Observations of a z ~ 0.9 cluster of galaxies

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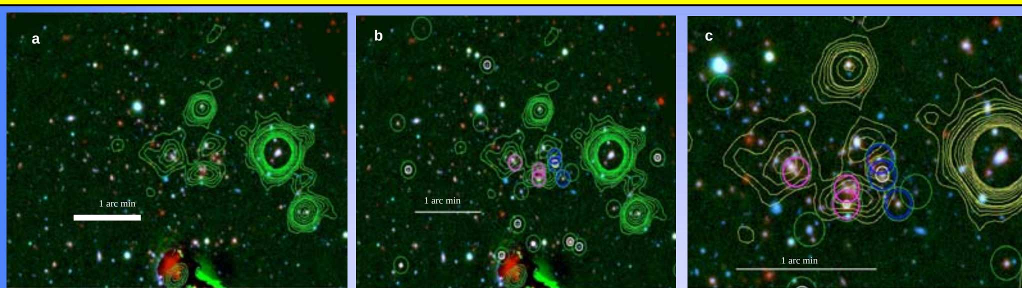
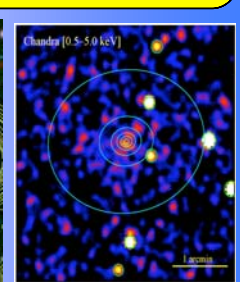
Introduction: The cluster Cl 1257+4738 was found by comparing a ROSAT image with red ground based images, taken to determine if the red galaxies were young dusty ones or old early type galaxies. This adds another cluster to the handful of clusters with z larger than about 0.9. Each one provides new insights as to the relationship between the evolution of galaxies and the ICM. We acquired Chandra, XMM-Newton, Spitzer IRAC plus MIPS 24 data to study this relationship between galaxies and the ICM. The Chandra plus Spitzer and ground based data gave us the unique opportunity to find candidate galaxies and AGNs that could be at redshifts from 3 up to as high as 10.





Figs. 1 a, b, c. Color image based on Spitzer IRAC 3.6 μm (R), Gemini z (G) and Gemini i (B) image. XMM contours in the 0.3-6 keV interval are superimposed in green (a and b) and in yellow, (tweaked to separate the northern AGN from the cluster emission). Green circles show galaxies inside the cluster). Pink and blue circles indicate galaxies in the two sub-clusters detected by the Serna & Gerbal (1996) method. Big and small white circles indicate the presence or absence of [OII] emission: no white circles = no [OII], small white circles = [OII] smaller than 2 times the noise, large white circles = [OII] stronger than 2 times the noise. The right most image is a blow up of the central one.
North is up and East to the left; a concordant cosmology is assumed, thus 463 kpc = 1 arcmin at the redshift of Cl 1257+4738 z=0.866.

Figure 2. Chandra image with a best fit 2-D beta model superimposed. The circled objects have been masked out before the fit was done.

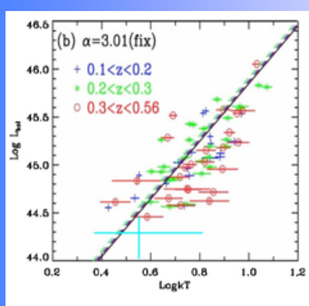


Fig 3. L_X versus kT for low redshift clusters from Ota et al. 2006, plus our data point shown as a blue cross.

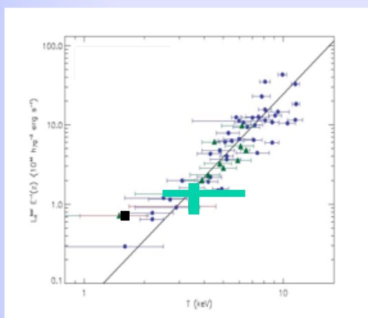


Fig 4. Small circles: z=0.5-1 (48 X-ray clusters). Small triangles: z=0.7-0.96 (optical surveys). Large black squares: members of supercluster at z = 0.9 from Kocevski et al. (2008). Blue square: this work.

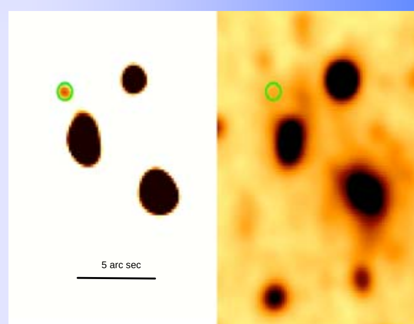


Fig. 5 Left: Spitzer IRAC 3.6 μm 2,000 sec exposure. Right: Gemini i-band 20 minute exposure smoothed to the same approximate angular resolution as the Spitzer image. The typical peak intensity to background is about 20-1. The thick green circle marks the location of a source clearly visible with Spitzer and invisible in the Gemini i'-band. The Gemini limit here is about 26th mag in i'.

Discussion: Fig. 1a shows how by eye the very red (remember the "blue" here is I-band) population of galaxies marks the cluster location. The cluster has a velocity dispersion based on only 6 galaxies of about 1,000 km/s, consistent with what one would expect for a cluster with a kT within the wide range of our 1σ uncertainties.

The position of most of the [OII] emitters suggest that the galaxies are young starburst systems whose starbursts were NOT caused by galaxy-galaxy harassment. This implies that the other red cluster members are early type. The galaxy distribution as found by the Serna & Gerbal method shown in Fig. 1b is bimodal, as is the X-ray emission. Fig. 2 demonstrates the difficulty in determining the true cluster emission profile due to a line of sight X-ray point source. If bi-modal, the brightest portions of the X-ray emission, however, seem offset from the right most (west) galaxy clump. Perhaps the western sub-clump of galaxies (including one [OII] emitter) is an entire group (too faint to be detected in X-rays with our short exposure) that is falling into the cluster. The cluster therefore, is perhaps dynamically young. Yet, the cluster L_X versus kT relation falls close to the lower redshift cluster relation for z ≤ 0.56 from Ota et al 2006 (Fig. 3) and on that of the z ≥ 0.7 self-similar corrected L_X-kT relation derived by Kocevski et al. 2008 (Fig. 4) for high z clusters.

Thus, it appears that although the infall of the galaxies may be related to the L_X and kT of the cluster, at least some clusters such as this one may also have another early-on (in terms of formation history) form of energy input, that could be related to SN (but with only 15 ksec of XMM observing time it was not possible to derive the ICM metallicity).

Spitzer IRAC and i-band data plus magnification via gravitational lensing of the background objects allowed us to find 34 distant (z > 10) candidates (Fig. 5). Perhaps many are only at z ~ 3, but if even just a few are at z > 10, they would give us new insights into the era of re-ionization and the birth of the first black holes. In Fig. 6 the candidates that are also X-ray detectable are shown. If z > 10 AGNs have the same spectra that produce the X-ray background (i.e., a spectral break at about 40 keV), then the objects with the harder X-ray spectra are likely to be at lower redshift than the softer sources. But only redshift measurements can tell the full story.

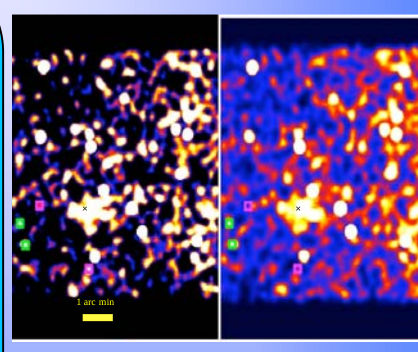


Fig 6. Smoothed Chandra images. Left: 0.3-2.0 keV, right: 2.-6 keV. Green boxes are locations of sources visible in both X-ray bands. Magenta boxes are those only visible in the soft band, easily detectable in IRAC 1 but barely visible in the Gemini i-band. X marks the approximate location of the cluster center.

Summary and Conclusions: We have found a z ~ 0.9 X-ray emitting cluster of galaxies that is still in the process of formation. Late-type galaxies are in-falling, and the cluster has an elongated structure that is bi-modal in X-ray and optical. The optical galaxy distribution westmost extension, however does not coincide with the westmost X-ray emission distribution. Most red galaxies are not emitting due to warm dust, and hence are early type and old. The morphology of the X-ray and galaxy distributions indicate that the cluster is relatively young, yet the X-ray emission falls on the L_X-kT relation of much older systems, which indicates that the X-ray emission is primarily not driven by infall but rather by energy input such as from SN. We have also shown that high z clusters can be used as gravitational magnifying lenses to give us a unique method of finding super distant objects when coupled with I-band and Spitzer IRAC observations.

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References: Ota, N 2006, ApJ, 640, 673; Kocevski et al, 2008, arXiv:0804.1955