The β-model Problem: The Incompatibility of X-ray and Sunyaev-Zeldovich Effect Model Fitting for Galaxy Clusters

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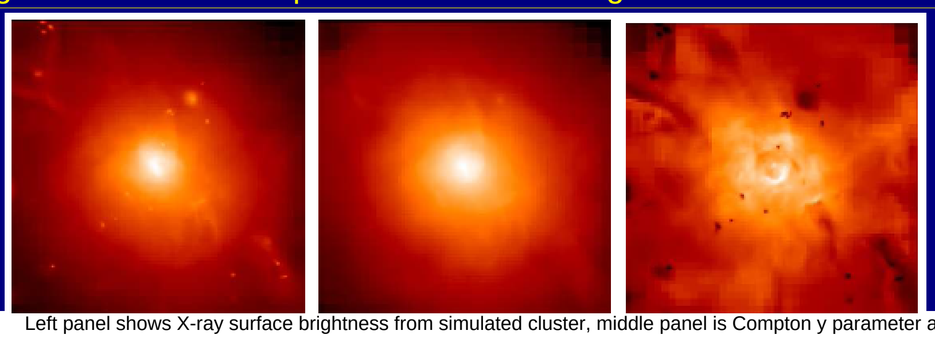
Introduction: We describe an analysis of a large sample of numerically simulated clusters which demonstrates the effects of using X-ray fitted β-model parameters with Sunyaev-Zeldovich effect (SZE) data. There is a fundamental incompatibility between β fits to X-ray surface brightness profiles and those done with SZE profiles. Since observational SZE radial profiles are in short supply, the X-ray parameters are often used in SZE analysis. We show that this leads to biased estimates of the integrated SZE inside r_{500} (represented here by y_{500}) calculated from clusters. The correlation between y_{500} and cluster total mass is very tight, and is a promising tool for cluster cosmology. We suggest a simple correction of the method, using a non-isothermal β-model modified by a universal temperature profile (UTP), which brings these calculated quantities into closer agreement with the true values.



Left panel shows X-ray surface brightness from simulated cluster, middle panel is Compton y parameter and right panel is emission weighted temperature. Images are ~5 h^{-1} Mpc on a side.

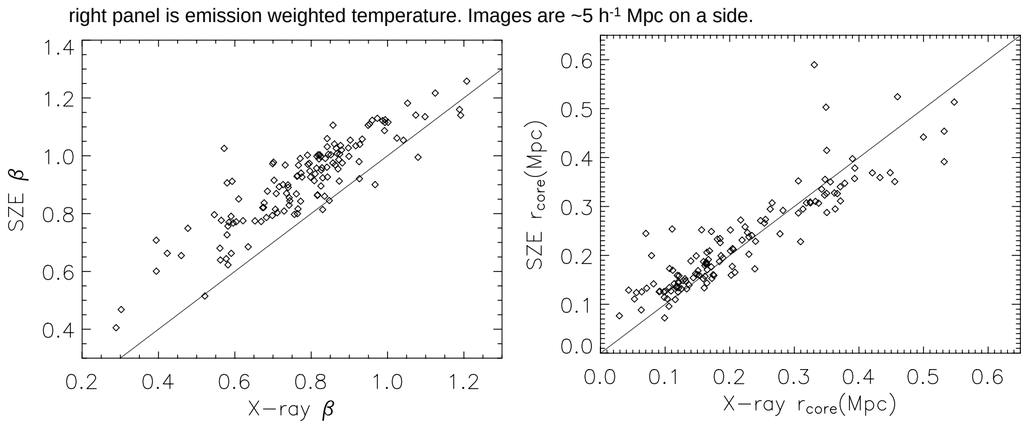


Figure 1: Left panel shows comparison of fitted β values for clusters in our numerical sample at z=0 out to r_{500} using the X-ray and SZE images. Right panel shows comparison of fitted value of r_{core} for same clusters.

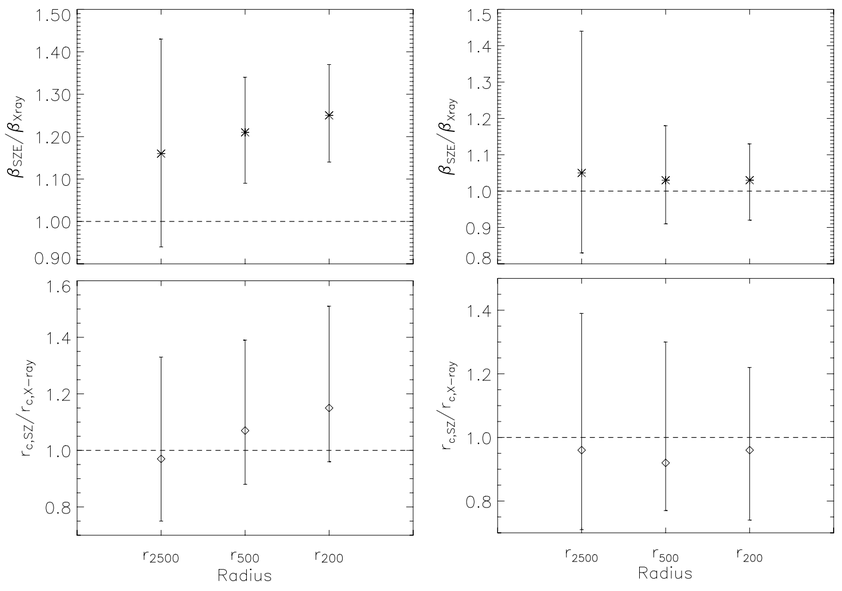


Figure 2: 1σ scatter in the ratio of the SZE deduced parameters and the X-ray parameters for each of three fiducial radii for all clusters in our catalog. Left panels are for isothermal model fits. While there is not a statistically significant bias in r_{core}, there clearly is one in β at the larger radii. Right panels show results from UTP modified fits. No bias is present.

Figure 3: Left panel: Histogram of 493 simulated cluster projections of ratio of estimated M_{500} to true value for isothermal (black lines) and UTP (blue lines) methods. Dotted lines indicate median values for each distribution. Right panel: Histogram of same cluster sample showing ratio of estimated y_{500} to true value for isothermal (black) and UTP (blue) methods.

Results: We have found that there are fundamental differences in the values of the fitted model parameters depending on whether the X-ray or SZE profiles are used. This is true both for individual clusters, and for the median values of the sample as a whole. Figure 1 shows the comparison of the values of β and r_{core} for individual z=0 clusters in our catalog fitted out to r_{500}. It is clear that there is a large amount of scatter in the relationship for the β values, and also a definite bias. Fitting SZE profiles results in a consistently higher value of β than does fitting X-ray profiles. Inconsistent values of these parameters lead to different deduced density profiles, and discrepant values for the cluster gas mass. The variation in model parameters between X-ray and SZE fitting is due to failure to account for the radial dependence of temperature in the intracluster medium. We have performed fitting with a model that includes this radial dependence in the form of a universal temperature profile (UTP). Figure 2 shows the comparison of model parameters for the isothermal and UTP model fits. Table 1 and Figure 3 show the result of each type of model fitting on deduced values of mass and integrated SZE. These estimates are critical in the use of clusters as cosmological probes. Our non-isothermal β-model fits result in more accurate and precise estimates of the gas mass as well as y_{500}.

RATIO OF ESTIMATED TO TRUE VALUES OF SIMULATED CLUSTER PROPERTIES TO r_{500}

	Isothermal	UTP
$\langle y_{500,est}/y_{500,true}\rangle$	1.28	1.13
$(y_{500,est}/y_{500,true}), median$	1.23	1.11
1σ upper	1.50	1.24
1σ lower	1.08	1.03
$\langle M_{500,gas,est}/M_{500,gas,true}\rangle$	1.17	1.05
$(M_{500,gas,est}/M_{500,gas,true}), median$	1.16	1.04
1σ upper	1.31	1.18
1σ lower	1.06	0.94

Acknowledgments: The simulations presented in this work were conducted at the National Center for Supercomputing Applications at the University of Illinois, Urbana-Champaign through computer allocation grant AST010014N. We also acknowledge the support of the NSF through grant AST-0407368.