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The Temperature Structure of the InterGalactic Medium and IntraCluster medium

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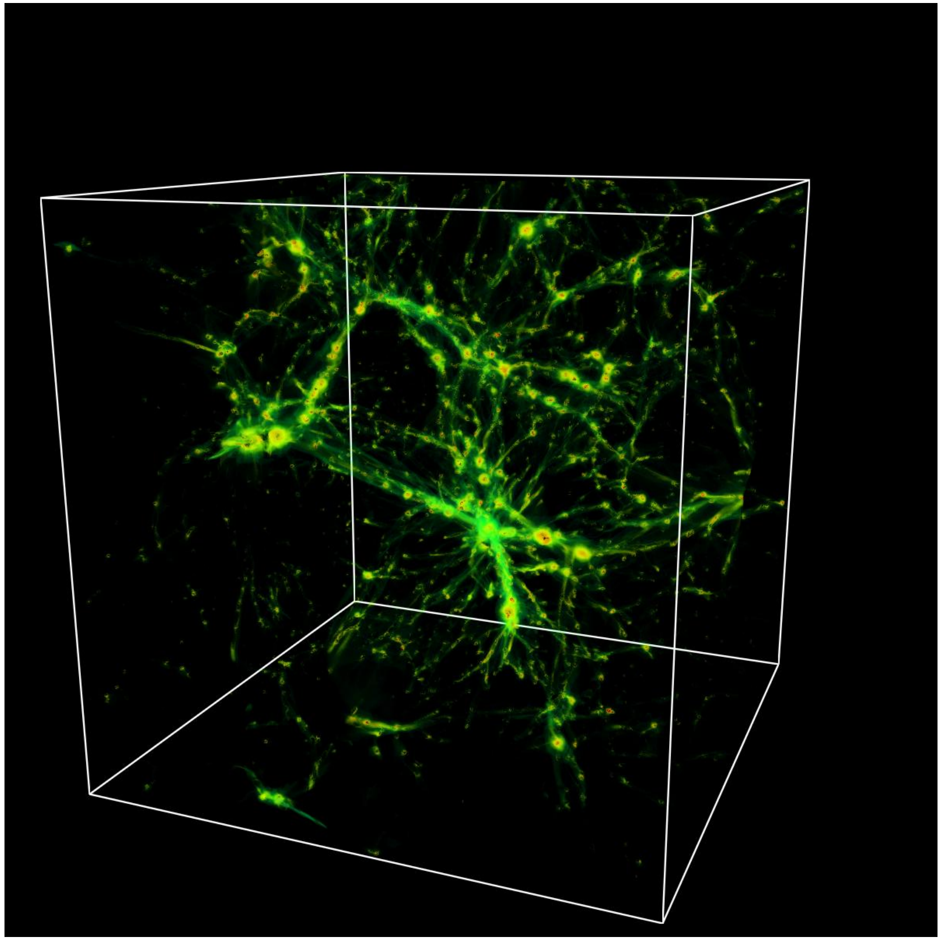
Yoshida, Furlanetto, Hernquist (2005) ApJ, 618, 91

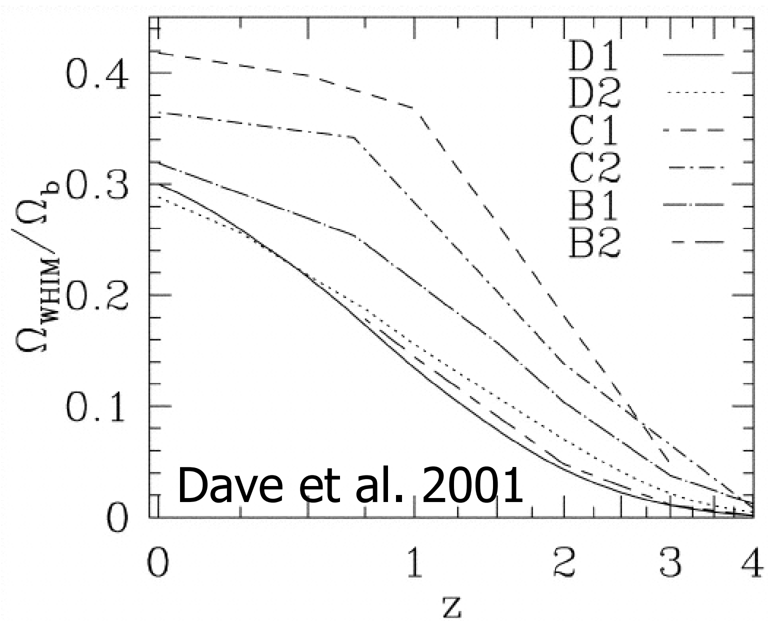
Baryons in Outskirts of Galaxy Clusters

Warm/Hot Intergalactic Medium



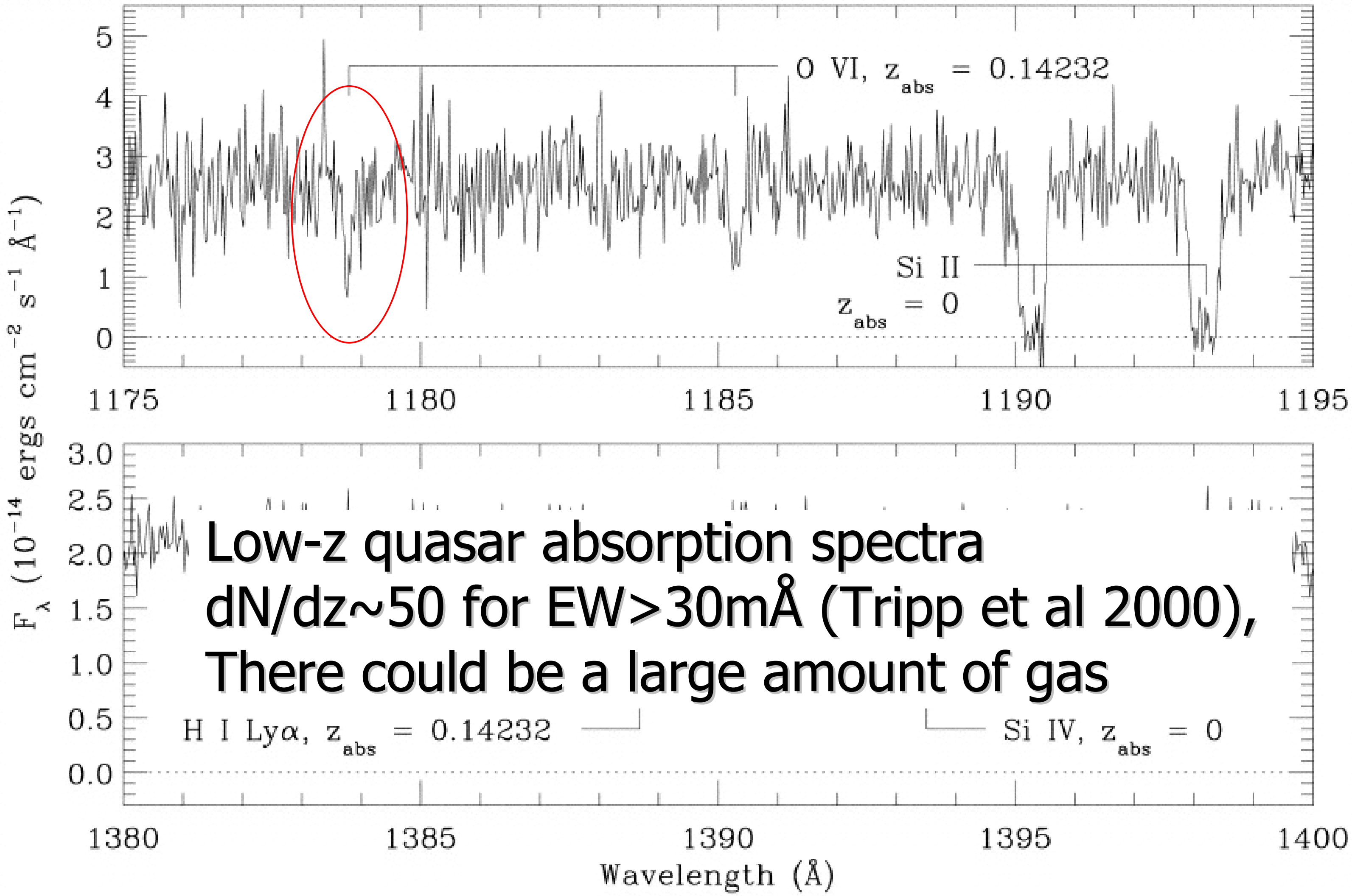
Cen & Ostriker (1999)

Temperature 10^5 -10^7 K
(shock-heated)
Density
1～10 times the mean
↓
Not bright in X-ray



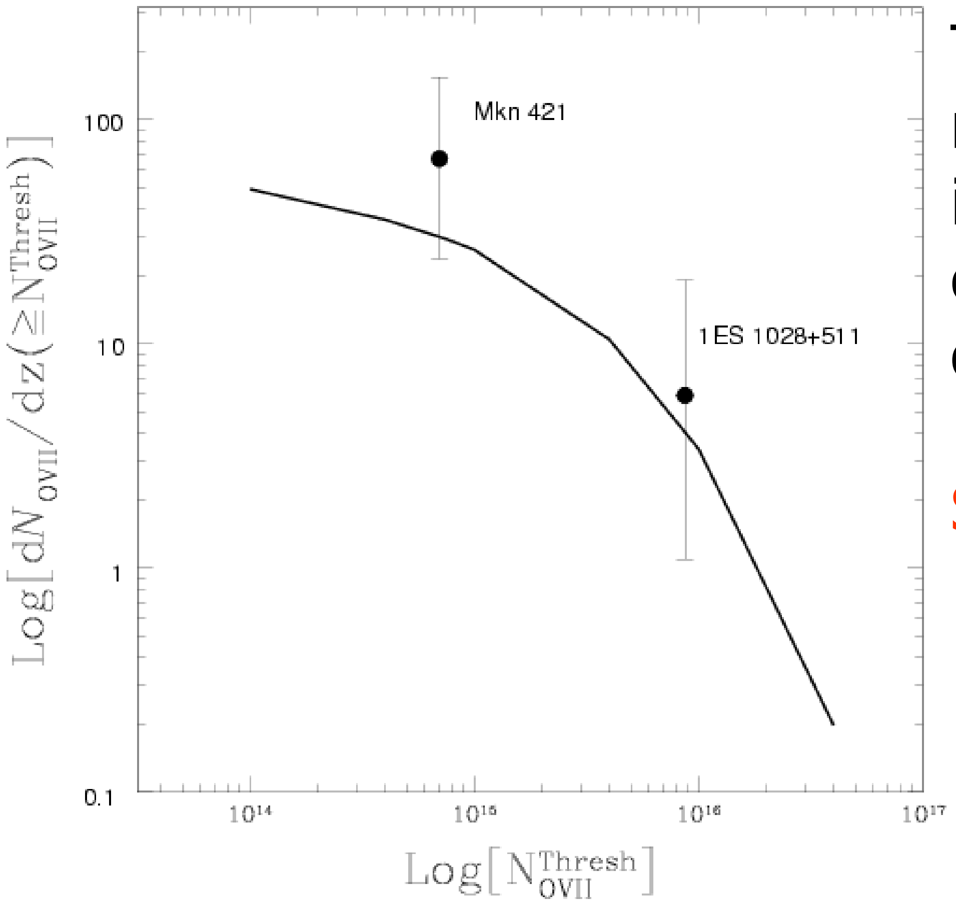
WHIM in QSO Spectra

OVI line



Low-z quasar absorption spectra
dN/dz~50 for EW>30mÅ (Tripp et al 2000),
There could be a large amount of gas

Total Mass Density of the WHIM



Nicastro et al. (2005)

The observed (estimated) number of warm absorbers in two blazar spectra is consistent with the predicted one from CDM simulations.

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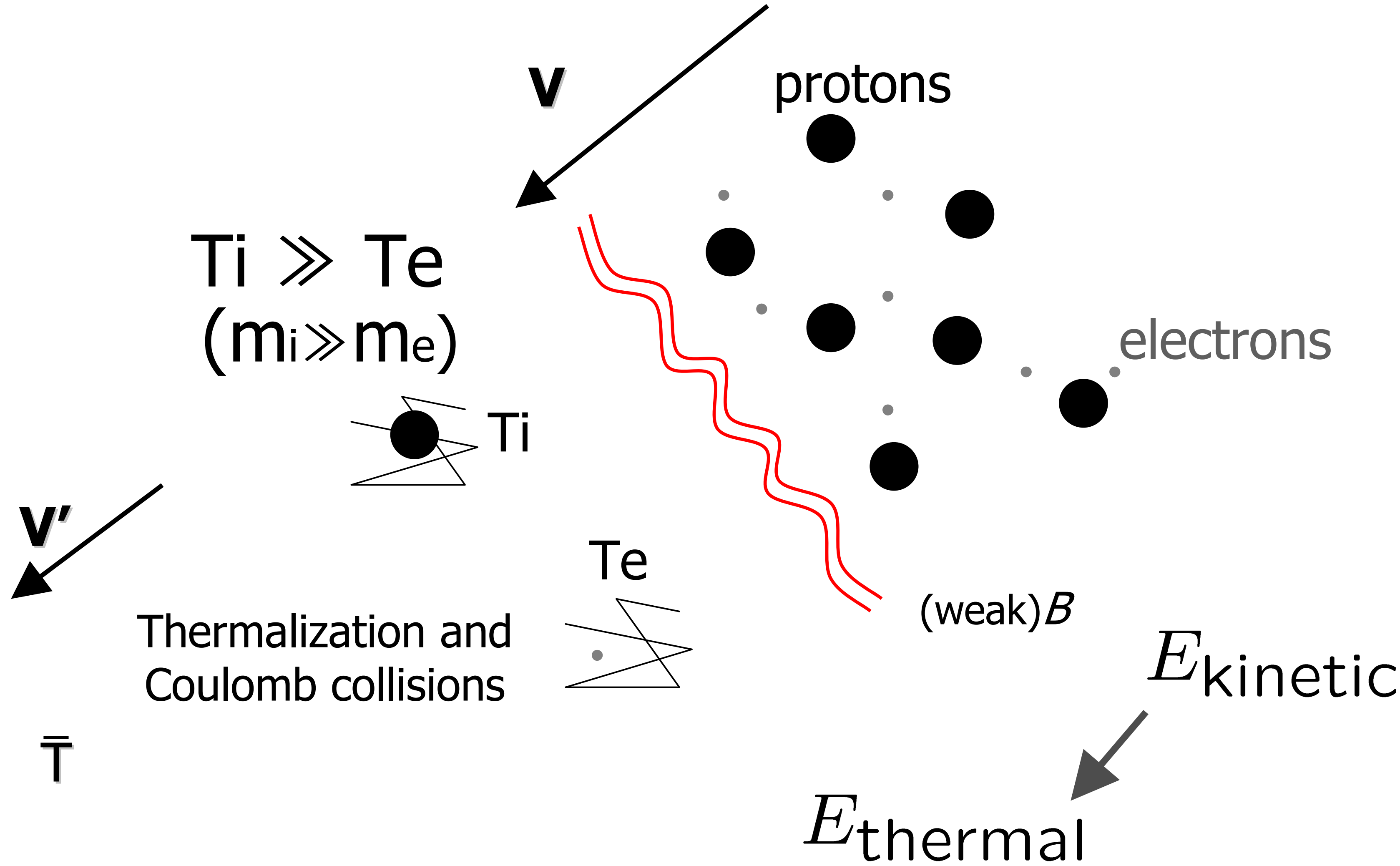
Significant mass is in WHIM.

WHIM Physics: Shock-Heating



WHIM Physics: Electron-Ion Equilibration

Electron temperature evolution:

$$\frac{dT_{\rm e}}{dt} = \frac{T_{\rm i} - T_{\rm e}}{t_{\rm ei}} + (\gamma - 1)\frac{T_{\rm e}}{n}\frac{dn}{dt}$$

Energy exchange time scale by Coulomb collisions:

$$t_{\rm ei} = \frac{3m_{\rm e}m_{\rm i}}{8(2\pi)^{1/2}n_i Z_i^2 e^4 \ln\Lambda}\left(\frac{kT_e}{m_e} + \frac{kT_i}{m_i}\right)^{3/2}$$

$$\sim 2 \times 10^8 \text{yrs}\, \frac{(T_e/10^8\text{K})^{3/2}}{(n/10^{-3}\text{cm}^{-3})}$$

Previous Works

Fox & Loeb (1998)
Self-similar collapse + two-temperature medium

Takizawa (1998, 1999) Chieze et al. (1998)
3D hydrodynamic simulations of cluster formation

Courty & Alimi (2004)
Cosmological set-up, two temperature structure and the effect on radiative cooling

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Cargill & Papadopoulus (1988) Laming (2000)
suggest electron heating mechanisms
(in the context of SNRevolution)
but none of them seems to work.

In this work:

Large-scale cosmological simulations

Hierarchical formation and shock–heating

Intrinsically 3D structure

Two–temperature medium

↓

Large volume ~$(140\mathrm{Mpc})^3$ CDM simulations

Smoothed Particle Dynamics (GADGET)

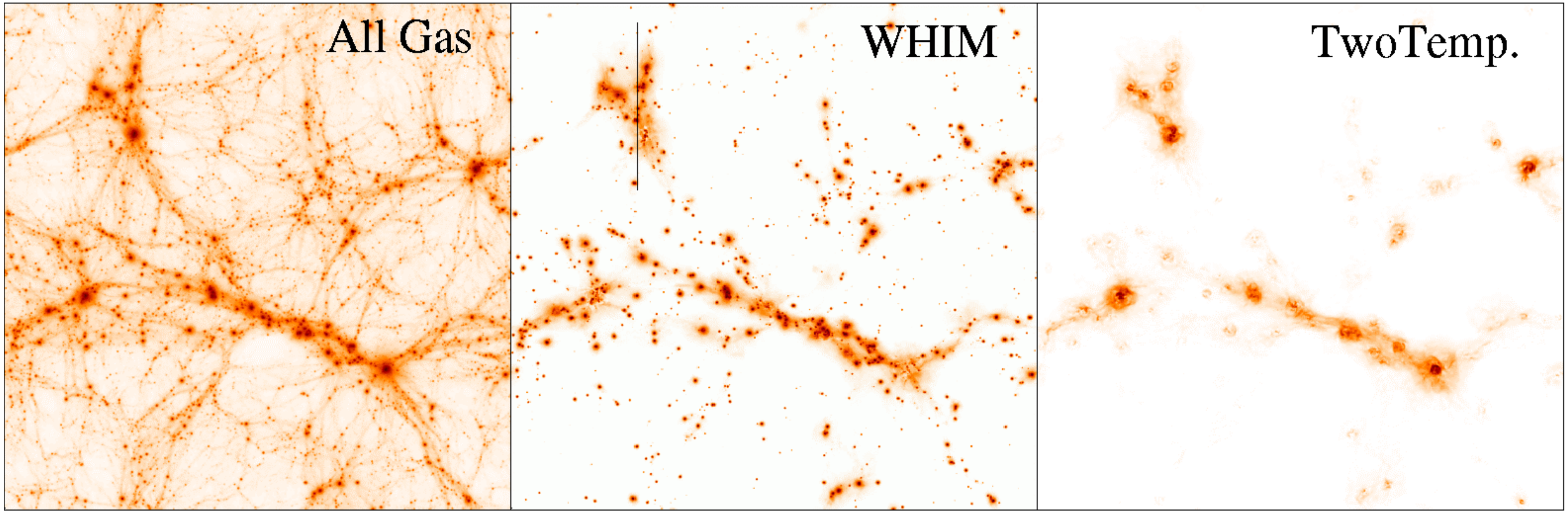
with 55 million particles

Electron–ion relaxation model

We revisit whether or not non-equipartion effect is important in diffuse IGM and in the ICM

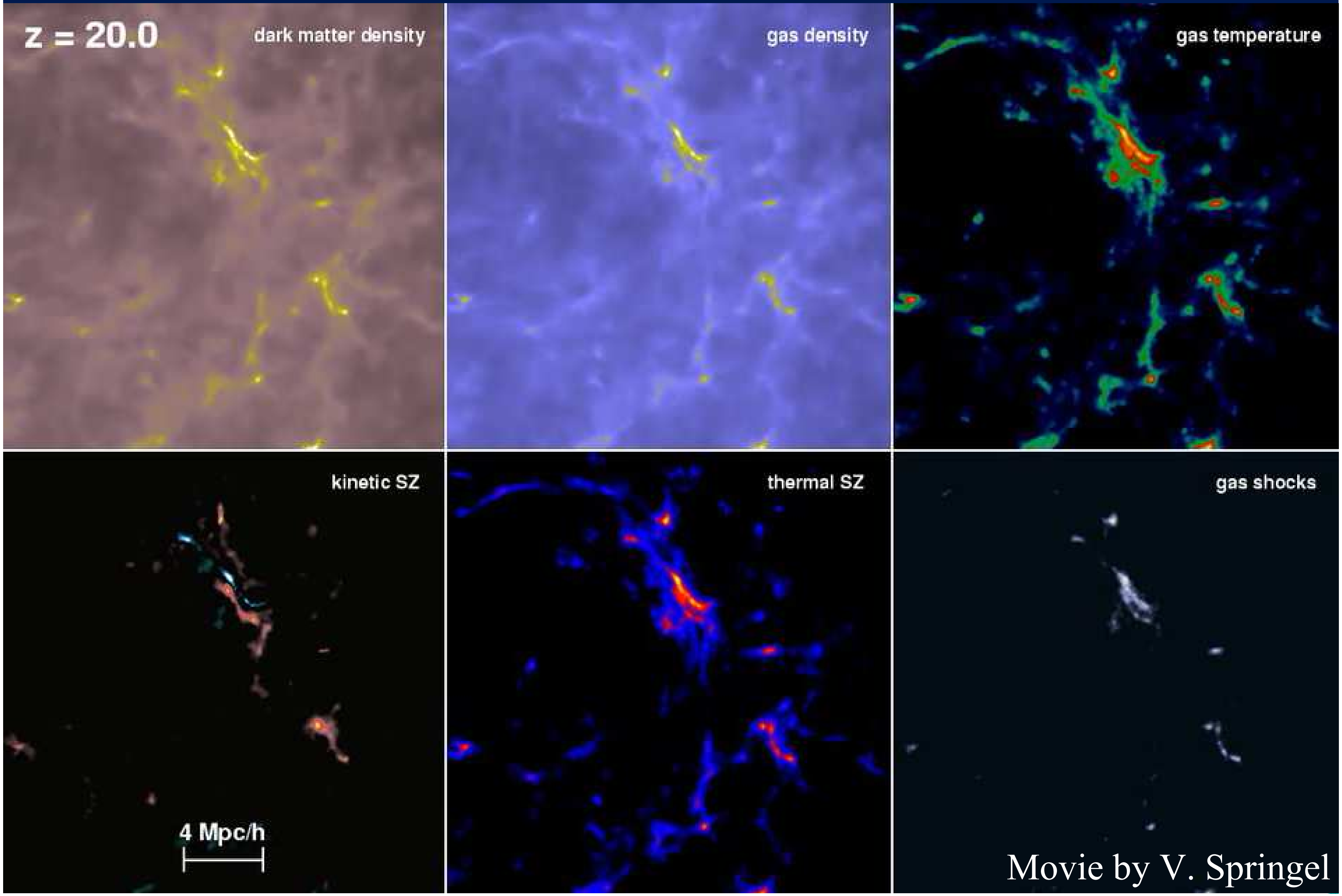
Results at z＝0

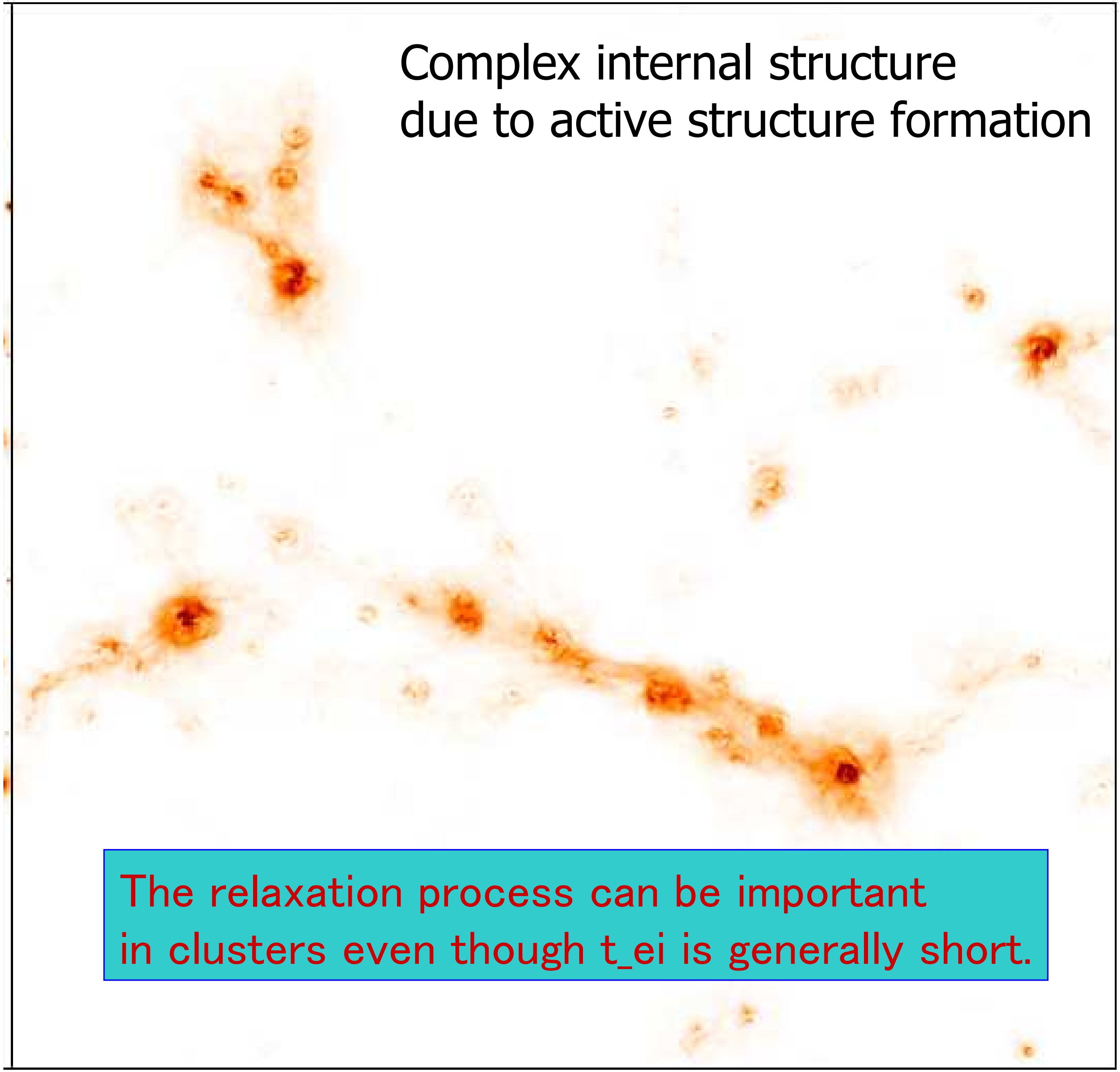
Gas | $10^6 < T < 10^7$ K | Te < 0.5Ti



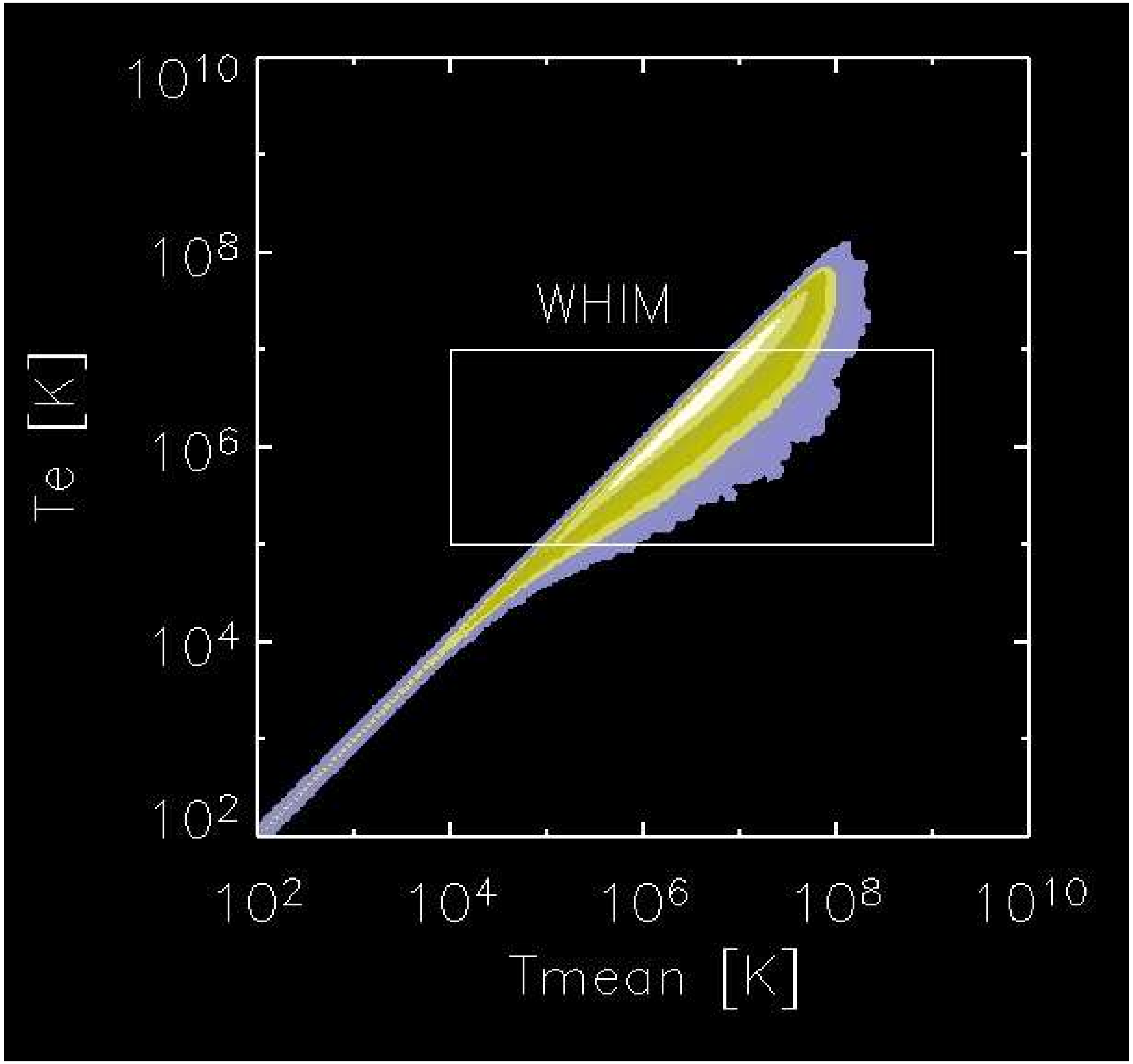
Bulk of the WHIM has a well-developped two-temperature structure

How does the gas around clusters get high-temperature?

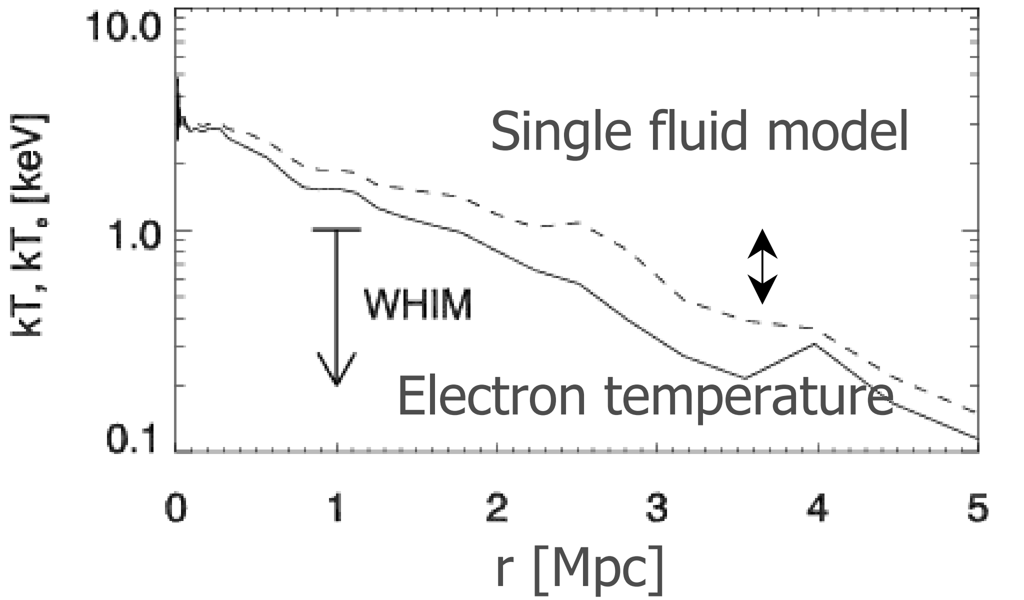



Complex internal structure
due to active structure formation
The relaxation process can be important
in clusters even though t_ei is generally short.

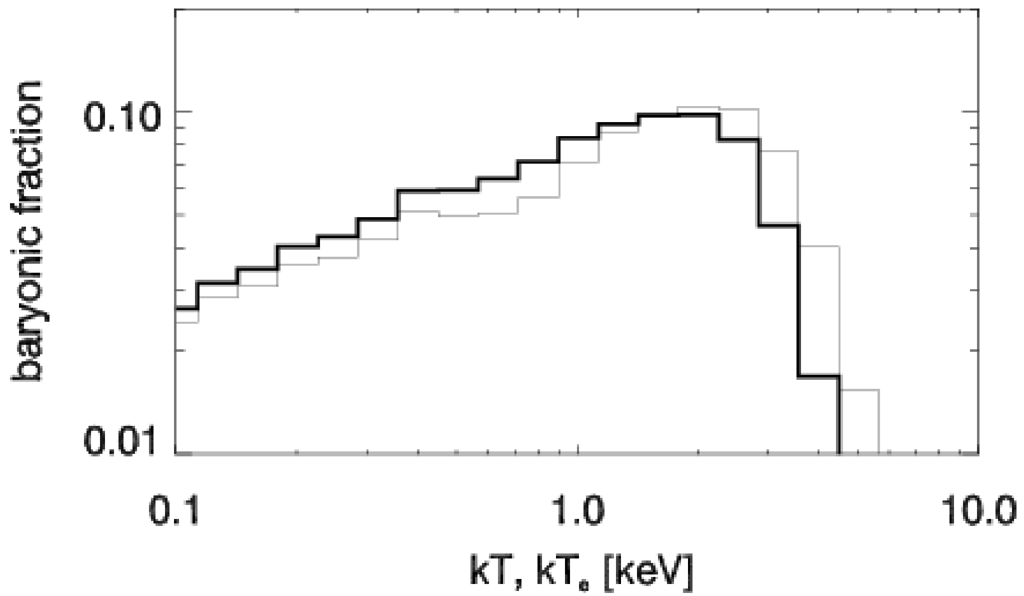
T_{elec} vs T_{mean}



Temperature Profile around a Cluster



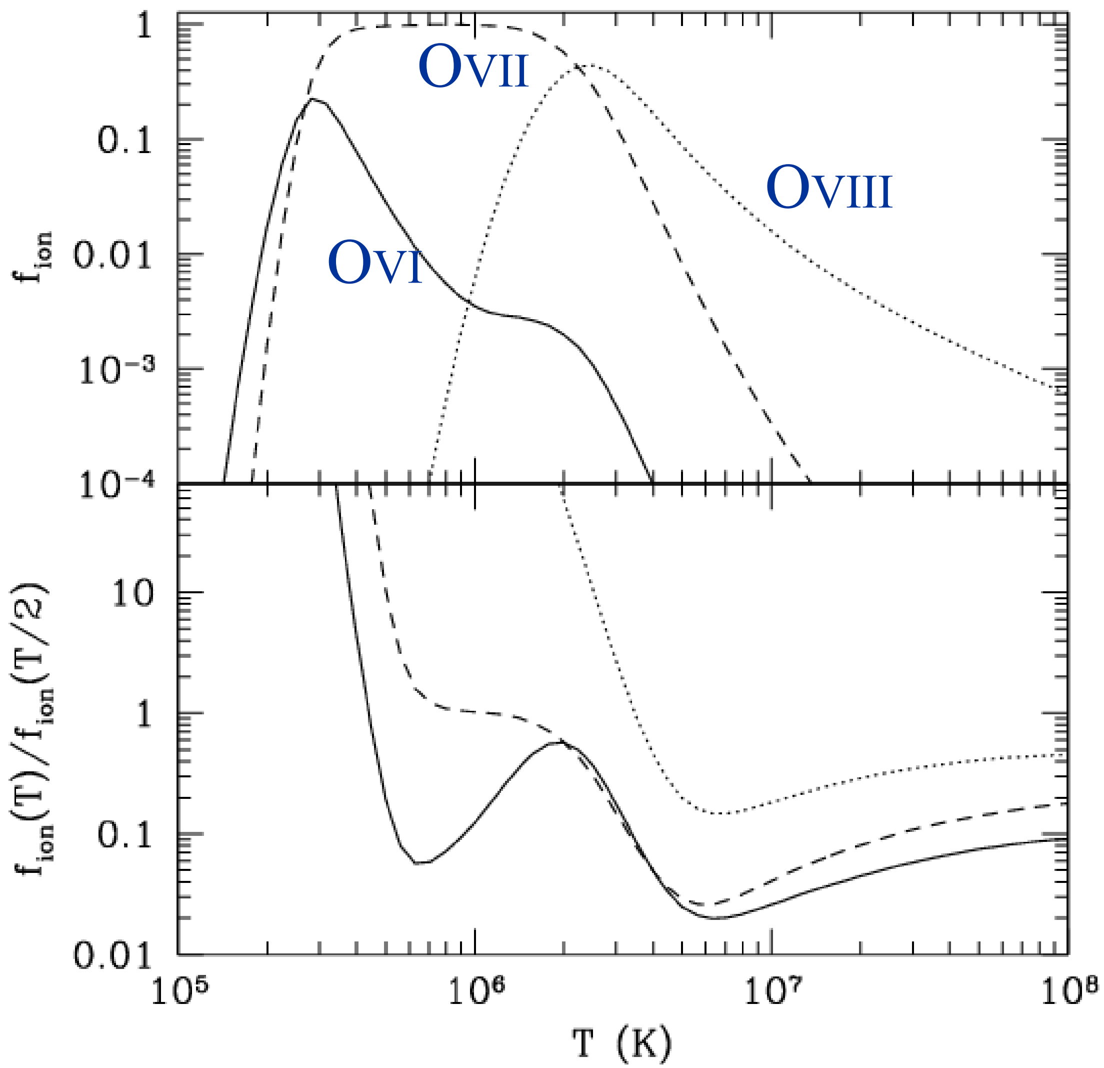
Warm component exists within 5Mpc.
The total mass of the warm gas is comparable to the cluster gas mass!



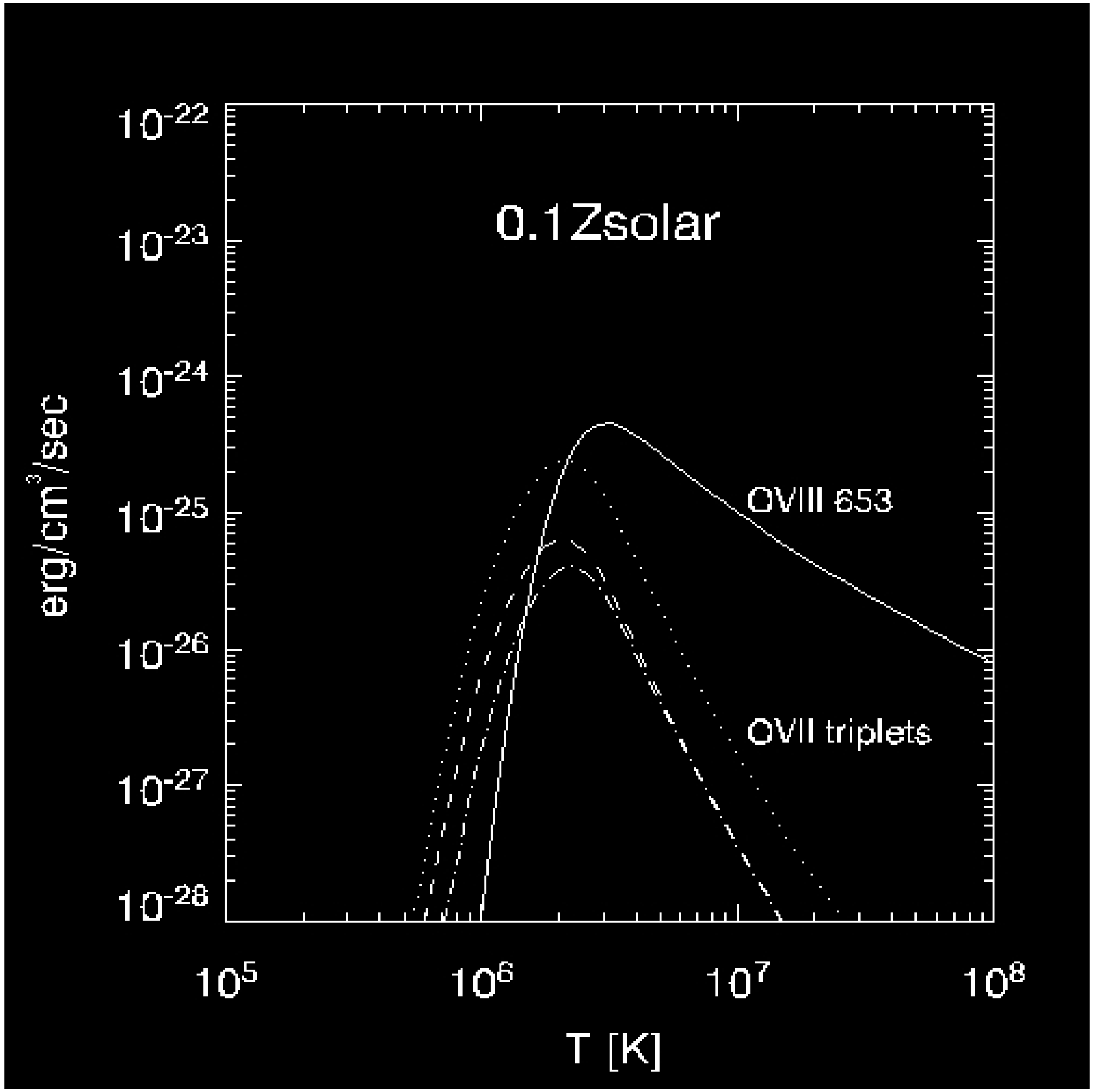
Gas temperature distribution

T_e distribution is shifted to lower values

Implications I: Ion Populations



Implications II: Line Emissivity



From Yoshikawa et al (2004).

Strong peak at ~ 2×10^6 K for OVII, and a broad tail ~ 3×10^6 K for OVIII.

Making Emission Map

Using the outputs of the simulations,
we compute the metallicity (as often assumed)

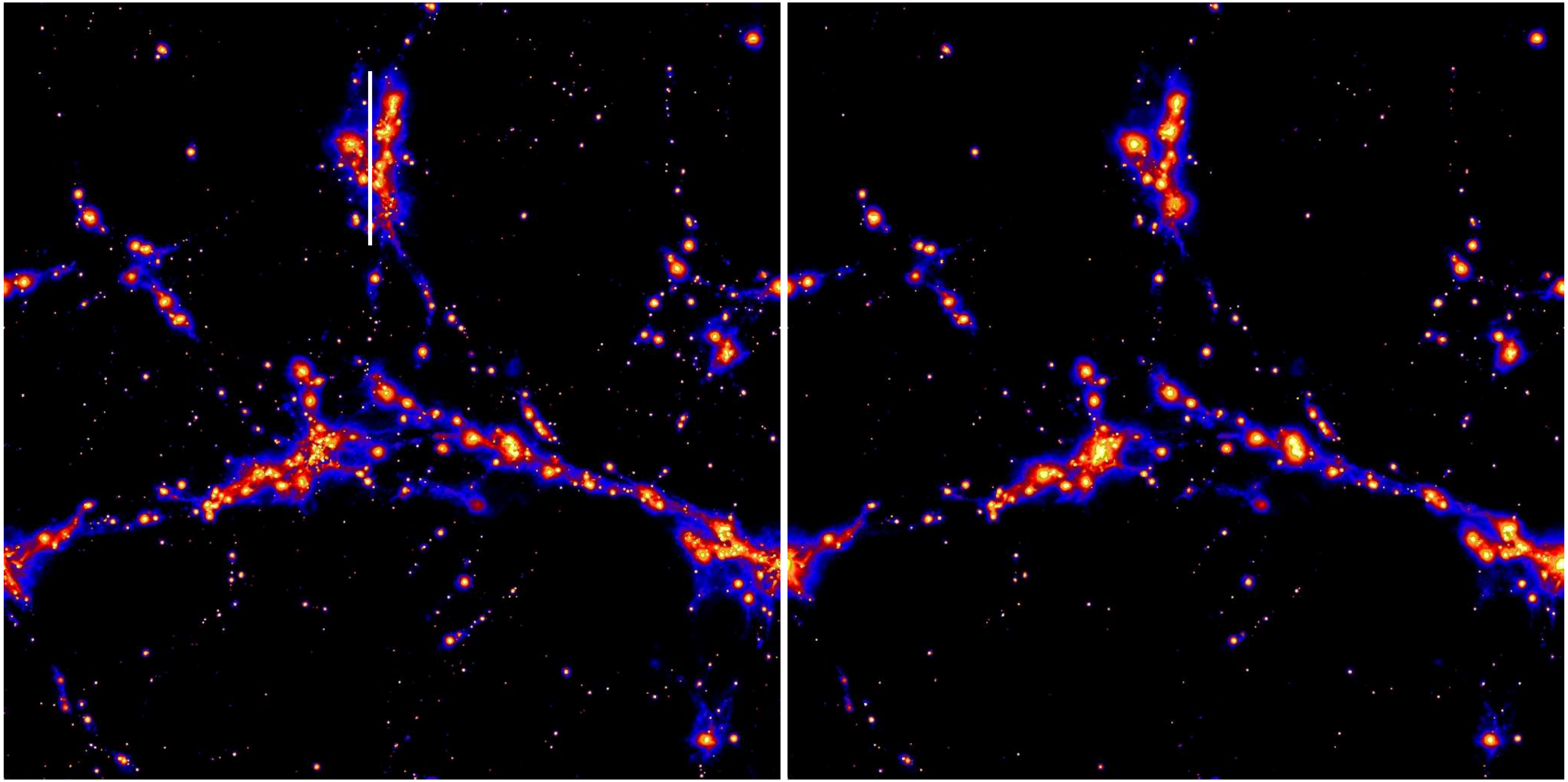
$$Z = 0.02(\rho/\bar{\rho})^{0.3} Z_{\odot}$$

and surface brightness in soft-Xray given by

$$S_{\mathrm{J}} = \int \frac{\rho m}{4\pi(1+z)^4 \Delta A} \left(\frac{X}{m_{\mathrm{p}}}\right)^2 f_{\mathrm{e,i}}^2 \epsilon(T, Z)$$

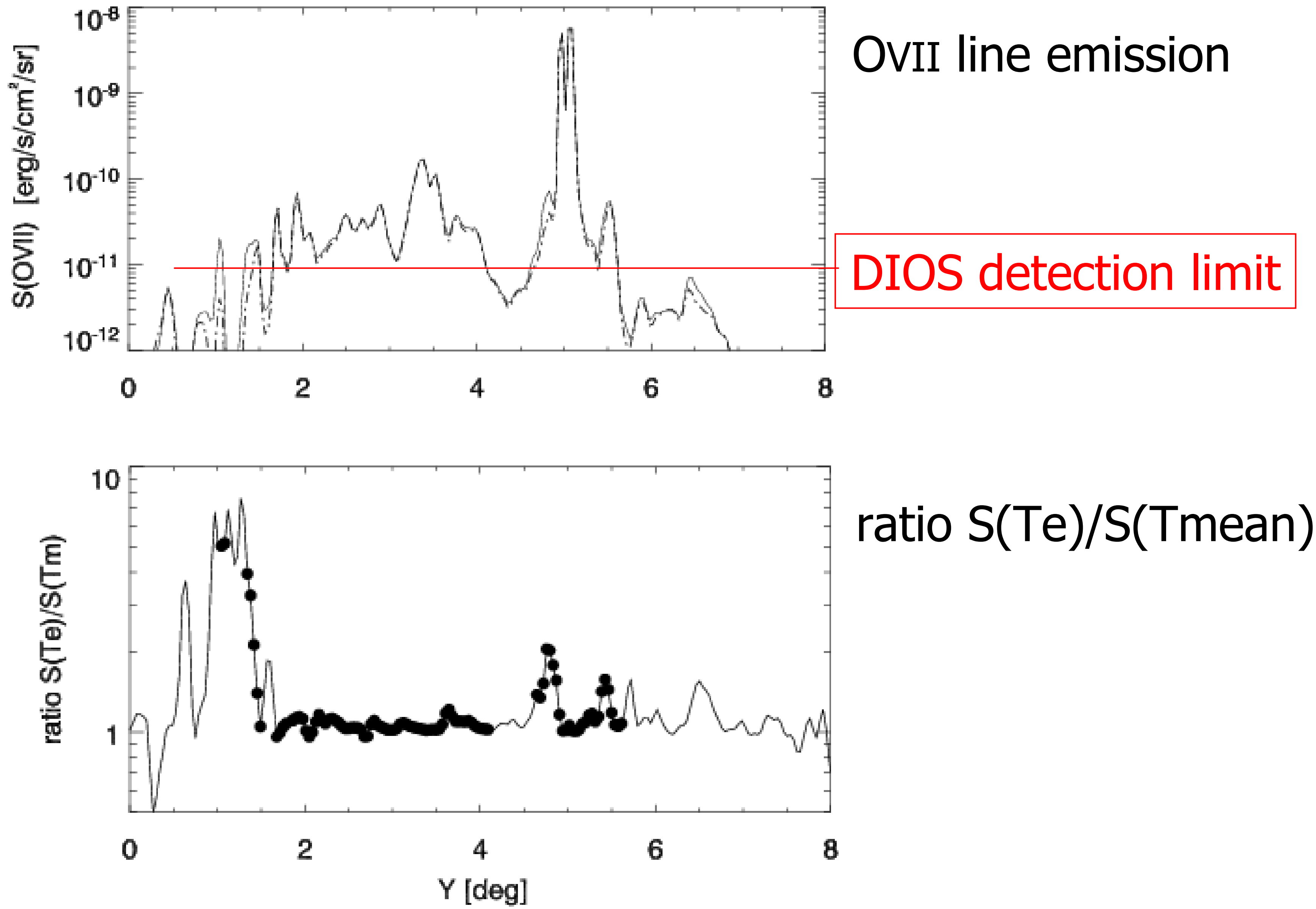
OVII/OVIII Emissivity Map

OVII(574,561,568,665eV) OVIII (653eV)

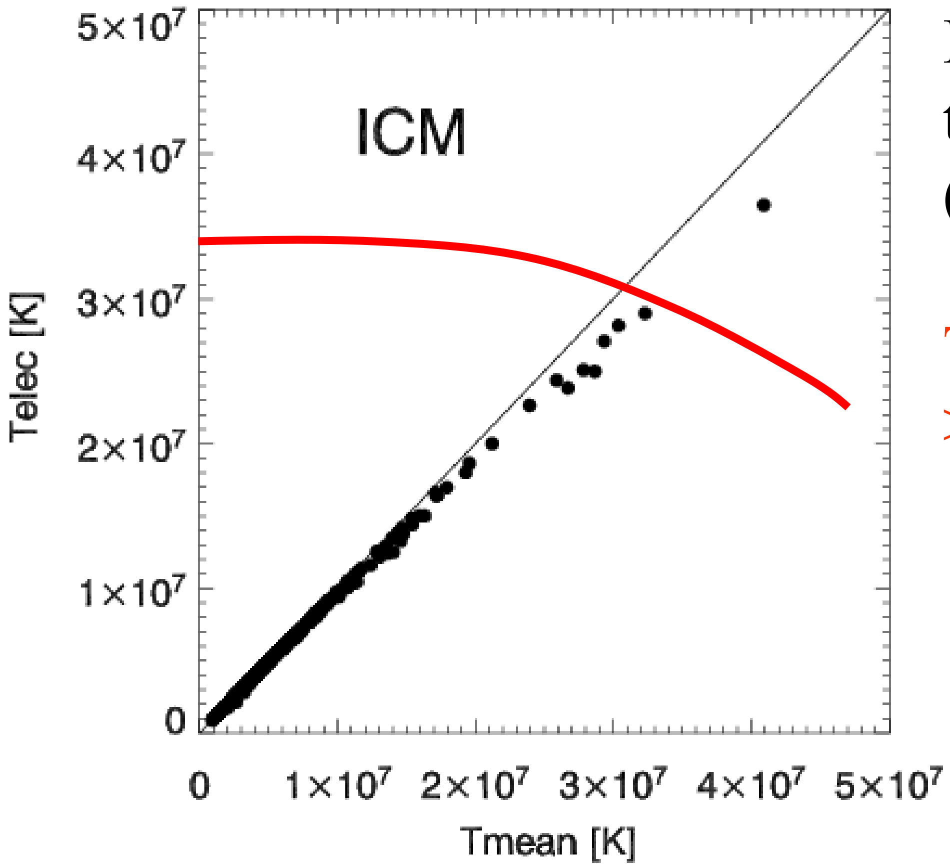


Note! logarithmic scale used in these maps

Comparison with a single-fluid model



Implications for SZ and Cosmology



Electron temperature is lower than the mean temperature (systematically!) in rich clusters.

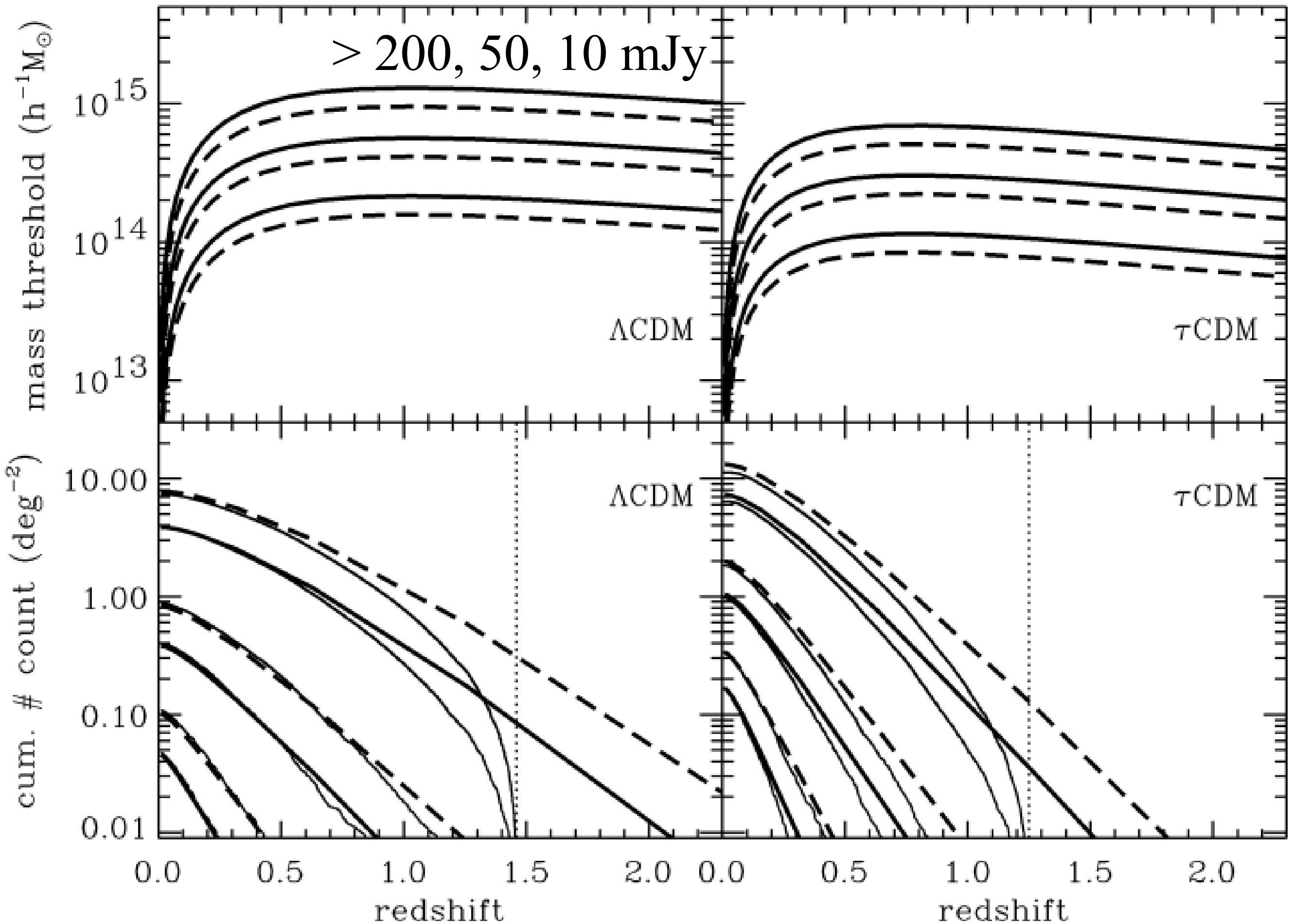
The fractional difference is >10% for M > 10^{14} Msun

Cluster M-T relation:

$$T_e \propto f M^{2/3}$$

Cluster Abundance and Parameter Estimation

Diaferio, Nusser, NY, Sunyaev (2003)



Conclusions

1 A factor of 2 difference between
T_i and T_e in the WHIM (T_e smaller in dense regions)

2 OVII emission is enhanced, making
cluster outskirts marginally detectable
by planed missions.
Necessary to follow the evolution of *T*elec.

3 A large reservoir of warm (<1 keV) component
in/around clusters
→ implications for cluster soft-Xray excess ?

4 Systematic ~10% deviations in ICM will
affect parameter estimation by future surveys

Future Work

- Effect on gas cooling (galaxy formation, cluster cooling flow) to be revisited
- Similar effects in shocks generated by galactic winds (and cosmic tsunamis)
- Non-equilibrium evolution needs to be taken into account for accurate predictions

Cooling time scale