J. Astrophys. Astr. (2011) **32**, 529–532

Discovery of a Giant Radio Halo in a Massive Merging Cluster at $z = 0.443$

K. S. Dwarakanath*, Siddharth Malu & Ruta Kale
Raman Research Institute, Bangalore 560 080, India.
**e-mail: dwaraka@rri.res.in*

Abstract. We have discovered a giant radio halo in the massive merging cluster MACSJ0417.5-1154. This cluster, at a redshift of 0.443, is one of the most X-ray luminous galaxy cluster in the MAssive Cluster Survey (MACS) with an X-ray luminosity in the 0.1–2.4 keV band of 2.9×10^{45} erg s^{-1}. Recent observations from GMRT at 230 and 610 MHz have revealed a radio halo of $\sim 1.2 \times 0.3$ Mpc^2 in extent. This halo is elongated along the North-West, similar to the morphology of the X-ray emission from Chandra. The 1400 MHz radio luminosity ($L_{\rm r}$) of the halo is $\sim2 \times 10^{25}$ W Hz^{-1}, in good agreement with the value expected from the $L_{\rm x} - L_{\rm r}$ correlation for cluster halos.

Key words. Galaxies: clusters: individual (MACSJ0417.5-1154)—radiation mechanisms: nonthermal.

1. Introduction

Diffuse non-thermal radio emission in clusters of galaxies that is not associated with any of the cluster galaxies is called a 'halo' or a relic depending on whether the diffuse radio emission is located near the center or the near the periphery of the cluster. The radio halos and relics are due to relativistic electrons and magnetic fields in the intra cluster medium. They exhibit steep non-thermal spectra in the radio regime, with the relics having steeper spectra compared to the halos.

Radio halos and relics are believed to be associated with cluster mergers although not all merging clusters host them (Brunetti *et al*. 2009; Venturi *et al*. 2008). The X-ray surface brightness distributions of merging clusters typically exhibit non-concentric iso-intensity contours, small-scale structures, multiple peaks and/or poor optical and X-ray alignments. The MAssive Cluster Survey (MACS) aims to compile a statistically complete sample of very X-ray luminous (and therefore massive) distant clusters of galaxies in the redshift range of 0.3 to 0.6 (Ebeling *et al*. 2010). All clusters in MACS have $L_{\rm x} > 10^{45}$ erg s^{-1}. The hottest and the most X-ray luminous clusters in this sample also exhibit disturbed X-ray morphologies implying that they might be the result of recent mergers.

While the detection probability of a radio halo is rather small (<10%) for all clusters, the probability increases to ~40% for clusters with $L_{\rm x} > 10^{44}$ erg s^{-1} (Venturi *et al*. 2008). Under these circumstances, majority of the MACS clusters might be expected to host detectable radio halos. The galaxy cluster MACSJ 0417.5-1154 is the second most X-ray luminous cluster of the MACS sample and exhibits disturbed X-ray morphology.

2. GMRT observations

The cluster MACSJ0417.5-1154 was observed for a total duration of 8 hours in the dual frequency (235/610 MHz) mode. The GMRT software back-end with a bandwidth of 6 and 32 MHz respectively was used in these observations. Data were analysed using the Astronomical Image Processing System (AIPS, developed by NRAO). Bad data due to radio frequency interference were excised. Wide-field imaging was carried out with appropriate number of self-calibrations. Images at 610 and 230 MHz were produced with rms values of 76 and 440 μJy/beam respectively. The synthesized beams at the two frequencies were $9'' \times 9''$ and $18'' \times 18''$ respectively. The resulting wide-field image at 610 MHz of the area surrounding the cluster MACSJ0417.5-1154 is shown in Fig. 1. The radio emission from the central region of the cluster is overlayed on the X-ray emission from the cluster in Fig. 2. An overlay of the 610 MHz radio emission on the 235 MHz image is shown in Fig. 3.

3. Discussion

The radio emission in the center of Fig. 2 consists of three components. First, the brightest radio source coinciding with the brightest X-ray emission has an optical counterpart and is a cD galaxy in the cluster. This is unresolved even at the highest

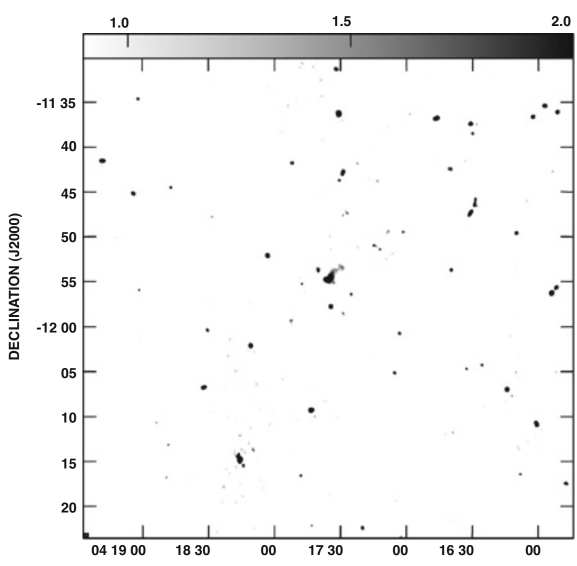

Figure 1. Wide-field GMRT image at 610 MHz of the region around the cluster MACSJ0417.5-1154. The grey scale ranges from 0.9 to 2 mJy/beam. This image has a resolution of $18'' \times 18''$.

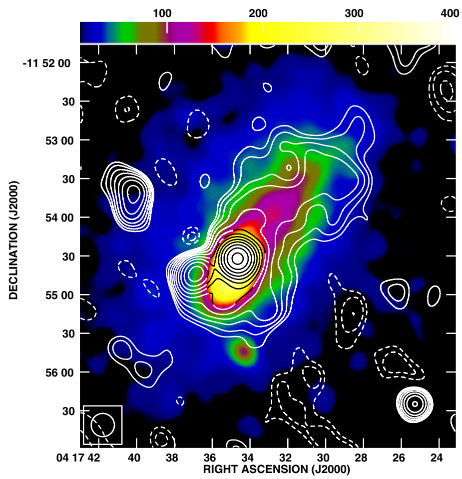

Figure 2. The GMRT radio image of the cluster source at 610 MHz (contours) overlaid on the Chandra X-ray image (colours). The radio image at the original resolution of $\sim 9''$ was convolved to $18''$ to highlight the diffuse extended emission. The first contour is at 0.4 mJy/beam and increases in steps of $\sqrt{2}$.

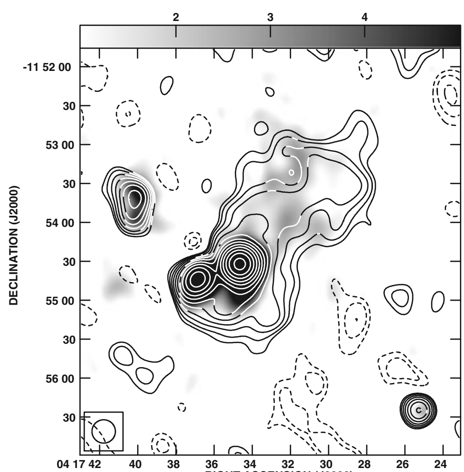

Figure 3. The GMRT 610 MHz image (contours) at $18''$ resolution overlaid on the corresponding 235 MHz image (grey scale) from GMRT. The contours are the same as in Fig. 2. The grey scale ranges from 1 to 5 mJy/beam.

resolution ($\sim 4''$) radio images at 610 MHz. Second, the source to the south-east of the cD galaxy is marginally extended, but, has no optical counterpart in the 2MASS images. Rest of the radio emission in the region of X-ray emission is diffuse. This diffuse radio emission is detected at both 235 and 610 MHz and is clearly elongated along a position angle similar to that of the X-ray emission from the cluster. In the highest resolution ($\sim 4''$) 610 images, this radio emission is completely resolved out and there are no unresolved sources. The radio emission appears confined by the X-ray gas as has been observed in many other clusters. The diffuse radio emission has no optical counterparts in the 2MASS images and is due to the synchrotron radiation from relativistic electrons in the magnetic field of the intracluster medium (the radio halo). The total flux density of the diffuse emission was estimated after subtracting the two radio sources mentioned earlier. The radio power of the halo at 1.4 GHz is $\sim 1.3 \times 10^{25}$ W Hz^{-1}. By modeling the halo as a cylinder of 1×0.3 Mpc^2, the equipartition field obtained is ~ 0.7 μG. The time scale for synchrotron and inverse Compton losses (corresponding to an equivalent CMB field of 6.7 μG) is $\sim$24 million years. Based on the temperature estimates from X-ray observations the estimated sound crossing time is $\sim$800 million years. So, the diffuse radio emission is from a relatively young plasma. Detection of a giant radio halo in a merging cluster is consistent with the currently prevailing scenario wherein turbulence generated in cluster mergers accelerate relativistic electrons to produce cluster-wide diffuse radio emission (Brunetti *et al*. 2009). A more detailed discussion will appear in a forthcoming publication.

Acknowledgements

We thank the staff of the GMRT who have made these observations possible. The GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research.

References

Brunetti, G., Cassano, R., Dolag, K., Setti, G. 2009, *Astron. Astrophys.*, **507**, 661.

Ebeling, H., Edge, A. C., Mantz, A., Barrett, E., Henry, J. Patrick, Ma, C. J., van Speybroeck, L. 2010, *Mon. Not. R. Astron. Soc.*, **407**, 83.

Venturi, T., Giacintucci, S., Dallacasa, D., Cassano, R., Brunetti, G., Bardelli, S., Setti, G. 2008, *Astron. Astrophys.*, **484**, 327.