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A Hidden Radio Halo in the Galaxy Cluster A 1682?

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Abstract. High sensitivity observations of radio halos in galaxy clusters at frequencies $\nu \leq 330$ MHz are still relatively rare, and very little is known compared to the classical 1.4 GHz images. The few radio halos imaged down to 150–240 MHz show a considerable spread in size, morphology and spectral properties. All clusters belonging to the GMRT Radio Halo Survey with detected or candidate cluster-scale diffuse emission have been imaged at 325 MHz with the GMRT. Few of them were also observed with the GMRT at 240 MHz and 150 MHz. For A 1682, imaging is particularly challenging due to the presence of strong and extended radio galaxies at the center. Our data analysis suggests that thew radio galaxies are superposed to very low surface brightness radio emission extended on the cluster scale, which we present here.

Key words. Galaxies: clusters: general—galaxies: clusters: individual: A 1682—radio continuum: general.

1. Introduction

The origin of radio halos and relics is strictly connected to the dynamics of the hosting cluster. Recent works, based on the GMRT Radio Halo Survey (Venturi *et al.* 2007, 2008), have highlighted a number of relevant statistical properties of radio halos, such as the *bimodality*: clusters are either *radio loud*, in which case the halo radio power correlates with the cluster X-ray luminosity, following the well-known $\log L_X - \log P_{1.4}$ GHz correlation, or *radio quiet*, with radio power upper limits well below the same correlation (Brunetti *et al.* 2009). Moreover, a quantitative radio/X-ray analysis of the radio halo/cluster merger connection shows that halos are found only in cluster mergers; relaxed clusters never host them, and only few massive, luminous and merging clusters are void of diffuse emission at the sensitivity level of the current radio interferometers (Cassano *et al.* 2010).

These results support the idea that radio halos are the result of relativistic particle re-acceleration by turbulence induced in the cluster volume by massive cluster mergers (the *re-acceleration model*, Petrosian 2001; Brunetti *et al.* 2001). This model further predicts the existence of a population of halos with 'ultra-steep spectrum', i.e. $\alpha \geq 1.5$, which would be connected to the less energetic, but much more frequent minor mergers (Cassano 2009; Cassano *et al.* 2011). A 521, with a spectral slope of $\alpha \sim 1.9$ is the first ultra-steep spectrum radio halo (USSRH) discovered (Brunetti *et al.* 2008; Dallacasa *et al.* 2009). Due to their spectral properties, USSRH are best detectable at low frequencies, i.e. $\nu \leq 330$ MHz.

To improve the knowledge of the low-frequency properties of radio halos, and possibly identify candidate USSRHs, all clusters in the GMRT radio halo survey with detected diffuse or candidate cluster-scale emission were observed with the GMRT at 325 MHz, and some of them were followed up at 240 and 150 MHz. Some results have already been published in recent papers (Giacintucci *et al.* 2009, 2011; Macario *et al.* 2010, 2011; Venturi *et al.* 2011). Here we present and briefly discuss the challenging case of A 1682.

2. A hidden radio halo in A 1682?

A 1682 ($z = 0.2260$) is a merging massive cluster (Morrison *et al.* 2003), with $L_{\rm X}[0.2-2.4\ \rm keV] = 7.02 \times 10^{44}$ erg s^{-1}, first imaged at high sensitivity and resolution with the GMRT at 610 MHz (Venturi *et al.* 2008). The radio emission is dominated by a strong tailed radio galaxy at the cluster center, and by two features of unclear nature, referred to as S–E and N–W ridge (see Fig. 6 in Venturi *et al.* 2008). Beyond those individual sources, residuals are present in the central cluster region, suggestive of a radio halo outshined by the bright individual radio sources. We carried out follow-up observations of A 1682 over a wide frequency range, in order to study the spectral properties of the individual sources, and possibly image the underlying residual cluster-scale emission.

Table 1 lists the observations and the available information. We completed the data imaging and analysis at 610 MHz and 240 MHz and at 74 MHz. The data reduction at 330 MHz and 150 MHz is currently in progress. At 240 and 610 MHz, after removal of the RFI, editing and self-calibration, we produced full resolution images with a $1 - k\lambda$ gap in the u–v plane in order to image the individual sources without the inclusion of the cluster scale diffuse emission. We subtracted the clean components from the GMRT datasets, and imaged the residuals using the whole u–v range and a resolution $\sim$35″–40″. The rms in the residual images are $\sim$0.12 mJy/b and 0.8 mJy/b at 610 MHz and 240 MHz respectively. The 74 MHz data reduction was carried out by applying the model of Cygnus A provided by the NRAO for the bandpass and amplitude calibration. Then editing and self-calibration were performed.

Table 1. A 1682 observing logs and information on the full resolution images.

ν (MHz)	Array	Date	Time (hr)	HPBW (″×″,°)	rms (mJy b^{-1})
610	GMRT	05-12-2006	6	6.2×4.1, 61.2	0.03
330	GMRT	06-02-2011	16	10.0×9.1, –	–
240	GMRT	05-12-2006	6	12.5×9.2,55.7	0.50
150	GMRT	17-08-2009	9	26.0×19.0, –	–
74	VLA–A	08-01-2009	4	23.8×22.4,–68	20

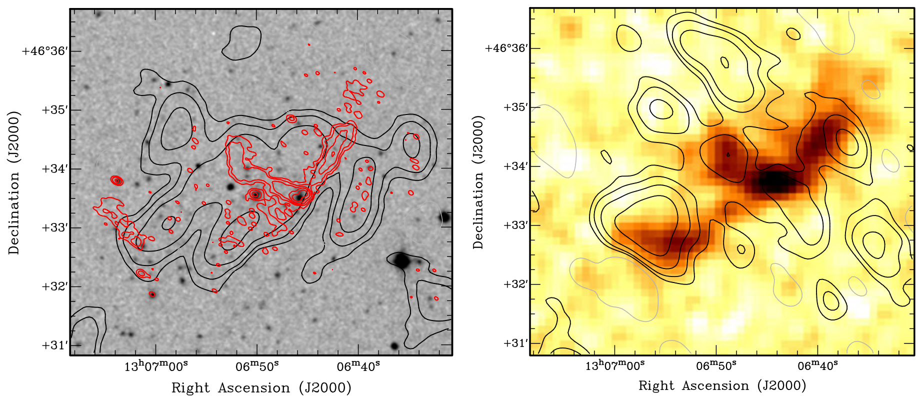

Figure 1. *Left*: 610 MHz GMRT contours on the optical DSS-2 frame. Red: Full resolution image (6.2″ × 4.1″, contours ±0.15,0.6,2.4 mJy/b). Black: Residual image (38″ × 33″, contours ±0.3, 0.6, 1.2, 2.4 mJy/b, 1σ ∼ 0.1). *Right*: 240 MHz GMRT residual image (40″ × 30″, black contours ± 0.6, 1.2, 2.4, 4.8 mJy/b, 1σ ∼ 0.3 mJy/b), overlaid on the 74 MHz VLA–A total intensity image (23.8″ × 22.4″, rms ∼20 mJy/b).

Our results are shown in Fig. 1. The left panel shows the 610 MHz residual and full resolution image (black and red contours respectively); the right panel shows the 240 MHz residual image overlaid on the VLA–A 74 MHz cluster emission. Excess emission spread over the cluster scale is clearly present at both frequencies. Re-analysis of archival VLA D-array data at 1.4 GHz also suggests hints of residual emission. The residual flux density values are $S_{1.4\ \mathrm{GHz}} \sim 14.5$ mJy, $S_{610\ \mathrm{MHz}} \sim 32$ mJy, $S_{240\ \mathrm{MHz}} \sim 80$ mJy, consistent with a spectral slope of $\alpha \sim 1$. Considering the uncertainties in the source subtraction procedure and the different u–v coverage at various frequencies, any detailed consideration on this emission and its nature is premature at this stage. An important piece of information is that all our images show excess emission at the center of A 1682, most likely spread over the Mpc cluster scale (1″ = 3.626 kpc at the distance of A 1682). At 74 MHz it is impossible to separate the contribution of the individual sources from the diffuse emission, however the colour scale image in the right panel of Fig. 1 clearly shows the presence of a blob, located S–E of the extended central radio galaxies, coincident with a similar feature in the 240 MHz residuals. Actually, a large fraction of the diffuse flux density both at 610 MHz and at 240 MHz comes from this region.

The nature of the S–E and N–W ridges is unclear. Their spectrum is steep, $\alpha^{610\ \mathrm{MHz}}_{240\ \mathrm{MHz}} \sim 1.3$ and 1.6 respectively. The brightness distribution of the N–W ridge (centrally peaked and symmetric in both directions) is suggestive of a FR–I radio galaxy rather than a relic.

We expect that the GMRT 150 MHz and 330 MHz will strengthen the suggestion of the hidden radio halo in A 1682, and provide important information on its spectral behaviour.

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