Exploring the outskirts of the galaxy clusters Abell 2029 and PKS 0745-191 to the virial radius

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Accurate measurements of the intracluster medium (ICM) of galaxy clusters to the virial radius (r_{200}) are important for many reasons. The virial radius represents the boundary within which the cluster ICM is expected to be in hydrostatic equilibrium, and outside of which matter is still accreting onto the cluster as it continues to form. Studying cluster outskirts allows the cluster formation process to be better understood, thus constraining simulations of cluster formation and models for the baryon fractions of clusters. We can also investigate where the assumption of hydrostatic equilibrium breaks down, which is important for calculating the masses of galaxy clusters. Accurate cluster masses are required for using galaxy clusters as probes of cosmological parameters using the cluster mass function and gas mass fraction methods.

Abell 2029

Walker et al. (2012a), MNRAS, 422, 3503 (arXiv:1203.0486)

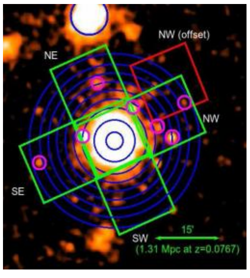
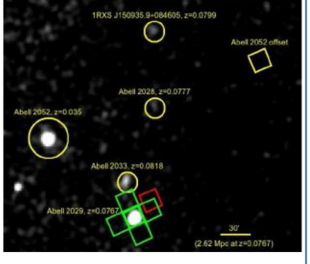


Fig. 1



Using *Suzaku* observations (Fig. 1) we explore the ICM of the galaxy cluster Abell 2029 (z=0.0767) to higher radius than before, with no statistically significant emission detected beyond 22′ (except for the northern pointing between Abell 2029 and Abell 2033), which is 1.9Mpc, and is equal to our measurement of r_{200}. Excess emission between Abell 2029 and Abell 2033 appears to originate from Abell 2033 indicating we are seeing the overlap of the outskirts of the two clusters to the north, supported by the galaxy overdensity map (compare Figs. 1 and 3).

We detect a cold feature to the SE extending out to the edge of the detected cluster (22′) where the ICM is significantly colder than in the other directions, consistent with the *XMM-Newton* findings of Bourdin & Mazzotta (2008) which found a temperature depression to the south east within the central 8′ (right column of Fig. 2).

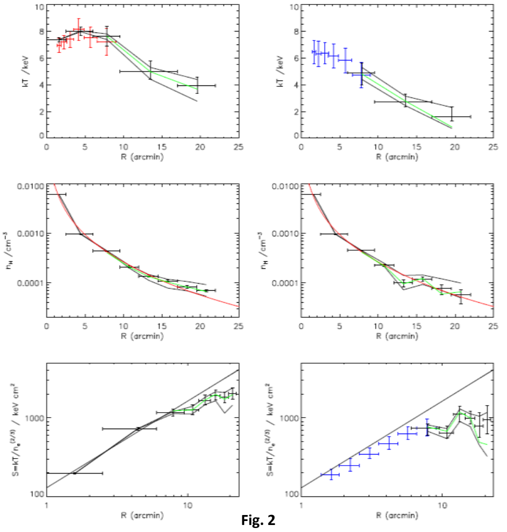
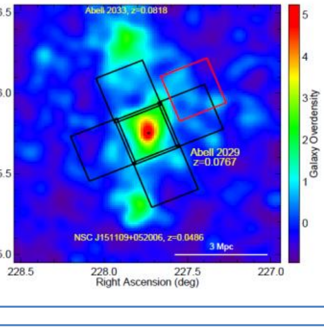


Fig. 2

The lower temperature causes the entropy profile to be lower and to flatten, indicating that the ICM in this direction is significantly out of hydrostatic equilibrium, possibly the result of the accretion of galaxy groups along the SE direction, which has disturbed the ICM.

Fig. 3



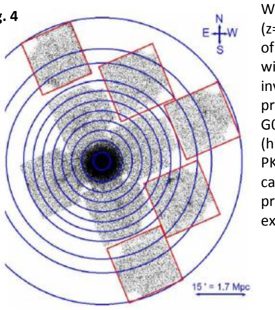
Away from this cold feature (left column of Fig. 2), the azimuthally averaged temperatures and densities are consistent with previous findings, with the entropy profile rising in the outskirts but not as steeply as the $r^{1.1}$ powerlaw predicted due to pure gravitational hierarchical structure formation (Voit et al. 2005).

The gas mass fraction rises with radius and reaches the cosmic mean baryon fraction (0.167, obtained from CMB data in Komatsu et al. 2011) near our calculated value of the virial radius.

PKS 0745-191

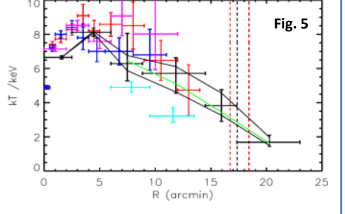
Walker et al. (2012b), MNRAS in press (arXiv:1205.2276)

Fig. 4



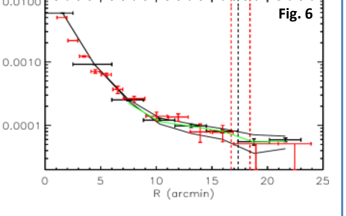
We use new *Suzaku* observations of PKS 0745-191 (z=0.1028) to measure the thermodynamic properties of its ICM out to and beyond r_{200} (reaching $1.25r_{200}$) with better accuracy than previously achieved. We investigate and resolve the tensions between the previous *Suzaku* results (George et al. 2009, hereafter G09) and *ROSAT, XMM-Newton* and *Swift* results (highlighted in Eckert et al. 2011a, hereafter E11a) for PKS 0745-191, which are found to be principally caused by incorrect background modelling in the previous *Suzaku* analysis. We perform a thorough examination of the systematic errors on the results.

Fig. 5



We find a temperature profile (Fig. 5) consistent with those already obtained using *XMM-Newton* and *Swift*, and conclude that the low temperatures found in G09 (cyan) in the 6.0′-14.5′ region were the result of incorrect background modelling. Our higher temperatures cause the entropy profile (Fig. 7) to obey the powerlaw relation, $S \propto r^{1.1}$, to higher radius than in G09 before flattening and decreasing above 15′ (≈1.7 Mpc). This brings the average temperature scaled entropy profile into strong agreement with those from other clusters investigated with *Suzaku* out to r_{200}, suggesting at a universal scaled entropy profile around which the scatter is low (Fig. 11).

Fig. 6



We find that the gas mass fraction increases significantly above the mean cosmic baryon fraction from around r_{200} onwards (Fig. 8), and is consistent with the profile found in Simionescu et al. (2011a) for Perseus (blue points). This suggests that the ICM may be clumped in the outskirts, causing the gas density to be overestimated. Correcting for the clumping factor causes the entropy profile to obey the powerlaw relation $S \propto r^{1.1}$ out to our estimate of r_{200} but above r_{200} the entropy profile still flattens and lies below the powerlaw prediction, (blue points in Fig. 7). This suggests that something other than clumping is responsible for the entropy profile flattening there. The most likely cause is that outside r_{200} the ICM is out of hydrostatic equilibrium and that we are seeing cold gas which has not yet been virialised as it accretes onto the cluster.

It is also possible that the observed gas mass fraction exceeds the cosmic mean baryon fraction in the outskirts because the total mass is being underestimated by using only the thermal pressure in the equation of hydrostatic equilibrium.

Fig. 7

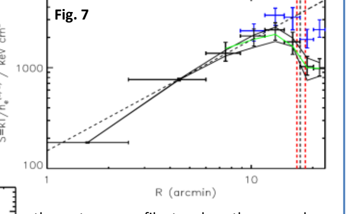


Fig. 8

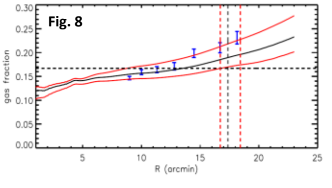


Fig. 9

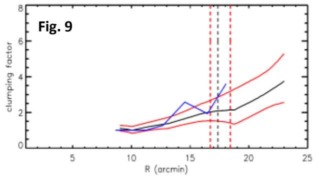
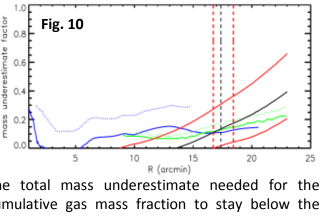
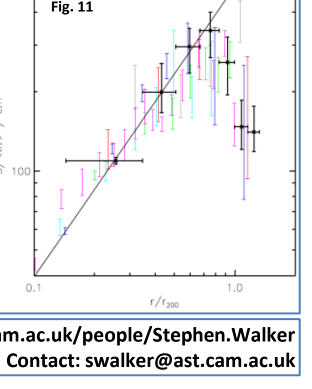


Fig. 10



The total mass underestimate needed for the cumulative gas mass fraction to stay below the cosmic mean baryon fraction (Fig. 10) agrees with the expected underestimate of the total mass from simulations (green, Lau et al. 2009), which is caused by the increasing contribution of nonthermal pressure in the outskirts which cannot be directly measured at present.

Fig. 11



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