We present a detailed imaging and spectral analysis of the merging environment of the bimodal cluster A3395 using X-ray and radio observations. X-ray images of the cluster show five main constituents of diffuse emission: A3395 NE, A3395 SW, A3395 NW, A3395 W, and a filament connecting NE to W. X-ray surface brightness profiles of the cluster did not show any shock fronts in the cluster. Temperature and entropy maps show high-temperature and high-entropy regions in the W, the NW, the filament, and between the NE and SW subclusters. The NE, SW, and W components have X-ray bolometric luminosities similar to those of rich clusters of galaxies but have relatively higher temperatures. Similarly, the NW component has X-ray bolometric luminosity similar to that of isolated groups but with much higher temperature. It is, therefore, possible that all the components of the cluster have been heated by the ongoing mergers. The NE subcluster is the most massive and luminous constituent and other subclusters are found to be gravitationally bound to it. The W component is most probably either a clump of gas stripped off the SW due to ram pressure or a separate subcluster that has merged or is merging with the SW. No X-ray cavities are seen associated with the wide-angle-tailed (WAT) radio source near the center of the SW subcluster. Minimum energy pressure in the radio emission peaks of the WAT galaxy is comparable with the external thermal pressure. The radio spectrum of the WAT suggests a spectral age of $\sim 10$ Myr.

Key words: galaxies: clusters: general – galaxies: clusters: individual (A3395) – galaxies: clusters: intracluster medium – radio continuum: galaxies – X-rays: galaxies: clusters

Online-only material: color figures

1. INTRODUCTION

Clusters of galaxies, the largest gravitationally bound structures, are believed to form hierarchically in a sequence of cosmic structure formation where smaller groups of galaxies merge to form larger and richer systems (Geller & Beers 1982; Dressler & Shectman 1988; Girardi et al. 1997; Kriessler & Beers 1997; Jones & Forman 1999; Schuecker et al. 2001; Burgett et al. 2004). The intra-group or intracluster medium (ICM) of these clusters contains a hot ($T \sim 10^7$–$10^8$ K) and tenuous ($n \sim 10^{-3}$ cm$^{-3}$) plasma which emits in X-rays mainly through bremsstrahlung and line emission (Kellogg et al. 1972; Mitchell et al. 1976; also see reviews by Sarazin 1988; McNamara & Nulsen 2007). Although many rich clusters show smooth X-ray surface brightness distributions with a central peak, a large fraction (at least, $\sim 30\%$ (Forman & Jones 1990) or even up to $\sim 40\%$–$60\%$ (Jones & Forman 1992, 1999; Schuecker et al. 2001)) shows double or multiple peaks in their X-ray surface brightness maps. As X-ray surface brightness is more sensitive to density than temperature these observations effectively show peaks in the density distribution of the ICM itself, which suggests the presence of subclusters or substructures which are possibly in the process of merging to form richer groups and clusters of galaxies (e.g., Nakamura et al. 1995). The presence of large inhomogeneities in the X-ray temperature of the ICM (greater than a few keV) on scales less than 0.5 Mpc provides additional observational evidence of mergers (Roettiger et al. 1996). As dynamical evolution rapidly removes substructures, their existence proves that such clusters are dynamically young systems (Flin 2003).

For studies of cosmology and the formation and evolution of large-scale structures, it is important to study the physical properties of clusters of galaxies containing subgroups which are young and in the process of merging. Mergers of subgroups can produce shocks, bulk gas flows, and turbulence in the ICM, and can disrupt cooling flows as has been seen in many clusters (see Fabian 1994; Markevitch & Vikhlinin 2007; Owen et al. 2011; Maurogordato et al. 2011). Mergers may also cause metal enrichment of the ICM through enhanced ram pressure stripping during mergers (Domaiakno et al. 2005), thereby affecting the evolution of the galaxies and the ICM. Subclustering information has also been used for estimating cosmological parameters such as the density parameter $\Omega_0$ (Richstone et al. 1992; Kauffmann & White 1993; Anglick & Bartelmann 2011).

At radio wavelengths, besides the diffuse emission which may be in the form of halos and relics, the tailed radio sources associated with individual galaxies can provide further insights toward understanding these systems. For example, the wide-angle-tailed (WAT) galaxies are usually associated with the dominant galaxy in a group or a cluster, with the jets flaring into tails of emission which can extend to over an Mpc in size (e.g., Roettiger et al. 1996; Douglass et al. 2008; Mao et al. 2010). Their relatively high luminosity, close to the upper range of the Fanaroff–Riley I (FRI) sources, and large sizes make these good tracers of galaxy clusters at moderate and high redshifts (e.g., Blanton et al. 2003; Douglass et al. 2008). Since the dominant galaxies with which WATs are associated are likely to have at most small peculiar velocities, their jets are unlikely to be bent by ram pressure caused by the motion of the galaxy (Burns 1981; Eilek et al. 1984; O’Donoghue et al. 1990). Cluster mergers where relative velocities between the systems can exceed $\sim 1000$ km s$^{-1}$, causing significant bulk motion of the ICM, have been invoked as the primary scenario for understanding the WAT structures (Eilek et al. 1984; Burns et al. 1994; Roettiger et al. 1996).
X-ray observatories, particularly *Chandra* and *XMM-Newton*, have brought to light new information leading to a more detailed understanding and new insights into the physical processes occurring in galaxy clusters (Weratschnig 2010). While *Chandra* with its unprecedented spatial resolution of 0.5″ can study small-scale phenomena, such as cold fronts, merger shocks, and active galactic nucleus cavities, *XMM-Newton* with its larger collecting area and sensitivity can study clusters to a much further extent and can detect fainter X-ray signals. Because of its large field of view (FOV) of ~30' and moderate resolution (6″ FWHM), *XMM-Newton* can also study the nearby clusters very well.

We have chosen A3395 for a detailed study of its merging environment since it is a well-known bimodal merging cluster (Henriksen & Jones 1996; Markevitch et al. 1998; Donnelly et al. 1998), very well. The positional coordinates of A3395 are R.A.(J2000) = 06h27m31.0498, the redshift of the cluster. The region between the two main subcluster components. By using Newtonian energy considerations Donnelly et al. proved that the system of the two subclusters is in a bound state and determined the virial masses of the two main subclusters (NE and SW) as $4.5^{+1.1}_{-0.8} \times 10^{14} M_\odot$ and $3.1^{+1.8}_{-1.4} \times 10^{14} M_\odot$, respectively. Tittley & Henriksen (2001) report the presence of a group of lower redshift galaxies ($z = 0.048$), at ~12' northwest from the center of the galaxy distribution, which is elongated in the NW–SE direction. They found an increase in the X-ray emission from this group and classified this as the third component of X-ray emission viz., A3395 NW (centered at R.A.(J2000) = 06°26′35″, decl.(J2000) = −54°20′). This is in addition to the two main X-ray peaks A3395 NE and A3395 SW, that coincide with subclusters, at slightly higher redshifts of 0.051 and 0.052, respectively. Using ASCA and wide FOV *ROSAT* observations, they also detected a filamentary structure that connects the clusters A3395 and A3391, shown by the presence of excess X-ray emission in a region between the two clusters and aligned with the distribution of galaxies.

A3395 has also been observed in radio with the Molonglo Cross Telescope at 408 MHz (Large et al. 1981) and with the Molonglo Observatory Synthesis Telescope (MOST) at 843 MHz (Jones & McAdam 1992; Burgess & Hunstead 2006). The observations showed a W AT inside the cluster. The cluster was also observed by ATCA at a frequency of 4.79 GHz (Gregorini et al. 1994). Reid (2000) used ATCA observations of this cluster at 1348 MHz and 2374 MHz, and detected eight radio sources of which five had optical counterparts. There are two prominent radio sources in the SW subcluster, a W AT at the center (close to the X-ray peak) and a head–tail (HT) galaxy at the periphery. We have used the ATCA data to understand the interaction of the WAT radio emission with the ICM.

### 3. OBSERVATIONS AND DATA REDUCTION

A journal of the *XMM-Newton* and *Chandra* observations of A3395 is given in Table 1.

#### 3.1. *XMM-Newton*

The cluster was observed with *XMM-Newton* on 2007 January 24 (Table 1). The three EPIC cameras MOS1, MOS2 (Turner et al. 2001), and PN (Strüder et al. 2001) were operated in full frame mode with the thin1 filter. The data have been obtained from the HEASARC archives. The raw MOS1, MOS2, and PN images are shown in Figure 1. Note that the observation has been performed after the loss of MOS1 CCD6 due to a meteorite hit in 2006 June. Also, during the analysis, MOS1 CCD5 was found to be in anomalous mode (because of a strong enhancement of the background at $E < 1$ keV) and hence, has not been used anywhere in the imaging and spectral analysis.

All data analysis has been done using the standard procedures from the Science Analysis System (SAS) software version 9.0. Calibrated photon event files were produced from the raw data using the SAS tasks *epchain* and *emchain* and the latest calibration files. These files were then filtered for the good time intervals using the SAS tasks *mos-filter* and *pn-filter*. Good time intervals found for MOS1, MOS2, and PN CCDs are 27.16 ks, 27.28 ks, and 22.44 ks, respectively (see Table 1).
The histograms of light curves from all three detectors had very well defined Gaussian shapes showing that the data are not much affected by the soft proton contamination. Also the temporal filtering using the tasks *mos-filter* and *pn-filter* removes the soft proton contamination sufficiently. The residual soft proton contamination left after this step was removed from the data by adding power laws to the models (see Snowden & Kuntz 2011, p. 17) used in the spectral analyses done in Sections 4.3, 4.4, and 4.5. The details have been provided in Section 4.3. For removing the quiescent particle-induced background and the cosmic background component we have used the blank-sky observations, which consist of a superposition of pointed observations that have been processed with SAS version 7.1.0 (Carter & Read 2007). Blank-sky event files were obtained for all three detectors by submitting an *XMM-Newton* EPIC Background Blank Sky Products Request Form with the request of a Galactic column in the range \((3.5–8.5) \times 10^{20} \text{ cm}^{-2}\). The blank-sky event files from the MOS(PN) detectors were then filtered for flares using an upper threshold of 0.35(0.40) counts s\(^{-1}\) and then again using the selection criteria of PATTERN \(\leq 12\) (PATTERN \(\leq 4\)) and FLAG = 0. The files were then recast to have the same sky coordinates as A3395. The resulting event files were used for generating all the background images and background spectra for this paper. The high-energy \((E \sim 10–12 \text{ keV})\) count rates for the MOS1, MOS2, and PN detectors from the filtered blank-
sky images were found to be very close to those from the source images showing that the observations were not affected by flares. We could not do the local background subtraction as the source fills almost the entire FOV of the detectors and it was impossible to find emission-free regions and therefore, using local background could have led to oversubtraction.

### 3.1.2. Point-source Subtraction

The MOS1 and MOS2 images were combined together using the SAS tasks `merge` and `evselect` to increase the signal-to-noise ratio of the sources and reach fainter flux levels. Only those events that were spread over less than 4 pixels (i.e., pattern = 0–12) were selected for producing the combined image. Point-source extraction was done simultaneously on the MOS1, MOS2 combined image, and the PN detector image using the SAS task `edetect_chain` which is a combination of several SAS tasks viz., `eb0dect` (in local mode), `esplinemap`, `eb0dect` (in map mode), and `emdetect`. When run in local mode `eb0dect` produced source lists by collecting source counts in the cells of 5 × 5 pixels and using a value of 8 for the minimum detection likelihood (`eb0x Likemin`) (i.e., a value of $e^{-8}$ for the minimum value of the probability of the Poissonian random fluctuation of the counts in the detection cell which would result in the observed number of source counts). Then `esplinemap` was used to generate background maps by using the source list generated by `eb0dect` (in local mode) to remove point sources from the original merged image. Then `eb0dect` (in map mode) uses these background maps to generate a new point-source list (with fainter sources included). A total of 258 point sources were thus detected. Each of these detected sources was checked for each of the detectors, and spurious sources (sources that did not look like actual sources in the individual detector images) were removed. Finally 77 sources for MOS1, 67 for MOS2, and 44 sources for PN were detected. Of these, 22 sources were found to be common in MOS1 and MOS2 and 13 were common in all three detectors. These detected sources were then removed from individual MOS1, MOS2, and PN images to create the cheesed images. The cheesed MOS1 and MOS2 images were combined using the procedure described in Snowden & Kunz (2011). A contour map of diffuse X-ray emission from A3395 using the combined MOS1 and MOS2 image after the removal of point sources and after applying the smoothing function is shown in Figure 2. Contours of the smoothed X-ray emission are also overlaid on the optical image of A3395 from the SuperCOSMOS survey in the $B_j$ band and shown in Figure 3. The optical image shows both the bright central galaxies (BCGs) for the NE and SW regions. The position of the BCG for the NE region coincides with the X-ray emission peak for the NE region whereas the BCG for the SW region is offset from the X-ray emission peak for the SW region by about $\sim 16''$ which is equivalent to $\sim 16$ kpc at the redshift of the cluster.

### 3.2. Chandra X-Ray Observatory

A3395 was observed with Chandra on 2004 July 11 (ObsID 4944) with ACIS-I detector for 22.2 ks (Table 1). The raw Chandra ACIS image is shown in Figure 1. The data were analyzed with the CIAO version 4.3 and CALDB version 4.4.0. No reprocessing of data and time-dependent corrections were required as the ASCDSVER (keyword that stores the processing version information) is DS 7.6.7.2 and time-dependent corrections have become a part of standard data processing after DS 7.3.0. The standard charge transfer inefficiency corrections have been applied. Point sources were detected using the CIAO task `wavdetect` with the detection threshold fixed to the default value $10^{-6}$. A total of 47 bright sources were detected; 16 of these sources were common with the sources detected in the MOS2 detector image, discussed in the previous section. The smoothed, point-source-removed and exposure-corrected Chandra image of the cluster in the 0.3–7.0 keV band is shown in Figure 4.
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A3395 was observed by A. D. Reid and R. W. Hunstead with ATCA on 1995 January 9. The pointing center was $06^h26^m58^s.0$, $-54^d31^m12^s.0$ (J2000) and center frequencies were 1348 and 2374 MHz with bandwidths of 128 MHz. The array was in the 6A configuration, with baselines ranging from 337 to 5939 m. The total integration time was 5.6 hr, consisting of multiple cuts spread over a wide range of hour angles. The primary flux density calibrator was B1934$-$638 and the phase calibrator was B0647$-$475.

Data reduction was carried out in MIRIAD (see Sault et al. 1995) using standard techniques. The restored beams were 11.0 × 8.9 arcsec$^2$ along P.A. = $-30^\circ.5$ at 1348 MHz, and 6.2 × 5.0 arcsec$^2$ along P.A. = $-32^\circ.5$ at 2374 MHz. The rms noise is 1.4 mJy beam$^{-1}$ in the 1348 MHz image and 1.3 mJy beam$^{-1}$ in the 2374 MHz image. A contour map of the 1348 MHz ATCA radio emission has been overlaid on the image from the SuperCOSMOS survey in the $B_J$ band and is shown in Figure 3.

4. ANALYSIS AND RESULTS

4.1. X-Ray Morphology

Figure 5 shows the unsharp-masked image produced from the combined MOS1, MOS2 detector image, by subtracting a large-scale (100″) smoothed image from a small-scale (15″) smoothed image. Five distinct regions can be seen: the A3395 NE, A3395 SW, A3395 W, A3395 NW, and a filament connecting the NE region to the W region. The W region is a small and relatively faint subclump of diffuse emission visible toward the west of the SW region. Only two main X-ray peaks, NE and SW, could be seen in the earlier X-ray images and are believed to be subclusters. Figures 2 and 4 show a strong gradient in the surface brightness in the southeast part of the SW component evident from the compression of X-ray contours in this part, indicating that the SW component is moving along the southeast direction. It appears that the small clump in the W region may also be a subcluster participating in the merger process. The Chandra image of the cluster (Figure 4) does not fully cover the NE and W regions. None of the three regions in A3395 cluster show a circular symmetry. Therefore, for the analyses that follow, we have made elliptical approximations for them. The NE, SW, and the W regions have been approximated as ellipses with semi-major axis lengths 432', 566', and 475', respectively, measured from the north in a counterclockwise direction (shown with the green ellipses in Figure 5). A3395 NW can be seen as a region of weak X-ray emission toward the north and northwest of the cluster in Figure 5. This excess emission was first reported by Tittley & Henriksen (2001). The optical image of A3395 NW shows a clustering of galaxies, however, its X-ray emission is very diffuse and does not seem to clump. The mean velocity of the group of galaxies associated with the NW, from the velocity data given in Teague et al. (1990) is $14540 \pm 70$ km s$^{-1}$, while the same calculated from the velocity data given in Donnelly et al. (2001) is $15110 \pm 130$ km s$^{-1}$. The data by Donnelly et al. put this group at almost the redshift of the NE and SW subclusters. Considering that A3395 NW lies along the filament joining the clusters A3395 and A3391 (Tittley & Henriksen 2001), it appears to be a part of the supercluster network.

4.2. X-Ray Surface Brightness Profiles

Merging clusters like A3395 can host both shock and cold fronts which can be confirmed by surface brightness and temperature discontinuities. The discontinuities are seen by a change in the slope of the profile. In order to search for these features, surface brightness profiles for the NE, SW, and W...
regions were made. We have used the raw MOS1, MOS2, PN detector images (without any smoothing applied but with the point sources removed by applying the cheese masks generated by the “cheese” task) and the point-source-removed the raw Chandra ACIS detector image to derive the surface brightness profiles. We used 25 annuli in the NE, 10 annuli in the SW, and 9 annuli in the W regions centered at the intensity peaks in each of the NE, SW, and W regions, which were further divided into 12 sectors of 30° each. The ellipses are such that the \( n \)th ellipse for the NE region has a semi-major axis of \( n \times 28'.0 \), the SW region has a semi-major axis of \( n \times 28'.1 \), and the W region has a semi-major axis of \( n \times 21'.6 \). The major-axis position angles and ellipticities for the ellipses in NE, SW, and W regions were the same as given in Section 4.1 and the 30° sectors have been arranged symmetrically about the major axes. To analyze the surface brightness in the region between NE and SW subclusters (which is not covered by the green ellipses in Figure 5) and also to avoid overlaps between the three subclusters, the area spanned by the ellipses in the NE subcluster is larger, whereas that for the ellipses in the SW and W subclusters is almost the same as compared to the green ellipses in Figure 5. In the SW region, certain sectors had holes (due to point-source removal) at the center. Also, in the NE region, a few outermost annuli in the sectors with position angles from 55° to 145° had no MOS1 data (because of the missing CCD6 in MOS1), and with position angles from 295° to 205° had no Chandra data. In addition to this, the raw images had spurious discontinuities at the positions where the individual CCDs in a detector overlap. Points from all affected annular sectors were removed from the plots, but the resulting gaps made it more difficult to identify discontinuities. Surface brightness profiles for all four detectors for each and every sector were obtained and were fitted by using single or multiple (for profiles showing more than one discontinuity) power laws. In order to make confident detections of discontinuities, we focused only on those discontinuities which are seen in all four detectors. All sectors in the NE and SW regions, in general, show a fairly uniform decreasing profile, except for a few sectors that show a change in the slope. The surface brightness profiles of all sectors in the W region show a nearly constant profile. Only those surface brightness profiles that show evidence for a significant change in slope are shown in Figure 6.

The 55°–85° sector (Figure 6(a)) in the NE region shows a discontinuity at a semi-major axis of \( \sim 350'.\). The sectors 205°–235° (Figure 6(b)) and 235°–265° (Figure 6(c)), in the NE region, show a flattening of the slope in all four detectors at a semi-major axis of \( \sim 400'.\). Starting from the center of the NE component, this discontinuity is found at \( \sim 3/4 \) times the distance between the centers of the NE and SW regions (\( d_{\text{NE-SW}} \sim 540' \)). The observed flatness or increase in the surface brightness in a region between the NE and SW subclusters is almost the same as compared to the green ellipses in Figure 5. In the SW region, certain sectors had holes (due to point-source removal) at the center. Also, in the NE region, a few outermost annuli in the sectors with position angles from 55° to 145° had no MOS1 data (because of the missing CCD6 in MOS1), and with position angles from 295° to 205° had no Chandra data. In addition to this, the raw images had spurious discontinuities at the positions where the individual CCDs in a detector overlap. Points from all affected annular sectors were removed from the plots, but the resulting gaps made it more difficult to identify discontinuities. Surface brightness profiles for all four detectors for each and every sector were obtained and were fitted by using single or multiple (for profiles showing more than one discontinuity) power laws. In order to make confident detections of discontinuities, we focused only on those discontinuities which are seen in all four detectors. All sectors in the NE and SW regions, in general, show a fairly uniform decreasing profile, except for a few sectors that show a change in the slope. The surface brightness profiles of all sectors in the W region show a nearly constant profile. Only those surface brightness profiles that show evidence for a significant change in slope are shown in Figure 6.

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4.3. Global X-Ray Spectra

Average spectra of the various components of A3395 were extracted from both the XMM-Newton and Chandra data. For XMM-Newton, these spectra were extracted from elliptical regions for the NE, SW, and W components, and from polygon-shaped regions for the NW component and the filament. The ellipses were centered on the peaks of the surface brightness. The ellipse for the NE region had a semi-major axis of 432″ and an ellipticity of 0.87, the SW region had a semi-major axis of 281″ and an ellipticity of 0.81, and the W region had a semi-major axis of 194″ and an ellipticity of 0.78. For the spectral extraction using Chandra data, the regions used for the SW and the filament were the same as those used for XMM-Newton, while for the NE and W, maximum possible areas were picked by using a polygon-shaped region, since Chandra field does not cover these regions fully. As the NW region was not covered by Chandra, its spectral analysis was done using only XMM-Newton detectors. All these regions are shown in Figure 5. All spectra were extracted in the energy band 0.5–9.0 keV. For MOS data, events with PATTERN \( \leq 12 \) were used, whereas for PN data, events with PATTERN \( \leq 4 \) were selected. For XMM-Newton detectors, the response matrices and effective areas were generated using the tasks rmfgen and arfgen. The neutral hydrogen column density along the line of sight to the cluster (i.e., along \( \alpha = 06^h27^m31^s, \delta = -54^d23'58'' \)) was taken to be \( 6.3 \times 10^{20} \) cm\(^{-2} \) based on Leiden/Argentine/Bonn Galactic H\(_{\text{I}}\) survey (Kalberla et al. 2005), and redshift was frozen to the value of 0.0498 (SIMBAD astronomical database).

Spectral analyses have been performed using the X-ray spectral fitting package Xspec (version 12.5.1). Spectra extracted from all detectors were fitted using the wabs photoelectric absorption model (Morrison & McCammon 1983) and apec plasma emission model (Smith et al. 2001). The relative elemental abundances used in wabs are as given by Anders & Ebihara (1982). The MOS1, MOS2, and PN spectra for each of the regions were fitted simultaneously using three separate wabs*apec models. The values of abundance, temperature, and apec normalization for the models were linked together but were not frozen. The MOS1, MOS2, and PN spectra of the weak emission regions viz., the NW, the W, and the filament showed the presence of residual soft proton contamination (shown by prominent residues in the high-energy end of the spectra) and the residual instrumental Al K-\( \alpha \) line at 1.49 keV. The residual soft proton contamination was modeled by using separate power-law models with diagonal redistribution matrix files (RMF) (see Snowden & Kuntz 2011, p. 17), and the instrumental Al K-\( \alpha \) line at 1.49 keV was modeled by adding Gaussian components separately for MOS1, MOS2, and PN (see Snowden & Kuntz 2011, p. 14). The power-law indices were found to be negative for most cases and hence were frozen to the value of 0.3 (i.e., the minimum recommended in Snowden & Kuntz 2011), while the power-law normalizations were left as free parameters. The center position and the widths of the Gaussian components were frozen to 1.49 keV and 0.02 keV, respectively, in all the spectra,
Figure 6. Surface brightness profiles from three sectors in the NE subcluster ((a)–(c)) made by using MOS1 (blue), MOS2 (red), PN (black), and Chandra ACIS (orange) raw images after removing point sources, obtained from 25 elliptical annuli, each divided into 12 sectors. The profiles have been fitted with single or multiple power laws which are shown using solid lines, and the positions of discontinuities are shown with dotted lines. The SW subcluster shows uniformly decreasing surface brightness profiles in all sectors (not shown here). The surface brightness profiles of the W region from the full $0^\circ$–$360^\circ$ range using five elliptical annuli and the filament from eight rectangular regions approximately parallel to the length of the filament have been shown in (d) and (e), respectively. Points affected by point-source removal, individual CCD overlaps in a detector, and those lying within MOS1 CCD5 and MOS1 CCD6 have been removed. All angles are measured from the north and in the counterclockwise direction.

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

and their normalizations were left as free parameters. The resulting spectra, along with the histograms of the best-fit model spectra are shown in Figure 7 and the best-fit values of the temperature, abundance, and apec normalizations from the XMM-Newton and Chandra spectral analyses are given in Tables 2 and 3, respectively. The confidence contours at the 68.3%, 90%, and 99% confidence levels for the free parameters are shown in Figure 8.

From the confidence contours produced from the spectral analysis using XMM-Newton, it can be seen that the values of the temperatures and abundances for the NE and the SW regions, the NE and W regions, and the NW and W regions are different only at a confidence level of 68.3%. However, the temperature and abundance values for the SW and W regions hardly differ. The temperature and abundance values for the filament appear to be distinct from the values for all other components except for the W region, which are distinct only at a confidence level of 68.3%. The best-fit parameters from Chandra have errors much larger than those from XMM-Newton because of fewer counts and hence, all four sets of confidence contours have large overlaps. While the results for all other regions are in agreement with those from XMM-Newton (within errors), the results from
Figure 7. (a)–(e): average spectra of the A3395 NE, SW, W subclusters, the filament connecting NE to W, and the NW region (reported by Tittley & Henriksen 2001), produced by using the XMM-Newton PN (green), MOS1 (black), and MOS2 (red). (f): average spectra of NE, SW, W subclusters, and the filament produced using Chandra data. All the spectra have been fitted with wabs*apec model shown as a histogram. The power law and Gaussian components in the XMM-Newton spectra have been added to model the residual soft proton contamination and the instrumental Al line at 1.49 keV. Details of the spectral analysis are given in Section 4.3, and the best-fit parameters are shown here as insets. (A color version of this figure is available in the online journal.)

Chandra for the NE region show a temperature slightly higher than that from XMM-Newton. This is possibly because the part of NE which is not covered by Chandra has a lower than average temperature, as is indicated by the temperature map produced from XMM-Newton data in Section 4.5. This was also confirmed by using the same polygon-shaped region for the extraction of spectrum from the NE with MOS1, MOS2, and PN, as was used for Chandra spectral analysis, and the results were in mutual agreement. The background systematic errors (assuming 10%) do not affect the results significantly.

4.4. Azimuthally Averaged Spectrally Determined Radial Profiles of Thermodynamic Quantities

We also produced azimuthally averaged profiles of temperature, density, entropy, and pressure for the cluster by extracting spectra in elliptical annuli using both XMM-Newton and Chandra data. The NE, SW, and W subclusters were divided into seven, five, and four elliptical annuli, respectively (shown in Figure 5). The centers of the ellipses were at the peak of the X-ray emission for all three regions. Ellipses in the NE regions
had semi-major axis lengths of 84″, 132″, 184″, 240″, 300″, 364″, and 432″. Similarly, ellipses in the SW region had semi-major axis lengths of 93″, 140″, 187″, 234″, and 280″, and the W region had semi-major axis lengths of 64″, 108″, 151″, 2, and 194″. Spectra were extracted from all the annuli for all three detectors of XMM-Newton. However, for Chandra data, only the innermost four annuli in the NE and innermost two annuli in the W region were used as Chandra did not cover the NE and W parts completely. For the SW (b) cluster, spectra were extracted from all five annuli. All the spectra were extracted in the energy band of 0.5–9.0 keV. Both the projected and deprojected profiles of temperature, density, entropy, and pressure were obtained.

### 4.4.1. Two-dimensional Projected Profiles

The details of spectral analyses performed are the same as given in Section 4.3 except that the elemental abundances were fixed to the respective average abundance value obtained from the spectral fitting of the NE, SW, and W regions using XMM-Newton data, i.e., 0.42, 0.35, and 0.3 times the solar value (Z⊙) (Table 2), respectively, for the annuli belonging to the respective region. The temperature profile was obtained directly from the spectral analysis and was used to derive the density, entropy, and pressure profiles. To derive the electron density \(n_e\), we used the apec normalization, \(K = 10^{-14}EI/(4\pi T\Delta a(1 + z)^2)\) (expressed in units of cm\(^{-3}\) in cgs system), where \(EI\) is the emission integral \(\int n_e n_p dV\). We assume \(n_p = 0.855n_e\) (Henry et al. 2004), which under the assumption of constant density within each ellipsoidal shell gives, \(EI = 0.855n_e^2V\), where \(V\) = volume of ellipsoidal shell. For the volume estimation of the ellipsoidal shells we have assumed oblate ellipsoids (i.e., line of sight axis = major axis of the ellipse). Then the volume of a shell, \(V = (4\pi/3)(a^{2/3}b_{out} - a^{2/3}b_{in})\), where \(a_{out}\) and \(b_{out}\) are the semi-major and semi-minor axes of the outer shell and \(a_{in}\) and \(b_{in}\) are those of the inner shell. From the commonly adopted definition, entropy is given by \(S = kTn_e^{2/3}\) and electron pressure \(P = n_e kT\) (Gitti et al. 2010). If the ions have the same temperature as that of the electrons then the total pressure is twice as large. We admit that the volume estimates may introduce errors ~20% (Finoguenov et al. 2004, and references therein; Henry et al. 2004), but even these errors are quite small as compared to the errors in temperatures obtained from the deprojection analysis because of poor statistics of the data. For confirmation we also estimated the entropy and pressure for prolate ellipsoidal shells (i.e., line of sight axis = minor axis of the ellipse) but the differences were very small (~20%).

### 4.4.2. Deprojected Profiles

Projection effects along the line of sight can smooth out the variations in the measured quantities. To correct for this we have performed the deprojection analysis on the same annular regions shown in Figure 5 by using the Xspec projct model, which estimates the parameters in three-dimensional space from the two-dimensional (2D) projected spectra of ellipsoidal shells, using the wabs*apec model. The model calculates the geometrical weighting factor according to which the emission is redistributed among the projected annuli. The elemental abundances for the annuli belonging to the NE, SW, and W
regions were fixed to 0.42, 0.35, and 0.3 times the solar value ($Z_\odot$), the same as in Section 4.4.1. The residual soft proton contamination and instrumental Al lines were modeled by adding power laws and Gaussian components to the models as described in Section 4.3 with the only difference that a single model for all MOS1, MOS2, and PN was used. This was because the \texttt{project} model requires all the spectra belonging to the same annulus to be part of the same group and therefore have to be modeled using the same model. 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 projected and deprojected temperature and density profiles are shown in Figure 9, and the projected and deprojected entropy and pressure profiles are shown in Figure 10. Best-fit parameters and the derived values of other dependent parameters are given in Tables 4–7. The projected spectral analysis resulted in a nearly constant temperature profile for all three subclusters, while the projected density, entropy, and pressure profiles show a uniform decrease, increase, and decrease, respectively, for all three subclusters from the innermost to the outermost annulus. The deprojected temperatures, entropies, and pressures of all the three subclusters show a nearly uniform profile. The deprojected density profiles from all three regions show a uniform decrease except for the outermost annulus where a slight increase in the density is seen. This is a common artifact of deprojection analysis because the excess emission from shells with radii larger than that of the outermost annulus gets added to the outermost annulus. The projected profiles from \textit{Chandra} and \textit{XMM-Newton} are in complete agreement with each other although the former has larger errors as compared to the latter. For the deprojected profiles also, there is a good agreement in the results between \textit{XMM-Newton} and \textit{Chandra} with a few anomalies. For example, the deprojected density for the innermost annulus in the NE region from \textit{Chandra} is greater while the density in the second annulus in the W region from \textit{Chandra} is lower as compared to those from \textit{XMM-Newton}. However, the higher deprojected density and pressure from \textit{Chandra} in the fourth annulus (outermost annulus for \textit{Chandra}) in NE as compared to those from \textit{XMM-Newton} can easily be explained as the artifact of deprojection described earlier in this section.

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

We have made projected temperature, abundance, density, entropy, and pressure maps of A3395, using box-shaped regions for spectral analysis to improve the spatial resolution of the spectral parameters and to look for anisotropy in their spatial distribution. To make the results more robust, both \textit{XMM-Newton} and \textit{Chandra} data have been used and the whole cluster was divided into 139 boxes for \textit{XMM-Newton} and only 42 boxes for \textit{Chandra}. The number of boxes used for \textit{Chandra} were less because of fewer counts and also because \textit{Chandra} did not cover the outer parts of the cluster significantly due to smaller FOV. The sizes of the boxes were chosen adaptively to get sufficient counts in each region. For \textit{XMM-Newton}, large-sized boxes ($\sim 3.1 \times 1.4$ or $\sim 1.6 \times 2.9$) for the outermost parts, small-sized boxes ($\sim 47^\prime \times 43^\prime$) for the innermost brightest parts, and medium-sized boxes ($\sim 1.6 \times 1.4$) for the regions in between were made to get more than 700 total counts from all three detectors in each box. For \textit{Chandra}, large-sized boxes ($\sim 3.1 \times 1.6$) for outer parts and small-sized boxes ($\sim 1.6 \times 1.6$) for the inner parts were made to get more than 700 counts in each box. Hence, spatial resolution of the thermodynamic maps obtained with \textit{XMM-Newton} is better than that from \textit{Chandra}. Spectra from all boxes were fitted using the \texttt{wabs*apec} model with fixed Galactic absorption. The residual soft proton contamination and instrumental Al lines were modeled by adding power laws and Gaussian components to the models as described in Section 4.3. For the boxes where MOS1 data could not be used (i.e., boxes lying in regions of MOS1 missing CCD6 and anomalous CCD5), only MOS2 and PN spectra were used. The electron density, entropy, and electron pressure were calculated using the same relations as in Section 4.4.1. The volume calculation for the box regions, however, was not as straightforward as in the case of ellipsoidal shells. We had to assume spherical geometry which can be justified because the volumes considered here are very small as compared to those for the ellipsoidal shells. We assumed the 139...
Figure 9. Projected and deprojected, temperature ($kT$) (a) and electron density (b) ($n_e$) profiles from the spectral analysis done using XMM-Newton (red) and Chandra (blue) data on elliptical annuli (shown in Figure 5) of NE, SW, and W regions. For projected spectral analysis, the spectra for all annuli in each of the regions were fitted using the model $wabs*apec$ while for deprojected spectral analysis the spectra for all annuli in each of the regions were fitted together using the model $projct(wabs*apec)$ for a fixed Galactic absorption. Power law and Gaussian components were also added to model the residual soft proton contamination and the instrumental Al line at 1.49 keV. Temperature, and $apec$ normalizations were left as free parameters and the best-fit values of the $apec$ normalizations were used for deriving the $n_e$.

(box regions as projections of parts of spherical shells (centered at the X-ray intensity peak of the subcluster nearest to the box) with inner and outer radii ($R_{in}, R_{out}$) equal to the smallest and largest distance from the center of their respective spheres. The volume for each box region was estimated as $D_A^3 \Omega (\theta^2_{out} - \theta^2_{in})^{1/2}$ (Ehlert et al. 2011; Henry et al. 2004), where $D_A$ is the angular diameter distance and $\Omega$ is the solid angle subtended by the region. $\theta_{in}$ and $\theta_{out}$ are equal to the distances $R_{in}$ and $R_{out}$ expressed in angular units, respectively.

The temperature, density, entropy, and pressure maps produced (from both XMM-Newton and Chandra) are shown in Figures 11, 12, 13, and 14, respectively. Maps obtained from Chandra had larger errors as compared to those from XMM-Newton, and in all the maps fainter regions had larger
Figure 10. Projected and deprojected, entropy (a) and pressure (P) (b) profiles from the spectral analysis done using XMM-Newton (red) and Chandra (blue) data on elliptical annuli (shown in Figure 5) of NE, SW, and W regions. For projected spectral analysis, the spectra for all annuli in each of the regions were fitted using the model \texttt{wabs*apec} while for deprojected spectral analysis the spectra for all annuli in each of the regions were fitted together using the model \texttt{projct(wabs*apec)} for a fixed Galactic absorption. Power law and Gaussian components were also added to model the residual soft proton contamination and the instrumental Al line at 1.49 keV. Best-fit values of the temperature, and \texttt{apec} normalizations were used for deriving the entropy and pressure.

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

The errors range from as low as \(\sim 15\%\) for the innermost regions of NE and SW subclusters to as high as \(\sim 60\%\) for the extreme outermost box regions and the highest temperature regions in the NW and toward the southeastern edge of the SW. Abundance values had large errors in the maps obtained from both XMM-Newton and Chandra, and for most of the boxes only the upper limit of abundance could be obtained, hence the abundance maps have not been shown. Maps from both XMM-Newton and Chandra show a high-temperature and high-entropy region where the NE and SW regions meet. The SW, on average, shows a temperature slightly higher than the average temperature of the NE and even higher temperature regions are seen in the W component, the region joining the NE and SW parts and the filament regions. The NE and SW components have similar average entropies and the W component has slightly higher average entropy. The filament and the region between the NE and SW components have even higher entropies. The highest temperatures and entropies are seen at the southeastern edge of the SW subcluster and in a few regions in the NW component lying above the filament, to the west of the NE subcluster. Although the single \texttt{apec} model provided a good fit for the source spectra of all the regions, for some of the
Fitting the spectra with non-thermal emission from shock-accelerated particles, none of the two models seemed to be statistically preferred. The residuals (for example, the region between the NE and SW) could also be very well fitted using the power-law model (in addition to the fixed index power laws used for modeling the residual soft proton contamination), thus pointing toward a completely non-thermal emission from shock-accelerated particles.

### Table 4
Best-fit Parameters Obtained from the Spectral Analysis of Elliptical Annuli in the NE, SW, and W Regions Using XMM-Newton Data

| Region | Annulus Number | $kT$ (keV) | $n_e$ $(10^{-4}$ cm$^{-3}$) | $P$ $(10^{-12}$ dyne cm$^{-2}$) | $S$ (keV cm$^2$) |
|--------|----------------|------------|-----------------------------|-------------------------------|------------------|
| NE     | 1              | 5.1±0.3    | 33.7±0.3                    | 27.6±2.5                      | 225±19           |
|        | 2              | 4.4±0.4    | 22.0±0.2                    | 15.6±2.0                      | 262±12           |
|        | 3              | 4.7±0.4    | 16.9±0.1                    | 12.8±1.2                      | 335±30           |
|        | 4              | 4.4±0.3    | 13.3±0.1                    | 9.4±0.9                      | 363±33           |
|        | 5              | 4.5±0.4    | 10.5±0.1                    | 7.6±0.7                      | 438±41           |
|        | 6              | 4.3±0.4    | 8.8±0.1                     | 6.0±0.6                      | 467±36           |
|        | 7              | 4.8±0.4    | 6.7±0.1                     | 5.2±0.5                      | 629±57           |
| SW     | 1              | 4.9±0.3    | 33.8±0.3                    | 26.4±1.9                     | 218±15           |
|        | 2              | 5.1±0.3    | 20.3±0.2                    | 16.7±1.1                     | 321±21           |
|        | 3              | 5.2±0.4    | 15.1±0.2                    | 12.5±1.3                     | 392±31           |
|        | 4              | 6.0±0.7    | 11.7±0.1                    | 11.3±1.4                     | 541±67           |
|        | 5              | 5.8±0.9    | 9.3±0.1                     | 8.7±1.3                      | 615±90           |
| W      | 1              | 5.2±0.9    | 30.0±0.6                    | 25.2±1.8                     | 252±27           |
|        | 2              | 5.2±1.0    | 19.2±0.4                    | 16.1±3.7                     | 338±69           |
|        | 3              | 5.4±0.9    | 14.4±0.2                    | 12.5±2.3                     | 423±75           |
|        | 4              | 6.1±1.2    | 11.8±0.3                    | 11.5±2.5                     | 547±116          |

**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 set to the value of 0.42, 0.35, and 0.3 times the solar values for NE, SW, and W regions, respectively. 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. The 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 5
Best-fit Parameters Obtained from the Spectral Analysis of Elliptical Annuli in the NE, SW, and W Regions Using Chandra Data

| Region | Annulus Number | $kT$ (keV) | $n_e$ $(10^{-4}$ cm$^{-3}$) | $P$ $(10^{-12}$ dyne cm$^{-2}$) | $S$ (keV cm$^2$) |
|--------|----------------|------------|-----------------------------|-------------------------------|------------------|
| NE     | 1              | 4.2±0.9    | 35.6±0.9                    | 24.0±5.5                      | 181±40           |
|        | 2              | 5.0±1.2    | 22.1±0.5                    | 17.5±1.5                      | 293±52           |
|        | 3              | 5.7±1.8    | 17.1±0.3                    | 15.7±2.2                      | 407±60           |
|        | 4              | 4.9±0.9    | 13.6±0.3                    | 10.7±2.0                      | 403±71           |
| SW     | 1              | 5.0±0.7    | 35.3±0.7                    | 28.1±5.5                      | 215±33           |
|        | 2              | 4.7±0.8    | 20.9±0.5                    | 15.8±1.0                      | 289±31           |
|        | 3              | 5.0±0.9    | 15.3±0.3                    | 12.2±2.1                      | 377±61           |
|        | 4              | 5.2±1.3    | 11.4±0.3                    | 10.0±2.6                      | 500±124          |
|        | 5              | 6.6±1.8    | 9.1±0.2                     | 9.5±2.8                      | 702±203          |
| W      | 1              | 3.2±1.0    | 27.6±1.6                    | 14.4±5.2                      | 165±57           |
|        | 2              | 5.1±1.3    | 18.3±0.7                    | 14.9±5.4                      | 341±92           |

**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 set to the value of 0.42, 0.35, and 0.3 times the solar values for NE, SW, and W regions, respectively. The 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.

### 4.6. Radio Sources

The ATCA images at 1348 and 2374 MHz show that the most prominent source in the field is the WAT source PKS B0625−545 (MRC B0625−545) which is identified with an elliptical galaxy at a redshift of 0.05174 (Teague et al. 1990).
have observed similar bends in the W AT source in A562 and have flow at toward the west and then again bend sharply further down the

Table 6
Best-fit Parameters Obtained from the Deprojected Spectral Analysis of Elliptical Annuli in the NE, SW, and W Regions Using XMM-Newton Data

| Region | Annulus Number | $kT$ (keV) | $n_e$ ($10^{-4}$ cm$^{-3}$) | $P$ ($10^{-12}$ dynes cm$^{-2}$) | $S$ (keV cm$^2$) |
|--------|----------------|------------|-----------------------------|-------------------------------|-----------------|
| NE     | 1              | 4.5$^{+2.0}_{-1.2}$ | 23.0 ± 1.3                 | 16.4$^{+3.3}_{-3.5}$          | 258$^{+124}_{-81}$ |
|        | 2              | 4.4$^{+2.4}_{-1.4}$ | 20.6 ± 1.2                 | 14.6$^{+5.4}_{-7.7}$          | 272$^{+57}_{-95}$ |
|        | 3              | 3.6$^{+3.5}_{-1.0}$ | 16.6 ± 0.8                 | 9.6$^{+3.8}_{-3.0}$           | 250$^{+228}_{-77}$ |
|        | 4              | 4.6$^{+0.9}_{-1.3}$ | 16.2 ± 0.5                 | 11.9$^{+2.7}_{-3.9}$          | 334$^{+72}_{-105}$ |
|        | 5              | 3.5$^{+3.0}_{-0.7}$ | 12.7 ± 0.5                 | 7.1$^{+6.4}_{-3.7}$           | 297$^{+263}_{-88}$ |
|        | 6              | 3.4$^{+1.4}_{-0.7}$ | 11.8 ± 0.5                 | 6.3$^{+2.9}_{-1.6}$           | 300$^{+135}_{-71}$ |
|        | 7              | 4.6 ± 0.6       | 14.8 ± 0.3                 | 10.9 ± 1.6                   | 355 ± 50         |
| SW     | 1              | 4.3$^{+1.7}_{-1.0}$ | 28.6 ± 1.0                 | 19.7$^{+5.2}_{-3.5}$          | 214$^{+57}_{-54}$ |
|        | 2              | 5.5$^{+1.6}_{-1.7}$ | 20.6 ± 0.8                 | 18.1$^{+0.6}_{-6.2}$          | 339$^{+108}_{-112}$ |
|        | 3              | 4.2$^{+1.7}_{-0.9}$ | 18.1 ± 0.7                 | 12.0$^{+5.3}_{-3.2}$          | 280$^{+118}_{-70}$ |
|        | 4              | 4.8$^{+1.9}_{-2.3}$ | 12.8 ± 0.7                 | 9.9$^{+4.3}_{-3.2}$           | 407$^{+725}_{-206}$ |
|        | 5              | 5.0$^{+1.7}_{-0.7}$ | 18.8 ± 0.5                 | 15.0$^{+5.4}_{-2.4}$          | 320$^{+51}_{-34}$ |
| W      | 1              | 3.8$^{+3.9}_{-1.8}$ | 19.0 ± 2.1                 | 11.5$^{+12.2}_{-6.6}$         | 245$^{+274}_{-132}$ |
|        | 2              | 6.7$^{+6.1}_{-3.6}$ | 18.8 ± 1.3                 | 20.0$^{+12.1}_{-5.2}$         | 438$^{+419}_{-254}$ |
|        | 3              | 3.2$^{+2.7}_{-1.4}$ | 11.7 ± 1.1                 | 6.1$^{+5.6}_{-3.2}$           | 292$^{+258}_{-146}$ |
|        | 4              | 5.4$^{+2.6}_{-1.1}$ | 21.4 ± 0.7                 | 18.4$^{+9.4}_{-4.4}$          | 322$^{+161}_{-74}$ |

Notes. The spectra for all annuli in each region were fitted together using the model project(wabs*apec) for a fixed Galactic absorption and with elemental abundances set to the value of 0.42, 0.5, and 0.3 times the solar values for NE, SW, and W regions, respectively. 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. The 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 Elliptical Annuli in the NE, SW, and W Regions Using Chandra Data

| Region | Annulus Number | $kT$ (keV) | $n_e$ ($10^{-4}$ cm$^{-3}$) | $P$ ($10^{-12}$ dynes cm$^{-2}$) | $S$ (keV cm$^2$) |
|--------|----------------|------------|-----------------------------|-------------------------------|-----------------|
| NE     | 1              | 3.6$^{+3.4}_{-1.4}$ | 30.0 ± 2.6                 | 17.3$^{+1.8}_{-3.1}$          | 174$^{+122}_{-78}$ |
|        | 2              | 3.2$^{+2.6}_{-1.0}$ | 23.3 ± 1.9                 | 11.9$^{+4.8}_{-4.8}$          | 182$^{+157}_{-60}$ |
|        | 4              | 13.7$^{+12.1}_{-7.8}$ | 16.6 ± 2.5                | 36.4$^{+20.2}_{-26.2}$        | 981$^{+972}_{-655}$ |
|        | 4              | 5.0$^{+0.7}_{-0.6}$ | 27.7 ± 0.5                 | 22.0$^{+3.3}_{-3.0}$          | 252$^{+36}_{-33}$ |
| SW     | 1              | 5.1 ± 1.4      | 30.7 ± 1.6                 | 25.0$^{+8.0}_{-8.0}$          | 241 ± 73        |
|        | 2              | 4.3 ± 1.2      | 21.9 ± 1.5                 | 15.2$^{+5.4}_{-5.4}$          | 256 ± 85        |
|        | 3              | 4.5 ± 1.1      | 19.0 ± 1.1                 | 13.6$^{+4.0}_{-4.0}$          | 291 ± 81        |
|        | 4              | 4.3$^{+3.4}_{-1.2}$ | 13.1 ± 1.1               | 9.1$^{+7.0}_{-3.2}$           | 361$^{+306}_{-118}$ |
|        | 5              | 6.4 ± 1.2      | 18.6 ± 0.5                 | 19.1$^{+4.2}_{-4.1}$          | 422$^{+98}_{-38}$ |
| W      | 1              | 2.4$^{+0.8}_{-0.5}$ | 19.5 ± 1.5                | 7.5$^{+3.1}_{-2.3}$           | 155$^{+60}_{-103}$ |
|        | 2              | 5.2$^{+2.0}_{-1.2}$ | 15.0 ± 0.6                 | 12.4$^{+5.4}_{-3.4}$          | 395$^{+166}_{-102}$ |

Notes. The spectra for all annuli in each region were fitted together using the model project(wabs*apec) for a fixed Galactic absorption and with elemental abundances set to the value of 0.42, 0.5, and 0.3 times the solar values for NE, SW, and W regions, respectively. The 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 $\chi^2_{\text{min}}+2.71$.

(Figure 15(a)). Both the oppositely directed jets bend initially toward the west and then again bend sharply further down the flow at ~90 kpc from the host galaxy so that the emission is approximately along the north–south axis. Douglass et al. (2008) have observed similar bends in the W AT source in A562 and have interpreted the bends further down the flow as the regions where the effects of buoyancy become important. Figure 15(b) shows the unsharp-masked Chandra image of the cluster (zoomed in to show the WAT source) produced by subtracting a large-scale (80') smoothed image from a small-scale (4') smoothed image, overlaid with the 1348 MHz radio continuum contours. It may be worth noting that there is no evidence of X-ray cavities associated with the regions of radio emission.

The flux densities of the WAT galaxy at a number of frequencies from low-resolution observations are listed in Table 8, including the values listed by Burgess & Hunstead (2006), and estimates from the ATCA images presented in this paper. The flux density estimated from the ATCA image at 1348 MHz is very close to the measurement at 1410 MHz, suggesting that the interferometric observations at this frequency have not missed
any significant amount of flux density. However, the expected flux density at 2374 MHz from the derived spectrum using the high-frequency points (>800 MHz) is higher than our measured value by \(\sim 20\%\). Although the high-frequency points are consistent with a straight spectrum with a spectral index of \(\sim 1.05\), a good fit to the spectrum is obtained for the Jaffe & Perola (1973) model using the SYNAGE package (Murgia et al. 1999). Excluding the ATCA estimate at 2374 MHz where some flux density is missing, the spectrum is well fitted with an injection spectral index of 0.62 and a break frequency of \(\sim 13.9\) GHz (Figure 16). Higher frequency observations would be useful to determine this more reliably.

Besides the WAT galaxy, there is an HT source located at R.A.(J2000): 06\h25\m56.7 and decl.(J2000): \(-54\d27.50\) which is associated with a galaxy at a redshift of 0.05955 (Teague et al. 1990) and is shown in Figure 3. The extent of the HT galaxy is smaller than the WAT, with an angular size of \(\sim 80\)" including the diffuse emission, which corresponds to a linear size of \(\sim 90\) kpc at the redshift of the galaxy. The peak and total flux densities of the HT source at 1348 MHz are 3128 mJy and \(\sim 150\) mJy. The tail is not as well imaged at 2374 MHz where the peak and total flux densities are 8 mJy beam\(^{-1}\) and

![Figure 11.](image1.png)

![Figure 12.](image2.png)

**Table 8**

Flux Densities of the WAT Source

| Frequency (MHz) | Flux density (mJy) | Refs. |
|----------------|--------------------|-------|
| 408            | 7860 \(\pm\) 680   | a     |
| 843            | 5000 \(\pm\) 500    | b     |
| 1348           | 3128 \(\pm\) 156    | P     |
| 1410           | 3200 \(\pm\) 160    | c     |
| 2374           | 1651 \(\pm\) 83     | P     |
| 2650           | 1800 \(\pm\) 90     | c     |
| 2700           | 1730 \(\pm\) 72     | d     |
| 4850           | 931 \(\pm\) 47      | e     |
| 4850           | 1021 \(\pm\) 54     | f     |
| 5000           | 870 \(\pm\) 44      | d     |
| 8400           | 460 \(\pm\) 23      | g     |

**Notes.** (a): Large et al. 1981; flux density estimated from the integrated flux ratio in the Molonglo Transit Catalogue (Burgess & Hunstead 2006); (b): integrated flux density at 843 MHz, measured with the Volume program from a MOST CUTS image as listed in Burgess & Hunstead (2006); Jones & McAdam (1992) quote a somewhat higher value of 5610 \(\pm\) 505 mJy; (c): Gardner et al. 1969; (d): Wall et al. 1975; (e): Gregory et al. 1994; (f): Wright et al. 1994; (g): PKS Catalogue 1990, as listed in NED (Wright & Otrupcek 1990), errors of \(\sim 5\%) have been assumed; (P): Present paper; ATCA observations. The 2374 MHz observation is missing flux and has not been used in the spectrum plot in Figure 16.
Figure 13. Projected entropy maps from 139 box regions using XMM-Newton data (top) and 42 box regions using Chandra data (bottom) with overlaid X-ray surface brightness contours having levels the same as in Figures 2 and 4, respectively. The scales are expressed in units of keV cm$^2$ shown in the bars alongside. Details of the spectral fittings are provided in Section 4.5. (A color version of this figure is available in the online journal.)

Figure 14. Projected pressure maps from 139 box regions using XMM-Newton data (top) and 42 box regions using Chandra data (bottom) with overlaid X-ray surface brightness contours having levels the same as in Figures 2 and 4, respectively. The scales are expressed in units of erg cm$^{-3}$ shown in the bars alongside. Details of the spectral fittings are provided in Section 4.5. (A color version of this figure is available in the online journal.)

4.7. X-Ray Luminosity Estimates

X-ray luminosities for the NE, SW, W, NW, and the filament regions using XMM-Newton and for the NE, SW, and W, and the filament regions using Chandra in the energy range 0.5–9.0 keV were estimated from the flux values obtained from the spectral analysis of these regions described in Section 4.3. The fluxes ($F_X$) were estimated by convolving the model used in Section 4.3 with the Xspec convolution model, cflux after freezing the apec normalization. The X-ray luminosities ($L_X$) were then obtained from the fluxes using the formula

$$L_X = 4\pi D_L^2 F_X,$$ (1)

where $D_L$ is the luminosity distance to the source. The luminosities ($L_X$) derived from the flux values obtained from the spectral analysis done using XMM-Newton and Chandra data are given in Tables 2 and 3, respectively. We also obtained the bolometric luminosities of the NE, SW, W, and NW components. For this purpose, we fitted the $0^\circ$–$360^\circ$ surface brightness profiles of the NE, SW, and W subclusters using $\beta$-profiles, and the average count rates were obtained from the same regions as in Section 4.3. For the NW component the average count rate was obtained from an elliptical region (an approximation to the polygon-shaped region used for the NW...
Figure 15. (a): optical image from the SuperCOSMOS survey in the $B_J$ band of the region surrounding the WAT source in A3395 SW overlaid by ATCA 1348 MHz radio continuum contours. Contour levels are at 0.005 times 1, 2, 4, 8, 16, and 32 Jy beam$^{-1}$.

(b): Chandra unsharp-masked image produced by subtracting a large-scale (80$''$) smoothed image from a small-scale (4$''$) smoothed image of the same region as (a) overlaid by the same ATCA 1348 MHz radio continuum contours (green). Positions of the northern and southern emission peaks have also been shown. The color scale shown as a bar is expressed in units of counts s$^{-1}$ arcsec$^{-2}$.

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

in Section 4.3) with semi-major and semi-minor axis lengths of 11.11 and 4.45, respectively. By using the HEASARC tool Web Portable, Interactive, Multi-Mission Simulator (WebPIMMS), these count rates were converted to fluxes in the energy range of 0.01–100 keV from which bolometric X-ray luminosities were obtained using the relation given above in this section. The results obtained from the $\beta$-model fitting along with the estimated X-ray bolometric luminosities of the NE, SW, W, and NW components of A3395 with those obtained from these relations, we find that the NE, SW, and W subclusters have bolometric X-ray luminosities within a factor of 1.5–2 of each other, and are close to the $L_X$–$kT$ relation for the rich clusters obtained by Xue & Wu (2000). The temperatures of these regions are almost twice those of the rich clusters of similar luminosities. However, the NW component is subluminous by about an order of magnitude, as compared to the rich clusters of similar temperatures and is hotter as compared to the isolated groups of similar luminosities. From these observations, it seems highly probable that all the components of the cluster have been heated up due to the ongoing merger processes.

4.8. Gas Mass

The projected gas densities obtained from Section 4.4.1 for different annuli in the NE, SW, and W regions were fitted using...
data and by using the equations from Sarazin (1988), we calculate the cooling times for the three regions NE, SW, and W of A3395, assuming them to be subclusters, as

$$\beta$$

Errors are quoted at 68% confidence level (1σ)

Notes. Errors are quoted at 68% confidence level (1σ) based on $\chi^2_{\text{red}} + 1.00$. The gas mass for the NW region was calculated by assuming a constant density (derived from the apec normalization obtained from the spectral analysis of the NW region in Section 4.3) in an oblate ellipsoid made from the ellipse used for the NW region in Section 4.7. The density was derived from the normalization obtained from the spectral analysis of the NW region in Section 4.4.1 and the value of the gas mass for the NW region was calculated by assuming a constant density in the NW component was also made 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 $\rho_0$ is the central density and $r_c$ is the core radius. The gas mass $M_{\text{gas}}(r)$ out to radii 0.5 Mpc and 1 Mpc for the NE, SW, and W regions were obtained by using the following formula:

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

5. DISCUSSION

The present X-ray observations of A3395 show that the cluster morphology is much more complex than the simple bimodal structure reported earlier. We identify four distinct regions of strong diffuse X-ray emission, namely, the NE, SW, and W, and the filament connecting the W to the NE part of the cluster. In addition, a fifth component A3395 NW is seen as a weak excess emission in the northwest of the cluster, which was also detected by Tittley & Henriksen (2001) and is most probably a part of the supercluster filament connecting the clusters A3395 and A3391. Because of a larger FOV, better sensitivity, and larger energy band coverage of the XMM-Newton, we have been able to better constrain the values of the X-ray temperature and luminosities for the NE and SW subclusters, as compared to their values from earlier observations that used ROSAT and ASCA data. The temperatures determined by us for the NE (4.8 ± 0.1 keV) and SW (5.1 ± 0.1 keV) subclusters are very close (within uncertainties) to the values reported earlier by Markevitch et al. (1998) (~5.8 ± 0.8 keV for the NE and ~5.5 ± 0.8 keV for the SW subcluster) based on ASCA data. We have estimated the X-ray luminosities of all the components of the cluster in the energy range of 0.5–9.0 keV and the values are given in Table 2.

Table 10

| Region | $\beta$ | $r_{c}$ (10^{-2} Mpc) | $\rho_0$ (10^{13} M_{\odot} Mpc^{-3}) | $r$ (Mpc) | $M_{\text{gas}}(r)$ (10^{15} M_{\odot}) |
|--------|--------|------------------------|-----------------------------|--------|-----------------------------|
| NE     | 0.36 ± 0.01 | 6.0 ± 0.6 | 6.8 ± 0.4 | 0.5 | 0.54 ± 0.07 |
| SW     | 0.55 ± 0.06 | 11.4 ± 2.2 | 4.7 ± 0.6 | 0.5 | 0.4 ± 0.1 |
| W      | 0.36 ± 0.07 | 7.4 ± 2.2 | 3.9 ± 0.4 | 0.4 | 0.4 ± 0.2 |
| NW     | ... | ... | ... | ... | 0.11 ± 0.02 |

5.1. Subclustering Analysis

A3395 W appears to be a distinct region of X-ray emission (Figures 2–5). The detection of an HT source at the periphery of the W subcluster, which is indicative of enhanced X-ray emission and a deep potential well, points toward a distinct atmosphere of the W subcluster. The surface brightness profile of the W subcluster (Figure 6(d)) which shows a peak at the center, also strengthens the idea of a distinct identity of the W subcluster. We have also re-examined the galaxy velocity sample for A3395 from Donnelly et al. (2001), which had velocity information for 157 cluster member galaxies to look for dynamical evidence for A3395 W being a separate group. We divided the galaxies into three subclusters by considering ellipses with major axes 0.4, 0.3, and 0.2 times $r_{160} (= 34.6$) for the NE, SW, and W subclusters, respectively, and counting the number of galaxies in these regions. The major-axis position angles and ellipticities for the ellipses in NE, SW, and W regions were the same as given in Section 4.1. This led to 71 galaxies in the NE, 32 galaxies in the SW, and 15 galaxies in the W subcluster, leaving 69 galaxies which could not be clearly identified as belonging to any particular subcluster. Also, there
Figure 17. Velocity histograms of the galaxies belonging to the NE, SW, W subclusters, and the remaining set of galaxies that did not belong to any of the subclusters. Bins are 300 km s$^{-1}$ wide. Overlaid are the Gaussian fits to the velocity distribution of the NE and SW subclusters. (A color version of this figure is available in the online journal.)

Table 11

| Region/Subcluster | No. of Galaxies | $\bar{v}$ (km s$^{-1}$) | $\sigma_v$ (km s$^{-1}$) | $M_{\text{virial}}$ ($10^{14} M_\odot$) |
|-------------------|----------------|-------------------------|-------------------------|--------------------------------------|
| NE                | 71             | 15170 ± 64              | 948 ± 64                | 8.1 ± 1.1                            |
| SW                | 32             | 15582 ± 55              | 405 ± 55                | 1.4 ± 0.4                            |
| W                 | 15             | 15298 ± 330             | 842 ± 330               | 3.5 ± 2.7                            |
| NW                | 17             | 15110 ± 130             | ···                     | ···                                  |
|                   | 10             | 14540 ± 70              | ···                     | ···                                  |

Notes. Errors are quoted at 68% confidence level (1$\sigma$) based on $\chi^2_{\text{min}}+1.00$. The two values quoted for the mean velocity of the NW region are obtained, the first one is from the velocity data given in Donnelly et al. (2001) while the second one is from Teague et al. (1990). Results for all other regions are from Donnelly et al. (2001) alone.

were some slight overlaps in the three sets of galaxies. For example, NE and SW subclusters had 13 galaxies in common; NE and W subclusters had 9 galaxies in common, and SW and W subclusters had 12 galaxies in common. The velocity histograms obtained for the four sets are shown in Figure 17, where the bin size was chosen to be 300 km s$^{-1}$ wide. Donnelly et al. (2001) had reported a high-velocity hump in A3395. From Figure 17, we observe that the galaxies in this hump belong to either the SW or the W parts or to none of the subclusters. The average subcluster velocities and their dispersions were obtained by fitting Gaussians to their velocity distributions and are given in Table 11. The velocity data in the W region show a very flat and wide distribution and are not sufficient for fitting a Gaussian. In addition, the galaxies in the W subcluster seem to follow the velocity distribution of the SW subcluster.

Though the velocity distribution of the W subcluster had a very poorly fitted Gaussian, we have force-fitted a Gaussian to it for getting an estimate for the velocity dispersion and a lower limit of the virial mass used in the bound system analysis in Section 5.1.1. We estimated the virial mass for each of the subclusters assuming that the galaxies included in each subcluster are bound and the velocity dispersions are isotropic. We used the following formula (see Beers et al. 1982):

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

where $\sigma_r$ 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 three subclusters thus estimated, are given in Table 11. Compared with Donnelly et al. (2001), our estimate of the virial mass for the NE subcluster ($\approx (8.1 \pm 1.1) \times 10^{14} M_\odot$) is slightly larger, while that for the SW subcluster ($\approx (1.4 \pm 0.4) \times 10^{14} M_\odot$) is almost equal (see Section 2) within uncertainties. A possible reason for a higher mass estimate for the NE region than Donnelly et al. is that our area for including subcluster member galaxies in the NE region ($\approx 1$ Mpc$^2$) is ~25% larger than the area used by them ($\approx 0.8$ Mpc$^2$), which leads to a larger velocity dispersion and harmonic mean distance between galaxy pairs.

Application of wavelet transform techniques to the positions of galaxies in A3395 by Flin & Krywult (2006) led to the detection of two subclusters which most probably correspond to the bimodal structure of the cluster at a scale of ~527 kpc. It should be noted that if the W component is indeed a possible subcluster, then its length scale is only ~250 kpc. However, considering the velocity distribution of galaxies in the W region, the W component is most probably either a clump that has been stripped off the SW subcluster by the ram pressure or a subcluster that has merged and relaxed into the SW subcluster (also see Section 5.2).
where $V_\alpha$ is the measured relative velocity of the subcluster pair and the cross-hatching shows its 68% confidence region.

A part of the NW component just above the filament shows a high-temperature region in the W component. The temperature map also shows high-temperature regions in the W component. A part of the NW component just above the filament shows the highest temperature and entropy in the 2D thermodynamic maps. Also, from Section 4.7, we find indications of a possible heating of all the components of the cluster due to the ongoing mergers. Taking into account the facts that non-detection of the shock front can also be due to projection effects and that some of the high-temperature regions could also be fitted by purely non-thermal models, the possibility of X-ray emission in these regions being purely non-thermal from shock-accelerated particles cannot be ignored.

Two different merging scenarios for the cluster A3395 are possible. If the W region is indeed a separate subcluster, it is possible that the cluster is going through its first merger, and SW and W subclusters are most probably falling and merging with the more massive and luminous NE subcluster. However, under this assumption, the origin of the filament joining the W to the NE subcluster cannot be explained. Another possibility is that the two main subclusters NE and SW have already gone through their first merger and the filament and the W region are likely results of two different phases of ram pressure stripping from the SW subcluster. The observed strong gradient in the surface brightness profile of the SW subcluster along the southeast direction is possibly due to an orbital motion of the SW subcluster around the NE subcluster. Under this assumption, the outer hot and diffuse layers of the SW subcluster were perhaps stripped off by the cooler and denser gas of the NE subcluster during the first phase of ram pressure stripping, resulting in the formation of the filament, and the W region was stripped off in a later (more recent) phase of ram pressure stripping where a relatively colder clump of the SW subcluster was stripped off the main subcluster by the hotter surrounding gas. Randall et al. (2008) have analyzed a similar merging scenario of the M86 galaxy with the ICM of the Virgo cluster in which a hotter tail and a colder plume were formed in two different phases of ram pressure stripping.

Clusters hosting a WAT with bent lobes are known to be the sites of ongoing mergers. Thus, the bent lobes of the WAT source in A3395 SW are consistent with its being a merging cluster. The WAT sources in merging clusters have been known to show some additional interesting characteristics, viz., the offset of the X-ray centroid from the position of the BCG hosting the WAT (Sakellion & Merrifield, 2000). In A3395 SW, we have found an offset of about $16$ kpc ($\sim 10\arcmin$) between the WAT hosting BCG and the X-ray centroid. Merging clusters hosting a WAT also show an elongation of the ICM distribution along the line of sight.

### Table 12

| Pair     | $R_p$ (kpc) | $V_r$ (km s$^{-1}$) |
|----------|-------------|---------------------|
| NE–SW   | 469         | 412 ± 118           |
| SW–W    | 386         | 283 ± 384           |
| NE–W    | 690         | 129 ± 393           |

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

#### 5.1.1. Bound System Analysis

In this section, we have tested whether the NE, SW, and W subclusters (pairwise) make a bound system or not. From simple Newtonian energy considerations for a bound system (see Donnelly et al. 2001)

$$V_r^2 R_p \leq 2GM \sin^2 \alpha \cos \alpha,$$

where $V_r$ is the relative radial velocity between the two subclusters (the difference in mean velocities of the two subclusters from Table 12), $R_p$ is the projected separation between the centers of the two subclusters, $M$ is the sum of the masses of the two subclusters (we used the lower limit of the sum of the two masses), and $\alpha$ is the projection angle from the plane of the sky. The values of $V_r$ and $R_p$ for the NE–SW, SW–W, and NE–W subcluster pairs are given in Table 12. Plots are shown in Figure 18. The hyperbolic curve represents the quantity $(2GM \sin^2 \alpha \cos \alpha / R_p)^{1/2}$ while the horizontal dashed line represents $V_r$ (with its 68% confidence region shown with the cross hatching). All orbit solutions below the hyperbolic curve are bound while those above it are unbound. Thus, all three pairs of subclusters are most probably bound systems.

#### 5.2. Evidence for Mergers

Among the three regions, the NE region is the most luminous and most massive (Tables 2, 3, 10, and 11). The region A3395 W is connected to A3395 NE via a filamentary structure which is at an average temperature of $6.5^{+0.8}_{-0.6}$ keV. The 2D thermodynamic maps show a high temperature of $\sim 7.5^{+2.2}_{-1.2}$ keV in a region between the NE and SW components along with a high entropy. As the surface brightness profiles of the NE and SW subclusters did not show any abrupt discontinuity, direct evidence for any shock heating could not be obtained. Possibly, the high temperature is not due to shock heating but due to viscous dissipation, which has also been invoked as the possible reason for heating in the merging binary cluster A115 by Gutierrez & Krawczynski (2005). The temperature also show high-temperature regions in the W component. A part of the NW component just above the filament shows the highest temperature and entropy in the 2D thermodynamic maps. Also, from Section 4.7, we find indications of a possible heating of all the components of the cluster due to the ongoing mergers. Taking into account the facts that non-detection of the shock front can also be due to projection effects and that some of the high-temperature regions could also be fitted by purely non-thermal models, the possibility of X-ray emission in these regions being purely non-thermal from shock-accelerated particles cannot be ignored.
that bisects the WAT (Gómez et al. 1997), which we do not find in the ICM distribution of the SW subcluster. Following these observations we propose a scenario where the subclusters SW and W are falling into and merging with the subcluster A3395 NE, although the actual merger geometries seem to be much more complex.

5.3. Radio and X-Ray Comparison

5.3.1. WAT Radio Galaxy

The radio properties of the WAT radio galaxy have been well determined over a large frequency range. We estimate the equipartition magnetic field and the minimum energy densities in the northern and southern peaks of emission which are closest to the core of the WAT radio galaxy, by assuming a value of unity for the particle to electron energy density ratio and also for the filling factor of the relativistic plasma. The formulae used to calculate the equipartition magnetic field \( B(U_{\text{min}}) \) and the minimum energy densities \( (U_{\text{min}}) \) are (see Moffet 1975, p. 211)

\[
B(U_{\text{min}}) = 2.3(aAL/V)^{2/7} \tag{7}
\]

and

\[
U_{\text{min}} = 0.5(aAL)^{4/7}V^{3/7}, \tag{8}
\]

respectively, where

\[
A = \frac{C_1^{1/2}}{C_2^{2/3}} \left( \frac{2\alpha + 1}{\nu_2^{\alpha+1/2}} - \frac{\nu_2^{\alpha+1/2}}{\nu_1^{\alpha+1/2}} \right), \tag{9}
\]

\[
L = 4\pi D_L^2S, \tag{10}
\]

\( C_1 = 6.266 \times 10^{18} \) and \( C_2 = 2.368 \times 10^{-3} \) in cgs units, \( L \) is the total luminosity calculated from the total flux \( S \) (obtained by integrating the flux density \( S \propto \nu^{-\alpha} \) from \( \nu_1 = 10 \) MHz to \( \nu_2 = 100 \) MHz), \( \alpha \) is the radio spectral index, \( V \) is the volume of the source region used, \( a \) is the ratio of the total particle energy to the energy in the electrons (assumed to be 1), and \( D_L \) is the luminosity distance to the source. The spectral index of the northern emission peak of the WAT is \( \sim 0.7 \) and its deconvolved size has been estimated to be \( \sim 16 \times 8 \) arcsec\(^2\) from 2D Gaussian fits using the AIPS task JMFIT. Assuming a cylindrical geometry, the equipartition magnetic field is \( \sim 20 \) \( \mu \)G and the minimum energy density is \( \sim 3.8 \times 10^{-11} \) erg cm\(^{-3}\), implying a pressure of \( \sim 1.3 \times 10^{-11} \) dynes cm\(^{-2}\). For the southern feature, \( \alpha \) is again \( \sim 0.7 \), and for a deconvolved size of \( \sim 26 \times 12 \) arcsec\(^2\), the equipartition magnetic field is \( 14 \) \( \mu \)G and the minimum energy density is \( \sim 1.9 \times 10^{-11} \) erg cm\(^{-3}\), implying a pressure of \( \sim 0.6 \times 10^{-11} \) dynes cm\(^{-2}\). The deprojected pressure near the center of the SW subcluster is \( \sim 4 \times 10^{-11} \) dynes cm\(^{-2}\). Although an estimate of the volume will also be affected by projection effects, a change in the volume by \( \sim 20\% \) will affect the pressure by only \( \sim 8\% \). Although the X-ray pressure appears somewhat larger than the internal pressure of the emission peaks of radio-emitting plasma, a ratio of particle to electron energy of 50 will increase the energy density and pressure by a factor of \( \sim 9.4 \). If this is the case the northern emission peak would be overpressured, while the southern emission peak would approximately be in pressure equilibrium with its environment. The pressure of the emission peaks would also increase if the radiating particles extend to lower energies and hence lower frequencies than have been assumed here.

We also estimate an average value of the equipartition magnetic field and pressure for the whole source with similar assumptions. The total length of the WAT radio source along its ridge line is \( \sim 6' \), and the average deconvolved width is \( \sim 16' \), although this varies significantly along the axis of the source. Here, the radio spectrum has been integrated from 10 MHz to 1 GHz using the injection spectral index of 0.62, and from 1 to 100 GHz using an estimated value of 1.05 for the high-frequency spectral index resulting from the steepening of spectra due to aging. A cylindrical geometry has been assumed. This yields an equipartition magnetic field of \( \sim 6 \) \( \mu \)G, which indicates a minimum energy density of \( 3 \times 10^{-12} \) erg cm\(^{-3}\) and a minimum pressure of \( \sim 10^{-12} \) dynes cm\(^{-2}\). Again, a contribution from heavier particles and/or integration to lower energies appears necessary to achieve pressure balance with the external environment where the deprojected pressure drops to \( \sim 10^{-11} \) dynes cm\(^{-2}\) at a distance of \( \sim 3' \). As suggested by O’ Sullivan et al. (2010), a possible source of additional pressure could be provided by the gas entrained and heated by the jets, which are mostly found in FRI jets (Worrall 2009). For a field strength of \( 5.7 \) \( \mu \)G, a spectral break at \( \sim 13.9 \) GHz as suggested by SYNGE (Murgia et al. 1999) fit for the Jaffe & Perola (1973) model, the spectral age of the WAT is \( \sim 10 \) Myr.

There appear to be no cavities in the X-ray maps near the location of the WAT radio source (Figure 15(b)). This is because the observations are not deep enough to detect the cavities or because the surrounding hot thermal plasma has had time to leak into and fill the cavities.

5.3.2. HT Galaxy

The properties of the HT source are less well determined compared with the WAT. Such HT sources are produced by galaxies moving at a high relative velocity into a high density of the ICM. The integrated flux densities discussed earlier suggest a rather steep spectral index of \( \sim 1.4 \). Although there are considerable uncertainties in this value, the equipartition magnetic field with the same assumptions as those for the WAT is \( \sim 4 \) \( \mu \)G, while the minimum energy density is \( \sim 1.6 \times 10^{-12} \) erg cm\(^{-3}\), implying a pressure of \( \sim 0.5 \times 10^{-12} \) dynes cm\(^{-2}\). This is again smaller than the deprojected pressure of the W subcluster where the pressure is \( \sim 1.5 \times 10^{-11} \) dynes cm\(^{-2}\). The deprojected electron density in the central region of the W subcluster is close to \( 2 \times 10^{-3} \) cm\(^{-3}\), indicating a ram pressure, \( \sim \rho v^2_g \) where \( v_g \) is the velocity of the host galaxy relative to the ICM, of \( \sim 3 \times 10^{-11} \) dynes cm\(^{-2}\). Considering the galaxies in the W subcluster, the HT host galaxy is moving at \( \sim 2000 \) km s\(^{-1}\) relative to the median velocity of this group (Figure 17) as would be expected for the tails to be bent by ram pressure of the ICM.

6. SUMMARY

X-ray observations of the cluster A3395 have revealed five main components in its X-ray morphology: the NE, SW, W subclusters, the NW region, and a filament connecting the NE subcluster to the W subcluster. The surface brightness profiles of the various components of the subcluster do not show any shock fronts in the cluster. The 2D thermodynamic maps of the cluster, however, provide evidence for high-temperature regions at the interfaces of the various components of the cluster. The very high temperature and entropy regions in the NW component, which is most probably a part of the supercluster filament
connecting the clusters A3395 and A3391, point to the merging environment in A3395 possibly being affected by a much larger supercluster network. The X-ray bolometric luminosities of the NE, SW, and W components, and the NW component are similar to those of the rich clusters and the isolated groups of galaxies, respectively. However, the temperatures of all the components of A3395 are unusually higher as compared to those of the rich clusters and groups of galaxies and suggest a possible heating of the whole cluster resulting from the ongoing mergers. None of the NE, SW, and W subclusters shows any cooling flows, as it is very likely that the cooling flows have been disrupted by the mergers in the cluster. The galaxy velocity distributions of the NE and SW subclusters have well-defined Gaussian fits and hence are confirmed as well-defined subclusters in the process of merging. Although the morphology, the surface brightness profile, and the presence of an HT galaxy in the W region show it as a separate subcluster, the galaxy velocity distribution of A3395 W could not be fitted with a Gaussian because of very few galaxies in it. Another possibility is that the cluster may have already gone through its first merger and the filament and the W components have been stripped off the SW subcluster in two different phases of ram pressure stripping. However, if the W component is indeed a separate subcluster, it is possible that the SW and W subclusters are falling into and merging with the more massive and luminous NE subcluster.

We have estimated the equipartition magnetic field and the minimum energy pressure for the WAT and the HT source seen in the ATCA radio images near the center of the SW subcluster and at the periphery of the W subcluster, respectively. Neither source shows any cavities associated with it in the unsharp-masked X-ray images, which could be either because the observations are not deep enough to detect the cavities or because the hot thermal plasma has leaked into and filled the cavities. Although the minimum energy pressure of both the radio sources is somewhat less than the external X-ray pressure, pressure equilibrium can be achieved by considering a larger contribution from heavier particles, integration to much lower energies, and additional pressure due to gas entrained and heated by the jets. From the spectral analysis of the source based on various radio observations, we have estimated a spectral age of \( \sim 10 \) Myr for the WAT source.

Deeper and higher resolution X-ray observations are required to properly understand the merging scenario and the geometry of the cluster, to quantify the structure of the shock fronts between the subclusters, and to understand the filamentary region in detail. Deeper radio observations of the HT source are required to better constrain the results from the imaging and spectral analysis of the source. Also, deeper radio observations at low frequencies (~300–500 MHz) are required to look for the extended sources of diffuse radio emission such as radio halos which are mostly found in merging clusters. The galaxy velocity distribution of the W region requires observations of redshifts from a larger sample of galaxies in this region and its surroundings in order to derive the velocity dispersion and mass estimates with better precision, and to confirm the distinct identity of the W subcluster. Pointed observations from \textit{XMM-Newton} in the NW region and also along the filament between the clusters A3391 and A3395 (discussed in Tittley & Henriksen 2001) can help in a better understanding of the merging environment of A3395 and its connection with the supercluster network.

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