Multi-temperature plasma and the spectroscopic-like temperature bias with the ATHENA X-IFU

F. Gastaldello[1], M. Rossetti[1], S. Molendi[1], S. Ghizzardi[1], S. De Grandi[2], S. Ettori[3], D. Eckert[4]
[1]INAF-IASF Milan,[2]INAF-OAB Milan,[3]INAF-OAS Bologna, [4]MPE

Abstract

Current X-ray observatories equipped with CCDs can not detect multi-temperature plasma when the temperature components are above 2 keV. This has important implications for the study of the thermal structure in galaxy clusters and groups especially when strong temperature gradients are present, such as in shock and cold fronts, or when plasma with different temperature components are co-spatial such as in cool cores. We will show the results of a series of idealized simulations with two temperature components to approximate the differential emission measure distribution of a multi-temperature plasma with the Athena X-IFU resolution to investigate how the scenario will change with the advent of a high resolution, high throughput calorimeter.

1 Introduction

In the work of Mazzotta+04 two important results were obtained focusing on X-ray spectra of clusters of galaxies obtained with CCDs like the ones on board Chandra and XMM: (i) given a multi-temperature source spectrum, if the lowest component has a temperature > 2-3 keV, then a fit made with a single temperature model is statistically acceptable regardless of the actual spread in the temperature distribution (see Fig.1); (ii) the temperature obtained in such cases by X-ray observers, called the spectroscopic-like temperature T_{sl}, is not properly estimated by the mass-weighted or emission weighted temperatures. The larger the spread in the temperature distribution, the larger the discrepancy as lower temperature components are preferentially weighted (see Fig.2).

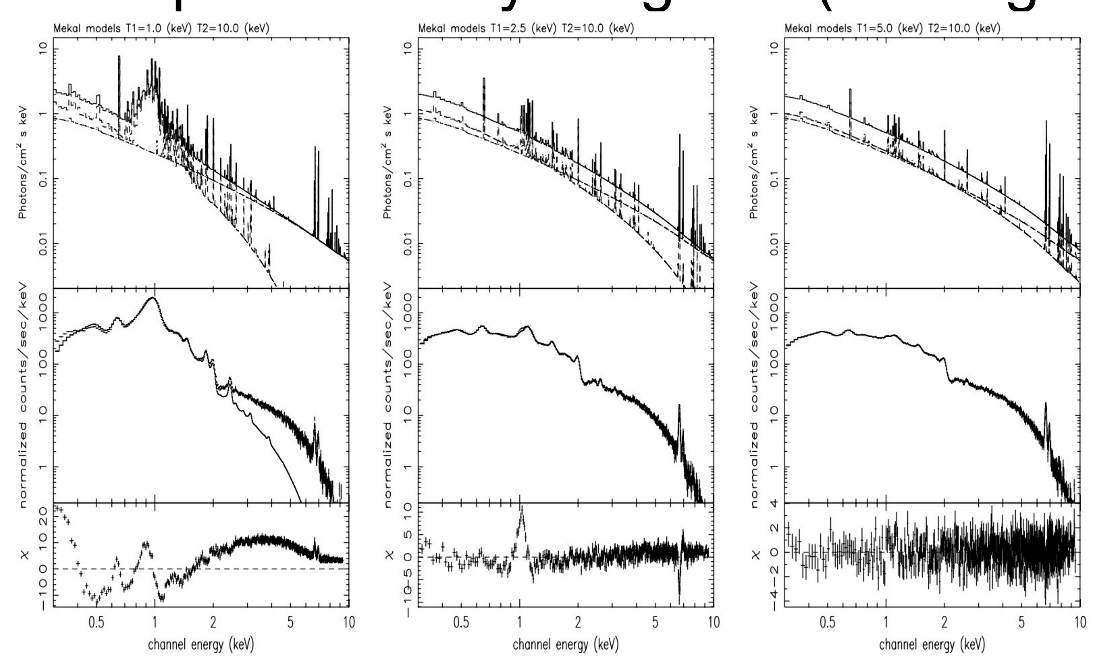

Figure 3. As Fig. 1, but for metallicity Z = 1.

Fig.1 *The upper panel show the two input thermal plasma used to perform the simulation, with T2=10 keV in all panels and T1=1, 2.5 and 5 keV in each panel. The middle panel show the corresponding simulated Chandra spectrum and the bottom panel the residuals of the fit with a single temperature model. Taken from Mazzotta+04.*

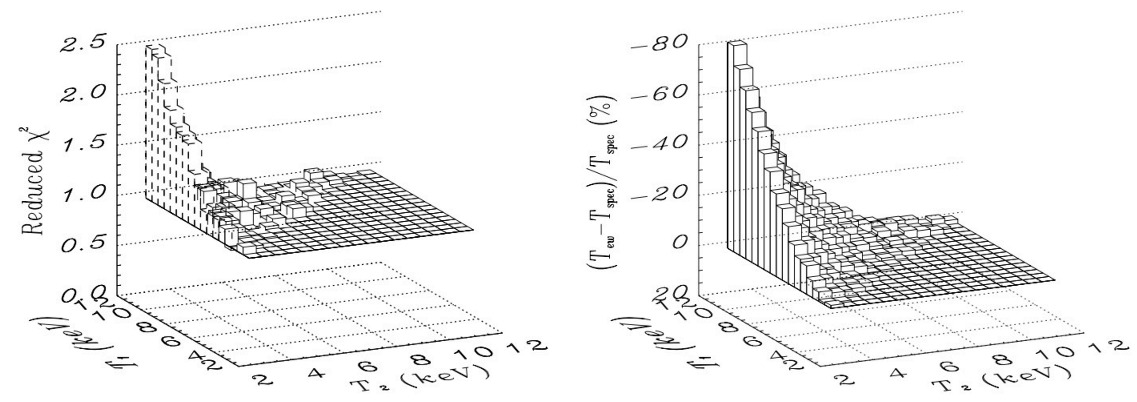

Fig.2 *(Left panel): statistical quality of the fit with a single temperature model to a simulated two-temperature model. (Right panel): percentile difference between the calculated emission-weighted T_{ew} and spectroscopic-like T_{sl} as a function of the temperatures of the two simulated thermal models. Taken from Mazzotta+04.*

The obtained results depend critically by the band pass and spectral resolution of CCD detectors. With this work we aim to investigate how these results will change with the advent of a high resolution spectrometer such as the X-IFU on board ATHENA.

Using the same approach of Mazzotta+04 we will simulate the combination of the two thermal models with temperatures T1 and t2 and fit the resulting X-IFU spectrum with a single temperature thermal model. The parameters of simulated spectrum are matched to the flux obtained within the central 1 arcmin of A1795. We used the baseline cost-constrained X-IFU response matrices.

2 Results

One of the key possibility opened by X-ray calorimeters is the ability to use the ratios of the spectral lines resulting from transitions from the n=2 level in He-like ions, in particular the iron complex which is the most prominent line in X-ray spectra of galaxy clusters as beautifully shown by the Hitomi spectrum of Perseus (see Fig.3).

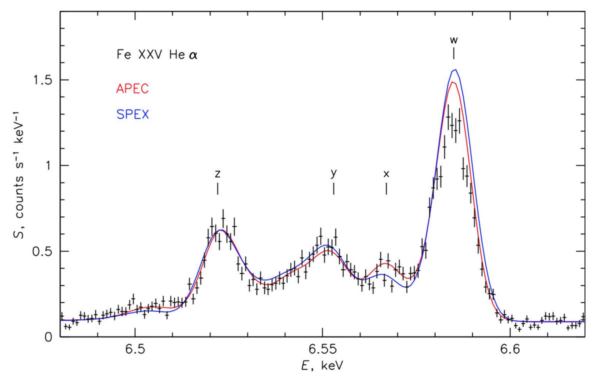

Fig.3 *The Fe He-α line complex in the core of Perseus as seen by Hitomi (Hitome+16). The resonant (w or R), forbidden (z or F) and intercombination (x,y or I) lines are shown. The ratio (F+I)/R is a powerful diagnostic of the plasma temperature (e.g. Porquet+10).*

The results of our simulations confirm these expectations: if for example it is still not possible to distinguish the combination of two temperature models with very similar temperatures, such as T1=8 keV and T2=7 keV, in the case of T1=8 keV and T2=5 keV the ratio of the lines of the 6.7 keV complex reveal a more complex thermal distribution (see Fig.4).

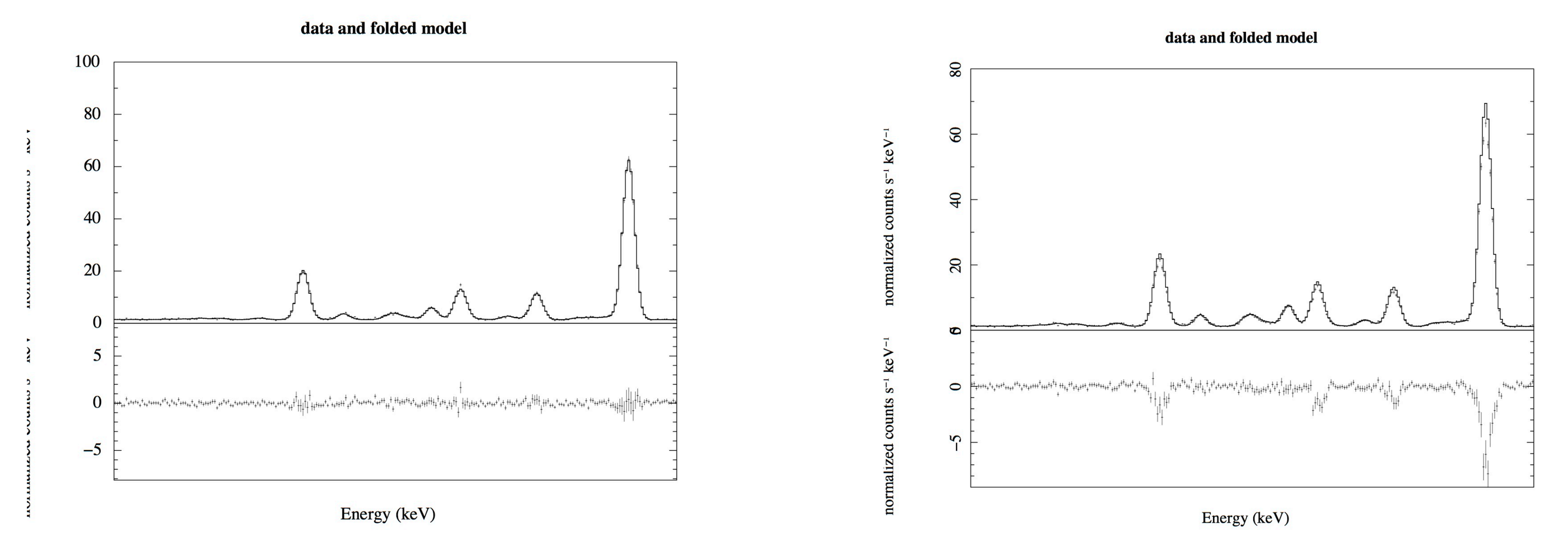

Fig.4 *The spectral region of the Fe He-α complex for a simulated two temperature spectrum with T1=8 keV and T2=7 keV (left panel) and T1=8 keV and T2=5 keV (right panel) with the corresponding best fit single temperature model and its residual. The two temperature components have the same emission measure. It is clear that in the case shown in the right panel the ratio (F+I)/R clearly shows the deviation from a single temperature model as it was not the case for a CCD spectrum.*

It is difficult to assess statistically that the global fit is not acceptable and this points to a more local approach to the temperature determination (but see the discussion in Hitomi+18, the "T paper"). The global fit temperature still suffer from a spectroscopic-like bias even though to a lesser degree than with CCD spectra (see Fig.5).

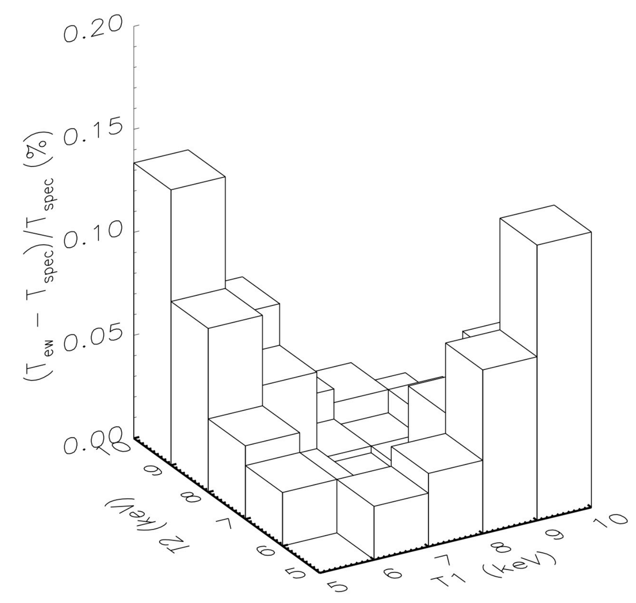

Fig.3 *(Left Same plot as the one of the right panel of Fig.2, but now for simulated X-IFU spectra. A discrepancy between spectroscopic-like and emission weighted temperatures is still present.*

3 Conclusions

A set of X-IFU simulations similar to the ones presented for CCD spectra in Mazzotta+04 has been performed, focusing in particular to multi-temperature plasma with temperatures greater than 4 keV, e.g the ones impossible to distinguish with CCD-like resolution. Thanks to the fantastic energy resolution of the X-IFU deviations from a single temperature model are easier to detect. The spectroscopic-like temperature bias is still present. The simulation of the impact on the results of turbulence and resonant scattering is on going.

References

Mazzotta et al. 2004, MNRAS, 354, 10
Hitomi collaboration 2016, Nature, 535, 117
Hitomi collaboration, 2018, PASJ, 70,11
Porquet et al. 2010, Space Sci. Rev., 157, 103