Title: Energetics of the Intracluster Medium

Date: Apr 27, 2009 02:00 PM

URL: http://pirsa.org/09040035

Abstract: "Taking gravitational potential wells from a dark matter simulation, and assuming a polytropic equation of state and hydrostatic equilibrium, one can predict the state of the hot gas in clusters of galaxies. With reasonable values for star formation efficiency, energy input, and nonthermal pressure support, these model clusters can reproduce observed X-ray trends of gas temperature and gas mass fraction with cluster mass, as well as observed entropy and pressure profiles.
Normalizing to X-ray observations is a vital step in using such models to predict the SZ signal. "

Energetics of the Intracluster Medium

Paul Bode

Princeton University

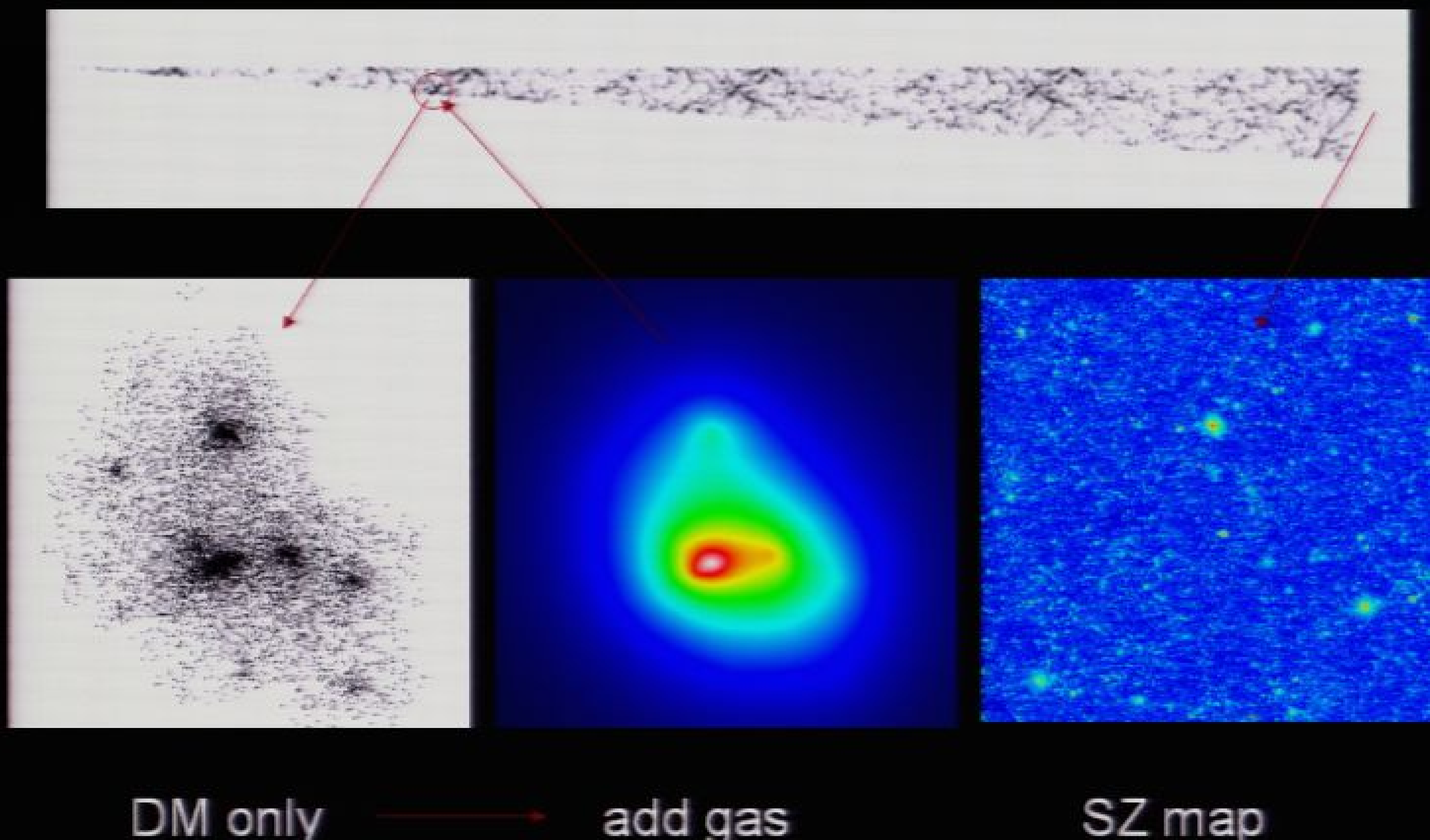
H. Trac et al, in prep.

PB, J. Ostriker & A. Vikhlinin 2009 submitted

N. Sehgal, H. Trac, K. Huffenberger & PB 2007 ApJ

PB, J. Ostriker, J. Weller & L. Shaw 2007 ApJ

J. Ostriker, PB & A. Babul 2005 ApJ


DM only
add gas
SZ map

How to fill DM potential with gas?

- Hydrostatic equilibrium
- Polytropic equation of state (Γ=1.2)

$$P = P_o \Theta^{\frac{\Gamma}{\Gamma-1}} \qquad \rho = \rho_o \Theta^{\frac{1}{\Gamma-1}}$$

$$\Theta \equiv 1 + \frac{\Gamma - 1}{\Gamma} \frac{\rho_o}{P_o} (\phi_o - \phi)$$

Need two equations to specify central density & pressure...

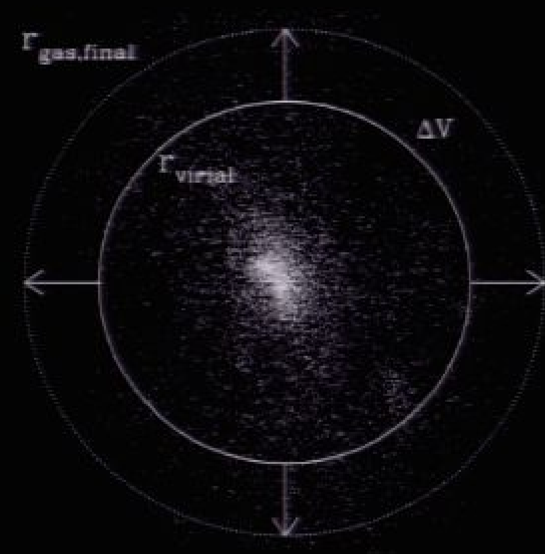
(ϕ from NFW: Suto+ 1998, Komatsu & Seljak 2001)

Assume gas initially followed DM:

$$\rho_{gas} = \frac{\Omega_b}{\Omega_m} \rho_{DM}$$

$$E_{K,gas} = \frac{\Omega_b}{\Omega_m} E_{K,DM}$$

inside virial radius. This sets initial energy and surface pressure. Constraints on final state are:



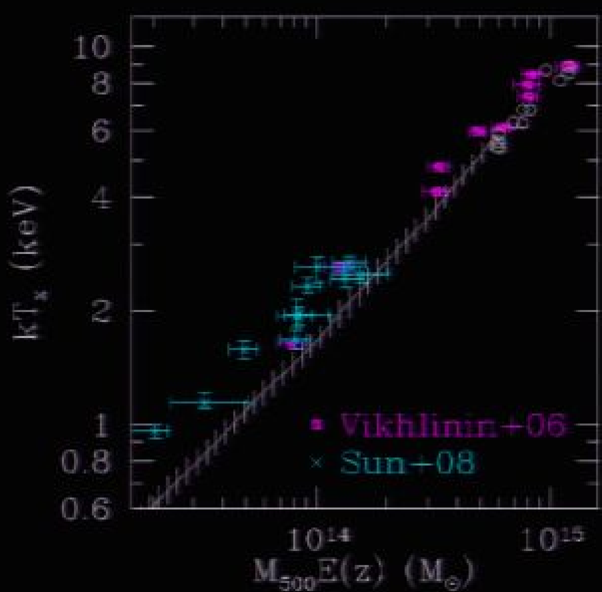
1: Match surface pressure

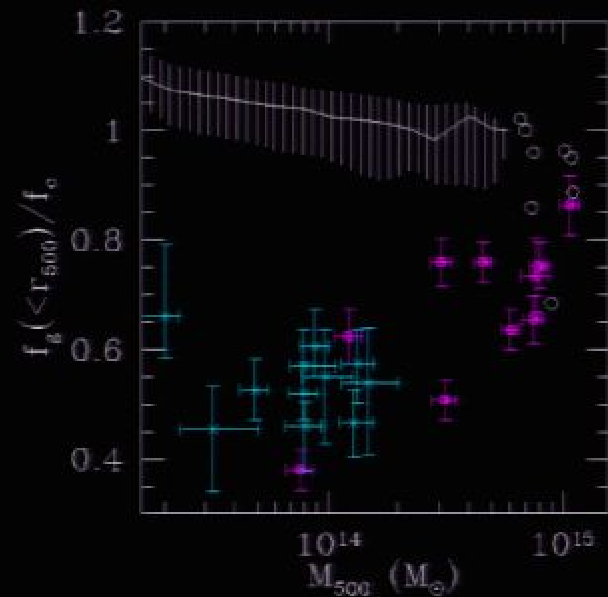
- gas can expand, doing work

2: Conservation of energy:

$$E_{final} = E_{init} - P_S \Delta V$$

(Test sample: all z<0.2 halos in light cone).

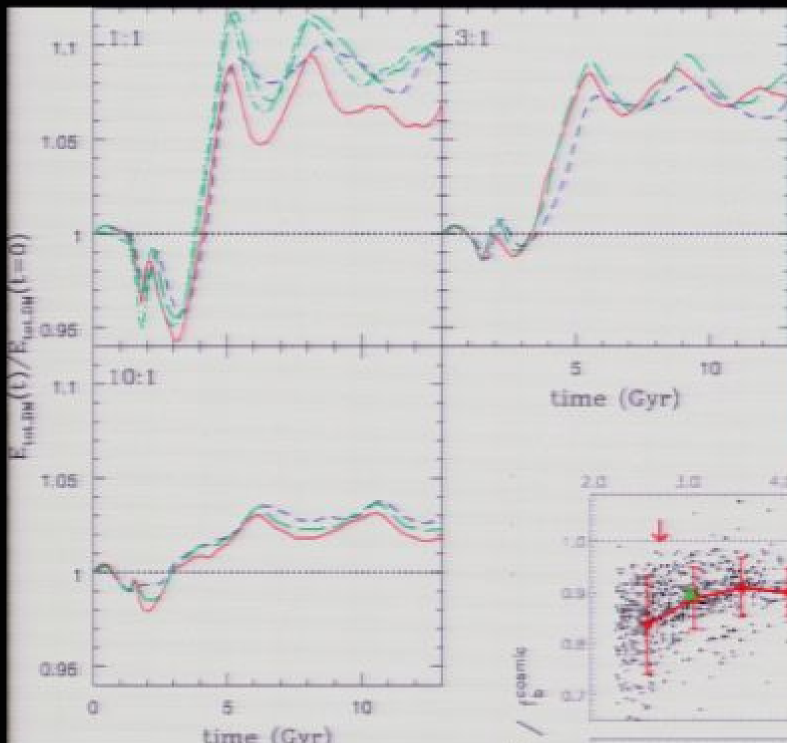




Simplest case gives wrong scaling (Kaiser 1986, 1991).

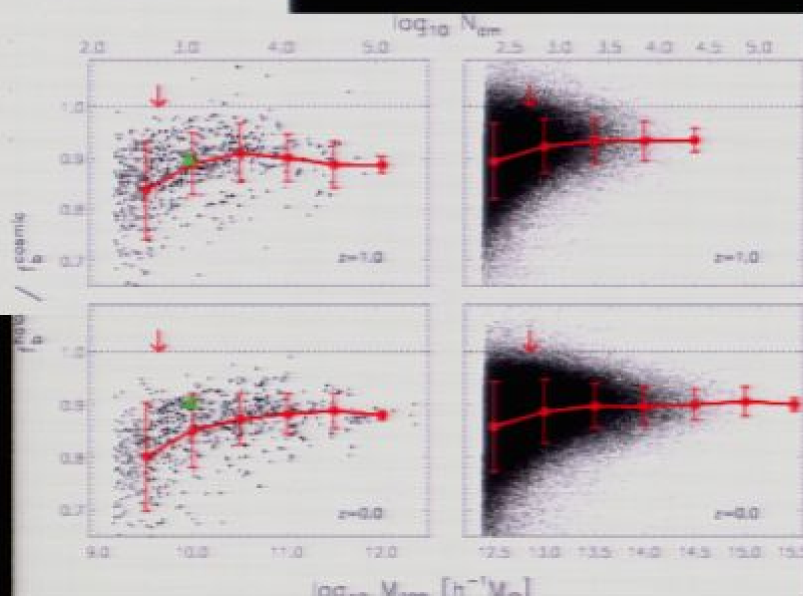
Need to include processes that change the energy of the gas:

- dynamics
- star formation
- feedback

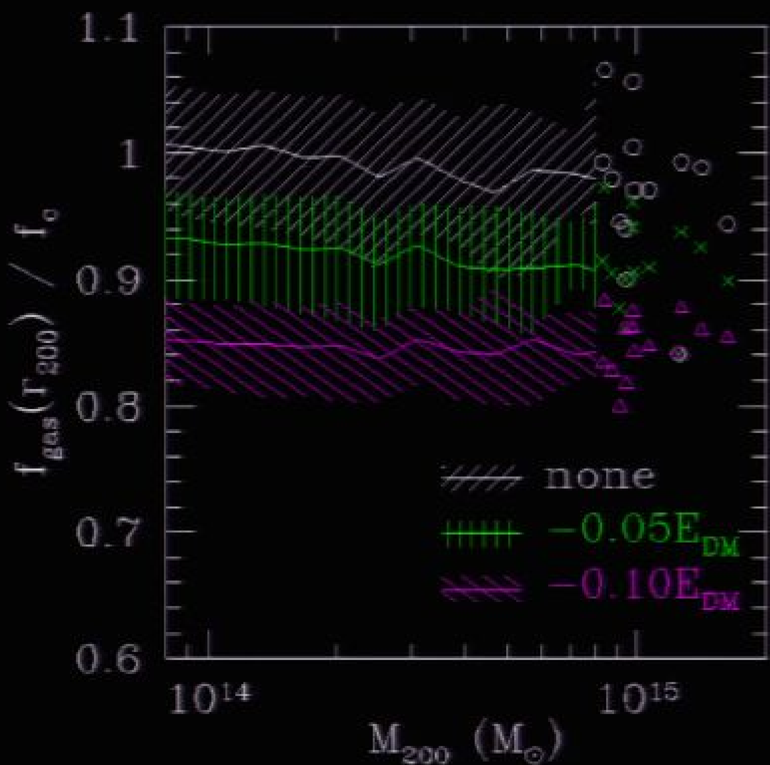


Mcarthy+07 MNRAS

Nonradiative hydro simulations:
DM loses energy to gas, reducing gas fraction



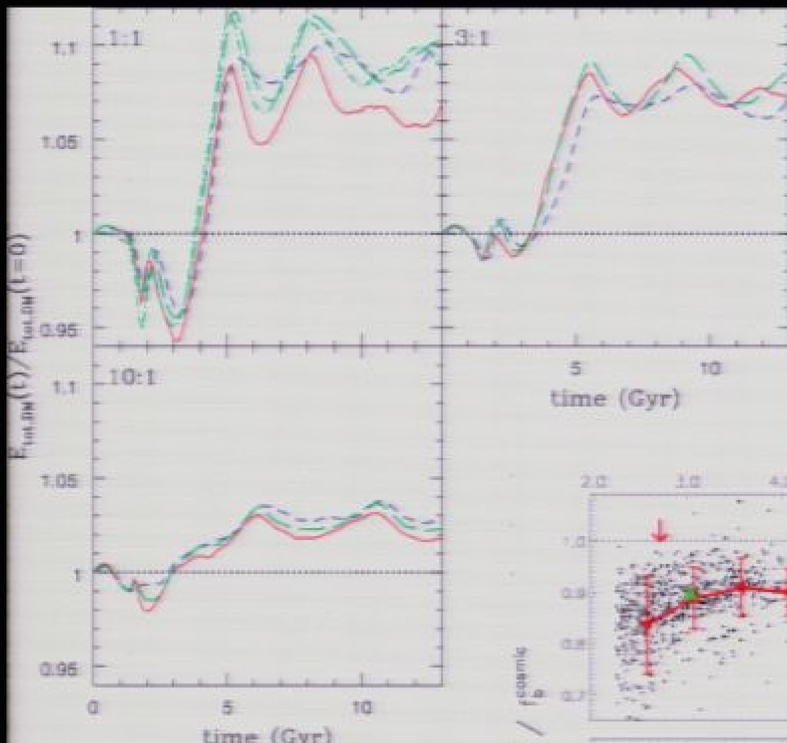
Crain+08 MNRAS



To match sims, must increase gas energy by additional amount proportional to E_{DM}

Modified energy equation:

$$E_{final} = E_{init} - P_S \Delta V - 0.05 E_{DM}$$



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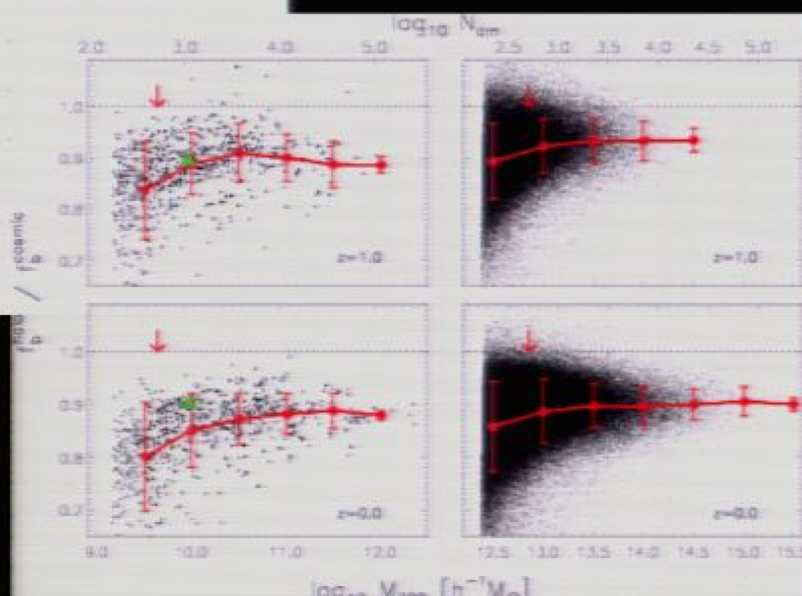

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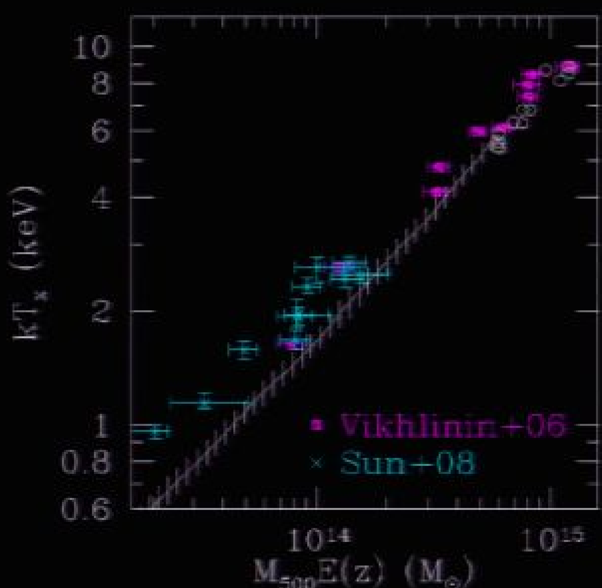

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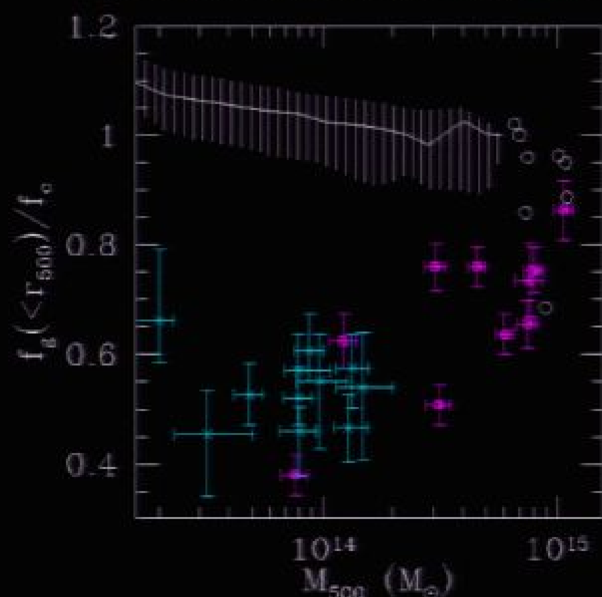

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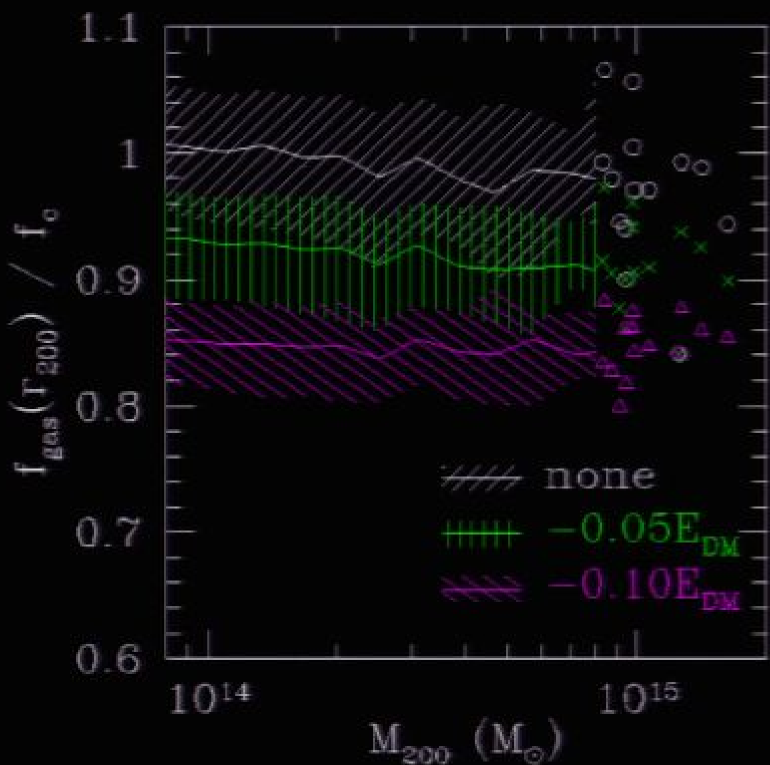

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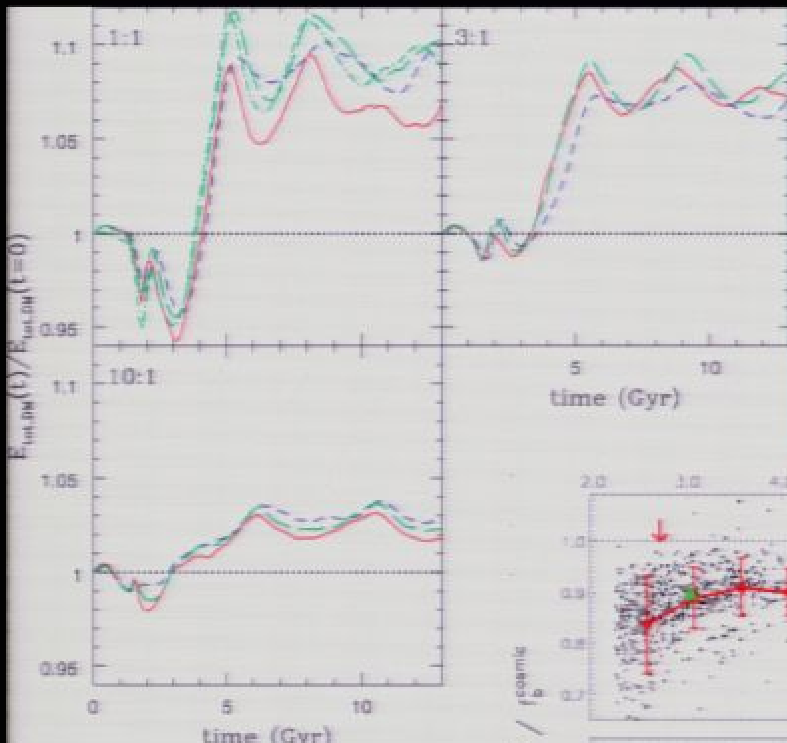

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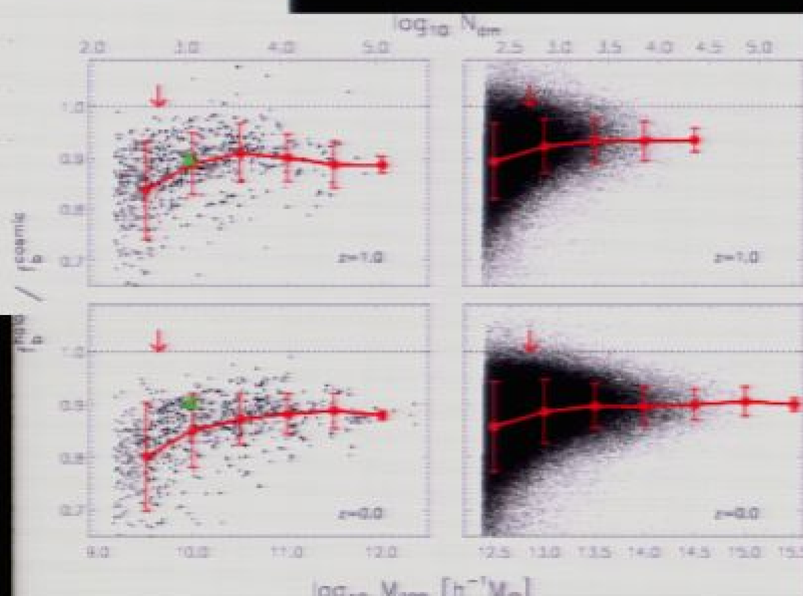

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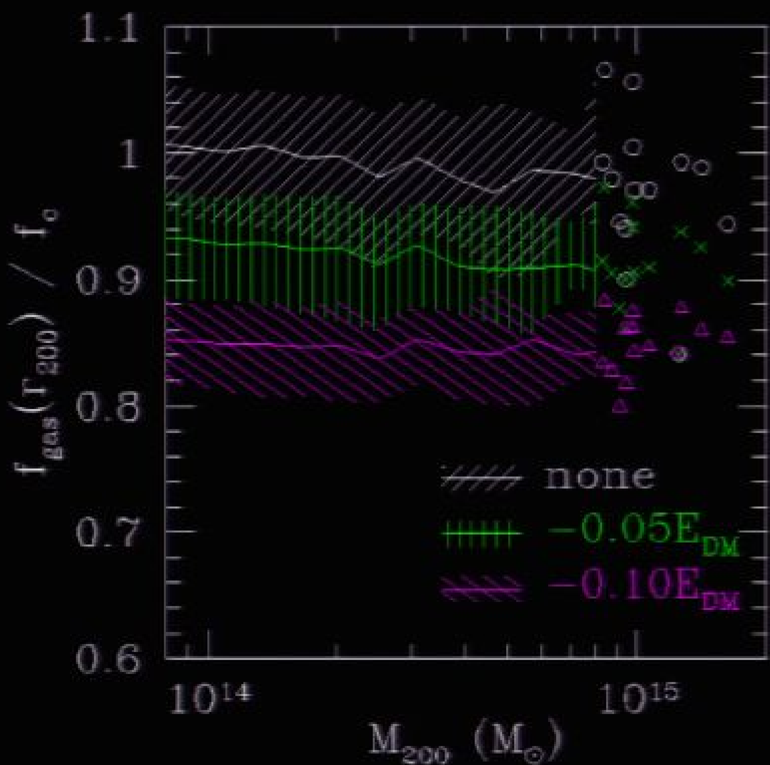

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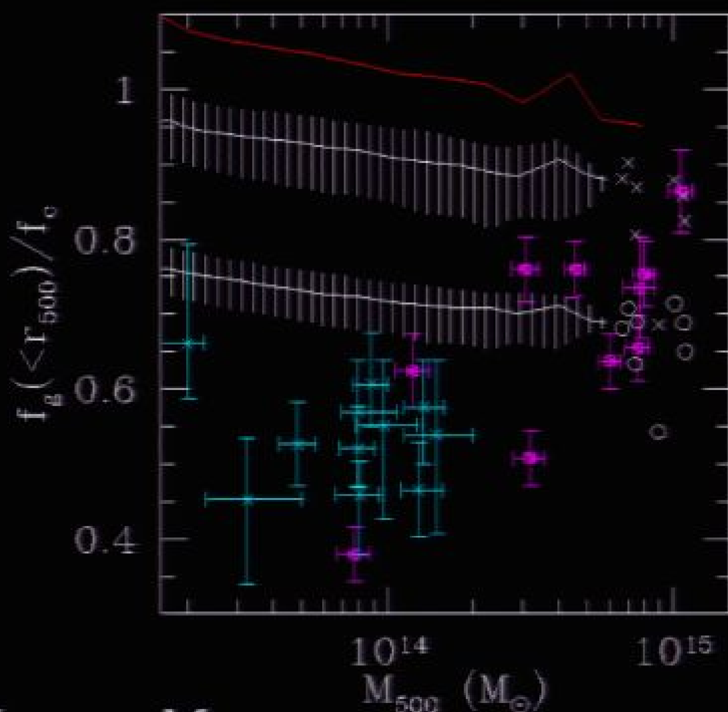
Star Formation

- Reduces mass in gas
- Removes lowest entropy gas--remainder has higher entropy on average
(Voit & Bryan 2001 ApJL)

9% of gas turned into stars:



$$M_{gas} = \frac{\Omega_b}{\Omega_m} M'_{DM} = \frac{\Omega_b}{\Omega_m} M_{DM} - M_*$$

$$E_{final} = E'_{init} - P_S \Delta V - 0.05 E_{DM}$$

Breaking scale-free behavior

1. Vary star formation efficiency with cluster mass

$$\frac{M_*}{M_{500}} \propto M_{500}^{-\alpha_*}$$

Lin, Mohr & Stanford 2003:

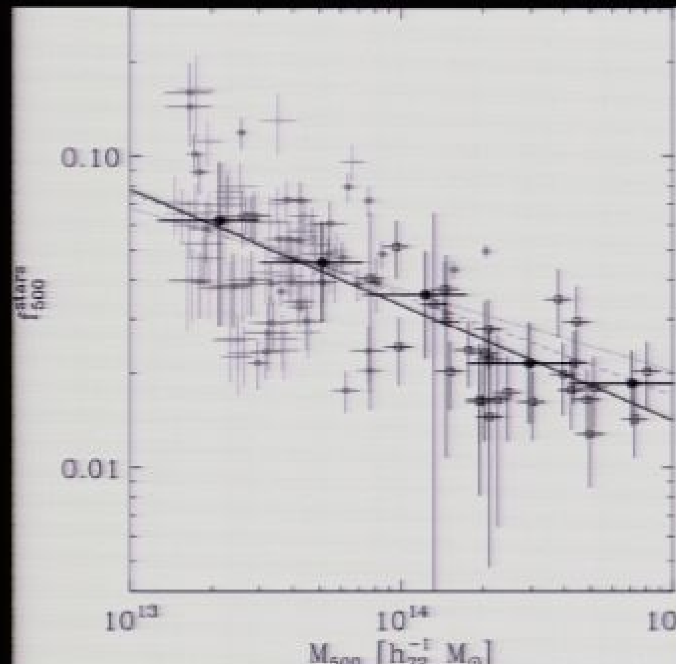
$\alpha_*=0.26\pm0.09$

Giodini etal 2009:

$\alpha_*=0.37\pm0.04$

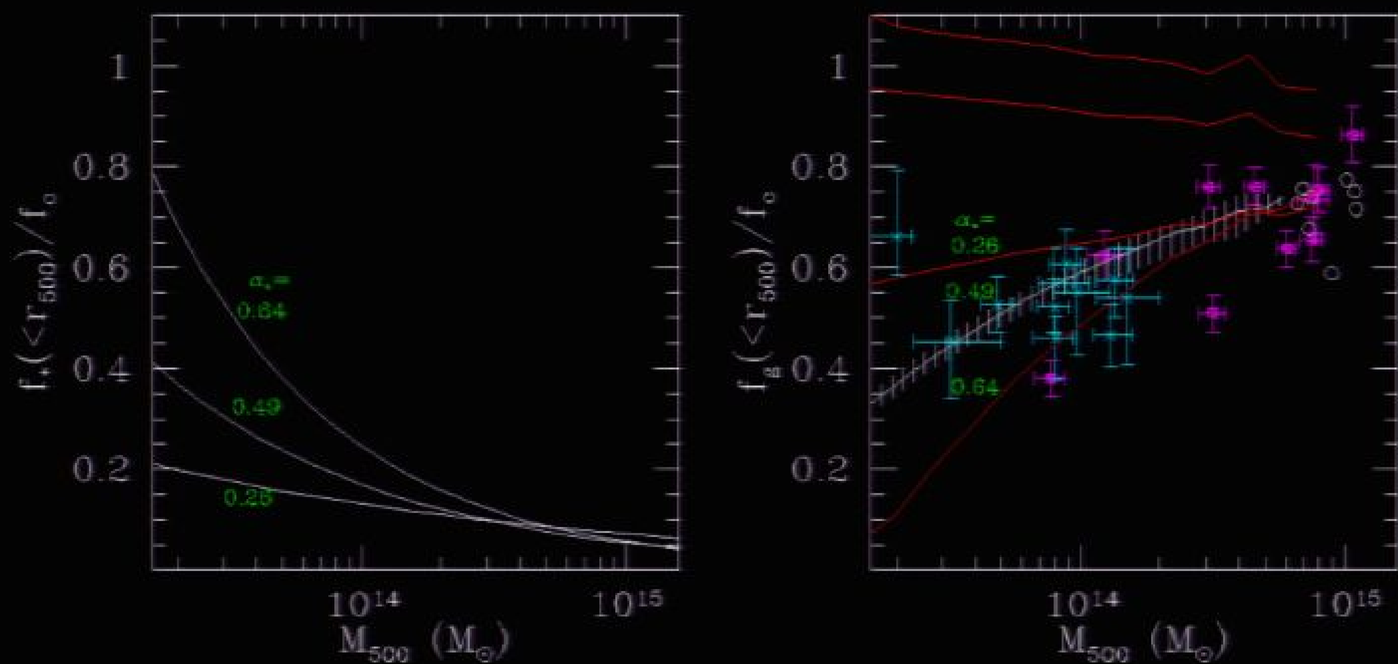
Gonzalez, Zaritsky & Zabludoff 2007:
(including ICL)

$\alpha_*=0.64\pm0.13$



Giodini+09 Arxiv/0904.0448

Varying stellar fraction can give the correct gas fraction scaling.



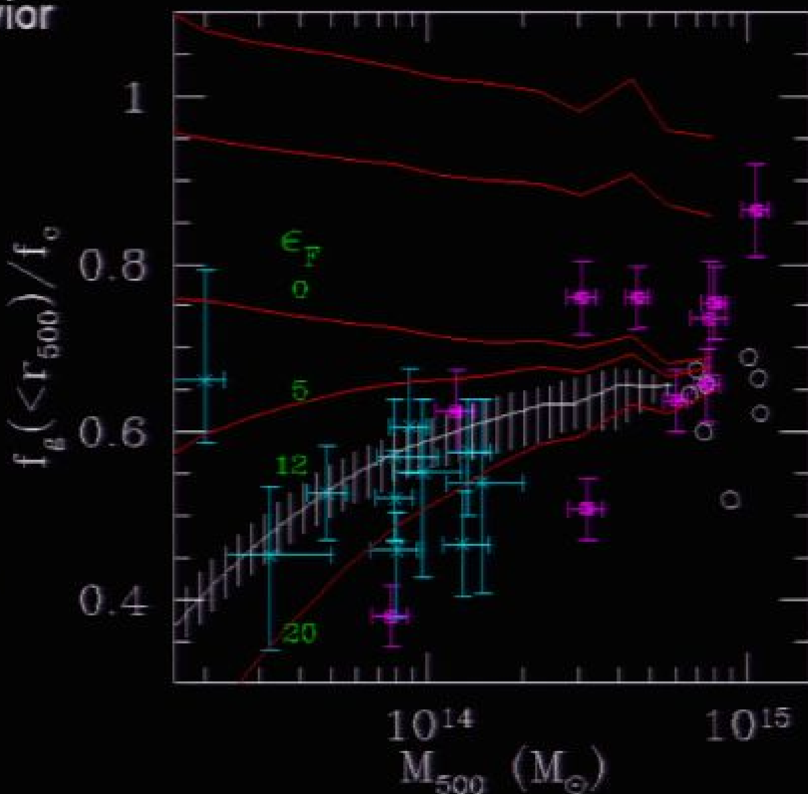
Starting with LMS03 and varying slope: best fit $\alpha_* = 0.49$

Breaking scale-free behavior

2. Feedback from supernovae and AGN.

For 9% of gas turned into stars-- what's (potentially) available?

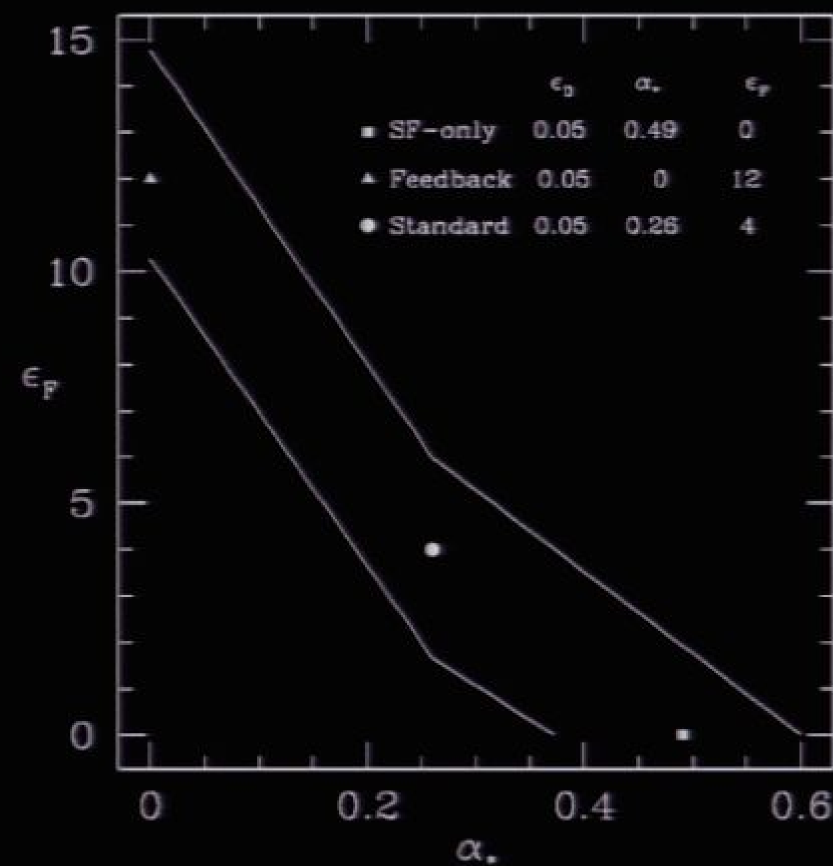
SNe: ~ 0.4 keV/particle
Black holes: ~ 0.02 $M_{BH}c^2$
~ $2\times10^{-5}M_*c^2$
~ 1.0 keV/particle



Final energy equation:

$$E_{final} = E'_{init} - P_S\Delta V - 0.05E_{DM} + \epsilon_F 10^{-6} M_* c^2$$

These two effects are degenerate--- difficult to distinguish between models based solely on ICM properties



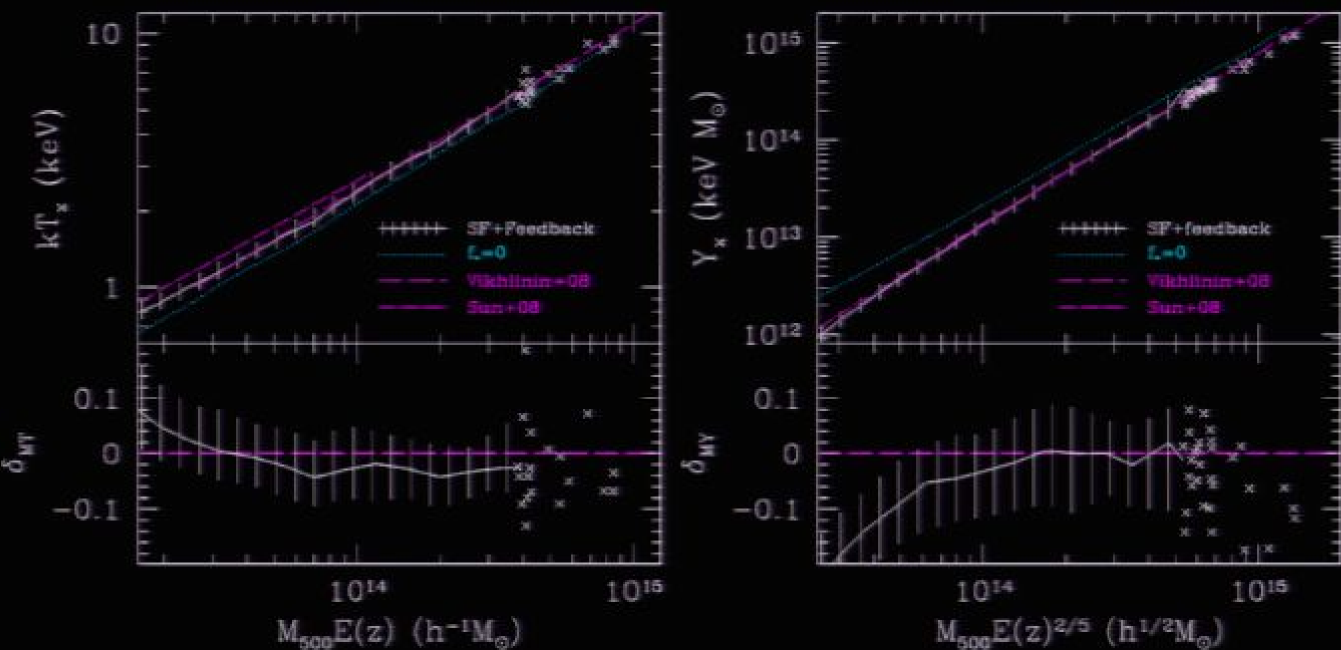
"Standard" model:

$M_*(M_{500})$ from LMS03

$4\times10^{-6}M_F c^2$ feedback

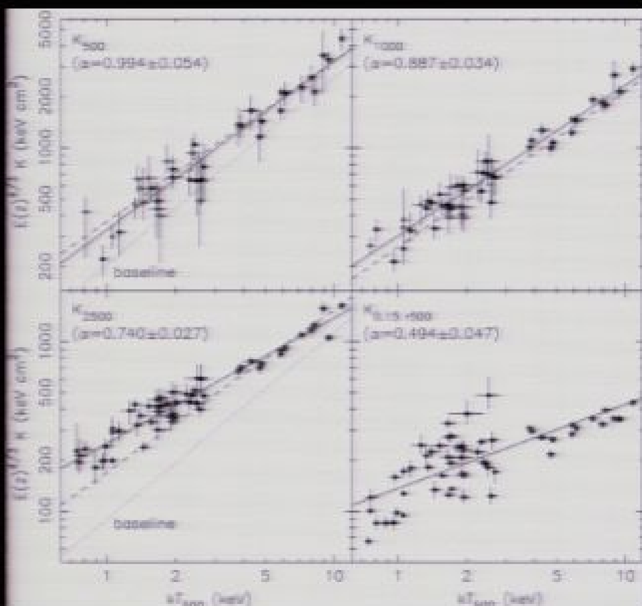
(~ 1/3 keV/particle)

“Standard” model

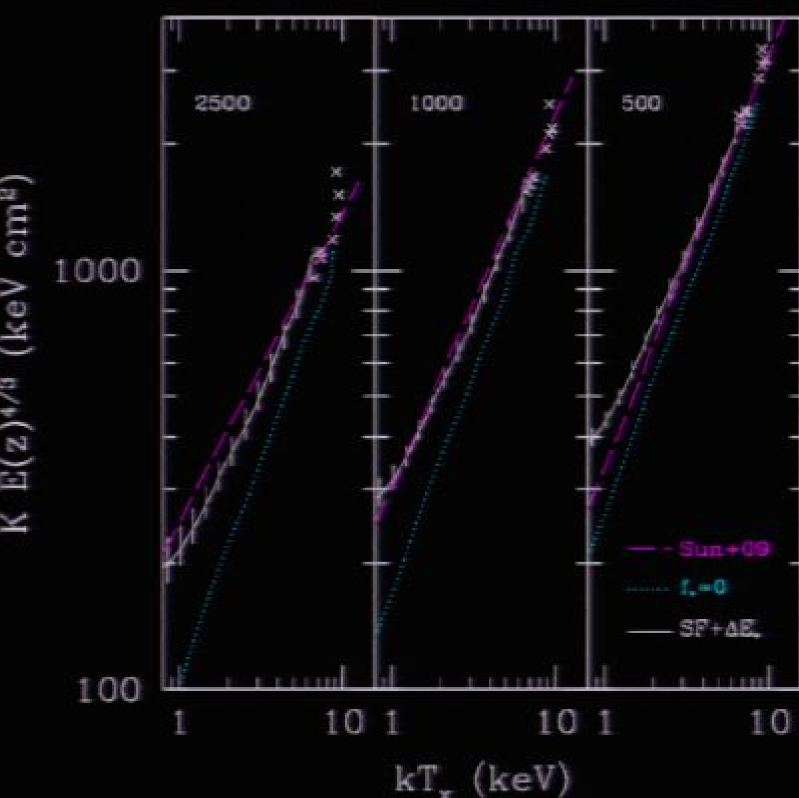


δ = *(model - obs.)/obs.*

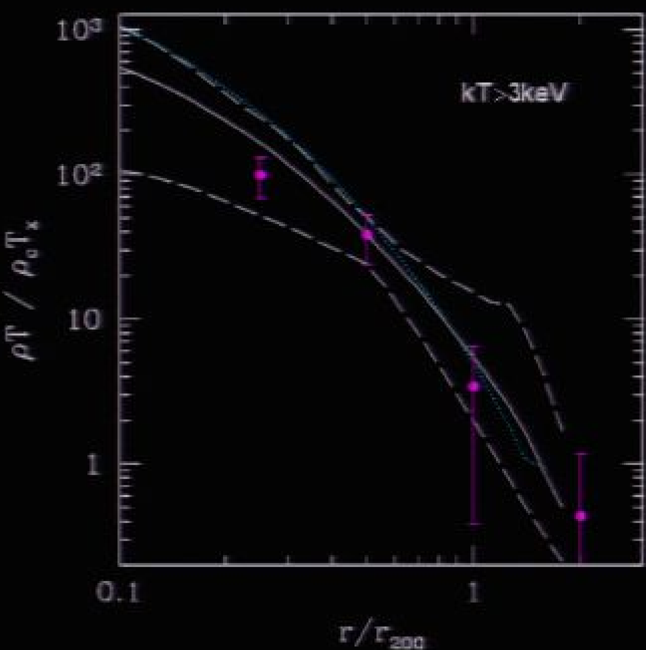
"Entropy" $K = kT/n_e^{2/3}$



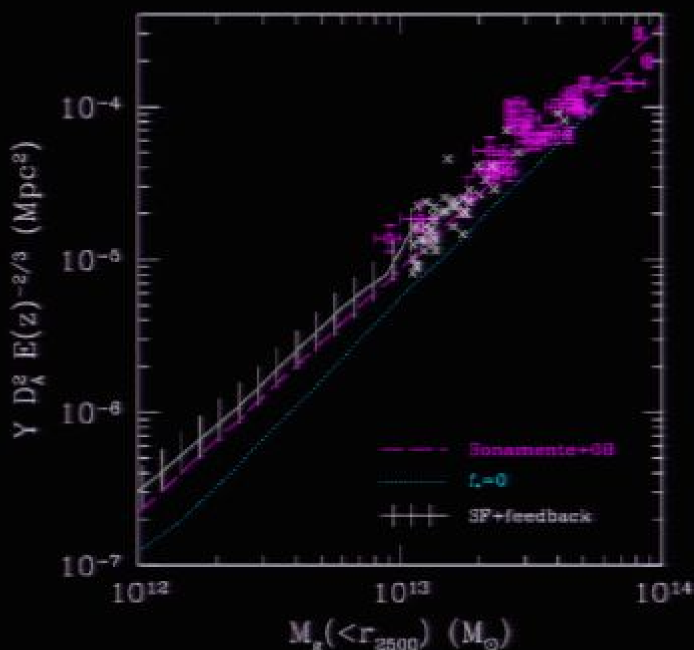
Sun+09 ApJ



Comparison to SZ data:



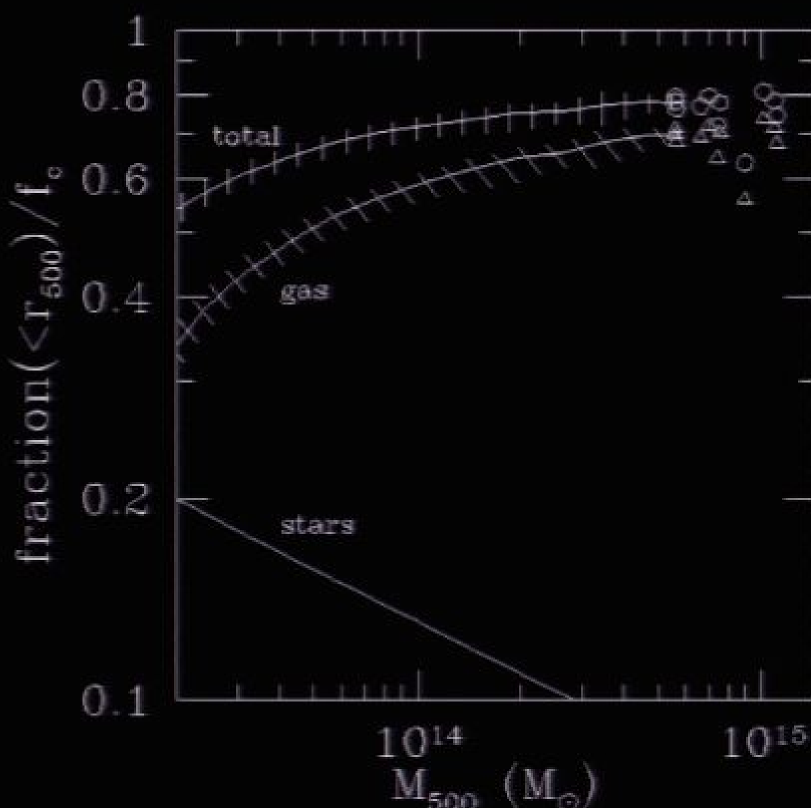
Afshordi, Lin & Sanderson 2005 ApJ
WMAP



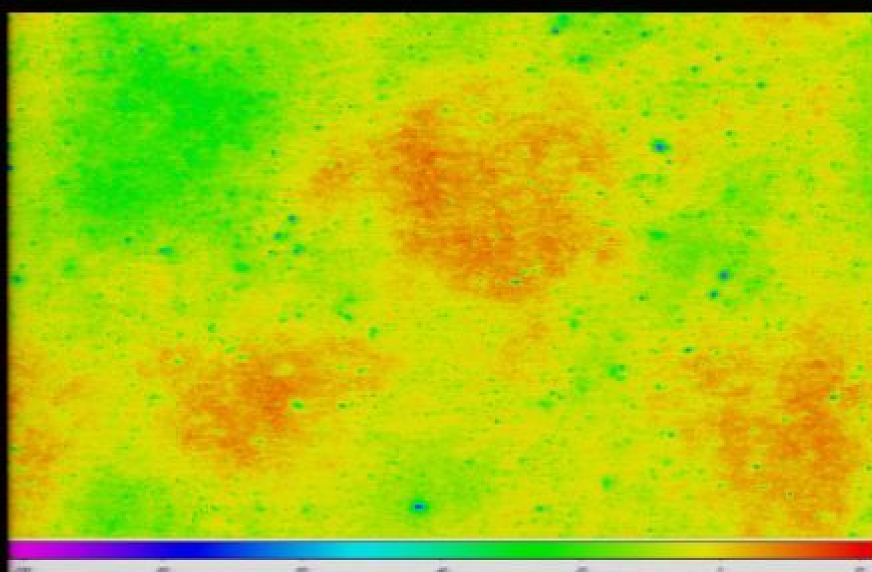
Bonamente+ 2008 ApJ
Chandra/BIMA/OVRO

Consequence: baryon fraction inside r_{500} is ~80% of mean

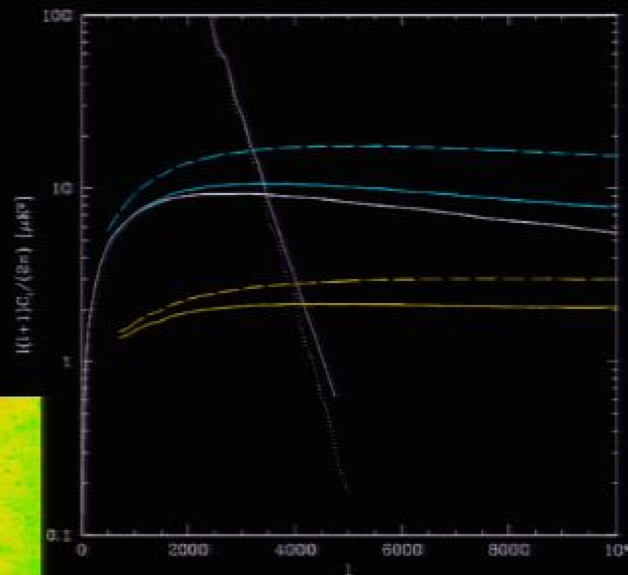
Baryon fraction reaches cosmic mean at
$1.2 \pm 0.1\ r_{vir}$



13x8 deg SZ @ 148 GHz



micro-K



Angular power spectrum
TSZ & KSZ

Figures by Hy Trac

Conclusions

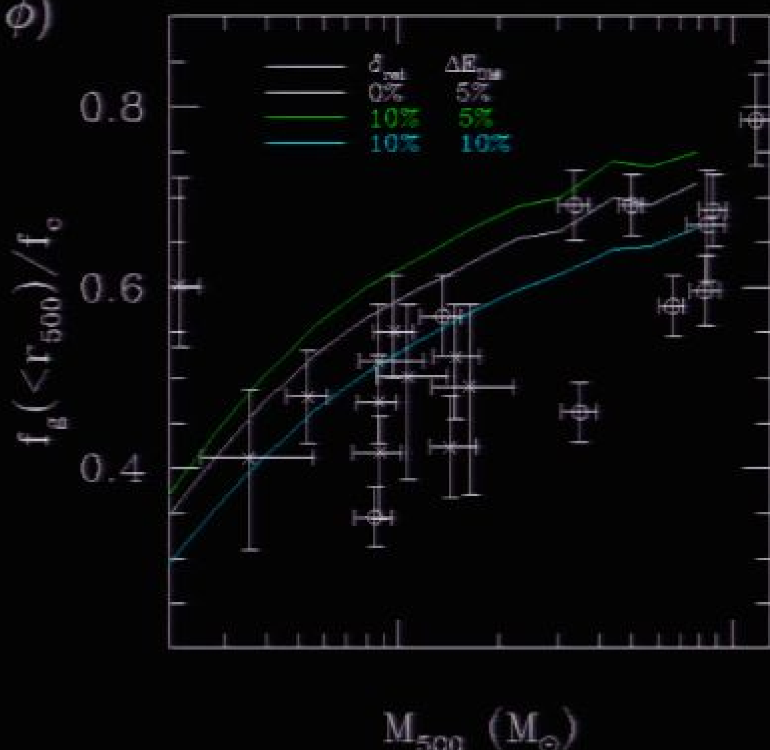
- Can model observed X-ray trends simply, once all changes to ICM energy are accounted for.
- Deviations from scale-free behavior due to:
    1. Decreasing star formation efficiency with increasing cluster mass
    2. Feedback energy proportional to stellar mass
- Important to normalize model clusters to X-ray observations when making predictions for SZ.

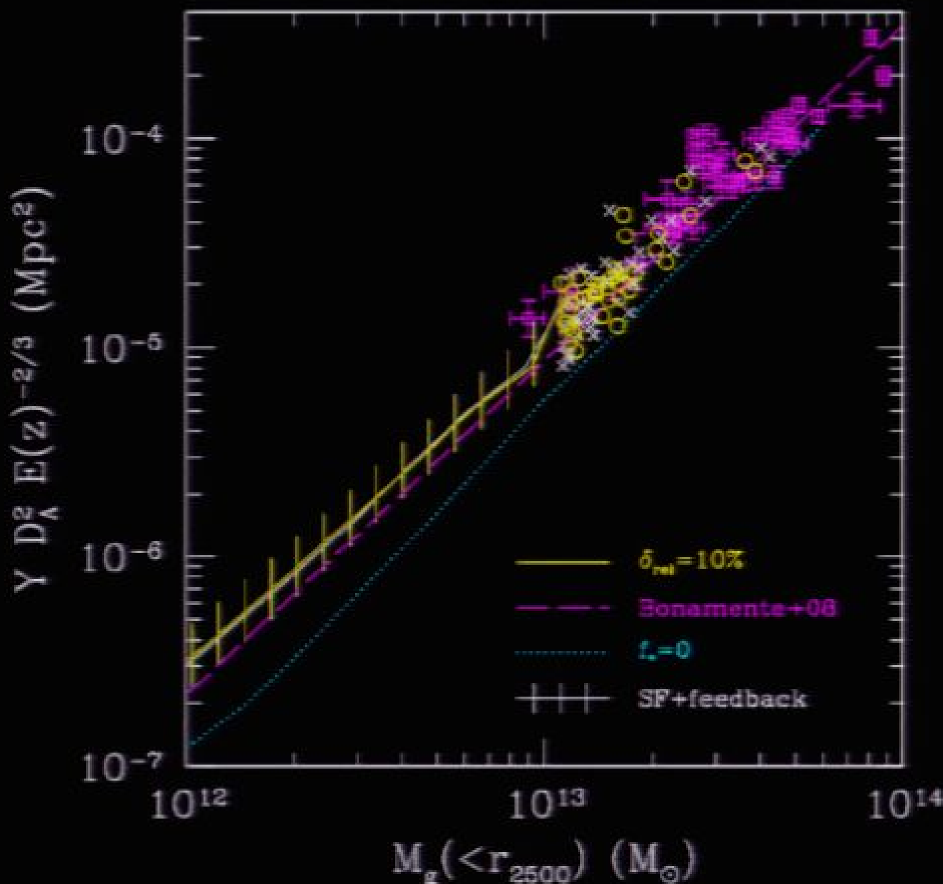
Nonthermal Pressure Support

$$P_{total} = (1 + \delta_{rel}) P_{gas}$$

$$\Theta \equiv 1 + \frac{\Gamma - 1}{(1 + \delta_{rel})\Gamma} \frac{\rho_o}{P_o} (\phi_o - \phi)$$

P_{gas} becomes lower, so gas is cooler and denser-- opposite effect of dynamical energy input.





Y D_A^2 E(z)$^{-2/3}$ (Mpc^2)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{12}
10^{13}
10^{14}
$M_g(<r_{2500})$ ($M_\odot$)
δ_{rel}=10%
Bonamente+08
f_*=0
SF+feedback

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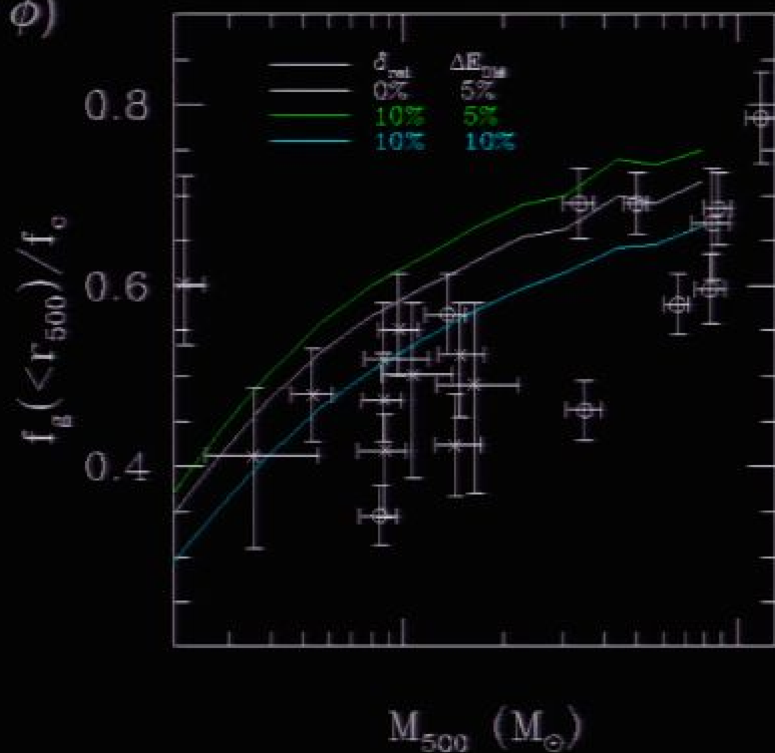

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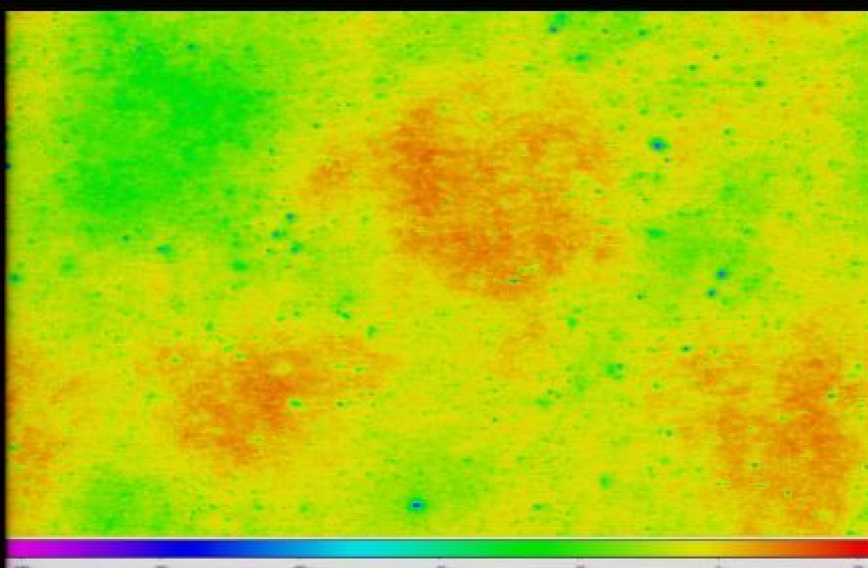

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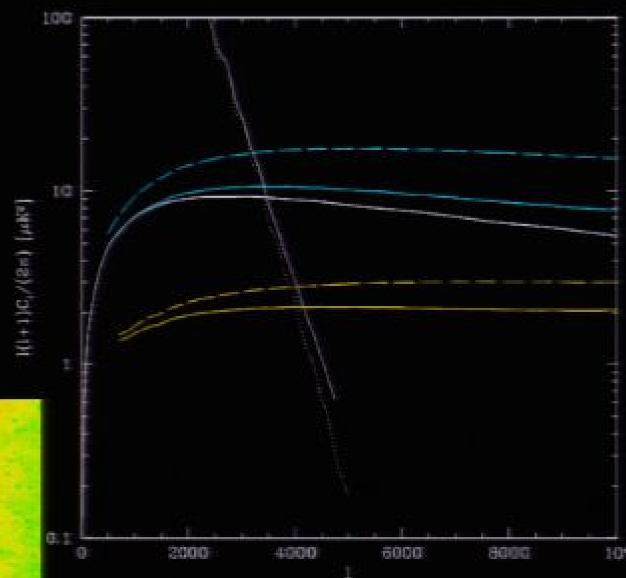

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