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Massive clusters of galaxies to z=1

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Abstract. The X-ray properties of a sample of high redshift (z>0.6), massive clusters observed with *XMM−Newton* and *Chandra* are described, including two exceptional systems. One, at z=0.89, has an X-ray temperature of T=$11.5^{+1.1}_{-0.9}$ keV (amongst the highest known at z>0.6), an X-ray mass of ≈(1.4±0.2)x10^{15} $M_\odot$, and appears relaxed. The other, at z=0.83, has at least three sub-clumps, probably in the process of merging, and also shows signs of faint filamentary structure observed in X-rays. The X-ray gas metallicities, gas mass fractions and surface brightness slopes of the relaxed systems are similar to those of low redshift clusters of the same temperature, suggesting that metal injection and the relaxation of the gas to its current distribution had occurred by z≈0.9. The evolution of the X-ray luminosity-temperature and mass-temperature relations are consistent with self-similar predictions.

Key words. X-rays – Galaxy clusters

1. Introduction

Massive clusters of galaxies are rare objects, providing powerful probes of cosmology and structure formation. However, the number of massive clusters known at high redshifts is very small.

2. A massive cluster at z=0.89

The *XMM* image of CLJ1226.9+3332 is shown in Fig. 1. The X-ray morphology appears generally relaxed. The *XMM* temperature of $11.5^{+1.1}_{-0.9}$ keV is consistent with the velocity dispersion of ≈1100 km s^{-1}. The bolometric X-ray luminosity is 5.4x10^{45} erg s^{-1}. We derive a mass of (1.4±0.2)x10^{15} $M_\odot$ within the virial radius. A temperature profile is consistent with the cluster being isothermal out to 45% of the virial radius. A short *Chandra* observation confirms the lack of significant point-source contamination.

This cluster is unique in being at high redshift, yet massive and generally relaxed. It must have been assembled when the age of the Universe was significantly less than 6 Gyr. Further details of the *XMM* analysis

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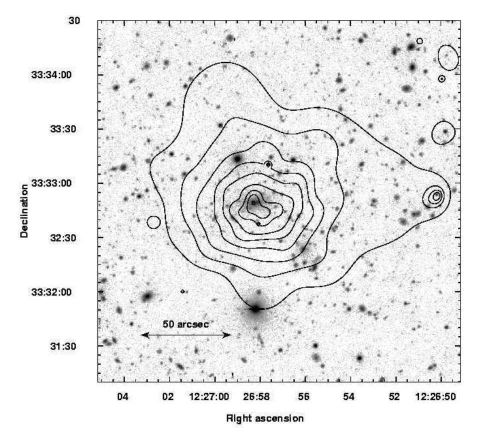

Fig. 1. *XMM* contours overlayed on a Subaru I-band image of the relaxed, massive cluster ClJ1226.9+3332 (z=0.89).

and the cosmological implications are given in Maughan et al. (2003b).

3. A massive cluster in formation at z=0.83

In stark contrast is the highly unrelaxed, massive cluster ClJ0152.7-1357. We discuss the *Chandra* data in Maughan et al. (2003a). A deep *XMM* image is shown in Fig. 1. The cluster consists of two major sub-clumps of mass $\approx$(5-6)x10^{14} $M_\odot$. A dynamical analysis shows that the subclusters are likely to be gravitationally bound. When merged, the system mass will be similar to that of the Coma cluster. To the east is a low luminosity system also at the cluster redshift (Demarco et al. 2003, in preparation). To the NW is a filamentary structure with one or two probable groups embedded within it. The filamentary emission is significant at $>5\sigma$ and has a hardness ratio consistent with a temperature of 1±0.7 keV. We may be observing the warm baryons predicted to lie within filaments, based on simulations of structure formation.

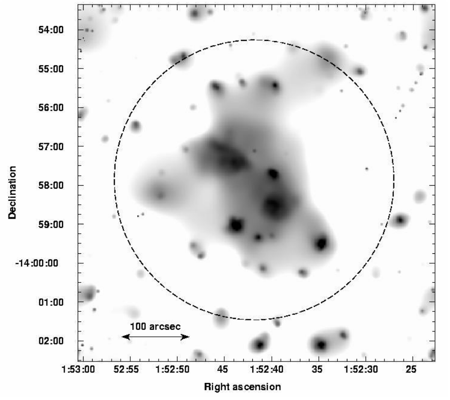

Fig. 2. *XMM* image of ClJ0152.7-1357 (z=0.83). The circle denotes the estimated virial radius of the final, merged, system. Note the filamentary structure, with embedded sources, to the NW.

4. Metallicities and scaling relations

Most of the metals in a cluster are in the X-ray gas, and so the evolution provides important information on the chemical history of the Universe. We find that cluster metallicities up to z=0.9 are consistent with the canonical value of 0.3 times the solar value found at lower redshifts.

The X-ray luminosity-temperature and mass-temperature relations at z=0.8 are both consistent with self-similar predictions of the evolution which reflect the higher density of the Universe at high redshifts. Here we measure the total mass within an overdensity radius of r_{2500}, where the mass measurements are most reliable.

References

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