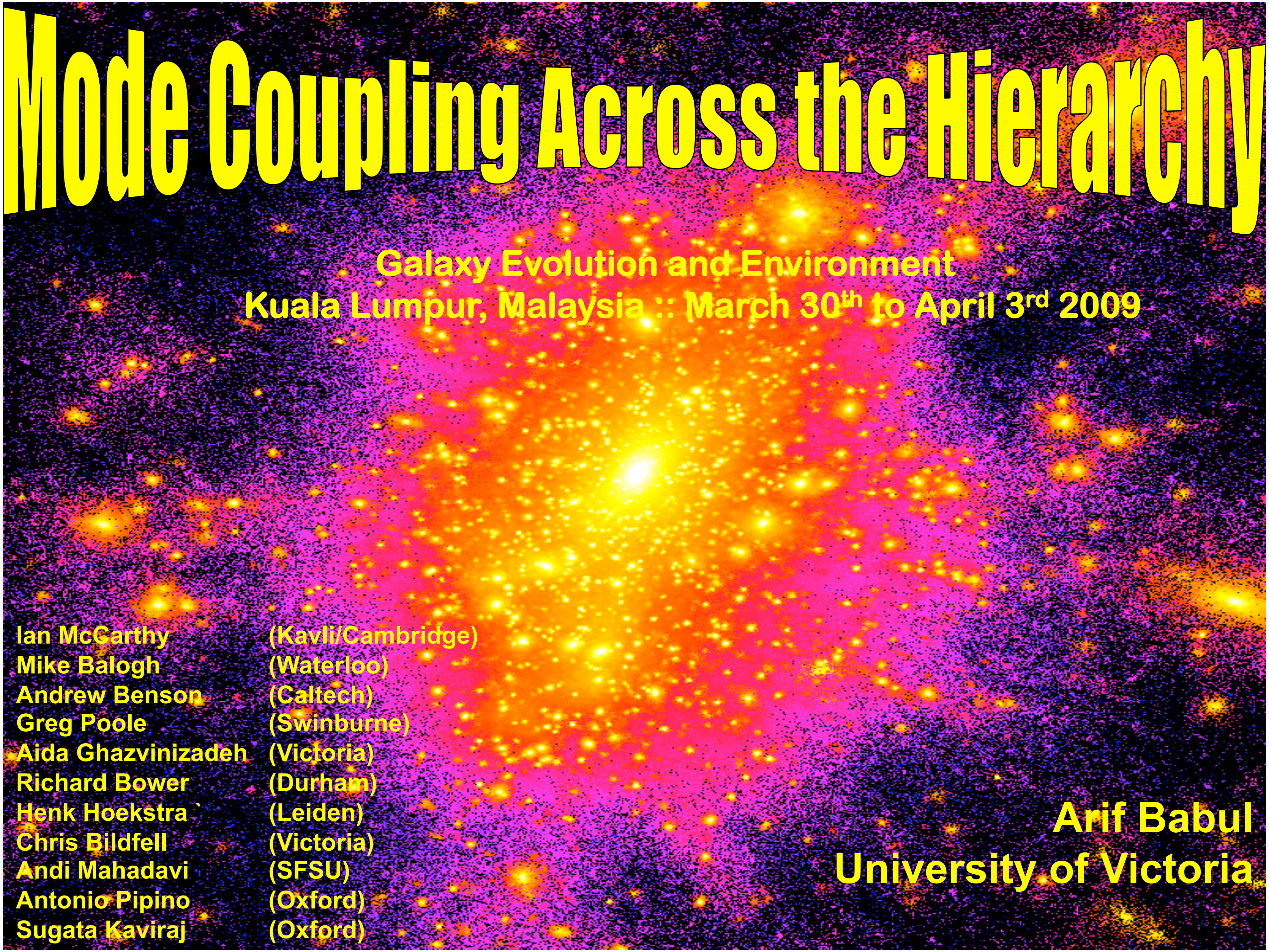


Mode Coupling Across the Hierarchy

Galaxy Evolution and Environment

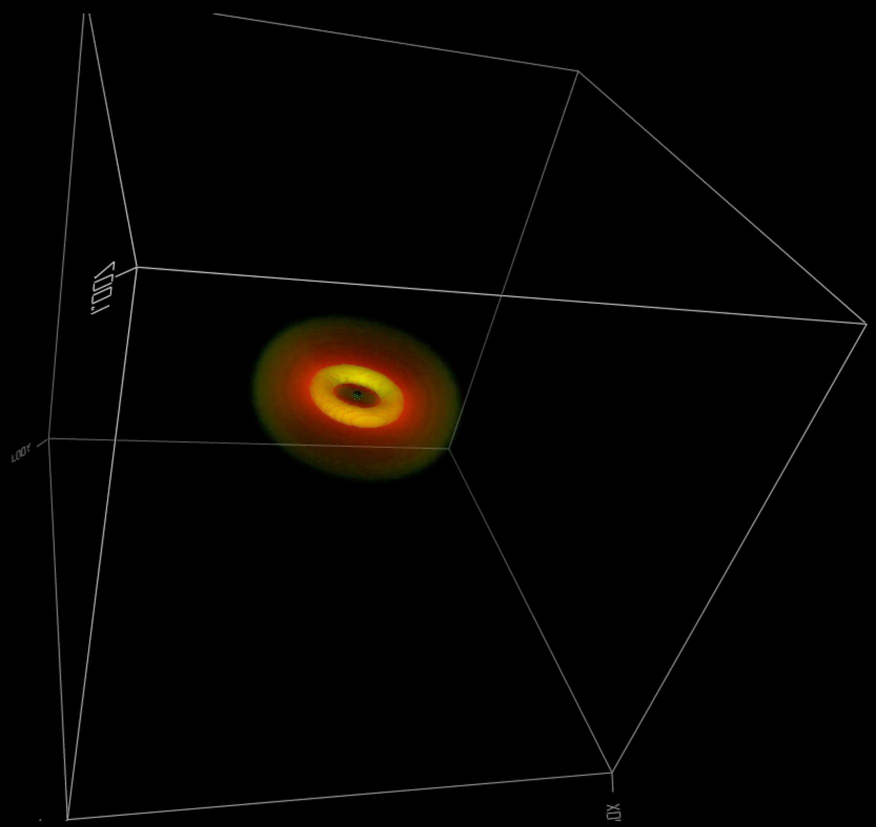
Kuala Lumpur, Malaysia :: March 30th to April 3rd 2009

Ian McCarthy	(Kavli/Cambridge)
Mike Balogh	(Waterloo)
Andrew Benson	(Caltech)
Greg Poole	(Swinburne)
Aida Ghazvinizadeh	(Victoria)
Richard Bower	(Durham)
Henk Hoekstra `	(Leiden)
Chris Bildfell	(Victoria)
Andi Mahadavi	(SFSU)
Antonio Pipino	(Oxford)
Sugata Kaviraj	(Oxford)

Arif Babul

University of Victoria

Jets and Winds from AGNs

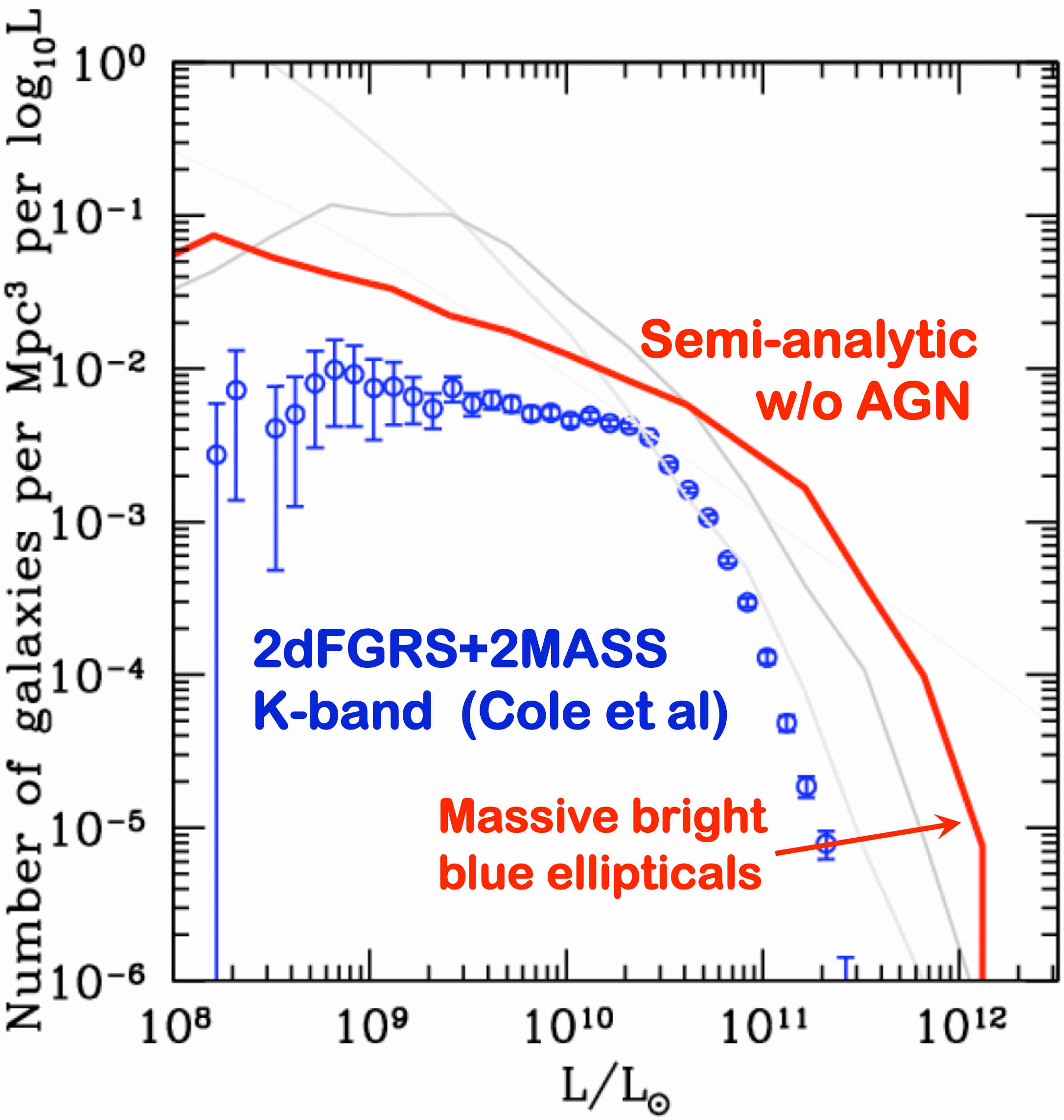


Credit: McKinney 2008

AGN feedback is a key element of theoretical models of galaxy form.

AGN feedback is called upon to quench star formation in massive galaxies through the removal of gas in the galaxy via heating and outflows.

Impact of Galaxies on their Environment, Part 1



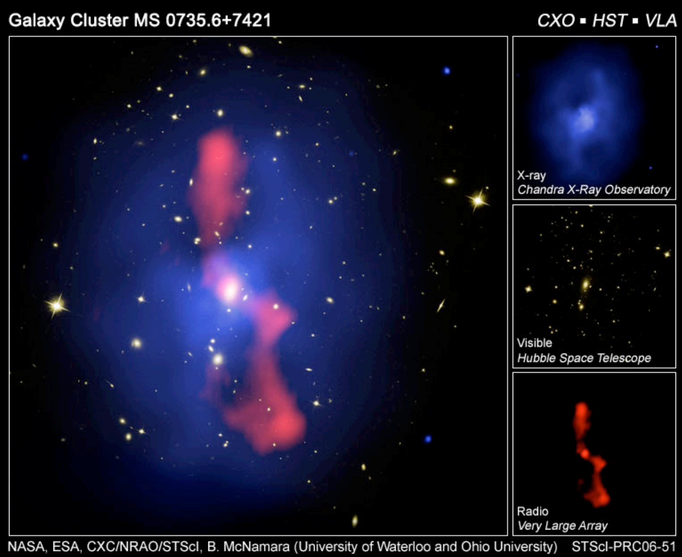
Credit: A. Benson

AGN feedback is required to prevent massive ellipticals from turning out blue and over-luminous.

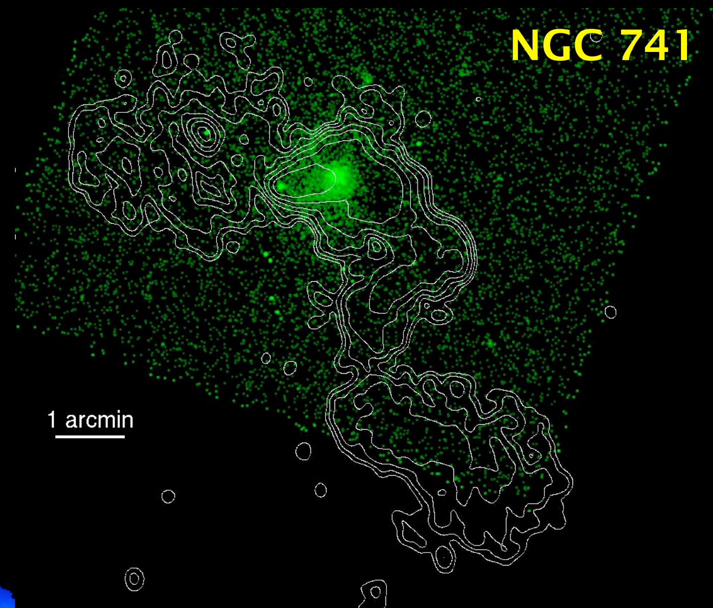
Processes such as AGN feedback do more than simply establish observed properties of these systems.

They can also impact the local environment in a profound way.

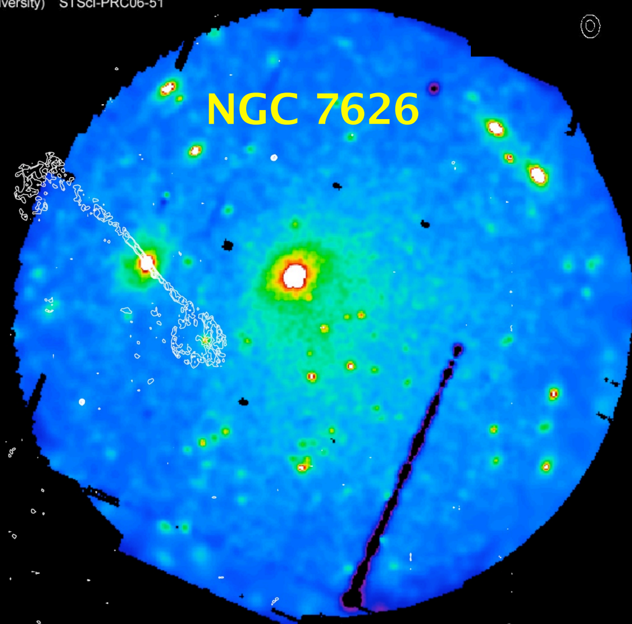
POWERFUL JETS CAN EXTEND WELL BEYOND HOST GALAXY



McNamara et al.



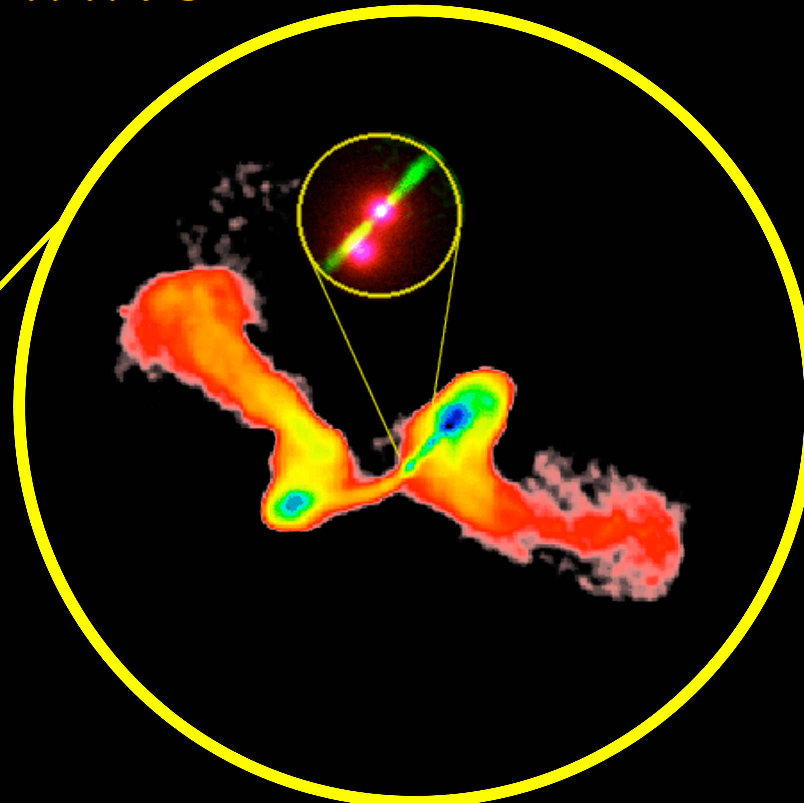
S. Raychaudhury

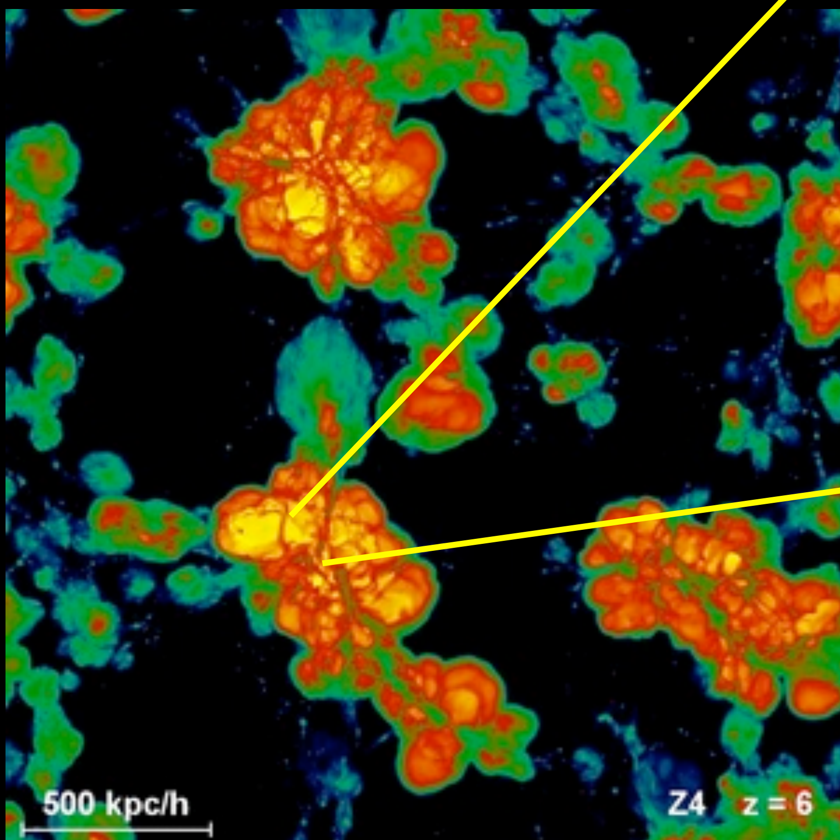


S. Giacintucci & E. O'Sullivan

PREHEATING

OUTFLOWS GENERATED DURING EPOCH OF AGNS (Z~1-3) WILL HEAT THE GAS IN THEIR ENVIRONMENT





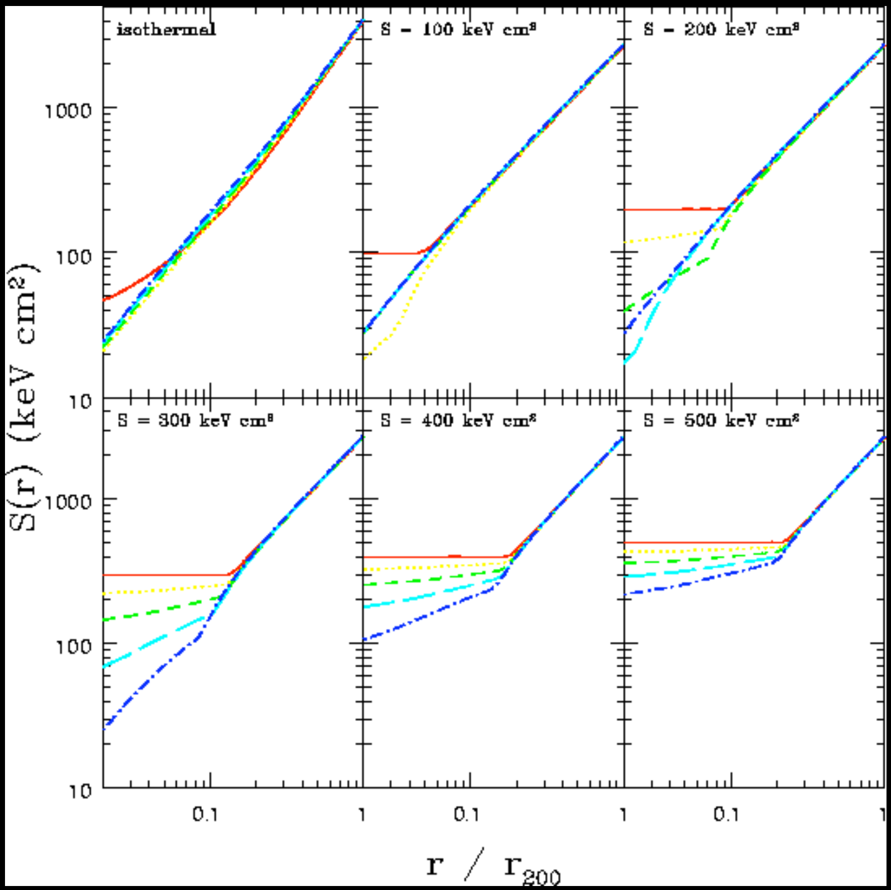
Credit: T. Theuns

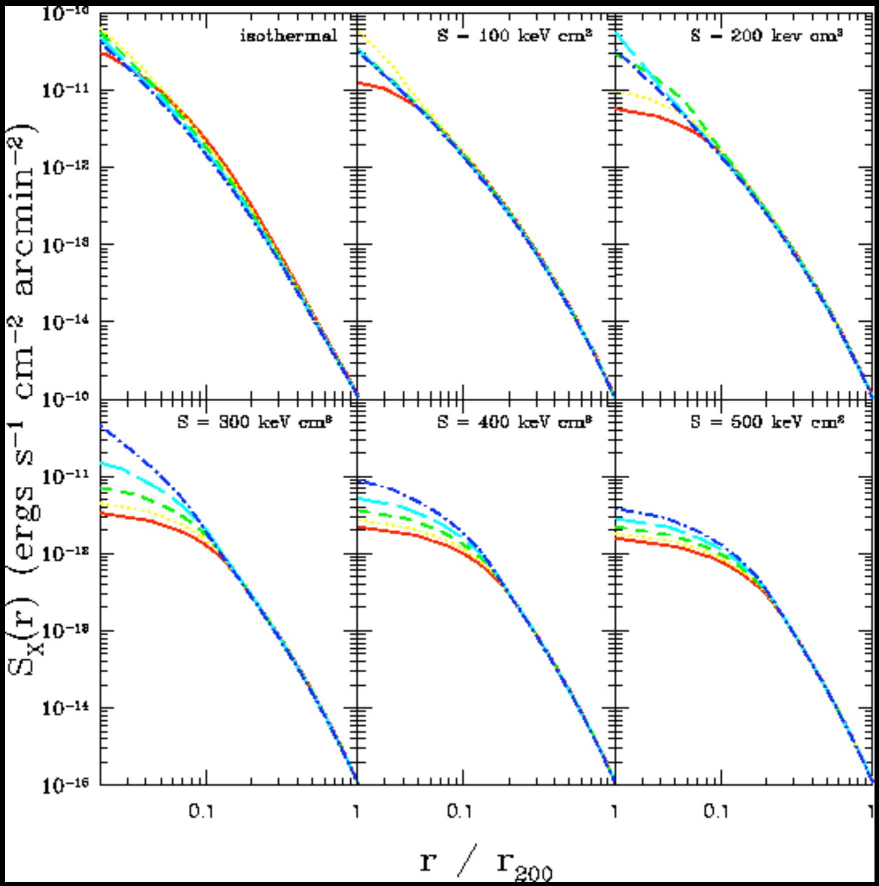
HEATING WILL VARY WITH AGN OUTFLOW POWER.

AS HEATED GAS COLLECTS IN GROUPS AND CLUSTER HALOS, IT WILL GIVE RISE TO CENTRAL CORES

SCHEMATIC ENTROPY & X-RAY SB (DENSITY) PROFILES

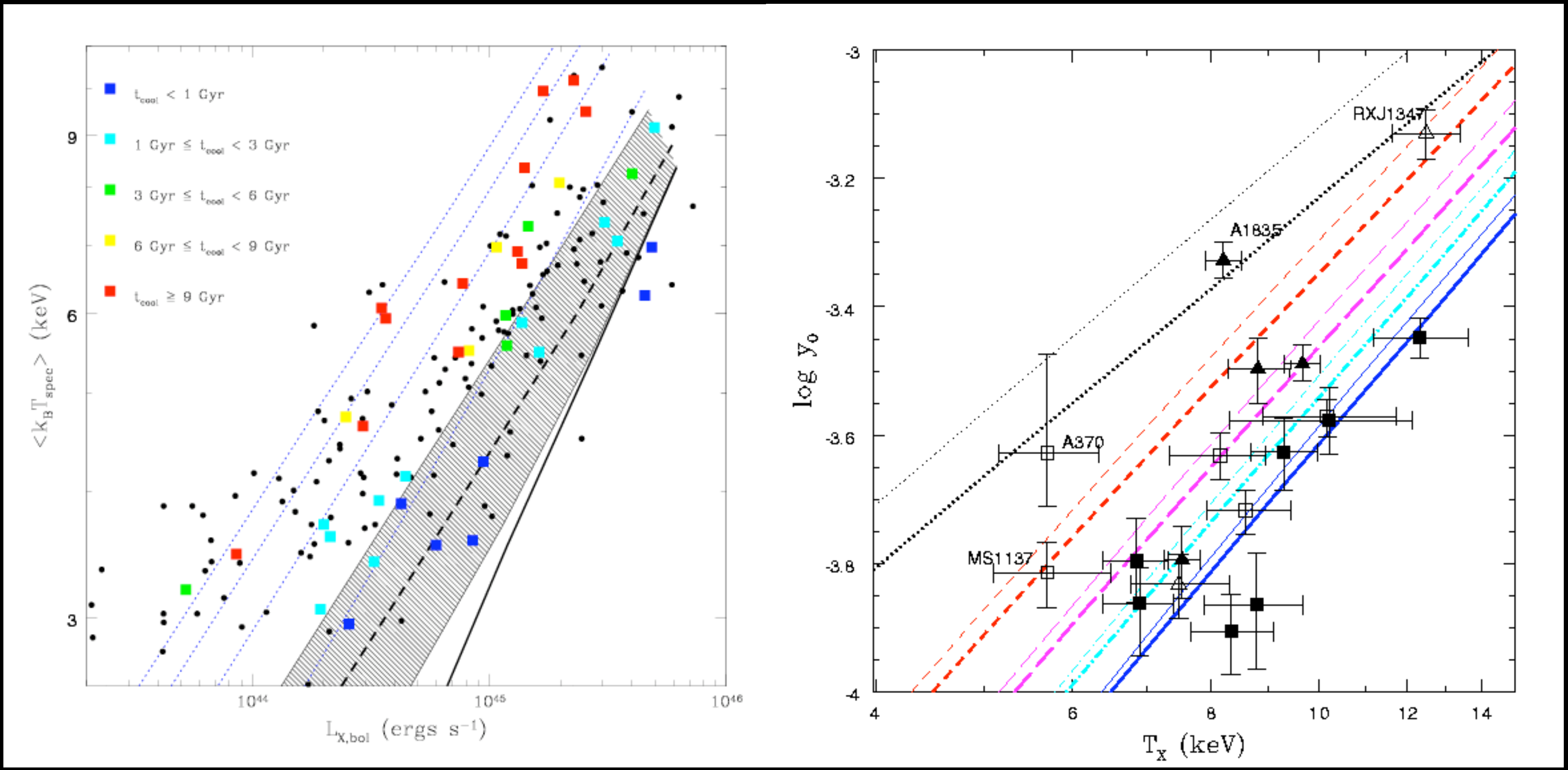
McCarthy et al. 2004; 2008



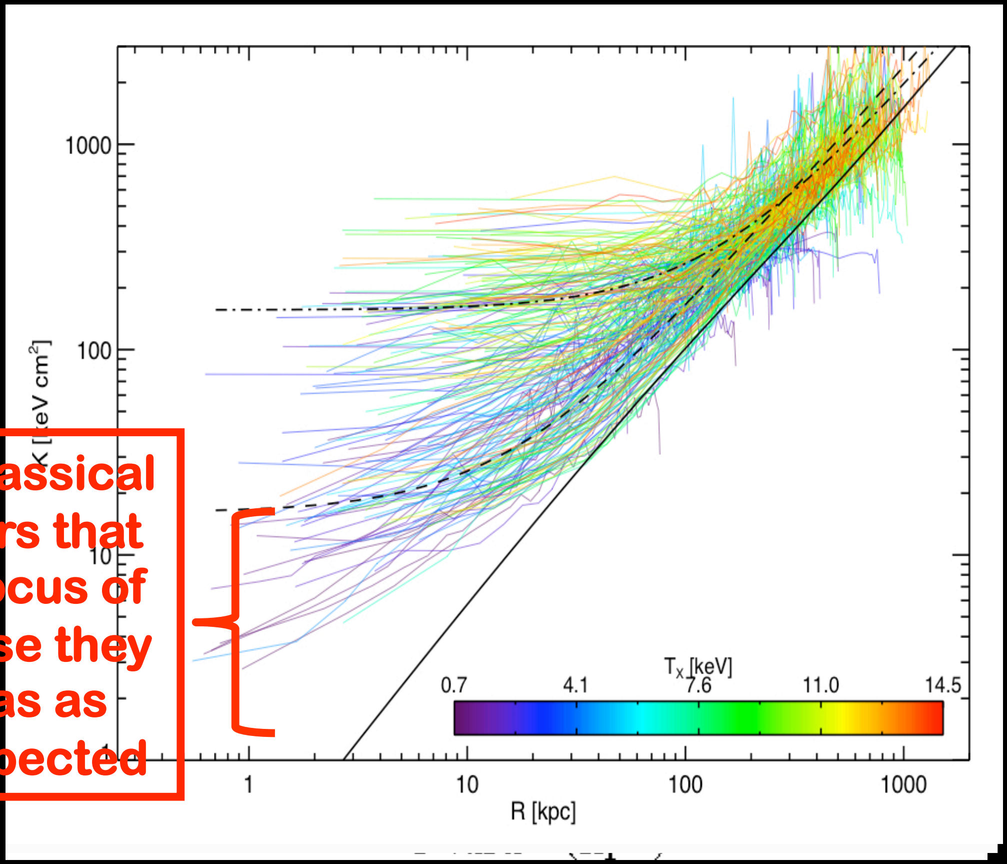


PREHEATING AFFECTS THE EFFICIENCY OF COOLING GIVING RISE TO A ROUGH DICHOTOMY: COOL CORE AND NON-CORE CLUSTERS

Distribution of core-entropy provides simple explanation for the significant scatter in various cluster correlations

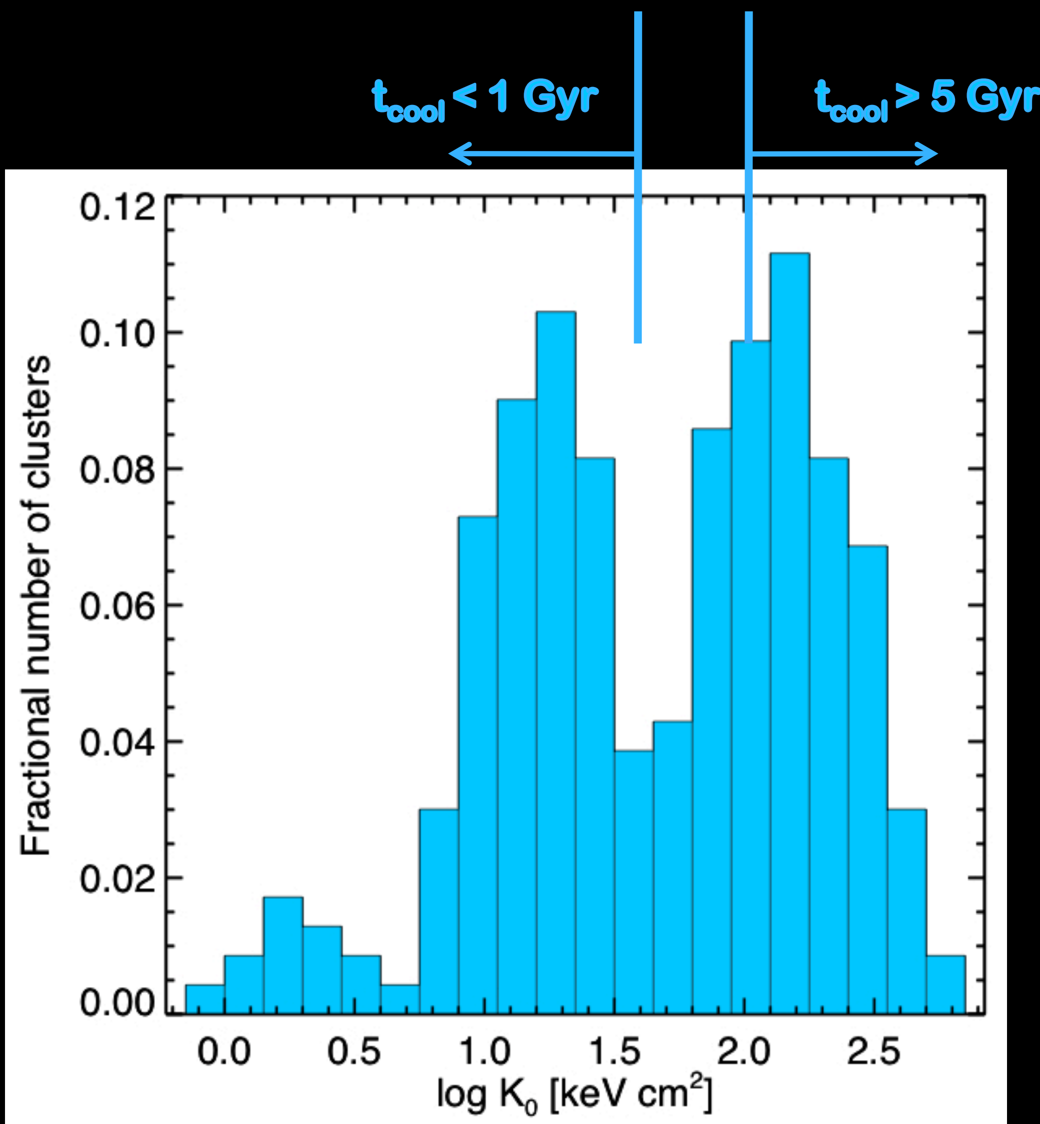


OBSERVED CLUSTER ENTROPY PROFILES



These are the classical cool core clusters that have been the focus of attention because they aren't cooling gas as efficiently as expected

McCarthy et al 2004, 2008
Cavagnolo et al 2008



Cavagnolo et al 2008

Fraction of clusters with $t_{cool} < 1$ Gyr: ~40-50%

Fraction of classical cool-core systems: ~15-20%

Fractions of clusters with $t_{cool} > 5$ Gyr: ~30-40%

Non-cool core systems have typical core entropy of 200-300.

Mergers and in-situ AGN feedback cannot give rise to the non-cool core population.

Have We Just Entered the Age of Cooling Flows?

Estimates based on AGN power suggest that preheating ought to generate initial core entropies in the range of 100-300 keV cm^2

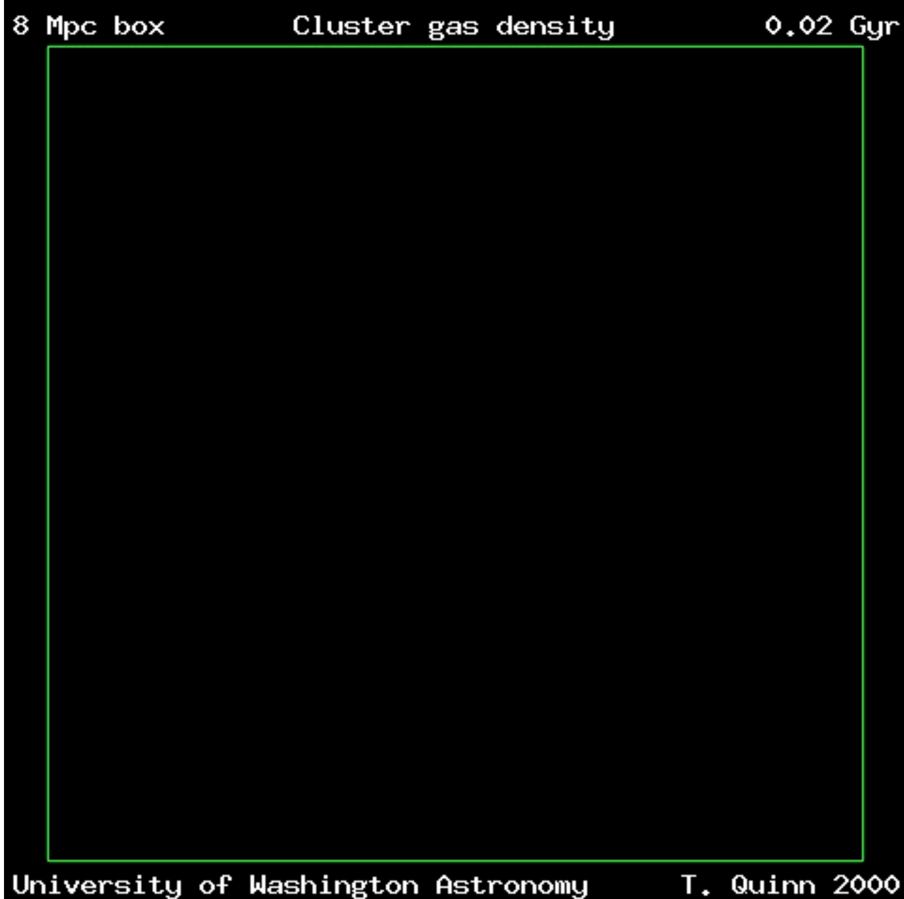
And though these systems have long cooling times, the central entropy values will – over 5 Gyrs – cool from

from ~200 to ~20
from ~300 to ~100

To explain the distribution seen by Cavagnolo and co:

a) NCC systems started out much hotter (energetically tough)
b) clusters are being observed at a special epoch
c) we are missing something…

SECONDARY HEATING BY GALAXY STIRRING



The idea that galaxy motions can heat the ICM through the dissipation of induced wakes has been around for decades:

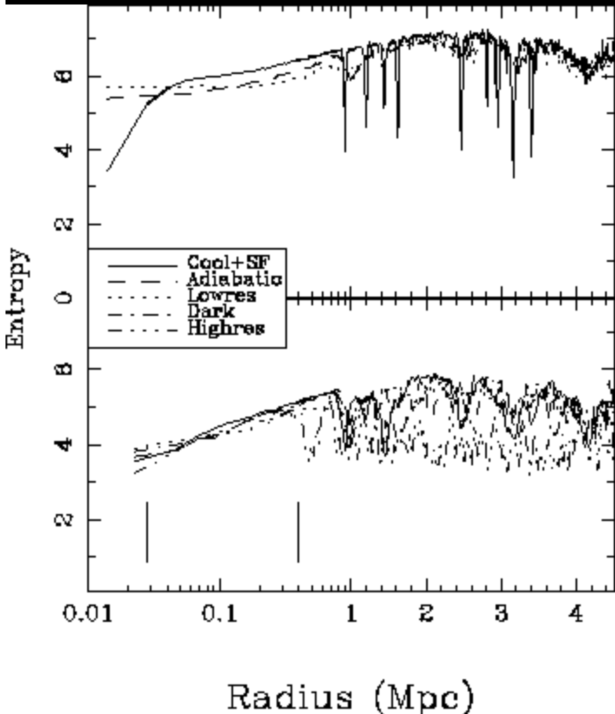
$$\frac{dE}{dt} \propto \rho_{ICM}(r) M_{gal}^{2} \, f(V / c_s)$$

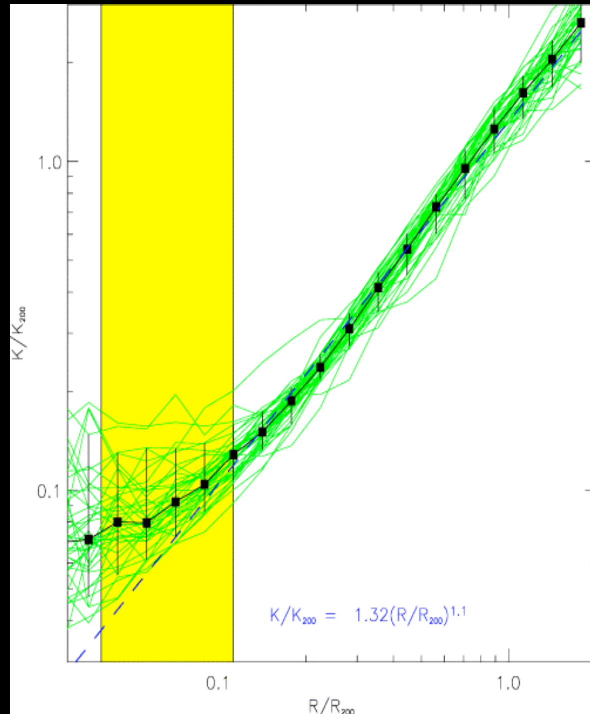
A galaxy with M_{gal}~10^{11} $M_{\odot}$ moving through cluster core at V~Cs would heat the gas at a rate: 10^{42-43} ergs/s.

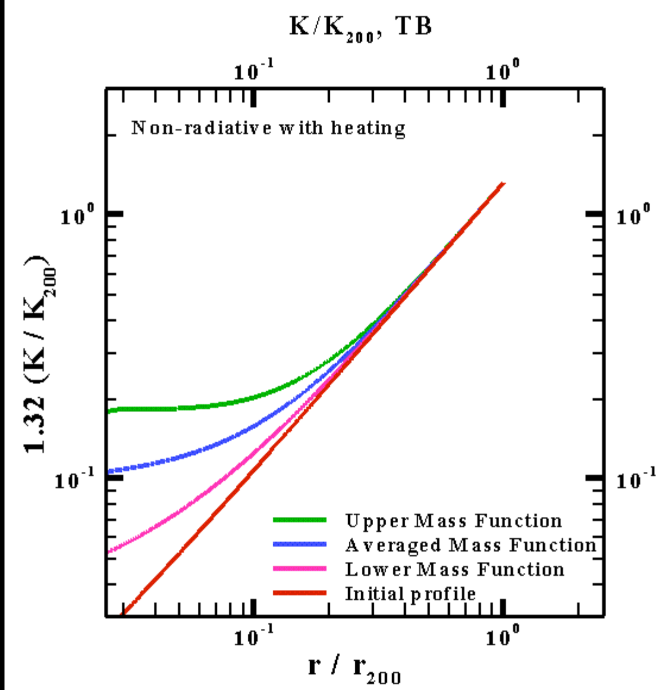
[radiative losses ~ 10^{44-45} ergs/s]

With several tens of massive galaxies and under right conditions, the rate can be interesting.

Effects of “stirring” are present in simulation results







Lewis et al. 2000, ApJ 536, 623

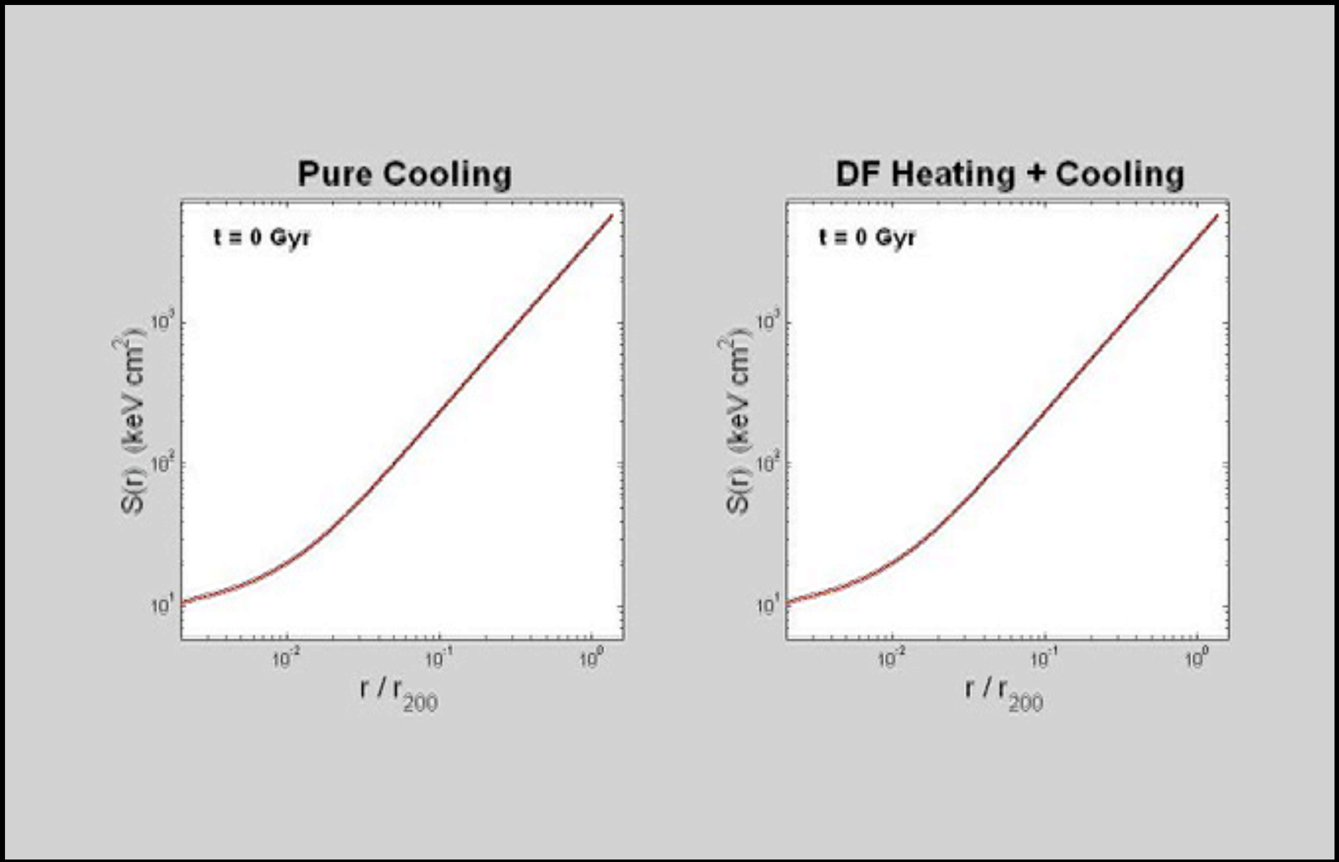
Voit, Kay, Bryan, 2005, MN 364, 909

Ghazvinizadeh et al., in prep

The details of heating are sensitive to shape of mass function as well as spatial distribution of substructure.

$$\rho_{gas} \quad vs. \quad \rho_{gas}^2$$

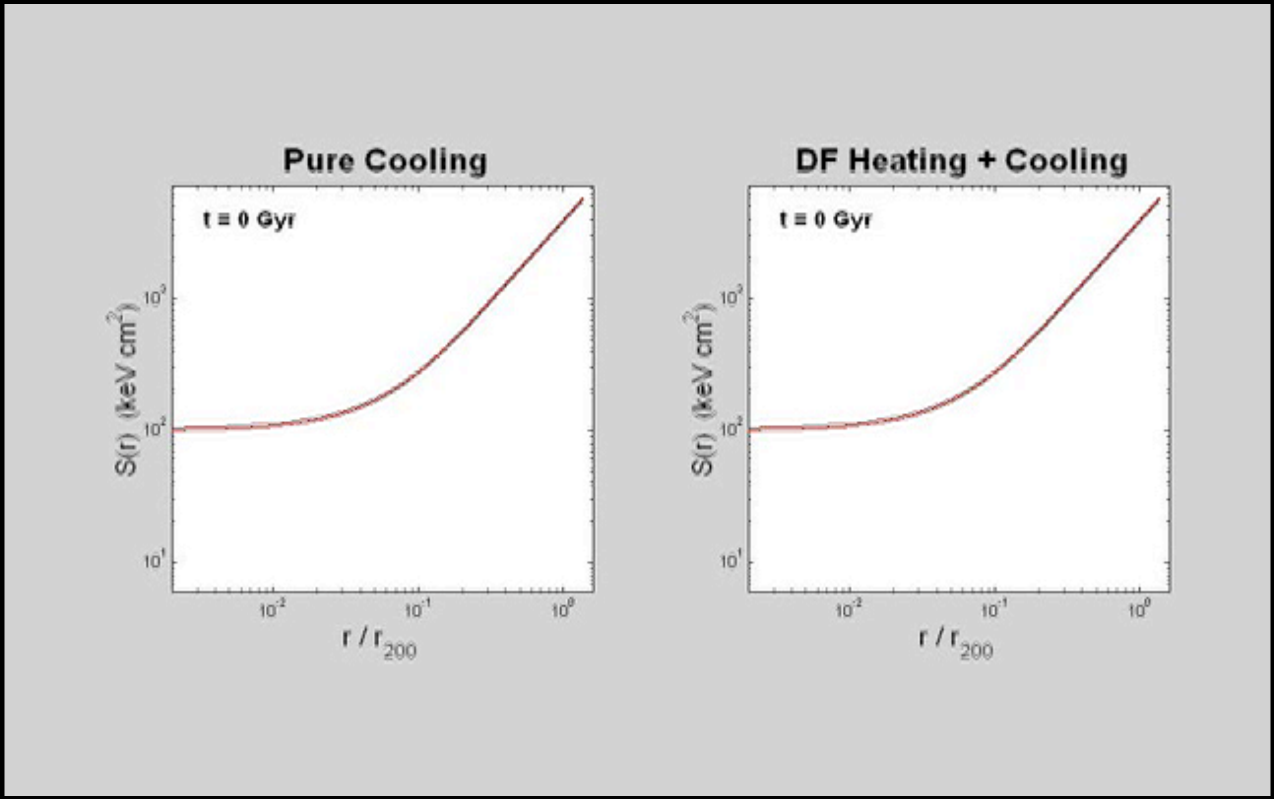
In clusters with dense gas cores, cooling wins over heating.



Heating via galaxies motions is insignificant.

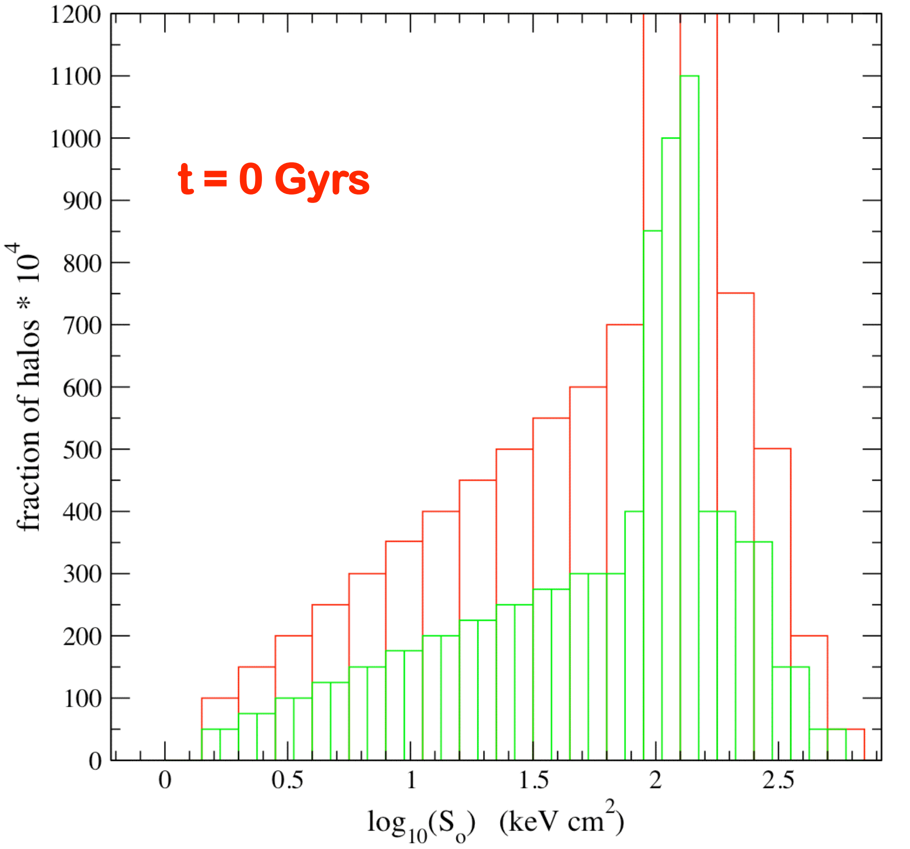
$$\rho_{gas} \quad vs. \quad \rho_{gas}^2$$

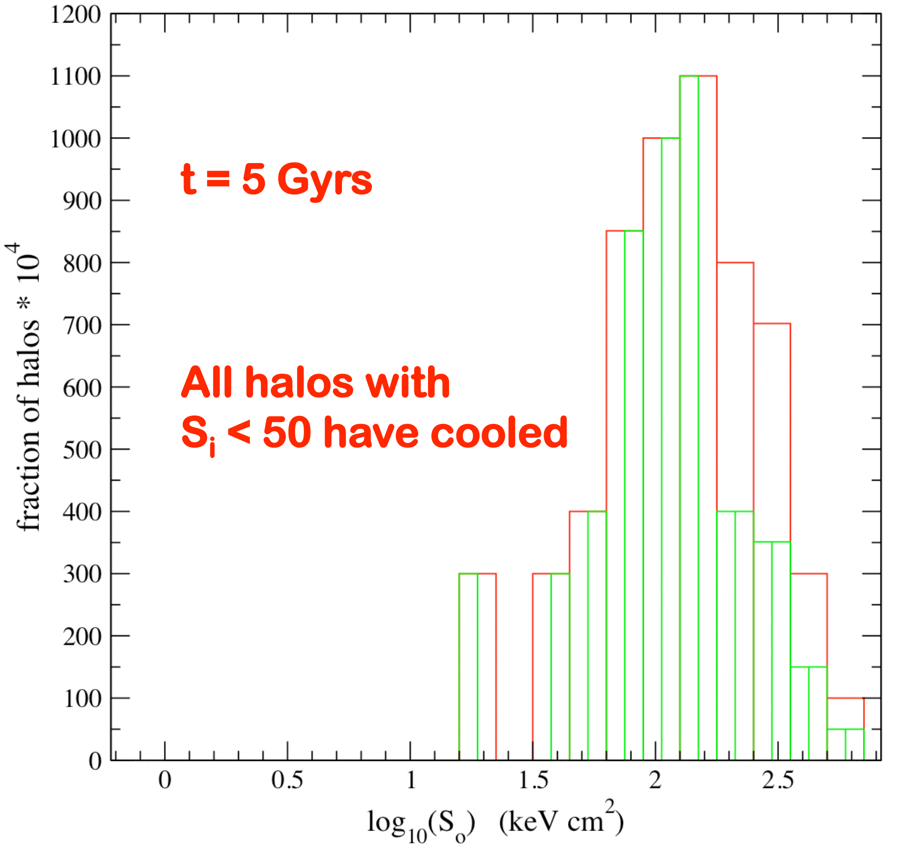
But if the gas is preheated and has reduced core density, galaxy heating grows in importance…reducing energy loss.



This can dramatically change the timescales over which "cooling flows" can establish..

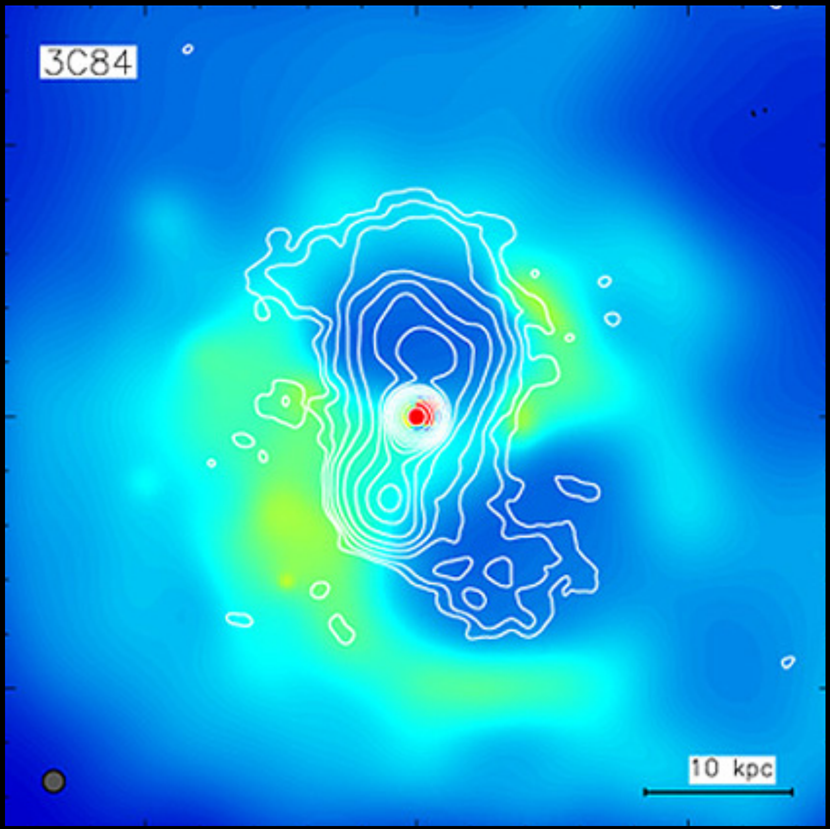
An Ensemble of Halos with Different Core Entropies

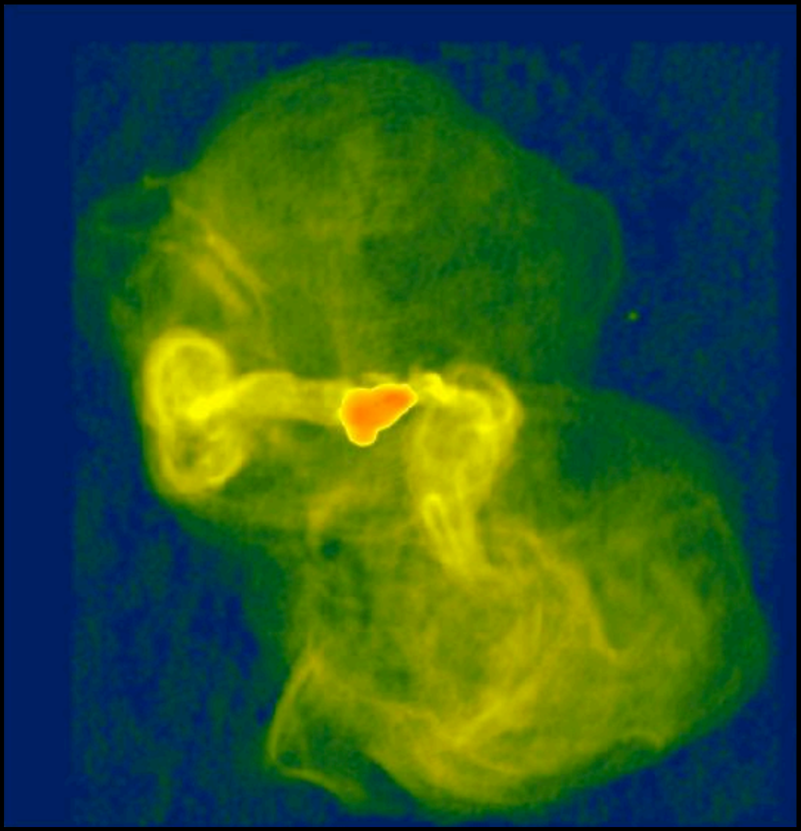


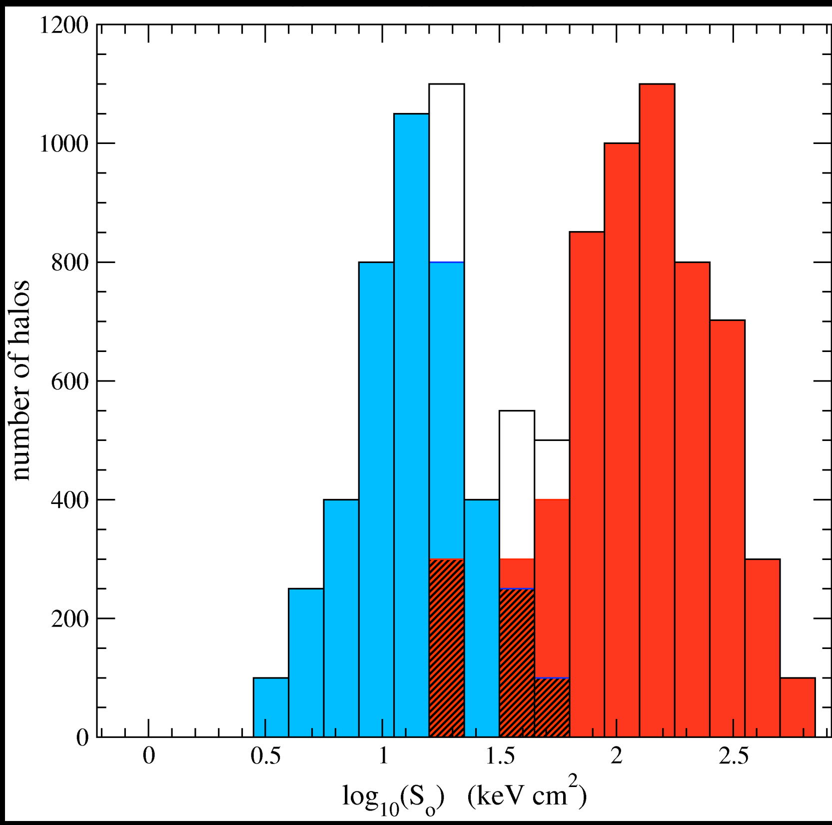


Galaxies at the centers of cool-core clusters host AGNs that are driving winds and jets, which heat the ICM and moderate the cooling flow.

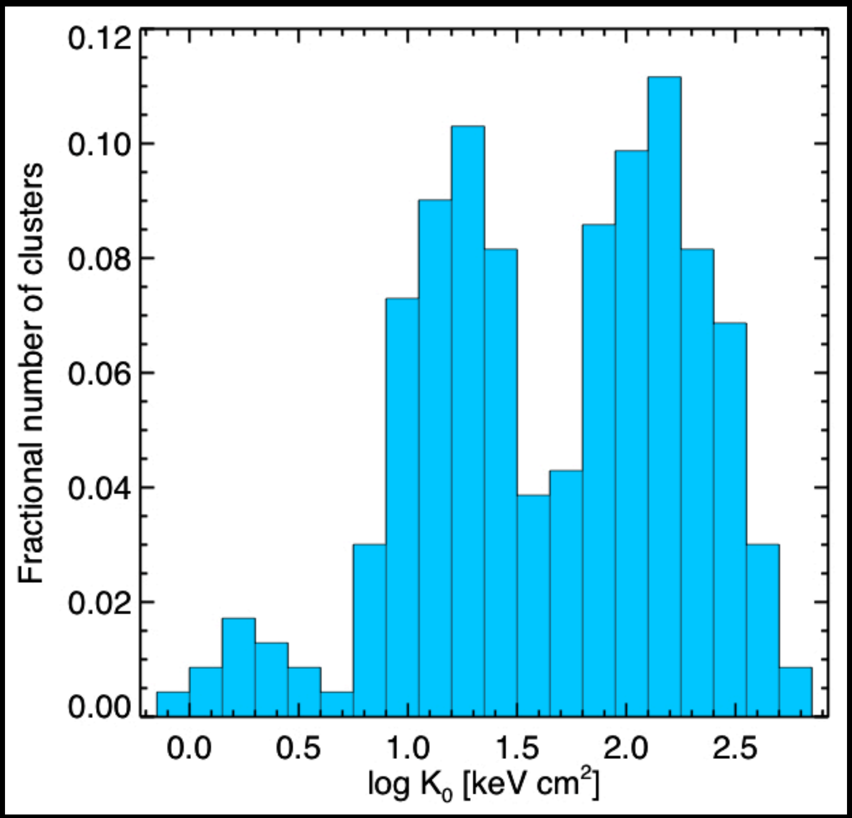
Consider a toy model where the AGN maintains the central gas entropy in CC clusters at some value between 3-30, with typical value being 10.





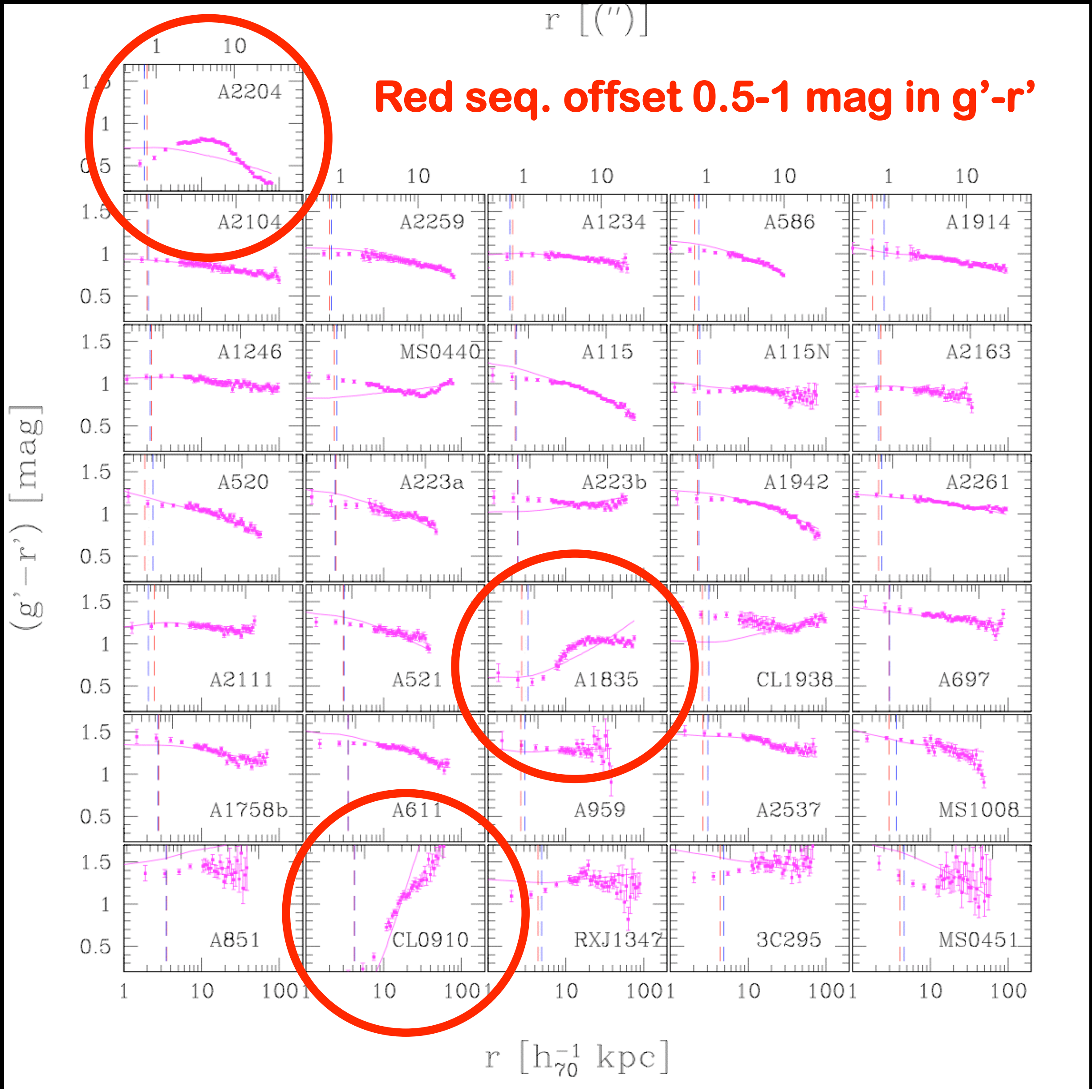


number of halos
1200
1000
800
600
400
200
0
0
0.5
1
1.5
2
2.5
log10(So) (keV cm2)

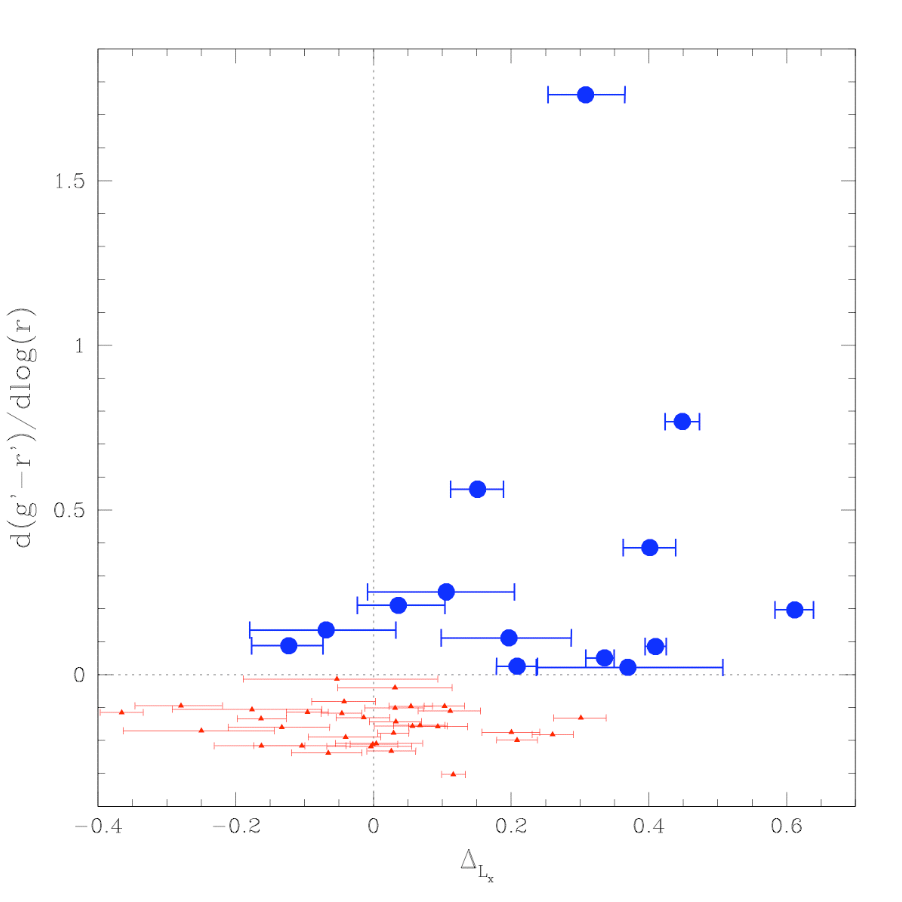


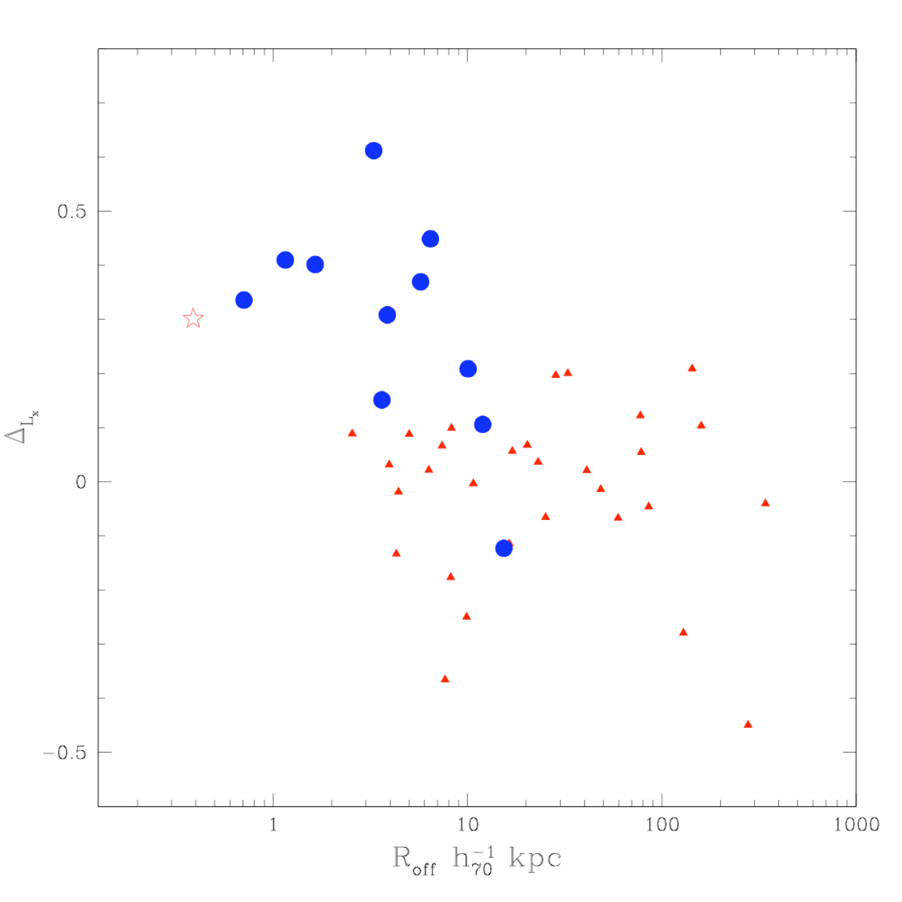
Fractional number of clusters
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.0
0.5
1.0
1.5
2.0
2.5
log K0 [keV cm2]

Better Red than Dead
Blue Core BCGs: SFR ~ 20-40 Msun / yr



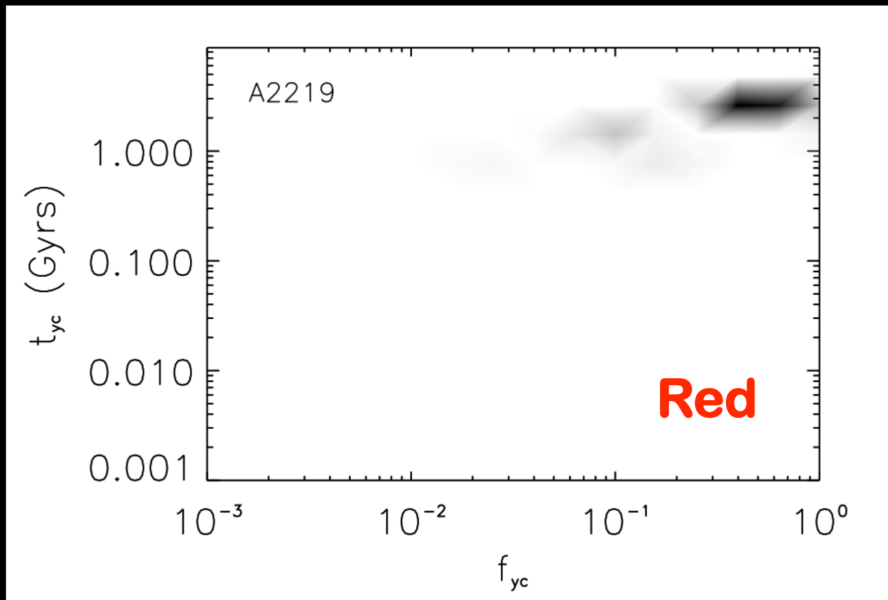
Blue Core BCGs located in centers of Cool Core clusters

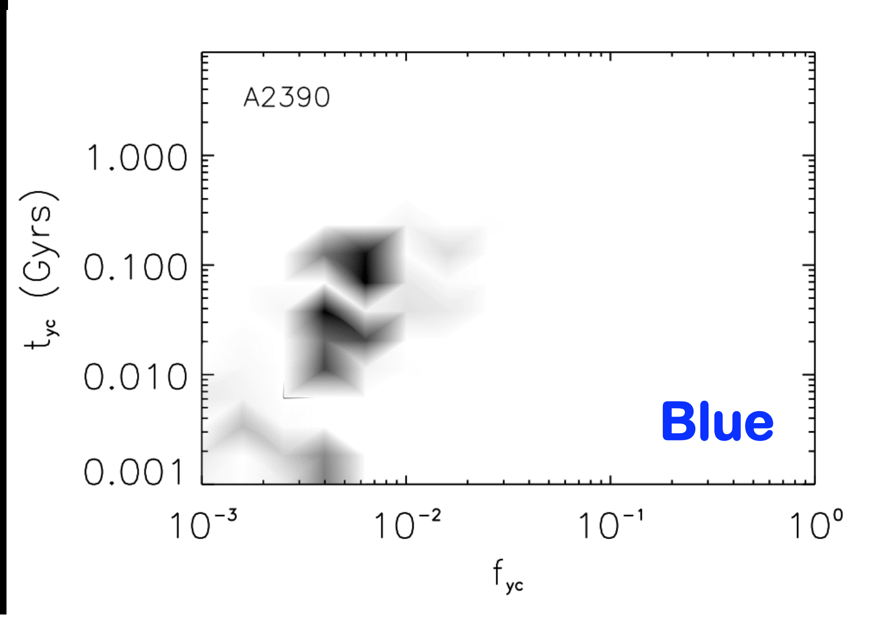




Bildfell et al. 2008

Youngest Stars in Blue Core BCGS





- Galex data for a handful of the systems.
- Stellar Pops analysis using optical and NUV.
- Most of the stars at 1+ Gyrs
- But always find young stars (< 200 Myrs) at < 1% level
- All BCGs in cool core clusters have young stars.
- Several have AGN
- AGNs do not appear to stop star formation.
- Most likely just temper the cooling flow.

As in biologist have been discovering, the issue is not binary: Nature vs. Nurture. Rather, it is a two-way process.

Galaxies act to shape their environments.
The environment acts back on the galaxies.

- **Galactic outflows will heat gas in their local environment.**

- **This will in turn affect larger systems like groups/clusters, resulting in cool core vs. non-cool core dichotomy and allowing for a number of otherwise negligible effects to become important (galaxy stirring).**

- **Evolution of (some) galaxies in such systems depends on the type of cluster they inhabit – red & dead or frosted**

DEEP X-RAY STUDIES OF DIM GROUPS IS THE BEST WAY TO TEST SOME OF THE KEY ELEMENTS OF THIS PICTURE