

The cooling flow problem

AC Fabian

With thanks to: Lisa Voigt, Jeremy Sanders, Carolin Crawford,
Roderick Johnstone, Glenn Morris, Steve Allen

Cooling Flows in cluster cores

Radiative cooling time

$$t_{\text{cool}} < 10^{10} \text{ yr}$$

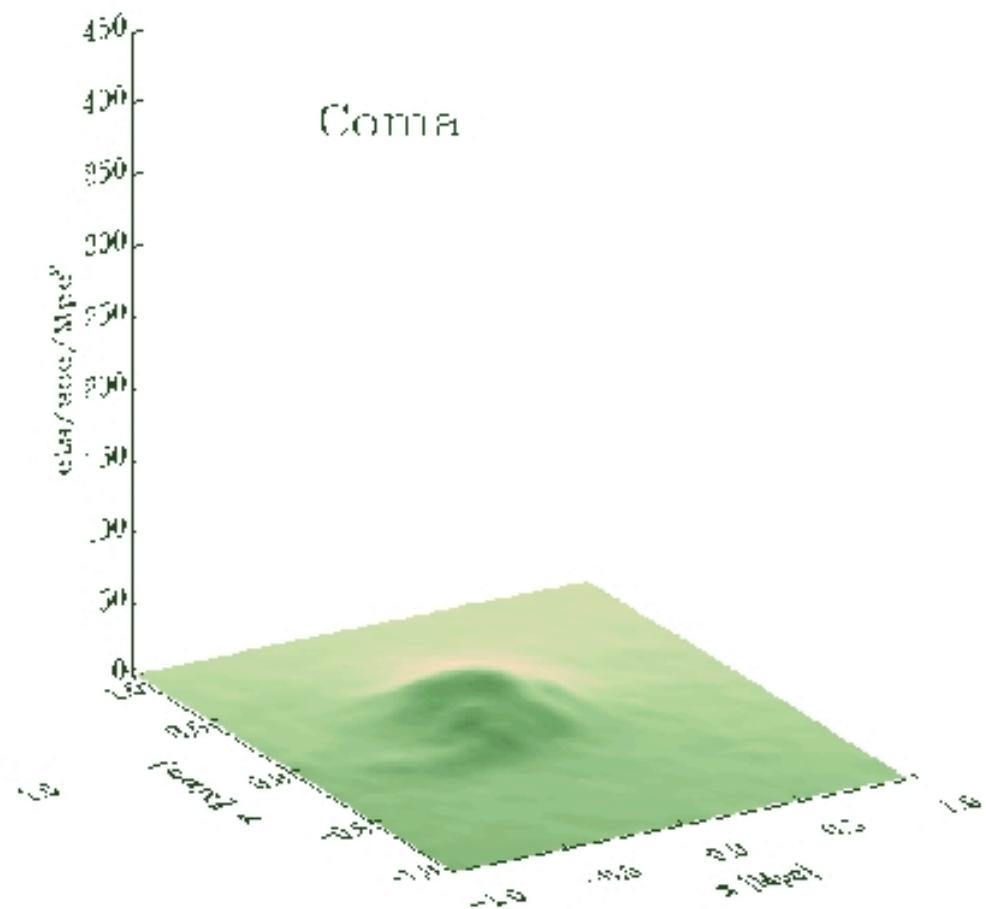
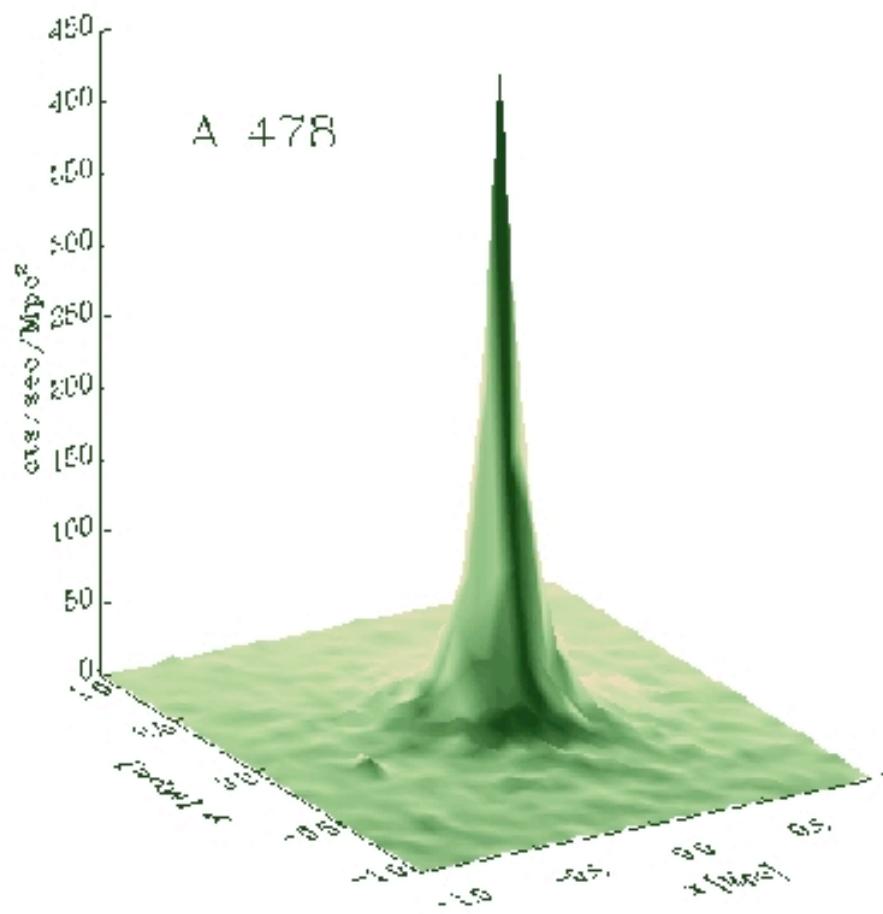
in central 100kpc of most clusters.

Gas temperature also seen to drop there.

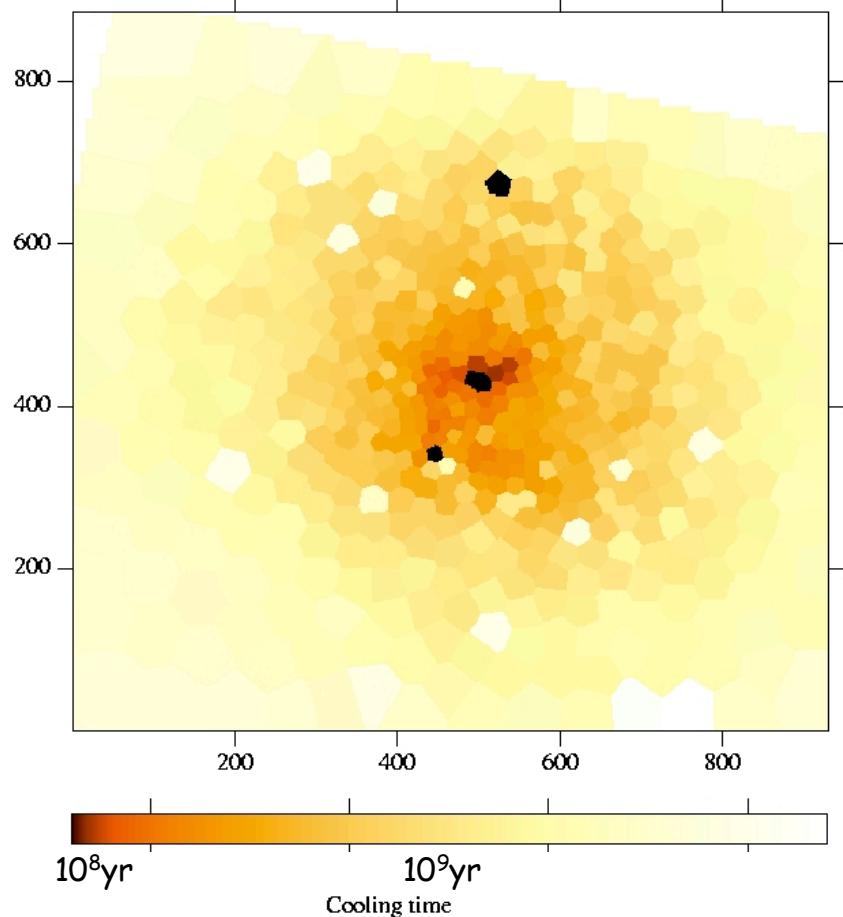
IF NO HEATING

$$\dot{M} \approx \frac{2}{5} \frac{L \mu m}{kT}$$

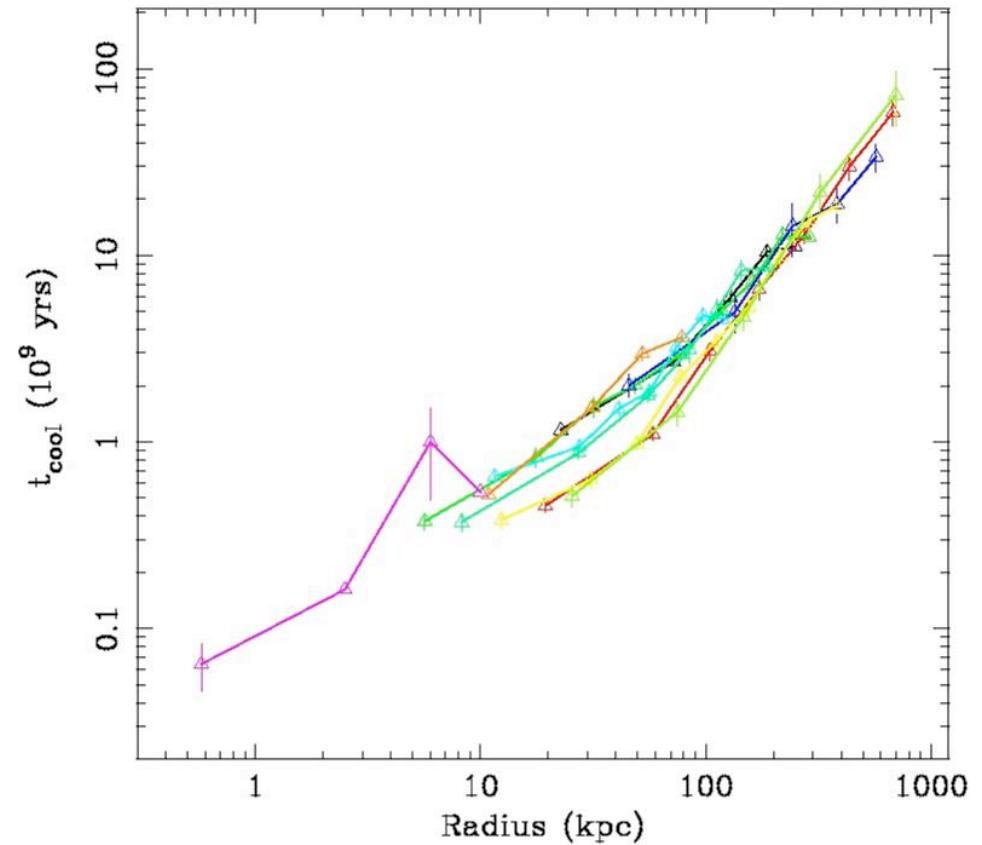
Before 2000 $M \sim 10^{-1000} M_\odot/\text{yr}$ around central cluster galaxies



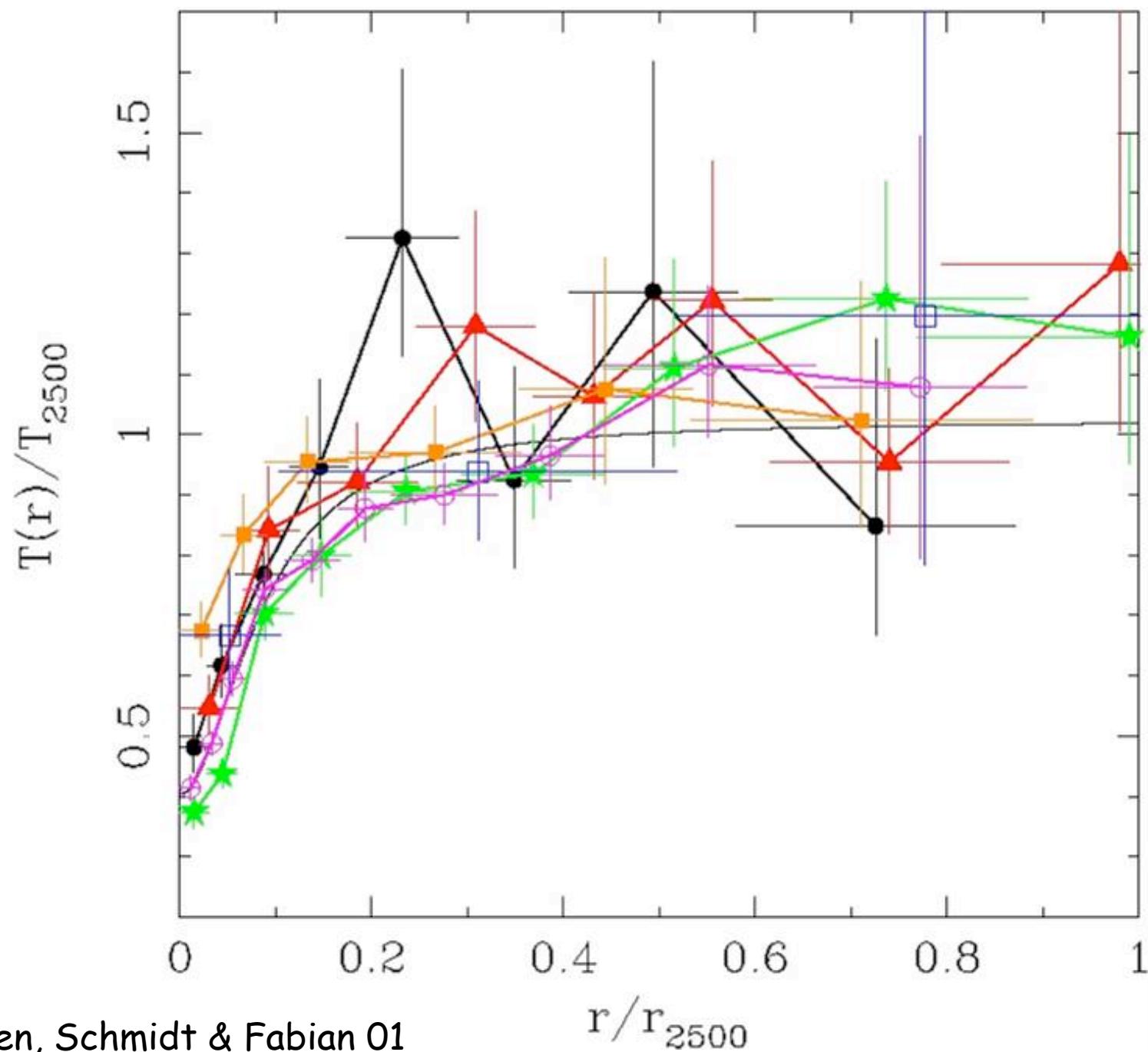
Radiative cooling times from *Chandra*



Perseus cluster

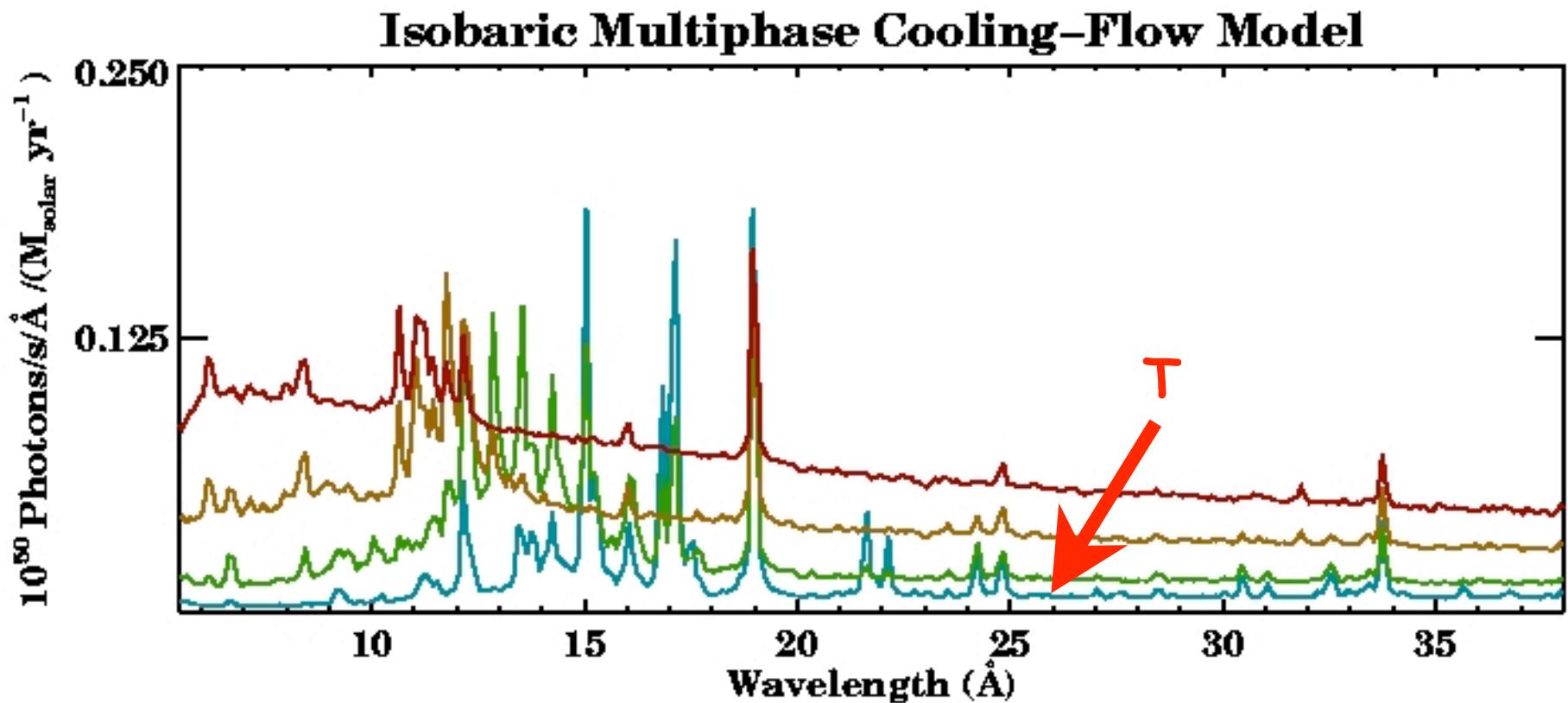


Other clusters

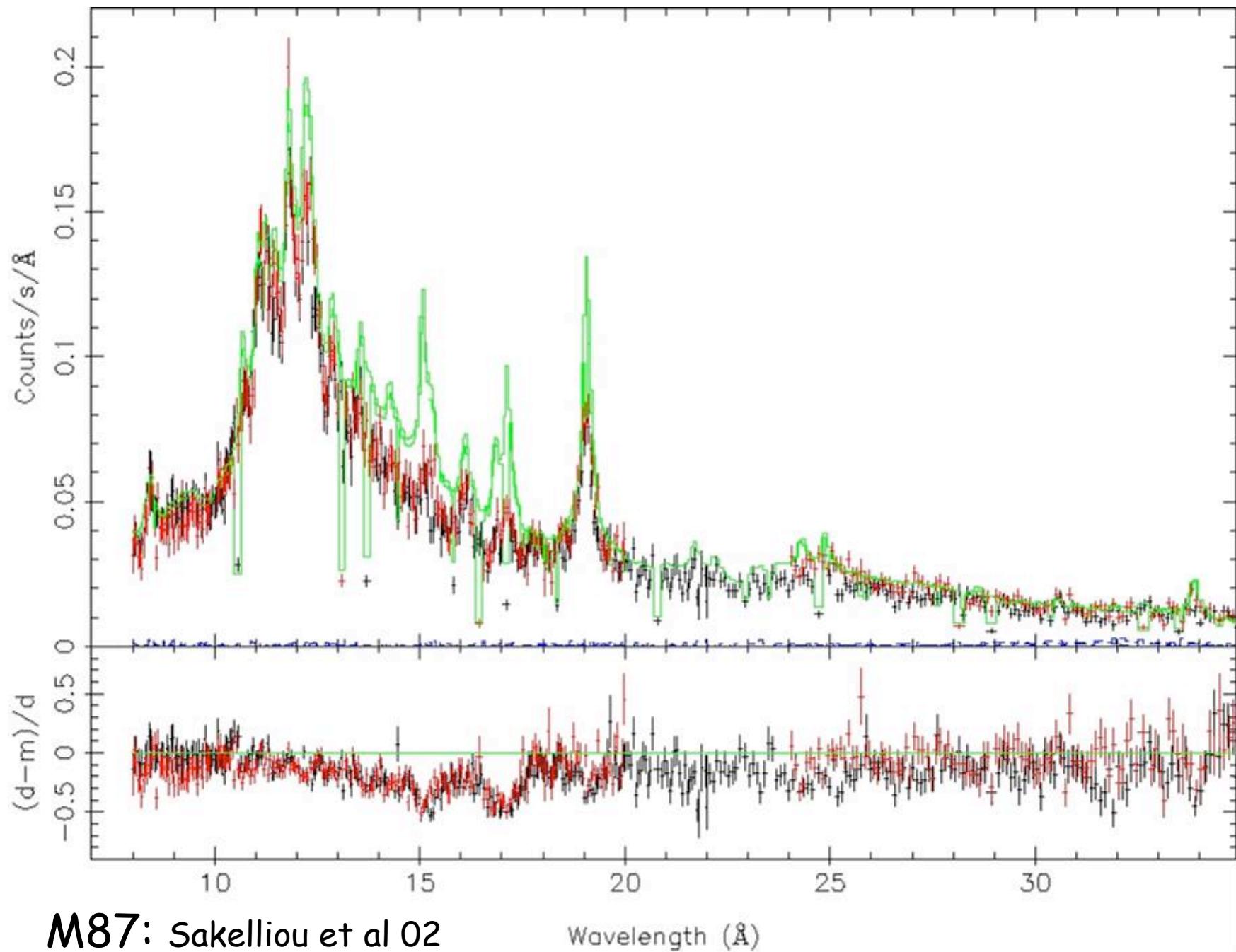


Allen, Schmidt & Fabian 01

The Cooling Flow Problem

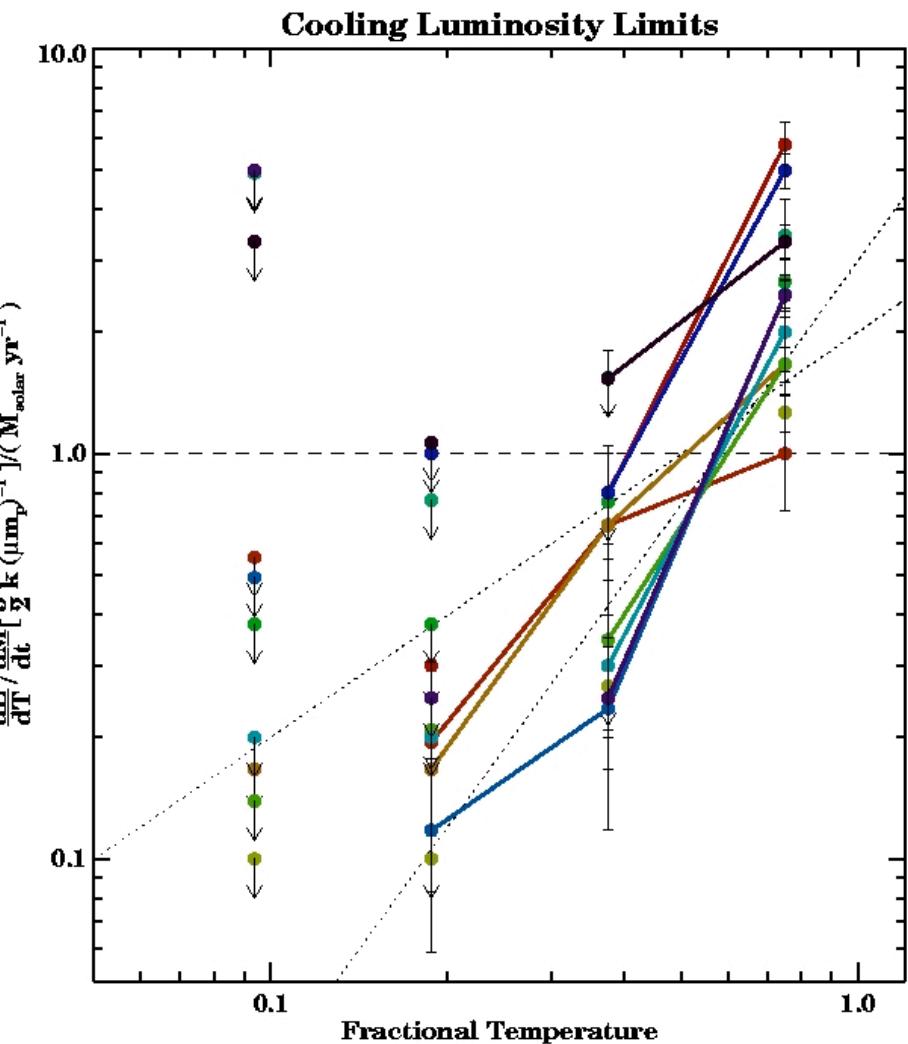
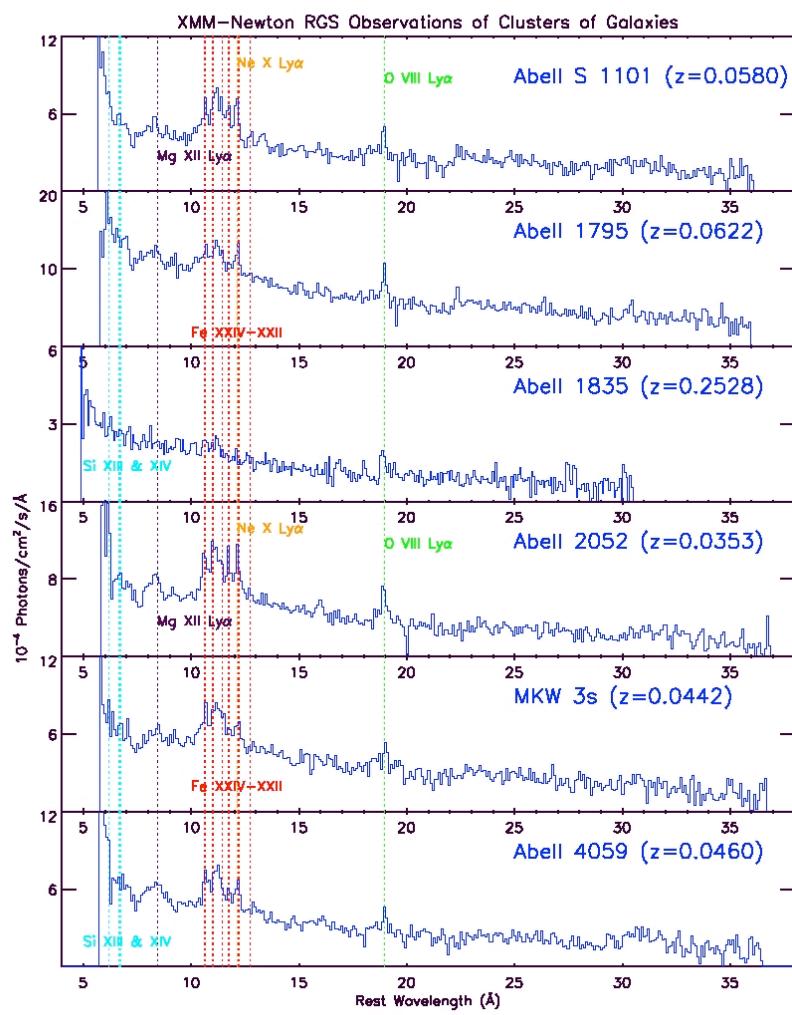


XMM-RGS: X-ray coolest gas not seen
(Peterson et al 01, 03; Tamura et al 01)



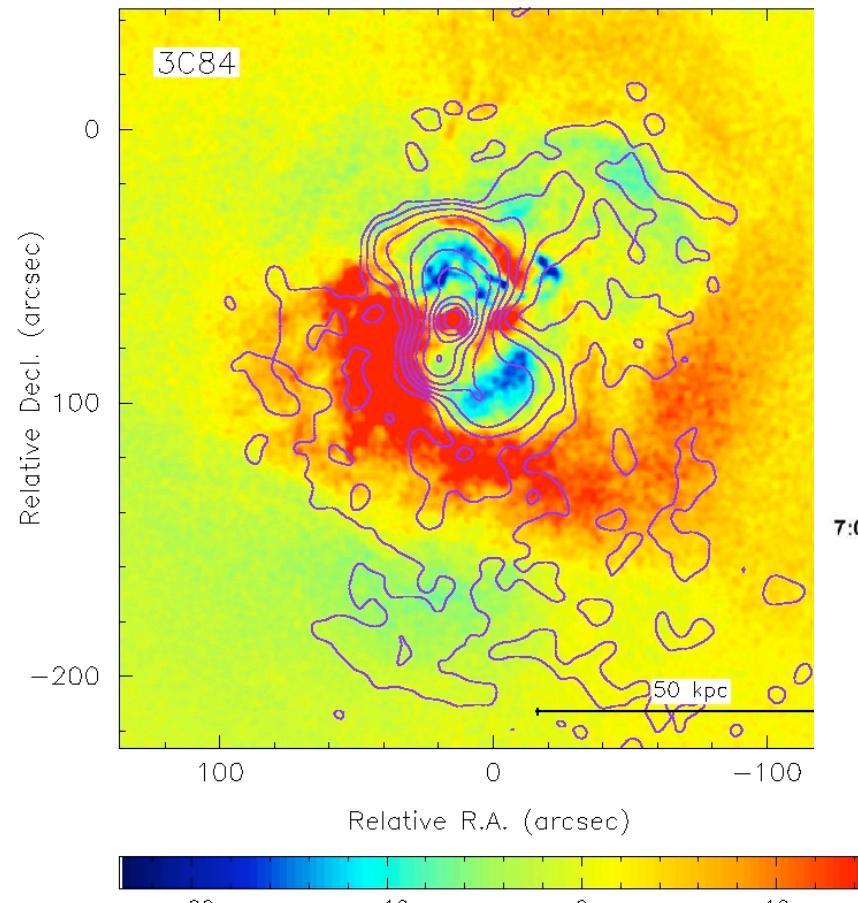
M87: Sakelliou et al 02

Wavelength (\AA)

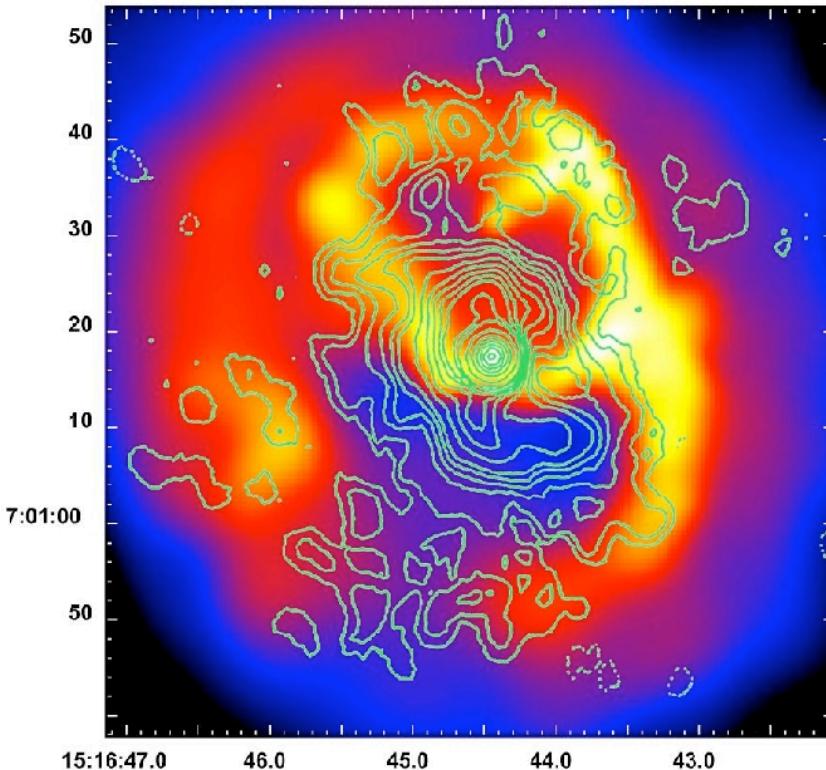


Peterson et al 03

Radio Bubbles



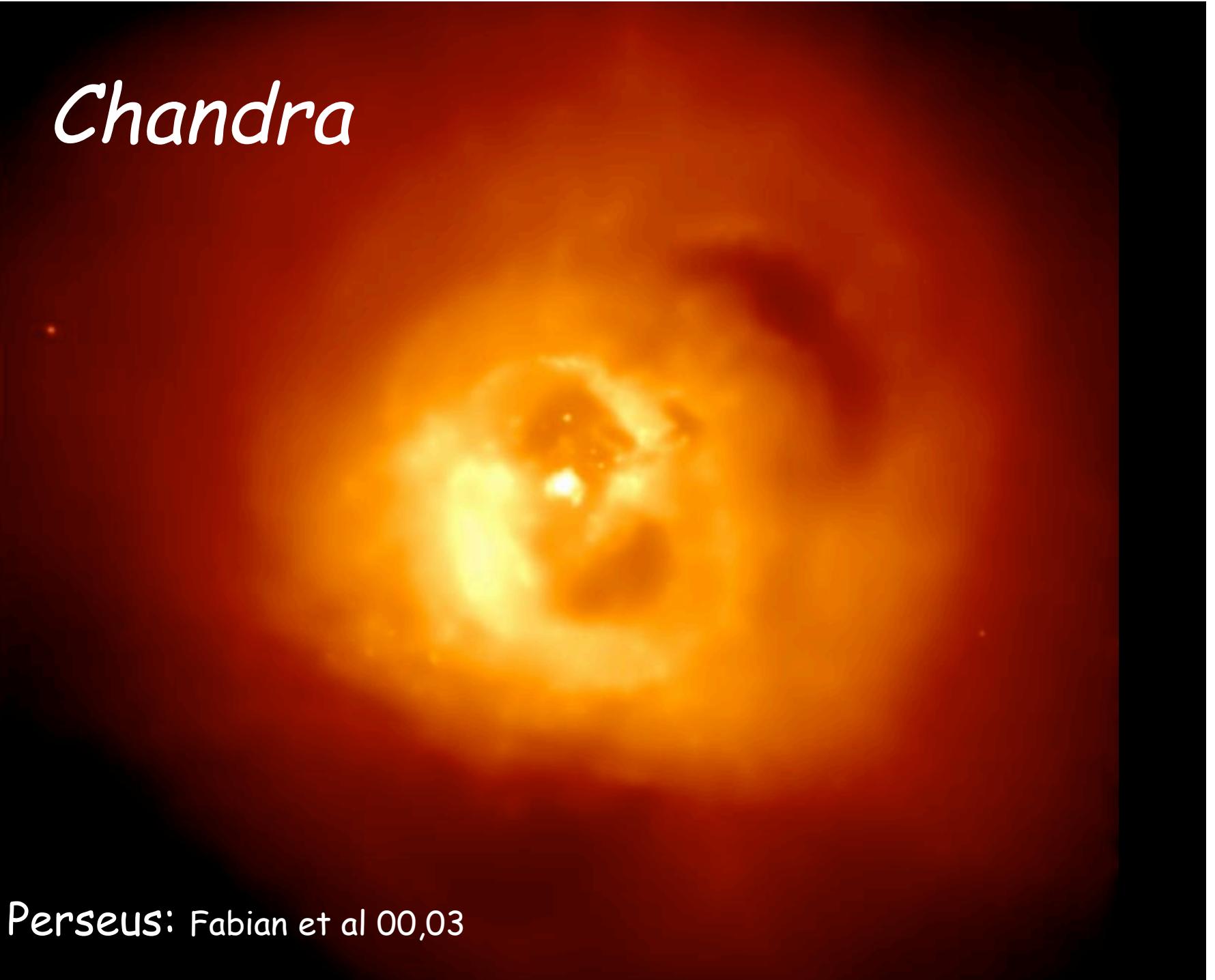
Perseus



A2052: Blanton et al 02

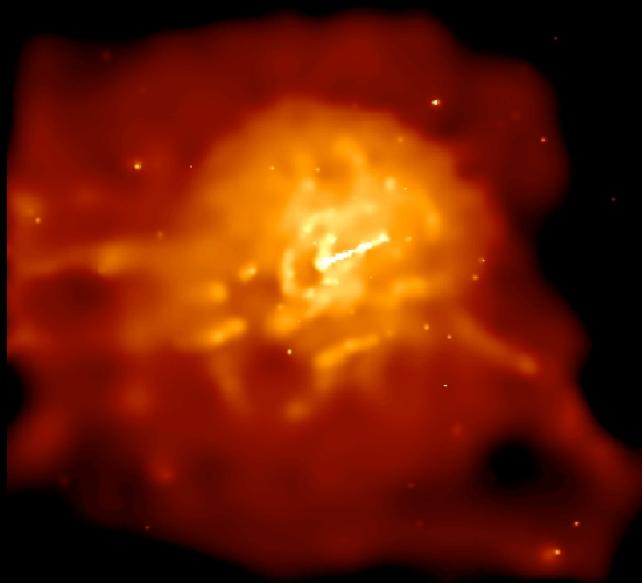
See also: McNamara et al 00; Heinz et al 02, Mazzotta et al 02; Nulsen et al 02

Chandra

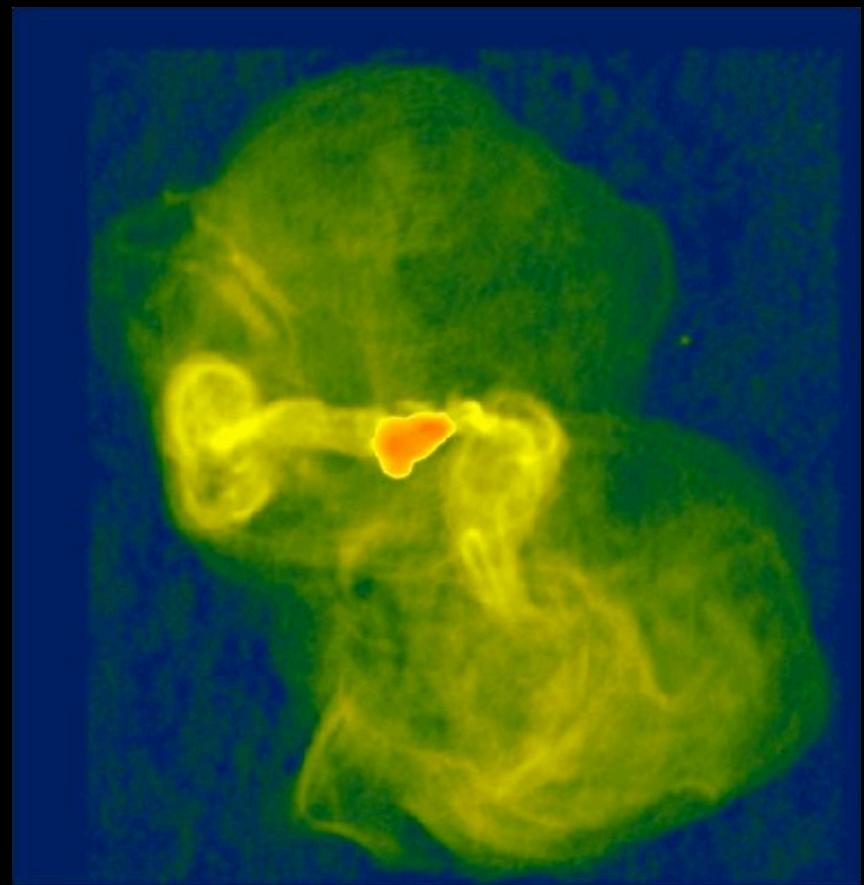


Perseus: Fabian et al 00,03

M87

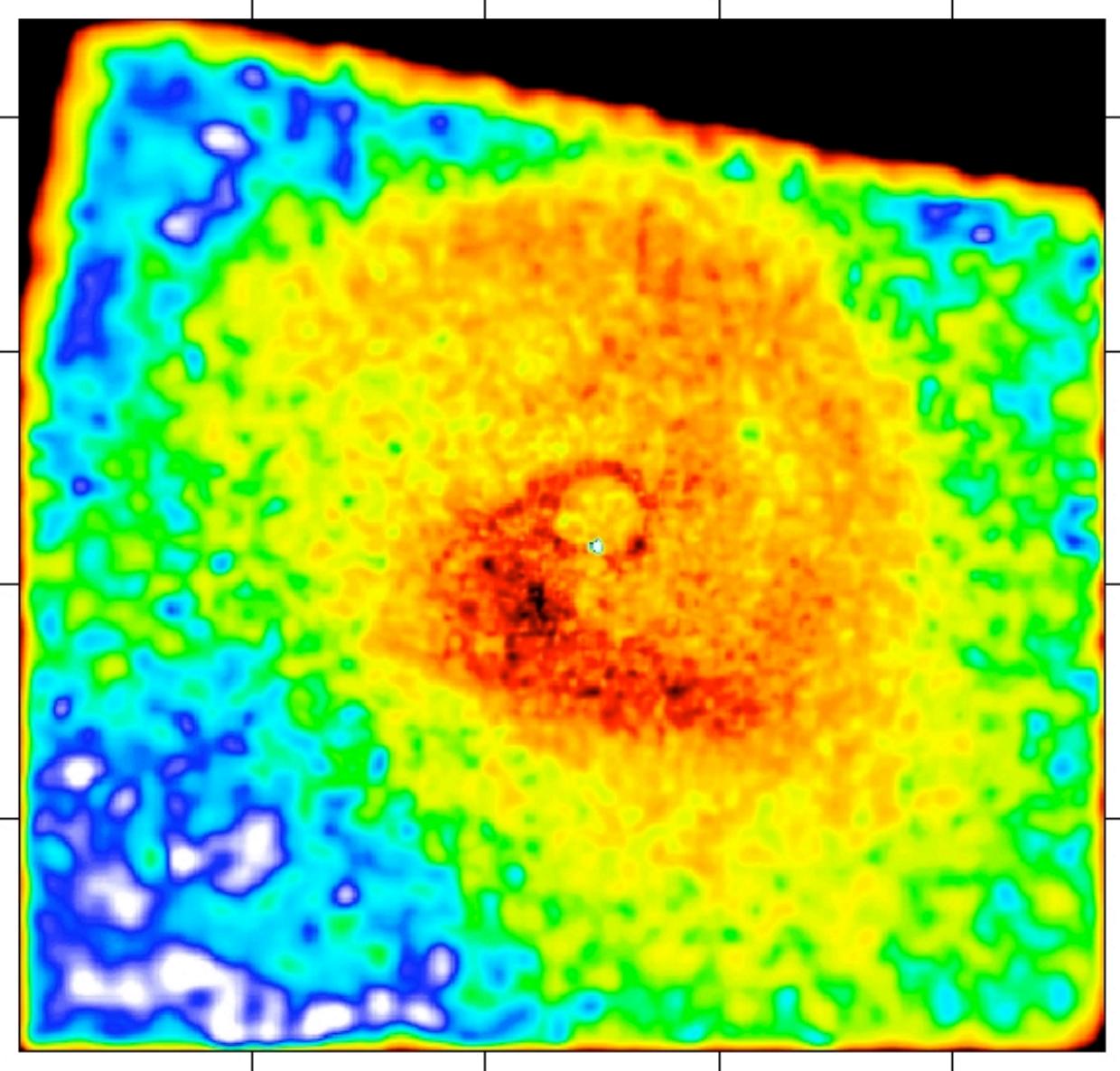


Wilson et al 02



Owen et al 99

BUT!



2

4

6

8

10

Temperature (keV)

Perseus: Fabian et al 03

Energy flux in bubbles from radio sources
at centre can be high (10^{43-45} erg/s)

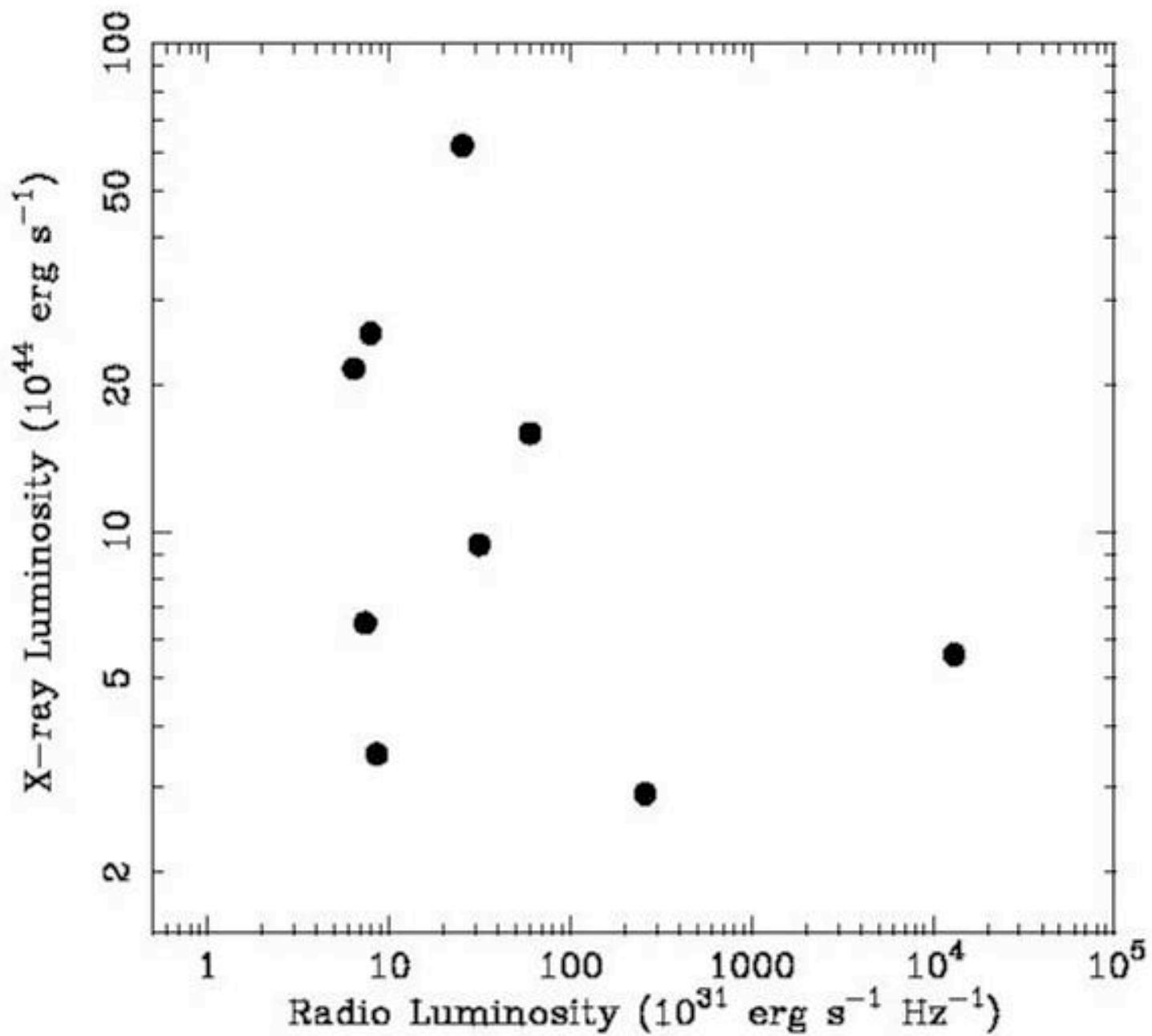
Is this the heat source?

BUT... 'coldest' gas *around* the bubbles

- Outer buoyant bubbles show energy may be transported to large r
- Heat transfer depends on details (weak shocks)

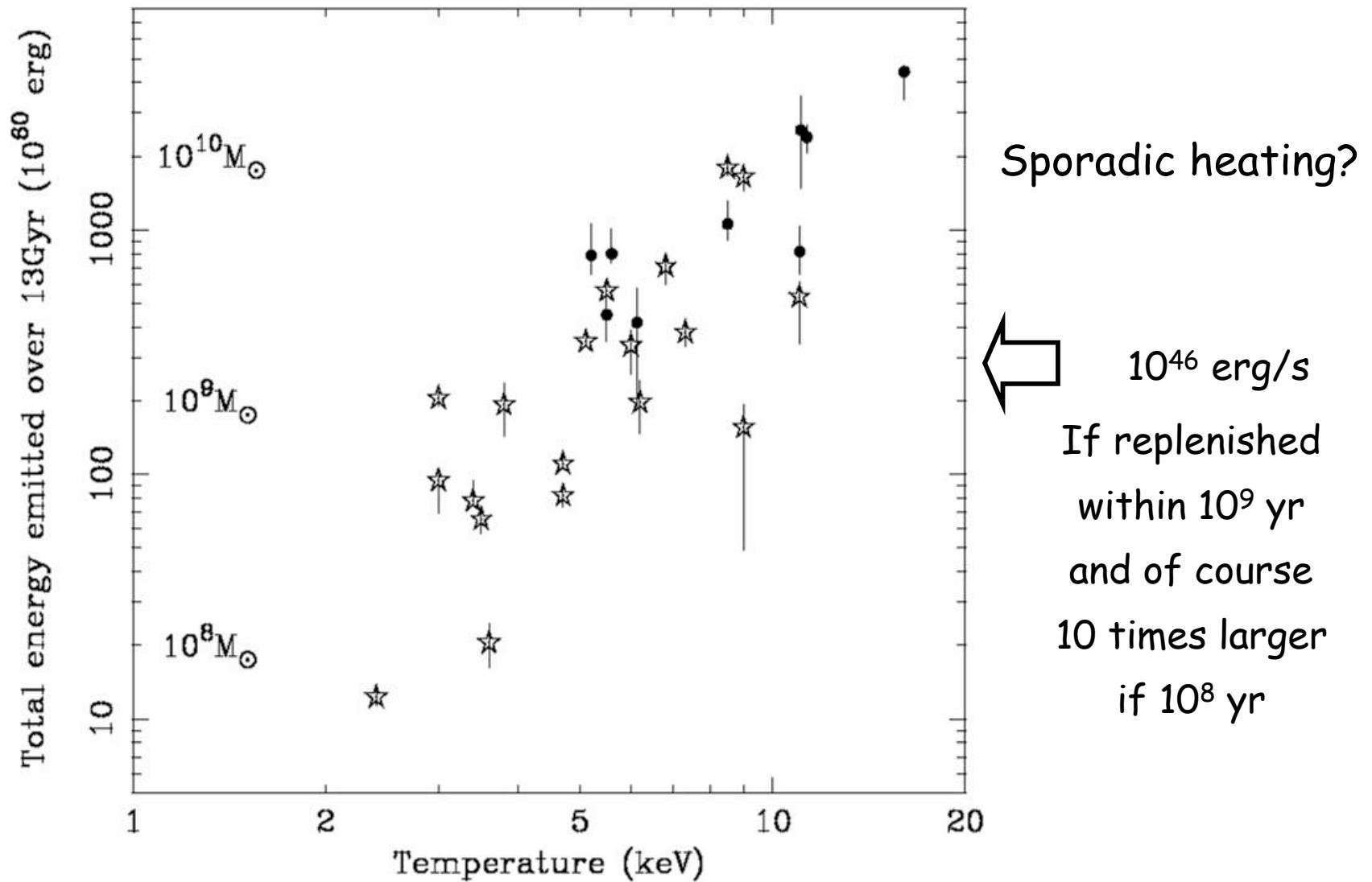
Churazov et al; Heinz et al ; Brüggen & Kaiser; Reynolds et al; Quilis et al;
Binney & Kaiser

L_x
 $(t_c < 5 \cdot 10^9 \text{ yr})$

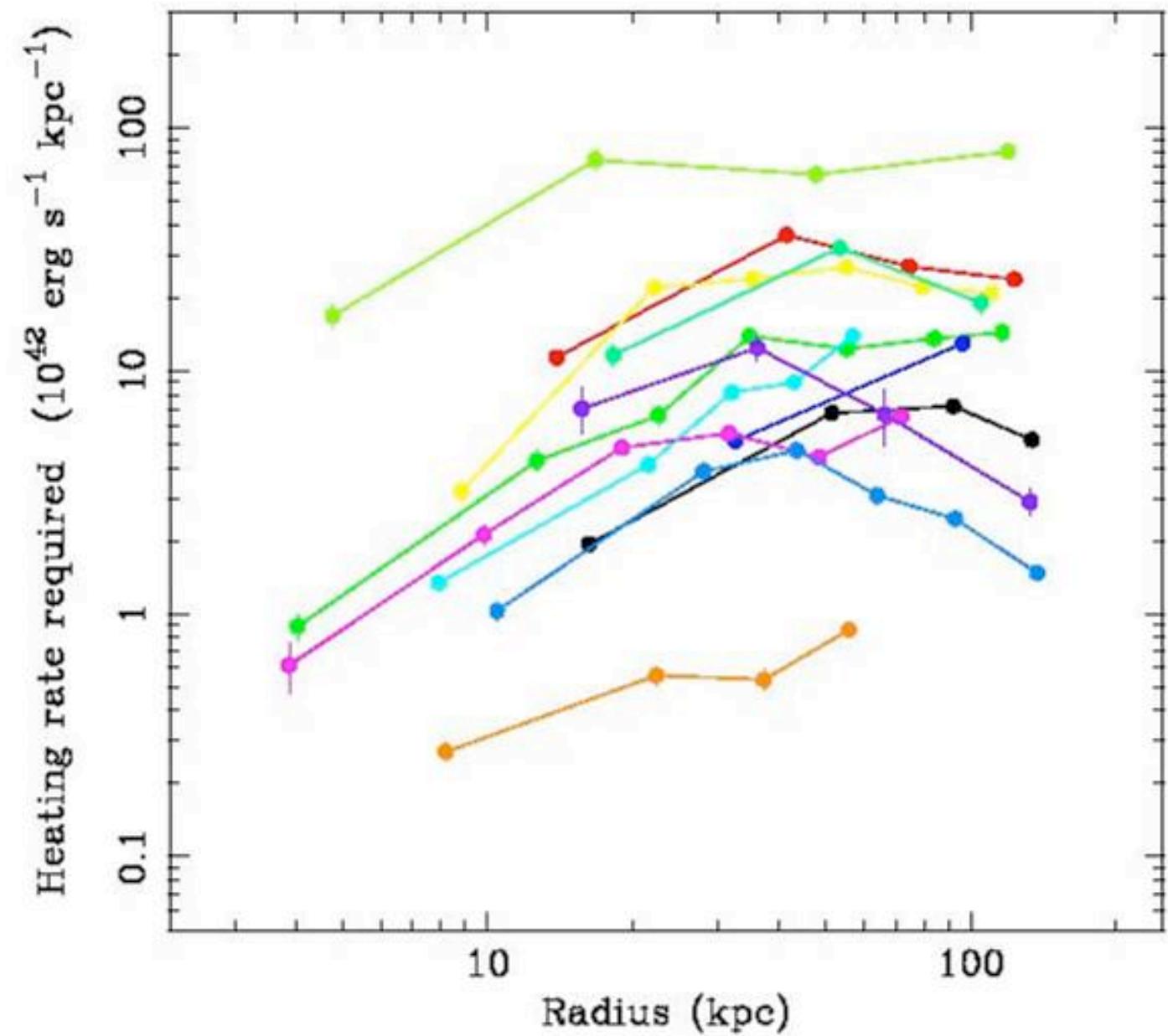


Voigt et al 03

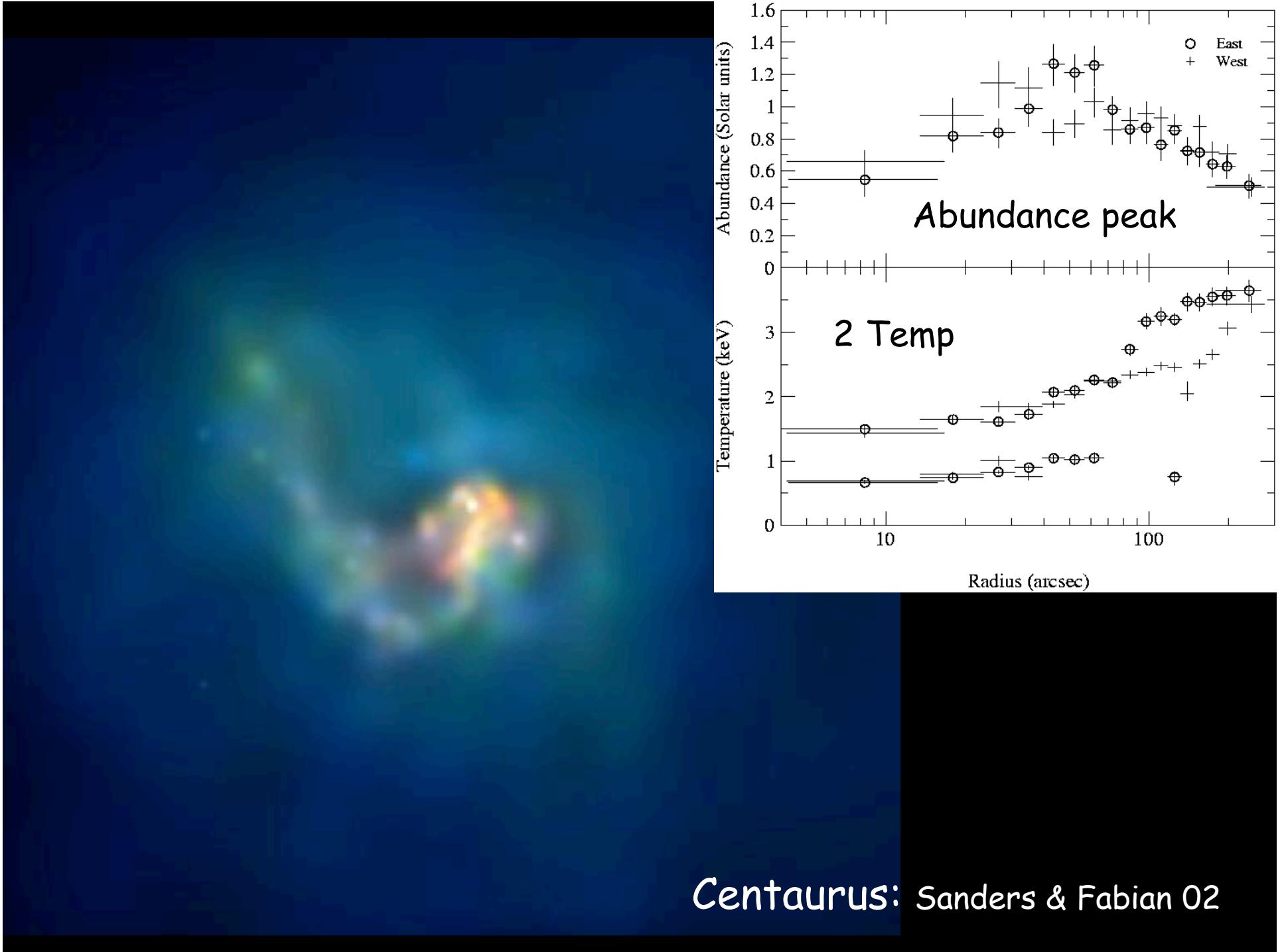
Much heat required and not all clusters have strong central radio sources



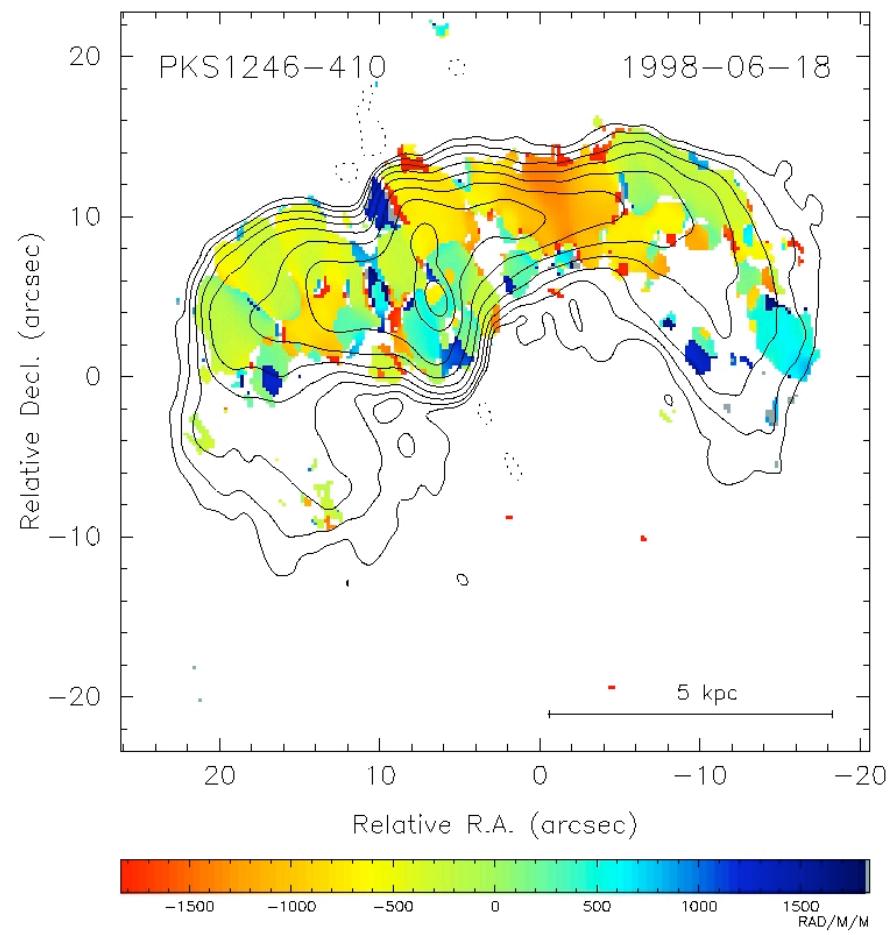
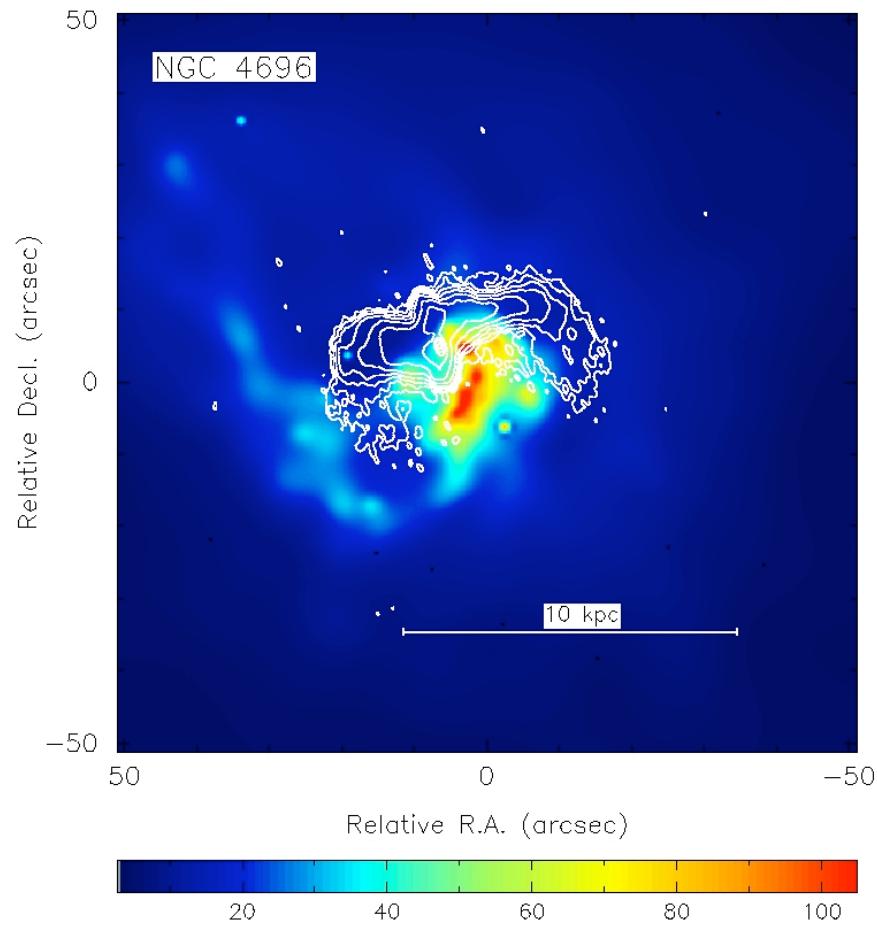
Heat must be distributed



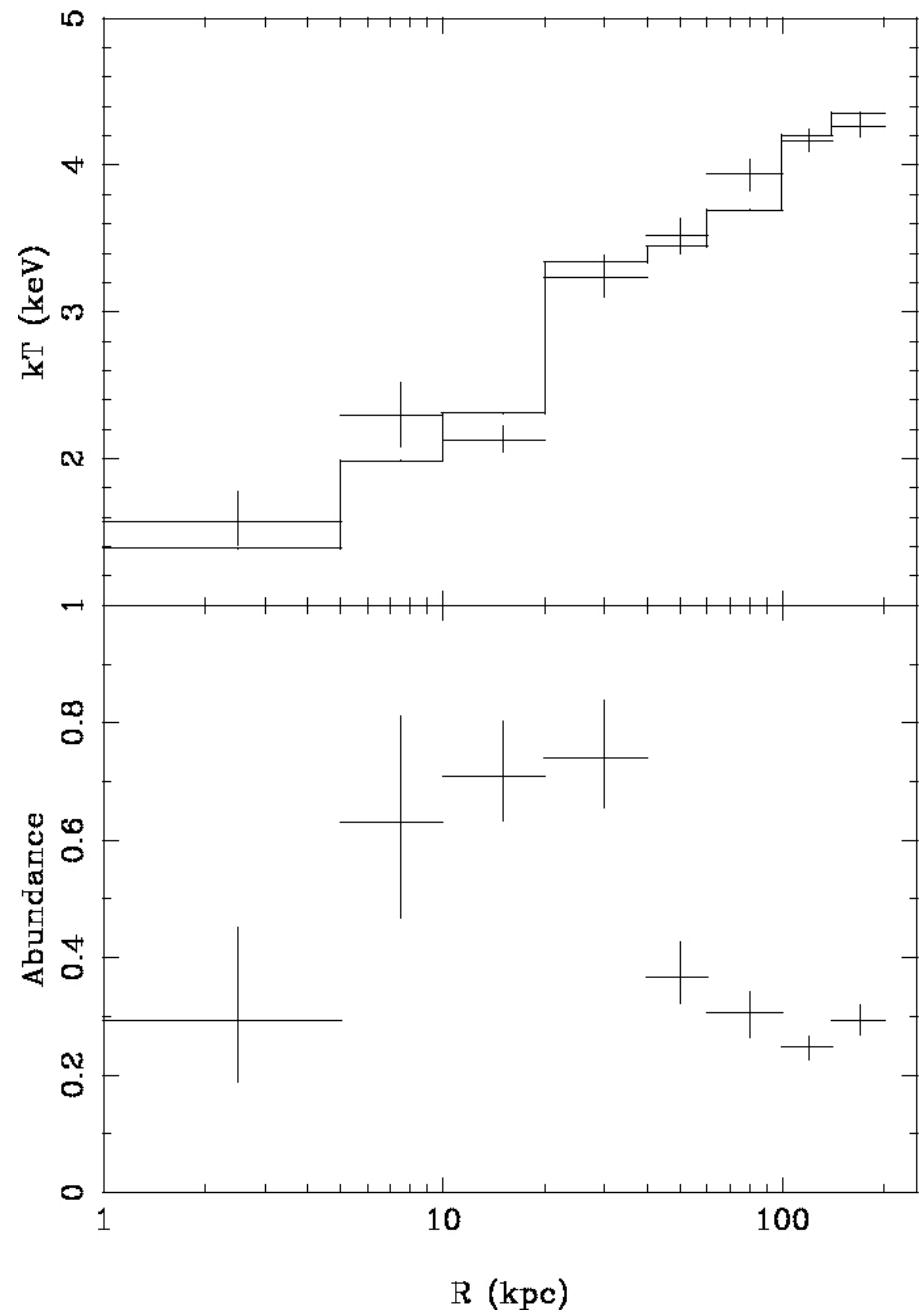
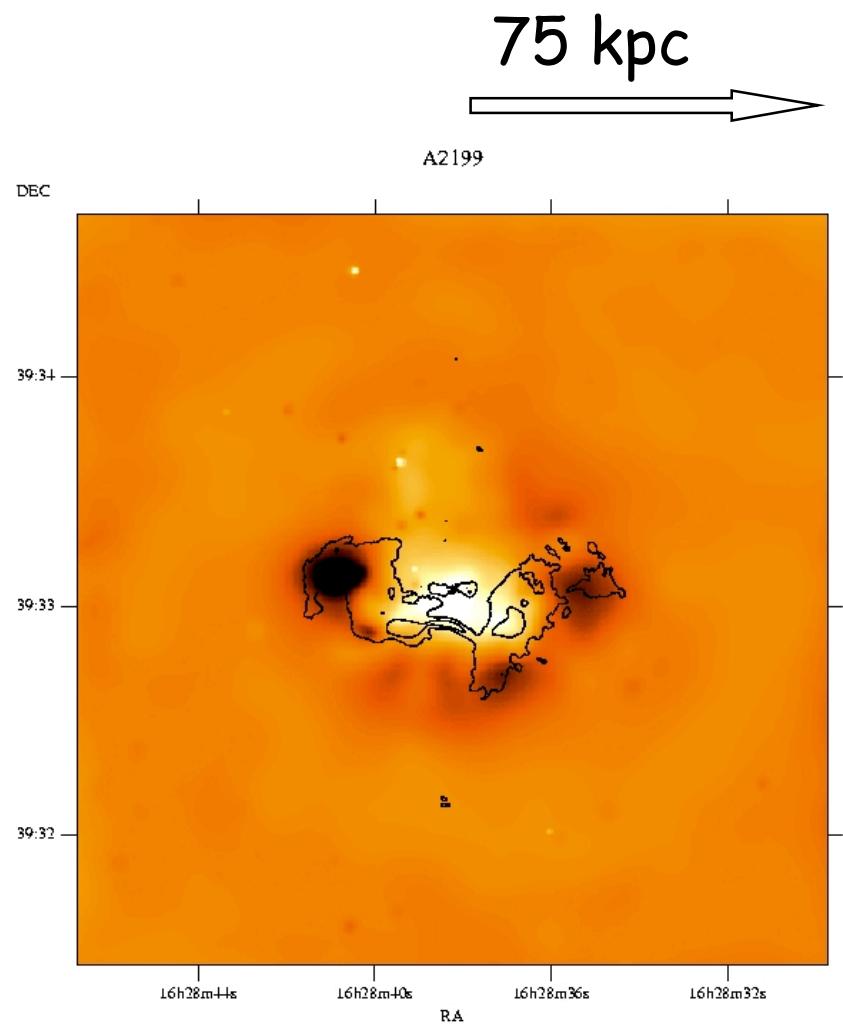
Voigt et al 03



Faraday rotation - strong B



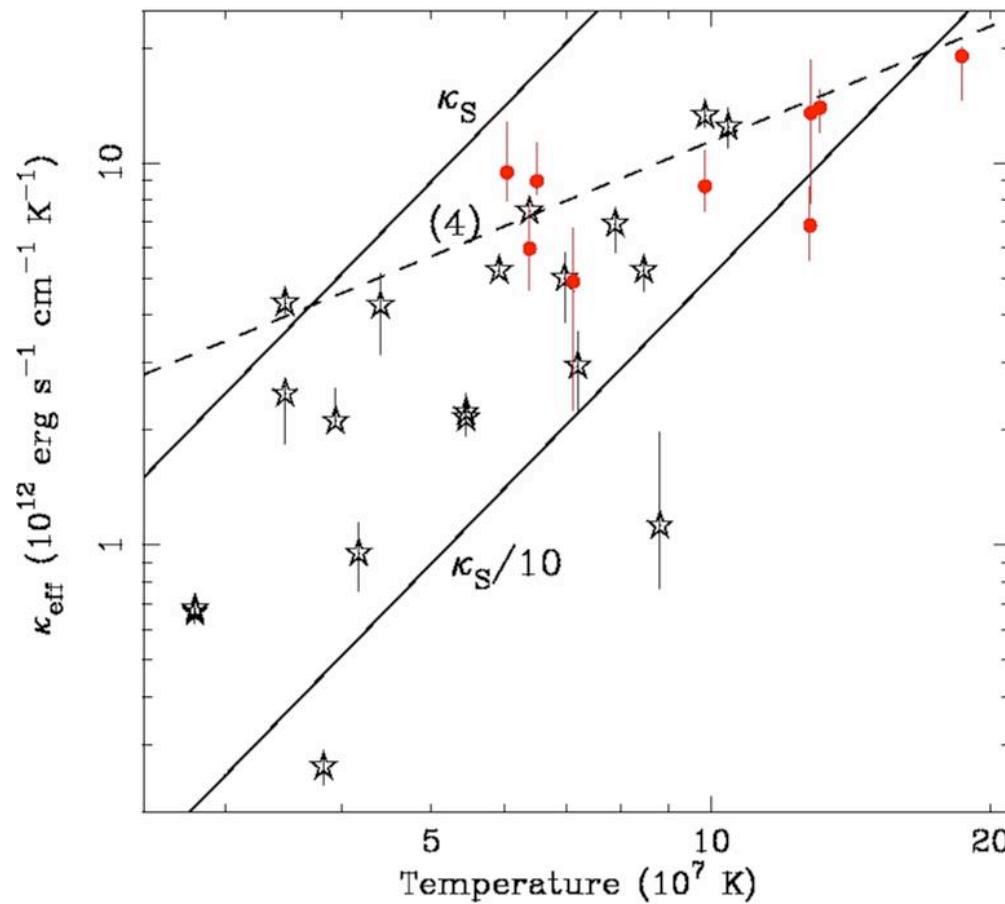
Centaurus: Taylor et al 02



A2199: Johnstone et al 02

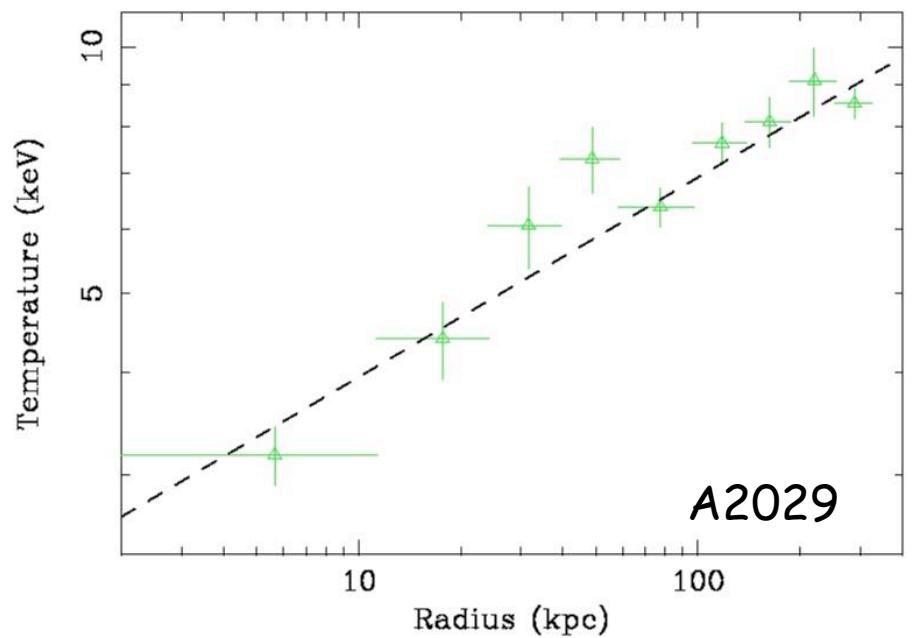
Thermal Conduction?

(Narayan & Medvedev 01; Voigt et al 02)

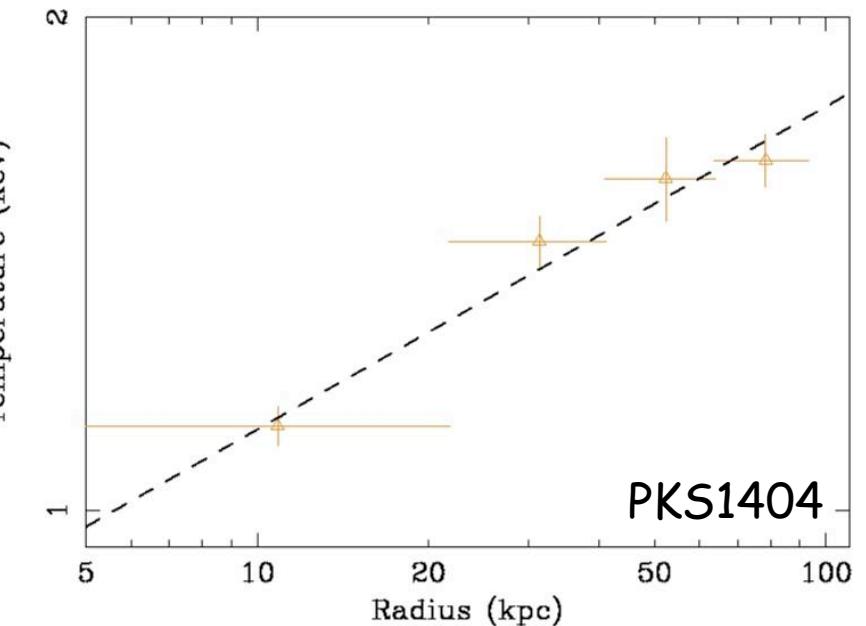


Fabian et al 02

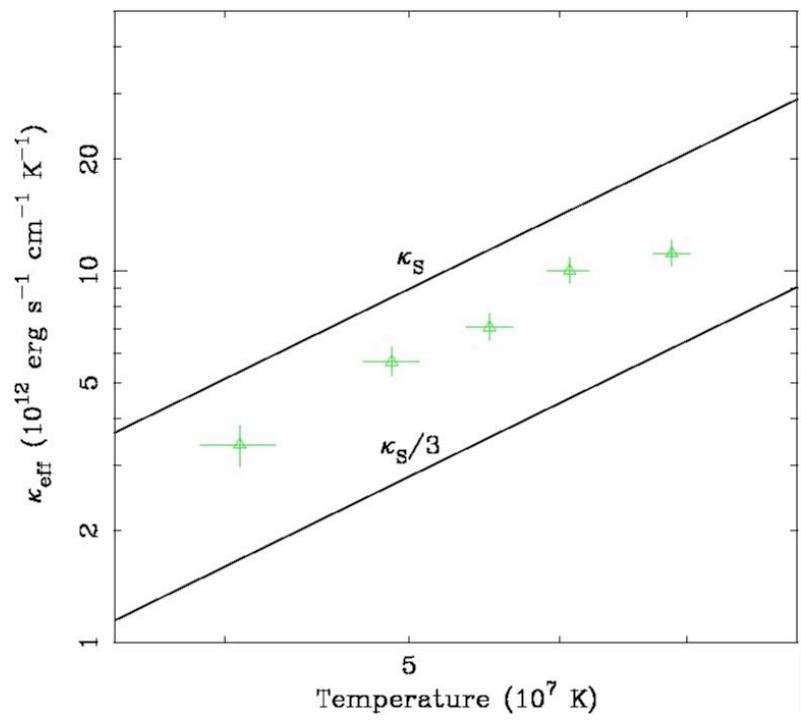
Possible if $\kappa_{\text{eff}} \sim \kappa_{\text{Spitzer}}$



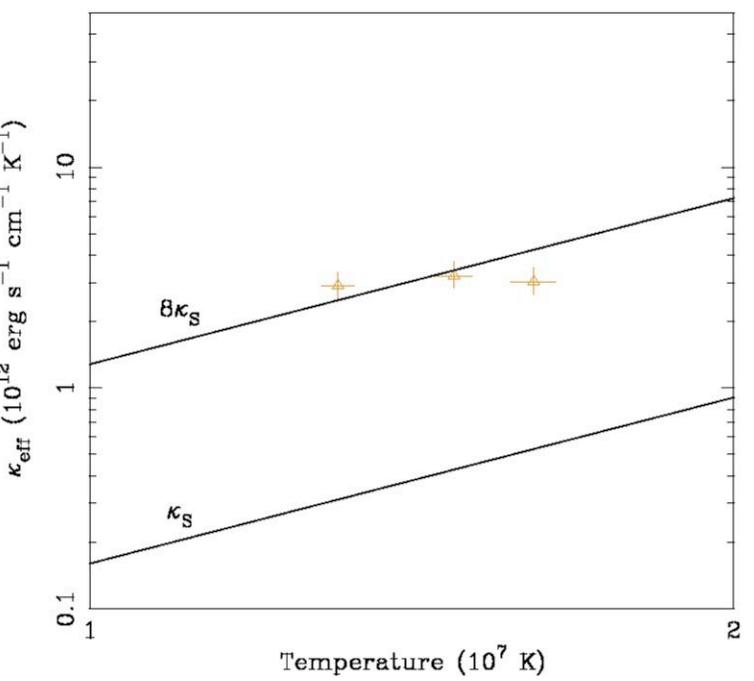
A2029



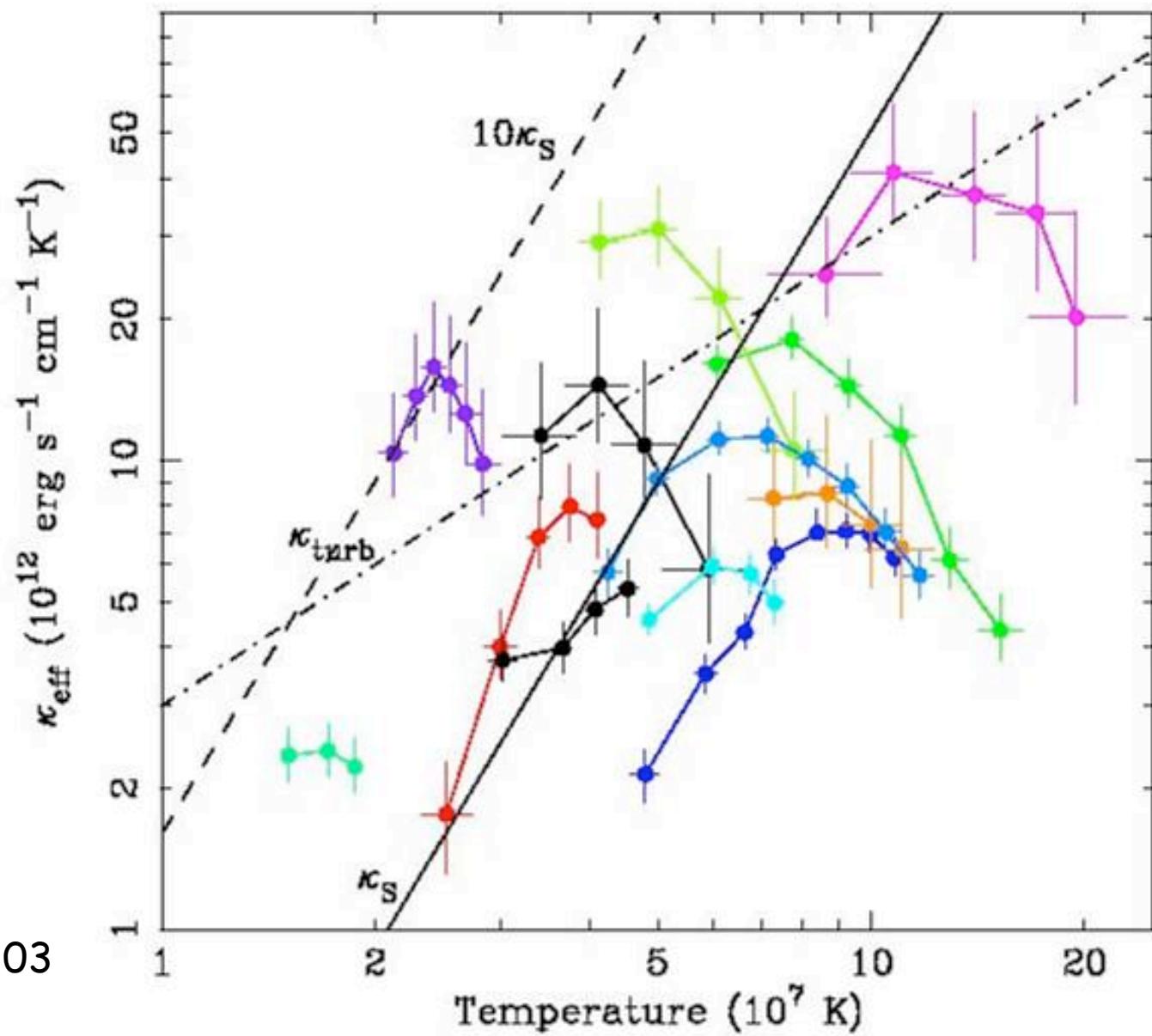
PKS1404



Voigt et al 03

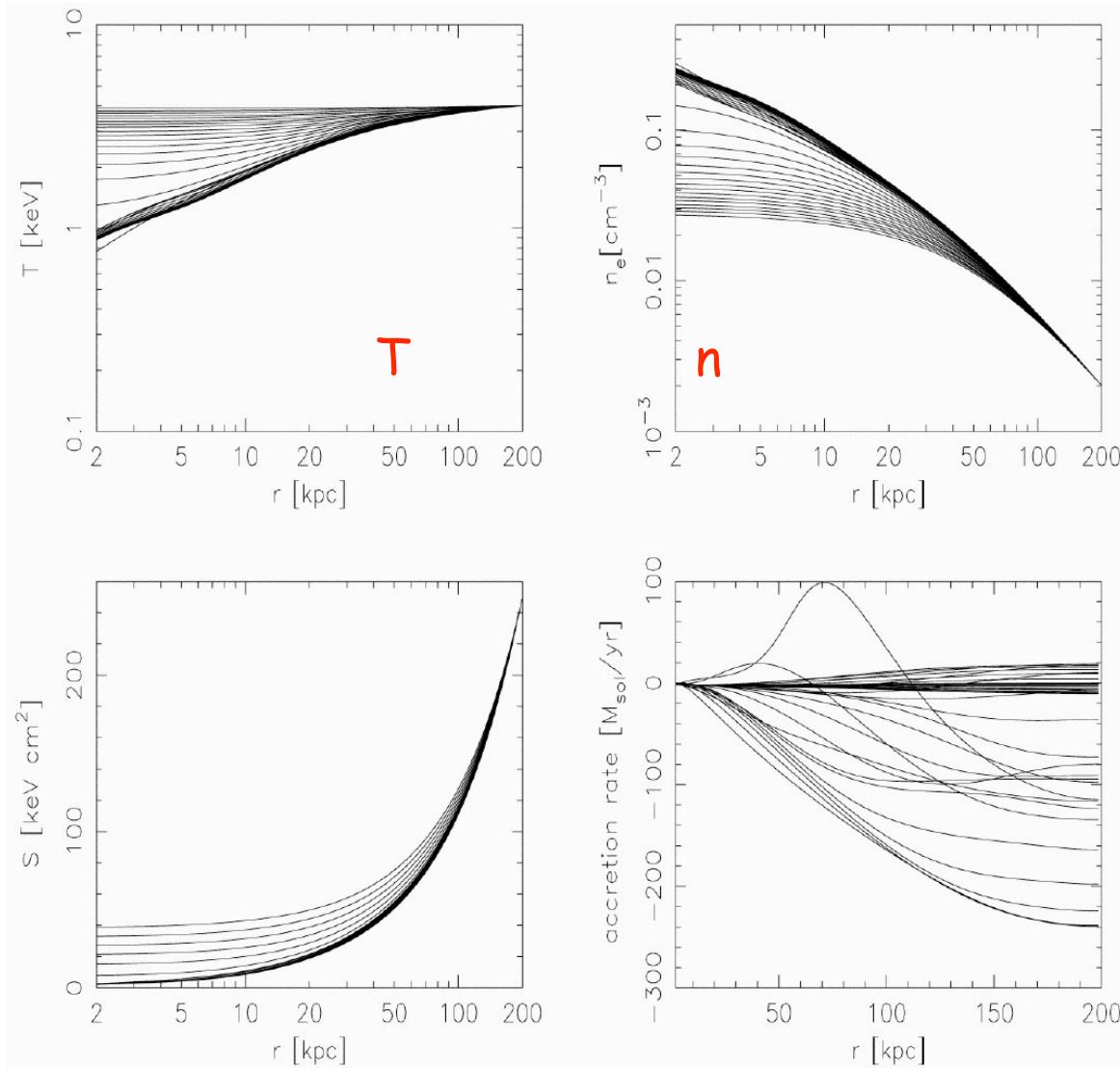


Required effective conductivity

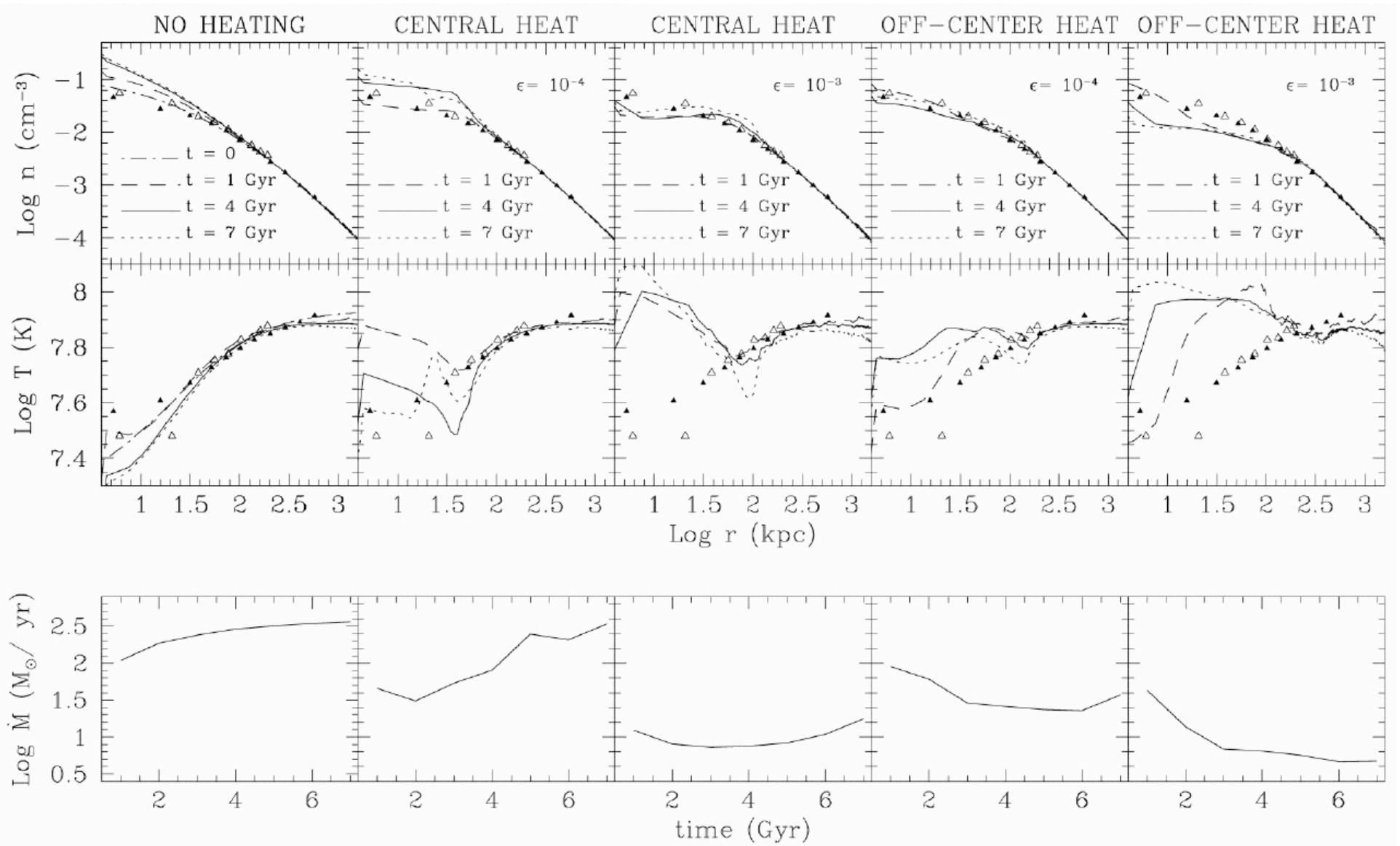


Voigt et al 03

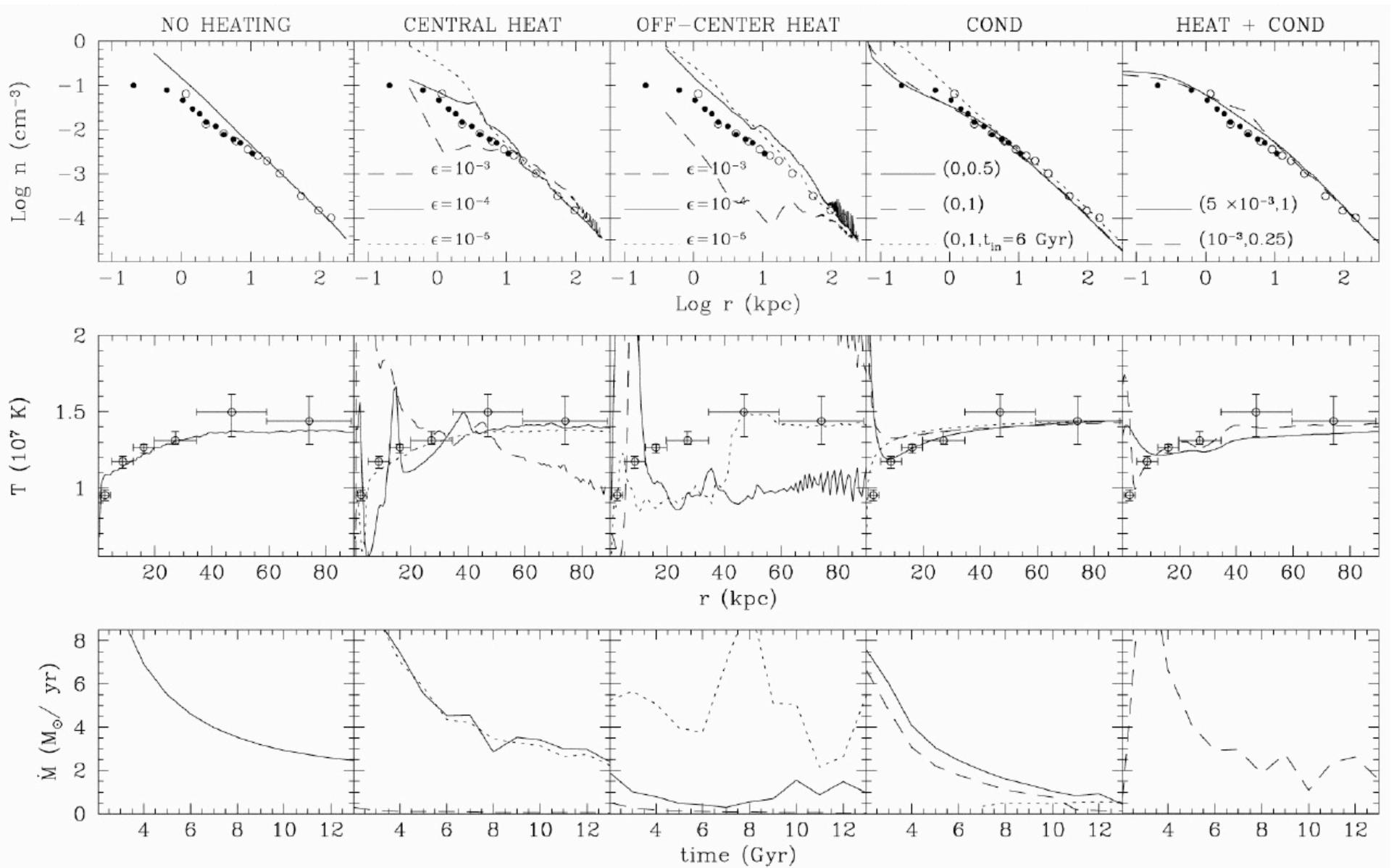
Heating + conduction



Ruszkowski & Begelman 02



Brighenti & Mathews 03



Brighenti & Mathews 03

There is surely *some* mass drop out:

- Cold gas (H_I , CO, H_2 etc)
- Dust ($\text{H}_\text{I}/\text{H}_\text{II}$, ISO, SCUBA...)
- Star formation (blue light, D_{4000} , Mg β ...)

Seen in many central cluster galaxies, but

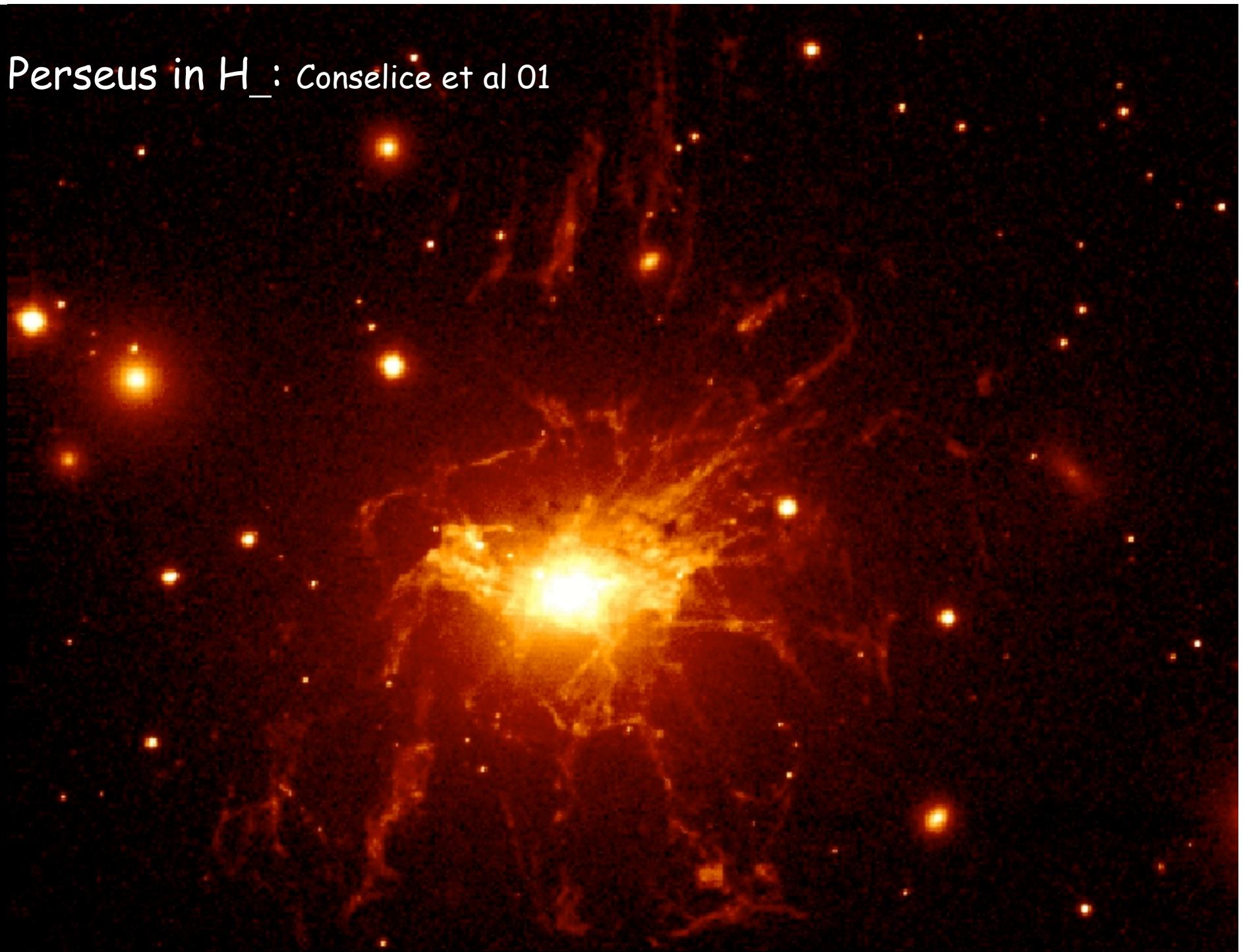
$$M_{\text{stars}} \ll M_X \approx 10 - 100 \text{ s} M_\odot / \text{yr}$$

Dust obscuration?

Stored in cold clouds?

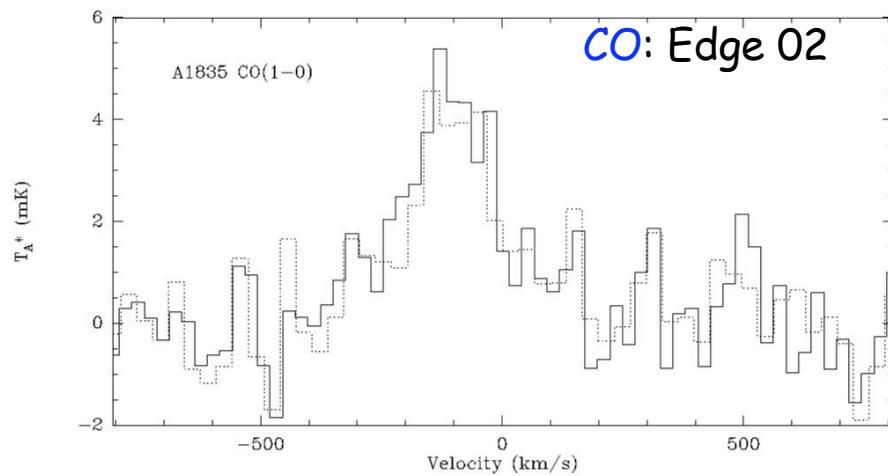
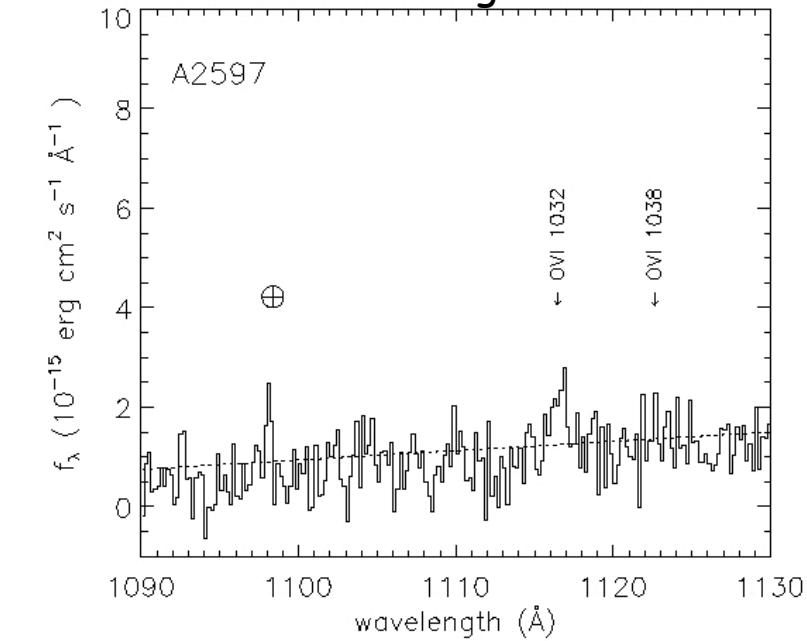
NOTE: missing soft X-ray luminosity \approx UV+opt+IR luminosity in
galaxy

Perseus in H_α: Conselice et al 01



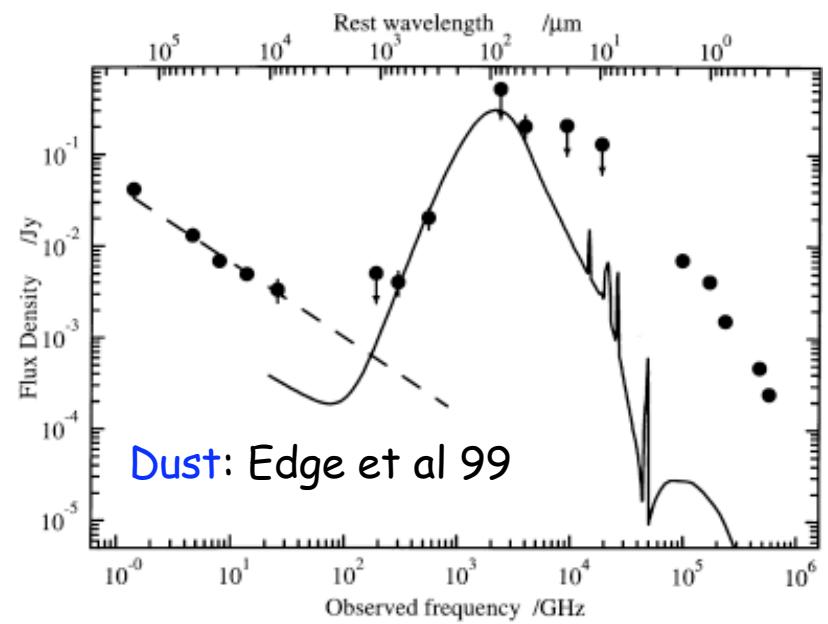
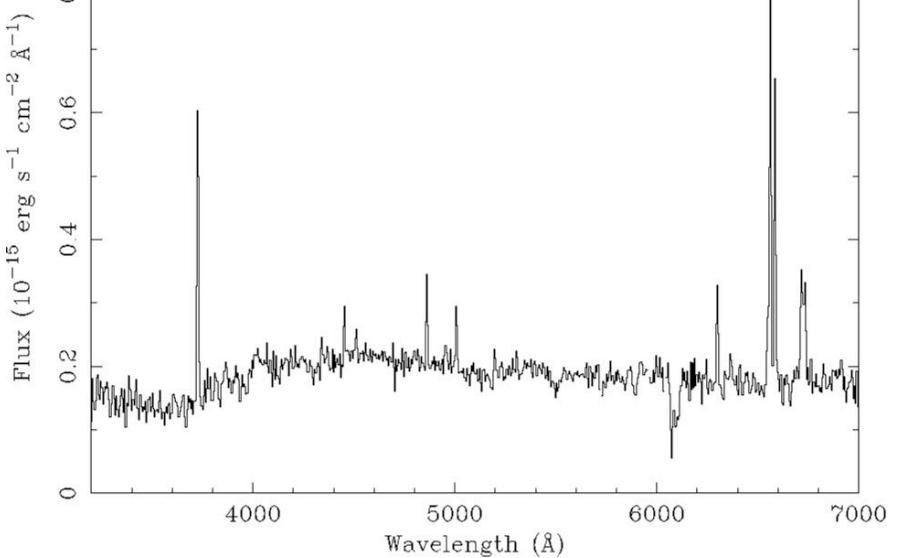
Non X-ray evidence for cool gas and young stars

UV: Oegerle et al 01



A1835 Log L(H α)=42.431

Optical: Crawford et al 99



Solutions to cooling flow problem?

NB: occurs in massive ellipticals to richest clusters, factor of $>10^4$ in L_x

PROBABLY:

$$\dot{M}_{cool} \approx \dot{M}_X / 10$$

To account for the blue light + cold gas

Can feedback from radio source be this good?

- Conduction alone?
- Is mixing occurring?
- Is multiphase slippage occurring (gravitational heating)?

Need:

- Deeper X-ray imaging
- Deeper low frequency radio imaging
- Deeper CO spectra/imaging
- More FUSE OVI spectra

Wider relevance of cooling flow problem?

Visible parts of galaxies due to gas cooling in dark matter potentials

(White & Rees 78; White & Frenk 90; Kauffmann et al; Frenk et al; Sommerville et al)

Cores of clusters should be a good example!

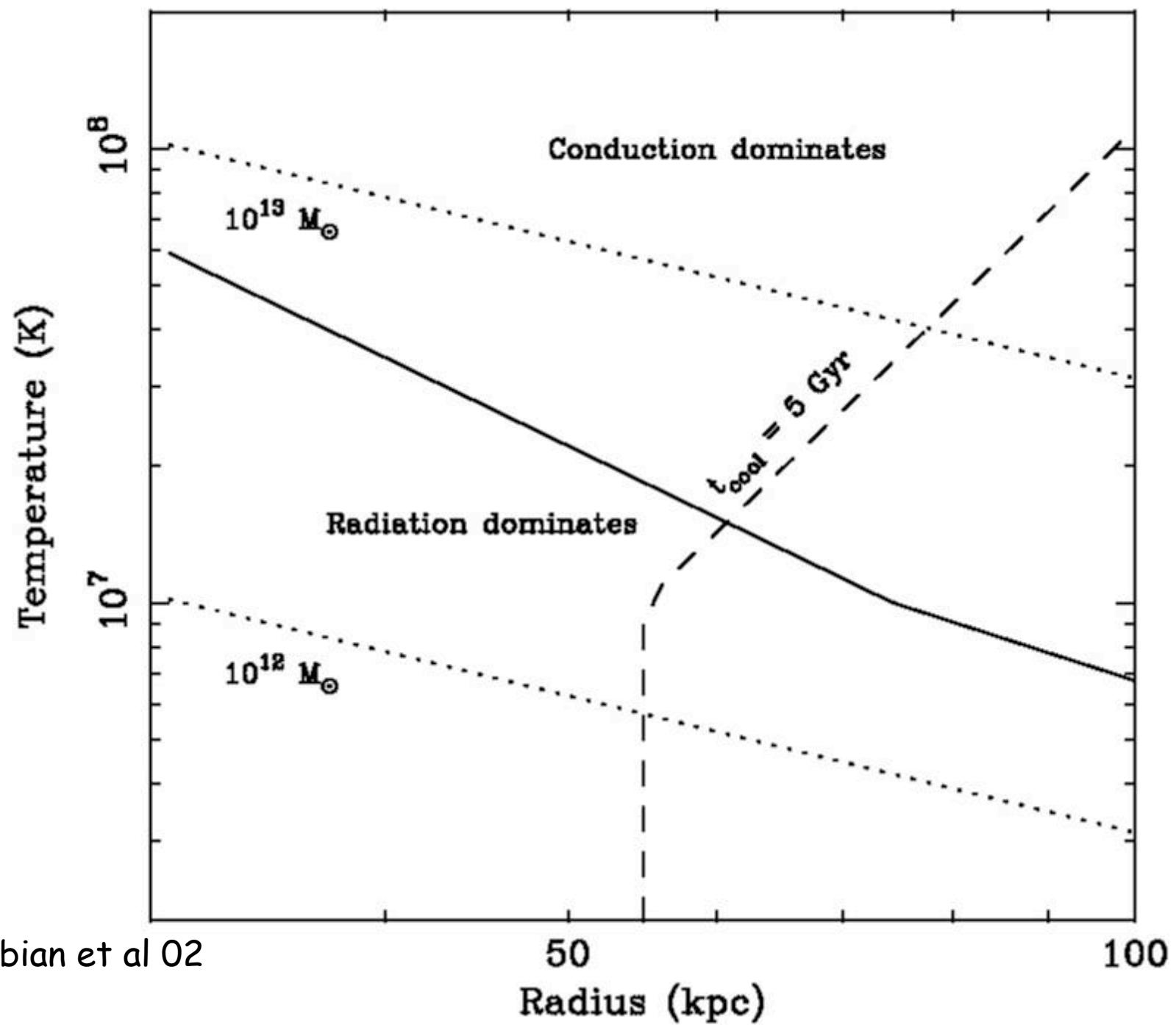
What determines upper mass limit of visible galaxy?

- AGN?

- Conduction?

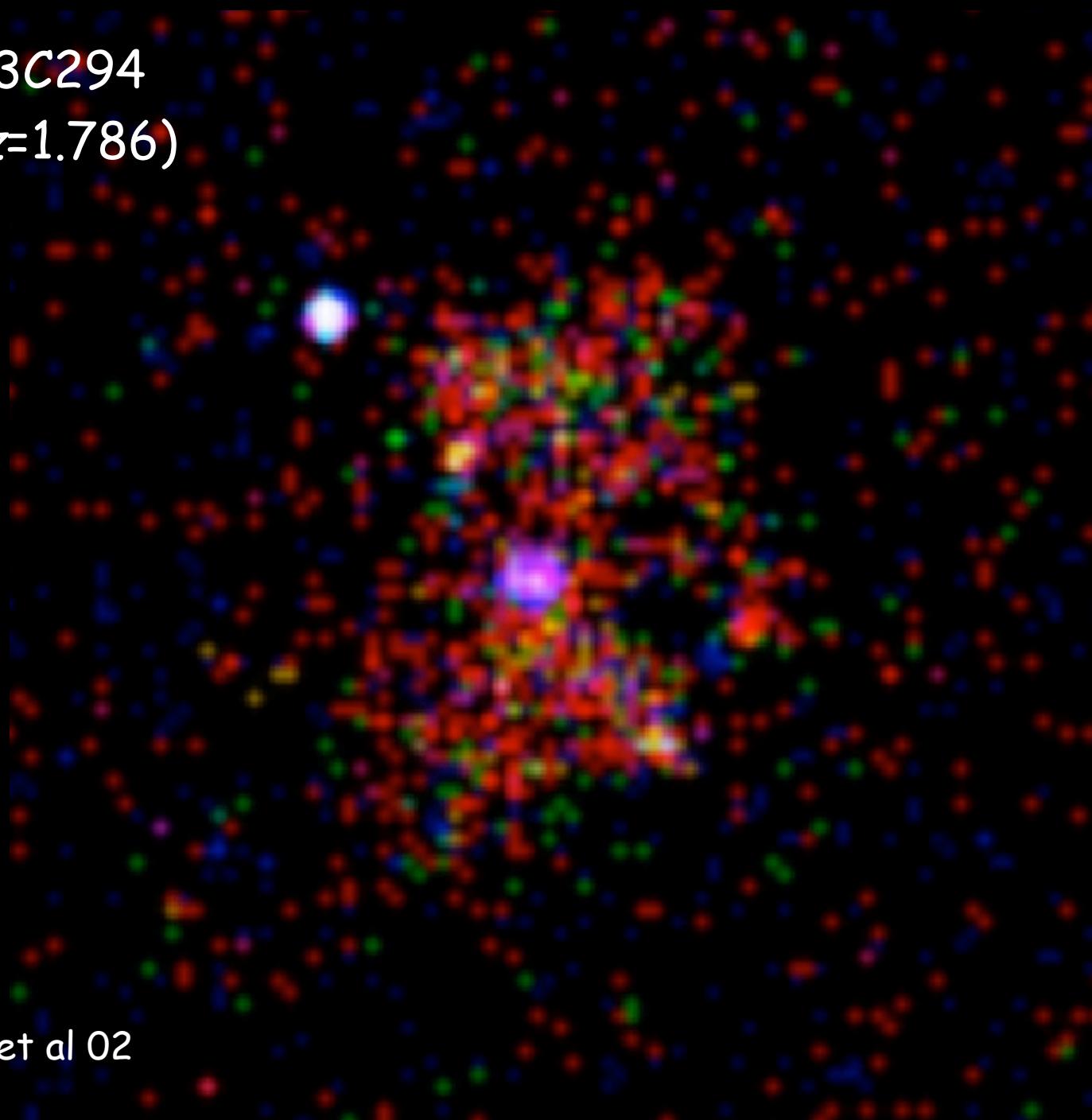
(Fabian et al 02; Benson et al 03)

If heating from AGN with efficiency of 0.1 is prevalent, then can easily destroy visible parts of individual



- Many cluster cores have T dropping in to centre, density rising ($n \propto r^{-1}$ approx) and radiative cooling time dropping to $\sim 10^8$ yr.
 - Cold gas and massive star formation common nr centre
- Little evidence of X-ray emitting components below $T_{cluster}/3$ (limits $\sim 5^{10} M_{rad}$ of M_{rad}).
- Central radio source can heat in some cases, but how?
 - (needs to be distributed heat)
 - Requires extreme heating in most luminous objects
(eg RXJ1347, A1835 etc)
- Conduction requires \sim Spitzer, and doesn't solve all objects.
- Similar situation in groups and ellipticals.

3C294
 $(z=1.786)$



Fabian et al 02