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NEW TESTS OF THE CLUSTER ENTROPY FLOOR HYPOTHESIS

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RESUMEN

Los intentos recientes para explicar la relación $L_X - T_X$ en cúmulos de galaxias han llevado a sugerir que el ICM tiene un aparente "piso de entropía" de $K_0 \gtrsim 300$ keV cm^2. Proponemos nuevas pruebas, basadas en el efecto SZ térmico y en la tendencia $M_{gas} - T_X$ revelada por los datos de rayos X, para sondear el exceso de entropía del ICM. Mostramos que estas pruebas apoyan la existencia de un piso de entropía alto en los cúmulos masivos.

ABSTRACT

Recent efforts to account for the observed $L_X - T_X$ relation of galaxy clusters has led to suggestions that the ICM has an apparent "entropy floor" at the level of $K_0 \gtrsim 300$ keV cm^2. Here, we propose new tests based on the thermal SZ effect and on the $M_{gas} - T_X$ trend (from X-ray data) to probe the level of the excess entropy in the ICM. We show that these new tests lend further support to the case for a high entropy floor in massive clusters.

Key Words: **COSMOLOGY: THEORY — GALAXIES: CLUSTERS — X-RAYS: GALAXIES**

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1. INTRODUCTION

Relationships between the global X-ray properties of clusters have proven to be important probes of the intracluster medium (ICM). Case in point are studies of the X-ray luminosity (L_X) - mean emission-weighted gas temperature (T_X) relation. Theoretical models that include only the effects of gravity and shock heating (self-similar models) predict $L_X \propto T_X^2$, yet the observed relation is $L_X \propto T_X^{2.6-3.0}$ (e.g., Markevitch 1998; Allen & Fabian 1998). This discrepancy has prompted a number of theorists to consider alternative models. Both the effects of heating (e.g., Kaiser 1991; Evrard & Henry; Wu et al. 2000; Babul et al. 2002) and radiative cooling (e.g., Bryan 2000; Voit & Bryan 2001; Davé et al. 2002) have been examined. These studies find that heating and/or cooling introduces a core into the entropy profiles of clusters (an "entropy floor") which, in turn, results in a steepening of the $L_X - T_X$ relation (as required). Ponman and collaborators (Ponman et al. 1999; Lloyd-Davies et al. 2000) have presented direct evidence for an entropy floor in nearby groups.

Investigations of the ICM are not limited to the $L_X - T_X$ relation, however. Other cluster observables can be used as alternative probes of the ICM. For example, McCarthy et al. (2002) have studied the effects of an entropy floor on the cluster gas mass (M_{gas}) - T_X relation and, through a detailed comparison with observations, have placed stringent limits on the entropy floors in nearby massive clusters. Because the $M_{gas} - T_X$ relation is derived from X-ray data, the test provides a valuable self-consistency check of the $L_X - T_X$ results. The main results of that study are presented below.

Ultimately, however, scaling relations that are independent of the $L_X - T_X$ and $M_{gas} - T_X$ relations are desirable. The thermal Sunyaev-Zeldovich (SZ) effect, which has a different dependence on the entropy of the ICM than does the X-ray emission, can be used for such a purpose (McCarthy et al. in preparation). Here, we derive a relation between the central and integrated cluster Compton parameters (which are both proportional to the SZ effect), analyze how this relation is affected by an entropy floor, and compare the results to recent SZ effect observations. This is the first time the SZ effect has been used as a probe of the entropy floors of clusters.

2. THE $M_{GAS} - T_X$ RELATION

In Figure 1 we present the $M_{gas} - T_X$ relation as predicted by the Babul et al. (2002) analytic models within r_{500}, the radius within which the mean dark matter mass density of the cluster is 500 times the mean critical density at $z = 0$. When compared to the observational data of Mohr et al. (1999), we find that only the models with a high entropy floor ($K_0 \gtrsim 300$ keV cm^2) are consistent with the data. The self-similar model is ruled out (> 99% confidence).

3. A SZ EFFECT SCALING RELATION

Figure 2 is a plot of the predicted $y_0 - S_\nu(r < 150$ kpc$)/f_\nu$ relations, where y_0 is the Compton pa-

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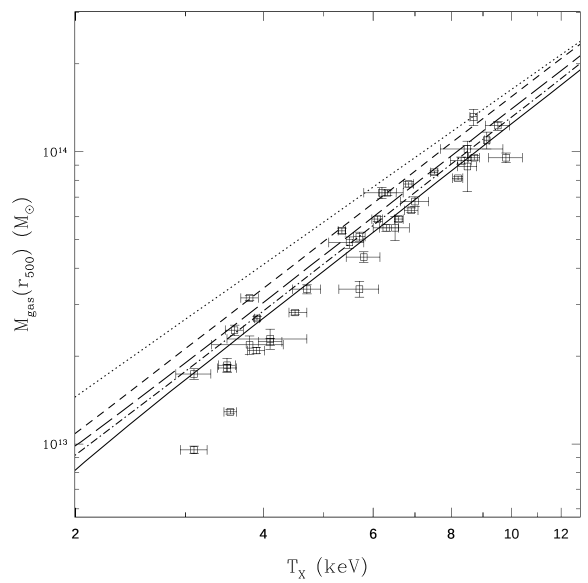

Fig. 1. A comparison of $M_{gas}(r_{500}) - T_X$ relations. The squares represent the observations of Mohr et al. (1999). The dotted line is the self-similar result. The short-dashed, long-dashed, dot-dashed, and solid lines represent the models with entropy floor constants of K_0 = 100, 200, 300, and 427 keV cm^2, respectively.

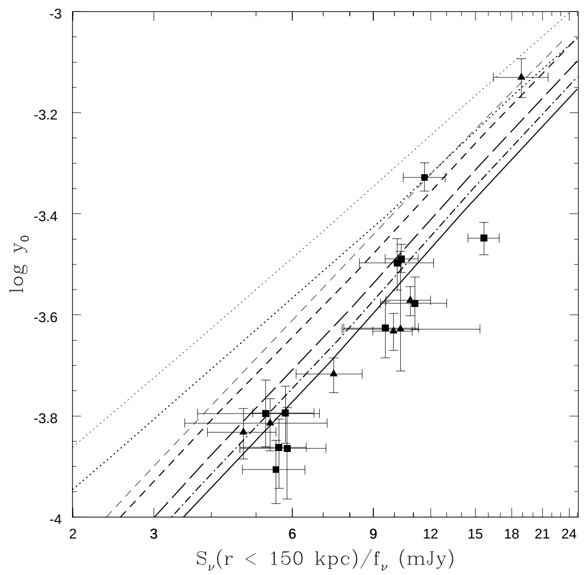

Fig. 2. A comparison of $y_0 - S_\nu(r < 150\text{kpc})/f_\nu$ relations. The squares ($0.14 \leq z \leq 0.3$) and triangles ($z > 0.3$) represent the data of Reese et al. (2002). The thick, thin lines are the $z = 0.2$, 0.5 predictions, respectively. For clarity, we plot the $z = 0.5$ lines for the self-similar and K_0 = 100 keV cm^2 models only. The integrated Compton parameters (both data and models) have been arbitrarily rescaled for $z = 0.2$.

rameter evaluated through the cluster center and $S_\nu(r < 150\text{kpc})/f_\nu$ is proportional to the integrated Compton parameter within the central (projected) 150 kpc. The lines hold the same meanings as in Figure 1. Again, we find that only models with $K_0 \gtrsim 300$ keV cm^2 are able to match the SZ effect observations of Reese et al. (2002; McCarthy et al. in preparation).

4. SUMMARY

The relations that we have described above demonstrate that a high entropy floor ($K_0 \gtrsim 300$ keV cm^2) is required to match the X-ray and SZ effect observations of massive clusters. This is consistent with previous investigations of the $L_X - T_X$ relation (e.g., Tozzi & Norman 2001). More work is required to determine the origin of the entropy floor.

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