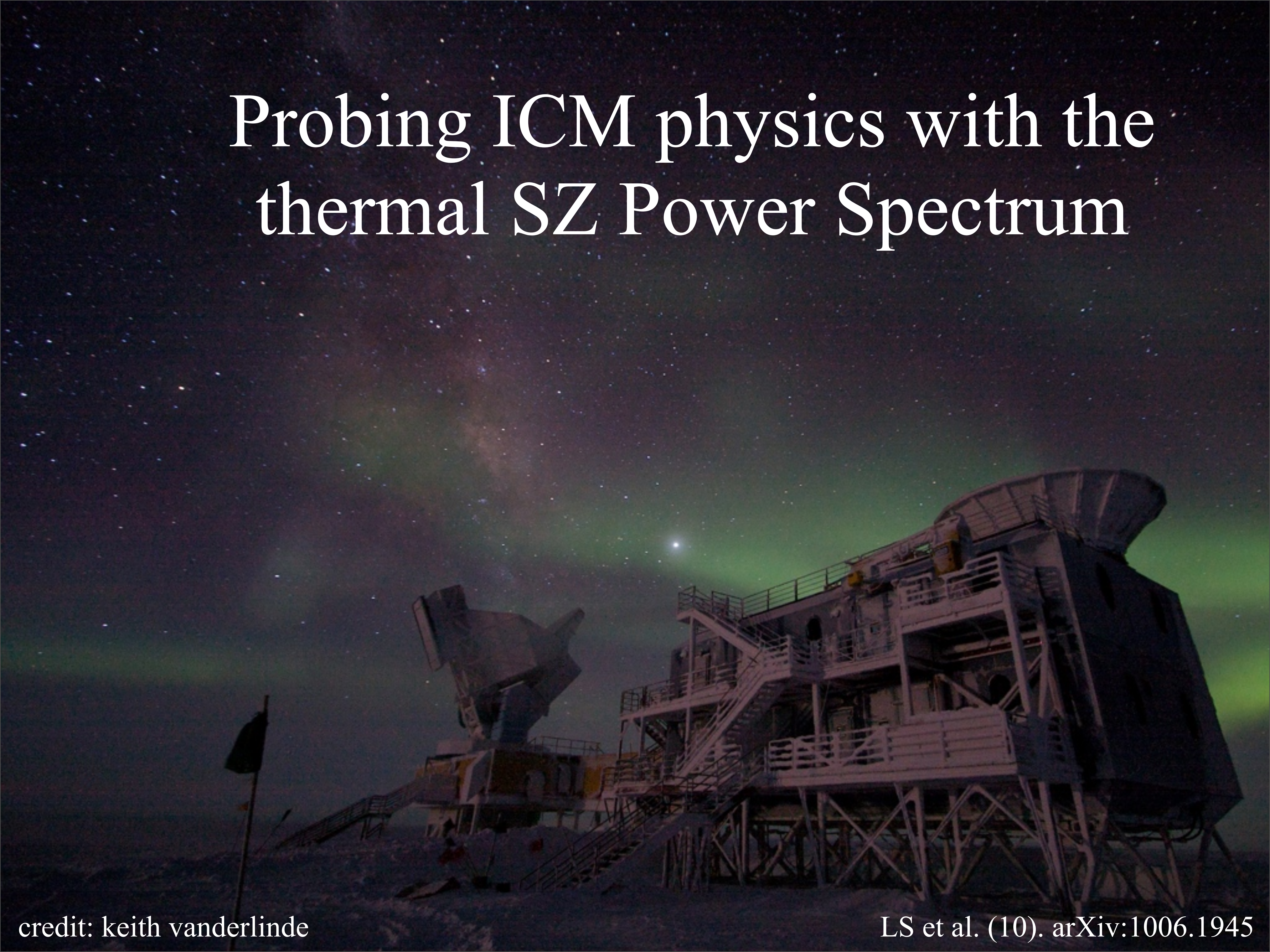
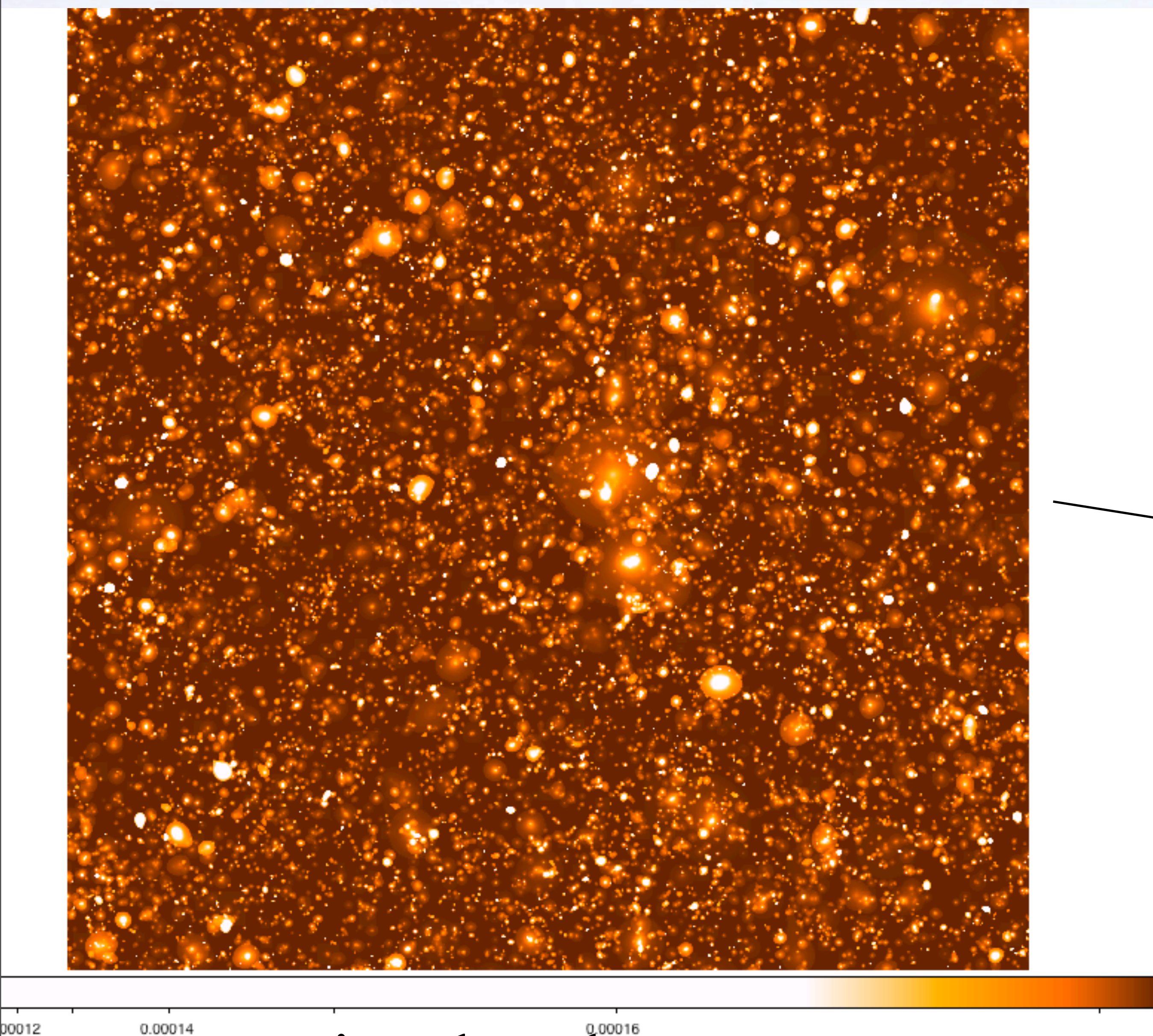
Probing ICM physics with the thermal SZ Power Spectrum



credit: keith vanderlinde

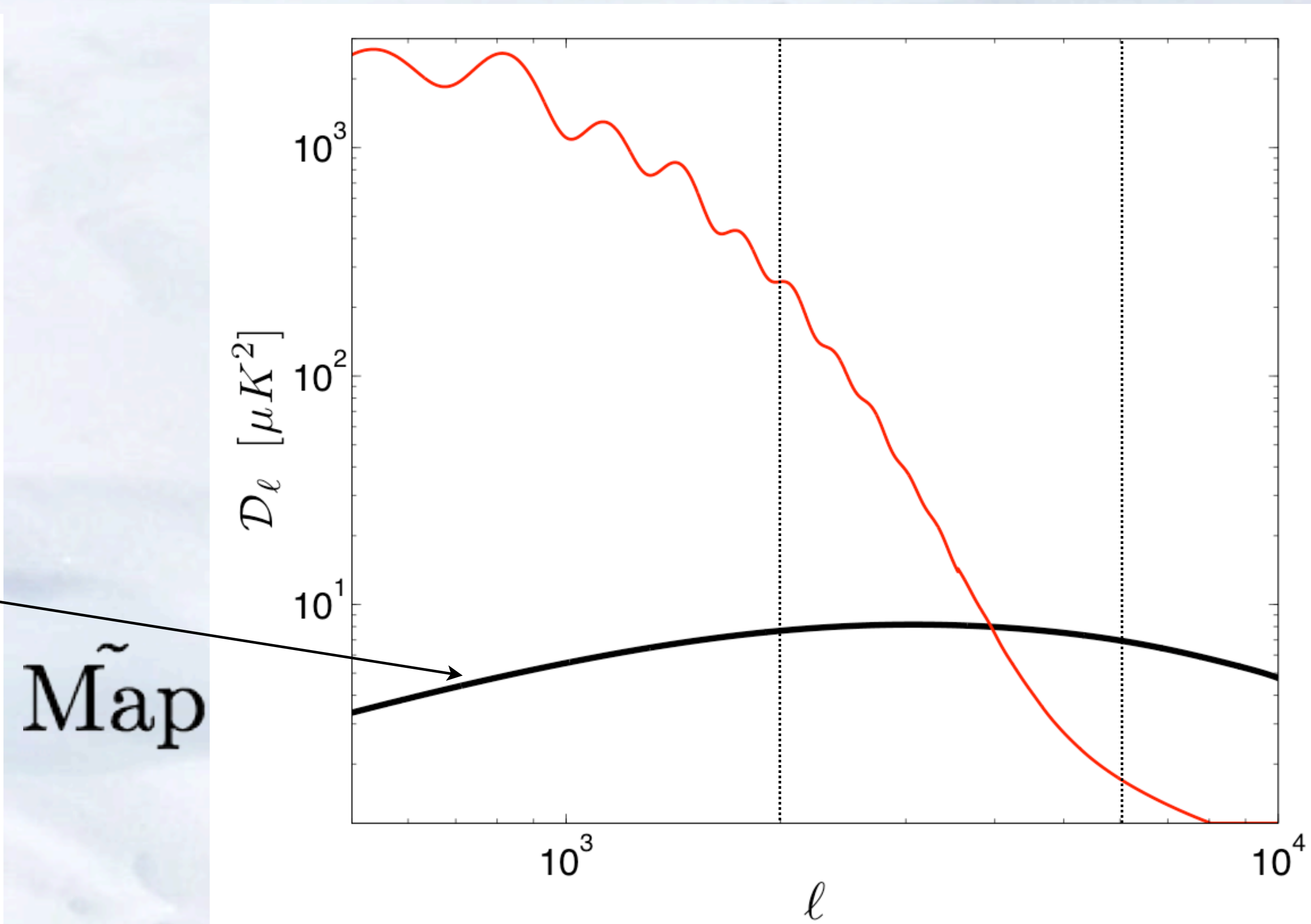
LS et al. (10). arXiv:1006.1945

Statistical detection of SZ by searching for anisotropy power at small angular scales



simulated tsz map

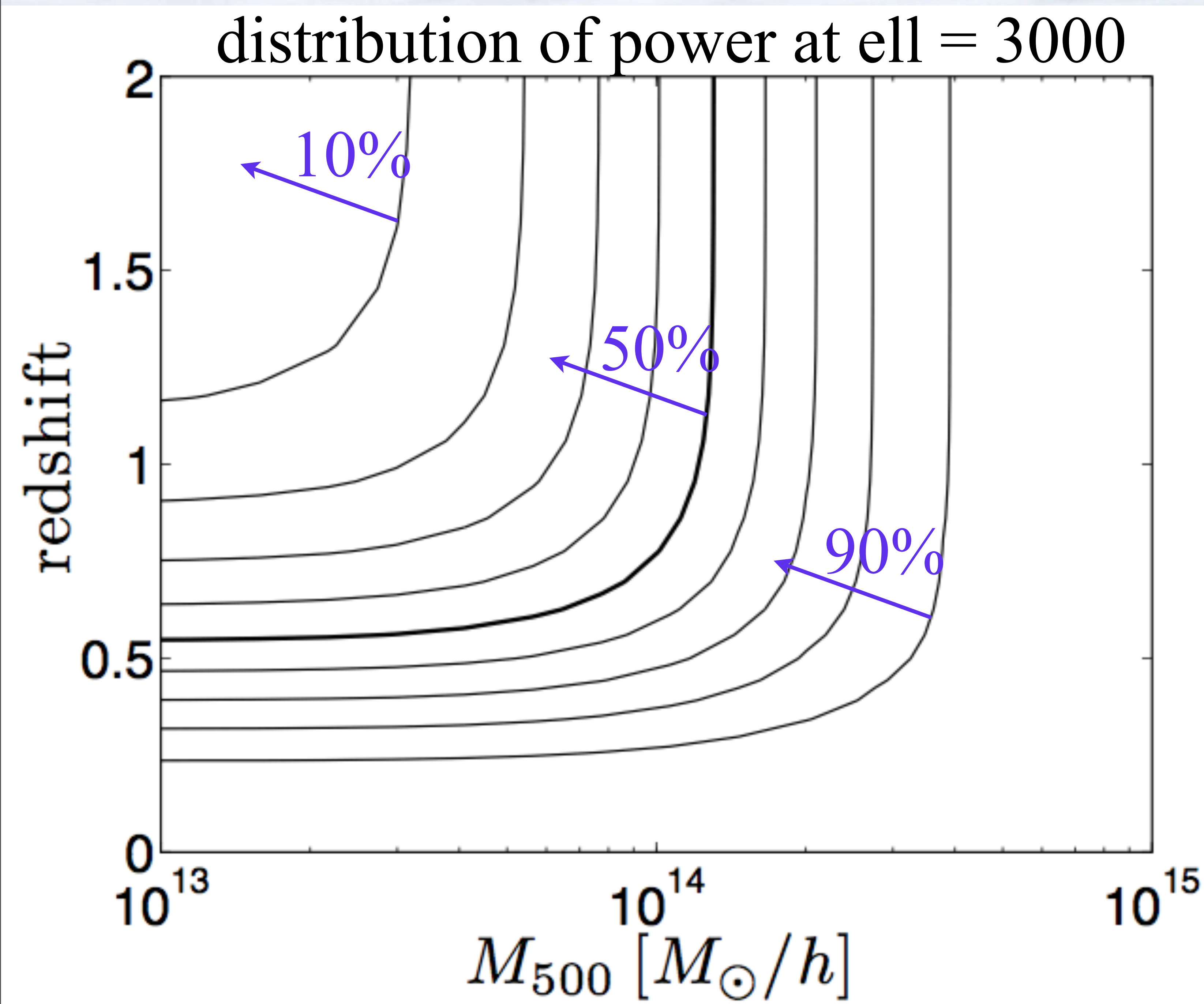
10deg



$$C_\ell \propto \sigma_8^{7-9}(\Omega_b h)^2$$

Sensitive to the total integrated electron pressure from now out to the epoch of reionization

Where does power come from?



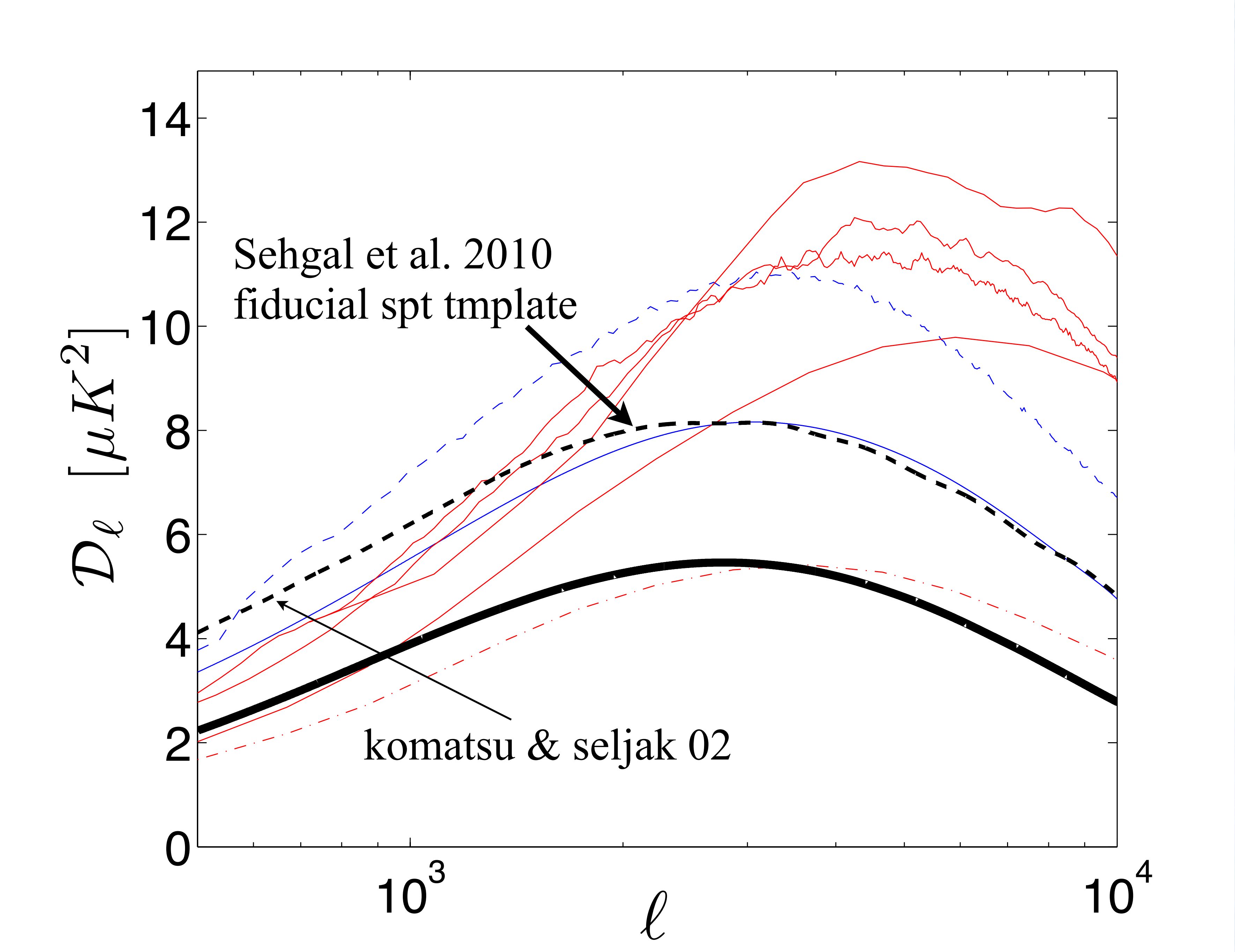
Direct Observations

	<2x10[14] M_{sun}	>2x10[14] M_{sun}
z>0.6	none	few
z<0.6	few	lots

mass

Low mass high redshift contribution significant.

models and simulations



hydro sims

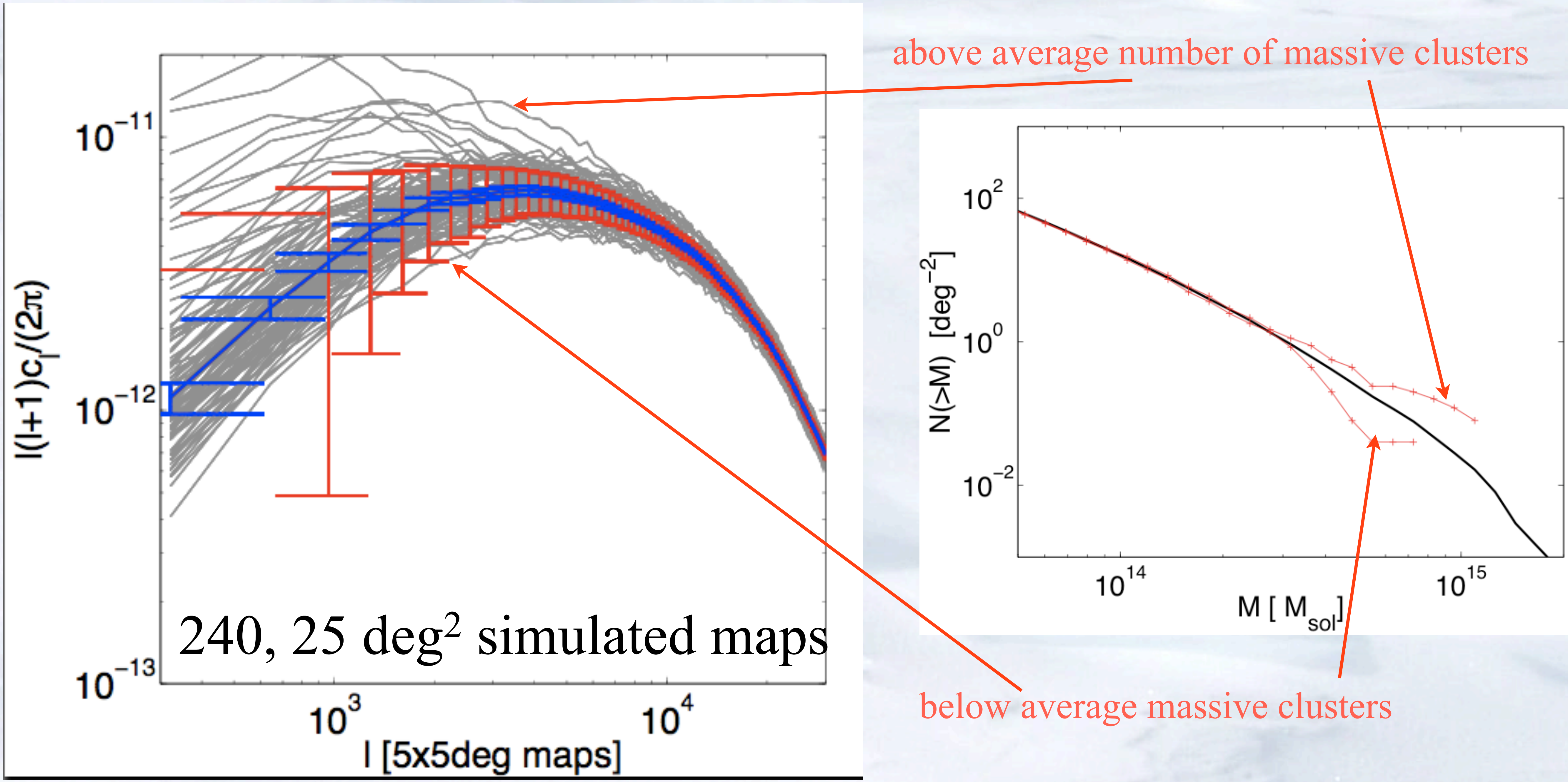
Dolag et al. 07
Battaglia et al. 10
Springel et al. 01
D. Rudd (PC)

semi-analytic models

analytic models

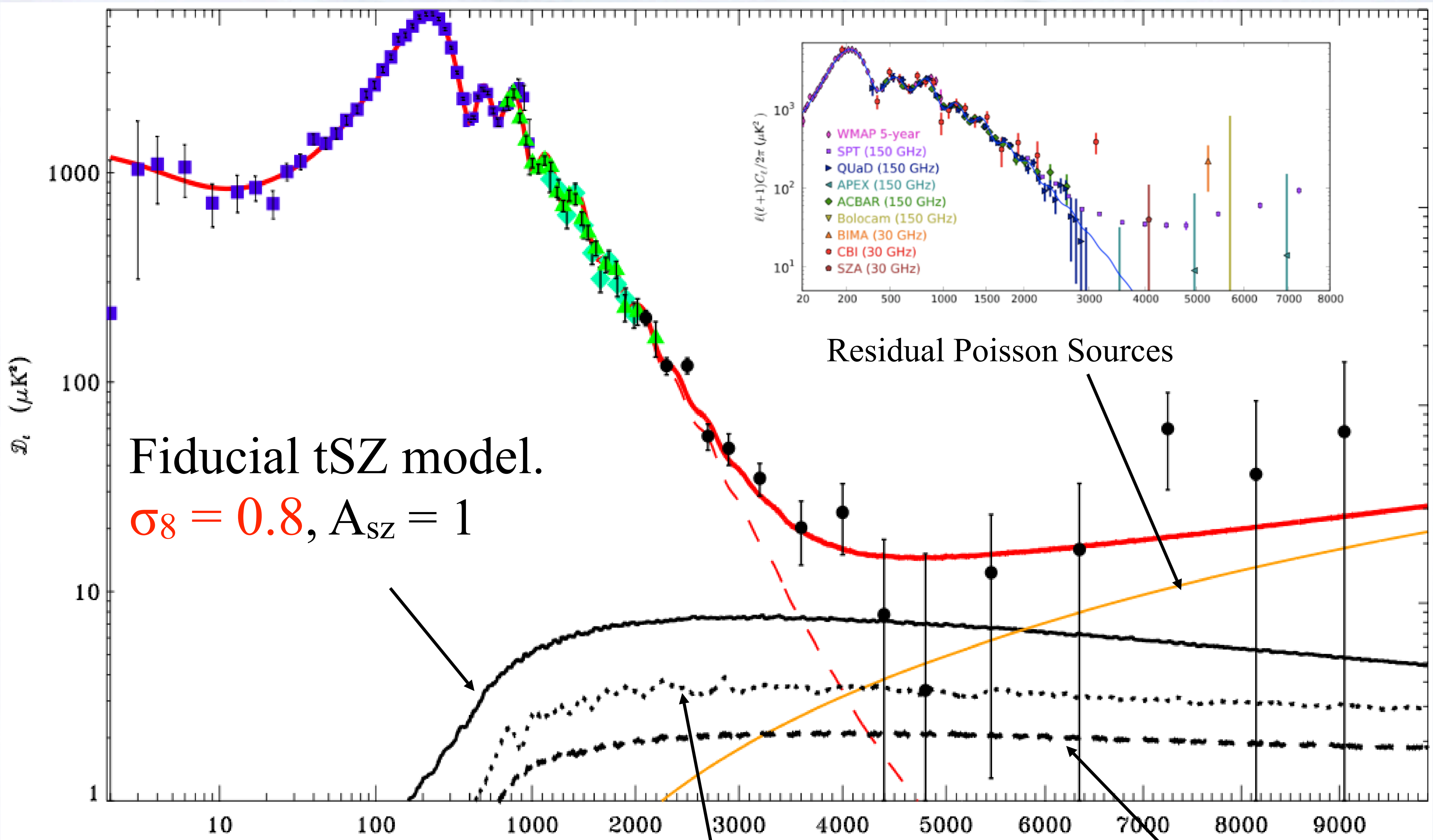
Variations in ICM physics source large variations in amplitude AND shape of signal

Simulations require large volumes



- variance in c_l between fields is non-gaussian
- several times greater than gaussian (cosmic) variance

First Detection of tSZ Power



SPT, Lueker et al. (10)

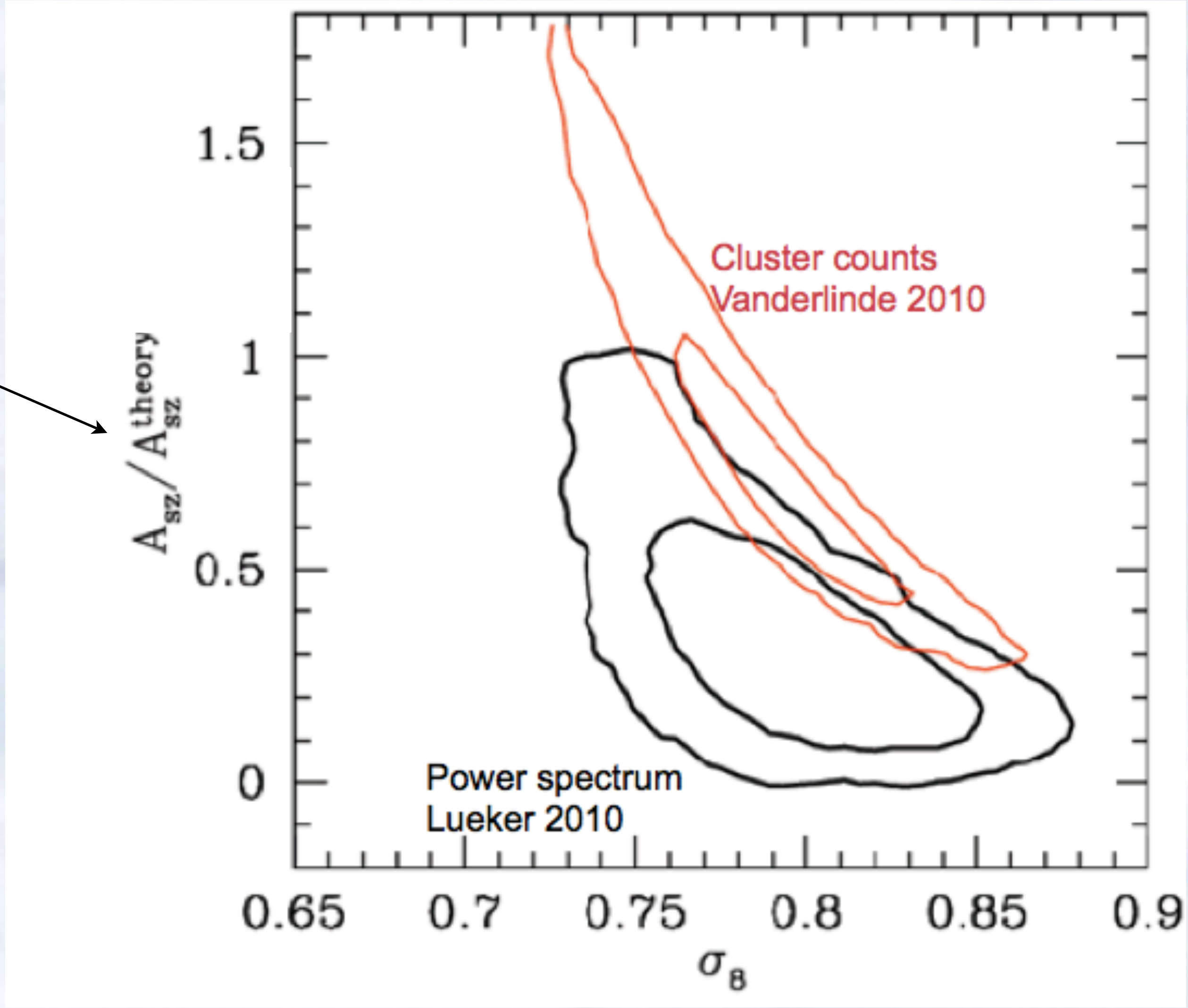
patchy reion. kSZ
(Sehgal et al. 2010 +
Zahn et al. 2005)

homog. reion. kSZ
(Sehgal et al. 2010)

Observations vs Simulations

SZ Power Ratio, A_{SZ}

$$\frac{\text{(ratio of measured power)}}{\text{(power for given value of } \sigma_8 \text{)}}$$



Detected power significantly below that predicted by simulations

- Two interpretations
  - σ_8 is lower than suggested by other probes
  - signal in low-mass / high-z objects over-estimated

Evaluating the Impact of Astrophysics on the tSZ PS

- Develop simple model for investigating impact of 'cluster physics' on shape and amplitude of the power spectrum

- vary input parameters and evaluate effect on amplitude and shape of power spectrum, exploring degeneracies with cosmological parameters

- Model must be able to reproduce direct observations of clusters
  - Scaling relations (M-T, Lx-T, M-fgas)
  - radial profiles (pressure profiles)

- computationally inexpensive
  - can be incorporated in MCMC analysis of real data.
  - marginalize over astrophysical parameters to account for theoretical uncertainty in signal

Halo model approach to calculating the tSZ power spectrum

Calculate SZ power spectrum by integrating the mass function over M and z, weighted by cluster signal at a given angular scale.

$$C_l = g_\nu^2 \int_0^{z_{max}} \mathrm{d}z \frac{\mathrm{d}V}{\mathrm{d}z} \int_0^{M_{max}} \mathrm{d}M \frac{\mathrm{d}n(M,z)}{\mathrm{d}M} |y_l(M,z)|^2$$

volume integral

cluster mass function
(e.g. Tinker et al 08)

gas thermal pressure profiles

Model for the ICM

- Assume NFW dark matter halos.

$$c(M,z) = 7.85 A_C \left(\frac{M_{\rm vir}}{2\times 10^{12}\,h^{-1}M_\odot}\right)^{-0.081}(1+z)^{-0.71}$$

Duffy et al. 08
$A_c = 1$

- Gas resides in hydrostatic equilibrium in DM potential

$$\frac{dP_{tot}(r)}{dr} = -\rho_g(r)\frac{d\Phi(r)}{dr}$$

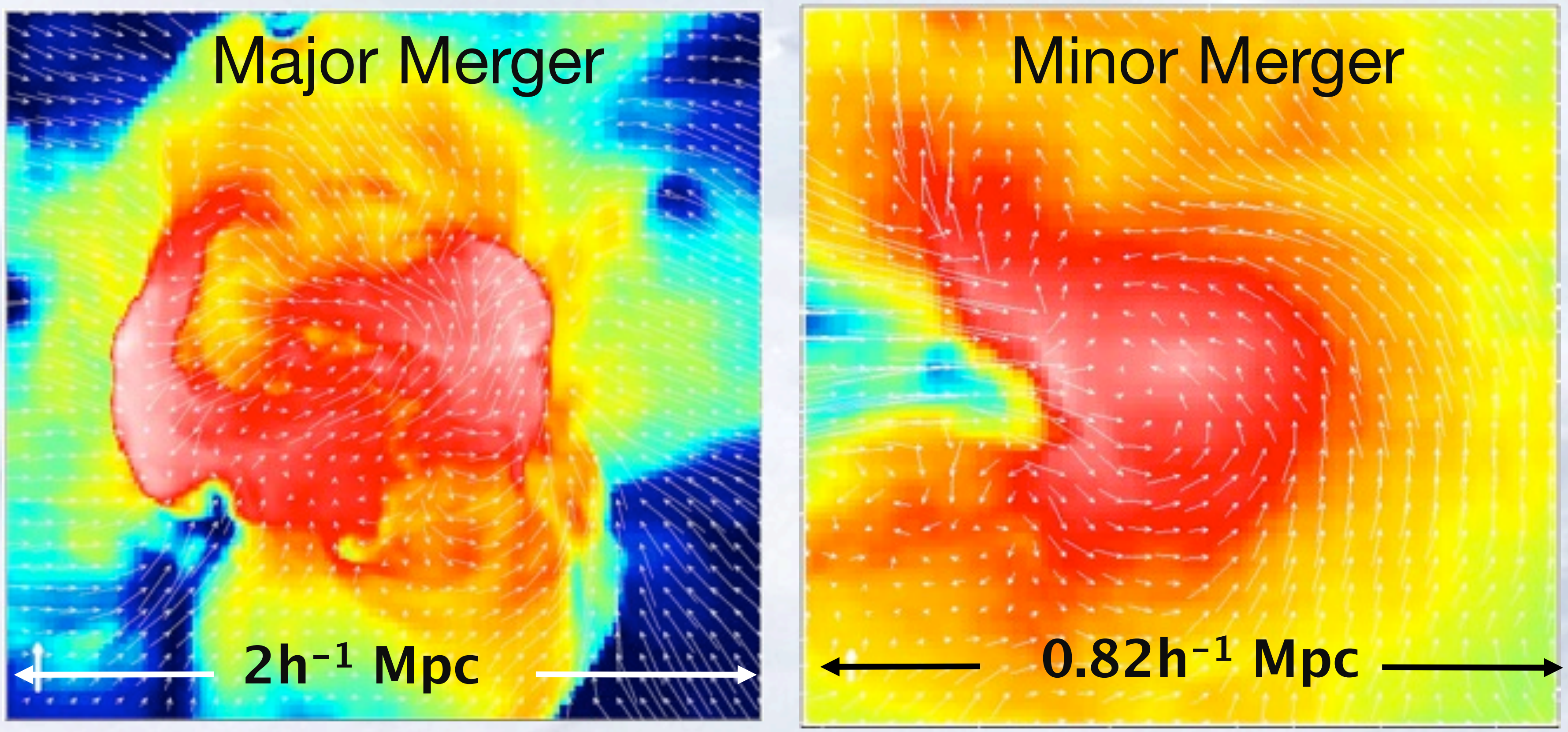
- Polytropic equation of state for the ICM: $P_{tot}=P_0(\rho_{gas}/\rho_0)^\Gamma$ with $\Gamma=1.2$ and $P_{tot}(r)=P_{therm}(r)+P_{nt}(r)$

- Assume some fraction of the gas has cooled and formed stars
  - Adopt stellar mass fraction - cluster mass relation of Gonzalez et al. (07)

Cluster Astrophysics

$$E_{g,f} = E_{g,i} + \epsilon_{\rm DM}|E_{DM}| + \epsilon_{\rm f} M_* c^2 + \Delta E_p$$

- Energy feedback from Supernovae/AGN: $\varepsilon_f \sim 10^{-6}$-$10^{-5}$
- Dynamical heating by mergers: $\varepsilon_{DM} \sim 0.05$
- Non-thermal pressure due to gas motions in galaxy clusters



Gas motions (bulk+turbulent) are ubiquitous in ΛCDM clusters

Cluster Astrophysics

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- Energy feedback from Supernovae/AGN: $\varepsilon_{\rm f} \sim 10^{-6}$-$10^{-5}$
- Dynamical heating by mergers: $\varepsilon_{\rm DM} \sim 0.05$
- Non-thermal pressure support: α_0, β, $n_{\rm nt}$

$$\frac{P_{nt}}{P_{tot}}(z) = \alpha(z)\left(\frac{r}{R_{500}}\right)^{n_{nt}}$$

where $\alpha(z)=\alpha_0(1+z)^\beta$

Calibrate with hydro simulations:

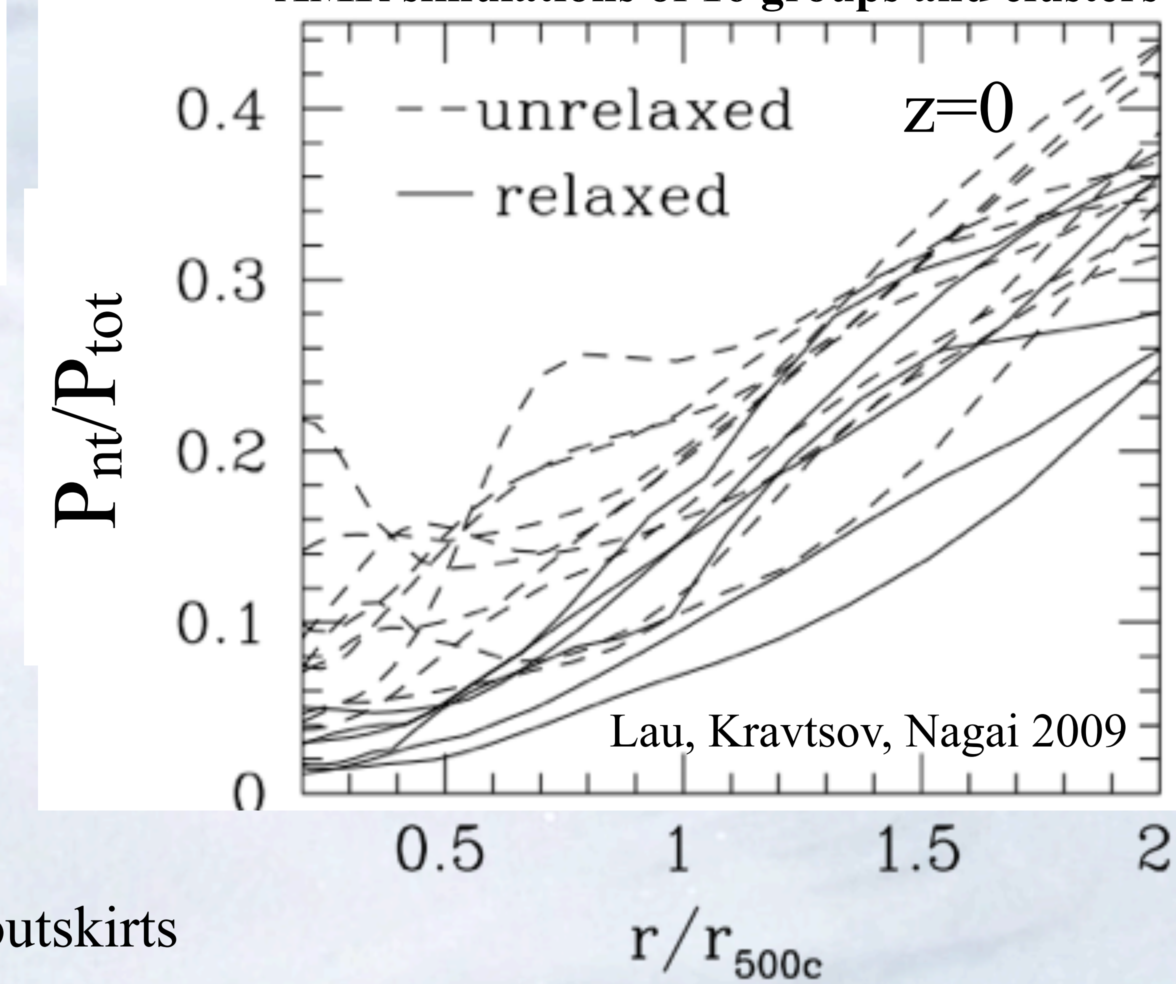
$\alpha_0=0.18$, $\beta=0.5$, $n_{\rm nt}=0.8$

18% at R_{500} at z=0

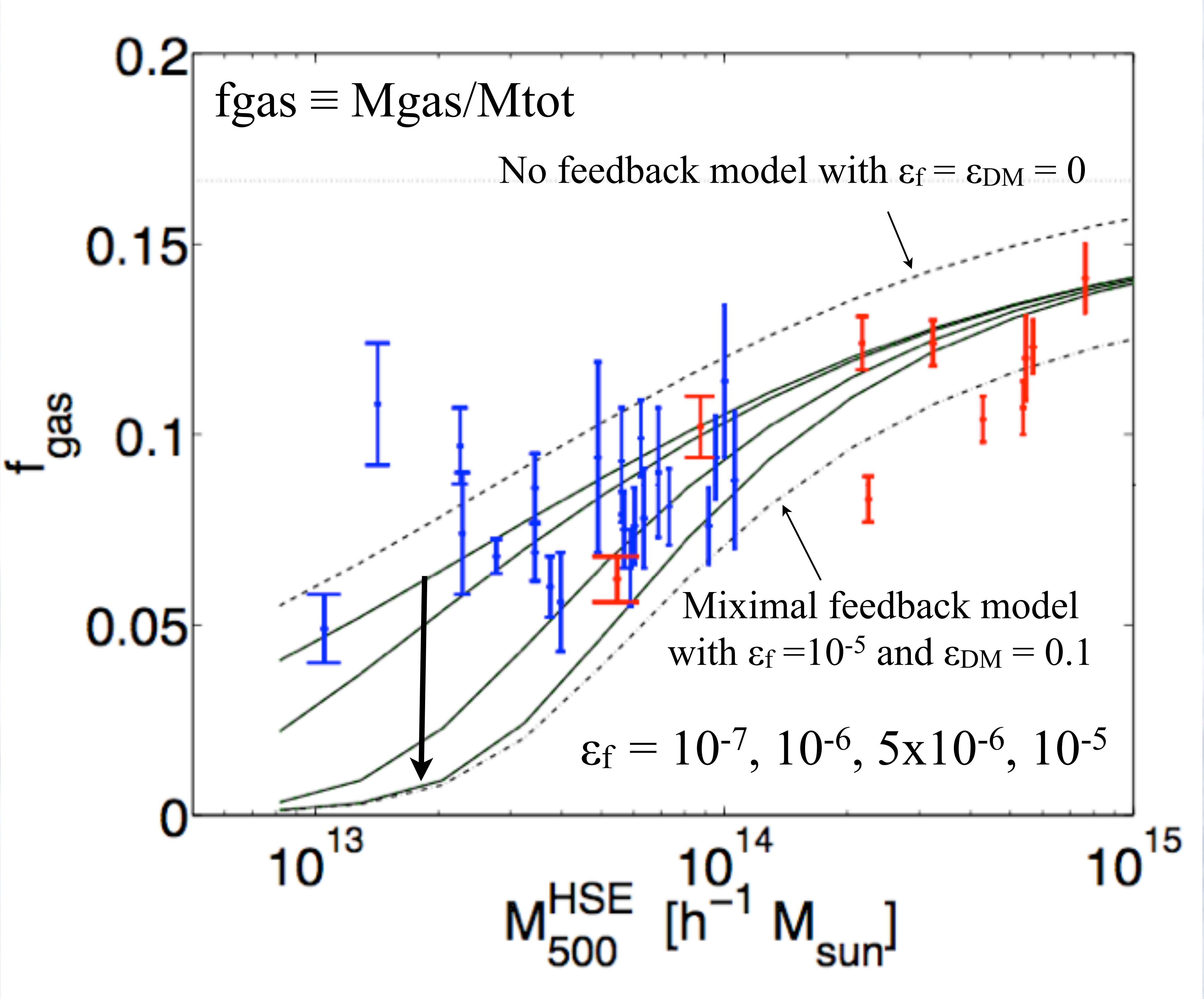
enhanced at high-z

enhanced toward outskirts

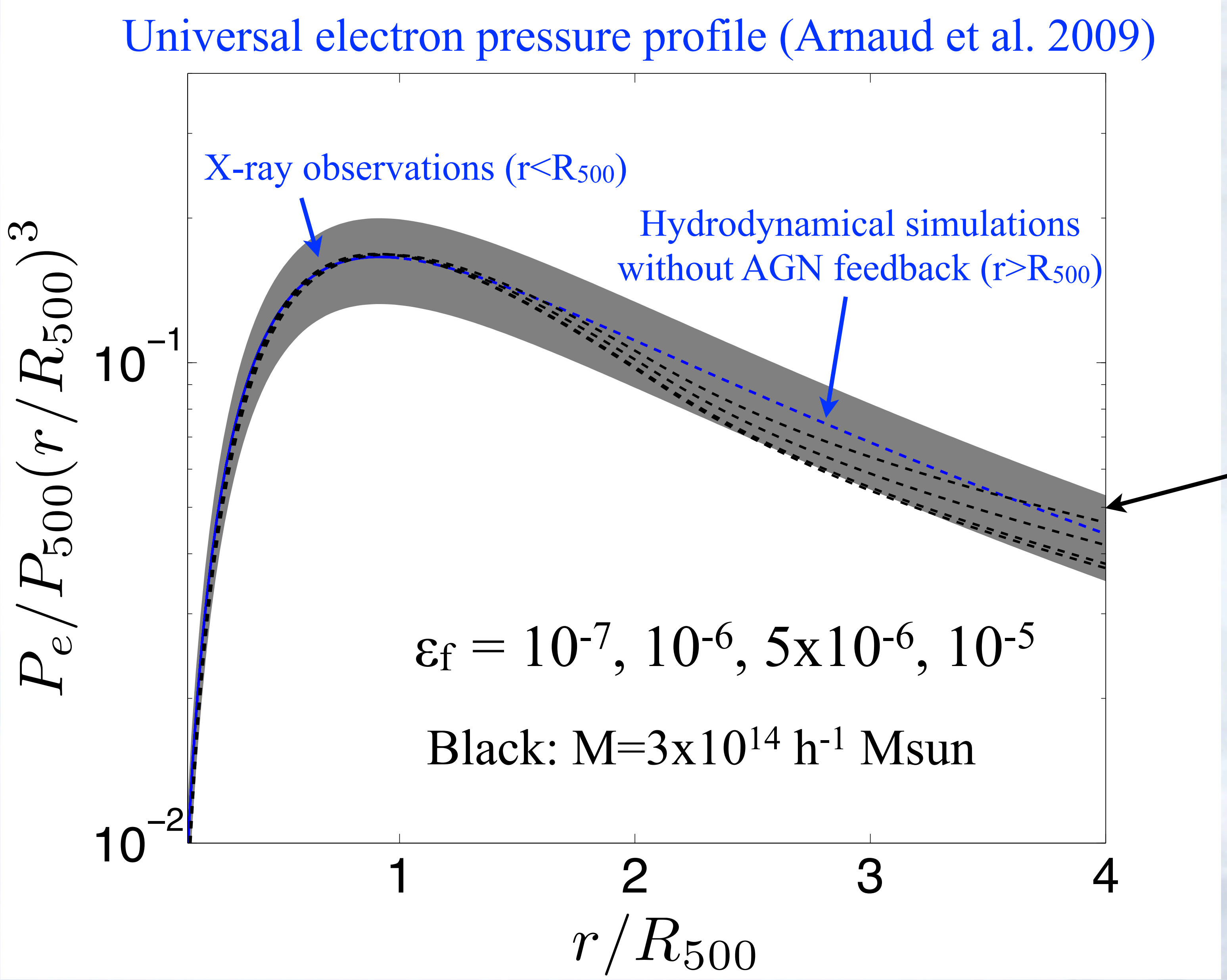
AMR simulations of 16 groups and clusters



Matching to fgas-M observations

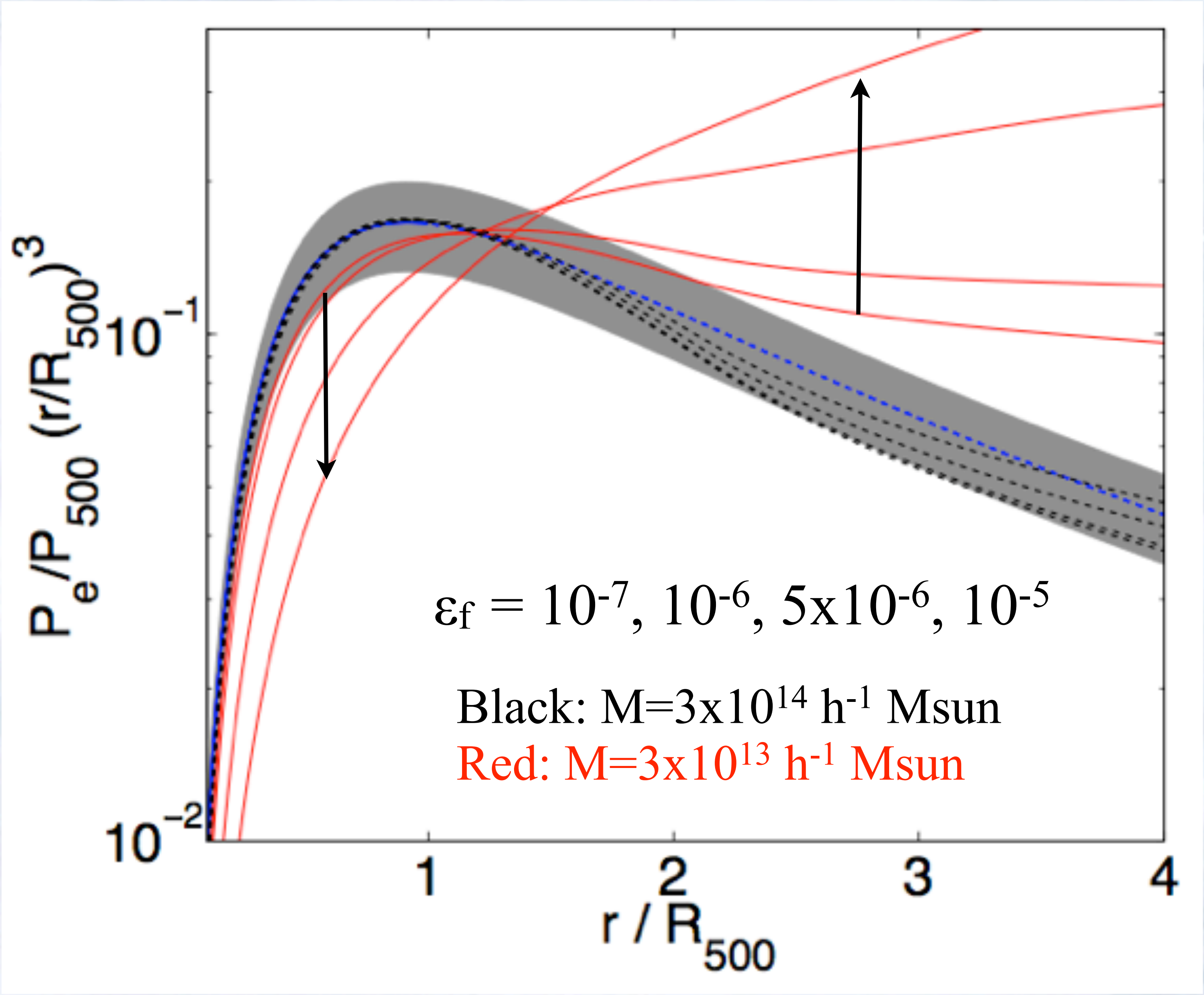


Impact of Energy Feedback on Pressure Profiles



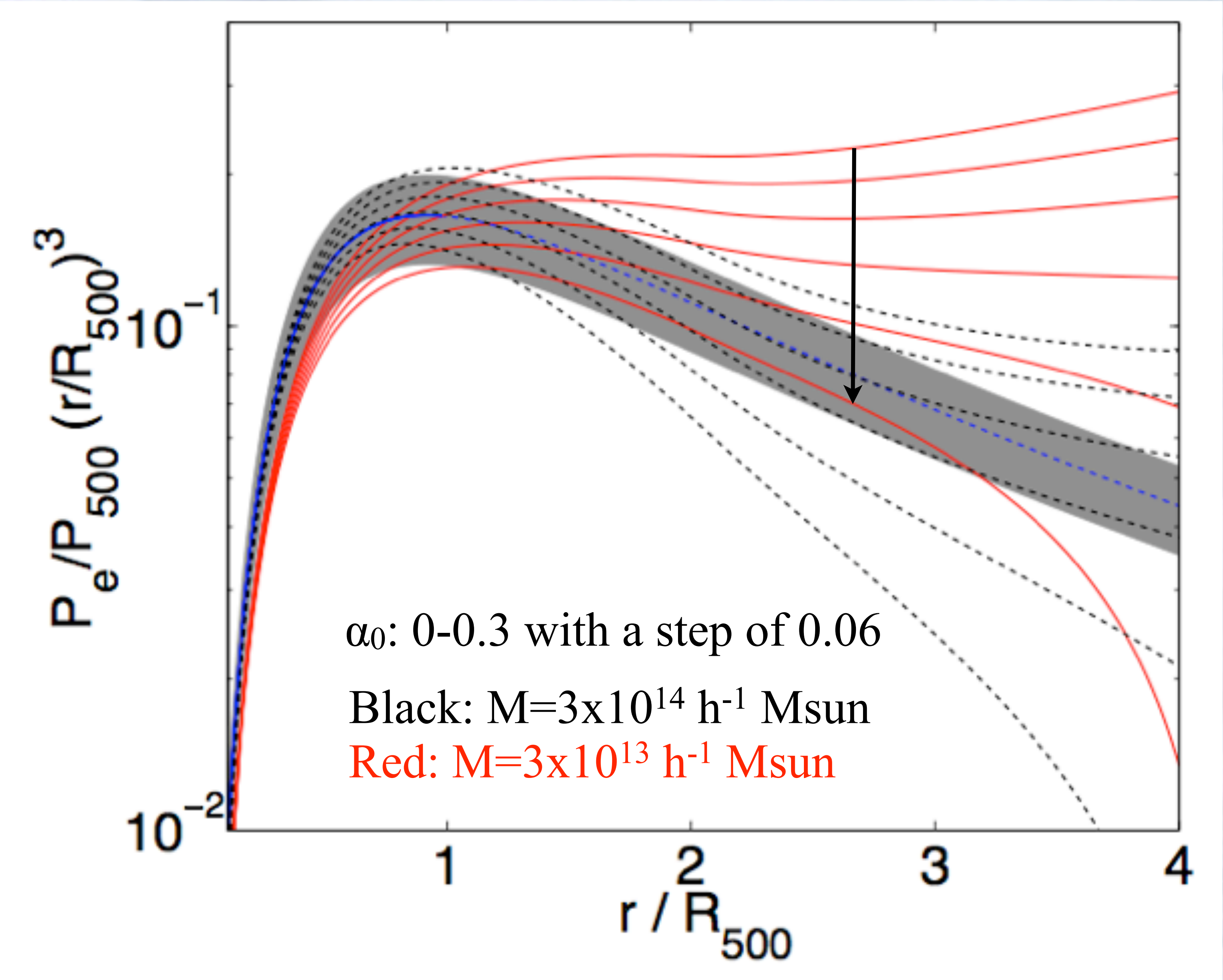
Energy feedback does NOT significantly modify the electron pressure profiles of massive clusters.

Impact of Energy Feedback on Pressure Profiles



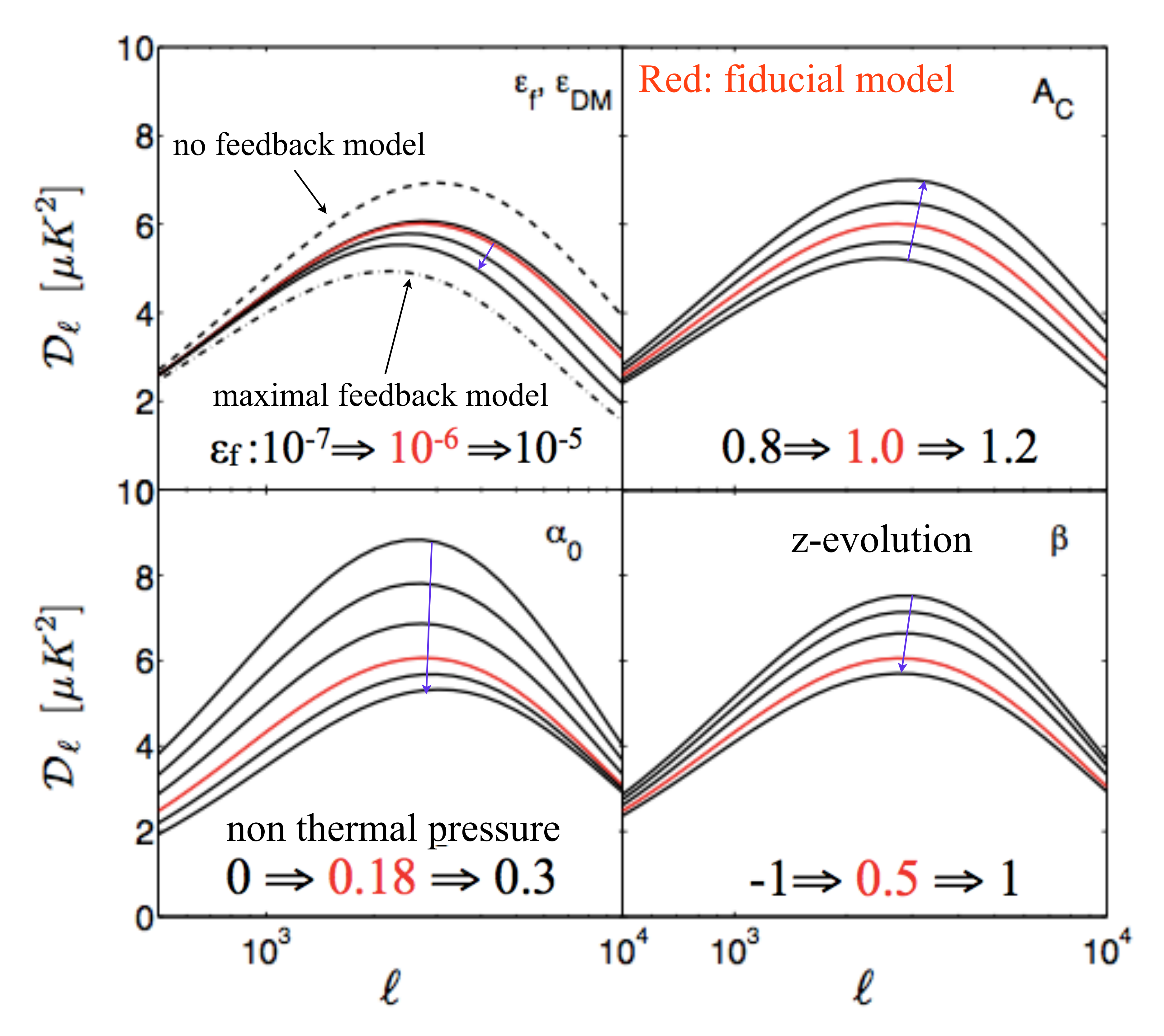
But, significant impact on groups!

Impact of Gas Motions on Pressure Profiles

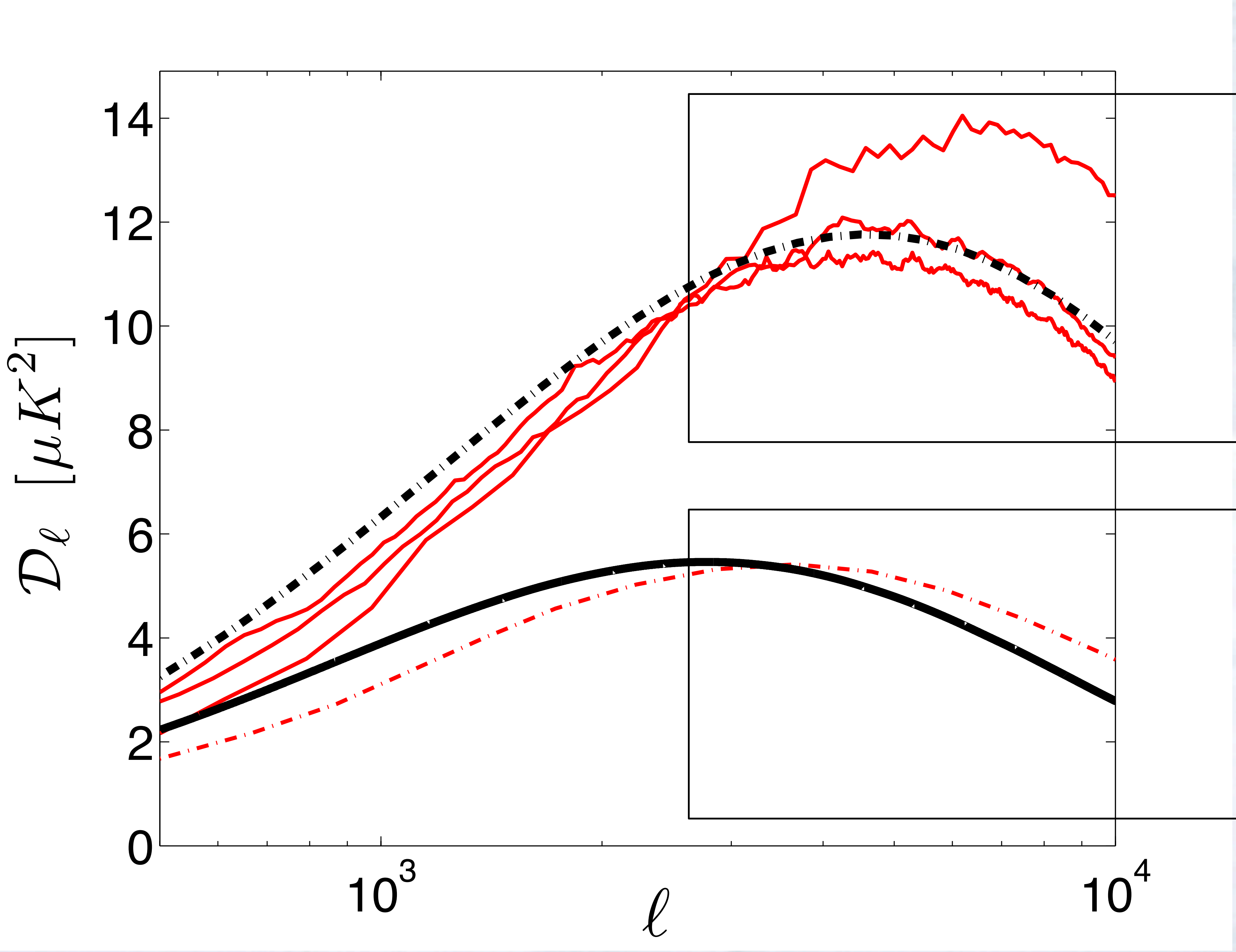


Non-thermal pressure due to gas motions suppress electron pressure in outskirts of both groups and clusters.

Impact of cluster physics on the SZ Power Spectrum



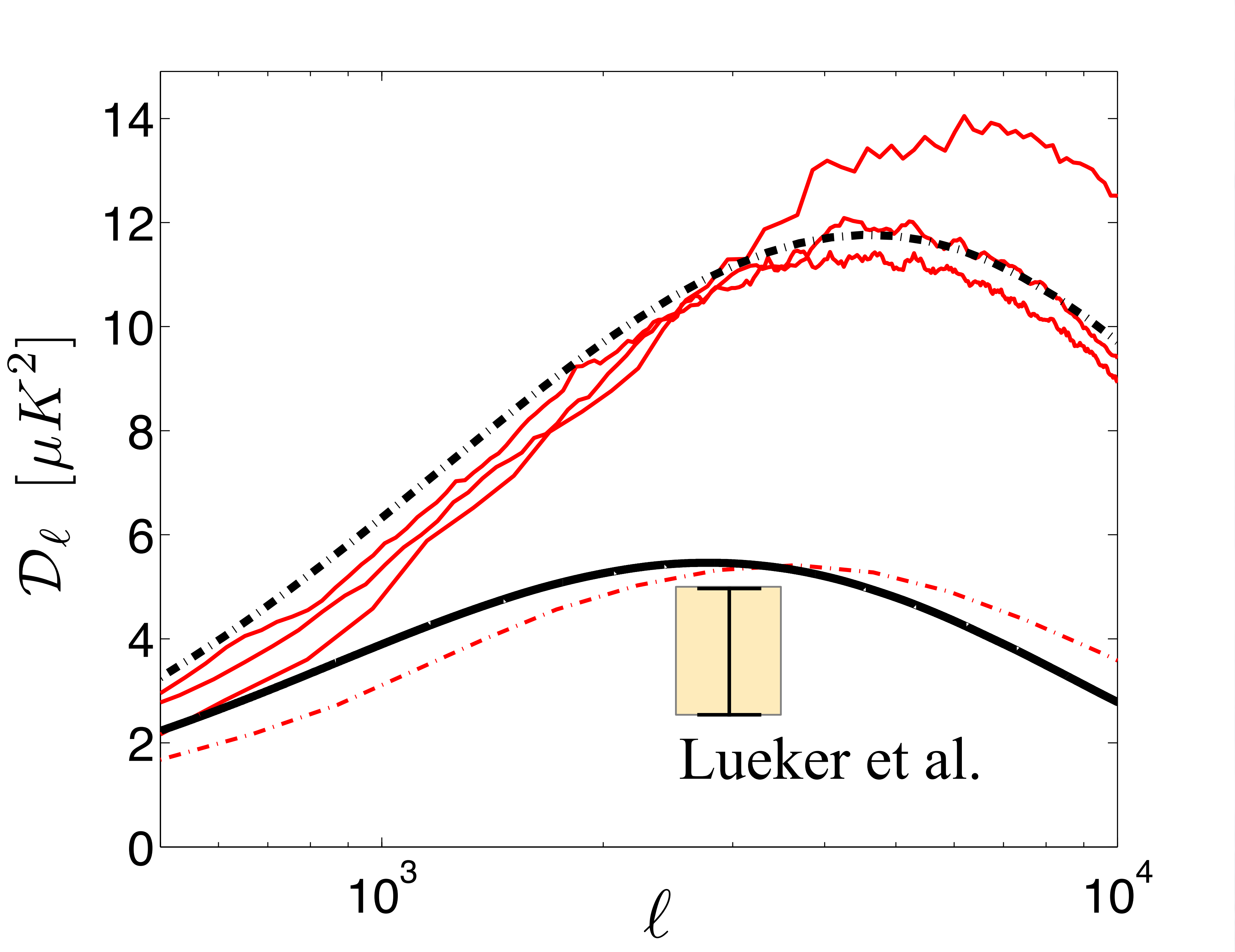
comparing with hydrosims



non-radiative hydrosims by K. Dolag and the CITA group.
Our model with no star-formation / feedback.

Hydro simulations including cooling, star-formation and AGN feedback (Battaglia et al.)
Our fiducial model

Model can reproduce results of hydro-simulations that incorporate different levels of ICM physics



But..latest models/simulations still exceed measured power.

Wrap-up

- SZ power spectrum provides probe of integrated line-of-sight pressure in structures encompassing a wide range of mass and redshift

- Amplitude of signal dependent on both cosmology and astrophysics.

- Shape of signal dependent mostly on astrophysical processes
  - feedback suppresses small-scale signal
  - non-thermal presssure reduces large-scale signal

- low value of measured power suggests that high-z/low-mass signal strongly suppressed