A 521 (Brunetti et al. 2008).

We present GMRT (Giant Metrewave Radio Telescope) observations of the newly discovered giant radio halo in the galaxy cluster A 2142, which helps improving our understanding of the influence of cluster mergers on the thermal and non-thermal components of galaxy clusters.

2. Thermal and non-thermal properties of A 2142

A 2142 ($z=0.0909$, $T \sim 9$ keV, $L_{X[0.5-2\text{keV}]} = 7.2 \times 10^{44}$) is the first cluster where “cold fronts” – sharp surface brightness discontinuities interpreted as contact edges between regions of different entropies – were detected with *Chandra* (Markevitch et al. 2000). Very recently, *XMM-Newton* observations led to the discovery of new a cold front located at the unprecedented distance of ~ 1 Mpc from the cluster centre, in the south-east direction (Rossetti et al. 2013). The X-ray analysis and optical spectroscopy suggest that the cluster is marginally disturbed, with observational properties consistent with a minor merger (Owers et al. 2011). Finally, 1.4 GHz observations performed with the Green Bank Radio Telescope (GBT), detected a Mpc scale radio halo with extremely low surface brightness sensitivity, $\sim 0.7 \mu\text{Jy/arcsec}^2$ (Farnsworth et al. 2013), which had escaped previous interferometric radio observations. As a matter of fact, A 2142 was classified as a mini-halo cluster (see Giacintucci et al. 2014, for a recent paper on this topic) in Giovannini & Feretti (2000), apparently consistent with a relaxed system.

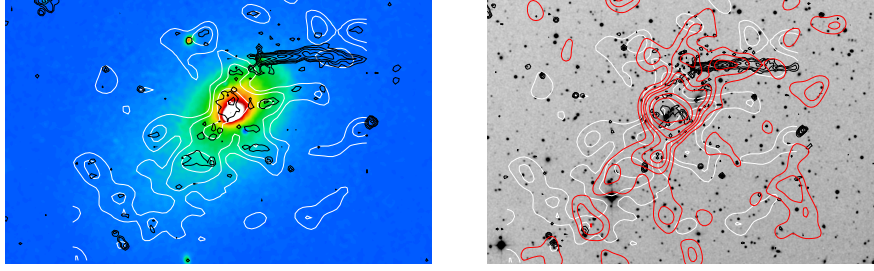


Figure 1. Fig. 1 – *Left panel:* GMRT 325 MHz images of A 2142 overlaid on the smoothed *XMM-Newton* surface brightness distribution. Black contours are the full resolution image (FWHM= $9.8'' \times 7.5''$, 1σ rms =0.15 mJy/b, contour levels $\pm 0.6, 1.2, \dots$ mJy/b); white contours show the residual emission of the radio halo (FWHM= $50'' \times 50''$, contour levels $\pm 1.8, 3.6, \dots$ mJy/b). *Right panel:* GMRT 610 MHz images of A 2142 overlaid on the DSS-2 red optical frame. Black contours are the full resolution image (FWHM= $7.5'' \times 6.8''$, 1σ rms ~ 0.03 mJy/b, contour levels $\pm 0.12, 0.24, \dots$ mJy/b); red contours show the residual emission of the radio halo (FWHM= $50'' \times 50''$, contour levels $\pm 0.4, 0.8, 1.2, 1.6, 2.4, 3.2$ mJy/b). For comparison the radio halo emission at 325 MHz (same as left panel) is shown in white.

3. GMRT observations and images

We observed A 2142 with the GMRT at 610 MHz, 325 MHz and 240 MHz to clarify the nature of the newly discovered giant radio halo, and derive hints on its spectral steepness. The logs of the observations and parameters of the full resolution images are reported in Table 1.

Table 1. Logs of the observations and image parameters

Project ID	Observing Date	ν MHz	$\Delta\nu$ MHz	Time hour	FWHM "	rms mJy/b
23_017	22-03-13	610	32	10	7.5×6.8	0.03
23_017	28-03-13	325	32	10	9.8×7.4	0.12 – 0.15
23_017	23-03-13	240	16	10	13.1×10.7	^a

Notes: ^a Data analysis in progress.

For each observation we made full resolution and tapered images, to cover the wide range of resolutions necessary to properly study the field. In order to image the diffuse radio halo we subtracted the individual radio galaxies from the $u-v$ plane, and imaged the residuals with appropriate tapering and weighting schemes.

4. Preliminary discussion

The radio halo is clearly imaged at both frequencies. The radio emission is peaked in coincidence with the X-ray brightness peak, and is elongated along the same south-east/north-west axis of the thermal ICM emission (Fig. 1, left panel). Beyond the central bright ridge of the radio emission, patches of positive residuals are detected all over the X-ray emission, to cover an extent of ~ 1 Mpc. The reliability of such residuals needs to be tested, as the present observations are not sensitive enough to properly image the faintest features of the radio halo and accurately subtract the contribution of the embedded individual sources.

The brightest part of the halo corresponds to the previous “mini-halo” (Giovannini & Feretti 2000). For consistency with our calibration and imaging approach, we re-analyzed the archival VLA 1.4 GHz data, and obtained an improved image compared to the previously published results (Giacintucci *et al.* in prep.), where emission south of the “mini-halo” is detected. To estimate the spectral steepness of the halo emission, we separated the morphology into two components, i.e. the “mini-halo” region and the fainter south-eastern emission, and measured the flux density at 325 MHz, 610 MHz and 1.4 GHz over the same areas. We obtained $\alpha_{325 \text{ MHz}}^{1.4 \text{ GHz}} \sim 1.34$ for the “mini-halo” region, and $\alpha_{325 \text{ MHz}}^{1.4 \text{ GHz}} \sim 1.98$ for the south-east extension. These values suggest that the spectrum of the emission is overall ultrasteep. This result would be consistent with the dynamical state of A 2142, classified as minor merger. It is also consistent with the possibility already mentioned in Rossetti *et al.* (2013) that large-scale sloshing motions in the cluster could be responsible both for the cold front at Mpc distance, and for the energy necessary to re-accelerate in-situ electrons to produce the observed giant radio halo.

5. Final considerations

A 2142 has been observed with the JVLA in the 1–2 GHz band (Farnsworth *et al.* in preparation). A preliminary comparison of the GMRT and JVLA data shows that our derivation of the spectral behaviour on different scales will be limited by the very different u – v coverage and sensitivities of the two datasets. Another challenge is the proper removal of the contribution of the cluster and background sources in a field as crowded as A 2142.

Acknowledgements

D.F. and L.R. acknowledge partial support through US-NSF grant AST-1211595 to the University of Minnesota. The VLA is operated by the NRAO, a facility of the US-NSF under cooperative agreement with AUI. The GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute for Fundamental Research.

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