Simulating the soft X-ray excess in clusters of galaxies

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Abstract

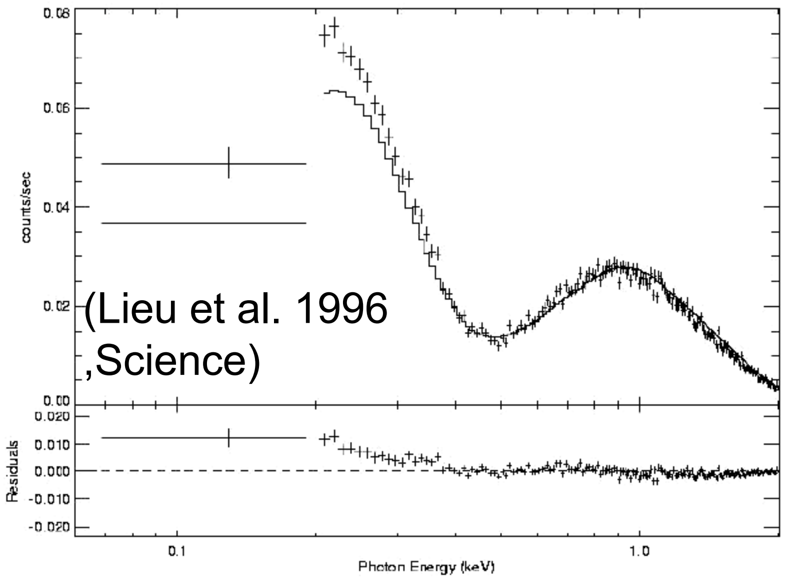
We use a large-scale hydrodynamical simulation to investigate the presence and possible thermal origin of soft x-ray excess.

- Introduction
- The simulation and simulated clusters
- Analysis method and the results
- Conclusion and future perspectives

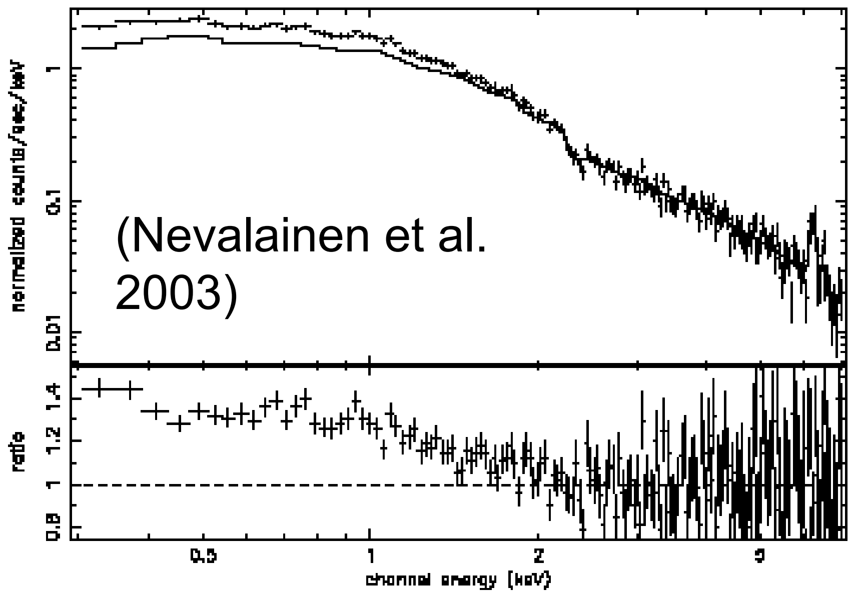
Introduction

Soft X-ray or Extreme-ultraviolet (EUV) emission in excess of that produced by the well-studied X-ray-emitting gas in clusters of galaxies.

Coma Cluster 6' – 9' ROSAT



A3112 1.5' – 4.5' XMM-Newton



Bowyer et al. (1999) , Arabadjis & Bregman (1999) ,Valinia et al.(2000), Dixon et al. (2001), Bonamente et al. (2002), Bonamente et al. (2003))

Debates on the soft excess

- The reality of the existence:

  Soft excess is an artifact (eg. Bregman et al. 2003, Berghofer & Bowyer 2002, Durret et al 2002, Bowyer et al. 1999)

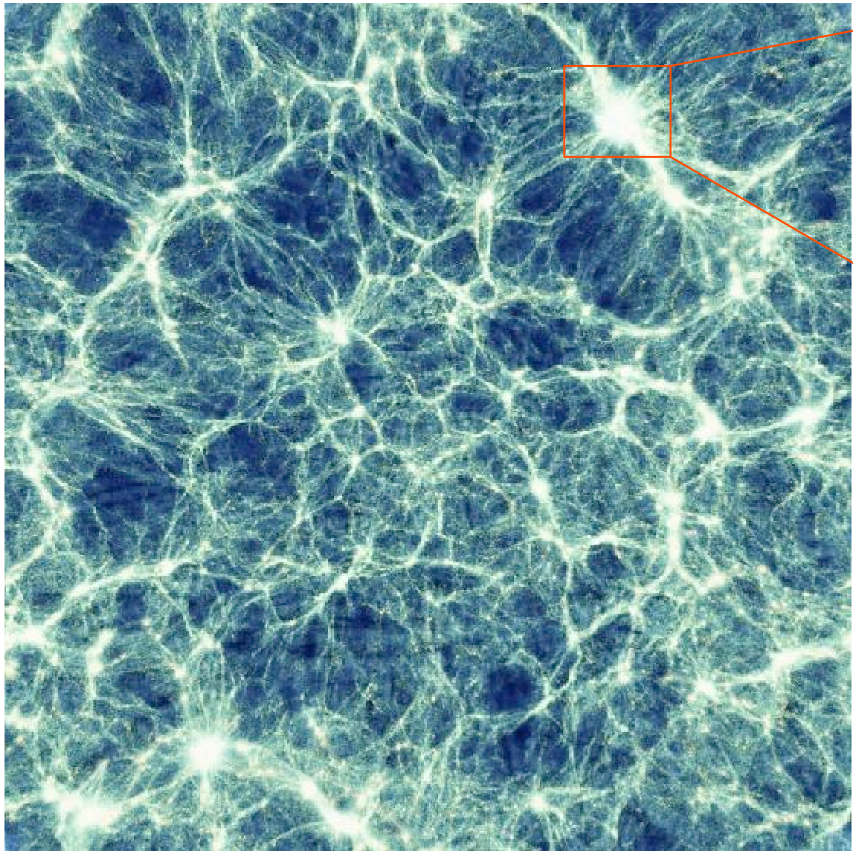
- The origination of the excess
  - Inverse Compton scattering between CMB photons and relativistic electrons (eg. Hwang 1997, Sarazin & lieu 1998...)
  - Warm gas at $T \sim 10^6$K
    - inside the cluster (eg. Lieu et al. 1996)
    - in very diffuse filamentary structures outside the clusters

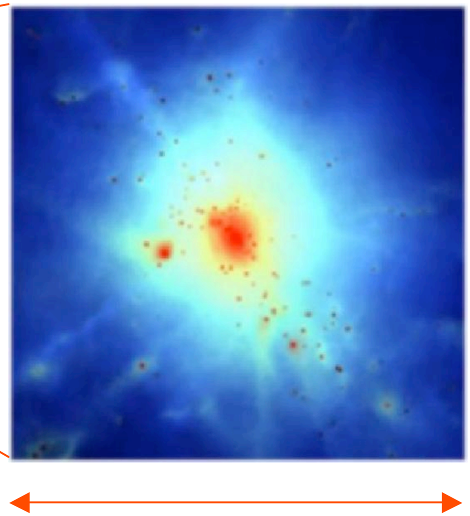
      (eg. Bonamente et al. 2001; Buote 2001; Bonamente et al. 2003; Kaastra et al. 2003; Finoguenov et al. 2003)

(a) Does warm gas account for a thermal soft excess as large as that observed in the clusters spectra ? → existence

(b) Is the warm gas residing within clusters, or to large-scale filaments observed in projection ? → origin

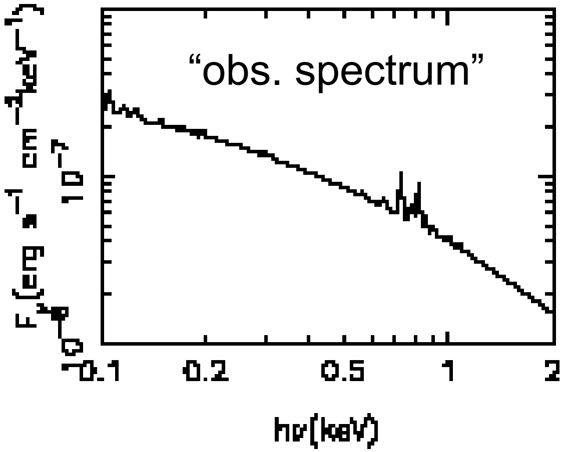
Borgani et al. (2004)





6 R_{vir}

$$L_X = \sum_i (\mu m_p)^{-2} \left(\frac{n_e}{n_H}\right)_i m_i \rho_i \Lambda(T_i, Z_i, \Delta E)$$



Code: Tree+SPH code GADGET
Boxsize: 192 h^{-1} Mpc
Resolution: 480^3 dark matter particles + 480^3 gas particles.
Physics: radiative cooling, star formation and supernova feedback, galactic winds.

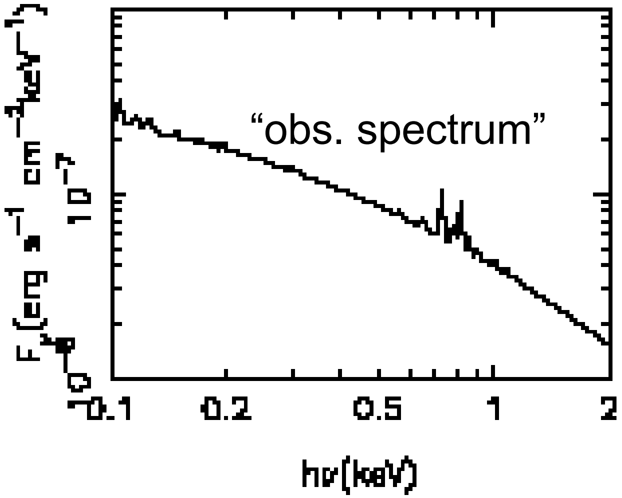
Mimicking the observation

- In observations: Apply a MEKAL model to fit the high-energy (1-2keV) portion of the spectrum, then take the extrapolation of the best-fitting model spectrum as the predicted spectrum at a lower energy(0.2-1keV) (eg. Bonamente et al. 2003).

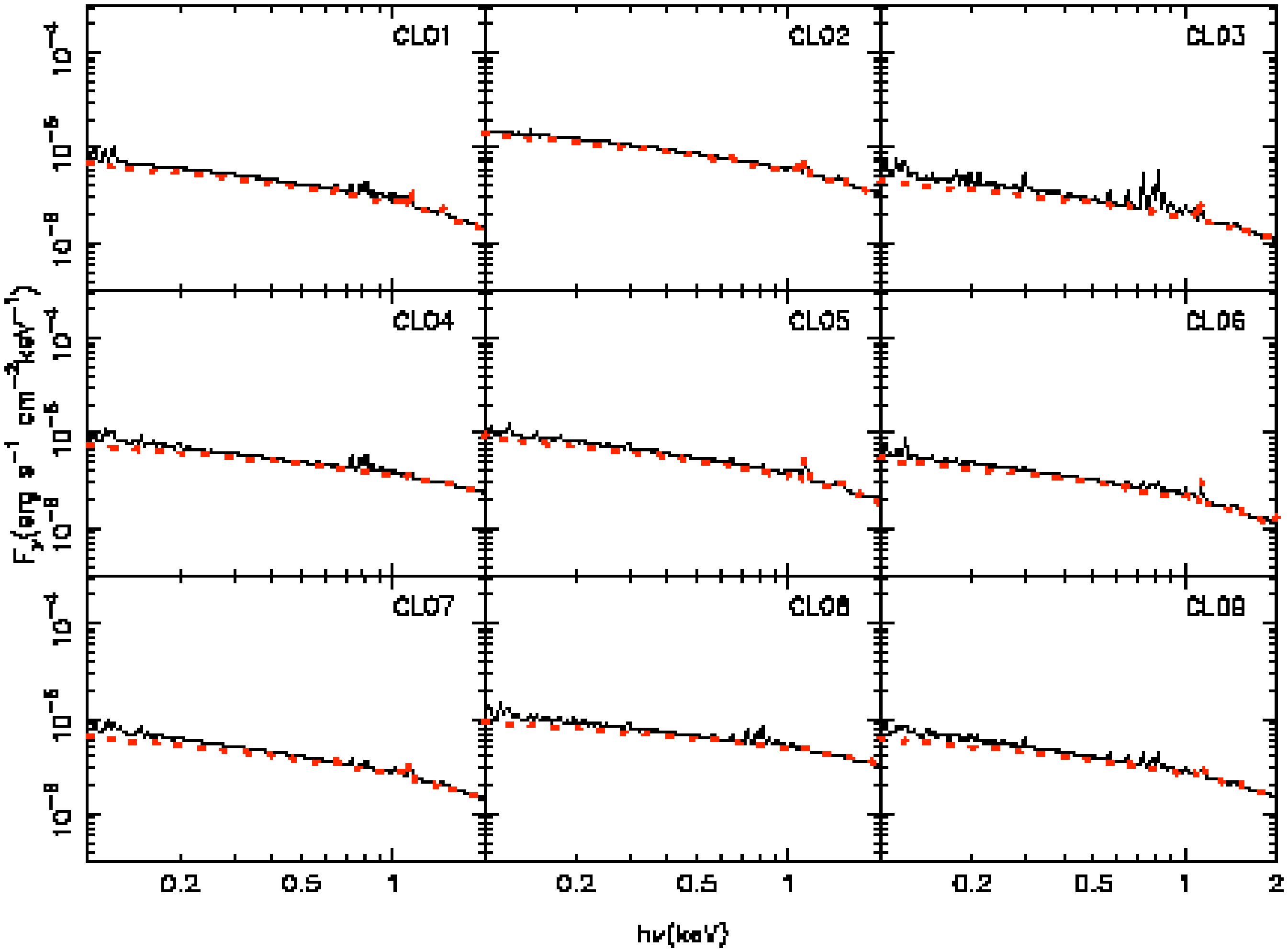
- In our simulations: compute the emission-weighted temperature in 1-2keV

$$T_{ew} = \frac{\sum_i m_i \rho_i \Lambda(T_i, Z_i; E_1, E_2) T_i}{\sum_i m_i \rho_i \Lambda(T_i, Z_i; E_1, E_2)}$$

$$Z_{ew} = \frac{\sum_i m_i \rho_i \Lambda(T_i, Z_i; E_1, E_2) Z_i}{\sum_i m_i \rho_i \Lambda(T_i, Z_i; E_1, E_2)}$$

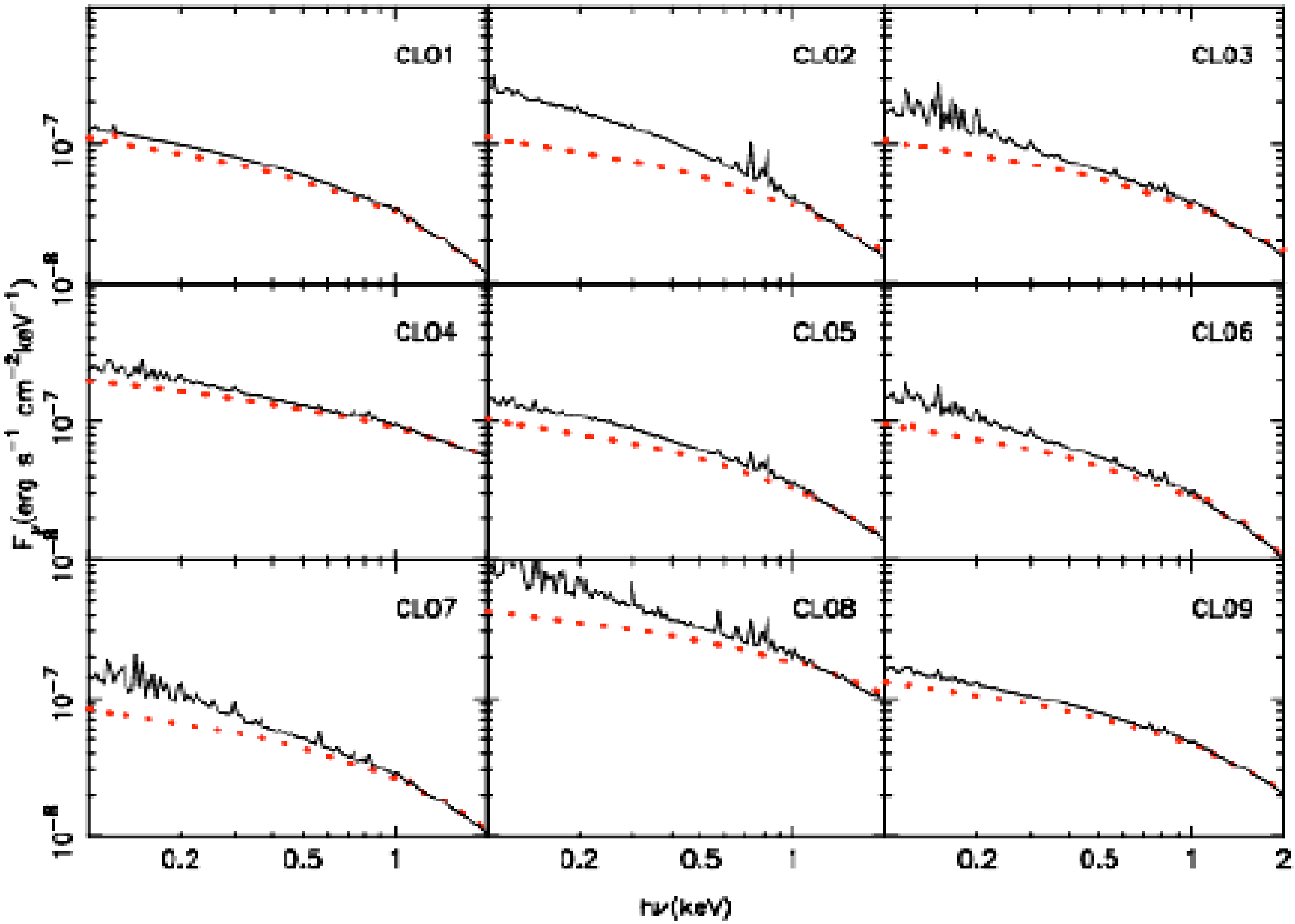


Simulated spectra of center region (< 0.4Rvir)

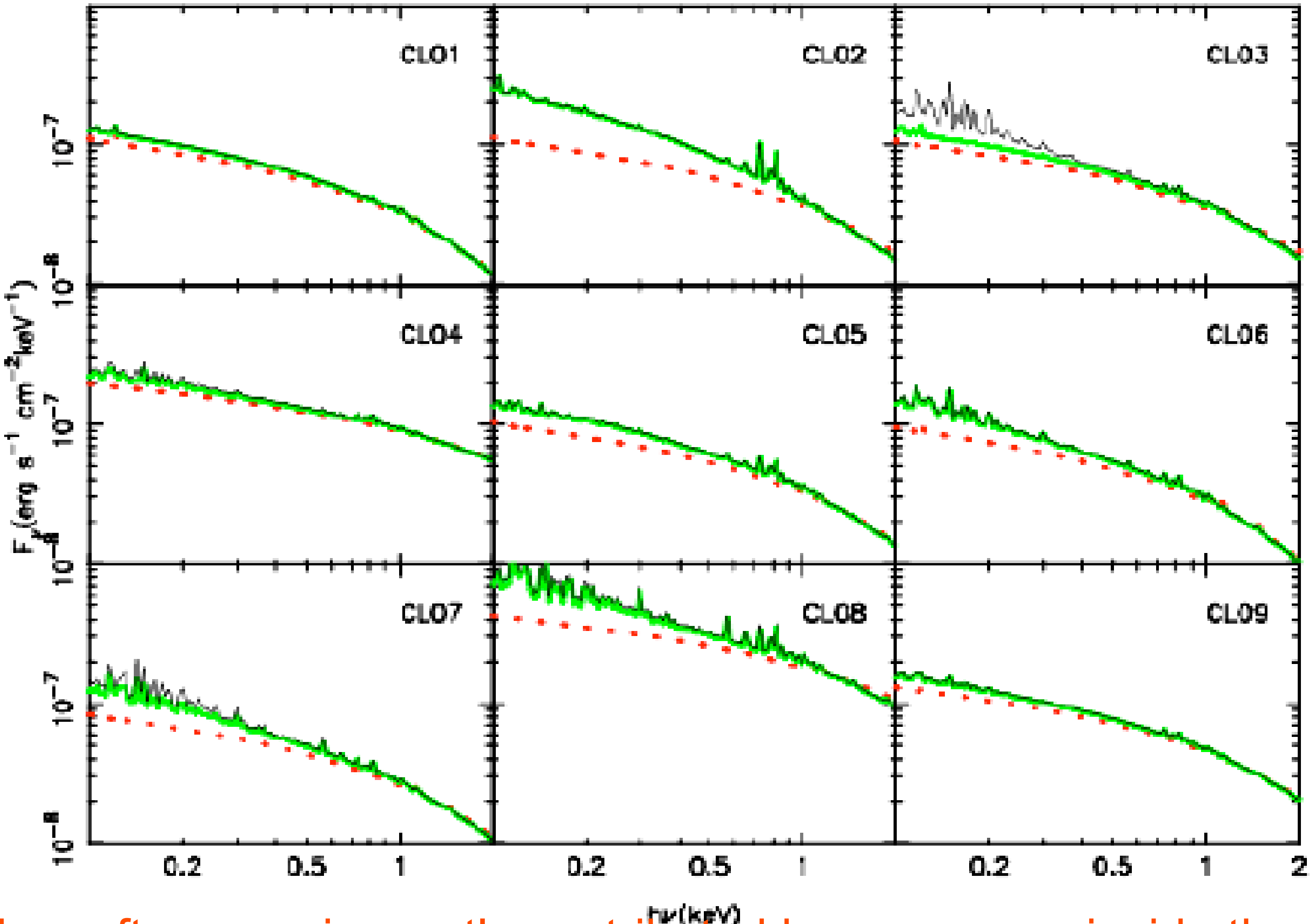


No significant excess !

0.4 – 0.7 R_{vir} projected region



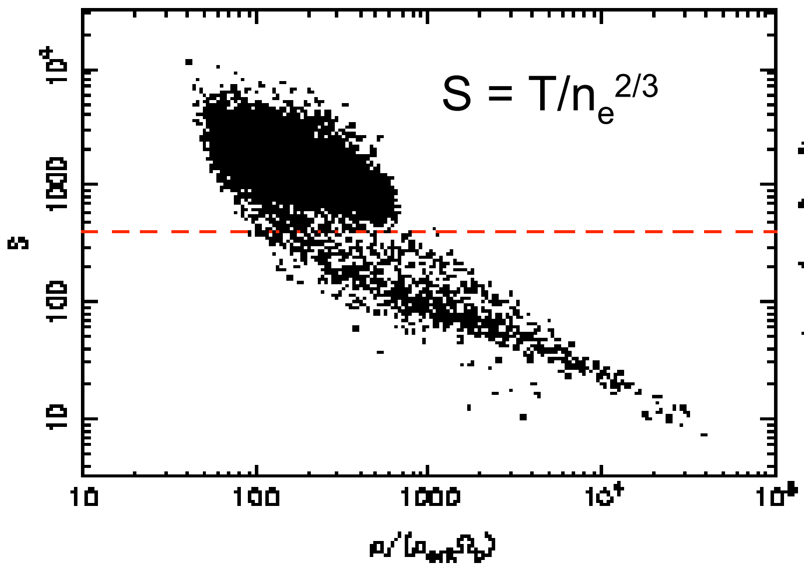
0.4 – 0.7 R_{vir} projected region

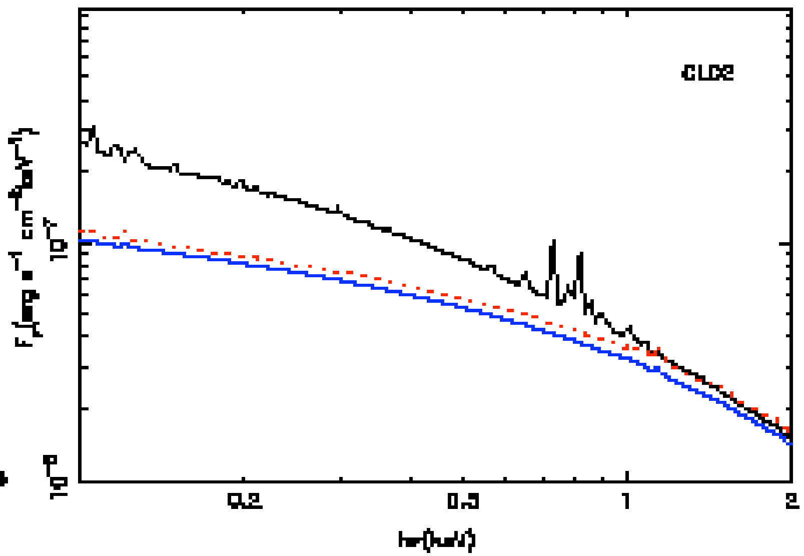


The soft excess is mostly contributed by warm gas inside the cluster.

(diffuse warm gas ? high-density gas within subhalos ?)

Tracing the gas particles responsible for the soft excess in CL02

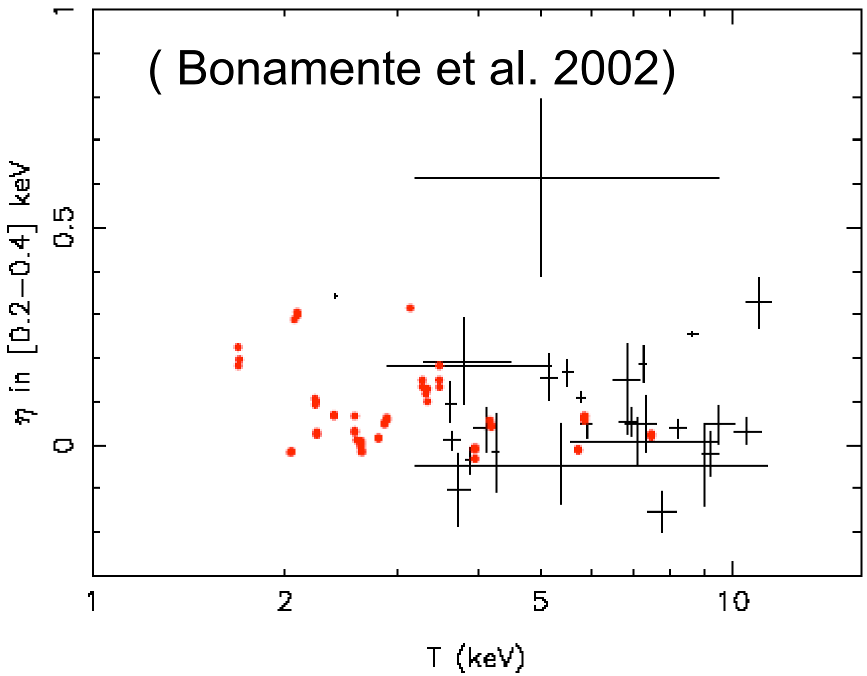




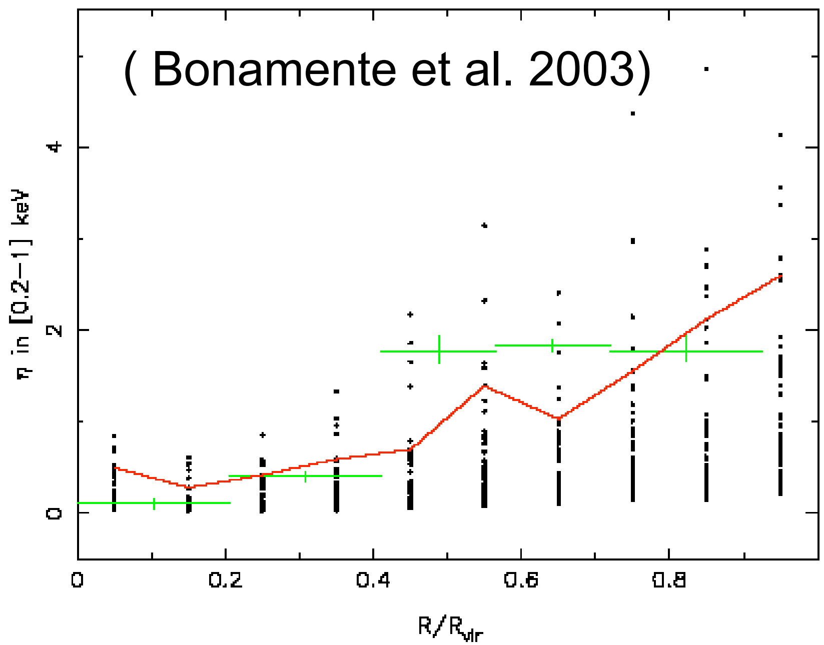
The soft excess is associated with the presence of previously virialized clumps of high density gas, rather than to a diffuse phase of warm gas superimposed on the hot cluster atmosphere.

Comparison with observations

$$\eta = \frac{q-p}{p}$$ (q: the observed flux; p: the prediction from hot ICM)



The global relative excess for different cluster systems.



The relative excess as a function of the projected distance.

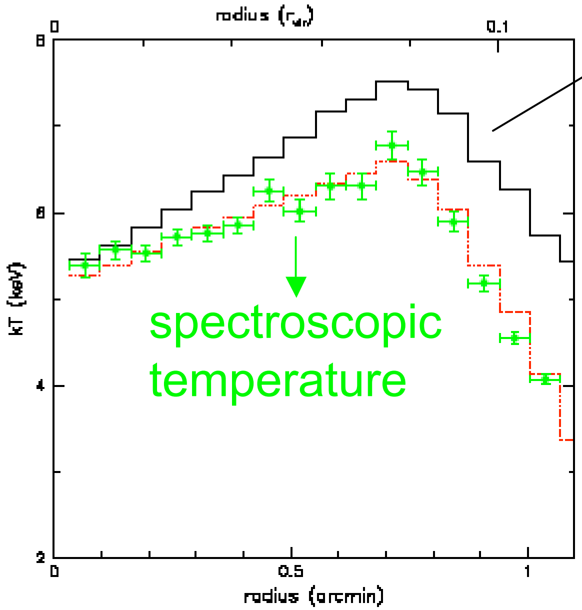
Conclusions

- There is no significant thermal soft excess in the center region of clusters.
- A significant soft X-ray excess is detected for distances $0.4<R/R_{vir}<0.7$.
- The excess originates inside the virial radius, and the filament projection is very slight.
- The excess comes from high-density and low-entropy gas.
- The relative excess increases with the distance from the cluster center, but an excess as large as that observed for Coma is a rather rare event.

What’s on going ……

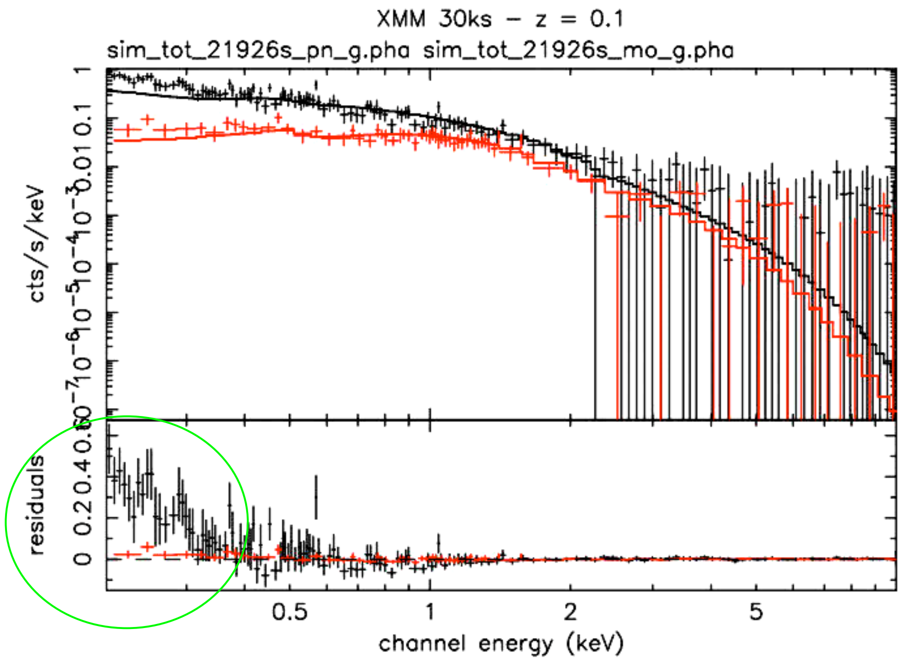
You may have note that:

We generate the synthetic spectra (the observed spectra) without including any observational effect; and we use the emission-weighted temperature to calculate the expected spectrum.



Mazzotta et al. (2004)

emission-weighted temperature



(1) Study how the level of the detected soft excess varies by changing the physics of the ICM.

(2) Investigate whether the small clumps, responsible for the excess would be observable as bright spots in X-ray imaging.

(For more details, kindly please refer to Cheng et al. 2005, A&A, 431, 405)