Radio observations of Planck clusters

Ruta Kale\textsuperscript{1,2,*}

\textsuperscript{1} INAF – Istituto di Radioastronomia, via Gobetti 101, 40129 Bologna, Italy
\textsuperscript{2} Dipartimento di Astronomia, Universita di Bologna, via Ranzani 1, 40126 Bologna, Italy

Received August 2012, accepted September 2012

Key words cosmology: cosmic microwave background – galaxies: clusters: general – acceleration of particles – radio continuum: general – radiation mechanism: non-thermal

Recently, a number of new galaxy clusters have been detected by the ESA-Planck satellite, the South Pole Telescope and the Atacama Cosmology Telescope using the Sunyaev-Zel’dovich effect. Several of the newly detected clusters are massive, merging systems with disturbed morphology in the X-ray surface brightness. Diffuse radio sources in clusters, called giant radio halos and relics, are direct probes of cosmic rays and magnetic fields in the intra-cluster medium. These radio sources are found to occur mainly in massive merging clusters. Thus, the new SZ-discovered clusters are good candidates to search for new radio halos and relics. We have initiated radio observations of the clusters detected by Planck with the Giant Metrewave Radio Telescope. These observations have already led to the detection of a radio halo in PLCKG171.9-40.7, the first giant halo discovered in one of the new Planck clusters.

1 Galaxy cluster surveys

Galaxy clusters are the most massive (masses \( \sim 10^{14} - 10^{15} M_\odot \)) gravitationally bound objects in the present Universe, with dark matter dominating the gravity. The baryonic matter in clusters consists of hot (\( 10^7 - 10^8 \) K) intracluster medium (ICM) and galaxies. Large surveys in optical and X-ray bands have resulted in discoveries of thousands of clusters (eg. Abell et al 1980; Bohringer et al 2004). These surveys rely on the surface brightness of the emission from stars in the galaxies (optical band) and on the thermal X-ray emission from the ICM for the detections of clusters. These result in ‘flux-limited’ catalogues of sources. Another signal that is used to detect clusters is the thermal Sunyaev Zel’dovich effect (SZ) - the spectral distortion of Cosmic Microwave Background (CMB) caused by inverse Compton scattering with the ICM (Sunyaev and Zel’dovich 1972). This signal is independent of redshift and the integrated thermal SZ effect is expected to trace cluster mass with low scatter (eg. Motl et al 2005). Thus SZ cluster surveys deliver mass limited catalogues to arbitrarily high redshift. Currently the South Pole Telescope (SPT, Carlstrom et al 2009), Atacama Cosmology Telescope (ACT, Fowler et al 2007) and Planck Satellite (Planck collaboration 2011d) are surveying the sky in mm-waves to detect clusters using the SZ signal.

There are a number of clusters discovered by these telescopes that have been confirmed by deep X-ray and optical observations. Notably, the Planck collaboration has published confirmation of 51 new galaxy clusters (Planck collaboration 2011a, 2011b, 2011c, 2012a, 2012b). The validation of the cluster candidates was carried out by snapshot observations in X-rays with the XMM \textit{Newton}. These newly discovered clusters were earlier missed by the blind all sky X-ray surveys such as with the ROSAT due to their low surface brightness. This is evident from the fact that the new clusters have flat electron density profiles (Planck collaboration 2011a) as compared to the clusters that were detected in surveys by the ROSAT. Thus apart from being massive, the newly discovered clusters using the SZ are likely to be merging systems with disturbed ICM.

2 Radio observations of clusters

Radio observations are the main probes of non-thermal activities in galaxy clusters. They lead to discoveries of radio galaxies related to active galactic nuclei (AGN), starburst galaxies and radio halos and relics in and around galaxy clusters. Knowledge of radio galaxies and starburst galaxies in galaxy clusters is important for learning about the accretion and feedback which are fundamental to understand the state of the ICM. It is now well-known that, with the thermal ICM are mixed a population of relativistic particles (Lorentz factors > 1000) and magnetic fields (\( \sim 0.1 - 1 \) \( \mu \)G). Radio halos and relics are diffuse radio sources associated with the relativistic electrons and magnetic fields in the ICM on \( \sim \) Mpc scales.

Radio halos are \( \sim \) Mpc size radio sources that are typically located at cluster centers, cospatial with the X-ray emission. They are possibly related to the turbulence in the ICM injected by cluster mergers (eg. Brunetti et al 2004) or to the amplified magnetic fields due to merger (eg. Kesket 2010). The secondary electron models are also being considered, though have found less observational evidence (eg.
Blasi & Colafrancesco 1999, Pfrommer & Enßlin 2004, Kesher & Loeb 2010). Arc-like radio relics located toward peripheries of clusters are believed to be accelerated plasma at merger-shocks (eg. Ensslin et al 1998).

The known radio halos and arc-like relics in clusters are hosted by clusters that show signatures of mergers such as disturbed X-ray morphologies (Cassano et al 2010). Therefore, the newly detected clusters in SZ surveys are promising targets for searching radio halos and relics. Even among those that are not new but are among the strong detections of Planck are massive clusters. Since some of these clusters do not have high resolution X-ray observations currently, the signatures of merger are not established. There is also evidence that radio halos occur in massive, X-ray luminous and hot galaxy clusters (see Feretti et al 2012 for a review and references therein). Thus, the Planck detected clusters and in general those detected using the SZ signal are likely to host radio halos and relics.

Majority of the observational studies of radio halos and relics have been carried out at 1.4 GHz band in which the VLA in its compact configurations (C and D) offered the best sensitivity. Radio halos and relics typically have synchrotron spectra with spectral indices $\alpha \sim -1.1$ to $-1.5$ ($S \propto \nu^{\alpha}$) – steeper as compared to standard radio galaxies ($\alpha \sim -0.8$). The $\sim$ Mpc extents imply angular sizes of a few to several tens of arcminutes in nearby ($z \sim 0.4 – 0.02$) clusters. These characteristics make them suitable for low frequency ($< \text{GHz}$) observations. In recent times, the Giant Metrewave Radio Telescope (GMRT) has proved to be an efficient instrument with its low frequency (150 – 610 MHz) capabilities for studying radio halos and relics (eg. Venturi et al 2007, 2008; Brunetti et al 2008; Giacintucci et al 2008; Macario et al 2010; Kale & Dwarkanath 2010, 2012).

### 3 GMRT observations of Planck clusters

We have initiated a radio observations of galaxy clusters selected from the SPT sample (Williamson et al. 2011) with the Australia Telescop Compact Array and the Planck Early SZ (ESZ) catalogue (Planck collaboration 2011a) with the GMRT. In this paper we discuss our work on the clusters selected from the ESZ.

The clusters detected in the ESZ catalogue were examined in the NRAO VLA Sky Survey (NVSS). The NVSS (Condon et al 1998) is a survey at 1.4 GHz with the VLA in D configuration of all the sky north of declination $-40^\circ$. It is sensitive to extended emission of the size of up to 15'. Several of the presently known radio halos and relics have been discovered from the NVSS (eg. Giovannini, Tordi & Feretti 1999; Bagchi et al 2006). All the clusters that showed the presence of extended sources of size $\geq 500$ kpc were proposed for observation with the GMRT to confirm the nature of the extended emission (Table 1). As an example, we show here the NVSS map of the cluster PLCKG200.9-28.2 (Fig. 1). The elongated source at the southern edge of the X-ray emission does not have any obvious optical counterpart. Its location at the edge of the cluster, along the same direction as the elongation in the X-ray distribution makes it a promising candidate for a radio relic.

GMRT observations of 8 clusters were carried out in Cycle 21 (Oct. – Nov. 2011) in the dual frequency band (610, 235 MHz) and of PLCKG200.9-28.2 will be carried out in Cycle 23 (Table 1). The clusters selected for GMRT observations span a redshift range of 0.06 to 0.55. To detect extended structures of $\sim 1$ Mpc extents at these redshifts, a telescope with a capability of detecting angular scales $\sim 15' – 3'$ is required. In addition, sufficient resolution to separate point sources from the extended emission is needed. The GMRT antennas are distributed in a hybrid configuration that consists of a central compact array and an extended Y-shaped array. At 610 and 235 MHz, it is possible to image angular scales up to $\sim 17'$ and $\sim 44'$, respectively. The highest possible resolutions at 610 and 235 MHz are $\sim 5''$ and $\sim 13''$ (FWHM), respectively. With $\sim 5$ hr observation of each field, sensitivities of $50 – 80$ $\mu$Jy beam$^{-1}$ at 610 MHz and 0.2 – 0.4 mJy beam$^{-1}$ are expected to be achieved.

The first outcome from these GMRT observations was the detection of a new giant radio halo in the cluster PLCKG171.9-40.7 (Plck171, hereafter) (Giacintucci et al 2012, submitted).

### 4 A radio halo in Plck171

The cluster Plck171 is a newly detected cluster with the Planck and confirmed with the XMM Newton. It is located at RA 03h12m57.4s DEC +08d22m10s (J2000). It has a redshift of 0.27 and X-ray luminosity (0.1 – 2.4 keV) of $1.13 \times 10^{45}$ erg s$^{-1}$ (Planck collaboration 2011a). The analysis of XMM Newton data shows that the X-ray surface brightness is elongated in the northwest-southeast direction (Fig. 2, colour). The temperature of the cluster is estimated to be $\sim 10$ keV. The X-ray morphology and temperature of the cluster suggest a merger in Plck171.

---

**Table 1** Candidates among the Planck clusters

| Cluster name | $z$   | Planck $S/N$ |
|--------------|-------|--------------|
| Abell 1795   | 0.0622| 12.4         |
| Abell 0478   | 0.0882| 12.8         |
| Abell 2302   | 0.1790| 6.5          |
| PLCKG171.94-40.65 | 0.2700| 10.6        |
| H1821+643    | 0.2990| 6.9          |
| MACS J1731.6+2252 | 0.3890| 7.3         |
| RXCJ1206.2-0848 | 0.4414| 7.3         |
| MACS J149.5+2223 | 0.5450| 7.1         |
| PLCKG200.9-28.2 | 0.22  | 5.2         |

Note: The Planck signal to noise is reported from Planck collaboration 2011a, 2012a.
Fig. 1 Plck200: Smoothed XMM Newton image (HEASARC) shown in colour with contours of NVSS (-1, 1, 2, 4, 8, 16, 32, 64 mJy beam\(^{-1}\)) overlaid. The horizontal segment denotes a distance of 1 Mpc at the redshift of Plck200. The elongated source located south of the X-ray emission is the suspected radio relic.

The radio halo suspected from the NVSS images was confirmed with the GMRT 235 MHz observations (Fig. 2, contours) and a re-analysis of the NVSS data. The radio halo has a size of \(\sim 1\) Mpc, typical of giant radio halos (eg. Feretti et al 2012).

5 Discussion

The discovery of new galaxy clusters with the SZ-effect shows that X-ray telescopes are not sufficient to trace all the galaxy clusters. These newly detected clusters affect the statistical studies that are based on samples of galaxy clusters selected from X-ray flux limited catalogues. We illustrate this point using the cluster Plck171. The cluster Plck171 is in the redshift and X-ray luminosity range in which the GMRT Radio Halo Survey (GRHS: Venturi et al 2007, 2008) was carried out. The discovery of Plck 171 itself and further of the radio halo can bias the statistics of the occurrence of radio halos obtained from X-ray-selected cluster samples such as the GRHS. We will investigate this using the results obtained on the nine clusters listed here.

Correlations between the radio power of radio halo and cluster parameters such as X-ray luminosity, temperature and mass have been explored to find the clues to the origin of radio halos. In the X-ray luminosity \(L_x\) and radio power at 1.4 GHz \(P_{1.4GHz}\) plane, the clusters with radio halos and those without are well separated (Brunetti et al 2009). The clusters with radio halos also follow a scaling of radio power with X-ray luminosity (eg. Cassano et al 2008). Recently, a correlation between the integrated SZ signal \(Y\) from the cluster and \(P_{1.4GHz}\) has been reported (Basu 2011). The scaling relations imply a connection between the thermal and non-thermal components in the clusters, if found significant over a large range of parameters. The cluster Plck171 follows both, the \(L_x - P_{1.4GHz}\) and the \(Y - P_{1.4GHz}\) correlations (Giacintucci et al 2012, submitted).

In general, a large number of clusters need to be surveyed in order to establish the statistical significance of the empirical correlations. With the present observing capabilities, sensitive radio surveys of galaxy clusters take long periods to reach completion. In future, surveys with instruments such as the LOFAR (www.lofar.org) and LWA (http://www.phys.unm.edu/~lwa/index.html) are expected to deliver sensitive images of the sky at low frequencies (20 - 200 MHz). With the availability of large statistical samples of galaxy clusters that are radio surveyed, it will be possible to study the implications of the scaling relations and test the present theoretical models.

6 Summary

Radio observations of Planck clusters, especially at low frequencies (\(\leq 1.4\) GHz), are interesting to detect new radio halos and relics. Planck detected clusters that have possible diffuse radio emission in the NVSS images are being observed with the GMRT at 610 and 235 MHz. Eight clusters have already been observed and one more, with a suspected relic, will be observed. Detection of a new radio halo in the cluster Plck171 is the first result from these observations. The analysis of data on other clusters is ongoing. The results will be used to study the impact of these clusters on the known statistical properties of radio halos and relics based on X-ray selected cluster samples.

Acknowledgements. We thank the anonymous referee for comments. RK thanks S. Giacintucci and M. Markevitch for help during the preparation of this paper. We thank the staff of the GMRT for their help during the observations. GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research has made use of data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA’s Goddard Space Flight Center.
Fig. 2 GMRT 235 MHz image of the radio halo (contours) overlaid on XMM Newton X-ray image (Giacintucci et al. 2012, submitted). The ′+′ symbols denote the locations of discrete radio sources from the 610 MHz map. These sources have been subtracted from the 235 MHz image.

References

Abell, G. O. et al.: 1989, ApJS, 70, 1
Bagchi, J. et al.: 2006, Science, 314, 791
Basu, K.: 2012, MNRAS, 421, L112
Blasi, P., & Colafrancesco, S.: 1999, APh, 12, 169
Bohringer et al.: 2004, A&A, 425, 367
Brunetti, G.: 2004, JKAS, 37, 493
Brunetti, G. et al.: 2008, Nature, 455, 944
Brunetti, G.: 2009, A&A, 507, 661
Brunetti, G.: 2011, JApA, 32, 437
Cassano, R. et al.: 2008, A&A, 480, 687
Cassano et al.: 2010, ApJ, 721, 82
Carlstrom, J. E., et al.: 2009, arXiv:0907.4445
Condon, J. J. et al.: 1998, AJ, 115, 1693
Ensslin, T. et al.: 1998, A&A, 332, 395
Feretti, L. et al.: 2012, A&ARv, 20, 54
Fowler, J. W., et al.: 2007, Appl. Opt., 46, 3444
Giacintucci, S. et al.: 2008, A&A, 486, 347
Giacintucci, S. et al.: 2012, submitted
Giovannini, G. et al.: 1999, NewAR, 4, 141
Kale, R. & Dwarakanath, K. S.: 2010, ApJ, 718, 939
Kale, R. & Dwarakanath, K. S.: 2012, ApJ, 744, 46
Keshet, U.: 2010, arXiv:1011.0729
Keshet, U., & Loeb, A.: 2010, ApJ, 722, 737
Macario, G. et al.: 2010, A&A, 517, 43
Motl, P. M. et al.: 2005, ApJ, 623, 63
Nagai, D.: 2006, ApJ, 650, 538
Pfrommer, C., & Enßlin, T. A.: 2004, JKAS, 37, 455
Planck collaboration: 2012b, arXiv:1204.2743
Planck collaboration: 2012a, A&A, 543, 102
Planck collaboration: 2012b, arxiv1205.3376
Planck collaboration: 2011a, A&A, 536, 8
Planck collaboration: 2011b, A&A, 536, 26

Planck collaboration: 2011c, A&A, 536, 9
Planck collaboration: 2011d, A&A, 536, 1
Sunyaev, R. A., & Zel’dovich, Y. B.: 1972, Comments on Astrophysics and Space Physics, 4, 173
Venturi, T. et al.: 2008, A&A, 484, 327
Venturi, T. et al.: 2007, A&A, 463, 937
Williamson et al.: 2011, ApJ, 738, 139