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Central gas entropy excess in galaxy groups and galaxy clusters

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Abstract. I'll present my recent study on the excess of central gas entropy, which can be considered as direct evidence for AGN feedback in galaxy groups and clusters. An expanded account of this study has been presented in RAA (Wang et al. 2010).

Key words. AGN feedback – X-rays – intergalactic medium

1. Introduction

Over the past few decades many observational and theoretical efforts have been devoted to the studies of galaxy groups and clusters. As of today, however, some fundamental astrophysical processes that determine the basic properties of these celestial systems are still poorly understood. For example, the scaling relations between Xray luminosity (L_X), gas temperature (T_X), gas entropy (K), and total gravitating mass (Mtotal), which are predicted by the self-similar gravitational collapse scenario (e.g., Kaiser 1986; Navarro, Frenk & White 1995), are challenged by observed deviations in such a distinct way that non-gravitational heating sources are invoked to dominate the gas heating process in the central ≃100 kpc (e.g., Ponman et al. 2003; Donahue et al. 2006; Sun et al. 2009)

Currently, most of the efforts have been focused on the AGN heating of the inter-galactic medium (IGM) (see McNamara & Nulsen 2007 for a review), since it is estimated that powerful AGN outbursts may repeat per 10^6 – 10^8 yr and release 10^{58} – 10^{62} ergs per outburst into the environment, and this amount of energy is sufficient to balance gas cooling and heating on group and cluster scales (e.g., Rafferty et al. 2006, 2008; Birzan et al. 2009).

The most popular non-gravitational heating source is AGN feedback. However, there also exist problems in this scenario. For example, the absence of X-ray cavities has been reported in about 40% of cool core systems (e.g., Birzan et al. 2009), and only about 10% of quasars are found to host powerful radio jets (e.g., White et al. 2007). This indicate that cavity- and jet-related feedbacks might not always operate. In NGC 4051, the observed mass and energy outflow rate due to the AGN activity is $4-5$ orders of magnitude below those required for efficient feedback Mathur et al. (2009). Also, Jetha et al. (2007) found no significant difference of gas entropy profiles between radio-loud and radio-quiet galaxy groups (see also Sun et al. 2009).

If AGN feedback does dominate the gas heating history in central regions of galaxy groups and clusters, it should be proportional to the central gas entropy excess ΔK, i.e., $E^{\rm AGN}_{\rm feedback} \propto \Delta K$ (Voit & Donahue 2005), where ΔK is measured beyond a power-law model

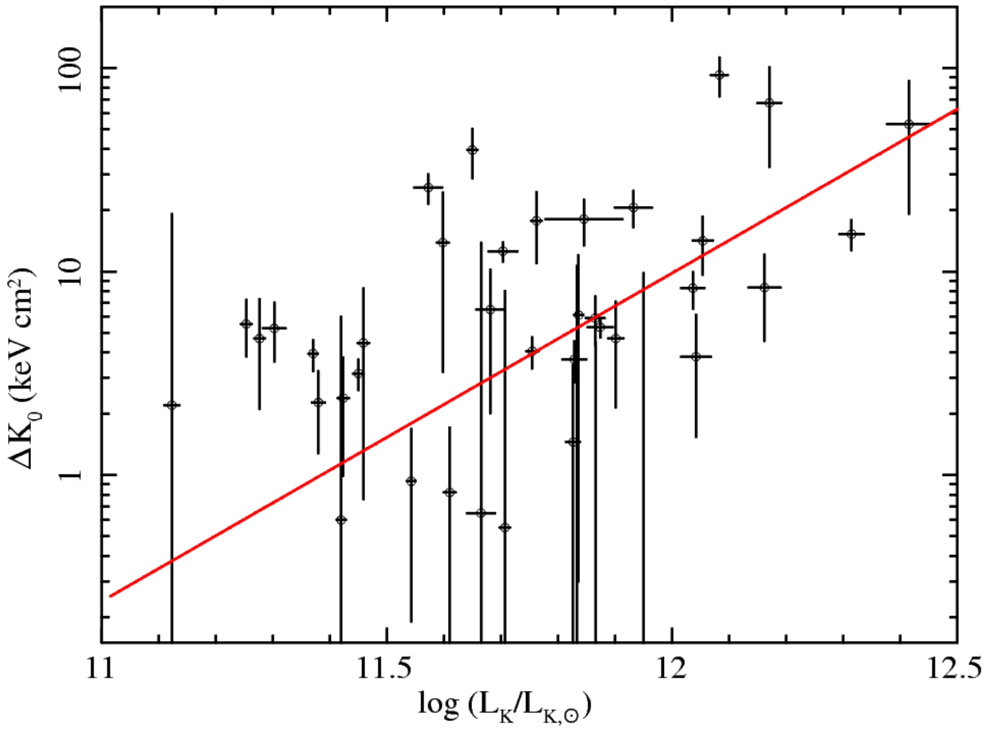

Fig. 1. Central gas entropy excess ΔK_0 vs K-band luminosity L_K for the 40 CDGs of our sample (see Fig. 2 in Wang et al. 2010). The solid line shows the best-fit model $\log(\Delta K_0) = -0.8 \pm 0.3 + (1.6 \pm 0.4)[\log(L_K/L_{K,\odot}) - 10.9]$.

that best describes the gas entropy distribution in the intermediate and outer regions. On the other hand, by studying AGN cavities embedded in the X-ray halos of galaxy groups and clusters, Allen et al. (2006) found a close relation between the AGN feedback energy $E^{\rm AGN}_{\rm feedback}$ and the Bondi accretion power $P_{\rm Bondi} = \eta \dot{M} c^2 \propto M^2_{\rm BH}$ (η is the mass-to-energy conversion efficiency, $\dot{M}$ is the accretion rate, and $M_{\rm BH}$ is the black hole mass), which indicates that the AGN feedback should scale with the SMBH mass as $E^{\rm AGN}_{\rm feedback} \propto M^2_{\rm BH}$. And we know that $M_{\rm BH}$ is related to the galaxy's bulge luminosity $L_{\rm bulge}$ and thus galaxy's K-band luminosity L_K via $M_{\rm BH} \propto L_{\rm bulge} \propto L_K$ Marconi & Hunt (2003). Given the above relations, we expect a tight correlation between the central gas entropy excess and the galaxy's K-band luminosity, i.e., $\Delta K \propto L^2_K$.

2. Central gas entropy excess as direct evidence for AGN feedback in galaxy groups and clusters

To investigate the interaction between the central AGN and the intergalactic medium (IGM), we select 40 bright, nearby galaxy groups and clusters, which are limited to have only one bright central-dominating galaxy (CDG) and show no significant merger signatures. The central galaxy of the selected systems can be well resolved with the *Chandra* ACIS. Some basic properties of the sample members are summarized in Wang et al. (2010).

After calculating the 3-dimensional azimuthally-averaged radial entropy distribution $K(R)$ for all of the sample systems, we fit the obtained radial entropy profiles with a power-law expression as $K(R) = \Delta K_0 + K_{100}(\frac{R}{100 h_{71}^{-1}\ \rm kpc})^{\alpha}$ Donahue et al.

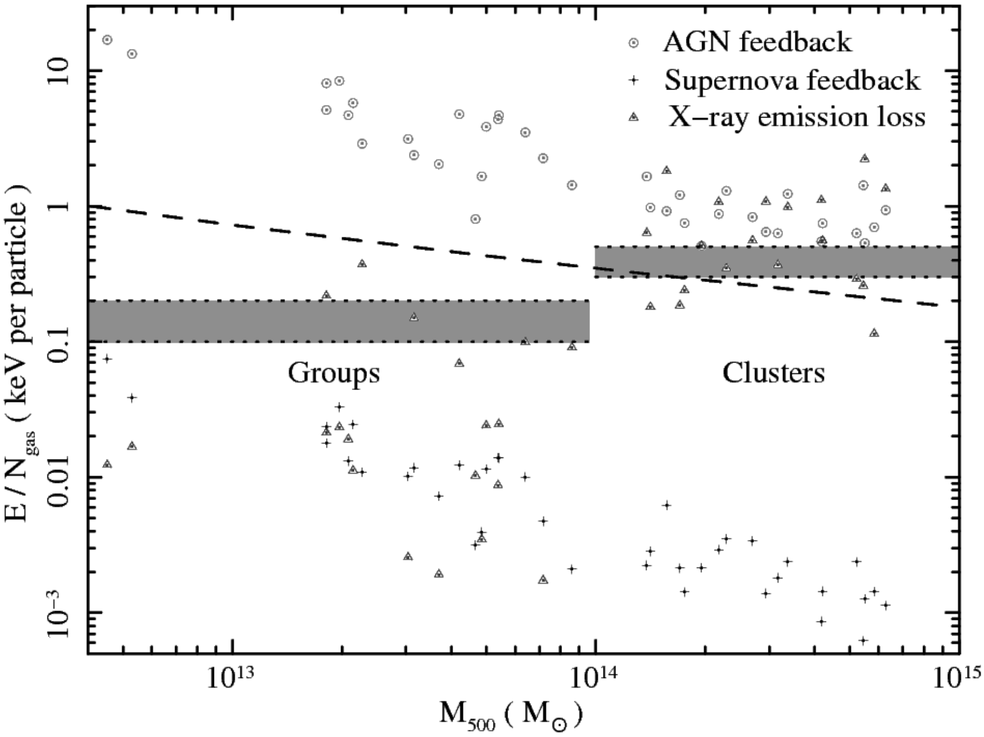

Fig. 2. Estimated energy feedback to the IGM by AGNs (circles) and supernova explosions (crosses), compared to the average gas energy excess of $\simeq$ 0.1 − 0.2 and $\simeq$ 0.3 − 0.5 keV per particle for galaxy groups and clusters (grey belts), respectively, the X-ray radiative loss since $z = 2$ (triangles), and the energy required to deviate scaling relations from self-similar predictions (dashed line; see Wang et al. 2010 for details).

(2006), where ΔK_0 represents the central gas entropy excess beyond the best-fit power-law model for larger radii. We find that in 31 sample systems there exists a significant central ($R \lesssim 10 h_{71}^{-1}$ kpc) gas entropy excess (ΔK_0), which corresponds to $\simeq$ 0.1 − 0.5 keV per gas particle, beyond the power-law model that best fits the radial entropy profile of outer regions.

In order to investigate the possible relation between the central gas entropy excess and the AGN heating, we show in Figure 1 the central gas entropy excess ΔK_0 versus the K-band luminosity L_K for the 40 CDGs in our sample (see Wang et al. 2010 for details), the latter of which is tightly associated with the mass of the supermassive black hole hosted in the CDG. The correlation is significant at 90% confidence level, according to the correlation coefficient and Kolmogorov-Smirnov (K-S) test. Using the bisector of ordinary least-squares regression, which is suitable to fit data with large scatter, we fit the log ΔK_0−log L_K relation with a linear model of $\log(\Delta K_0) = A + B\,[\log(L_K/\mathrm{L_{K,\odot}}) - 10.9]$, and obtain $A = -0.8 \pm 0.3$ and $B = 1.6 \pm 0.4$ (Fig. 1).

In fact, if an effective mass-to-energy conversion-efficiency of 0.02 is assumed for the accretion process, the cumulative AGN feedback $E_{\mathrm{feedback}}^{\mathrm{AGN}} \simeq \eta M_{\mathrm{BH}} c^2$ yields the extra heating of $\simeq$ 0.5 − 17.0 keV per particle (Fig. 2), which is sufficient to explain the central entropy excess. In most cases the AGN contribution can compensate for the radiative loss of the X-ray gas within the cooling radius ($\simeq$ 0.002 − 2.2 keV per particle), and apparently exceeds the energy required to deviate the scaling relations from the self-similar predictions ($\simeq$ 0.2 − 1.0 keV per particle). In contrast to AGN feedback, the extra heating provided by supernova explosions accounts for $\simeq$ 0.01 − 0.08 keV per particle in groups and is almost negligible in clusters. Therefore, the observed correlation between ΔK_0 and L_K can be considered as a direct evidence for AGN feedback in galaxy groups and clusters.

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