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Active Galactic Nuclei Feedback and Clusters

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Abstract. The Intracluster Medium (ICM) is believed to have been affected by feedback from Active Galactic Nuclei (AGN) and/or supernovae-driven winds. These sources are supposed to have injected entropy into the ICM gas. The recently determined universal pressure profile of the ICM gas has been used and after comparing with the entropy profile of the gas from gravitational effects of the dark matter halo, the additional entropy injected by non-gravitational sources, as a function of the total cluster mass is determined. The current observational data of red-shift evolution of cluster scaling relation is shown that allow models in which the entropy injection decreases at high red-shift.

Key words. Galaxies: cluster: general—galaxies: intergalactic medium—X-rays: galaxies: clusters—cosmology: miscellaneous.

1. Introduction

X-ray observations of the ICM gas suggest that non-gravitational processes have affected its entropy profile. Observational results do not match the expectations from the case when ICM gas is acted upon only by the gravitational field of the dark matter halo. These non-gravitational processes are believed to have raised the entropy of the IGM gas, essentially pushing it outward, making it less dense and thereby decreasing the X-ray luminosity. The possible non-gravitational processes include radiative cooling, feedback from AGN and/or supernovae-driven winds (Voit & Bryan 2001; Nath & Roychowdhury 2002; Roychowdhury *et al.* 2004, 2005; Balogh *et al.* 2008; Battaglia *et al.* 2010).

A number of questions however remain unanswered. In the case of AGN feedbacks, it is not yet clear how the energy from relavistic plasma injected by AGN jets is transferred to the ICM gas. Scannapieco & Brueggen (2009) have recently shown with the help of numerical gas simulations that ICM turbulence is important in this transfer of energy, and also in setting the time-scale for the cold gas to be accreted by the AGN and for triggering it. Another aspect of AGN feedback that remains uncertain is the evolution of feedback with red-shift.

Arnaud *et al.* (2010) have recently determined a universal pressure profile for the ICM gas that fits the X-ray observations. This pressure profile can yield a gas density and temperature profile if one assumes a dark matter halo. The entropy profile that corresponds to this universal pressure profile assuming a Navarro–Frenk–White (NFW) halo profile for the dark matter is determined (Navarro *et al.* 1997). This is compared with the entropy profiles expected from gravitational processes only, and the additional entropy that is required to reconcile with the observations are determined.

2. Results

The radial entropy profile that is expected from gravitational processes is used, as given by Voit (2005), and then converted to an entropy profile in terms of gas mass ratio contained within gaseous shells, $F_g (= M_g(< r)/M_{vir})$, where M_{vir} is the total virial mass of the cluster. We also use a NFW profile for the halo, with an estimation of the concentration parameter 'c' from observations by Comerford & Natarajan (2007), given by $c_{vir} = \frac{14.5\pm6.4}{1+z}(M_{vir}/1.3 \times 10^{13}\,\mathrm{h}^{-1}\,M_\odot)^{-0.15\pm0.13}$. After comparing with the entropy expected from the universal pressure profile, we have found that the following prescription for the injected entropy works within an accuracy of $\sim 15\%$:

$$S_{inj}(F_g) = 200\,\mathrm{keV\,cm^{-2}} + 2 \times \left(\frac{M_{vir}}{10^{14}\,\mathrm{h}^{-1}\,M_\odot}\right)^{-0.2} \times S_i(F_g). \qquad (1)$$

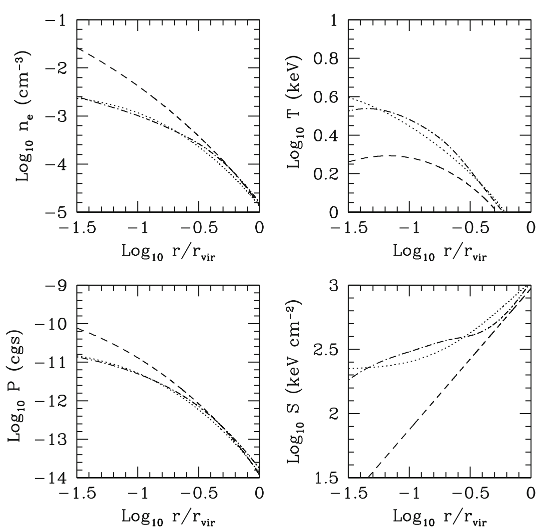

Figure 1. Comparison between the initial and final profiles, before (dashed) and after (dotted) entropy injection, and those obtained from universal pressure profile (dot-dashed), for $M_{vir} = 10^{14}\ \mathrm{h}^{-1}\ M_\odot$. The top-left panel shows the density profiles, the top-right panel shows the temperature profiles, the bottom-left panel shows the pressure profiles and the bottom-right panel shows the entropy profiles.

This form of the feedback implies that low mass clusters need an overall feedback than rich clusters, although (from the constant term) all clusters appear to need feedback in their central regions. These two modes are likely to refer to preheating and AGN/SN feedback processes, one in which all the gas particles in the ICM are affected upon and another, in which gas in the inner region acquires more entropy than in the outer regions. We show in Fig. 1 an example of how this prescription yields a final pressure profile that matches the observed universal pressure profile (Nath & Majumdar 2011).

Next, we assume a red-shift evolution of this injected entropy of the type $S_{\rm inj}(z) = (1+z)^{\alpha} S_{{\rm inj},z=0}$, and study its effect on the variation of the normalizations of different scaling relations with red-shift. We use the normalizations of the $L_X - T$ and the SZ decrement $Y_X - M$ relation. For the $L_X - T$ relation, we assume a power-law relation, $L_X\, E(z)^{-1} = C1(T_{\rm sl}/6\ {\rm keV})^{\alpha}$, where L_X is the X-ray luminosity at 0.5–1 keV band and $T_{\rm sl}$ is the spectroscopic-like temperature, as defined by Mazzotta *et al.* (2004). For the other relation, the normalization $C2$ is defined as $Y_x\, E(z)^{-2/3} = C2\left(\frac{M_{500}}{5\times10^{14}\,{\rm h}^{-1}\,M_{\odot}}\right)^{\alpha}$.

The expected variation of $C1$ and $C2$ with red-shift for different entropy injection models, along with data points from REXCESS (blue points: Pratt *et al.* 2010 and red points: Maughan *et al.* 2006) are shown in Figures 2 and 3. Results of simulations without feedback, with AGN feedback and with pre-heating are marked GO, FO and PC respectively (see Nath & Majumdar (2011) for details).

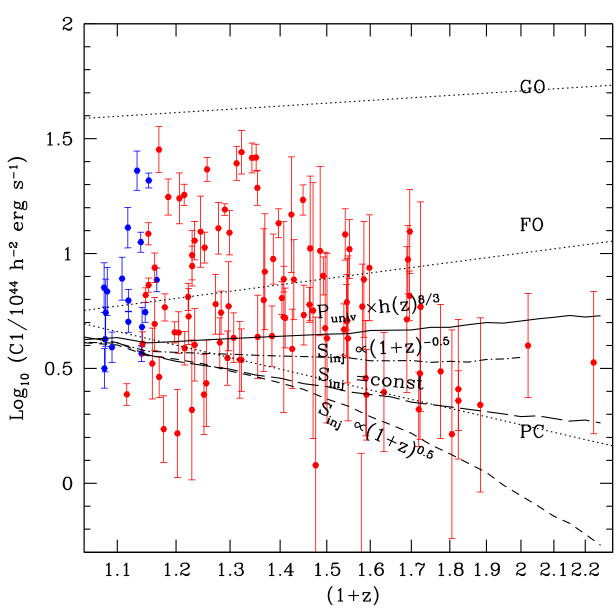

Figure 2. The evolution of the normalization $C1$ of $L_X - T$ relation is shown with red-shift, for universal pressure profile with self-similar scaling (solid line) and three cases of enhanced pressure profile: for a constant entropy injection at all red-shifts (long dashed line), for $S_{\rm inj} \propto (1+z)^{-0.5}$ (dot-dashed line), and $S_{\rm inj} \propto (1+z)^{0.5}$ (short dashed line).

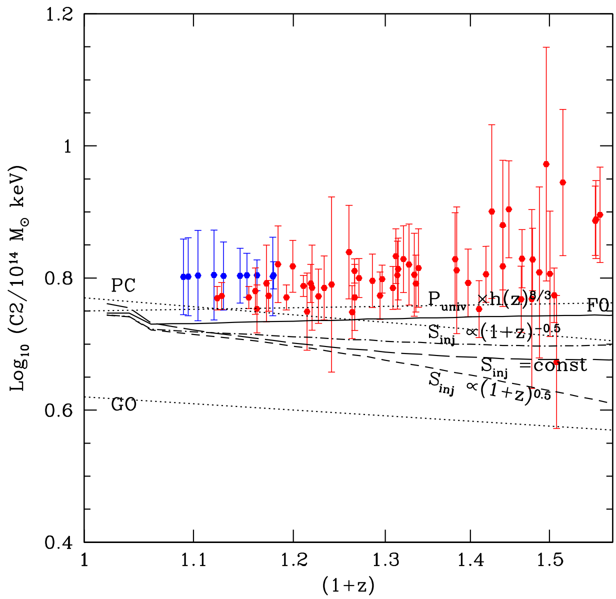

Figure 3. Same as Figure 2, but for the normalization parameter $C2$ of $Y_X - M_{500}$ relation.

3. Conclusions

The curves in Figures 2 and 3 show that currently available data for red-shift evolution of cluster scaling relations favour a negative evolution of the entropy injection with red-shift.

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