# Effects of the Non-Equipartition of Electrons and Ions in the Outskirts of Relaxed Galaxy Clusters

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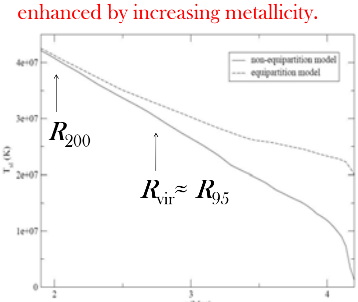
**ABSTRACT:** We have studied the effects of electron-ion non-equipartition in the outer regions of relaxed clusters for a wide range of masses in the ΛCDM cosmology using one-dimensional hydrodynamic simulations. Signatures of non-equipartition on X-ray and SZ observables are studied systematically. The effects of the non-adiabatic electron heating efficiency, $\beta$, on the degree of non-equipartition are also studied. We have calculated the effect of non-equipartition on the projected temperature and X-ray surface brightness profiles using the MEKAL emission model. Non-equipartition effects on the SZ temperature decrements and the integrated Comptonization parameters are also calculated. We found that for our model in the ΛCDM Universe, the integrated SZ bias, $Y_{\rm non\text{-}eq}/Y_{\rm eq}$, evolves slightly (at a percentage level) with redshift, which is in contrast to the self-similar model in the Einstein-de Sitter Universe. This may introduce biases in cosmological studies using the $f_{\rm gas}$ technique.

**INTRODUCTION:** The collisionless accretion shock at the virial radius of a cluster should primarily heat the ions since they carry most of the kinetic energy of the infalling gas. Assuming that cluster accretion shocks are similar to those in supernova remnants, the electron temperature ($T_e$) immediately behind the shock would be lower than the ion temperature. The equilibration between electrons and ions would then proceed by Coulomb collisions. Near the virial radius, due to the low density, the Coulomb collisional time scale can be comparable to the age of the cluster, and the electrons and ions may not achieve equipartition in these regions (Fox & Loeb 1997). In fact, non-equipartition of ions and electrons is also known in various astrophysical shocks. Since X-ray and SZ observations measure the properties of the electrons in the ICM, the net effect is to underestimate the total thermal energy content within clusters. This might account for some or all of the missing thermal energy in the ICM derived by recent X-ray and SZ observations (Afshordi et al. 2007, Evrard et al. 2008).

## Effects of Non-equipartition on Projected Temperature Profiles:

- The non-equipartition effect can introduce a ~10% bias in the projected temperature at around $R_{\rm vir}$ for a wide range of $\beta$.
- The effect of non-equipartition on the projected temperature profiles can be enhanced by increasing metallicity.



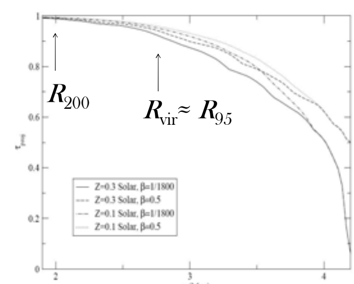
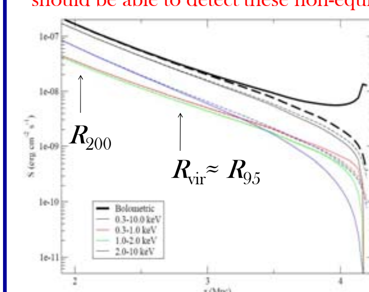




**Figure 1** ***(left panel):*** Projected X-ray spectroscopic-like temperature profiles for both equipartition model and non-equipartition models. Non-adiabatic electron heating efficiency $\beta = 1/1800$ and metallicity $Z = 0.3 Z_\odot$ are assumed here.
**Figure 2** ***(right panel):*** Ratio of the projected X-ray spectroscopic-like temperature profiles of the nonequipartition (with $\beta$ = 1/1800 and 0.5) and the equipartition models at z = 0. Models with $Z$ = 0.1 and 0.3 $Z_\odot$ are presented.
Cluster model with mass $M_{\rm vir}$=1.19x$10^{15} M_\odot$ at z = 0 is assumed in these two figures.

## Effects of Non-equipartition on X-ray Surface Brightness Profiles:

- In the low energy band ~1 keV, the non-equipartition model surface brightness can be higher than that of the equipartition model in the cluster outer regions.
- Future X-ray observations extending to ~$R_{\rm vir}$ or even close to the shock radius should be able to detect these non-equipartition signatures (see, e.g., Fig. 2).



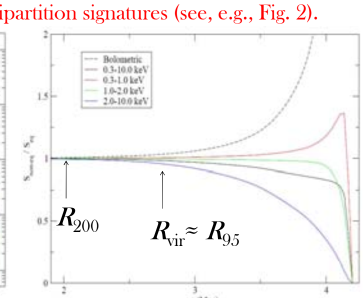
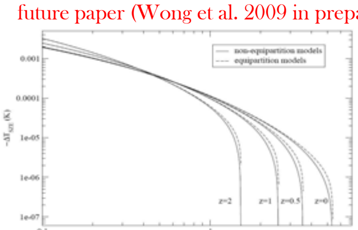




**Figure 3** ***(left panel):*** Surface brightness profiles, $S$, for various energy bands for the non-equipartition (solid lines) and equipartition (dashed lines) cluster models at $z$ = 0. Models are the same as in Figure 1.
**Figure 4** ***(right panel):*** Ratios $S_{\rm non\text{-}eq}/S_{\rm eq}$ as a function of radius. Models are the same as in Figure 3. The ratio of the bolometric surface brightness near the shock radius reaches ~35 (outside the scale of the figure).

## Effects of Non-equipartition on SZ Signatures:

- For a given cluster, the difference between the SZ temperature decrements for the equipartition and the non-equipartition models, $\delta\Delta T_{\rm SZE}$, is larger at a higher redshift.
- For the most massive clusters at z ≈ 2, the differences can be $\delta\Delta T_{\rm SZE} \approx$ 4 - 5 μK near the shock radius.
- Assuming that the shock positions can be determined by other means, ALMA may be able to distinguish between equipartition and non-equipartition models near the shock region with $S/N$ as high as 7. We defer a more detail study to a future paper (Wong et al. 2009 in preparation).



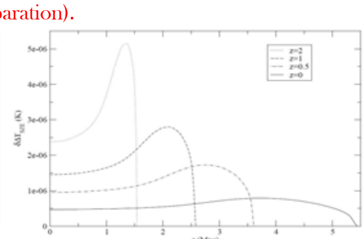




**Figure 5** ***(left panel):*** SZ temperature decrement profiles, $-\Delta T_{\rm SZE}$, of our simulated cluster at four different redshifts. The non-equipartition models ($\beta$ = 1/1800) are shown in solid lines while the equipartition models are shown in dashed lines.
**Figure 6** ***(right panel):*** Difference $\delta\Delta T_{\rm SZE}$ between the SZ temperature decrements of the equipartition and the non-equipartition models ($\beta$ = 1/1800) at four different redshifts.
Cluster model with mass $M_{\rm vir}$=2.31x$10^{15} M_\odot$ at $z$ = 0 is assumed in these two figures.

## Impact of Non-equipartition on SZ Integrated *Y* functions:

- For our model in the ΛCDM Universe, the integrated SZ bias, $Y_{\rm non\text{-}eq}/Y_{\rm eq}$, evolves slightly (at a percentage level) with redshift, which is in contrast to the self-similar model in the Einstein-de Sitter Universe. This may introduce biases in cosmological studies using the $f_{\rm gas}$ technique.
- For relaxed clusters with $M_{\rm vir} \sim 10^{15} M_\odot$, the non-equipartition effect can account for only about 2 − 3% of the missing thermal energy globally. For the most massive clusters, up to 4 − 5% of the thermal energy beyond the equipartition value may be stored in the thermal energy of ions near the shock radius, but for clusters with $M_{\rm vir}$ < 4 $10^{14} M_\odot$, the non-equipartition effect is less than 1%.

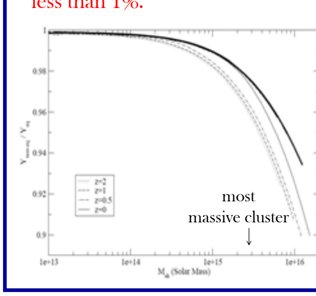



**Figure 7:** Integrated SZ biases, $Y_{\rm non\text{-}eq}/Y_{\rm eq}$, as a function of $M_{\rm sh}$ for both our simulated realistic NFW model in the ΛCDM Universe (thin lines) and the numerical simulated self-similar (SS) model in the Einstein-de Sitter Universe (thick lines) at four different redshifts. We assume $f_{\rm gas}$ = 0.17 for the SS model. The four lines for the SS model lie almost along the same line which cannot be easily distinguished on the graph.
(Note: $M_{\rm sh} \approx 1.3 M_{\rm vir}$)

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Evrard, A. E., et al. 2008, ApJ, 672, 122
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