Comparing predictions of a Warm Hot Intergalactic Medium (WHIM) with XMM-Newton observations of the cluster soft excess

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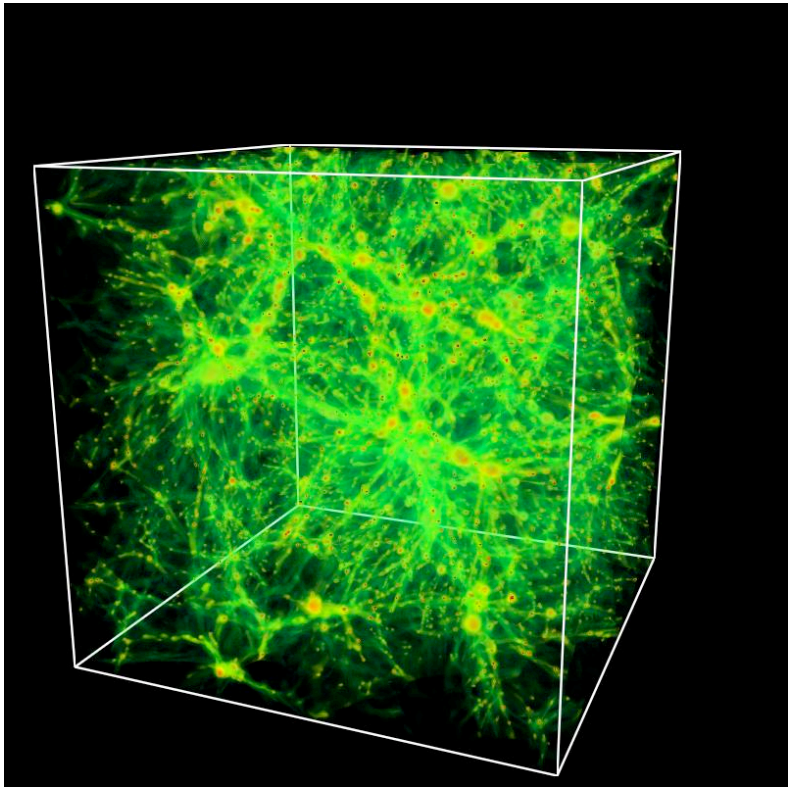
Material T ~ 10^{5-7} K see in models of large scale structure – the Warm Hot Intergalactic Medium (WHIM)



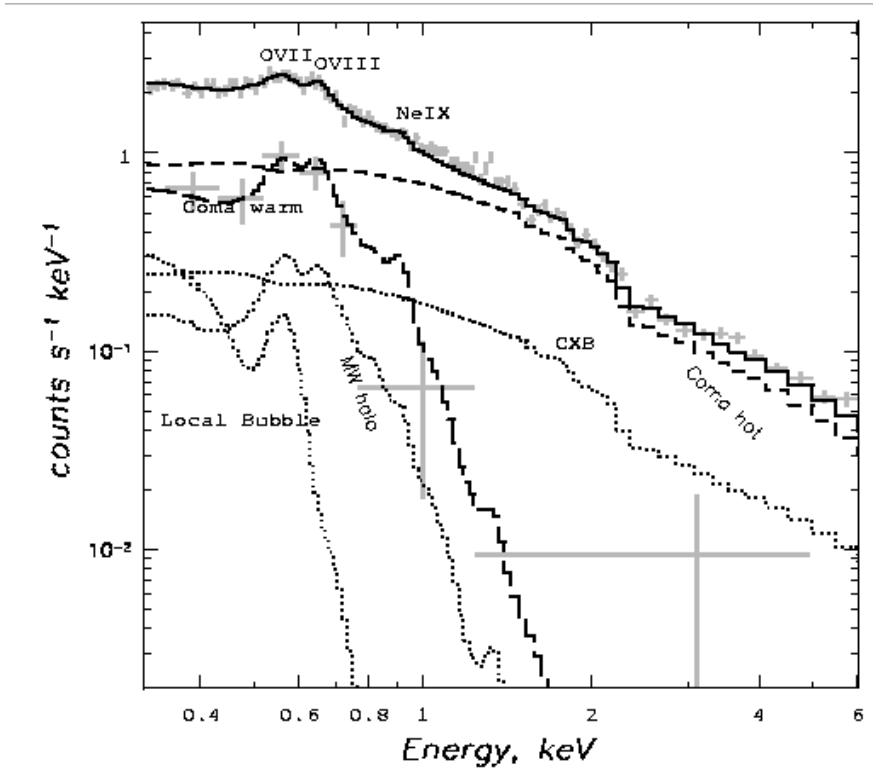
Filaments of material between clusters – contain up to 40% of the baryons in the Universe (e.g. Cen & Ostriker 1999)

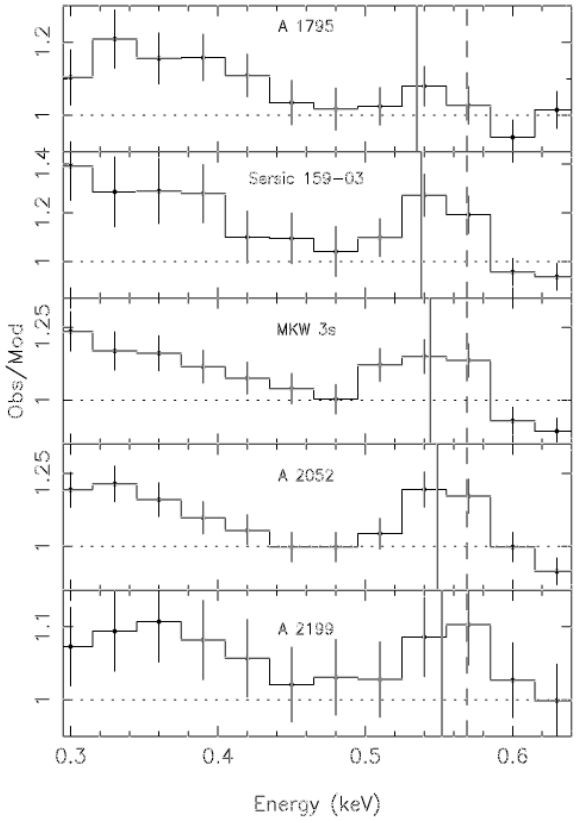
Has it been seen?

Perhaps in the cluster soft excess

Cluster soft excess shows characteristics of the WHIM near the `nodes'

1) Thermal emission with T ~ few 10^6 K
2) Increases in importance on the outskirts of clusters



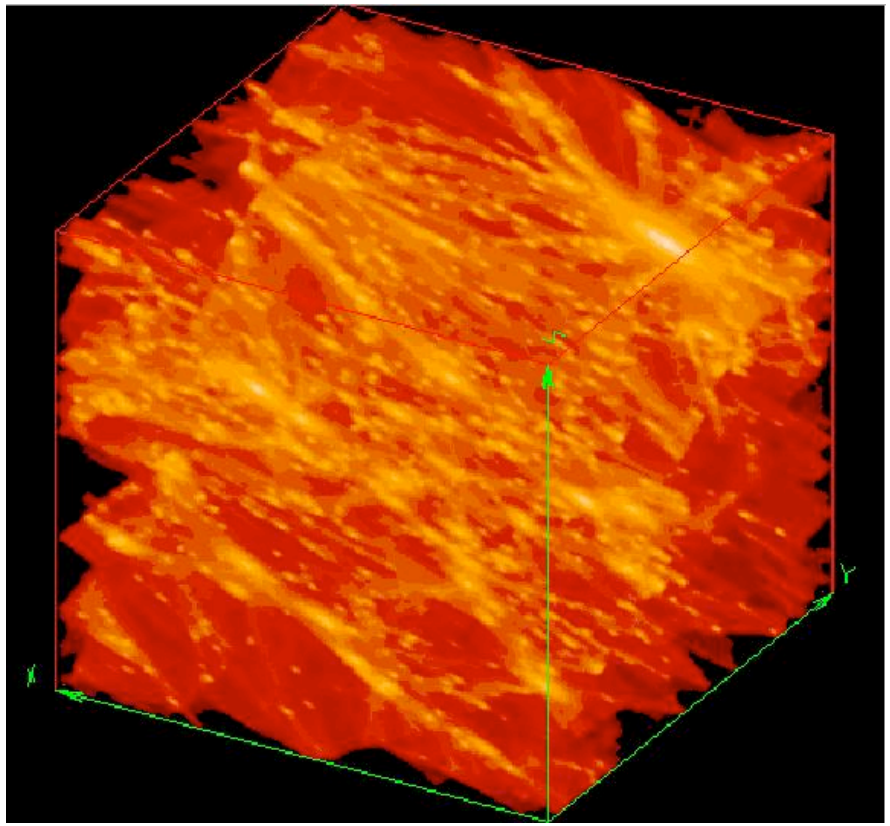


WHIM also solves some problems with thermal soft excess model.

BUT: Do models give rise to a soft excess?

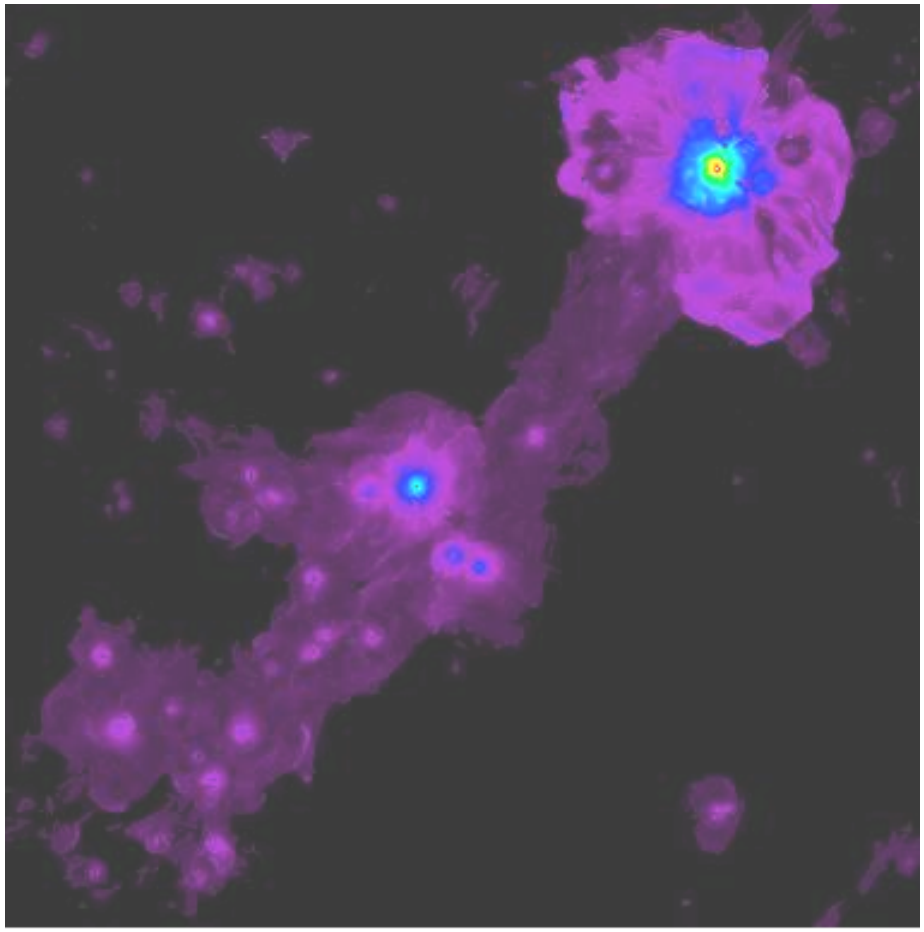
Preliminary comparison with observations of a simulation from Renyue Cen for z = 0

- **3 data cubes containing temperature, density, abundance**
- **Cube volume 25 h^{-1} Mpc in 768^3 cells**
- **Parameters Ω_M=0.3, Ω_Λ=0.7, $\Omega_b h^2$=0.017, h=0.67**



Density map from a simulation

Simulation shows wide range of temperatures:



0 5.6

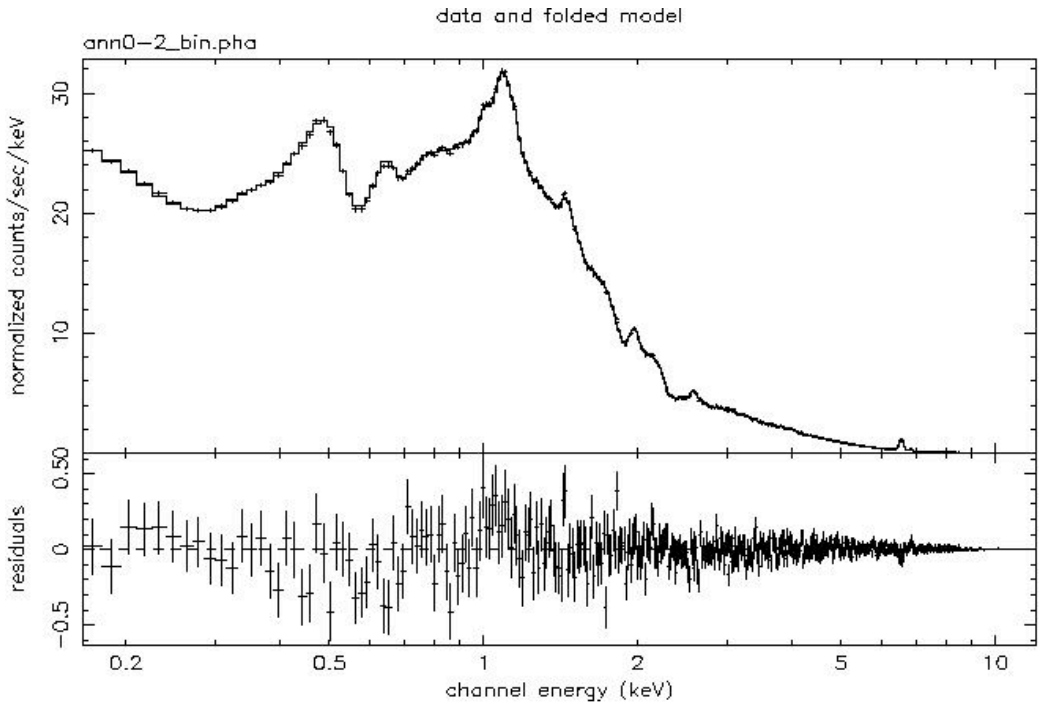
Emission weighted temperature map

Image shows range 0.08– 5.6 keV

Low Temperature structures 0.1-0.4 keV (in purple) – typical temperatures of soft excess

High temperature structure top right – cluster candidate

From simulation we have generated XMM spectra



- Assumed Galactic $N_H = 9x10^{19}$ cm^{-2} , z = 0.02
- Exposure time 50 ksec
- Added astrophysical background (Lumb et al. 2002)
- Added noise and spectrum grouped to minimum 25 counts/bin

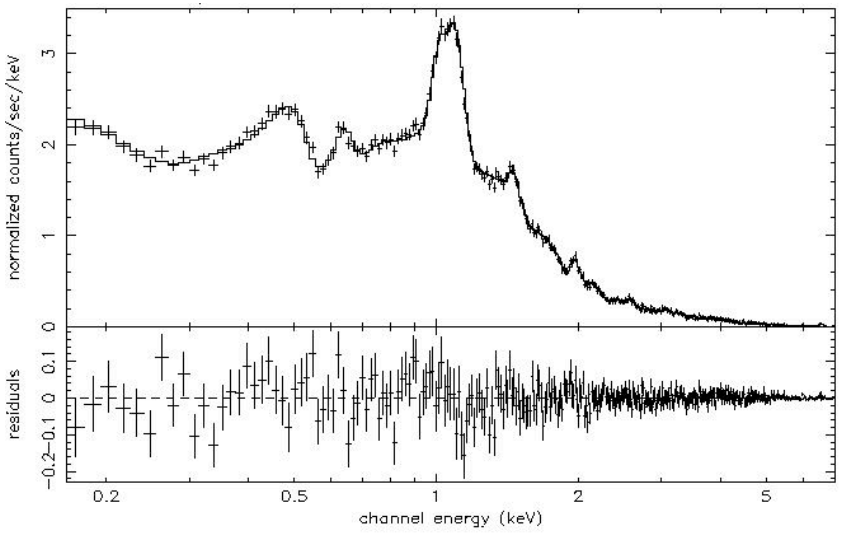
0-2 cells (0-4 arcmin, central 100kpc)

Best fit temperature : 4.7 keV
Best fit abundance : 0.5

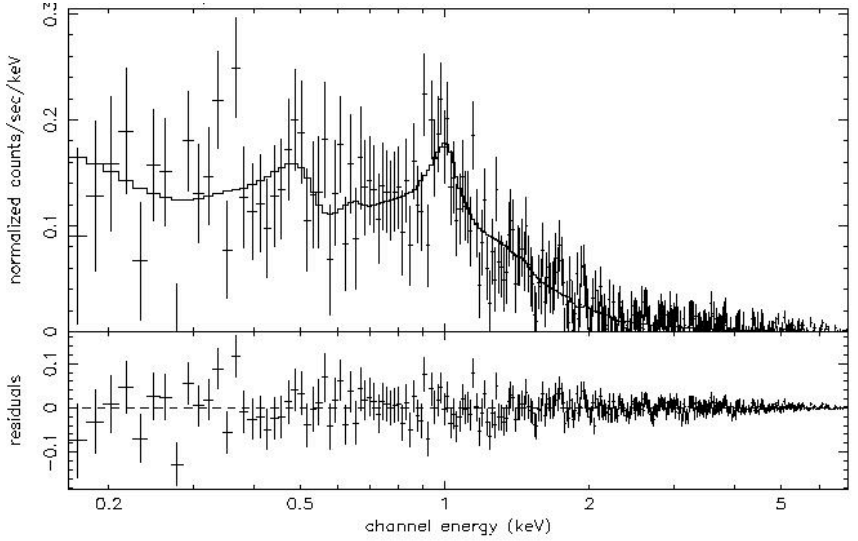
Single temperature is a very good fit to data

Outer annuli show the same effect

22-27 arcmin (580-680kpc)



45-49 arcmin (1.17-1.26 Mpc)



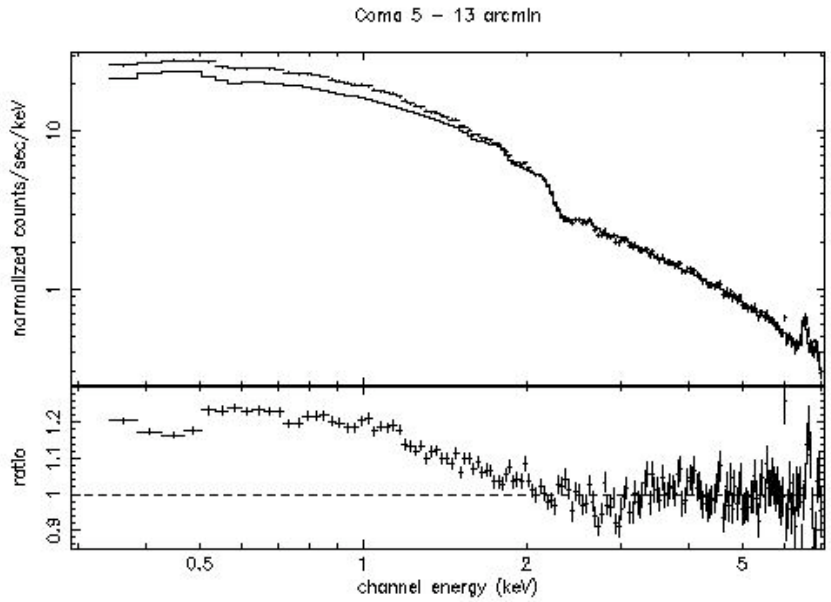
Temperature : 2.27 keV
Abundance : 0.29

Temperature : 1.25 keV
Abundance : 0.06

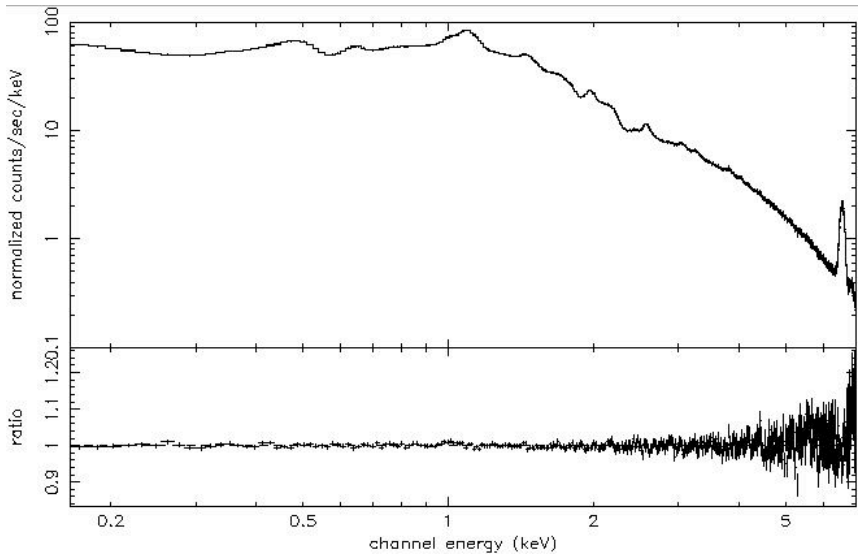
And no evidence for a soft excess!

Comparison with observations

Compare simulation with Coma cluster observations



Coma spectrum 5-13 arcmin (Nevalainen et al. 2002)

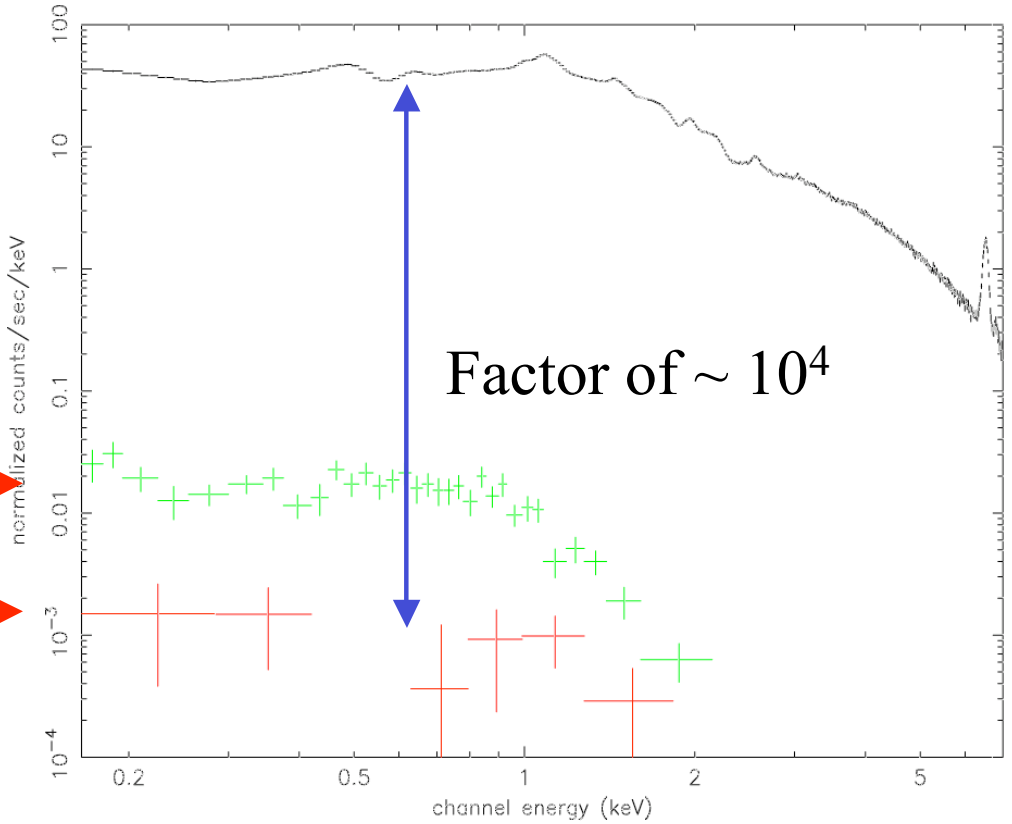


Simulated spectrum showing no soft excess

Low temperature component extremely weak

(Maximum possible emission)

Emission from cells < 1keV



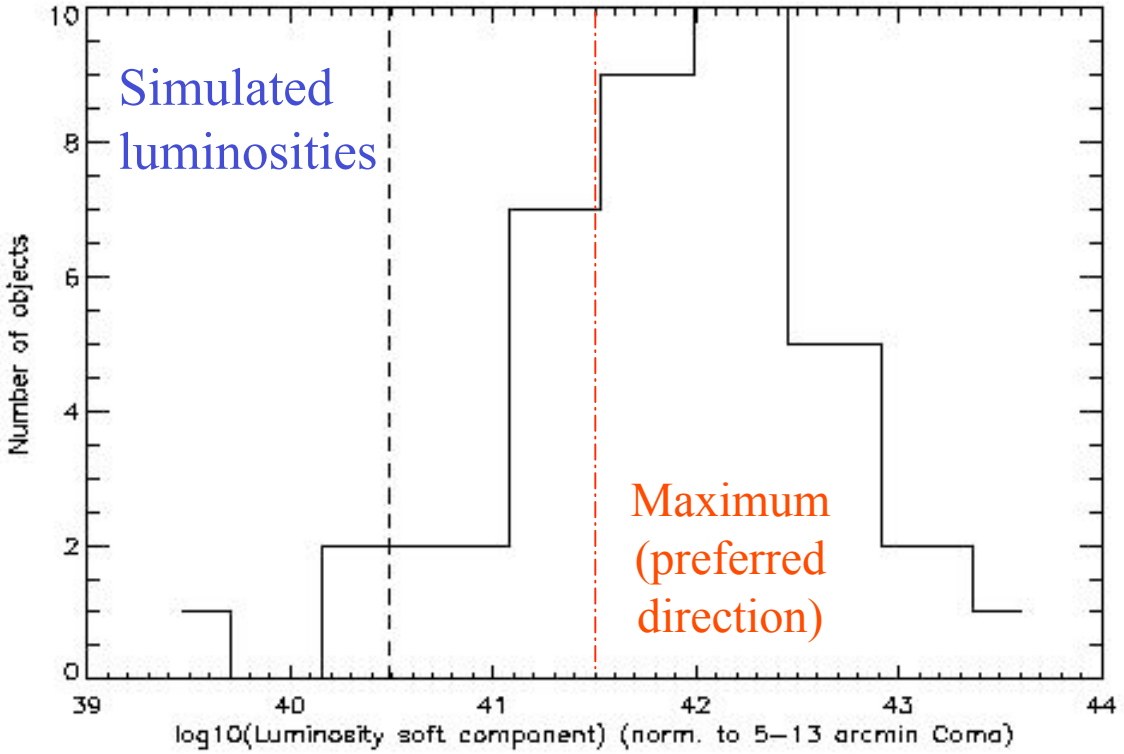
		Simulated	Observed
Comparing Luminosities	Hot component	8 x 10^{44}	2 x 10^{44}
	Warm component	3 x 10^{40}	3 x 10^{43}

Simulated hot component ~ agreement

Simulated warm component much fainter than observations

This seems generally to be true:

Compared with > 1σ soft excesses observed with ROSAT (Bonamente et al. 2002)



Generally no strong source of soft excess at centre of simulated cluster (max possible fraction explained by model ~ 30%)

CONCLUSION

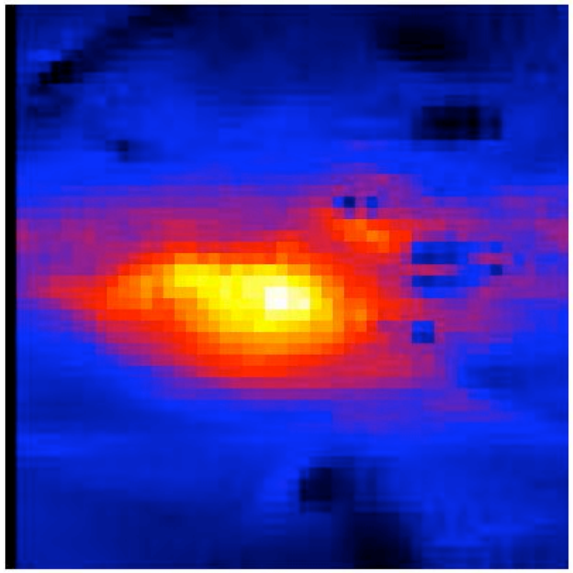
From studying this one simulation much of the soft excess seen in clusters *cannot* be explained by the currently simulated WHIM filaments. But:

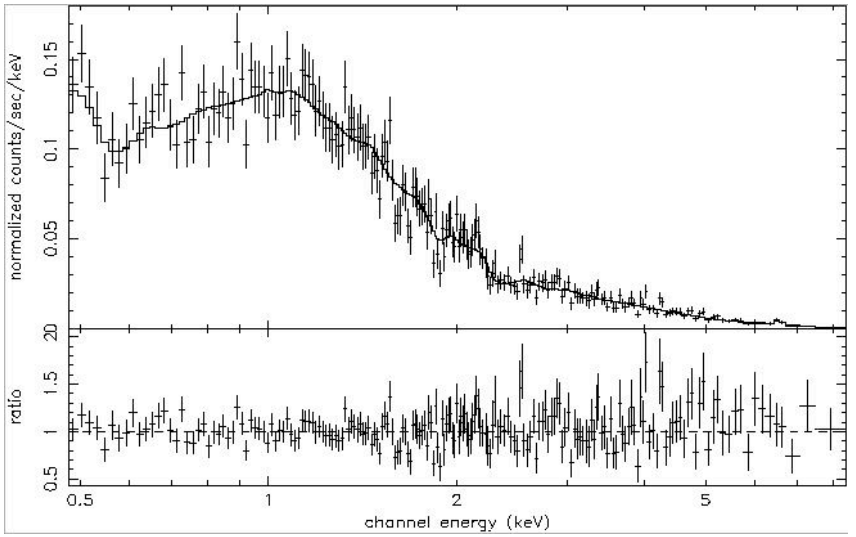
1. Note that the soft excess is not seen in all clusters (e.g. 5/14 Kaastra et al. 2003) – is there some environmental difference (superclustering Kaastra et al. 2003)?

2. Soft excess at or near centre of clusters is strong + weak or absent line emission – some other mechanism (non-thermal?).

3. Only one structure + one simulation studied in detail – need to look at wider range of simulated clusters from different models. Preliminary work suggest same problem exists (D. Nagai private communication + LCA simulated cluster sample). Not enough resolution? Missing physics?

No apparent soft excess seen in one available cluster in the LCA simulated cluster archive





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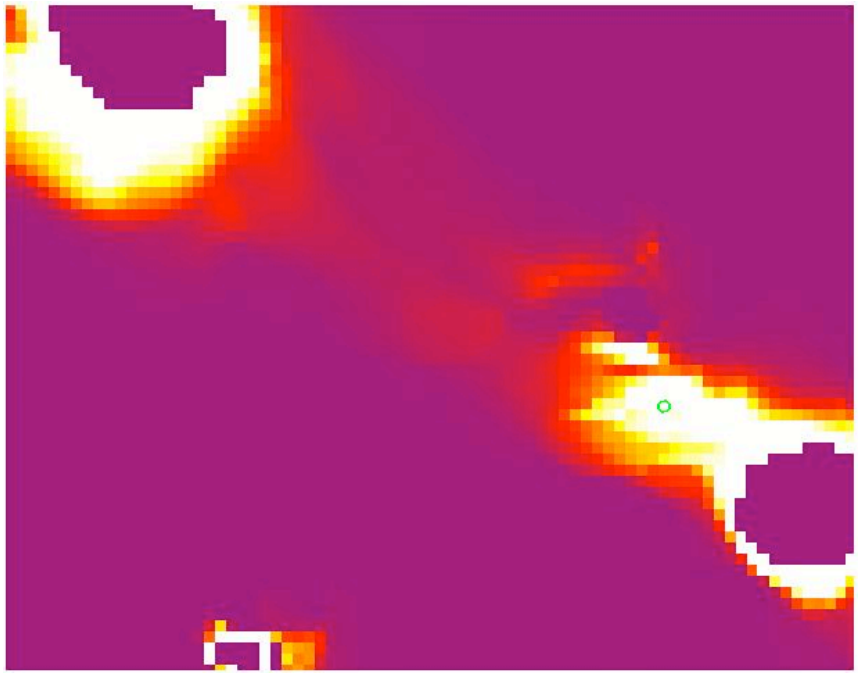
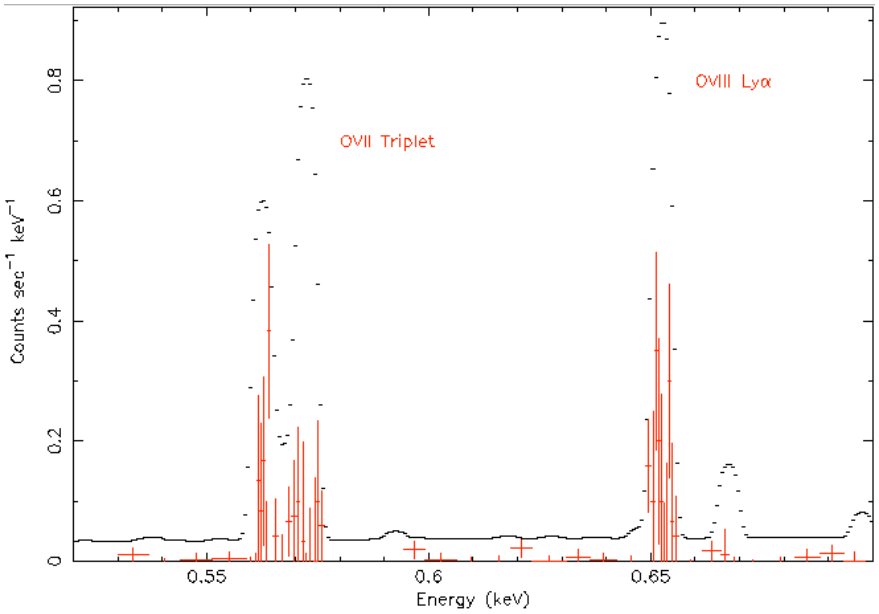
3. Only one structure + one simulation studied in detail – need to look at wider range of simulated clusters from different model.

4. Constellation-X will have no trouble seeing soft excess, but seeing the WHIM at $z \sim 0$ will be hard according to these simulations.

Simulation of WHIM material. Weak signal in 10^5 seconds





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From studying this one simulation much of the soft excess seen in clusters *cannot* be explained by WHIM filaments.
But:

1. Note that the soft excess is not seen in all clusters (e.g. 5/14 Kaastra et al. 2003) – is there some environmental difference or some physical process that is missing from this simulation (superclustering, Kaastra et al. 2003)?

2. Soft excess at or near centre of clusters is strong + weak or absent line emission – some other mechanism (non-thermal?).

3. Only one structure + one simulation studied in detail – need to look at wider range of simulated clusters from different model.

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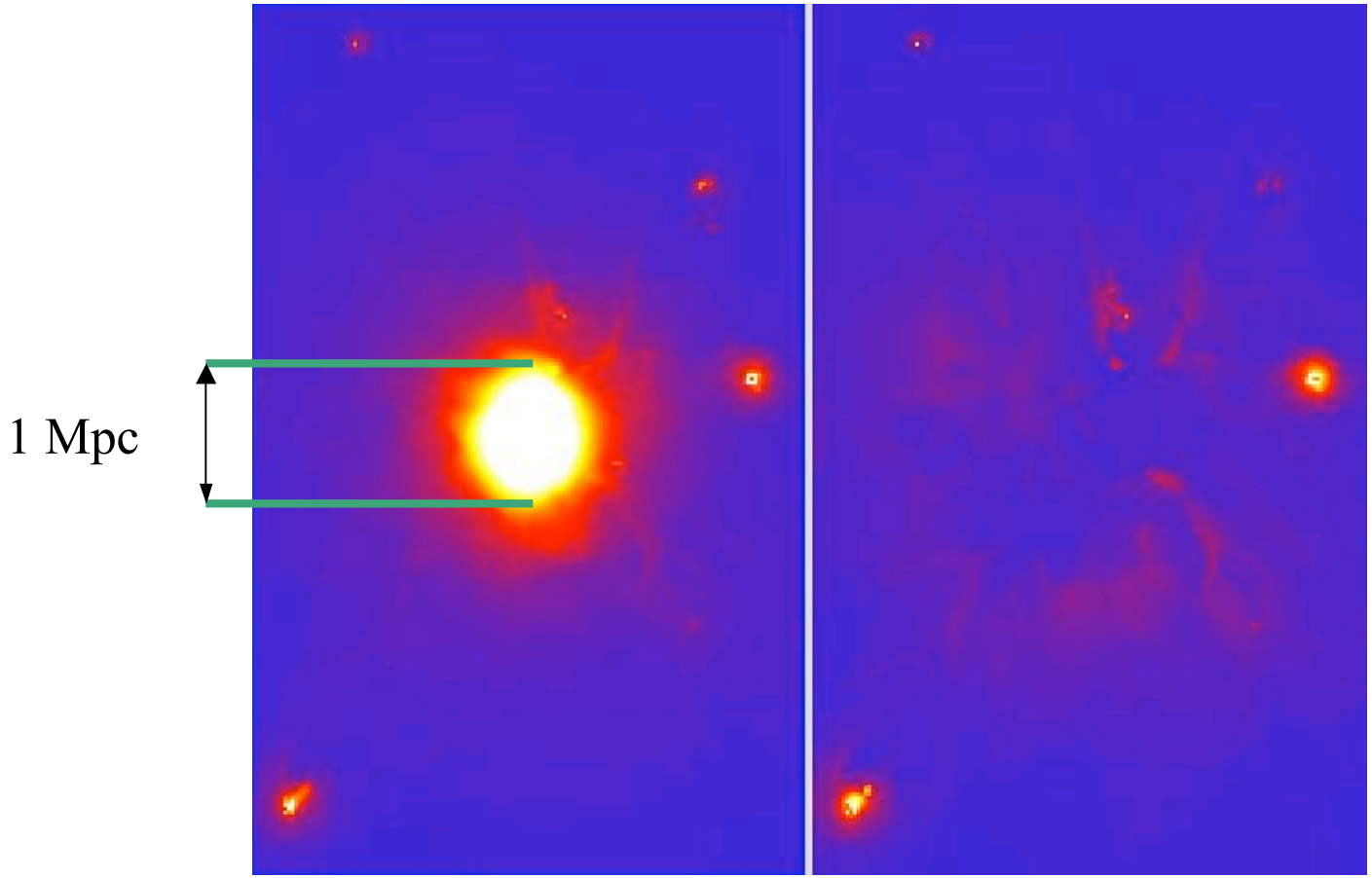
Just not enough low temperature material:



Column density of low temperature components is much less than that of the hot component at the cluster