The Impact of AGN Feedback on Galaxy Groups

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Groups as canaries

Groups are sensitive probes of the action of “baryon physics”:

- Steepened L_X-T relation
- Large excess entropy in the IGM
- Higher stellar and lower gas fraction than clusters
- Possibly lower overall baryon fraction
- Lower metal/light ratio cf clusters
- Common activity from a central AGN in CC groups
- Evolution in CC properties different from clusters

Implications of these properties?

➔ Explore via feedback simulations

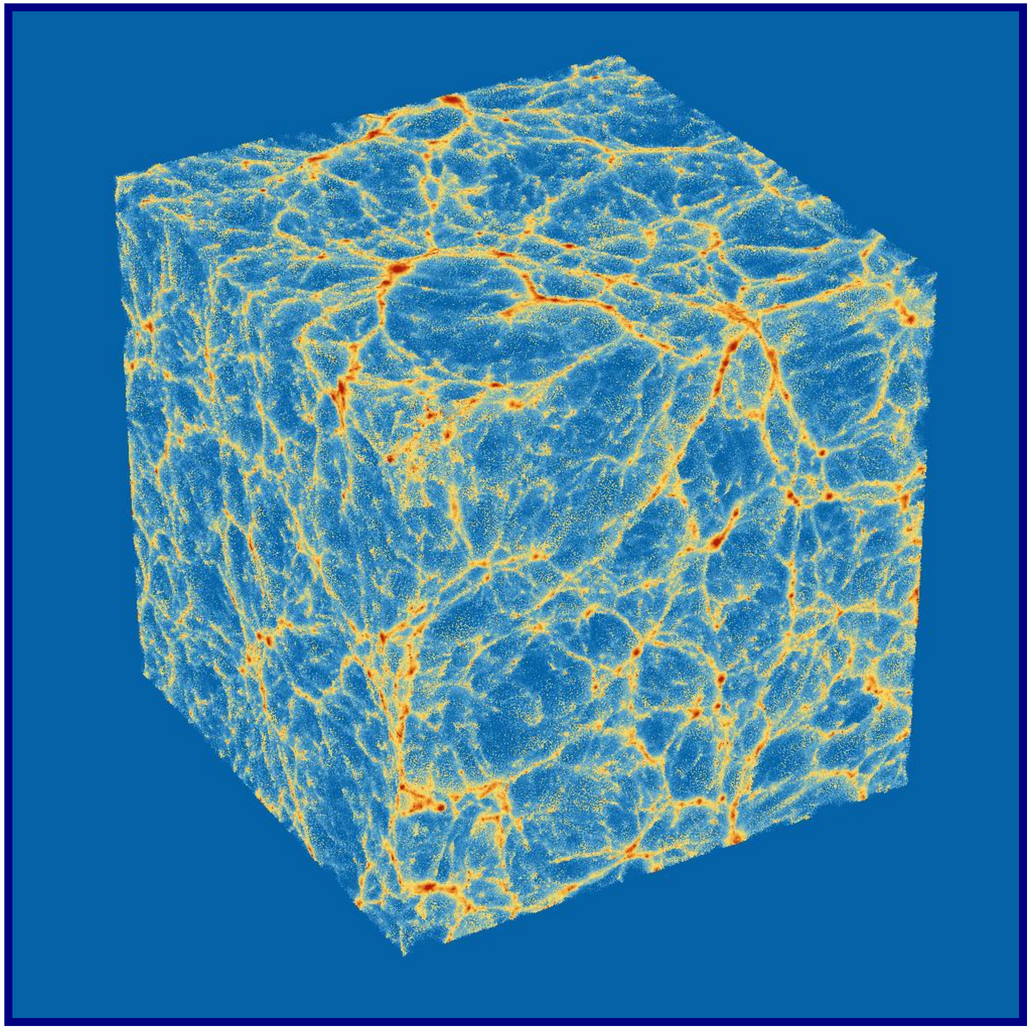
Group simulations - OWLS

See Schaye et al. (2010)

OWLS is a suite of >40 cosmological (100 h^{-1} Mpc) simulations specially designed to explore different feedback models.

Runs with same initial conditions but different baryon physics – cooling, SF, chemistry, SNe, AGN.

Compare results with group properties (McCarthy et al 2010a, 2010b) .



OWLS simulations

Physics on small scales from simple sub-grid recipes

Physics Modules:

Star formation (Schaye & Dalla Vecchia 2008)

SN feedback (Dalla Vecchia & Schaye 2008)

Radiative cooling (Wiersma, Schaye & Smith 2008)

Chemodynamics (Wiersma et al. 2009)

AGN feedback (Booth & Schaye 2009)

- Cosmological (default: WMAP3)
- Hydrodynamical (SPH)
- Gadget III
- $2xN^3$ particles, N = 512 for most
- Two sets:
  - L = 25 Mpc/h to z=2
  - L = 100 Mpc/h to z=0

Gravity and hydrodynamics simulated explicitly

Analyse systems with $M_{200} > 10^{13}\ M_{sun}$ (about 200 groups).

OWLS – AGN feedback

Booth & Schaye (2009)

- Black hole (BH) seeds placed at the centre of haloes that exceed some threshold mass.
- BHs grow by mergers with other BHs and by accretion of neighbouring gas.
- Gas accretion rate is the *smaller* of Bondi and Eddington rates:

$$\dot{m}_{\rm accr} = \alpha \frac{4\pi G^2 m_{\rm BH}^2 \rho}{(c_s^2 + v^2)^{3/2}} \qquad \dot{m}_{\rm Edd} = \frac{4\pi G m_{\rm BH} m_{\rm p}}{\epsilon_{\rm r} \sigma_{\rm T} c}$$

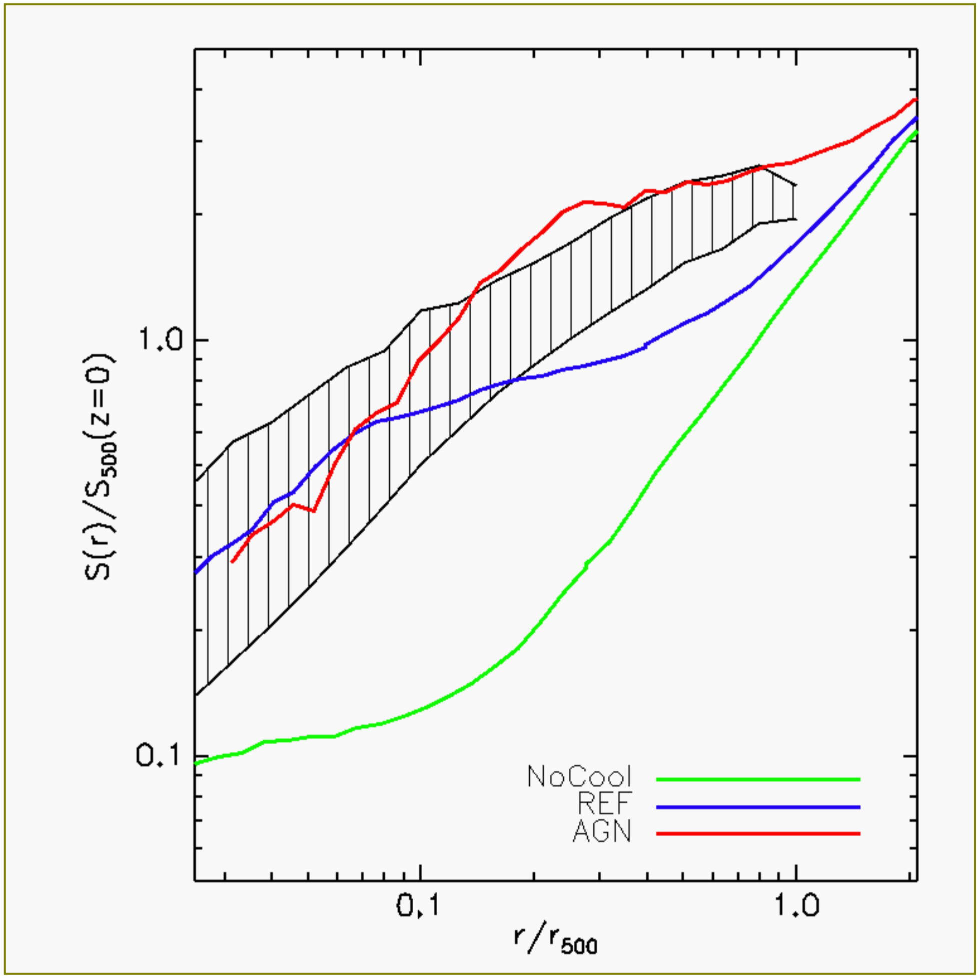
- α is a factor which scales with the local gas density, allowing for the inability to resolve the Bondi radius in many cases.
- A certain fraction (typically 1-2%) of the rest mass energy of accreted gas is used to heat local gas by $\Delta T=10^8$K.

OWLS vs observed groups

- REF model includes cooling and SN-powered winds. AGN model also has AGN feedback (Booth & Schaye 2009).

- Both models show excess entropy with respect to the purely gravitational self-similar model (green).

$$S \equiv \frac{k_B T}{n_e^{2/3}}$$



Data (hatched) from M. Sun et al. (2009)

OWLS vs observed groups

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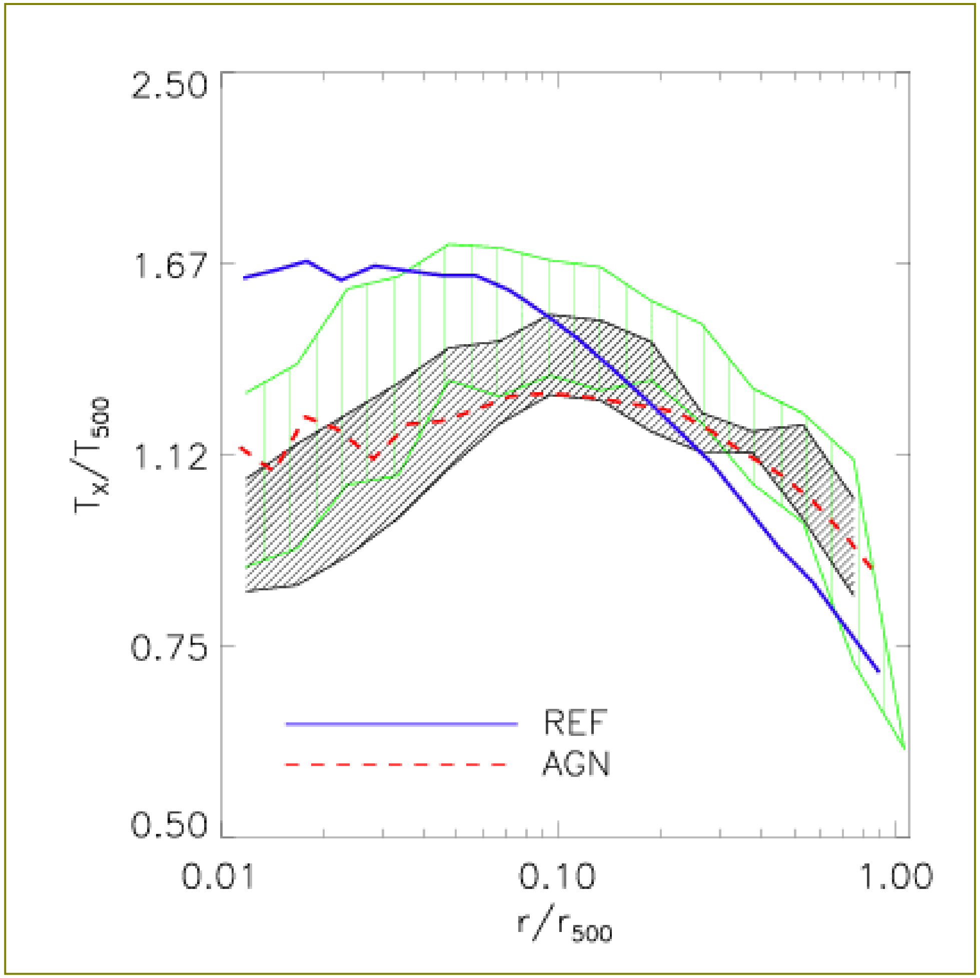
- The REF model gives too high a gas temperature in the core. This is due to the central potential being too deep, as a result of too much central baryon deposition.

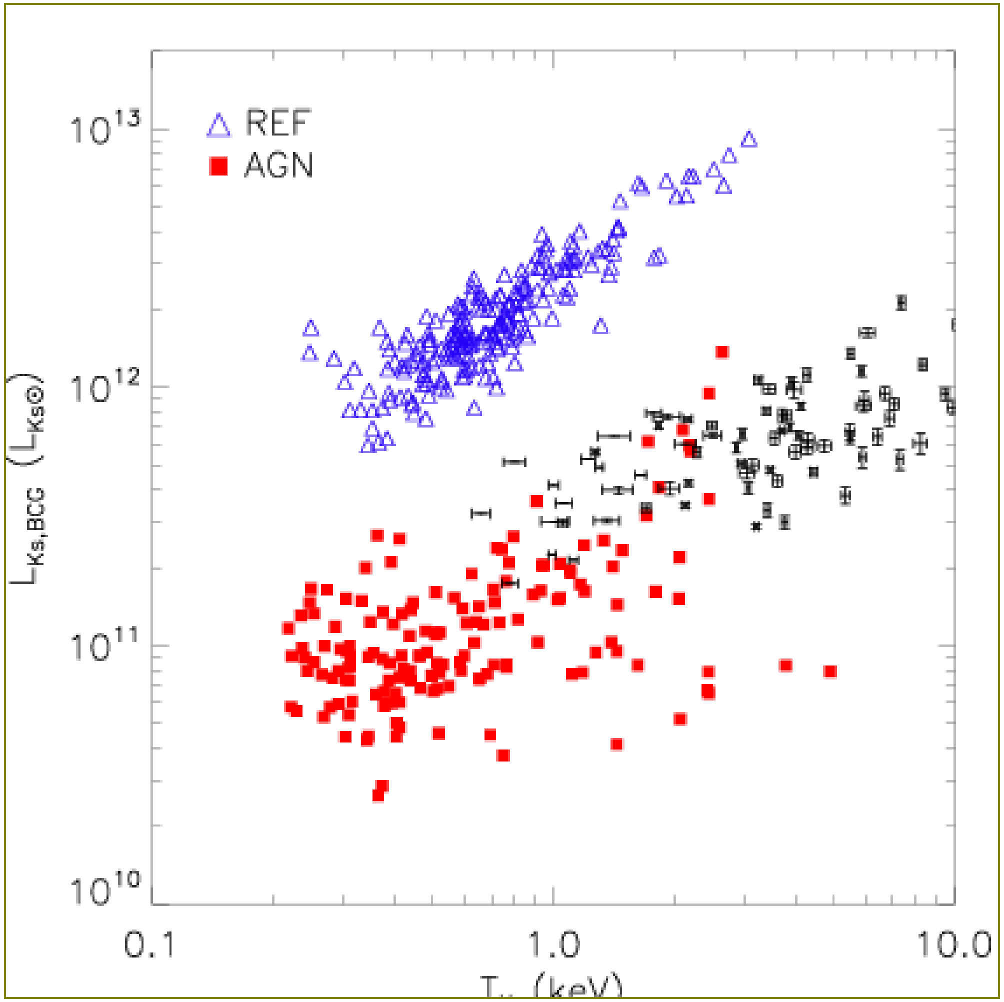


Data (hatched) from M. Sun et al. (2009) and Rasmussen & Ponman (2009)

OWLS vs observed groups

• This excessive buildup of cool baryons in the centre of the halo for the REF model can be clearly seen by looking at the K band luminosity of the BGG.

• The AGN feedback model avoids this, and matches the observed luminosities quite well.

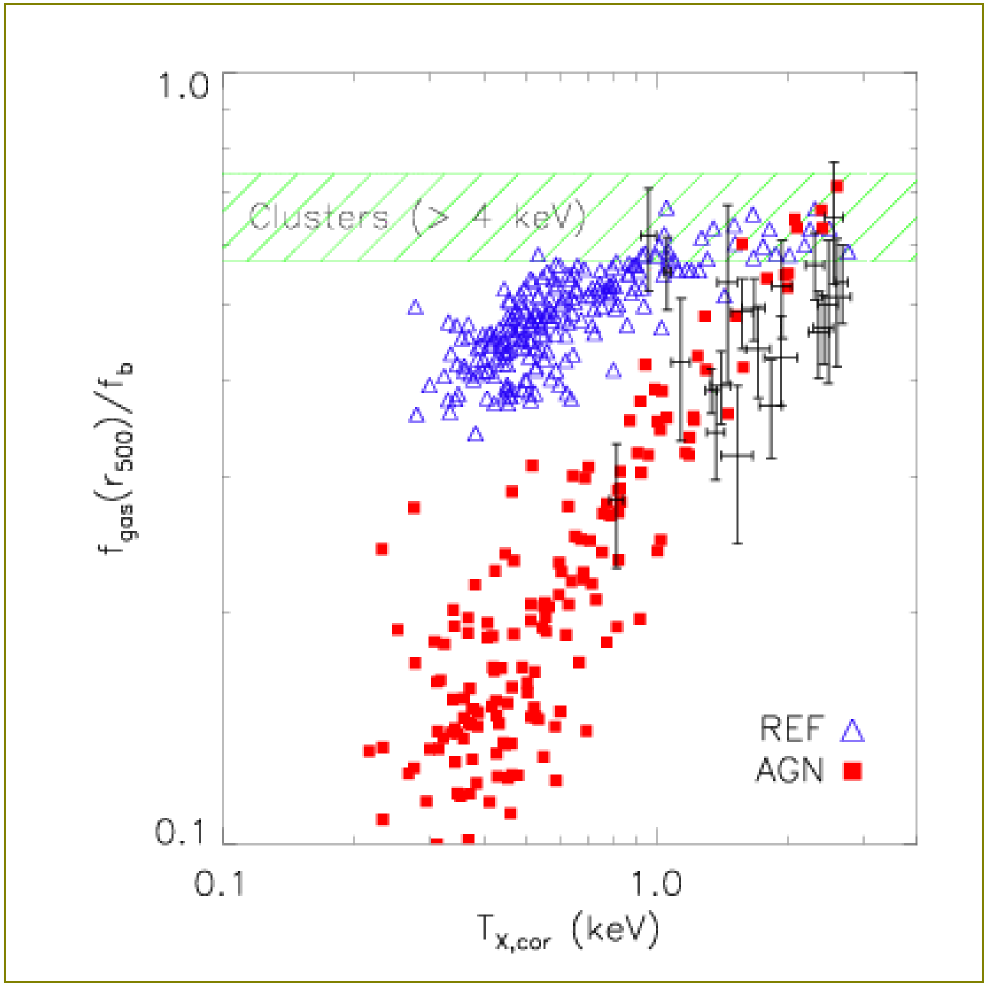


Data from Rasmussen & Ponman (2009) and Horner (2001)

OWLS vs observed groups

The extra feedback in the AGN model reduces the hot gas fraction in groups, giving good agreement with observations.

The REF model gives gas fractions higher than observed at T<2 keV.



Data (black) from Sun et al (2009)

OWLS vs observed groups

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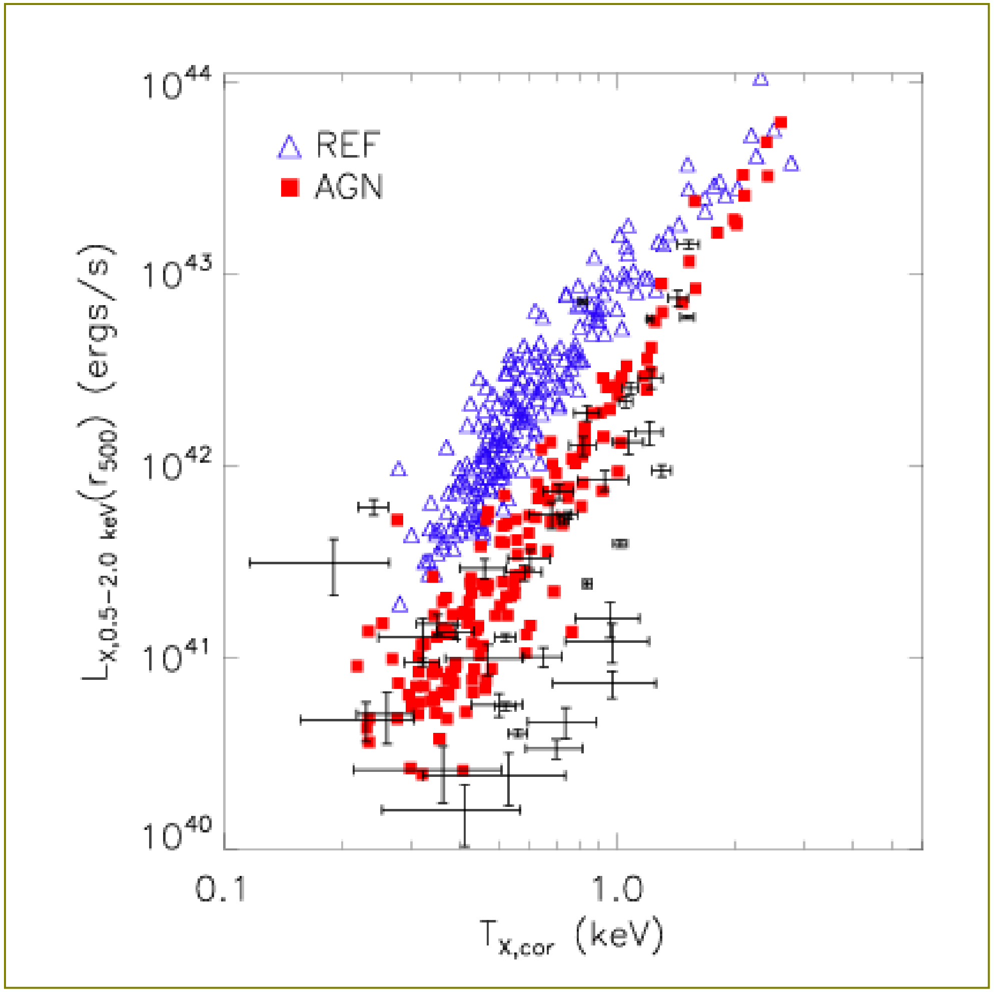
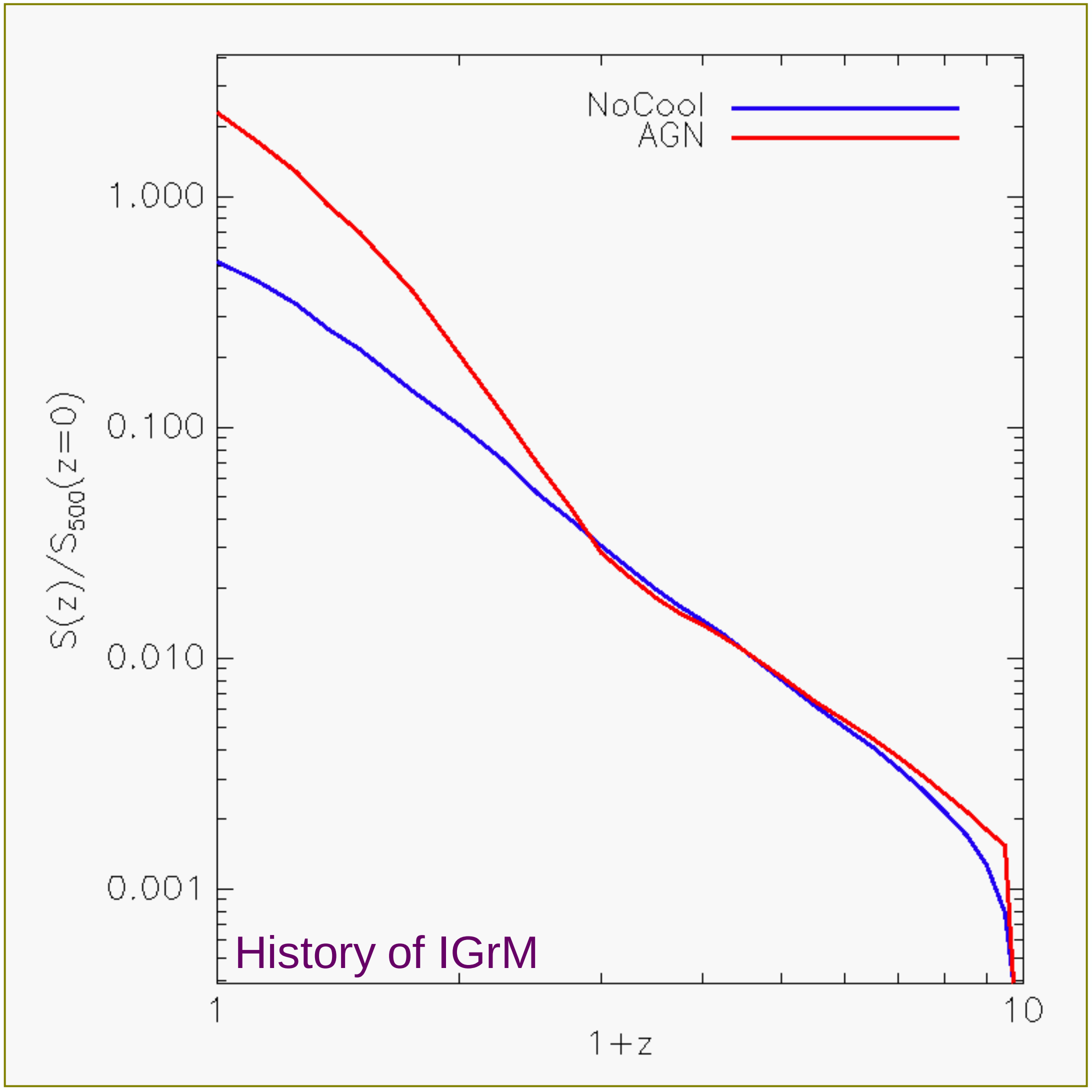
The REF model gives gas fractions higher than observed at T<2 keV.

As a result, the AGN model provides a better match to the observed L_X-T relation.



Data (black) from Osmond & Ponman (2004) and Sun et al (2009)

How does the AGN feedback work?

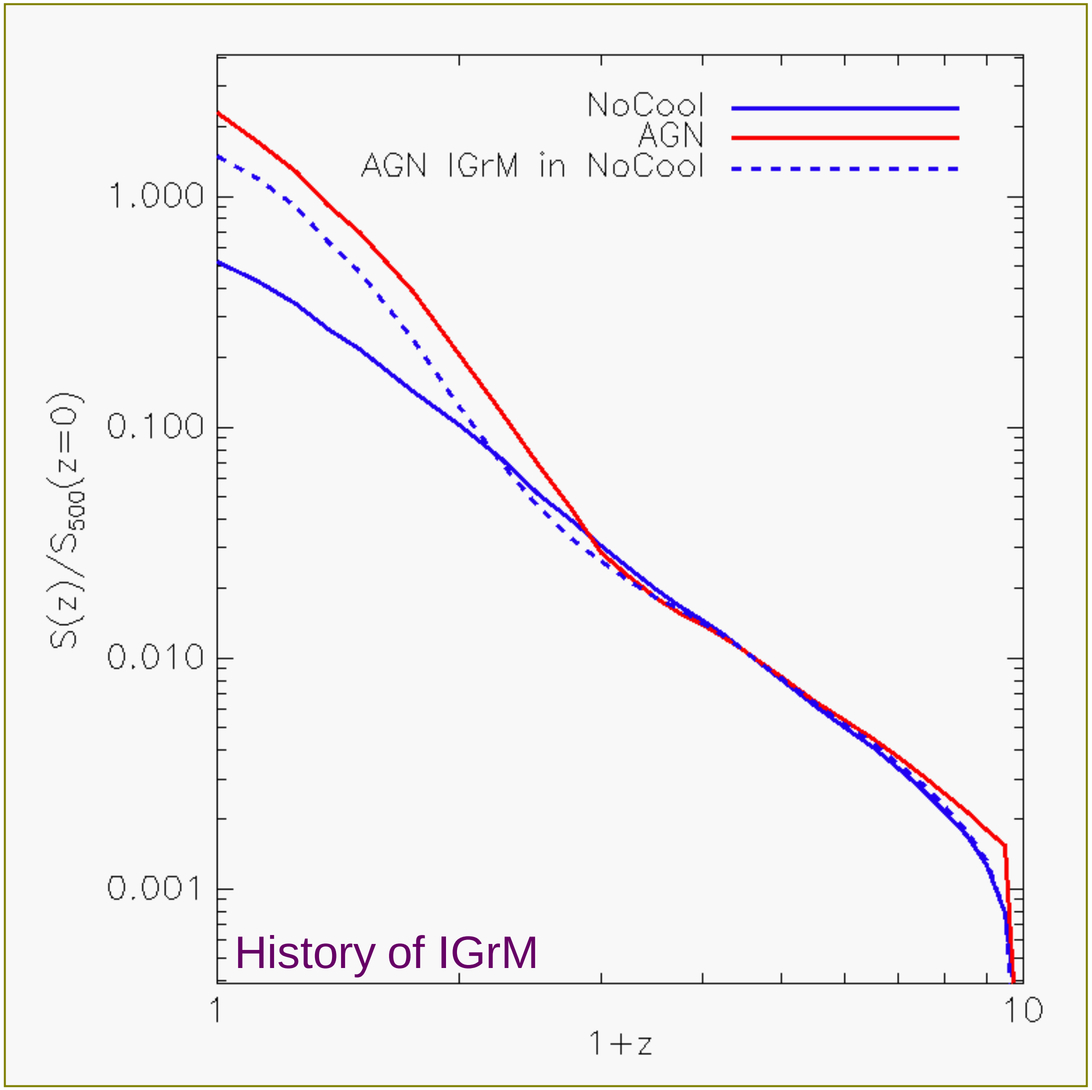


Simulations have identical initial conditions.

Follow gas particles over cosmic time in different simulations to isolate effects of feedback, cooling, etc.

Here plot median entropy history of gas which lies within r_{500} at z=0, for NOCOOL and AGN runs.

How does the AGN feedback work?



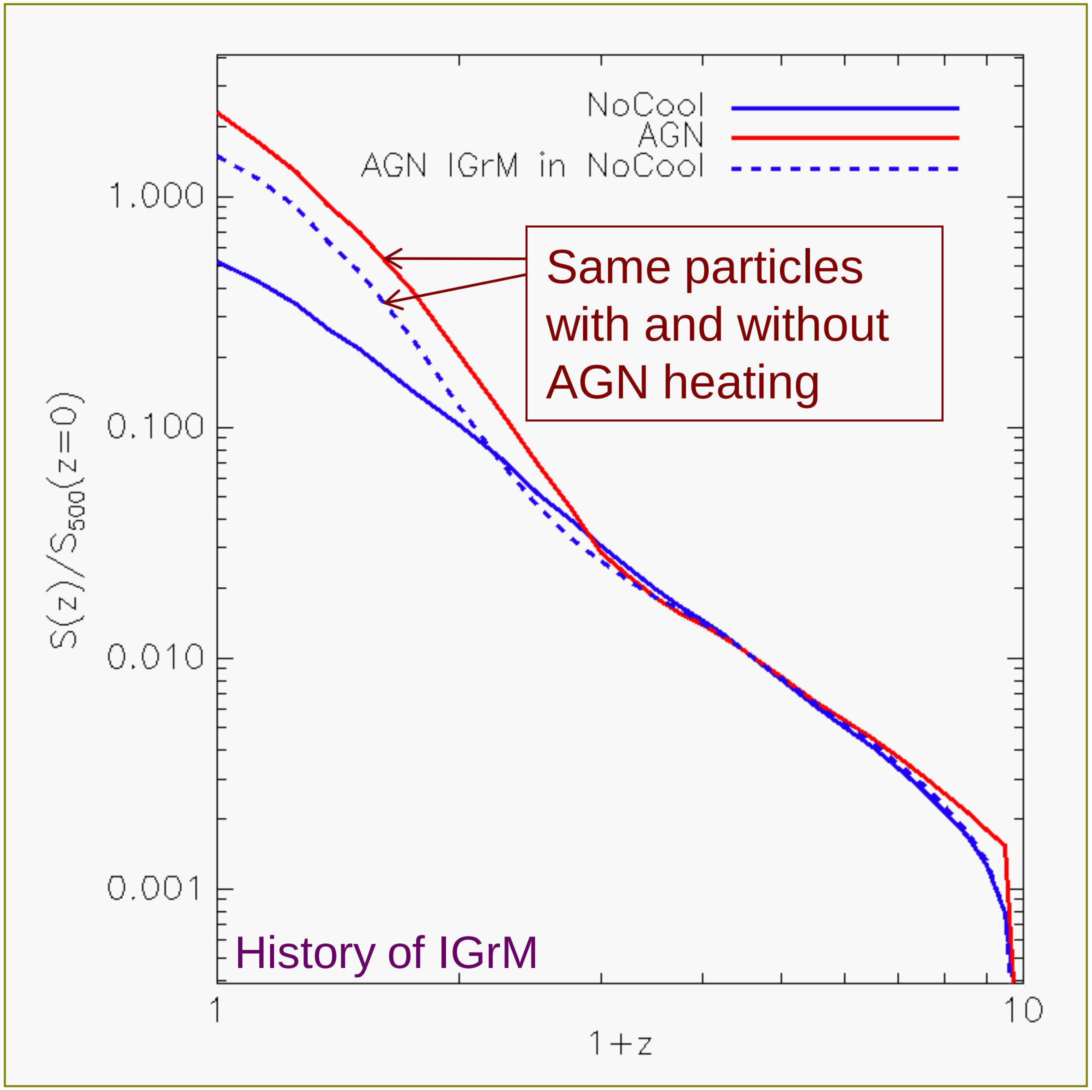
Simulations have identical initial conditions.

Follow gas particles over cosmic time in different simulations to isolate effects of feedback, cooling, etc.

Here plot median entropy history of gas which lies within r_{500} at z=0, for NOCOOL and AGN runs.

Dashed line is history in NOCOOL of just the particles which end up the the IGrM in the AGN run.

How does the AGN feedback work?



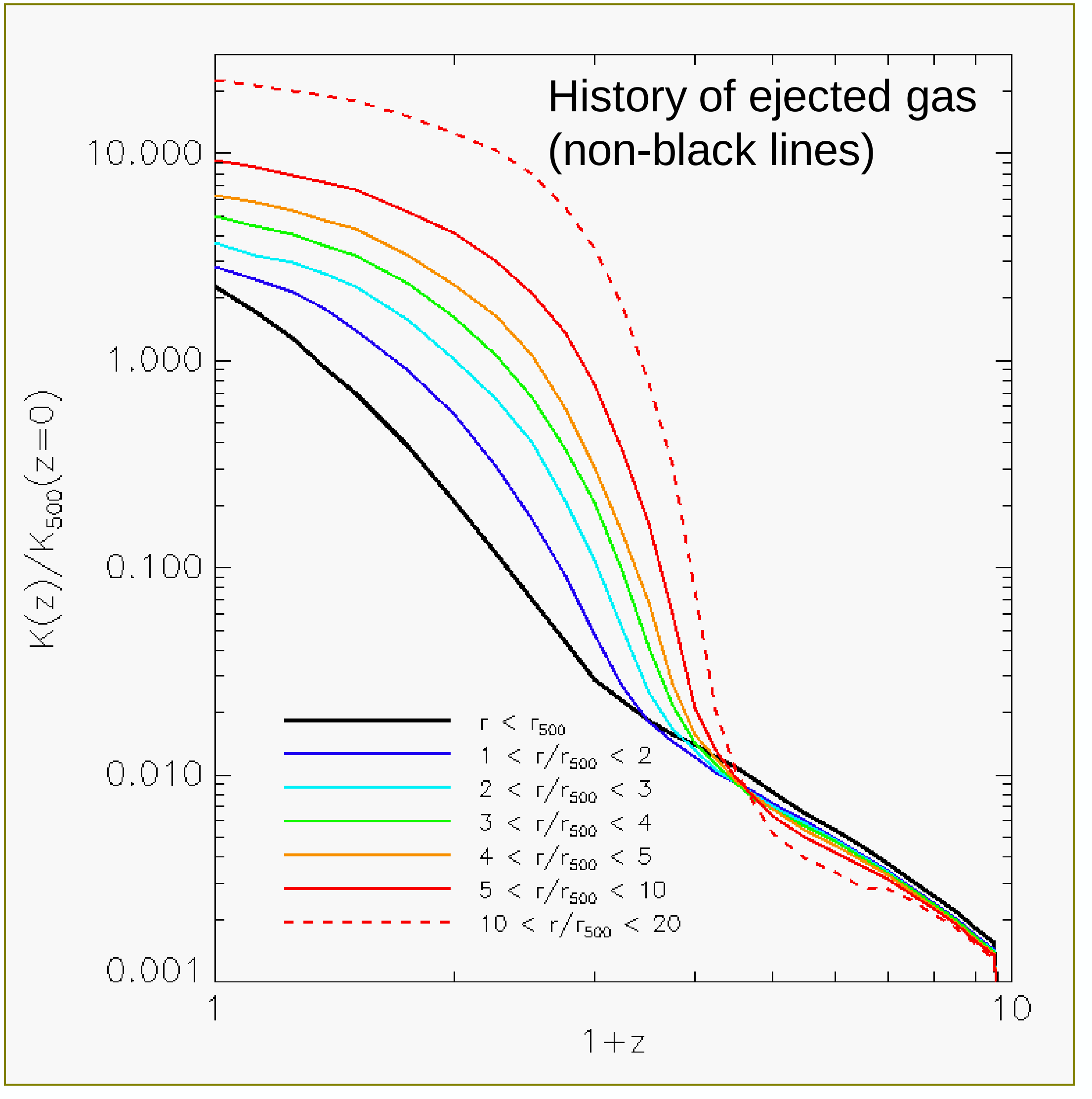
The similarity of the history for the AGN IGrM particles in the NOCOOL and AGN runs implies that these particles are <u>not</u> strongly heated by AGN.

i.e. the main effect of AGN feedback is to heat particles which are thereby <u>removed</u> from the final group.

How does the AGN feedback work?

When does this ejection take place?

- Plot entropy histories of particles which lie within the IGrM in NOCOOL, but not in the AGN run.
- Steep rise in entropy of these particles takes place mostly at $z \cong 2$-4.
- This means that AGN heating is driving them out of <u>precursor</u> halos.



Conclusions

- Cooling plus supernova feedback can generate the excess entropy seen in groups
- However, AGN feedback appears to be required to match observed gas and stellar fractions
- AGN also match the observed L_X-T relation, prevent excessive growth in the BGG and reduce the metal mass in the hot IGrM
- The AGN feedback in the OWLS model works primarily by removing gas from precursor halos, allowing higher entropy gas to take its place (cf Voit & Bryan 2001).

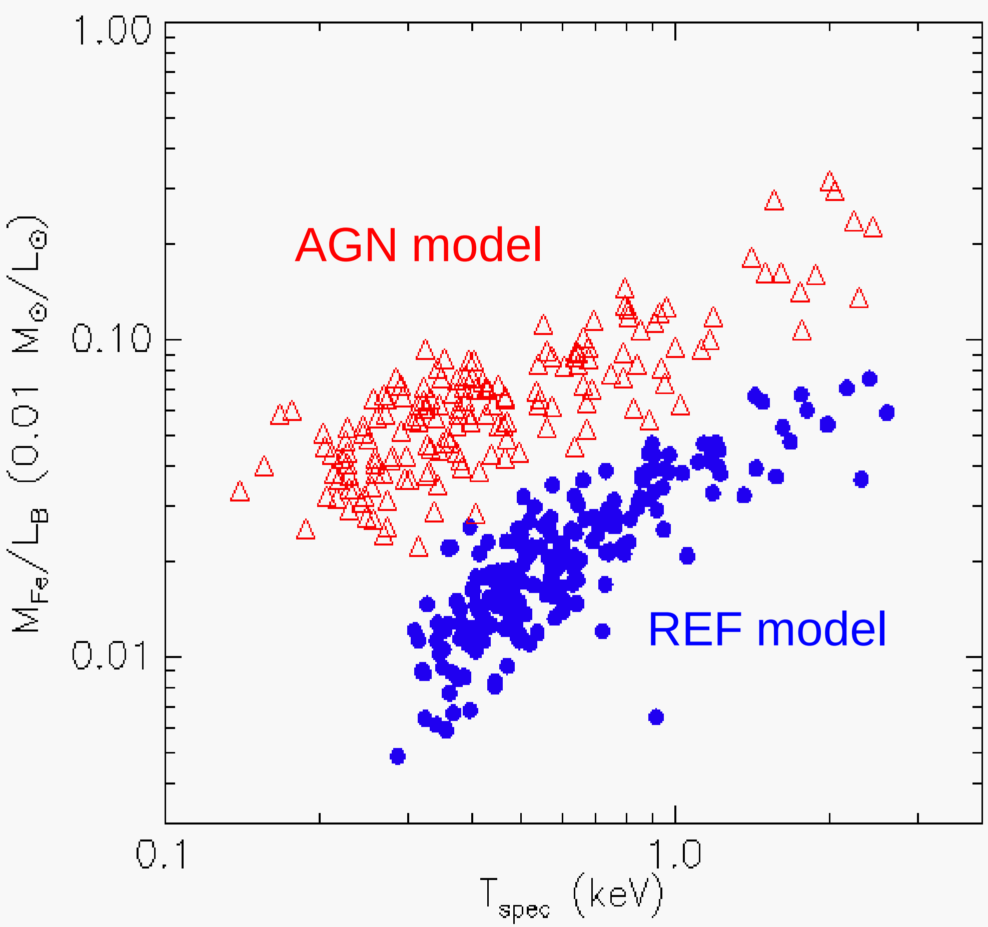
Still to be explored:

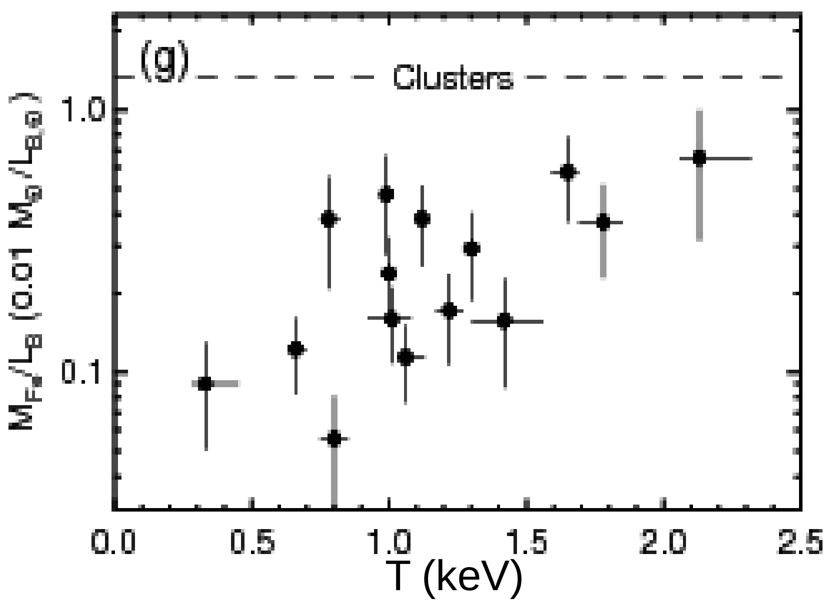
- Abundance ratios (SNIa and SNII input)
- Properties of CC and NCC groups
- Evolution in group properties

OWLS vs observed groups

Iron-mass-to-light ratio is far too low for the default wind model (due to the its excessive star formation).

It is also low for the AGN feedback model, but this may be within yield uncertainties.



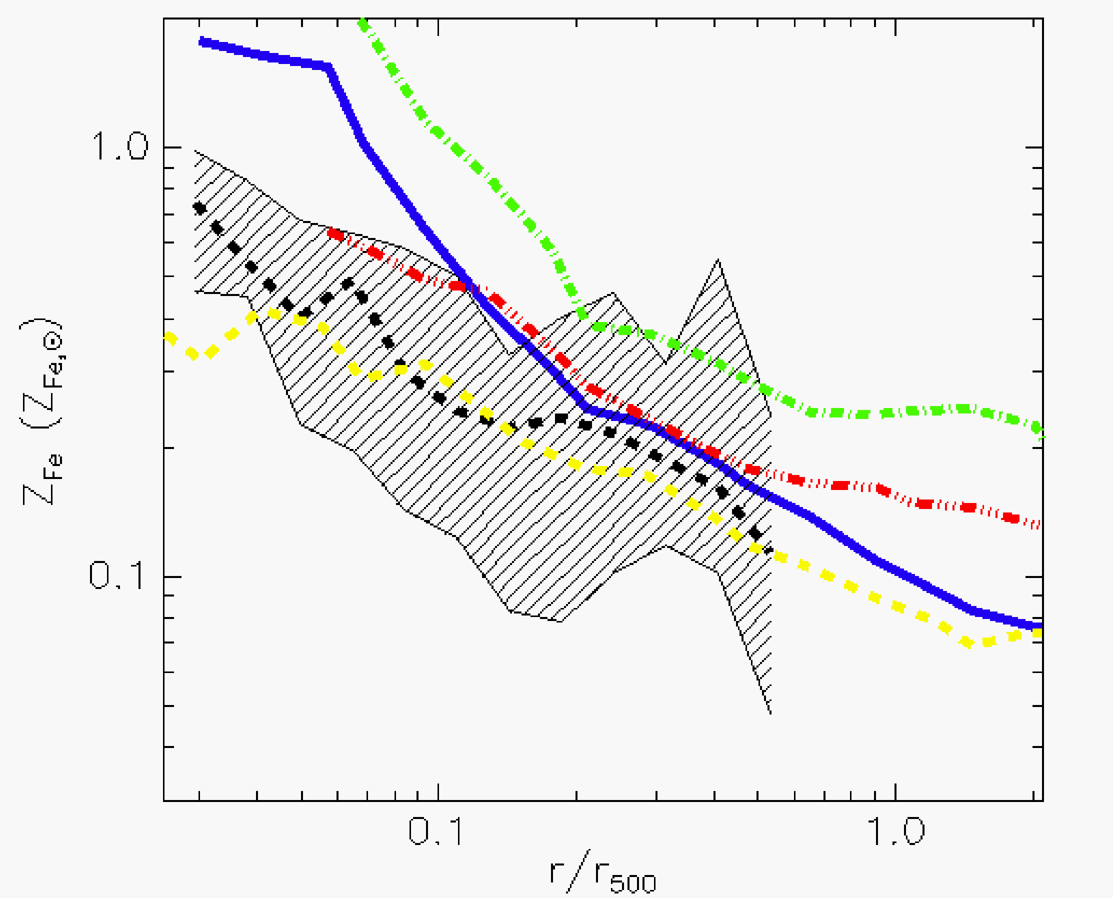


Rasmussen & Ponman (2009)

Galaxy groups in OWLS

Comparison between some model Fe profiles and those from the Rasmussen & Ponman (2009) study.

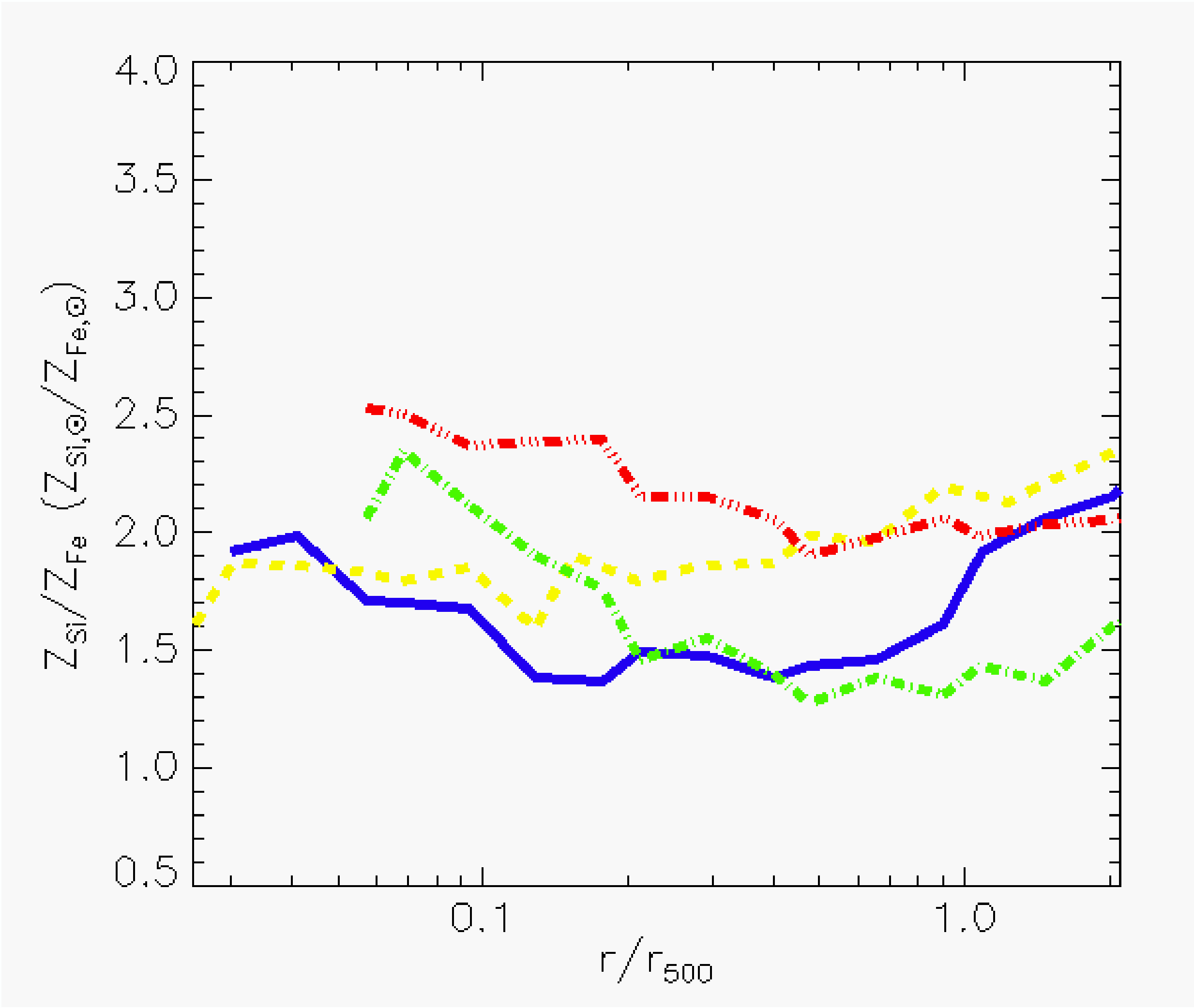
The AGN feedback model (red) does not do badly.



Data (hatched) from Rasmussen & Ponman (2009)

Galaxy groups in OWLS

However, at present none of the models produces solar abundance ratios in group cores, nor the rise in Si/Fe seen in the RP study at $r > 0.2 r_{500}$.

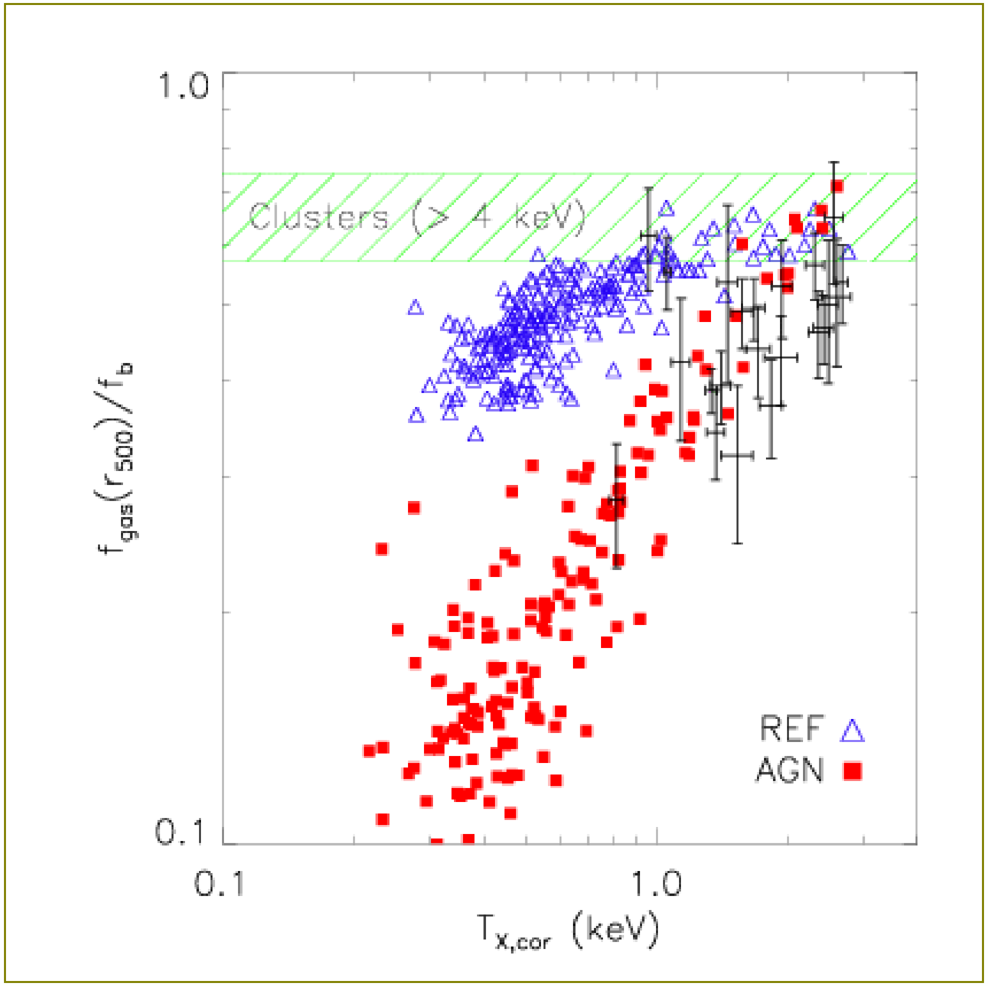


OWLS vs observed groups

In the AGN model, energy input from supermassive black holes blows gas out of haloes at z~2.

This yields gas mass fractions in good agreement with observations.

The REF model gives gas fractions higher than observed at T<2 keV.



Data (black) from Sun et al (2009)