A CLUSTER PAIR: A3532 AND A3530

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ABSTRACT

We present a detailed study of a close pair of clusters of galaxies, A3532 and A3530, and their environments. The Chandra X-ray image of A3532 reveals the presence of substructures on scales of ∼20′′ in its core. XMM-Newton maps of the clusters show excess X-ray emission from an overlapping region between them. Spectrally determined projected temperature and entropy maps do not show any signs of cluster scale mergers either in the overlapping region or in any of the clusters. In A3532, however, some signs of the presence of galaxy scale mergers are visible, e.g., anisotropic temperature variations in the projected thermodynamic maps, a wide-angle-tailed (WAT) radio source in the brighter nucleus of its dumbbell brightest cluster galaxy, and a candidate X-ray cavity coincident with the northwestern extension of the WAT source in the low-frequency radio observations. The northwestern extension in A3532 seems either a part of the WAT or an unrelated diffuse source in A3532 or in the background. There is an indication that the cool core in A3532 has been disrupted by the central activity of the galactic nucleus. A reanalysis of the redshift data reinforces the close proximity of the clusters. The excess emission in the overlapping region appears to be a result of tidal interactions as the two clusters approach each other for the first time. However, we cannot rule out the possibility of the excess being due to the chance superposition of their X-ray halos.

Key words: galaxies: clusters: general – galaxies: clusters: individual (A3532, A3530) – galaxies: clusters: intracluster medium – radio continuum: galaxies – X-rays: galaxies: clusters

Online-only material: color figures

1. INTRODUCTION

Clusters of galaxies are believed to form hierarchically by the merger of smaller groups and clusters. Major cluster mergers, which are believed to be the most energetic events in the universe (Sarazin 2002), involve two clusters of similar masses (Planelles & Quilis 2009). Many clusters are often found to form large concentrations, called superclusters (Shapley 1933), which are the largest (size ∼10–100 Mpc) systems of galaxies known to us (Vogeley et al. 1994). Rich superclusters are also appropriate systems for studying major cluster mergers. The galaxy number density in superclusters is ∼10 times that in the field on length scales of ∼10−20 h−1 Mpc (Bardelli et al. 2000). This results in high peculiar velocities of the galaxies in superclusters, which increases the probability of cluster–cluster collisions (Bardelli et al. 2001). One such example of a rich supercluster environment is the central region of the Shapley Supercluster (SSC). Raychaudhury et al. (1991), by using X-ray observations from Einstein Observatory and EXOSAT, and optical data from Automatic Plate Measuring facility at Cambridge, studied 17 clusters from the core region of the SSC. The X-ray data showed an exceptionally high density of rich clusters (∼10−50) and multiple X-ray peaks in most of the clusters belonging to this region. By using the optical data they estimated an exceptionally large mass (between 1.4 × 1016 and 1.6 × 1017 h−1 M⊙) for the “core” region (diameter 74 h−1 Mpc) of the SSC. The optical data also revealed a large deviation from the Hubble flow within the SSC which suggested that it might be a nearby bound system. By using the X-ray observations from the ROSAT All Sky Survey, de Filippis et al. (2005) discovered 14 new cluster candidates, and also observed that the overdensity of clusters in the SSC outskirts is mainly due to an excess of low X-ray luminosity clusters. This led to a suggestion that the whole region is still accreting small clusters with low luminosities from the outskirts (de Filippis et al. 2005).

The SSC hosts two major cluster complexes dominated by A3558 and A3528. This concentration of clusters is a rich system for observing cluster mergers at various evolutionary stages (Bardelli et al. 2001). The A3558 complex comprises three rich clusters of galaxies, viz., A3556, A3558, and A3562, and several other poor clusters and groups, while the A3528 complex is formed by the galaxy clusters A3528, A3532, and A3530. The properties of the A3558 complex have been extensively studied using multiwavelength studies (optical: Bardelli et al. 1994, 1998a, 1998b; radio: Venturi et al. 1997, 1998, 2000; X-ray: Bardelli et al. 1996; Ettori et al. 2000). The less well-studied A3528 cluster complex has a mean redshift of z = 0.0535 and is elongated in the north–south direction. Using ROSAT Position Sensitive Proportional Counter (PSPC) observations, Schindler (1996) found that A3528 is a double cluster comprising A3528N and A3528S. Using a redshift survey of galaxies, Bardelli et al. (2001) detected substructures in the A3528 complex by using the non-parametric and scale-independent DEDICA method (Pisani 1993, 1996) in both bi-dimensional and three-dimensional (3D) samples. From the bi-dimensional sample the cluster A3528 was found to contain a total of ten groups, two of which appear to be associated with A3528N and A3528S. From the 3D sample, the A3532–A3530 system was found to contain five groups, out of which two seem to be associated with A3530 and A3532, while two others are found at the intersection of the Abell radii of the two clusters, with a mean velocity in agreement with the main components. The cluster complex has been studied in the radio by Venturi et al. (2001) using 13 cm and 22 cm observations carried out with the Australia Telescope Compact Array (ATCA). Mauduit & Mamon (2007) studied the radio continuum emission from galaxies in the SSC core.
region and found that the galaxies in the A3528 complex are marginally more radio luminous than elsewhere, contrary to what is observed in the neighboring A3558 cluster complex, where the galaxies have lower radio luminosity and radio loudness compared to the field galaxies. They have attributed the decrease in the radio loudness in the A3558 cluster to starvation of the active galactic nucleus (AGN) in them, and reduced star formation activity due to the enhanced ram pressure stripping in merging clusters. The lack of decrease in the radio loudness for the A3528 cluster complex is, therefore, probably because in this region the clusters are approaching for the first time (Mauduit & Mamon 2007). In this paper, we present a detailed study of the environments, interactions, and internal dynamics of the two less well-studied clusters of galaxies, viz., A3530 and A3532, from the A3528 cluster complex, using mainly radio and X-ray observations.

The paper is organized as follows. Detailed information about the two clusters and a summary of their previous X-ray, radio, and optical observations are given in Section 2. Details of the X-ray and radio observations used here, along with the data reduction, are presented in Section 3. The X-ray, optical, and radio morphologies of the clusters are described in Section 4.1. Results from the global spectral analyses and the X-ray luminosity estimates are provided in Sections 4.2 and 4.3, respectively. Results from the azimuthally averaged (projected and deprojected) spectral analyses and the two-dimensional (2D) projected thermodynamic maps of the clusters are described in Sections 4.4 and 4.5, respectively. The estimates of the cooling time, gas mass, and virial mass for the two clusters are given in Sections 4.6, 4.7, and 4.8, respectively. A discussion based on the results is in Section 5. A lambda cold dark matter cosmology with $\Omega_M = 0.3$ ($\Omega_\Lambda = 0.7$) has been assumed throughout.

2. THE A3530–A3532 SYSTEM

Both A3532 and A3530 are regular clusters of richness class 0, with 36 and 34 member galaxies, respectively (Abell et al. 1989). The positional coordinates (R.A.(J2000), decl.(J2000)) of A3532 are 12h57m19s, 767:91 (22pp), and A3530 are 12h55m36s, 767:91 (22pp), respectively. Note that Ikebe et al. have provided the temperature values of the hot components only, as these are the temperatures of the main extended emission components of the clusters and, therefore, are good measures of the virial temperatures of the clusters (Ikebe et al. 2002). A comparison of the values obtained by Ikebe et al. with those obtained from our analysis has been made in Table 3.

By using ASCA and ROSAT observations, Chen et al. (2007) identified both A3532 and A3530 as non-cool core (NCC) clusters with cooling times of $(2.4^{+0.5}_{-0.4}) \times 10^{10}$ and $(5.3^{+0.6}_{-0.7}) \times 10^{10}$ yr, respectively. The virial radii $R_{200}$ of A3532 and A3530, computed by Vincenzi et al. (2011), using their respective velocity dispersions of 621 ± 53 km s$^{-1}$ and 563 ± 52 km s$^{-1}$ (Cava et al. 2009), are 1.50 $h^{-1}_{50}$ Mpc and 1.36 $h^{-1}_{50}$ Mpc, respectively.

A3530 is seen to host a pair of elliptical brightest cluster galaxies (BCGs) at its center (Venturi et al. 2001), whereas A3532 is found to be dominated by a dumbbell system of BCGs at the center (Wirth et al. 1982; Parma et al. 1991; Machacek et al. 2007; Gregorini et al. 1994). Pimbblet (2008) studied a complete sample of dumbbell galaxies in the southern rich clusters listed in Gregorini et al. (1994), and found that while most of the dumbbell BCGs (including that in A3532) have at least one dumbbell component with a significant peculiar velocity, the absence or presence of subclustering in the dumbbell BCG clusters is due to the different stages of post-merger activity.

Clusters of galaxies are found to host a wide variety of radio source morphologies, such as the characteristic wide-angle-tailed (WAT) structure (Owen & Rudnick 1976; Roettiger et al. 1996; Douglass et al. 2008; Mao et al. 2009). Especially, the dumbbell galaxy systems, as seen in A3532, are very often seen to host radio sources in one or both of their members. A WAT radio source is indeed associated with the brighter nucleus of the dumbbell BCG in A3532 in the ATCA 13 cm and 22 cm images (Venturi et al. 2001). Close proximity of the galaxies (∼10–30 $h^{-1}_{70}$ kpc) in the dumbbell systems can dynamically affect the radio jets through gravitational interaction with the confining gas cloud (Wirth et al. 1982). Here, it should be noted that the separation between the dumbbell galaxies in A3532 is only ∼25 $h^{-1}_{70}$ kpc in projection. The radio sources associated with the dumbbells are often found to be different from single galaxy radio sources because of their more distorted (irregular) structures, and flatter radio luminosity functions, indicating a triggering of the radio source in the main galaxy by its close companion (Parma et al. 1991; Gregorini et al. 1994), or alternatively causing an increase in the luminosity of the existing radio source (Parma et al. 1991). The total radio flux densities estimated for the WAT source in A3532 at 13 cm and 22 cm, as reported by Venturi et al. (2001), are 651.7 mJy and 1056.6 mJy (with errors ∼10%–15%), respectively. Combining these with the 6 cm flux density of the source as given in Gregorini et al. (1994), Venturi et al. also computed the spectral index $\alpha \sim 0.85$, for the 6–22 cm wavelength range.
3. OBSERVATIONS AND DATA REDUCTION

The cluster A3532 has been observed with both XMM-Newton and Chandra, whereas A3530 has only been observed using XMM-Newton. A journal of the X-ray observations is given in Table 1. Throughout Sections 3 and 4, we have adopted an average redshift of 0.0554 (Cristiani et al. 1987) for A3532 and 0.0543 (Vettolani et al. 1990) for A3530.

3.1. X-Ray Data

3.1.1. XMM-Newton

A3532 and A3530 were observed with XMM-Newton on 2002 July 3 and 2004 January 15, respectively (see Table 1). For both the observations, the three EPIC cameras MOS1, MOS2, and PN (Strüder et al. 2001), and PN (Strüder et al. 2001) were operated in the full frame mode with the medium filter. The data were obtained from the HEASARC archives.

All data analyses have been done following the standard procedures from the Science Analysis System (SAS) software version 11.0.0. The good time intervals (GTIs), obtained after the initial filtering of the MOS1, MOS2, and PN observations of A3530, are 11.4 ks, 11.5 ks, and 10.2 ks, respectively, while for A3532 the GTIs are 7.4 ks and 7.9 ks for the observations done using MOS1 and MOS2, respectively. The PN observation of the cluster A3532 was strongly affected by soft proton (SP) flares. Only 4.7 ks (of the total exposure time of 16.9 ks) exposure was left after the light curve cleaning, which was still likely to be contaminated with residual SPs. Hence, the PN observations of A3532 were found unusable for the study.

3.1.1.1. Background Treatment. The residual SP contamination, left after the routine temporal filtering was modeled as described in Snowden et al. (2008). The quiescent particle-induced background and the cosmic background component were removed by using the blank-sky observations described in Carter & Read (2007). The blank-sky event files were filtered as described in Lakhchaura et al. (2011). Local background subtraction could not be done for either observation, since the sources fill almost the entire field of view of the detectors and emission-free regions were difficult to find.

3.1.1.2. Point-source Removal and Mosaicking. Point sources were detected and removed using the SAS task cheese. Each of the detected sources was then checked in the MOS detector images of both the clusters and spurious sources (detections that did not look like real sources in the images) were removed. Finally, a total of 26 sources for the cluster A3532 and 12 sources for the cluster A3530 were confirmed. Images and exposure maps were created from the filtered and point-source-removed event files from MOS observations of both the clusters in the energy band 0.3–9 keV. From these, the mosaicked and exposure-corrected image with a pixel bin size of 5′′ was created using the SAS task emosaic. The final contour map of the diffuse X-ray emission after smoothing with a Gaussian kernel of width 35′′ is shown in Figure 1. Note that the galaxy groups found by Bardelli et al. (2001; see Section 1), at the intersections of the Abell radii of A3532 and A3530, have not been covered by either of the two XMM-Newton pointings. An overlay of the X-ray contours (black) superimposed on an optical image of the two clusters from the SuperCOSMOS survey in the B_f band is shown in Figure 2.

Table 1

| Cluster | Satellite | Detector | \(\alpha\) (J2000) | \(\delta\) (J2000) | Observation ID | Date of Observation | Exposure Time |
|---------|-----------|----------|-------------------|-------------------|-----------------|---------------------|--------------|
| A3532   | XMM-Newton| MOS1, MOS2, PN | 12 57 16.85      | −30 22 11.1      | 0030140301     | 2002 Jul 3          | 16.9 ks      |
| A3532   | Chandra   | ACIS-I   | 12 57 21.50       | −30 22 10.0      | 10745          | 2008 Nov 30        | 9.8 ks       |
| A3530   | XMM-Newton| MOS1, MOS2, PN | 12 55 35.87      | −30 19 51.4      | 0201780101     | 2004 Jan 15        | 21.9 ks      |

Figure 1. Combined and contoured image of A3532 and A3530 clusters from the XMM-Newton MOS detectors, smoothed with a Gaussian kernel of width 35′′, as described in Section 3.1.1.2. Contour levels are \(1.25, 1.69, 2.50, 3.75, 5.00, 10.00, 11.25 \times 10^{-8}\) counts s\(^{-1}\) arcsec\(^{-2}\). Positions of the clusters A3532 and A3530, and their overlapping region (OR) are shown. The surface brightness peaks of the two clusters are separated by approximately 1.7 Mpc. The outermost contour is about 3\(\sigma\) level above the neighboring local background. (A color version of this figure is available in the online journal.)
Figure 2. Combined image of the clusters A3532 and A3530 from the SuperCOSMOS survey in the $B_J$ band, overlaid with the X-ray contours (black) from Figure 1 and also with the VLA 20 cm contours (red, contour levels: $-0.3, 0.3, 0.6, 1.2, 2.4, 4.8, 9.6, 19.2, \text{ and } 38.4 \text{ mJy beam}^{-1}$). (A color version of this figure is available in the online journal.)

Figure 3. Exposure-corrected Chandra ACIS image of the A3532 cluster in the 0.3–7.0 keV band (after point-source removal and smoothing with a Gaussian kernel of width 8″). The overlaid X-ray emission contours (black) are linearly distributed between $1 \times 10^{-7}$ and $9 \times 10^{-7}$ counts cm$^{-2}$ s$^{-1}$ pixel$^{-1}$. (A color version of this figure is available in the online journal.)

3.1.2. Chandra

A3532 was observed with Chandra on 2009 December 2 with ACIS-I detector for 9.8 ks (Table 1). For the analysis of Chandra data, we have used CIAO version 4.3 and CALDB version 4.4.0. The data were reprocessed using the CIAO script $\text{chandra repro}$. For all the GTIs, no significant flaring was seen in the light curves. Point sources were detected using the CIAO task $\text{celldetect}$, which were then checked by comparing them with those detected with XMM-Newton and with the ones seen in the optical image (Figure 2). The confirmed point sources were then removed from both the image and the event files and the holes created in the image were filled with values equal to the average counts in their immediately surrounding pixels, using the CIAO task $\text{dmfilth}$. The image was then exposure corrected and smoothed using a Gaussian kernel of width 8″. The resultant image is shown in Figure 3.

3.2. Radio Data

We have analyzed archival data from pointed observations of A3532 with the ATCA, the Giant Metrewave Radio Telescope (GMRT), and the Very Large Array (VLA). In addition to the pointed observations, we have used survey data from the TIFR (Tata Institute of Fundamental Research) GMRT Sky Survey (TGSS), the NRAO (National Radio Astronomy Observatory) VLA Sky Survey (NVSS), the Sydney University Molonglo Sky...
Survey (SUMSS), the Molonglo cross telescope, and the VLA Low-frequency Sky Survey (VLSS). All details of the radio observations are given in Table 2.

The ATCA observations were made simultaneously at 1380 and 2378 MHz in multiple-cut mode. The primary flux density calibrator was B1934–638 and the phase calibrator was B1308–220. Data reduction was carried out in MIRIAD (Sault et al. 1995) using standard techniques. The GMRT observation at 614 MHz was made with 3C286 as primary flux density calibrator and J1311 −42.30 as phase calibrator. The VLA observations were made with two intermediate frequencies, bandwidths of 50 MHz, and center frequencies of 1490 MHz and 4860 MHz. The primary flux density calibrator for both VLA observations was 3C286, and the phase calibrators were B1245−197 and B1255−316. The GMRT and VLA data were both processed using the NRAO Astronomical Image Processing System software and standard procedures. Figures 4(a)–(g) show the radio images produced from the VLA 20 cm, ATCA 13 cm, GMRT 50 cm, VLA 6 cm, TGSS 2 m, VLSS 4 m, and SUMSS 36 cm observations, respectively.

4. ANALYSIS AND RESULTS

4.1. X-Ray, Optical, and Radio Maps

The smoothed and point-source-removed X-ray image of the two clusters A3530 and A3532 from the XMM-Newton MOS (MOS1 + MOS2) detectors (Section 3.1.1.2, Figure 1) shows that the X-ray emission from A3532 fills the entire field of view and is slightly elliptical with the major axis oriented along the NE−SW direction (∼45° to the north). X-ray emission from A3530 is much less extended but much more elongated along the NW−SE direction (∼52° to the north). The X-ray contours in the inner parts of A3532 seem to be compressed toward the NE and stretched out toward the SW, and those of A3530 seem to be stretched out toward the SE. The projected separation between the X-ray peaks of the two clusters is ∼26.5′, which, at their average redshift, corresponds to a linear projected separation of ∼1.7 Mpc. The X-ray contours of the two clusters overlap in a region common to both clusters (marked in Figure 1), where they may be tidally interacting with each other. Like XMM-Newton, the Chandra image of A3532 also shows an elongation of the X-ray emission in the NE−SW direction with the X-ray contours stretching out more toward the SW than in the NE direction (Figure 3). The inner parts of the Chandra image show very disturbed morphology with multiple peaks and subpeaks. This is discussed in detail in Section 4.9.

The overlay of the X-ray contours on the optical image of the two clusters from the SuperCOSMOS survey in the B_j band is shown in Figure 2. It can be seen that the X-ray emission peaks of both clusters coincide with the positions of their respective BCGs. The 20 cm radio contours (red) in Figure 2 show a “C”-shaped WAT source at the center of A3532, coincident with the position of the brighter nucleus of its dumbbell BCG. In Figure 4, the WAT source is seen at all the radio wavelengths with sufficient angular resolution. The projected radio emission of the WAT galaxy is aligned in the NW−SE direction, i.e., approximately orthogonal to the major axis of the X-ray emission. The structure of the WAT is complicated somewhat by our viewing angle. It comprises two hot spots (locations of enhanced radio emission caused by the sudden slowing of the relativistic electrons as they emerge from the host galaxy into the intracluster medium, ICM) “H1” and “H2”, and two closely aligned tails “T1” and “T2” (Figure 4(a)), trailing back from the hot spots. The GMRT 50 cm, TGSS 2 m, and SUMSS 36 cm images (Figures 4(c), (e), and (g), respectively) show an extension of the radio emission in the northwest direction. The VLSS observation also shows some emission in this part of the WAT but it is not well resolved.

In Figures 4(a)–(c), the tails of the WAT source appear to be very closely aligned and seem to eventually merge with each other. This makes the apparent morphology of the source intermediate to that of a WAT and a narrow-angle-tailed (NAT) source. However, the NAT sources are usually associated with galaxies found at the cluster peripheries with their tails highly bent as a result of very high velocity (∼ a few thousand km s$^{-1}$) motions of the host galaxies through the relatively stationary ICM (Jones & Owen 1979; Klamer et al. 2004; Mao et al. 2009). On the other hand, the dominant cluster galaxies with which the WAT sources (like the one in A3532) are associated do not have peculiar velocities more than a few hundred km s$^{-1}$ and, therefore, the ram pressure due to the galaxy’s motion is not very high (Burns 1981; Eilek et al. 1984; O’Donoghue et al.

### Table 2

| Observation | Wavelength (m) | Beam Size (arcsec) | Position Angle | Array Configuration | Date of Observation | rms (mJy beam$^{-1}$) | Flux Density (Jy) | Reference |
|-------------|----------------|--------------------|----------------|---------------------|---------------------|----------------------|------------------|------------|
| VLA         | 0.06           | 13′37″ × 9′56″      | −54.49         | VLA-DnC             | 1991 Feb 5          | 0.035                | 0.36 ± 0.02      | P          |
| ATCA        | 0.13           | 6′28″ × 4′08″       | −0.26          | 6C                  | 1994 Mar 15         | 0.3                  | 0.69 ± 0.03      | P          |
| VLA         | 0.20           | 4′87″ × 2′91″       | −52.73         | VLA-BnA             | 1990 Jul 9          | 0.12                 | 1.05 ± 0.05      | P          |
| VLA (NVSS)  | 0.21           | 45′ × 45′           | 0              | ...                 | 1.93                | 0.48                 | 1.16 ± 0.04      | 1          |
| ATCA        | 0.22           | 10′72″ × 6′45″      | 0.02           | 6C                  | 1994 Mar 15         | 0.4                  | 1.06 ± 0.05      | P          |
| MOST (SUMSS)| 0.36           | 85′ × 45′           | 0.0            | ...                 | 1.8                 | 1.78 ± 0.05         | 2              |
| GMRT        | 0.50           | 7′45″ × 4′62″       | 28.90          | 2004 Apr 4          | 0.13                | 1.9 ± 0.3          | P              |
| Molonglo Cross (MRC)| 0.74 | 2′87″ × 2′62″ | 0.0 | ... | 50 | 3.03 ± 0.08 | 3 |
| GMRT (TGSS) | 2.0            | 24′ × 15′           | 30             | ...                 | 23                  | 8.7 ± 2.2          | P              |
| VLA (VLSS)  | 4.0            | 58′8″ × 36′2″       | −47.9          | ...                 | 102                 | 11.7 ± 1.2         | 5              |

Notes. (a) Errors of ~5% have been assumed for both the ATCA observations, the VLA 1.49 and 4.86 GHz observations. For the GMRT TGSS and 508 MHz observations errors of ~25% and ~15% have been assumed, respectively. (b) For the ATCA observations, the pointing center (R.A. (J2000), decl. (J2000)) was 12h57m20s, −30°23′44″ (J2000), the bandwidth was 128 MHz, and the total integration time was approximately 2 hr. For the GMRT observations, the pointing center for the observation was 12h57m30s, −30°30′ (J2000), the bandwidth was 16 MHz, and the total integration time was about 2 hr 12 minutes. For the VLA L-band and C-band observations, the pointing centers were 12h57m13s, −30°21′51″64 and 12h57m21′99, −30°21′47′42, and the total integration times were ~25 minutes and ~15 minutes, respectively. The bandwidth for both observations was 50 MHz.

References. (P) Present paper; (1) Condon et al. 1998; (2) Mauch et al. 2003; (3) Large et al. 1981; (4) TGSS Data Products; (5) Cohen et al. 2007.
Figure 4. Contoured radio images of the WAT source in A3532 from (a) VLA 20 cm, (b) ATCA 13 cm, (c) GMRT 50 cm, (d) VLA 6 cm, (e) TGSS 2 m, and (f) VLSS 4 m observations, with the contour levels starting at 0.3, 1, 1.5, 0.2, 50, and 300 mJy beam$^{-1}$, respectively, and increasing by factors of two. (g) The contoured image of the WAT source from SUMSS 36 cm observation, with contour levels starting at 12 mJy beam$^{-1}$ and increasing by factors of $\sqrt{2}$. The images have been arranged in increasing order of beam sizes. The hot spots “H1” and “H2”, and tails “T1” and “T2” of the WAT source, are marked in (a).

(A color version of this figure is available in the online journal.)
It is also quite unlikely that the ram pressure from the ICM (resulting from the motions induced by the galaxy scale mergers), which is generally responsible for the bent tails of the WAT sources (Eilek et al. 1984; Burns et al. 1994; Roettiger et al. 1990). It is also quite unlikely that the ram pressure from the ICM (resulting from the motions induced by the galaxy scale mergers), which is generally responsible for the bent tails of the WAT sources (Eilek et al. 1984; Burns et al. 1994; Roettiger et al. 1990), could lead to the observed alignment of the WAT tails in A3532. Considering these facts, a likely interpretation is that the plane of the WAT is aligned at a small angle to our line of sight and the observed close alignment of the tails is due to the projection effects.

The northwestern extension of the radio emission is only seen at the lowest frequencies. Figure 5 shows the GMRT 50 cm, TGSS 2 m, and SUMSS 36 cm contours overlaid on the optical image of A3532. The northwestern extensions seen in the three sets of contours seem to coincide, strengthening the reality of the feature. However, the exact shapes and extents of these extensions do not match, mostly due to the different beam sizes. It should also be noted that in the TGSS survey observation, each source is observed for a very short duration of time (∼3.5 minutes) and therefore the final image may have certain artifacts. The extension does not seem to have an optical counterpart, therefore it may either be a part of the WAT radio emission or a diffuse source unrelated to the WAT, e.g., a radio relic in the cluster or a background source. Using the flux density estimates obtained from the GMRT 50 cm, TGSS, and SUMSS observations, the extension is found to have a steep spectrum with a power-law spectral index, $\alpha \sim -2$. Deeper and high-resolution radio observations at lower frequencies will be required to make a detailed study of the morphology and spectral properties of the extension.

The estimated rms and flux densities of the full WAT source obtained from observations at various frequencies are given in Table 2. The spectrum of the WAT source (as shown in Figure 6) is consistent with a single power law with a spectral index $\alpha$ of $-0.88 \pm 0.02$ ($S_\nu \propto \nu^{\alpha}$). The flux density of the WAT source obtained from the 50 cm GMRT observation seems to be a bit low, even after correcting for the primary beam pattern using the standard GMRT values. In this archival data set, the source was observed about 15′ away from the phase center, and this along with the low declination of the source accounts for the large flux density error of ∼15%. Also, the 20 cm flux densities obtained from the VLA and ATCA seem to be slightly low, compared with that from the NVSS, possibly as a result of missing flux in high-resolution images.

### 4.2. Global X-Ray Spectra

We extracted XMM-Newton spectra averaged over the cluster sizes for each of the clusters A3532 and A3530, and for the overlapping region (OR) between them. For A3532 and A3530, spectra were extracted from circular regions (radii ∼9.6 and 7.9, respectively) centered on their respective X-ray emission peaks. For the OR the spectra were extracted from a small elliptical region, common to both A3530 and A3532. For A3532, spectra from Chandra were also extracted. As Chandra did not cover the full circular region that was used to extract the XMM-Newton spectra of A3532, a polygon-shaped approximation to the circular region was made to extract the Chandra spectrum. For this spectrum, an emission-free region near the cluster was used for extracting the background spectrum. The extraction of the background spectrum for the XMM-Newton observations is described in Section 3.1.1.1.

The X-ray spectral fitting package XSPEC (version 12.5.1) was used for all the spectral analyses. All spectra were fitted in the energy band 0.5–8.0 keV. The neutral hydrogen column densities along the line of sight to A3532 and A3530 were fixed to be $6.47 \times 10^{20}$ cm$^{-2}$ and $6.24 \times 10^{20}$ cm$^{-2}$, respectively, based on Leiden/Argentine/Bonn Galactic H$\text{I}$ survey (Kalberla et al. 2005) and the redshifts were frozen to their average values for the respective clusters. The wabs photoelectric absorption model (Morrison & McCammon 1983) and apec plasma emission model (Smith et al. 2001) have been used for fitting all the spectra. The relative elemental abundances given in Anders & Ebihara (1982) were used for wabs. For XMM-Newton analyses, the MOS1, MOS2, and PN (only MOS1 and MOS2 for A3532) spectra were fitted simultaneously using three separate wabs*apec models. For the spectra belonging to the same region, the values of abundance, temperature, and apec normalizations for the models were linked together but were kept

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**Figure 5.** GMRT 2 m (TGSS; red) and 50 cm (blue), and SUMSS 36 cm (green) contours overlaid on the optical image of the central part of A3532 from the SuperCOSMOS survey. The northwestern extensions of the WAT source seen in the three sets of radio contours seem to coincide.

(A color version of this figure is available in the online journal.)

**Figure 6.** Radio spectrum of the complete WAT source in A3532 on a log–log scale, fitted with a power-law model. The flux densities used and the details of the observations are given in Table 2.
free. To model the residual SP contamination, separate power-law models (see Snowden & Kuntz 2011) were used, and to model the instrumental 1.49 keV Al Kα line, separate Gaussian components for MOS1, MOS2, and PN (see Snowden & Kuntz 2011) were used. The Chandra spectrum of A3532 was fitted using only the wabs*apec model. The resulting spectra from all detectors, along with the histograms of the best-fit model spectra, are shown in Figures 7(a)–(d). The best-fit values of

\[ kT = 4.8^{+0.2}_{-0.2} \text{ keV} \]

\[ \text{Abundance} = 0.36^{+0.08}_{-0.08} \text{ solar} \]

\[ \chi^2 = 1.23 \text{ (364 DOF)} \]

Model: 1T apec + Gauss, \( \lambda_0 = 1.49 \text{ keV} \) + pow

Figure 7. (a)–(c) Average spectra of the clusters A3532 and A3530, and their overlapping region (OR) from XMM-Newton MOS1 (black), MOS2 (red), and PN (green) detectors. All the spectra have been fitted with wabs*apec model shown as a histogram. Details of the spectral analysis are given in Section 4.2, and the best-fit parameters are shown here as insets. (d) Average spectra of A3532 from Chandra data, fitted with the wabs*apec model shown as a histogram. (e) The \( \chi^2 \) contours of the temperature and abundance measurements for the cluster A3532 (pink: XMM-Newton; black: Chandra) and A3530 (blue: XMM-Newton), and the overlapping region (OR) (red: XMM-Newton). The confidence levels for the innermost, middle, and outermost contours for each of the four sets of contours are at 68.3%, 90%, and 99%, respectively.

(A color version of this figure is available in the online journal.)
temperature, abundance, and $apec$ normalizations are provided in Table 3.

The confidence contours of the fitted temperatures and abundances, resulting from the spectral analyses at the 68.3%, 90%, and 99% confidence levels are shown in Figure 7(e). It can be seen that the temperatures of the three regions are distinct at the 99% confidence level. The cluster A3532 has the highest temperature ($4.8 \pm 0.2$ keV) and the OR has the lowest temperature ($2.1^{+0.3}_{-0.2}$ keV). The abundance for the cluster A3532 is not distinct from that for the cluster A3530, even at the confidence level of 68.3%. The OR has a distinct abundance and the lowest one (at 90% confidence level) among all the cluster regions. The Chandra and XMM-Newton results for A3532 are in good agreement, although results from Chandra have larger errors.

4.3. X-Ray Luminosity Estimates

X-ray luminosities of A3532 and A3530 in the energy range of 0.5–8.0 keV were estimated using the XMM-Newton data (for A3532, using Chandra data as well) from the flux values obtained from the spectral analysis of these regions described in Section 4.2. The fluxes ($F_X$) were estimated by convolving the model used in Section 4.2 with the XSPEC convolution model $cflux$ after freezing the $apec$ normalization. The X-ray luminosities ($L_X$) were derived from the fluxes using the formula

$$L_X = 4\pi D_L^2 F_X,$$

where $D_L$ is the luminosity distance to the source. The values of luminosities ($L_X$) derived using this relation for the two clusters are given in Table 3. The 0.1–2.4 keV luminosities have also been estimated for the two clusters for comparison with values obtained by Ikebe et al. (2002) by fitting 2-T thermal plasma models to the ASCA spectra of the clusters. The luminosities obtained by Ikebe et al. have been scaled for the currently used value of the Hubble constant, i.e., 70 km s$^{-1}$ Mpc$^{-1}$.

Table 3

| Region     | Satellite          | $kT$ (keV) | Abundance (Rel. to solar) | $apec$ norm. | $L_X$ (0.5–8.0 keV) (10$^{39}$ erg s$^{-1}$) | $L_X^a$ (0.1–2.4 keV) (10$^{36}$ erg s$^{-1}$) | ($\chi^2$/dof) |
|------------|-------------------|-----------|--------------------------|--------------|------------------------------------------|------------------------------------------|----------------|
| A3532      | XMM-Newton        | 4.8 ± 0.2 | 0.36 ± 0.08              | 16.2 ± 0.4   | 14.0 ± 0.3                               | 10.2 ± 0.1                               | 1.23(364)     |
| A3532      | Chandra           | 5.2$^{+0.6}_{-0.8}$ | 0.4$^{+0.3}_{-0.5}$        | 14.6 ± 1.1   | 13.2 ± 0.6                               | ...                                      | 0.97(47)      |
| A3532      | ASCA$^b$          | 4.4 ± 0.2 | ...                      | ...          | 12.0 ± 0.4                               | ...                                      | ...            |
| A3530      | XMM-Newton        | 3.5 ± 0.1 | 0.26$^{+0.05}_{-0.04}$    | 9.9 ± 0.2    | 7.6 ± 0.1                               | 4.9 ± 0.1                               | 1.13(705)     |
| A3530      | ASCA$^b$          | 4.1 ± 0.3 | ...                      | ...          | 6.6 ± 0.3                               | ...                                      | ...            |
| OR         | XMM-Newton        | 2.1$^{+0.3}_{-0.2}$ | 0.09$^{+0.09}_{-0.07}$   | 1.6 ± 0.2    | 0.81 ± 0.05                             | ...                                      | 1.15(76)      |

Notes. X-ray luminosities of the two clusters derived in Section 4.3 are given. Results from Ikebe et al. (2002) based on ASCA data are also given for comparison. The spectrum for each region is fitted with a single-temperature $apec$ model for a fixed Galactic absorption. For the XMM-Newton spectral analysis, the residual soft proton contamination and the instrumental Al line at 1.49 keV have been modeled by adding power laws and Gaussians, respectively (separately for MOS1, MOS2, and PN) to the models. Best-fit values for the temperature ($kT$), elemental abundance relative to the solar values, normalization of the $apec$ model, X-ray luminosity ($L_X$), and minimum reduced $\chi^2$ are given along with the degrees of freedom (dof). For the XMM-Newton spectral analysis of the cluster A3532, only MOS1 and MOS2 data have been used while for the cluster A3530 and the overlapping region, PN data have also been used. All errors are quoted at 90% confidence level based on $\chi^2_{\text{min}} + 2.71$.

$^a$The column shows the 0.1–2.4 keV luminosities of A3532 and A3530 obtained by us using XMM-Newton data, for a comparison with the results of Ikebe et al. (2002). The values of hydrogen column density and the redshifts have been frozen to the values used by Ikebe et al., although their values, which were used for the rest of the analyses, do not change the results significantly.

$^b$The rows show the X-ray temperatures of the hot components and the 0.1–2.4 keV luminosities of A3532 and A3530, obtained by Ikebe et al. (2002) by fitting 2-T thermal plasma model to the ASCA spectra of the clusters. The luminosities have been scaled for the currently used value of the Hubble constant (= 70 km s$^{-1}$ Mpc$^{-1}$).

Table 4

| Cluster | $\beta$ | $r_c$ (10$^{-2}$ Mpc) | $F_X^b$ (10$^{-11}$ erg cm$^{-2}$ s$^{-1}$) | $L_X^b$ (10$^{34}$ erg s$^{-1}$) |
|---------|--------|-----------------------|------------------------------------------|---------------------------------|
| A3532   | 0.41 ± 0.01 | 8.1 ± 0.5             | 3.4 ± 0.3                               | 2.5 ± 0.2                      |
| A3530   | 0.47 ± 0.01 | 9.7 ± 0.5             | 1.3 ± 0.2                               | 0.9 ± 0.1                      |

Notes. Errors are quoted at 68% confidence level (1σ) based on $\chi^2_{\text{min}} + 1.00$. $F_X^b$ = bolometric X-ray flux, $\beta = -1/3$(slope$–0.5$), and $r_c$ = core radius.

0.1–2.4 keV luminosity estimates obtained by us, the values of the hydrogen column density and the redshifts have been frozen to the values used by Ikebe et al. for consistency. However, 2-T thermal plasma models could not be fitted to our spectra as the normalizations of the second $apec$ components were negligibly small. We have, therefore, used only the 1-T $apec$ models throughout our analyses. The 0.1–2.4 keV luminosities obtained by us are only slightly lower than those obtained by Ikebe et al. (2002), possibly due to the different spectral models used for the two analyses. These results have also been listed in Table 3.

We have also estimated the bolometric X-ray luminosities of the clusters A3532 and A3530. The average count rates of the two clusters were obtained by fitting their $0^\circ$–360$^\circ$ surface brightness profiles with the $\beta$-model. These count rates were converted to fluxes in the 0.01–100 keV energy band, by using the HEASARC tool Web Portable, Interactive, Multi-Mission Simulator, from which the bolometric X-ray luminosities were estimated using the formula $L_X^b = 10^{-0.32\pm0.065} T^{2.79\pm0.08}$.
and the radius of the centers were at the peak of the X-ray emission of each cluster, only the first five annuli were used for profiles. A3532 and A3530 have also been shown.

4.4. Radial Profiles of Thermodynamic Quantities Based on Azimuthally Averaged Spectra

We have produced the azimuthally averaged profiles of temperature, density, entropy, and pressure by extracting spectra in eight circular annuli in each of the clusters A3532 and A3530. The two clusters lie very close to the left-hand side images in Figures 9 and 10. The temperature profiles for A3532 and A3530 are shown plotted on the right-hand sides of Figures 9 and 10, for A3532 and A3530, respectively. The entropy (S) and the electron pressure (P) are obtained from the relations $S = k T n_e^{2/3}$ and $P = n_e k T$, respectively (Gitti et al. 2010). The resulting entropy profiles for A3532 and A3530 are shown in Figures 9(e) and 10(e), and the pressure profiles are shown in Figures 9(g) and 10(g), respectively. The values of all the thermodynamic quantities for each of the annuli are tabulated in Tables 5 and 6 for A3532 and A3530, respectively. The temperature profiles obtained using XMM-Newton data show low temperatures in the innermost annuli of both the clusters. For the rest of the annuli in A3532, temperature is almost a constant, whereas for A3530, the temperature profile shows a gradual decrease outward. The density, entropy, and pressure profiles of both the clusters show an average decrease, increase, and decrease, respectively, from the innermost to the outermost annulus. The projected profile of the elemental abundance in A3532 is shown in Figure 9(i), and due to large errors, does not show significant variations in the values obtained for different annuli. The elemental abundance in A3530 shows a gradual decrease from the innermost to the outermost annulus (Figure 10(i)), which indicates an enrichment of the ICM toward the center of the cluster. The errors in the abundance profile of A3532 obtained using XMM-Newton spectra are much larger than those for A3530. This is because only MOS spectra were used for A3532 while both MOS and PN spectra were used for A3530. All the profiles of thermodynamic quantities obtained using Chandra data are consistent with those obtained using XMM-Newton data.

4.4.2. Deprojected Profiles

To get a better idea of the variations in the thermodynamic quantities which may get smoothed out due to projection effects, we carried out a deprojection analysis on the annuli described in Section 4.4.1. For this purpose, we used the XSPEC project model, which can estimate the parameters in 3D space from the 2D projected spectra of annular ellipsoidal shells, along with the wabs*apec model. As the elemental abundances for all the annuli belonging to A3532 and A3530 did not show significant variations, their values were frozen to 0.36 and 0.28 times the solar value ($Z_\odot$), respectively. For XMM-Newton spectra, the residual SP contamination and instrumental Al lines were modeled by adding power laws and Gaussian components to the models as was also done in Section 4.2. Note that, as the project model requires all the spectra belonging to the same annulus to be part of the same group, for each annulus a single power law and Gaussian were used for all MOS1, MOS2, and PN detectors. Electron density ($n_e$), entropy (S), and electron pressure (P) have been calculated using the same relations as given in Section 4.4.1. The resulting deprojected profiles of temperature, density, entropy, and pressure obtained for A3532 and A3530 are shown plotted on the right-hand sides of Figures 9 and 10, and listed in Tables 7 and 8, respectively.

The deprojected profiles of both clusters have errors larger than the projected profiles. The XMM-Newton temperature profiles of the clusters A3532 and A3530 do not change.
Figure 9. (a)–(h) Projected and deprojected temperature ($kT$), electron density ($n_e$), entropy ($S$), and pressure ($P$) profiles obtained from the spectral analysis of the XMM-Newton MOS spectra from eight circular annuli (red points) and Chandra spectra from five circular annuli (blue points) in the cluster A3532. The value of elemental abundance was frozen to 0.36 times the solar value. (i) The abundance profile of A3532 from projected spectral analysis, after freeing the abundance parameter. The details of the projected and deprojected spectral analysis are given in Sections 4.4.1 and 4.4.2, respectively.

(A color version of this figure is available in the online journal.)
Figure 10. (a)–(h) Projected and deprojected temperature ($kT$), electron density ($n_e$), entropy ($S$), and pressure ($P$) profiles obtained from the spectral analysis of the XMM-Newton (MOS+PN) spectra from eight circular annuli in the cluster A3530. (i) The abundance profile of A3530 from projected spectral analysis. For the deprojected spectral analysis, the value of elemental abundance was frozen to 0.28 times the solar value. The details of the projected and deprojected spectral analysis are given in Sections 4.4.1 and 4.4.2, respectively.

(A color version of this figure is available in the online journal.)
Results from innermost to the outermost annulus, as in their projected profiles. Density, entropy, and pressure profiles of both the clusters show a significantly lower temperature. On average, the outermost annulus, except for the innermost annulus of A3530, significantly and are almost constant from the innermost to the outermost annulus, except for the innermost annulus of A3530, which shows a significantly lower temperature. On average, the density, entropy, and pressure profiles of both the clusters show a gradual decrease, increase, and decrease, respectively, from the innermost to the outermost annulus, as in their projected profiles. Results from Chandra and XMM-Newton for the cluster A3532 are in good agreement with each other. However, the errors from Chandra data are much larger than those from XMM-Newton, as also observed for the projected profiles. The projected and deprojected profiles of both the clusters do not seem to be significantly different, except for a few anomalies. The density values in the inner annuli of both the clusters, obtained from the projected spectral analysis, are higher than those from the deprojected spectral analysis. Similarly, the pressure values in the inner annuli of both the clusters, obtained from the XMM-Newton projected spectral analysis, are higher than those from the deprojected spectral analysis.

4.5. Spectrally Determined 2D Projected Thermodynamic Maps at a Higher Resolution

The 2D projected temperature, density, entropy, and pressure maps for the combined system of the A3532 and A3530 clusters have also been made, using XMM-Newton spectra from a total of 77 box-shaped regions. As Chandra data (available only for the A3532 cluster) had large errors (evident in Sections 4.2, 4.4.1, and 4.4.2), we have not used the Chandra data in this section. Of the 77 box regions, 41 boxes were from A3532 and 37 were from A3530, with one box in common. An adaptive approach was followed for choosing the sizes of the boxes, so as to get sufficient counts in each region. Large size boxes (∼7.7 × 3.8) significantly and are almost constant from the innermost to the outermost annulus, except for the innermost annulus of A3530, which shows a significantly lower temperature. On average, the density, entropy, and pressure profiles of both the clusters show a

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### Table 5

Best-fit Parameters Obtained from the Spectral Analysis of Eight Circular Annuli in the Cluster A3532 using XMM-Newton MOS1 and MOS2 Data and of Five Circular Annuli using Chandra Data

| Data           | Annulus Number | $kT$ (keV) | $n_e$ (10$^{-4}$ cm$^{-3}$) | $P$ (10$^{-12}$ dyn cm$^{-2}$) | $S$ (keV cm$^2$) |
|---------------|----------------|-----------|----------------|----------------|----------------|
| XMM-Newton    | 1              | 4.1 ± 0.4 | 43.2 ± 0.7     | 28.3 ± 3.2     | 155 ± 17       |
|               | 2              | 5.2 ± 0.4 | 21.6 ± 0.3     | 18.0 ± 1.6     | 311 ± 26       |
|               | 3              | 4.8 ± 0.4 | 13.3 ± 0.2     | 10.2 ± 1.4     | 398 ± 36       |
|               | 4              | 5.1 ± 0.6 | 8.9 ± 0.1      | 7.3 ± 1.0      | 550 ± 69       |
|               | 5              | 4.6 ± 0.6 | 6.4 ± 0.1      | 4.7 ± 0.7      | 619 ± 97       |
|               | 6              | 4.3 ± 0.7 | 4.7 ± 0.1      | 3.0 ± 0.6      | 711 ± 125      |
|               | 7              | 4.1 ± 0.9 | 3.6 ± 0.1      | 2.4 ± 0.7      | 810 ± 192      |
|               | 8              | 3.3 ± 0.9 | 2.8 ± 0.1      | 1.5 ± 0.5      | 765 ± 225      |
| Chandra       | 1              | 5.1 ± 0.8 | 42.8 ± 0.9     | 35.0 ± 6.5     | 193 ± 33       |
|               | 2              | 4.8 ± 0.6 | 21.0 ± 0.4     | 16.1 ± 2.3     | 292 ± 40       |
|               | 3              | 4.8 ± 0.6 | 12.2 ± 0.2     | 9.4 ± 1.5      | 420 ± 67       |
|               | 4              | 5.1 ± 1.1 | 8.3 ± 0.2      | 6.8 ± 1.6      | 576 ± 133      |
|               | 5              | 3.7 ± 1.1 | 5.5 ± 0.2      | 3.2 ± 0.8      | 554 ± 177      |

**Notes.** The spectra for all the annuli were fitted using the model wabs*apec for a fixed value of Galactic absorption and with elemental abundances frozen to 0.36 times the solar value. For XMM-Newton spectra, the residual soft proton contamination and the instrumental Al line at 1.49 keV have been modeled by adding power laws and Gaussians, respectively (separately for MOS1 and MOS2) to the models. Annulus number represents the position of the annulus from the innermost to the outermost annuli in increasing order. Values of temperature ($kT$), electron density ($n_e$), pressure ($P$), and entropy ($S$) are listed. All errors are quoted at 90% confidence level based on $\chi^2_{min}$+2.71.

### Table 6

Best-fit Parameters Obtained from the Spectral Analysis of Eight Circular Annuli in the Cluster A3530 Using XMM-Newton Data

| Annulus Number | $kT$ (keV) | Abundance (Relative to Solar) | $n_e$ (10$^{-4}$ cm$^{-3}$) | $P$ (10$^{-12}$ dyn cm$^{-2}$) | $S$ (keV cm$^2$) |
|---------------|-----------|-----------------|----------------|----------------|----------------|
| 1             | 3.7 ± 0.2 | 0.5^0.2 0.10^0.1 | 31.4 ± 0.8 | 18.6 ± 1.5 | 172 ± 12 |
| 2             | 4.2 ± 0.2 | 0.3 ± 0.1       | 16.1 ± 0.3 | 10.8 ± 0.7 | 306 ± 18 |
| 3             | 3.6 ± 0.2 | 0.2 ± 0.1       | 9.8 ± 0.2  | 5.7 ± 0.4 | 364 ± 25 |
| 4             | 3.1 ± 0.2 | 0.3 ± 0.1       | 6.6 ± 0.2  | 3.3 ± 0.3 | 411 ± 33 |
| 5             | 2.9 ± 0.3 | 0.1 ± 0.1       | 5.0 ± 0.1  | 2.3 ± 0.3 | 460 ± 56 |
| 6             | 2.6^0.4 0.2 | 0.2 ± 0.1       | 3.8 ± 0.2  | 1.6^0.3 0.2 | 491^0.9 0.2 |
| 7             | 1.9 ± 0.2 | 0.1 ± 0.1       | 3.2 ± 0.1  | 1.0 ± 0.1 | 407 ± 55 |
| 8             | 1.6 ± 0.2 | 0.04^0.06 0.04 | 2.6 ± 0.1  | 0.7 ± 0.1 | 397 ± 65 |

**Notes.** The spectra for all the annuli were fitted using the model wabs*apec for a fixed value of Galactic absorption. The residual soft proton contamination and the instrumental Al line at 1.49 keV have been modeled by adding power laws and Gaussians, respectively (separately for MOS1, MOS2, and PN) to the models. Annulus number represents the position of the annulus from the innermost to the outermost annuli in increasing order. Values of temperature ($kT$), abundance, electron density ($n_e$), pressure ($P$), and entropy ($S$) are listed. All errors are quoted at 90% confidence level based on $\chi^2_{min}$+2.71.
for a fixed value of Galactic absorption and with elemental abundances frozen for the outermost parts, small size boxes (\(R = 0.36\) times the solar value. For XMM-Newton spectra, the residual soft proton contamination and the instrumental Al line at 1.49 keV have been modeled by adding power laws and Gaussians, respectively, to the models. Annulus number represents the position of the annulus from the innermost to the outermost annuli in increasing order. Values of temperature (\(kT\)), electron density (\(n_e\)), pressure (\(P\)), and entropy (\(S\)) are listed. All errors are quoted at 90% confidence level based on \(\chi^2_{\text{min}}+2.71\).

Table 7

Best-fit Parameters Obtained from the Deprojected Spectral Analysis of Eight Circular Annuli in the Cluster A3532 Using XMM-Newton MOS1 and MOS2 Data and of Five Circular Annuli Using Chandra Data

| Data    | Annulus Number | \(kT\) (keV) | \(n_e\) \((10^{-4} \text{ cm}^{-3})\) | \(P\) \((10^{-12} \text{ dyn cm}^{-2})\) | \(S\) \((\text{keV cm}^2)\) |
|---------|----------------|------------|----------------|----------------|----------------|
| XMM-Newton | 1              | 3.7\(^{+0.9}_{-0.6}\) | 30.3 ± 1.1       | 17.9\(^{+3.0}_{-2.6}\) | 177\(^{+43}_{-33}\) |
|         | 2              | 4.0\(^{+0.8}_{-0.7}\) | 15.8 ± 0.6       | 10.1\(^{+2.6}_{-2.1}\) | 292\(^{+74}_{-59}\) |
|         | 3              | 4.4\(^{+1.0}_{-0.7}\) | 11.8 ± 0.4       | 8.5\(^{+3.6}_{-2.1}\)  | 395\(^{+74}_{-59}\) |
|         | 4              | 5.0\(^{+1.8}_{-1.1}\) | 8.2 ± 0.3        | 6.5\(^{+2.6}_{-1.7}\)  | 572\(^{+221}_{-141}\) |
|         | 5              | 5.0\(^{+1.8}_{-1.1}\) | 6.6 ± 0.4        | 5.3\(^{+2.2}_{-1.9}\)  | 661\(^{+265}_{-225}\) |
|         | 6              | 4.3\(^{+1.9}_{-1.0}\) | 5.0 ± 0.3        | 3.4\(^{+3.7}_{-3.0}\)  | 682\(^{+325}_{-333}\) |
|         | 7              | 3.4\(^{+2.4}_{-1.2}\) | 3.3 ± 0.3        | 1.8\(^{+0.8}_{-0.5}\)  | 713\(^{+573}_{-301}\) |
|         | 8              | 2.5\(^{+0.3}_{-0.4}\) | 4.5 ± 0.2        | 1.8\(^{+0.4}_{-0.3}\)  | 426\(^{+96}_{-79}\)  |
| Chandra  | 1              | 5.4\(^{+2.2}_{-1.4}\) | 29.5 ± 1.3       | 25.5\(^{+11.2}_{-7.7}\) | 263\(^{+155}_{-76}\) |
|         | 2              | 4.8\(^{+1.4}_{-1.0}\) | 17.8 ± 0.7       | 13.7\(^{+4.5}_{-3.4}\) | 327\(^{+104}_{-76}\) |
|         | 3              | 4.5\(^{+1.8}_{-1.1}\) | 11.0 ± 0.5       | 7.9\(^{+3.5}_{-2.3}\)  | 423\(^ {+183}_{-117}\) |
|         | 4              | 6.1\(^{+4.7}_{-1.8}\) | 8.5 ± 0.4        | 8.3\(^{+6.8}_{-2.9}\)  | 680\(^{+547}_{-224}\) |
|         | 5              | 3.9\(^{+1.6}_{-0.7}\) | 8.2 ± 0.3        | 5.1\(^{+3.6}_{-1.6}\)  | 445\(^ {+135}_{-90}\) |

Notes. The spectra for all the annuli were fitted using the model \(\text{wabs+apec}\) for a fixed value of Galactic absorption and with elemental abundances frozen to 0.28 times the solar value. The residual soft proton contamination and the instrumental Al line at 1.49 keV have been modeled by adding power laws and Gaussians, respectively, to the models. Annulus number represents the position of the annulus from the innermost to the outermost annuli in increasing order. Values of temperature (\(kT\)), electron density (\(n_e\)), pressure (\(P\)), and entropy (\(S\)) are listed. All errors are quoted at 90% confidence level based on \(\chi^2_{\text{min}}+2.71\).

Table 8

Best-fit Parameters Obtained from the Deprojected Spectral Analysis of Eight Circular Annuli in the Cluster A3530 Using XMM-Newton Data

| Annulus Number | \(kT\) (keV) | \(n_e\) \((10^{-4} \text{ cm}^{-3})\) | \(P\) \((10^{-12} \text{ dyn cm}^{-2})\) | \(S\) \((\text{keV cm}^2)\) |
|---------------|------------|----------------|----------------|----------------|
| 1             | 2.5\(^{+0.2}_{-0.1}\) | 21.4 ± 0.7 | 8.6\(^{+1.0}_{-0.6}\) | 150\(^{+15}_{-10}\) |
| 2             | 3.7\(^{+0.6}_{-0.3}\) | 12.4 ± 0.3 | 7.3 ± 0.1 | 321\(^{+57}_{-54}\) |
| 3             | 3.9\(^{+0.8}_{-0.5}\) | 8.4 ± 0.2 | 5.2\(^{+1.2}_{-0.8}\) | 438\(^{+97}_{-104}\) |
| 4             | 2.7\(^{+0.4}_{-0.2}\) | 6.0 ± 0.2 | 2.6\(^{+0.5}_{-0.3}\) | 380\(^{+107}_{-104}\) |
| 5             | 2.7\(^{+0.4}_{-0.3}\) | 4.2 ± 0.2 | 1.8\(^{+0.4}_{-0.3}\) | 470\(^{+85}_{-67}\) |
| 6             | 3.2\(^{+0.6}_{-0.5}\) | 4.0 ± 0.2 | 2.1\(^{+0.5}_{-0.3}\) | 586\(^{+127}_{-108}\) |
| 7             | 2.7\(^{+0.5}_{-0.4}\) | 2.9 ± 0.2 | 1.3 ± 0.3 | 611\(^{+139}_{-116}\) |
| 8             | 2.2\(^{+0.3}_{-0.2}\) | 3.9 ± 0.1 | 1.4\(^{+0.3}_{-0.2}\) | 412\(^{+82}_{-63}\) |

Notes. The spectra for all the annuli were fitted using the model \(\text{wabs+apec}\) for a fixed value of Galactic absorption and with elemental abundances frozen to 0.28 times the solar value (\(Z_\odot\)) for the boxes belonging to A3532 and A3530, respectively. The electron density, entropy, and electron pressure were calculated using the same relations as in Section 4.4.1. Spherical geometry was assumed for the volume calculation. All 77 box regions were assumed to be projections of parts of spherical shells (centered at the X-ray intensity peak of the cluster to which the box belongs) with inner and outer radii \((R_\text{in}, R_\text{out})\) equal to the smallest and largest distance from the center of their respective spheres. The volume for each box region was estimated as \(D_\odot^3 \Omega \left(\frac{R_\text{in}}{D_\odot} - \frac{R_\text{out}}{D_\odot}\right)^{1/2}\) (Henry et al. 2004; Ehleit et al. 2011), where \(D_\odot\) is the angular diameter distance of the cluster to which the box belongs and \(\Omega\) is the solid angle subtended by the box. \(R_\text{in}\) and \(R_\text{out}\) are equal to the distances \(R_\text{in}\) and \(R_\text{out}\) expressed in angular units, respectively. For a box region common to both A3532 and A3530 an average of results from the two observations was used.

The temperature, density, entropy, and pressure maps produced are shown in Figures 11(a), 11(b), 12(a), and 12(b), respectively. The temperature in both clusters appears to decrease as we move outward from the center. However, A3532 shows a lot of anisotropic variations in the temperature, especially in its central parts, though the statistical significance is low. Both density and pressure maps show a peak at the center of the clusters followed by an almost uniform decrease outward. The entropy maps of both clusters show the presence of a few high entropy regions in their outer parts while almost a constant entropy is observed in their inner parts. The OR between the two clusters does not show the presence of high temperature or high entropy, as would have been expected if an active merger was taking place between the two clusters. We have also made an estimate of the density \((n_e)\) in the OR by using the \(\text{apec}\) normalization obtained in Section 4.2. For volume calculation, we assumed a prolate ellipsoid made using the ellipse used in Section 4.2 for the OR. We obtained a density of \((6.4 \pm 0.4) \times 10^{-4} \text{ cm}^{-3}\) for the OR, which is consistent with its value from Figure 11(b).
4.6. Cooling Time

A commonly used relation for estimating the cooling time of a cluster from Sarazin (1988), is as follows:

$$t_{\text{cool}} = 8.5 \times 10^{10} \, \text{yr} \left[ \frac{n}{10^{-3} \, \text{cm}^{-3}} \right]^{-1} \left[ \frac{T_g}{10^8 \, \text{K}} \right]^{1/2}. \quad (2)$$

Using this relation and the central gas temperatures ($T_g$) and densities ($n$) (derived from the deprojection analysis in Section 4.4.2, the cooling times estimated for both A3532 and A3530 ($\approx 1.8 \times 10^{10} \, \text{yr}$ and $1.7 \times 10^{10} \, \text{yr}$, respectively) seem to be longer than the Hubble time ($\approx 1.35 \times 10^{10} \, \text{yr}$). Note that the innermost annuli in Section 4.4.2 have radii equal to 75″ ($\approx 80 \, \text{kpc}$). It should also be noted that the above relation is derived by assuming thermal bremsstrahlung as the only cooling mechanism. However, additional cooling by line emission may result in a smaller value of the cooling time. Using the continuum and line emissivity relations given in Sarazin (1988), the cooling time of A3530 ($\approx 1.02 \times 10^{10} \, \text{yr}$) seems to be slightly lower while that of A3532 ($\approx 1.26 \times 10^{10} \, \text{yr}$) seems to be very close to the Hubble time. A discussion regarding the possibility of cool cores in the cluster pair, based on the results obtained in this section along with some other results, is given in Section 5.
4.7. Gas Mass Estimation

We have estimated the gas masses for A3532 and A3530 by using the gas density profiles obtained in Sections 4.4.1 and 4.4.2. The projected and deprojected gas density profiles for both clusters were fitted using a $\beta$-model, i.e.,

$$n_e(r) = n_e(0) \left(1 + \frac{r^2}{r_c^2}\right)^{(3/2)\beta},$$

where $n_e(0)$ is the central density and $r_c$ is the core radius. The gas masses $M_{\text{gas}}(r)$ out to radii 0.5 Mpc and 1 Mpc for the two clusters were obtained by using the following formula (see Donnelly et al. 2001):

$$M_{\text{gas}}(r) = 4\pi \rho_0 \int_0^r s^2 \left[1 + \left(\frac{s}{r_c}\right)^2\right]^{(3/2)\beta} ds,$$

where $\rho_0 = \mu n_e(0)m_p$, $m_p$ is the mass of a proton, and $\mu = 0.609$ is the average molecular weight for a fully ionized gas (Gu et al. 2010). The values of $\beta$, $r_c$, $\rho_0$, and $M_{\text{gas}}$ based on fitting the density profiles with the above model are listed in Table 9. The results obtained from both projected and deprojected analysis show A3532 to be marginally more massive than A3530.

4.8. Galaxy Velocity Distribution and Virial Mass

The presence of substructures and mergers in clusters of galaxies often results in multimodal and asymmetric/non-Gaussian velocity distributions. Therefore, to look for the presence of substructures and mergers in A3532 and A3530, we used the galaxy velocity samples from Cristiani et al. (1987) and Bardelli et al. (2001), respectively. As Bardelli et al. have given velocity information for a large number of galaxies located in the core of the SSC, the galaxies selected for A3530 might also have included background and foreground galaxies. Therefore, upper and lower velocity thresholds of 15,000...
Figure 13. Positions of the galaxies used for the analysis in Section 4.8 marked on the SuperCOSMOS image. The circles mark the 0.5 $R_{200}$ radii of the clusters and the crosses mark the positions of the galaxies. Blue and red colors have been used for A3532 and A3530, respectively.

(A color version of this figure is available in the online journal.)

Table 9

| Spectral Analysis | Cluster | Data       | $\beta$       | $r_c$ (kpc) | $\rho_0$ ($10^{13}$ $M_\odot$ Mpc$^{-3}$) | $r$ (Mpc) | $M_{\text{gas}}(r)$ ($10^{13}$ $M_\odot$) |
|-------------------|---------|------------|---------------|-------------|------------------------------------------|-----------|------------------------------------------|
| Projected         | A3532   | XMM-Newton | 0.68 ± 0.01   | 77 ± 3      | 10.3 ± 0.1                               | 0.5       | 0.70 ± 0.04                             |
|                   |         | Chandra    | 0.68 ± 0.03   | 71 ± 1      | 10.6 ± 0.2                               | 0.5       | 0.6 ± 0.1                               |
|                   | A3530   | XMM-Newton | 0.64 ± 0.01   | 67 ± 2      | 8.0 ± 0.1                                | 0.5       | 0.53 ± 0.03                             |

| Deprojected       | A3532   | XMM-Newton | 0.54 ± 0.03   | 71 ± 9      | 7.1 ± 0.2                                | 0.5       | 0.7 ± 0.1                               |
|                   |         | Chandra    | 0.52 ± 0.08   | 72 ± 2      | 7.1 ± 0.3                                | 0.5       | 0.7 ± 0.2                               |
|                   | A3530   | XMM-Newton | 0.54 ± 0.02   | 73 ± 8      | 5.1 ± 0.1                                | 0.5       | 0.5 ± 0.1                               |

Note. Errors are quoted at 68% confidence level (1 $\sigma$) based on $\chi^2_{\text{min}} + 1.00$.

and 17,600 km s$^{-1}$, respectively, were applied to the sample of Bardelli et al. In addition, to avoid overlaps, galaxies only within 0.5 $R_{200}$ circles, centered on the X-ray surface brightness peaks were used for this analysis (see Figure 13), for both the clusters. This led to 40 galaxies with velocity information in A3532 and 35 galaxies in A3530. The histograms of galaxy velocity distributions of the two clusters overlaid with their Gaussian fits are shown in Figure 14. The bin size used for both the clusters was 350 km s$^{-1}$. A single Gaussian can be fitted to the velocity histogram of each of the two clusters. Therefore, neither cluster shows the presence of substructures in its optical redshift distribution. This result is in agreement with the findings of Pimbblet (2008) for the cluster A3532, based on the Dressler & Shectman (1988) $\delta$-test. Based on Gaussian fits, we obtain the average radial velocities of A3532 and A3530 as 16211 ± 159 km s$^{-1}$ and 16213 ± 246 km s$^{-1}$, respectively, which translate to average redshifts of 0.0556 ± 0.0005 and 0.0556 ± 0.0009, respectively. The result, therefore, strengthens the argument that the two clusters are at the same distance and much closer to each other than previously thought and, therefore, have a very high probability of tidally interacting with each other.

We have also estimated the virial masses of the two clusters by using these galaxy velocity samples and the relation given by Beers et al. (1982):

$$M_{\text{virial}} = \frac{3\pi}{G} \frac{\sigma_v^2}{(1/r_p)^{-1}},$$

where $\sigma_v$ is the velocity dispersion along the line of sight and $(1/r_p)^{-1}$ is the harmonic mean projected separation between galaxy pairs. The mean velocity ($\bar{v}$), velocity dispersion ($\sigma_v$), and the virial masses of the clusters, thus estimated, are given in Table 10. The underlying assumption in the relation used is that the galaxies included in each of the clusters are bound and their velocity dispersions are isotropic. The virial masses obtained for the two clusters have large errors (especially for A3530) and therefore do not differ significantly. A better estimation of the virial masses requires more redshift data for both the clusters.

4 The values of $R_{200}$ (radius within which the mean density of the cluster equals 200 times the critical density) obtained by Vulcani et al. (2011; 1.50 Mpc for A3532 and 1.36 Mpc for A3530) have been used.
Figure 14. Galaxy velocity histograms for the clusters A3532 (left) and A3530 (right) overlaid with the Gaussian fits. The bin size used for both the clusters is 350 km s$^{-1}$.

(A color version of this figure is available in the online journal.)

Table 10
The Values of Virial Mass and the Parameters Used (Derived in Section 4.8) for A3532 and A3530

| Cluster | No. of Galaxies | $\bar{v}$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $M_{\text{virial}}$ ($10^{14} M_\odot$) |
|---------|-----------------|-------------------------|-------------------------|----------------------------------------|
| A3532   | 40              | 16211 ± 157             | 615 ± 159               | 3.4 ± 1.8                              |
| A3530   | 35              | 16213 ± 246             | 794 ± 286               | 5.5 ± 4.0                              |

Note. Errors are quoted at 90% confidence level based on $\chi^2_{\text{min}}+2.71$.

4.9. X-Ray–Radio Interaction

Figure 15 shows a moderately smoothed (Gaussian kernel width $\sim 4''$) Chandra image of the central part of A3532 in the 0.3–7.0 keV band, smoothed using a Gaussian kernel of width $\sim 4''$, and overlaid with the GMRT 50 cm contours (blue; levels the same as in Figure 4(c)), and the TGSS 2 m radio contours (green; levels the same as in Figure 4(e)). Positions of the two brightest galaxies (BCG 1 and BCG 2; marked with black stars) and the candidate cavity (cavity 1) have been shown.

(A color version of this figure is available in the online journal.)

Figure 15. Exposure-corrected and point-source-removed Chandra ACIS images of the central part of A3532 in the 0.3–7.0 keV band, smoothed using a Gaussian kernel of width $\sim 4''$, and overlaid with the GMRT 50 cm (blue) and TGSS 2 m (green) contours. The image shows highly anisotropic X-ray emission with four main peaks at the center. The brightest peak coincides with the brighter nucleus of the dumbbell BCG (shown as BCG 1). Another adjacent peak is seen toward its west, coinciding with the position of the second nucleus of the dumbbell BCG (shown as BCG 2). Two more peaks are seen at distances of about 1' and 40', northwest from the center of the brightest peak. The image also shows a number of apparent cavities or depressions in the X-ray surface brightness, both on large scales and small scales, and in various parts of the cluster. However, because of the very small exposure time of the Chandra observation, the detection significance of these cavities is very low. In the following analysis, we have focused on one “candidate” cavity which is most prominent and visible in the Chandra images at all resolutions. In Figure 15, the northwestern radio extension of the WAT in both sets of radio contours seems to coincide with a large-scale candidate cavity (“cavity 1”, hereafter) and in the TGSS 2 m contours (green), it seems to fill the cavity completely. To estimate the significance of “cavity 1”, we used the X-ray surface brightness profile, made by using annular sectors along the direction of the cavity (see Figure 16). “Cavity 1” shows up as a significant dip ($\sim 4\sigma$ average; $\sim 5\sigma$ at the minimum) in the X-ray surface brightness profile. It seems possible that the “cavity 1” and the radio emission from the WAT are related to each other. Assuming “cavity 1” is indeed real, we have investigated the energy requirements of the cavity, below.

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4.9.1. Cavity Energetics

The total energy required to create a cavity ($E_{\text{cav}}$) is the sum of the work done in expanding the cavity ($\int P \, dV = PV / (y - 1)$) plus the energy in the cavity ($PV$) (see Dunn & Fabian 2004), where $P$ is the pressure of the hot gas surrounding the cavity, $V$ is the volume of the cavity, and $y$ is the ratio of the specific heats ($= c_p / c_v$). By using $y = 4/3$ for the relativistic jets, we obtain, $E_{\text{cav}} = \gamma PV / (y - 1) = 4PV$ (see Birzan et al. 2004; McNamara & Nulsen 2007, 2012; Fabian 2012). The power required by the jet to create the cavity ($P_{\text{cav}}$) is given by the total energy of the cavity divided by the age of the cavity. For our analysis, we have approximated the age of the cavity ($t_{\text{cav}}$) as the sound crossing time, which is the time taken by the sound waves to travel from the center of the AGN to the current location of the cavity (see Hlavacek-Larrondo et al. 2012). The pressure of the hot gas and the density (required for calculating the sound speed) have been estimated by using their approximate average values at the location of the cavities in the thermodynamic maps. To estimate the volumes of the cavities, prolate ellipsoidal shapes were assumed. The semi-major and semi-minor axes ($R_1$ and $R_2$) of the ellipse, the average radius $R$ ($= \sqrt{R_1 R_2}$), the pressure of the hot gas surrounding the cavity ($P$), the volume of the cavity ($V$), the total energy required for the cavity ($E_{\text{cav}}$), the age of the cavity ($t_{\text{cav}}$), and the power of the jets required ($P_{\text{cav}}$) to create the cavity, calculated for the “cavity 1”, are given in Table 11. Here, it should be noted that the errors associated with the shape and volume of the ellipse used to describe the cavity 1 were very large ($\sim 30\%$–$80\%$) because of the very crude approximation and also because of the projection effects.

We have also calculated the radio power (luminosity) of the WAT source ($L_{\text{radio}}$) by integrating $L_\nu = 4\pi D_L^2 S_\nu$, from 10 MHz to 10 GHz. $D_L$ is the luminosity distance to the source, $S_\nu(\propto \nu^\alpha)$ is the flux density at frequency $\nu$, and $\alpha$ is the radio spectral index of the WAT. The radio power so obtained is given in Table 11. $L_{\text{radio}}$ is found to be lower than $P_{\text{cav}}$, by about a factor of 80. Note that $P_{\text{cav}}$ might have errors as large as $70\%$ due to the very crude approximation of the shape of the cavity and additional errors in the pressure of the hot gas and the age of the cavity. Figure 17 shows the relationship between the jet power required to create the cavity and the radio power (integrated for the 10 MHz–10 GHz band) reproduced from O’Sullivan et al. (2011; OS11, hereafter). The sample shown in the figure is based on cavities found in the nine groups of galaxies studied by OS11 and 24 groups of galaxies studied by Birzan et al. (2008; B08, hereafter). The point corresponding to the “cavity 1” is found to be well within the scatter in Figure 17. This result further supports that “cavity 1” and the radio emission from the WAT might be related to each other. The temperature in the box region at the location of “cavity 1” is found to be marginally higher than that in the immediately surrounding boxes. There is a possibility that the

### Table 11

Energetics of the Candidate “Cavity 1” (See Section 4.9.1)

| $R_1$ (kpc) | $R_2$ (kpc) | $R$ (kpc) | $P$ (10^{-11} erg cm^{-3}) | $V$ (10^{60} cm^{3}) | $E_{\text{cav}}$ (10^{50} erg) | $t_{\text{cav}}$ (10^4 yr) | $P_{\text{cav}}$ (10^{53} erg s^{-1}) | $L_{\text{radio}}$ (10^{45} erg s^{-1}) |
|-------------|-------------|-----------|---------------------------|---------------------|--------------------------|-----------------|-------------------|------------------|
| 23.9        | 21.3        | 22.6      | 2.2                       | 1.2                 | 1.2                      | 7.5             | 4.6               | 0.065_{-0.03}^{+0.02} |

Notes. $R_1$, $R_2$, and $R$ represent the semi-major axis, the semi-minor axis, and the average radius ($= \sqrt{R_1 R_2}$) of the approximate ellipses describing the cavities, respectively. $P$ is the pressure of the hot gas surrounding the cavities, $V$ is the volume of the (prolate) ellipsoidal cavities, $E_{\text{cav}}$ is the total energy required to create the cavities, $t_{\text{cav}}$ is the cavity age, $P_{\text{cav}}$ is the jet power required, and $L_{\text{radio}}$ is the 10 MHz–10 GHz integrated radio power of the WAT source. Details are given in Section 4.9.1.
“cavity 1” is formed by the energy deposited into the ICM by the radio jets of the WAT source in A3532 from a past central AGN outburst. In that case, $P_{\text{cav}}$ can provide an estimate for the energy released during that AGN outburst. From the results obtained by Birzan et al. (2004) and Rafferty et al. (2006), we find that the typical observed deficit in the cooling luminosity of clusters with X-ray cavities is between $10 - 1000 \times 10^{42}$ erg s$^{-1}$ and for a cluster with A3532-like bolometric X-ray luminosity, it is $\sim 400 \times 10^{42}$ erg s$^{-1}$ for “cavity 1” is about one-tenth of this value (see Table 11). One can, therefore, speculate that only the combined effect of a few such past outbursts could have led to the disruption of the cool core in A3532 (see Birzan et al. 2004; Dunn et al. 2005, 2010; Rafferty et al. 2006). However, due to the short exposure of the Chandra observation, it is not possible to reliably estimate and compare the deficit in the cooling luminosity of A3532 and the total energy requirements of all the X-ray cavities in it.

5. DISCUSSION AND CONCLUSIONS

The combined image of the diffuse X-ray emission of the cluster pair A3532–A3530 shows excess X-ray emission in an OR between the clusters (Figure 1). In the thermodynamic maps described in Section 4.5, this OR is found to have a significantly lower temperature and abundance than the clusters themselves, thereby nullifying the possibility of cluster scale mergers taking place between them. This observation is in agreement with the findings of Mauduit & Mamon (2007; see Section 1). The results obtained by us can have two possible interpretations. In the first scenario, the clusters are approaching each other for the first time and are tidally interacting in their OR, as a precursor to a possible merger at a later time. The interaction between the two clusters has just started and, therefore, the X-ray gas in the OR is neither very hot nor highly enriched with metals. In the second possible scenario, the individual X-ray halos of the two clusters are well separated from each other and the OR seen between the clusters is merely due to their chance superposition (see Section 1). However, from our analysis of the galaxy velocity information available for the clusters (see Section 4.8), both A3532 and A3530 seem to be at the same redshift, and therefore, we believe that the probability of the OR being a result of a chance superposition is very low.

A3530 shows almost constant or smoothly varying thermodynamic maps and profiles. Therefore, no significant merger activity within A3530 could be detected. However, there are many indications of ongoing galaxy scale mergers in the inner regions of the cluster A3532. These are described in the following. First, the average temperature of A3532 is significantly higher than that of A3530. Second, the thermodynamic maps show high temperature regions in various parts of the cluster. Third, it is seen to host a dumbbell system of BCGs at its center, and the brighter nucleus of the dumbbell contains a WAT radio source, which is mostly seen in merging clusters of galaxies. However, gravitational interaction between the galaxies of the dumbbell may also be responsible for the presence of the WAT. The overall geometry of the WAT, which has very closely aligned tails, may be attributed to the projection effects due to an apparently small angle between the plane of the WAT and our line of sight. At low frequencies, the radio emission shows an extension toward the northwest, which is either a part of the WAT radio emission or a separate source. The extension seems to have a steep spectrum and a rough estimate of the power-law spectral index is close to $-2$.

The bolometric X-ray luminosities of the two clusters are found to be close to those of the rich clusters but with slightly higher average temperatures. While a high temperature in A3532 is possibly due to ongoing galaxy scale mergers in its inner regions, high temperature in A3530 is not clear. However, an interaction between the pair of galaxies located at the center of A3530 may have resulted in increasing the temperature. A deeper exposure with the Chandra will be required to test this scenario.

The gas mass estimates of the clusters (Section 4.7) show A3532 to be marginally more massive than A3530, while their virial mass estimates (Section 4.8) have large errors and do not show any significant difference. On comparing with the $M_{\text{vir}}$ estimates of the two clusters obtained by Ettori et al. (1997; see Section 1), the virial mass obtained by us for A3530 is found to be consistent while that for A3532 is smaller. This discrepancy is probably because the method used by Ettori et al. and the underlying assumptions were different from our analysis and also because a small number of galaxies was used for the virial mass estimation, which might have led to large errors in fitting the galaxy velocity distribution.

A3532 and A3530 have been classified as non-cooling flow clusters in the literature (see Section 1). The cooling time estimates of both clusters (see Section 4.6) are also found to be close to the Hubble time, as is observed for the NCC clusters. However, A3530 shows some other properties which are similar to the cool core clusters. A significantly low value of the deprojected temperature is found at its center, where the temperature drops to about $\sim 70\%$ of the average value obtained for the cluster (see Section 4.4.2). The elemental abundance in A3530 is found to peak at the center (see Section 4.4.1), with a gradual decrease outward. Negative metal abundance gradients are typical of cool core clusters (Johnson et al. 2011; De Grandi & Molendi 2001; Irwin & Bregman 2001; Finoguenov et al. 2000). The projected global and central values of elemental abundance for A3530 obtained by us ($0.28^{+0.05}_{-0.04}$ and $0.48^{+0.10}_{-0.14}$ solar, respectively) are consistent with those of the cool core clusters ($0.37 \pm 0.4$ and $0.42 \pm 0.06$ solar, respectively; Irwin & Bregman 2001). In addition, A3530 shows smooth, isotropic, and centrally peaked profiles of X-ray surface brightness and the thermodynamic quantities (see Sections 4.1, 4.4.1, 4.4.2, and 4.5), which are usually found in the relaxed cool core clusters. Based on all these observations, the possibility of a weak cool core in A3530 cannot be ignored. To confirm the weak cool core, deeper high-resolution X-ray observations of the central region of A3530 will be required. A3532, unlike A3530, shows many properties similar to the NCC clusters, e.g., the presence of high temperature regions at the center as well as in the other parts of the cluster, anisotropic variations in the X-ray surface brightness and thermodynamic maps, and no definite trend in the abundance profile of the cluster. A3532, therefore, seems to be an NCC cluster where cooling flows may have been disrupted by past activity in the central AGN (see Fabian 2002; McNamara & Nulsen 2007; Mittal et al. 2009; Baldi et al. 2009; Ehler et al. 2011; and the discussion given in Section 4.9.1 of this paper).

In agreement with the findings of Pimbblet (2008), neither cluster shows any signs of subclustering in either optical or large-scale ($\sim 5'$) X-ray emission, which is believed to be a prerequisite for an ongoing merger. However, in the high-resolution Chandra images of A3532 (Figures 3 and 15), we do see the presence of small-scale (20') substructures in its central region. The Chandra images show a distorted X-ray...
The X-ray data used in this research have been obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA's Goddard Space Flight Center. We have used observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA member states and the USA (NASA), and the Chandra X-Ray Observatory, managed by NASA's Marshall Center. We thank the Chandra and XMM helpdesk for their assistance on X-ray data analysis. Data were also obtained from the Australia Telescope Compact Array which is a part of the Australia Telescope National Facility, funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO. We have also made use of the survey data from the TGSS (http://tgss.nrao.tifr.res.in) with the GMRT, and from the VLSS and NVSS with the VLA. VLA is maintained by the NRAO, which is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. Finally, we thank the anonymous referee for his valuable comments and suggestions that have helped us improve many of our results.

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