

Intracluster entropy from quasar activity

A. Lapi and A. Cavaliere

Università “Tor Vergata”, Via Ricerca Scientifica 1, I-00133 Roma, Italy

Abstract. We discuss how the energy feedback from active galactic nuclei and quasars is essential in explaining the observed X-ray luminosities and entropy levels of the intracluster and intragroup medium.

1. Introduction

Clusters, groups, and many single galaxies shine in X-rays because they contain large masses of hot plasma that radiate strong luminosities by thermal bremsstrahlung and line emission. Simple conditions are found to prevail in rich clusters; they emit copious X-ray powers $L_X \propto n^2 R^3 \sqrt{T} \sim 10^{45} \text{ erg s}^{-1}$ integrated over sizes $R \sim \text{Mpc}$. The temperatures $kT \gtrsim 4 \text{ keV}$ are close to the virial values $kT_v \propto GM/R$ in the gravitational potential wells provided by dark matter (DM) masses $M \sim 10^{15} M_\odot$. The gas densities $n \sim 10^{-3} \text{ cm}^{-3}$ are consistent with baryon to DM fractions $m/M \sim 1/5$, the universal value.

However, surprises arise in moving to groups and galaxies. Similarly simple conditions would imply the “gravitational” scaling $L_X \propto T^2$ (Kaiser 1986), or $L_X \propto T$ when lines become important. Instead, the luminosities, recently observed or revised, are *lower* by factors $10^{-1} - 10^{-2}$, see Fig. 1. This also shows how the emissions from small groups and galaxies *scatter* widely and often downward, a feature of non-Gaussian, largely intrinsic nature (Mushotzky 2004).

Thus in the smaller structures the plasma is clearly underdense for its observed temperatures. The issue is reinforced on considering that the specific entropy s of the plasma (or rather the adiabat $K = kT/n^{2/3} \propto e^{2s/3k}$, see Bower 1997) is enhanced relative to the scaling $K \propto T$ that is expected if the gas had been gravitationally heated by shocks in the cluster outskirts as it was accreted, see Fig. 2. This implies that extra energy *inputs* occurred during the formation of groups and clusters.

2. External preheating from AGNs

We focus on the substantial energies fed back to the gaseous baryons, when part of them condense into massive stars then exploding as type II supernovae (SNe), or accrete on to central supermassive black holes energizing active galactic nuclei (AGNs; see Valageas & Silk 1999; Nath & Roychowdhury 2002).

During the hierarchical buildup such energy inputs *preheat* the gas before it falls into new groups and clusters, so hindering its flow into the latter. In smaller systems the accretion shocks are increasingly *modulated*, thus inducing lower baryon densities and higher entropy levels relative to a pure gravitationally-driven infall (Lapi, Cavaliere & Menci 2004).

But SNe provide only a mild preheating, around 1/4 keV per particle; the resulting luminosity depressions or entropy enhancements are shown by the light strips in Figs. 1 and 2 to be limited both in amplitude and in scatter (see Cavaliere, Lapi & Menci 2002).

Including the additional contribution of AGNs raises the preheating to 3/4 keV per particle, if their energy outputs are coupled to the ambient baryons at fractional levels

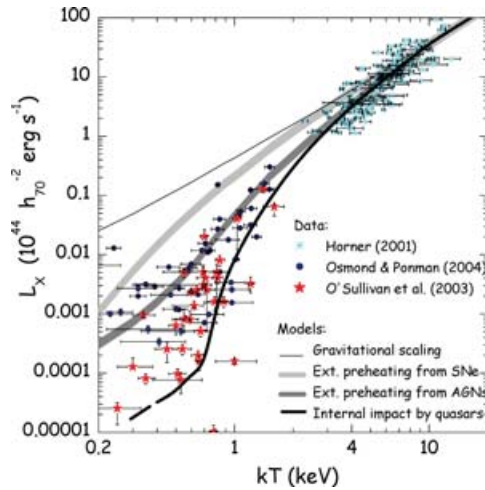


Figure 1. Integrated X-ray luminosity L_X vs. X-ray temperature T .

$f \sim 5\%$, as independently gauged by observations with CHANDRA and XMM-Newton (see Chartas, Brandt & Gallagher 2003; Pounds et al. 2003). Such a preheating value provides a sizeable step toward the locus of the data, as shown in Figs. 1 and 2 by the heavy strips.

However, the observations in groups and galaxies are only marginally fitted, while the wide scatter in the $L_X - T$ correlation is still unaccounted for.

3. Internal impact of quasars

But right in groups and galaxies the impulsive inputs by powerful quasars have an additional impact from inside. This occurs when the energy $\Delta E \sim 2 \times 10^{62} f (M_\bullet / 10^9 M_\odot) (1+z)^{-3/2}$ ergs injected over 10^8 yr for an accreted mass M_\bullet competes with the value $E \sim 2 \times 10^{61} (kT/\text{keV})^{5/2} (1+z)^{-3/2}$ ergs for the gas in equilibrium. The ratio $\Delta E/E \sim 0.5 (f/5\%) (M_\bullet / 10^9 M_\odot) (kT/\text{keV})^{-5/2}$ approaches unity in poor groups or galaxies. Then over 10^2 pc a quasar wind can act as an efficient piston to drive through the gas a blastwave terminated by a shock (Granato et al. 2004).

We derive (Lapi, Cavaliere & De Zotti 2003) self-similar solutions for the blast flow perturbing an equilibrium plasma density $n(r) \propto r^{-2}$ (or steeper) under the push of the energy addition $\Delta E(t) \propto t$ (or flatter). These blasts also include the restraints set by a finite initial pressure and by DM gravity; still, the ratio of the kinetic to the thermal energy ranges from 10^{-1} up to 2.

Thus within a dynamical time the blast *ejects* beyond the cluster outskirts a considerable gas mass $\Delta m/m \simeq \Delta E/2E$ (for $\Delta E/E \lesssim 2$), and cause an average temperature raise $\Delta T/T \simeq \Delta E/10E$ of the residual medium. In the equilibrium recovered after ejection, the X-ray luminosity $L_X \propto (1 - \Delta m/m)^2 T^2$ is *depressed* and the entropy $K \propto (1 - \Delta m/m)^{-2/3} T$ *enhanced* relative to the initial values (see solid lines in Figs. 1 and 2). We find that the current X-ray data require the diffuse baryons to absorb a fraction $f \sim 5\%$ of the full quasar output. Furthermore, in terms of increasingly strong, sporadic quasar impacts we can understand why the intrinsic scatter seen in the data *widens* toward poor groups.

On approaching the galactic scales no further density depletion takes place (knee in the solid line of Fig. 1), because the internal feedback from quasars is *self-regulated* (Silk

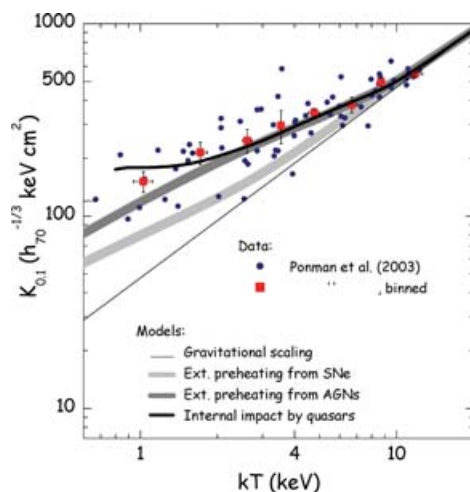


Figure 2. Central entropy K vs. X-ray temperature T .

& Rees 1998; King 2003). In other words, $\Delta E/E$ cannot exceed a few, lest the energizing accretion is stopped (Cavaliere et al. 2002). Pleasingly, with the same value $f \sim 5\%$ indicated by the X-ray data, such a limiting condition yields the *steep* correlation $M_{\bullet} \approx 5 \times 10^8 M_{\odot} (f/5\%)^{-1} (\sigma/300 \text{ km s}^{-1})^5 \propto \sigma_{*}^4$ observed in the optical band (Ferrarese 2002) between the black hole masses and the galaxian velocity dispersions. In the microwave and submm bands (Lapi et al. 2003) *real-time* evidence of quasar impact in action may be caught from Sunyaev-Zel'dovich signals enhanced by overpressure in running blastwaves.

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