CHANDRA X-RAY SPECTRA FROM HYDRO SIMULATIONS OF GALAXY CLUSTERS

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ABSTRACT

Hydrodynamic cluster simulations are used to construct spatially resolved X-ray spectra as expected from Chandra. The constructed spectra are fitted using a single temperature emission model. The biasing of spectral temperatures with respect to mass-weighted temperatures is found to be influenced by two independent processes. The first scale dependency is absent in adiabatic runs and is due to cooling, whose efficiency to transform cold gas into stars is higher for cool clusters and this in turn implies a strong dependency of the spectral versus mass-weighted temperature relation on the cluster mass. The second dependency is due to photon emission because of cool gas which is accreted during merging events and biases the spectral fits. The behavior of the simulated temperature profiles can also be interpreted according to these two scale dependencies. Moreover, the temperature profiles of cooling clusters is scale dependent and can not be considered universal, the profile of massive clusters being shallower than that of cool clusters.

Key words: hydrodynamic simulations; clusters; X-rays.

1. INTRODUCTION

Results from a large sample of hydrodynamical/N-body simulations of galaxy clusters in a ΛCDM cosmology are used to simulate cluster X-ray observations. The physical modeling of the gas includes radiative cooling, star formation, energy feedback and metal enrichment that follow from supernova explosions. Mock cluster samples are constructed grouping simulation data according to a number of constraints which would be satisfied by a data set of X-ray measurements of cluster temperatures as expected from *Chandra* observations. The simulated events take into account the effects of quiescent background noise, detector geometry and energy response. The X-ray spectra from simulated clusters are fitted into different energy bands using the XSPEC *mekal* model. Relationships between spectral and mass-weighted global cluster temperatures are investigated for different cluster overdensities. Moreover, spatially resolved X-ray spectra of the simulated clusters are also used to investigate how the measured temperature profiles differ from the projected profiles obtained directly from simulations. The numerical sample is also subdivided according to the amount of substructure present in a given cluster, this allows us to investigate how spectral measurements are affected by the cluster dynamical state.

2. CONSTRUCTION OF THE SPECTRAL SAMPLES

The cosmological model assumes a flat CDM universe, with matter density parameter $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $\Omega_b = 0.019h^{-2}$ and $h = 0.7$ is the value of the Hubble constant in units of $100 Km sec^{-1} Mpc^{-1}$. The power spectrum has been normalized to $\sigma_8 = 0.9$ on a $8h^{-1}Mpc$ scale. In order to construct the numerical sample, the 120 most massive clusters were selected from a N-body cosmological simulation with box size $L_1 = 200h^{-1}Mpc$. The procedure is repeated with a simulation having box size $L_2 = 400h^{-1}Mpc$ and the 32 most massive clusters are chosen to be part of the final sample. These 152 clusters are then resimulated individually according to the multi-mass technique using a multistep hydrodynamic TREESPH code in which the modeling of the gas physics takes into account: gas cooling, star formation, energy and metal feedback from SN explosions. A more detailed description of the simulations can be found in Valdarnini (2003). A large sample of hydrodynamic simulations of galaxy clusters is then constructed and for each cluster all of the hydro variables are output at various redshifts.

In order to obtain simulated spectral fit temperatures the simulated photon spectra are first calculated from the simulated clusters observed at various redshifts along a given line of sight. To the binned source spectra are then added properly normalized background spectra. The files are subsequently convolved with a template pair of area response file (ARF) and redistribution matrix file (RMF) of the *Chandra* observatory. Finally, the generated event files are fitted by a single temperature *mekal* model available with the XSPEC library, provided a certain number of constraints are satisfied. These constraints take into account the instrumental limits of the receiver. The *mekal* model with which the fits are performed has three free parameters: the gas temperature, the metallicity abundance and the normalization; the other parameters being kept fixed.

3. RESULTS

The global cluster spectral fits temperatures are obtained by applying the prescriptions previously described to a cluster sample which is constructed by grouping data from the simulation ensemble at redshifts $z = 0.087, 0.47$ and $z = 0.85$. The spectral fits are performed in the energy band $[0.5-10] keV$ and the source spectra are computed from gas emission within spherical volumes with radii r_Δ such that $M_\Delta = 4\pi r_\Delta^3 \Delta\rho_c(z)/3$ is the enclosed mass, where $\rho_c(z)$ is the critical density and $\Delta = 2500,\ 500,\ 200$. The spectral fit temperatures T_S^Δ are then compared against mass-weighted temperatures T_{mw}^Δ. The results indicate that the biasing of temperatures with respect to mass-weighted temperatures is found to be governed by two independent processes.

The first scale dependency is absent in adiabatic runs and is due to cooling, whose efficiency to transform cold gas into stars is higher for cool clusters and this in turn implies a strong dependency of the spectral versus mass-weighted temperature relation on the cluster mass. Mathiesen & Evrard (2001) argue that spectroscopic temperatures are biased toward lower values of the mass-weighted temperatures because spectroscopically determined temperatures are weighted by the fitting process according to the photon counts, From the spectral samples it is found that for massive clusters spectral temperatures are lower than mass-weighted temperatures, whereas $T_s \simeq T_{mw}$ as cool clusters are considered. This behavior follows from two effects: the way in which the sample is constructed and the introduction of the physical modeling of cooling in the simulations. At high redshifts the sample is dominated by massive clusters for which $T_s \lesssim T_{mw}$, because of selection effects at low redshifts the sample population is dominated by cool clusters. For these clusters the efficiency of galaxy formation is higher than in hot clusters. This implies a removal of the low-entropy cooled gas, transformed into stars, and a subsequent inflow of the surrounding high-entropy gas. Therefore, in this scenario, it follows that for cool clusters the central cluster temperature, in units of a characteristic cluster temperature, is higher than for massive clusters. The second scale dependency is correlated with the amount of cluster substructure and is independent from the first. This dependency is due to photon emission because of cool gas which is accreted during merging events and biases the spectral fits. These events have been quantified according to the power ratio method (Buote & Tsai 1995). The method works as follows. The X-ray surface brightness Σ_X along a given line of sight is the source term of the pseudo potential which satisfies the 2-D Poisson equation. The pseudo potential is expanded into plane harmonics and the $m-th$ coefficients of the expansion are calculated over a circular aperture of radius R_{ap}. The $m-th$ power ratios are then defined as $\Pi^m = log_{10} P_m/P_0$. The ratios P_m/P_0 are a measure of the amount of structure present on a given scale. For a relaxed configuration $\Pi^{(m)} \rightarrow -\infty$. For global cluster temperatures the results indicate the existence of a robust correlation between the spectral bias, which is defined as $(T_s^\Delta - T_{mw}^\Delta)/T_{mw}^\Delta$, and the amount of cluster substructure.

The behavior of the projected emission-weighted temperature profiles is investigated in the energy band $[0.5-7]keV$. The profiles have been calculated keeping fixed the chosen line of sight and the radial binning, in units of r_{200}, for all of the clusters. The profiles have been averaged over samples at redshifts $z = 0.116, 0.052, 0.039$ and $z = 0.025$. Because of the scale dependencies previously discussed, the sample of temperature profiles has been subdivided by grouping individual profiles into subsample according to the degree of regularity of the gas distribution of its cluster members. A cluster is part of a subsample denominated 'quiescent' if the value of Π_3 is below the threshold value which defines the 25% percentile of the cumulative distribution of the power ratios. Similarly, clusters which are members of the 'active' subsample have their value of Π_3 above the threshold which defines the 75% of the percentile of the distribution. The results indicate that quiescent clusters have scaled profiles which rise toward the cluster center, reaching their peak values at $r \simeq 0.02 r_{200}$ and with a steep decline thereafter. The profiles of active clusters are shallower than those of quiescent clusters and the peak heights are much more modest. These dependencies of the shape of the profiles on the value of P_3/P_0 have been obtained with $R_{ap} = r_{200}/2$ and indicate that the effects of merging on the gas distribution of the clusters are the main source for the differences in the profiles. According to this framework active clusters have profiles much shallower than quiescent clusters because their cores have accreted from subclumps a significant amount of cool gas through a number of merging events. For small values of the aperture radius ($R_{ap} \lesssim r_{200}/4$) the differences between the shape of the profiles from active and quiescent clusters are not as significant as those obtained with $R_{ap} = r_{200}/2$. This suggests that cools gas can significantly accrete into cluster cores only through major merging events, where the mass of the subclump is a significant fraction of the cluster mass. Moreover, the shape of the profiles is not universal and it is steeper at the cluster center for cool clusters than for the massive ones. This follows owing to the scale dependency introduced by cooling which implies for cool clusters higher central temperatures, in scaled units, than for massive clusters.

REFERENCES

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