Chandra Observations of Abell 222 & Abell 223

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Abstract

We present the analysis of *Chandra* observations of two rich clusters in a binary pair, Abell 222 & Abell 223. The clusters were observed with the ACIS-I detector for a total of 45 ksecs in "VERY FAINT" mode. After screening the data we fit the surface brightness of both clusters we find that both exhibit signs of a past merger. Fitting the surface brightness of the clusters reveal significant changes in the ellipticity and position angle of the fitted ellipses, which are signs that the clusters have not fully relaxed after a past merger. Neither cluster shows evidence of shocks in the temperature maps. The temperature of each cluster is very similar, $4.89^{+0.31}_{-0.31}$ keV for A 222 and $4.72^{+0.33}_{-0.31}$ keV for A 223. The temperature of the bridge region between the two clusters does not show any temperature enhancement and therefore the two clusters have not yet begun to interact strongly.

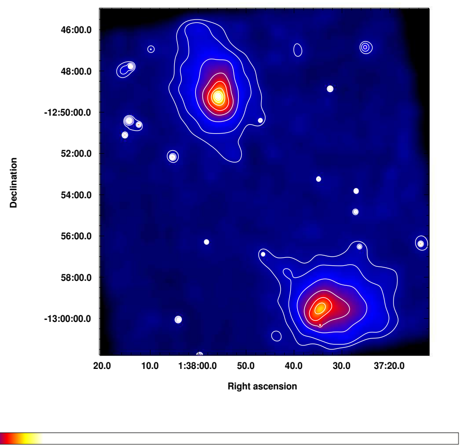

Figure 1

Conclusions

The 45 ksec ACIS-I observation reveals that these two systems are most likely in an early stage of merging. The temperature of the hot gas shows no significant features that could be interpreted as shocks. In addition the bridge region between these two clusters does not show any temperature enhancement that would indicate a strong interaction is occurring at the present. However fitting the surface brightness reveals isophotes that rapidly change position angle and ellipticity indicating that both clusters have recently undergone a merger. Additional evidence for this can be seen in the optical data for A 223 which shows that the galaxies form a bimodal system (Dietrich et al 2002). This is consistent with the numerical simulations of Frenk et al. (1996) showing two clusters forming at a close proximity, by the merging of smaller units, before the two merge to form a single rich cluster at the present epoch.

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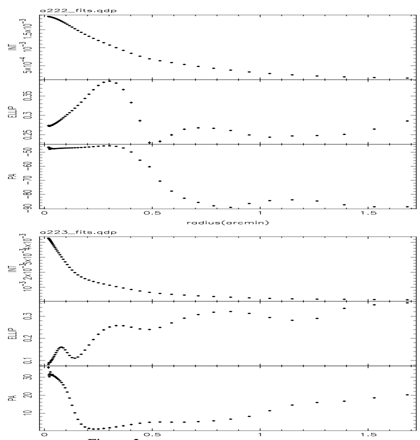

Figure 2

Elliptical Surface Brightness Fits

The X-ray contours of A 222 (fig. 1)shows that in inner regions and the outer regions have a different position angle. To characterize this difference we use the ellipse fitting package `ellipse` in IRAF to interactively fit the surface brightness of the cluster. We fit the image data in the 0.5 to 7.0 keV band and to improve the stability of the fit we first smoothed the image using a Gaussian with a width of 0.″5, comparable to the PSF in the central region. We masked out the known point sources so that they would not influence the fit. We then fit the surface brightness from 1″ to a maximum of 101″ where the profile became flat enough to affect the fit. This provides us a smooth model of the cluster surface brightness. We then fit this data with the β-model where r is now the semi-major axis of the fitted ellipse. For A 222 we find that a single β-model is a poor fit leaving an excess of emission in the center. We find that $r_c = 144''^{+33}_{-17}$, and the fitted β value is $0.73^{+0.28}_{-0.12}$.

The shifts in the centroid, position angle (P.A.) and the ellipticity also are indicators of a non-relaxed cluster. Figure 2 shows the intensity, ellipticity, and position angle of each of cluster fits. For A 222 the ellipticity in the center is 0.27 rising to 0.39 at 0.′3 and then flattening to about 0.26 in the outer cluster. The P.A. of the fitted ellipses also starts a dramatic change at about 0.′3; changing by ∼40° in only 0.′2. In addition to the changes in ellipticity and P.A.the center of the fitted ellipses also begins to shift dramatically at about 0.′3. The maximum radial shift inside 0.′3 is less than 0.′01 while outside this radius it is ∼0.5′ in R.A. and 0.′2 in Dec. For A 223 the ellipticity shows a general rise from being mostly round in the center to an ellipticity of 0.3 in the outer cluster. The position angle drops rapidly in the first 0.′3 to be almost North-South and then slowly rises by about 20deg in the outer parts of the cluster. The centroid of the ellipses changes by only about 0.′13 in R.A. and by 0.′3 in Dec.

The Spectral "Color" Map

To search for complicated temperature structure in the cluster which may have been missed by using the regular regions in the spectral analysis above, we generated a spectral ratio map of the cluster. Relatively soft and hard images were constructed from 0.75–1.3 keV photons and 1.3 – 6.0 keV photons, respectively. After adaptively binning (Saunders et al. 2001) both images we created a hardness ratio map by dividing the hard map by the soft image. We used *XSPEC* to determine the approximate temperatures corresponding to these ratios (figure 4). Fixing the abundance to 0.37 solar and N_H to the best fit value found in the global spectral fit, we find that these ratios are consistent with a smooth distribution of temperature.

Spectral Analysis

We used *XSPEC 11.3.2c* software (Arnaud et al. 1996) to fit a Apec plasma model to the extracted spectra. The temperature and abundance were allowed to vary in the global fit to the clusters and the fits include a variable absorption component due to the column density of Galactic hydrogen in the line-of-sight. The redshift of the model spectrum was fixed to the cluster redshift. For A 222 z=0.2126 and for A 223 z = 0.2079 (Dietrich, Clowe & Soucail 2002). The extracted spectra were fit between ∼0.5 and 9.0 keV, the exact energy boundaries being set by the channel grouping. Once a minimum in χ^2 was found, the 90% confidence errors were determined for the free parameters. A "global" spectrum extracted for each of the clusters using an ellipse. For A 222 the ellipse has ∼102″ in the north-south direction and ∼132″ in the east-west direction. The fitted spectrum yields a temperature of $4.89^{+0.31}_{-0.31}$ keV and a metal abundance of $0.38^{+0.52}_{-0.11}$ solar with a χ^2_ν=1.10 for 233 degrees of freedom (figure 3). For A 223 the ellipse has ∼189′ in the north-south direction and ∼137″ in the east-west direction. The fitted spectrum yields a temperature of $4.72^{+0.33}_{-0.31}$ keV and a metal abundance of $0.36^{+0.11}_{-0.11}$ solar with a χ^2_ν=1.08 for 210 degrees of freedom.

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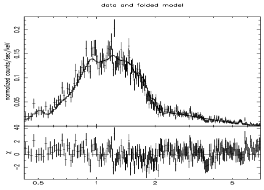

Fig. 3.— The extracted spectrum for Abell 222. The data is shown as crosses. The model is an absorbed *APEC* plasma model with Galactic absorption and is shown as the solid line.

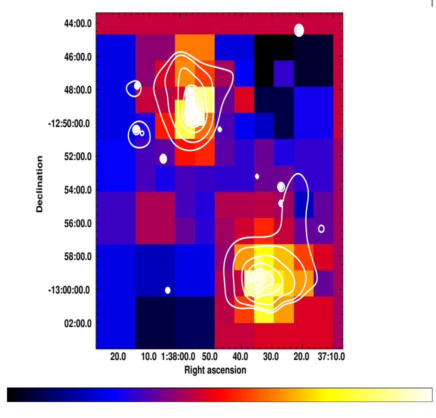

Figure 4.