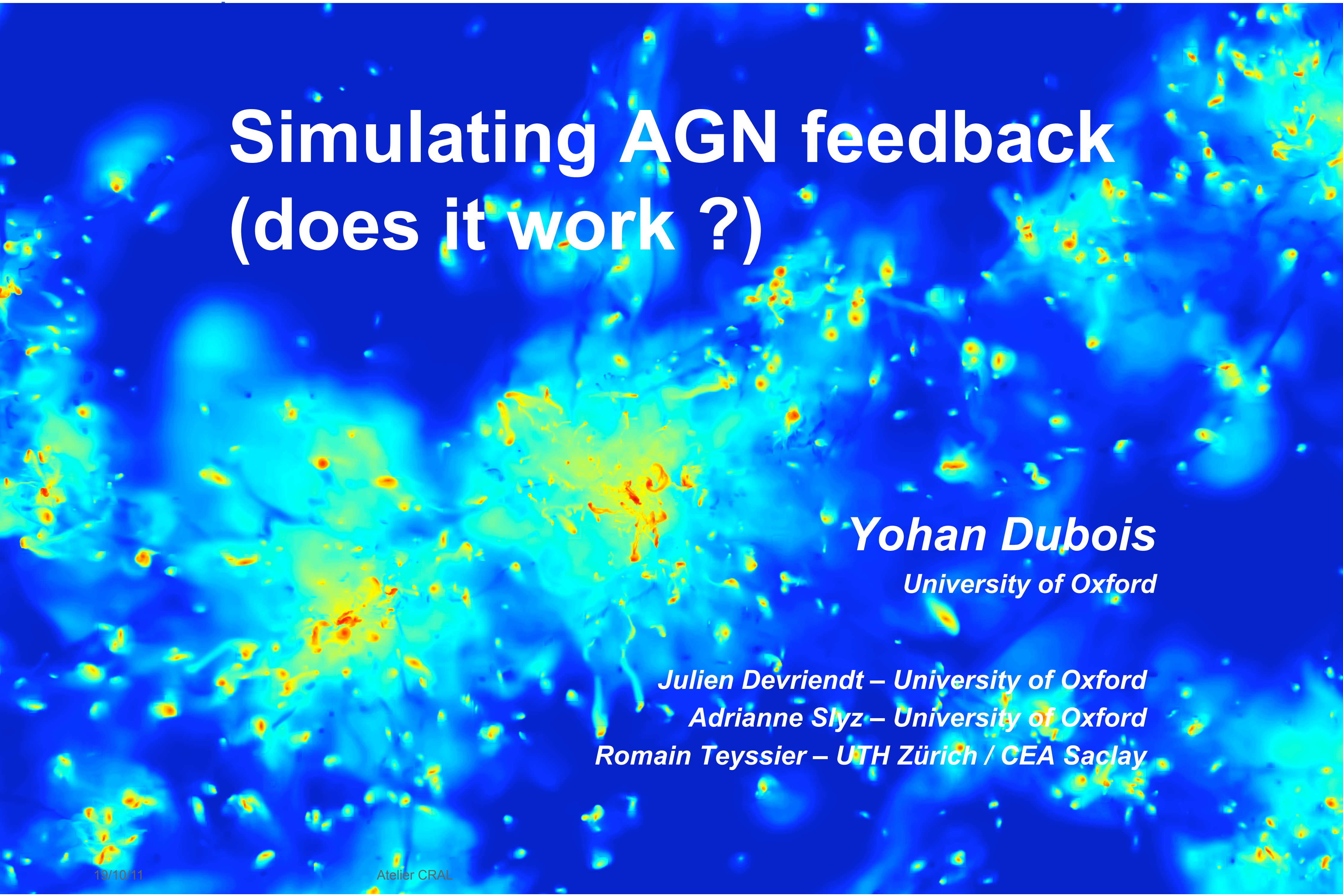


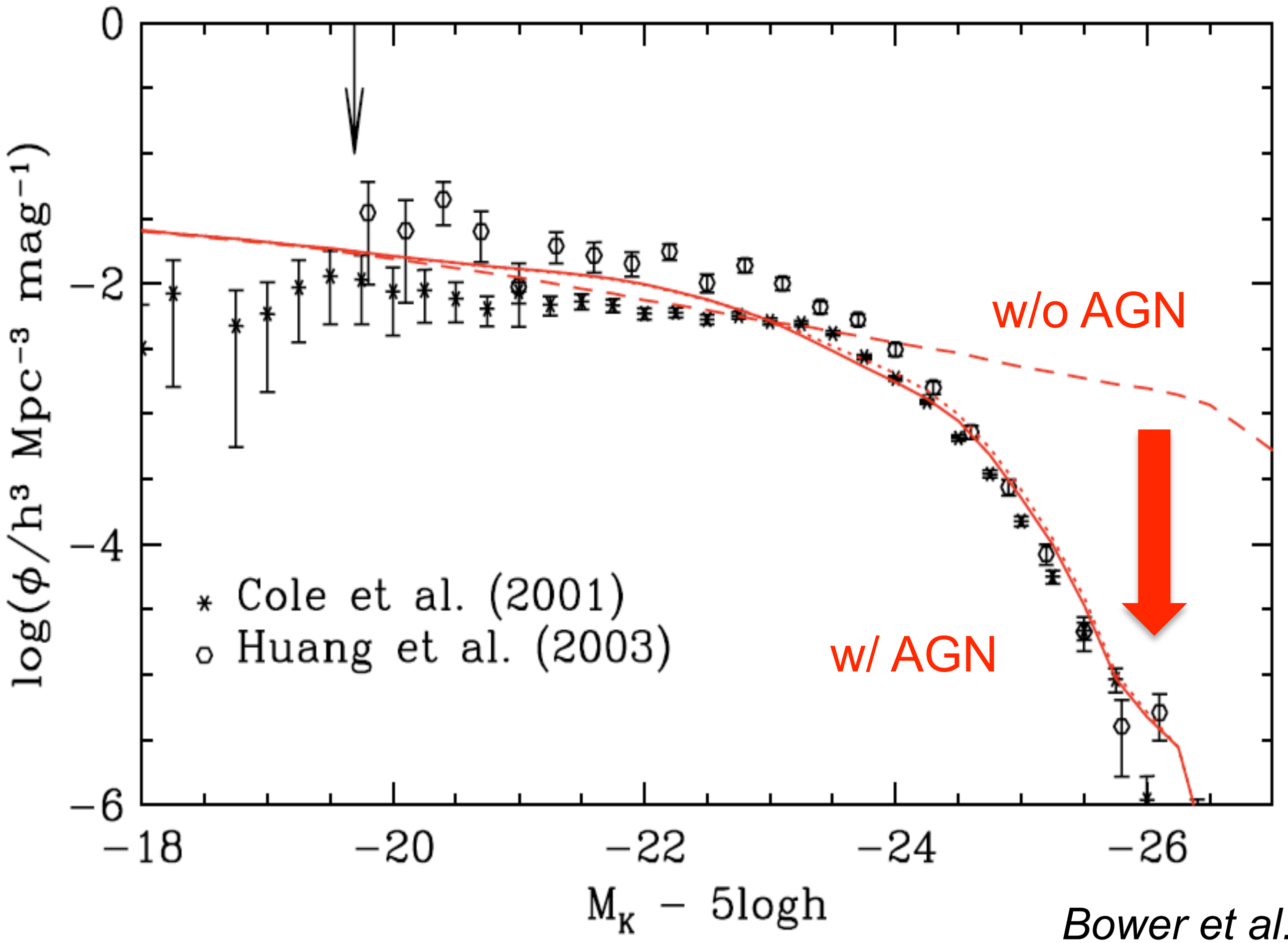
Simulating AGN feedback (does it work ?)

Yohan Dubois
University of Oxford

Julien Devriendt – University of Oxford
Adrianne Slyz – University of Oxford
Romain Teyssier – UTH Zürich / CEA Saclay

Motivation for AGN feedback

Galaxy luminosity (~mass) function
Semi-analytic models



Bower et al., 2006

AGN in cosmological simulations

<u>First</u> AMR simulations of self-consistent AGN feedback in a cosmological context

- Mimic the formation of black holes (where and when) In the centre of galaxies in high gas and stellar-density regions

$$M_{\rm seed} = 10^5\,{\rm M}_\odot$$

AGN in cosmological simulations

First AMR simulations of self-consistent AGN feedback in a cosmological context

- Mimic the formation of black holes (where and when)
- Mimic the gas accretion onto black holes

In the centre of galaxies in high gas and stellar-density regions

$$M_{\rm seed} = 10^5\,{\rm M}_\odot$$

Bondi accretion rate

$$\dot{M}_{\rm BH} \propto \rho \frac{M_{\rm BH}^2}{c_{\rm s}^3}$$

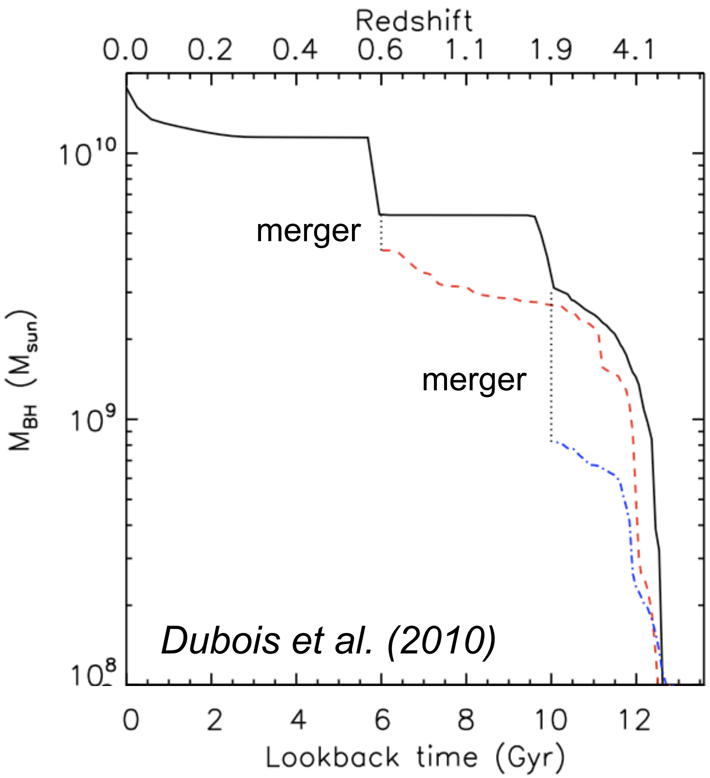
Fast accretion in dense and cold regions

AGN in cosmological simulations

<u>First</u> AMR simulations of self-consistent AGN feedback in a cosmological context

- Mimic the formation of black holes (where and when)
- Mimic the gas accretion onto black holes
- Mimic the mergers between black holes (Friend-of-friend algorithm)

sink particles (Bate et al., 1995, Krumholz et al., 2004)

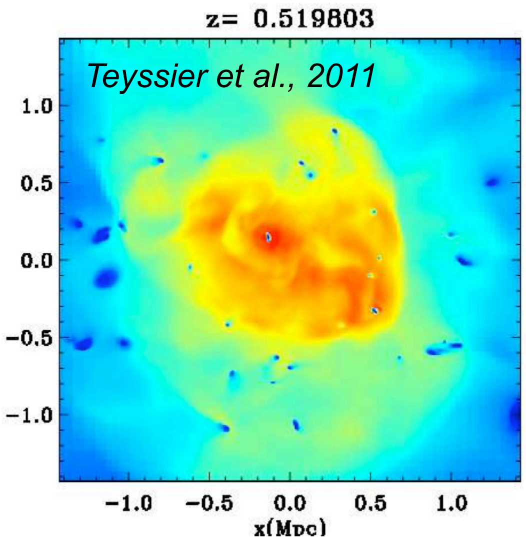


AGN in cosmological simulations

First AMR simulations of self-consistent AGN feedback in a cosmological context

- Mimic the formation of black holes (where and when)
- Mimic the gas accretion onto black holes
- Mimic the mergers between black holes (Friend-of-friend algorithm)
- Mimic the feedback from black holes (AGN)

With thermal input (Teyssier et al., 2011)
(see Sijacki, Di Matteo et al. papers, and Booth & Schaye papers)



Modification of the internal energy

-> increase the gas temperature

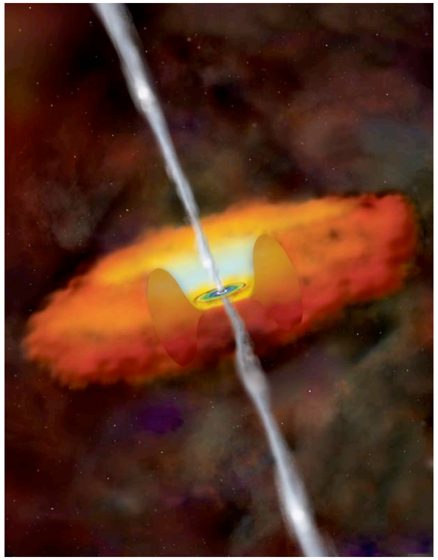
AGN in cosmological simulations

<u>First</u> AMR simulations of self-consistent AGN feedback in a cosmological context

- Mimic the formation of black holes (where and when)
- Mimic the gas accretion onto black holes
- Mimic the mergers between black holes (Friend-of-friend algorithm)
- Mimic the feedback from black holes (AGN)

With thermal input (Teyssier et al., 2011)
or with jets (Dubois et al., 2010)

$$L_{\rm AGN} = \epsilon_f \epsilon_r \dot{M}_{\rm BH} c^2$$



Compute gas angular momentum around the black hole
-> jet axis

Kinetic energy with bipolar outflow

Mass ejected with velocity 10 000 km/s

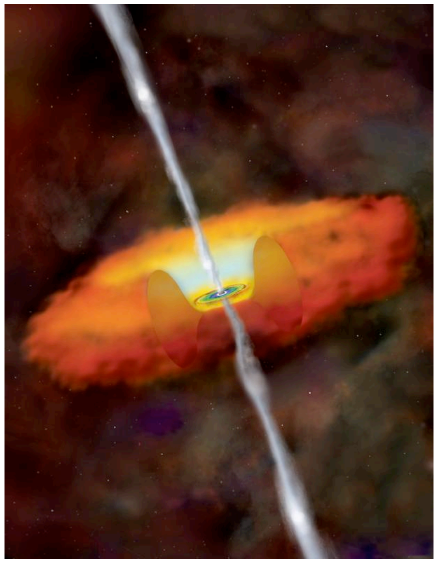
(jet-model based on Omma et al. 2004)

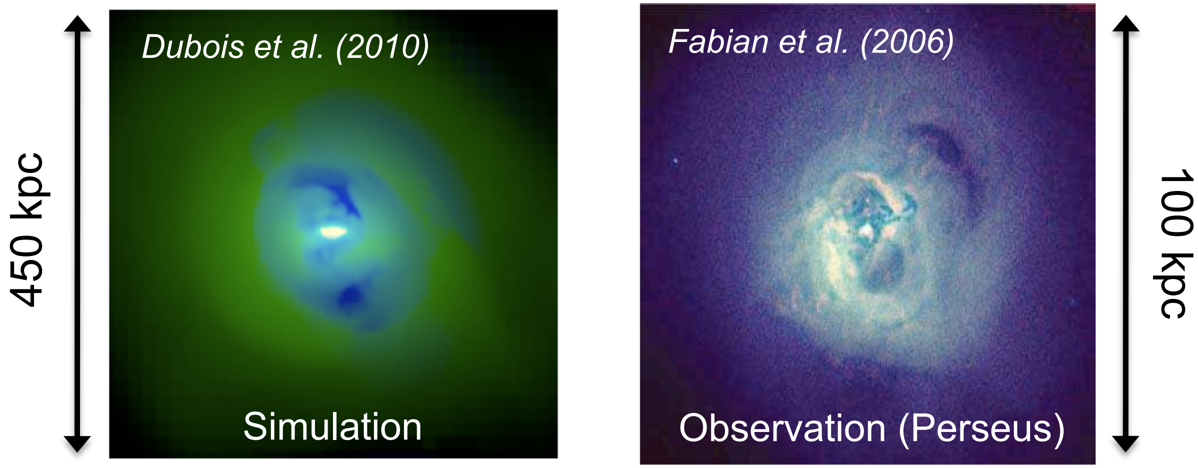
<u>First</u> AMR simulations of self-consistent AGN feedback in a cosmological context

- Mimic the formation of black holes (where and when)
- Mimic the gas accretion onto black holes
- Mimic the mergers between black holes (Friend-of-friend algorithm)
- Mimic the feedback from black holes (AGN)

With thermal input (Teyssier et al., 2011)
or with jets (Dubois et al., 2010)

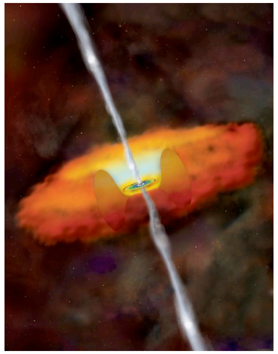
$$L_{\rm AGN} = \epsilon_f \epsilon_r \dot{M}_{\rm BH} c^2$$



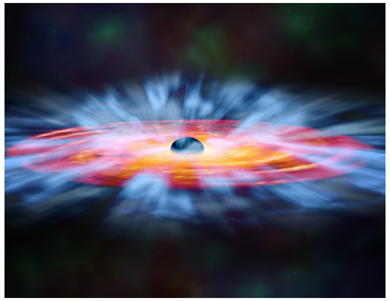


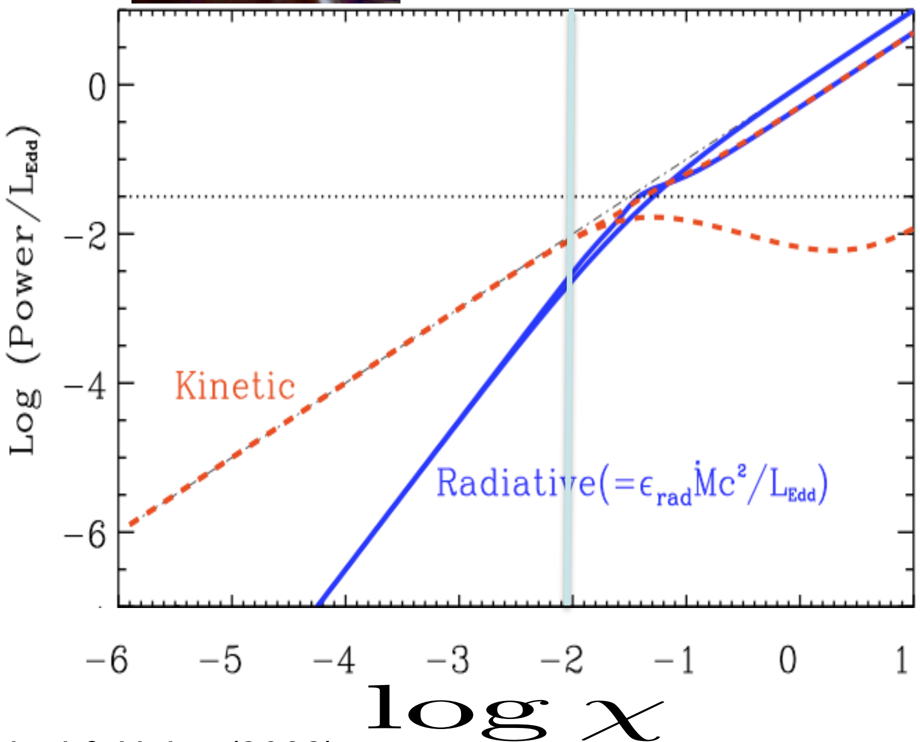
X-ray (3 bands)

Two modes for AGN feedback



or





Merloni & Heinz (2008)

Eddington ratio of the accretion rate

$$\chi = \frac{\dot{M}_{\rm BH} c^2}{L_{\rm Edd}}$$

Radio mode (kinetic jet) when

$$\chi \leq 0.01$$

$$L_{\rm radio} = 0.1 \dot{M}_{\rm BH} c^2$$

Quasar mode (heating) when

$$\chi > 0.01$$

$$L_{\rm quasar} = 0.015 \dot{M}_{\rm BH} c^2$$

Heuristic efficiencies calibrated from simulations

$L_{\rm box} = 12.5\,{\rm Mpc/h}$

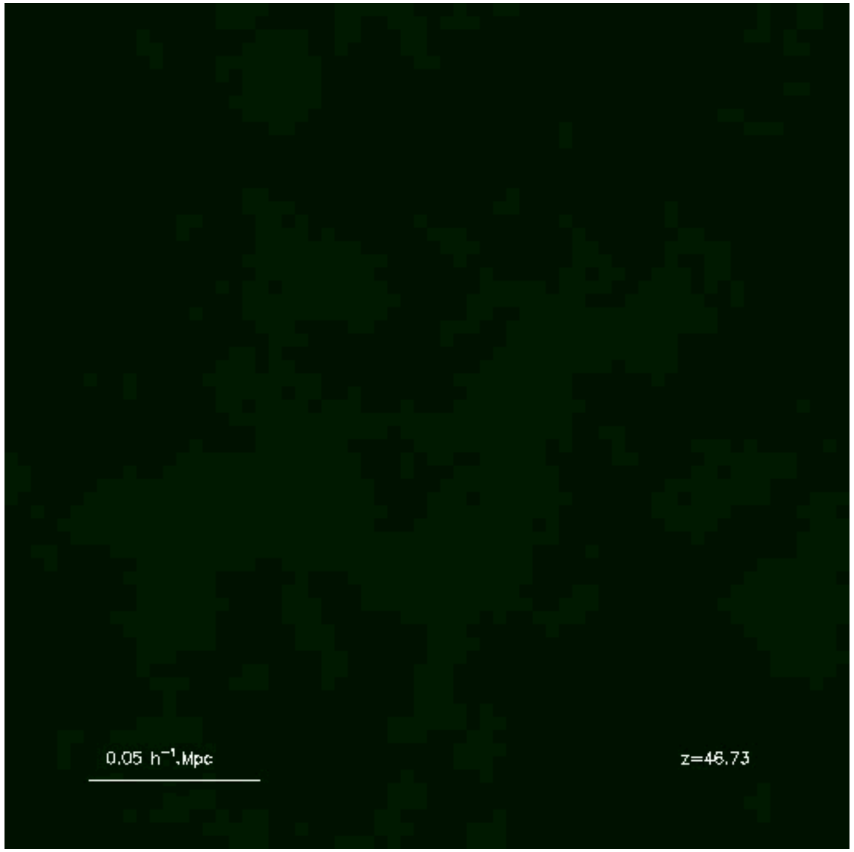
$\Delta x_{\rm min} = 0.38\,{\rm kpc/h}$

WMAP 5-year cosmology

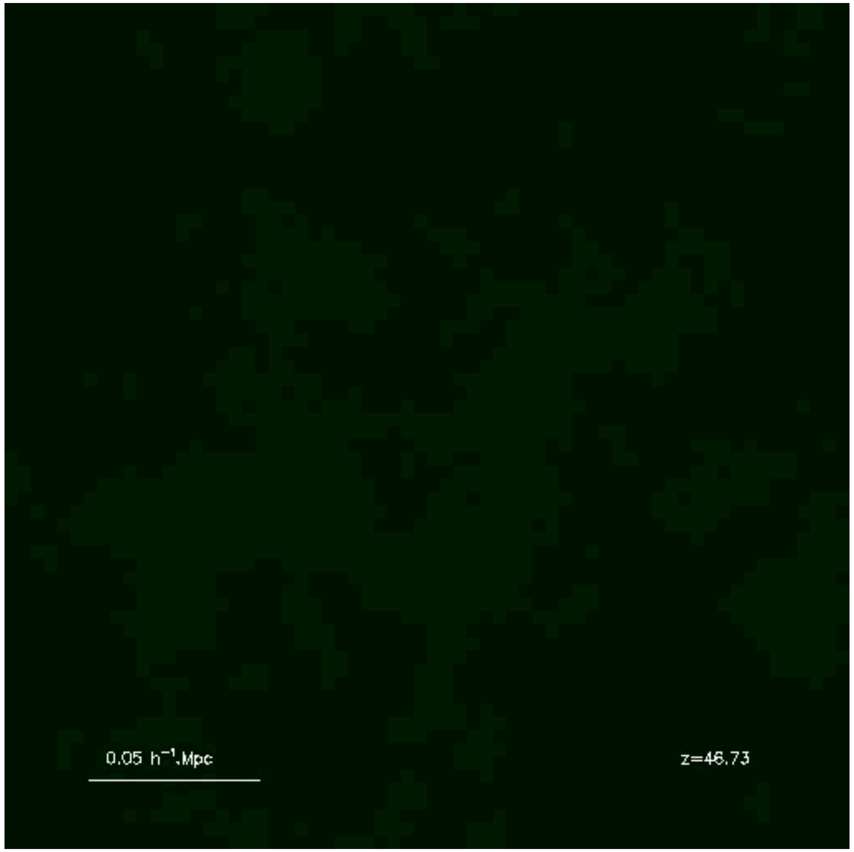
17.10^6 DM particles

$M_{\rm DM} = 6.9\,10^6\,{\rm M_\odot/h}$

Red = gas temperature / Green = gas density / Blue = gas metallicity



No AGN



AGN

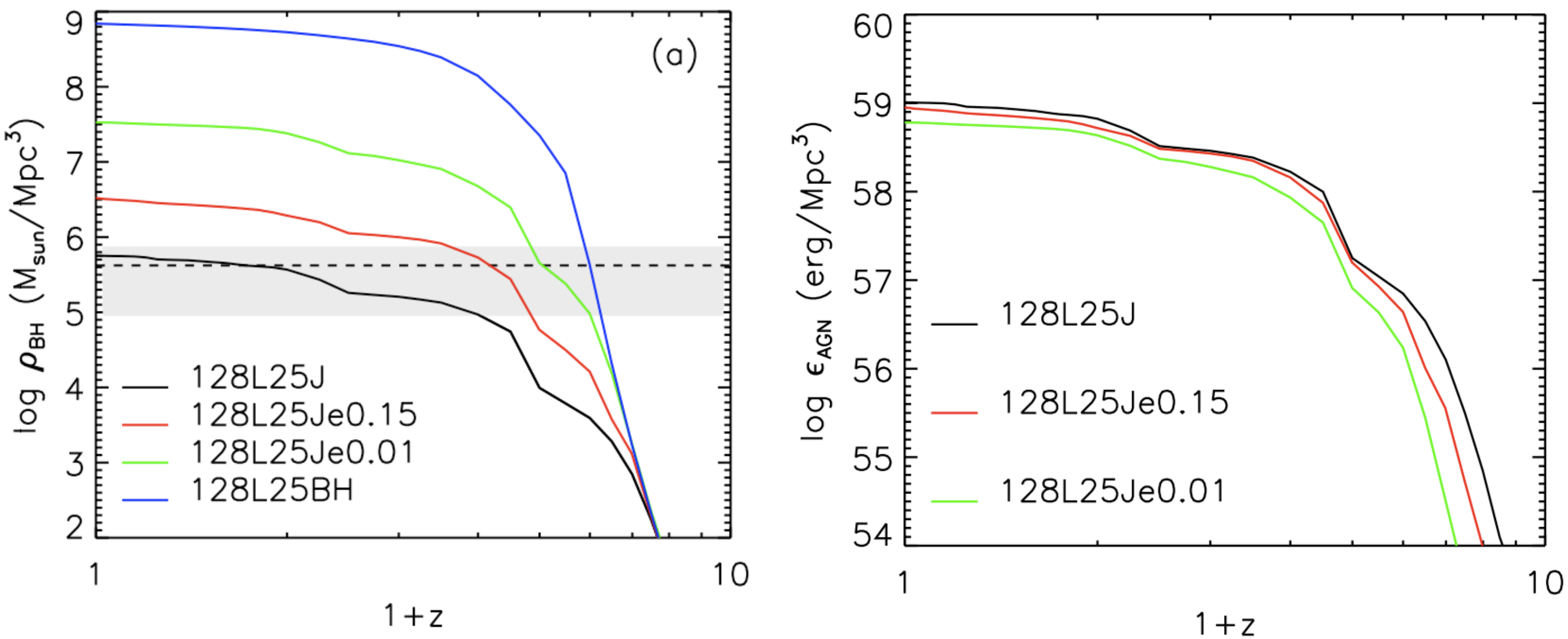
Testing the model: parameters and resolution

Table 1. Simulations performed with different sub-grid galactic models, different parameters for the AGN feedback mode, and different resolutions. (a) Name of the simulation. (b) Number of DM particles. (c) Mass resolution of a DM particle. (d) Size of the simulation box. (e) Minimum resolution reached at $z = 0$. (f) Presence of feedback from SNe. (g) Presence of AGN feedback: "BH" stands for the formation and growth of BHs without AGN feedback, "Jet" stands for the radio mode only, "Heat" stands for the quasar mode only, and "JET/HEAT" stands for the quasar and radio mode both triggered in the same simulation (see text for details). (h) AGN feedback efficiency. (i) AGN energy delay. (j) Maximum relative velocity of the gas to the BH. (k) Mass loading factor of the jet. (l) Initial BH mass. (m) Size of the AGN energy input.

Name	$N_{\rm DM}$	$M_{\rm DM}$ ($M_\odot$/h)	$L_{\rm box}$ (Mpc/h)	Δx (kpc/h)	SN	AGN	ϵ_f	$\Delta M_{\rm d}$ %	$u_{\rm max}$ (km/s)	η	$M_{\rm seed}$ ($M_\odot$)	$r_{\rm AGN}$
256L12noAGN	256^3	$6.9\,10^6$	12.5	0.38	Yes	No	–	–	–	–	–	–
256L12JH	256^3	$6.9\,10^6$	12.5	0.38	Yes	Jet/Heat	1/0.15	0/–	10	100/–	10^5	Δx
64L25JH	64^3	$3.5\,10^9$	25	3.04	Yes	Jet/Heat	1/0.15	0/–	10	100/–	10^5	Δx
128L25BH	128^3	$4.4\,10^8$	25	1.52	Yes	BH	–	–	10	–	10^5	–
128L25J	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	10	100	10^5	Δx
128L25Je0.15	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	0.15	0	10	100	10^5	Δx
128L25Je0.01	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	0.01	0	10	100	10^5	Δx
128L25Jm1	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	1	10	100	10^5	Δx
128L25Jm10	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	10	10	100	10^5	Δx
128L25Jv100	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	100	100	10^5	Δx
128L25Jv1000	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	1000	100	10^5	Δx
128L25Jη10	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	10	10	10^5	Δx
128L25Jη1000	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	10	1000	10^5	Δx
128L25Js0.1	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	10	100	10^4	Δx
128L25Js10	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	10	100	10^6	Δx
128L25J2dx	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	10	100	10^5	$2\Delta x$
128L25J4dx	128^3	$4.4\,10^8$	25	1.52	Yes	Jet	1	0	10	100	10^5	$4\Delta x$
128L25H	128^3	$4.4\,10^8$	25	1.52	Yes	Heat	0.15	–	10	–	10^5	Δx
128L25H2dx	128^3	$4.4\,10^8$	25	1.52	Yes	Heat	0.15	–	10	–	10^5	$2\Delta x$
128L25H4dx	128^3	$4.4\,10^8$	25	1.52	Yes	Heat	0.15	–	10	–	10^5	$4\Delta x$
128L25JH	128^3	$4.4\,10^8$	25	1.52	Yes	Jet/Heat	1/0.15	0/–	10	100/–	10^5	Δx
256L25noSNAGN	256^3	$5.5\,10^7$	25	0.76	No	No	–	–	–	–	–	–
256L25noAGN	256^3	$5.5\,10^7$	25	0.76	Yes	No	–	–	–	–	–	–
256L25JH	256^3	$5.5\,10^7$	25	0.76	Yes	Jet/Heat	1/0.15	0/–	10	100/–	10^5	Δx
128L50noAGN	128^3	$3.5\,10^9$	50	3.04	Yes	No	–	–	–	–	–	–
128L50JH	128^3	$3.5\,10^9$	50	3.04	Yes	Jet/Heat	1/0.15	0/–	10	100/–	10^5	Δx
256L50noAGN	256^3	$4.4\,10^8$	50	1.52	Yes	No	–	–	–	–	–	–
256L50JH	256^3	$4.4\,10^8$	50	1.52	Yes	Jet/Heat	1/0.15	0/–	10	100/–	10^5	Δx

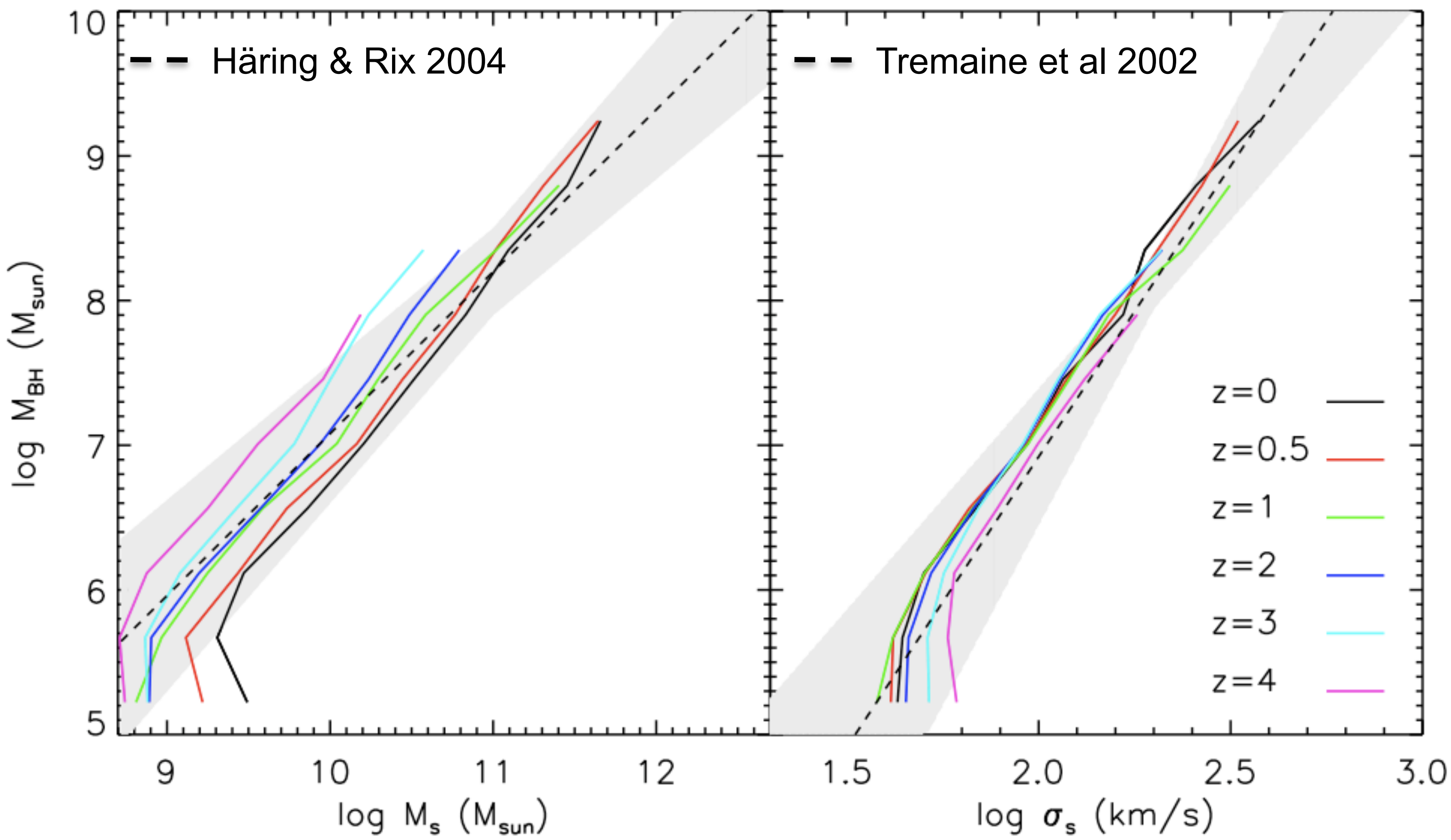
Dubois et al., 2011

Parameter test: the efficiency



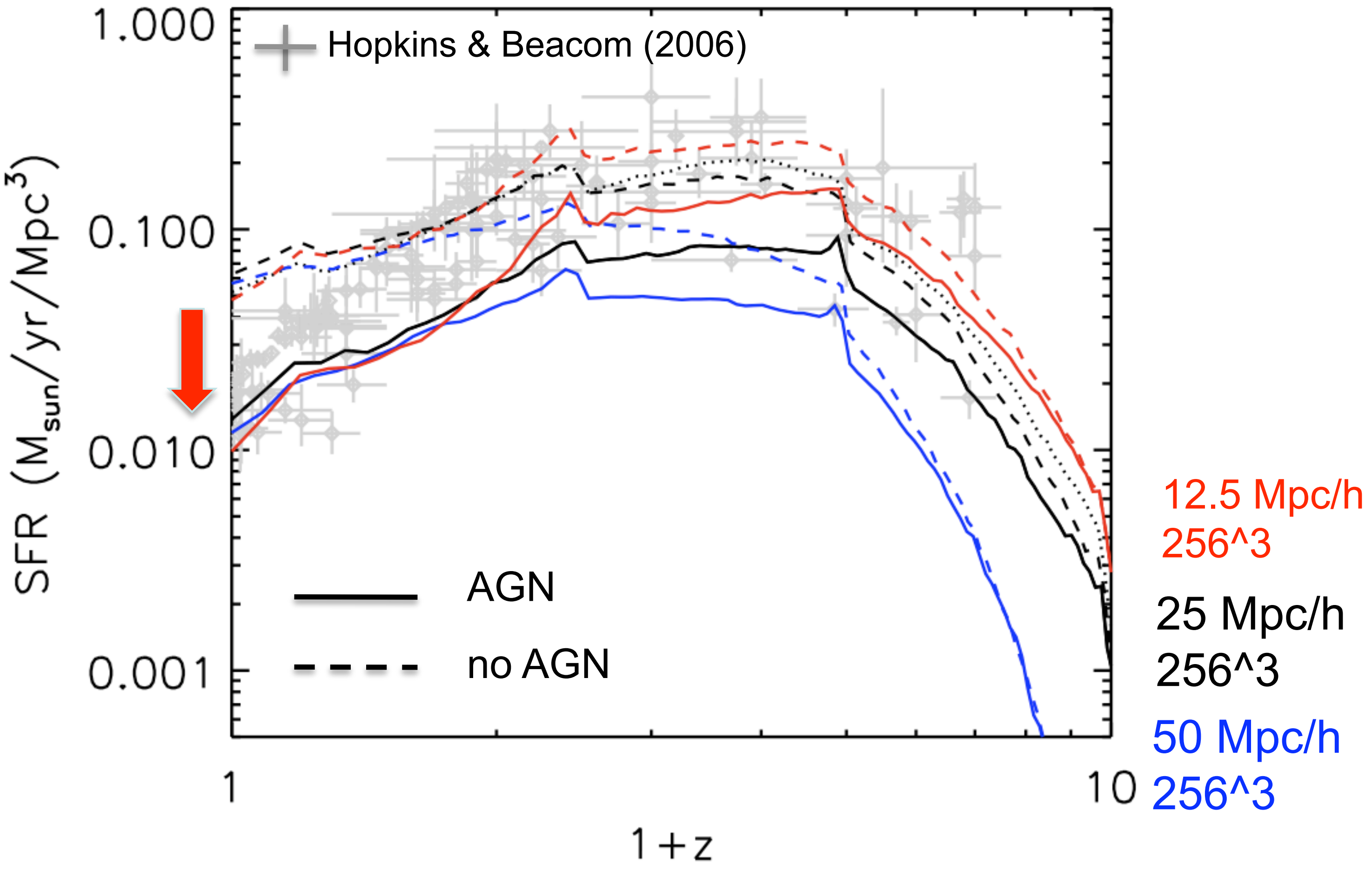
BHs deposit the same energy / independant of the AGN efficiency

Fitting observationnal M_{BH}-M_* / M_{BH}-σ_* laws



Dubois et al., 2011

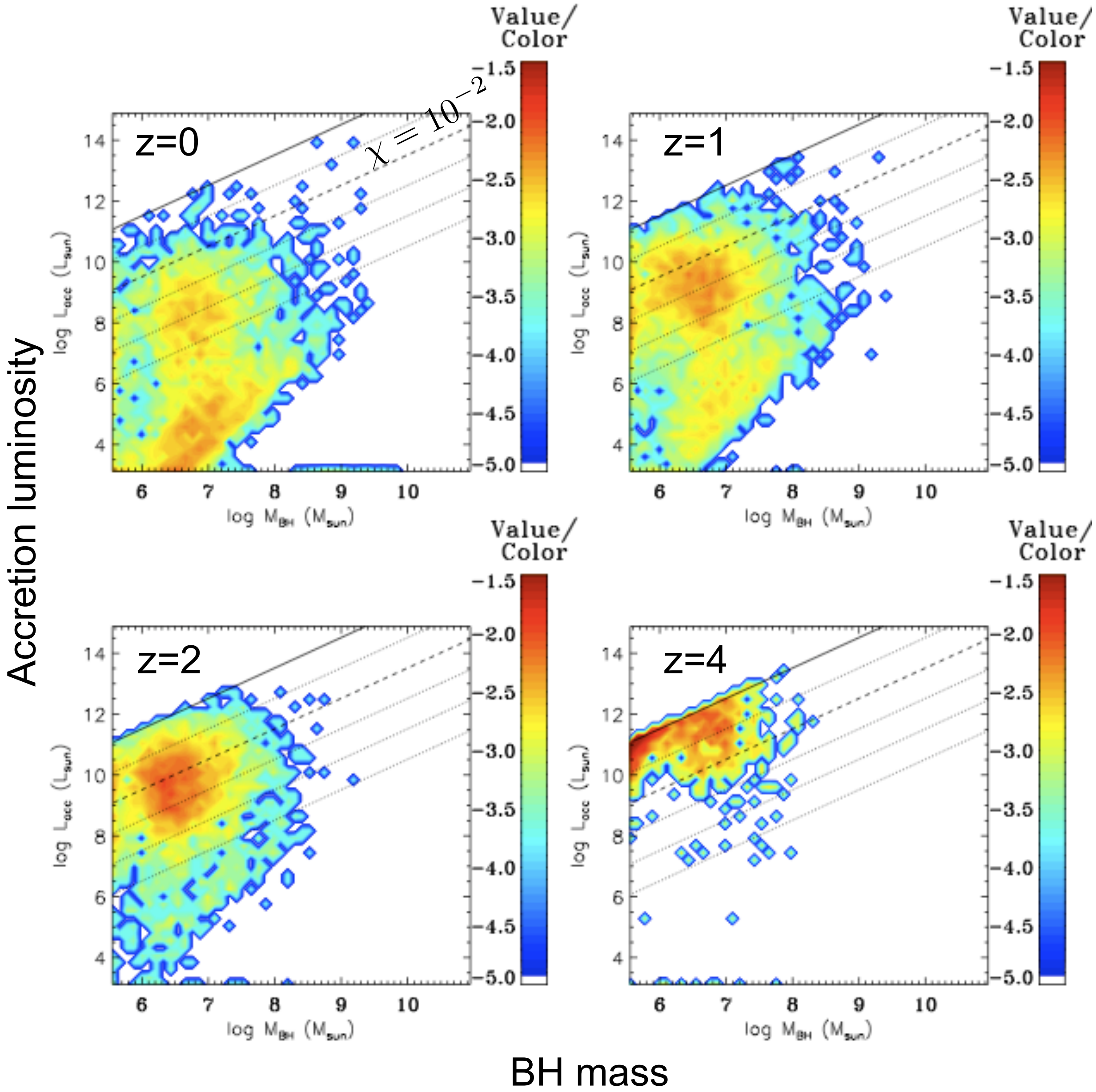
AGN impact massive structures



AGN: reduce star formation

Dubois et al., 2011

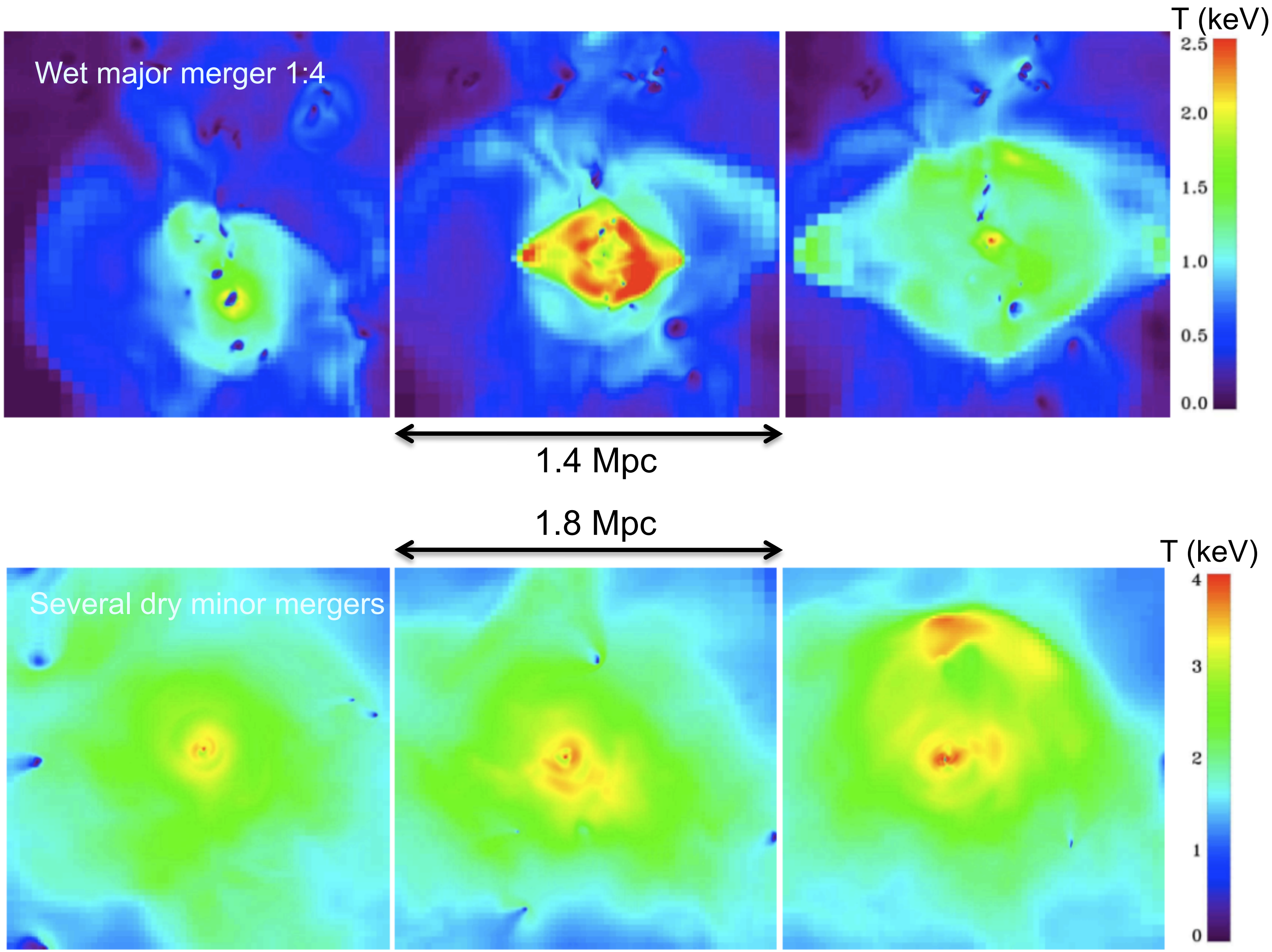
Radio mode or quasar mode ?



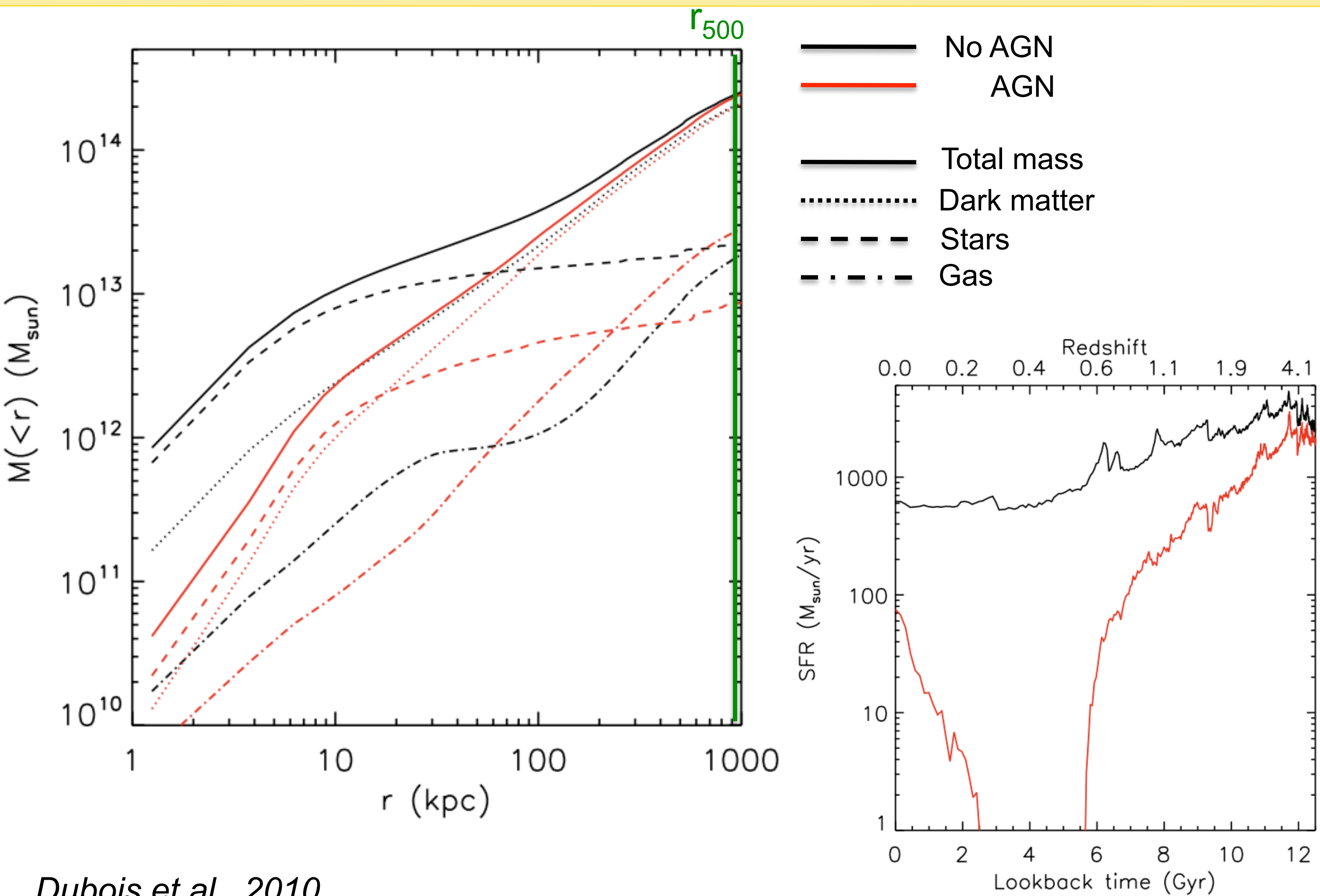
Quasar mode versus radio mode

z=1.5
Quasar
mode

z=0
Radio
mode



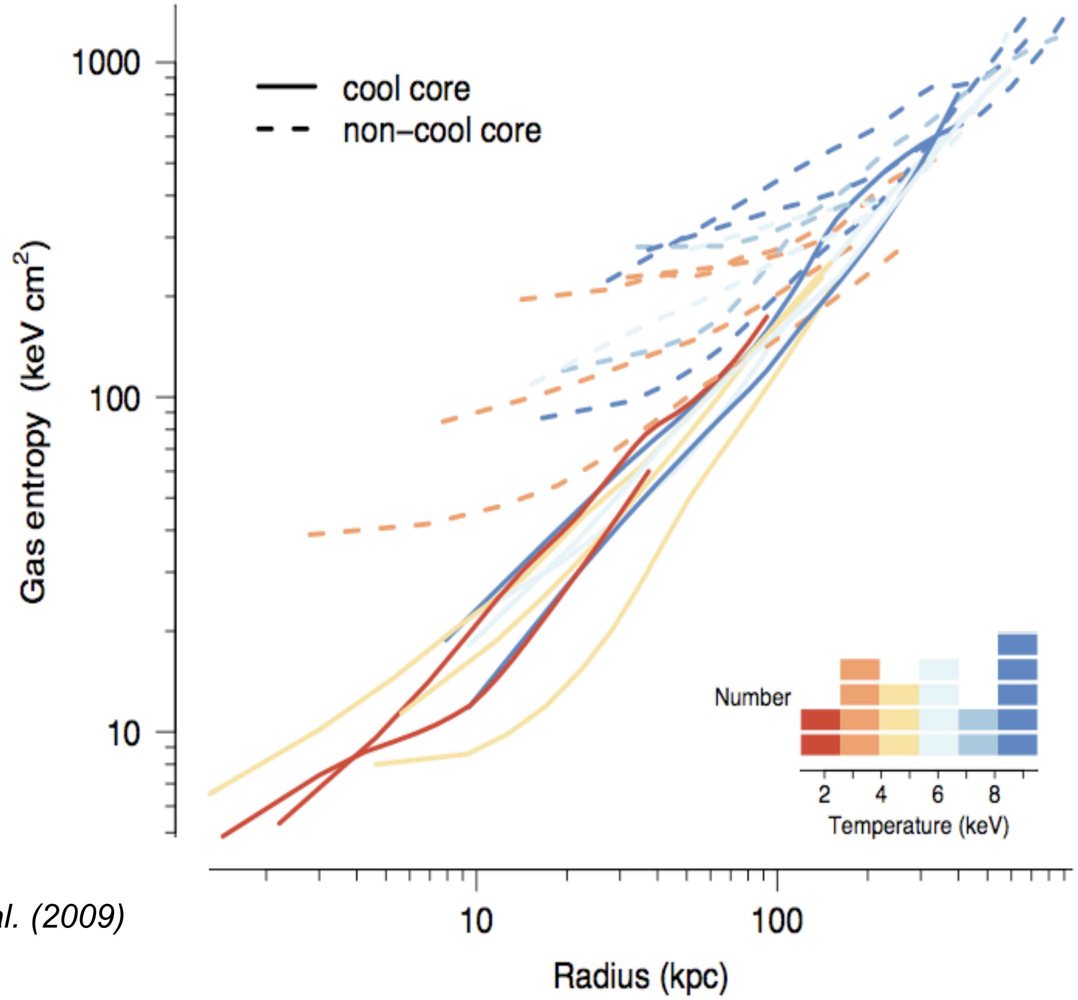
Mass distribution in a cluster of galaxies



Dubois et al., 2010

« Bimodality » in cluster cores

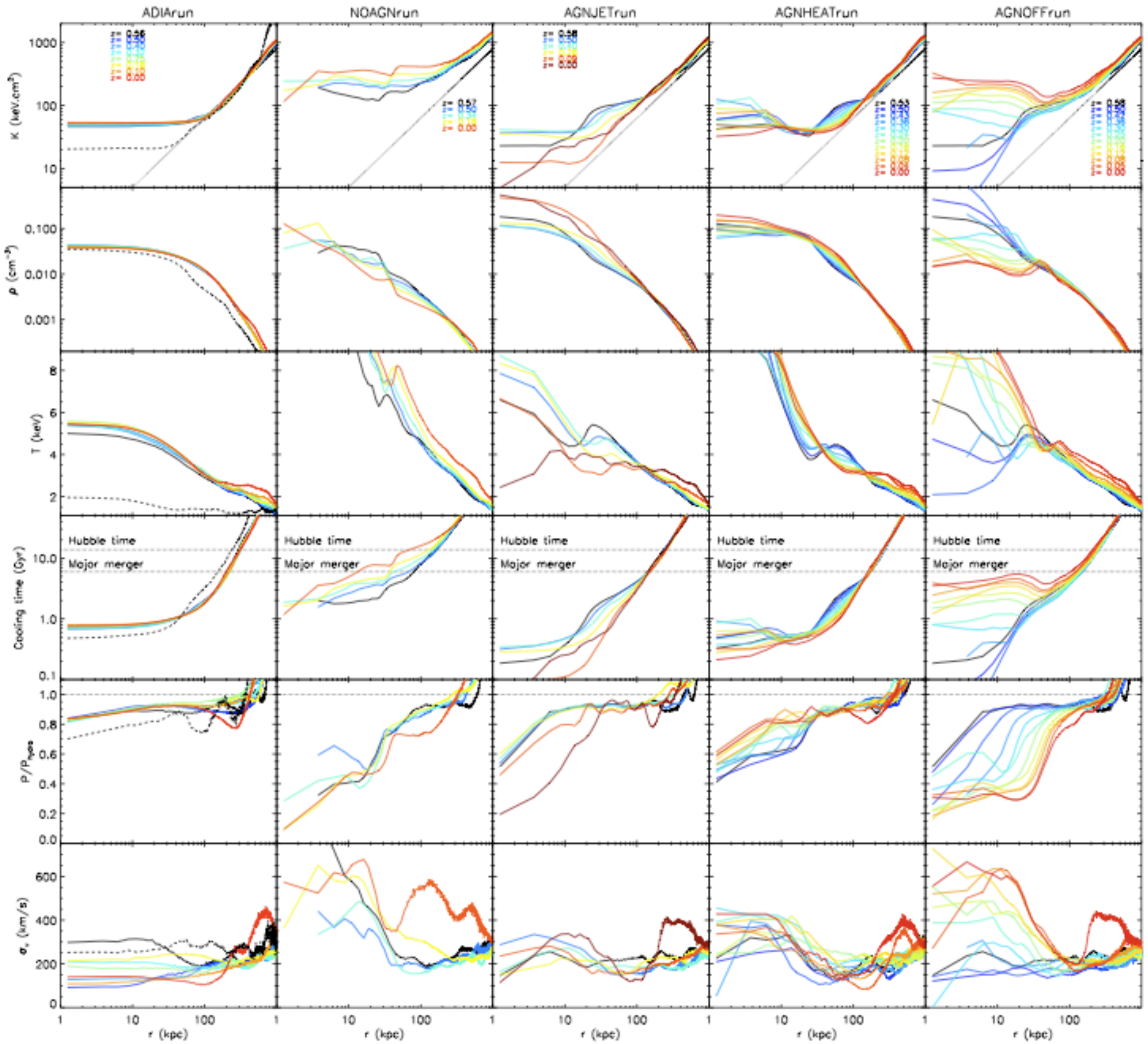
Chandra X-ray observations



Sanderson et al. (2009)

What physics drives the entropy profiles ?

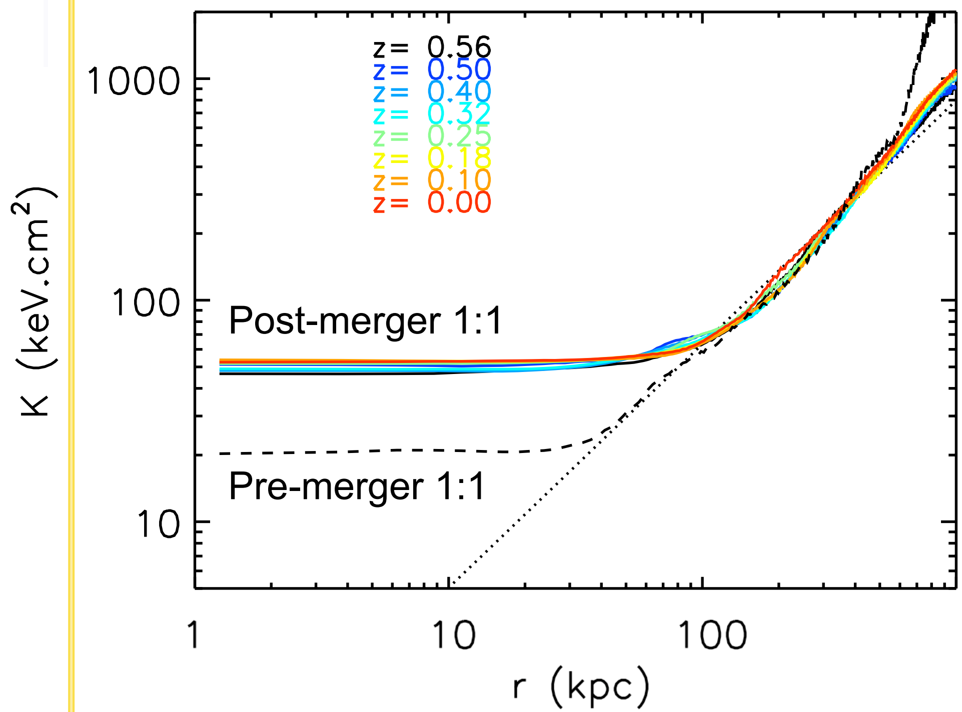
Some hints on the origin of entropy cores



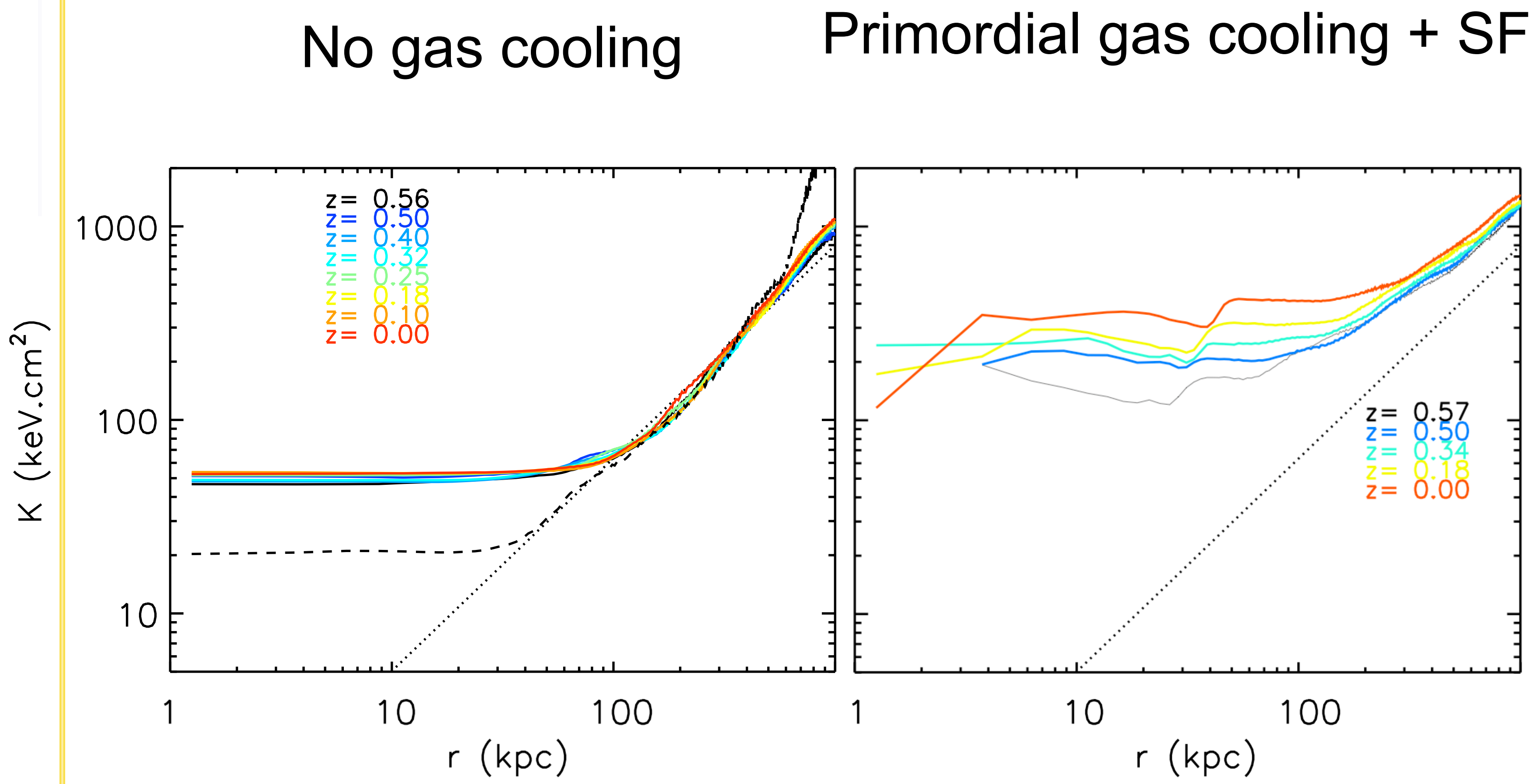
Dubois et al., 2011

Some hints on the origin of entropy cores

No gas cooling



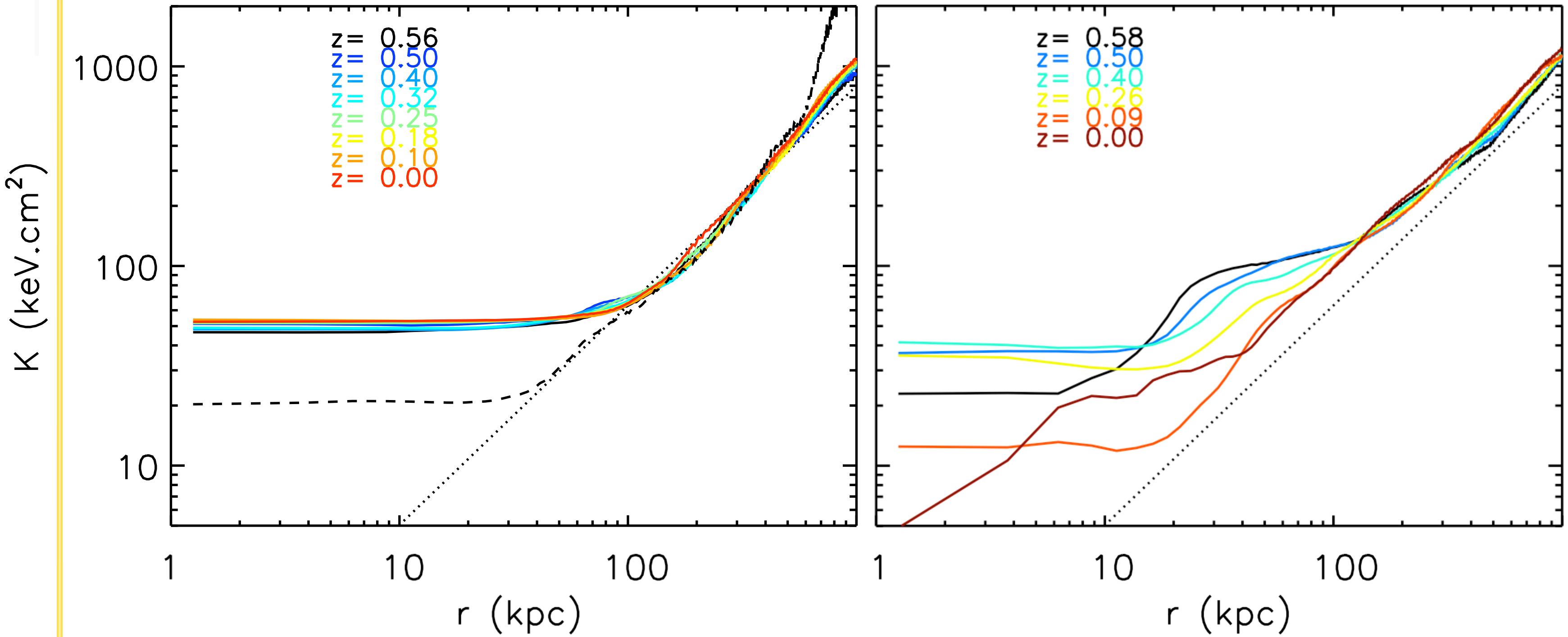
Some hints on the origin of entropy cores



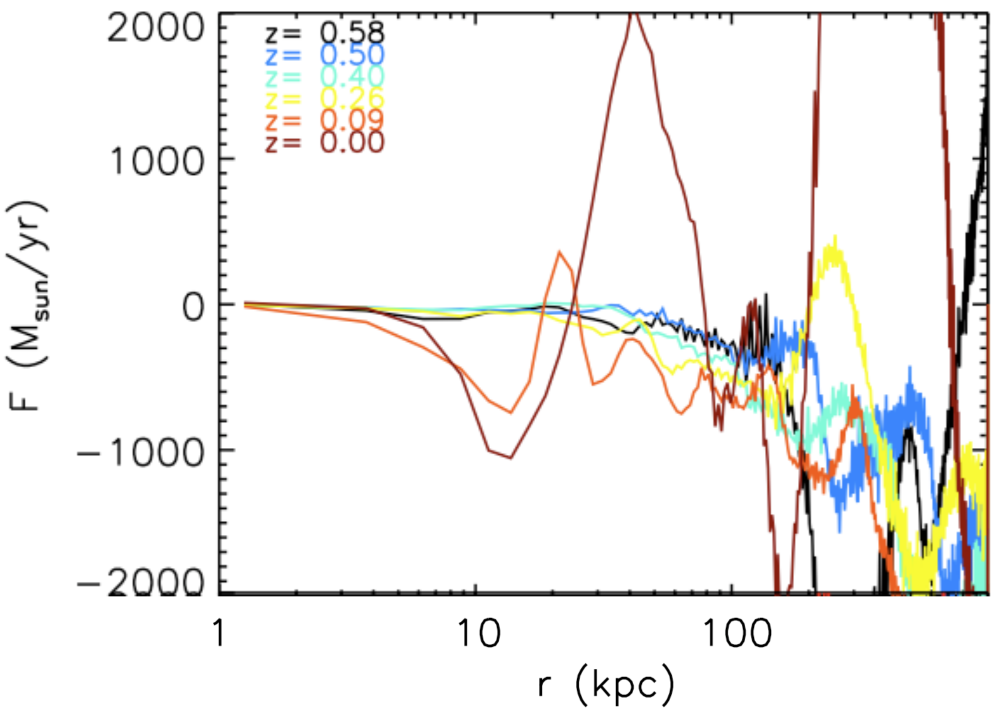
Some hints on the origin of entropy cores

No gas cooling

Primordial gas cooling + SF + AGN feedback



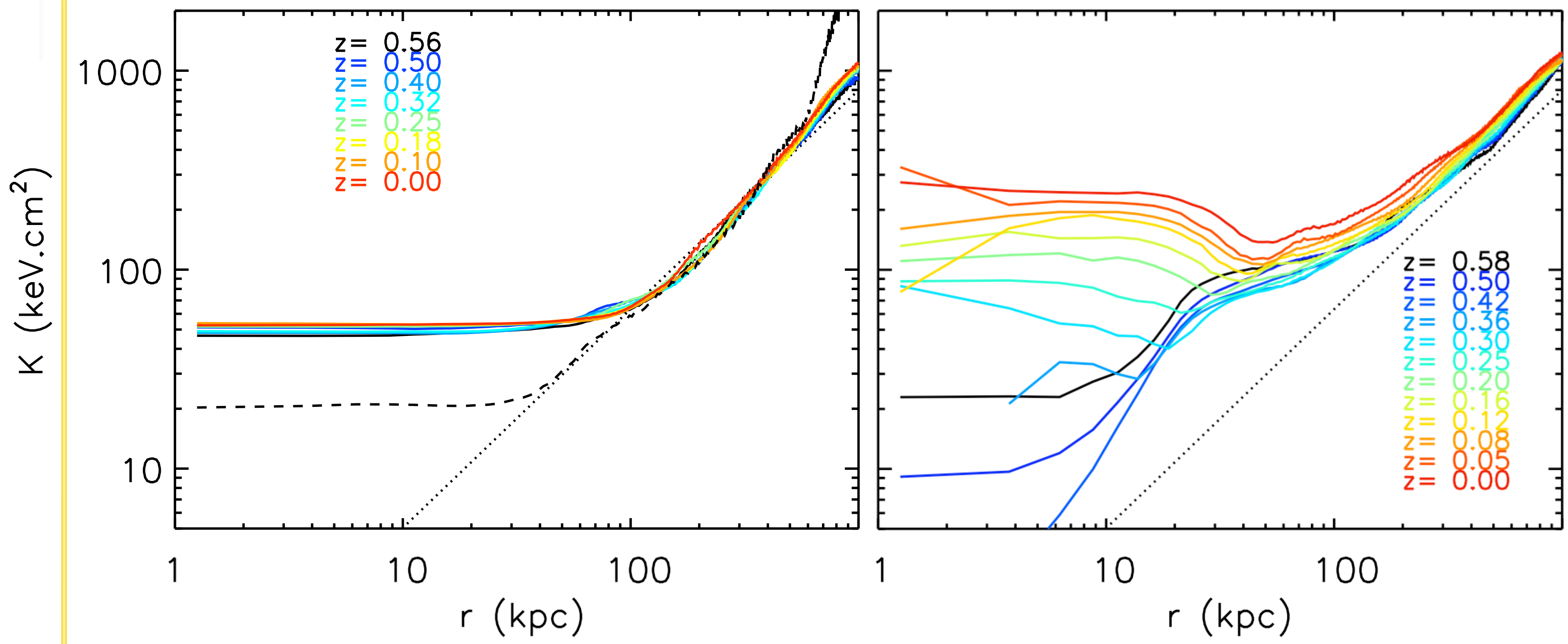
Primordial gas cooling + SF
+ AGN feedback



Some hints on the origin of entropy cores

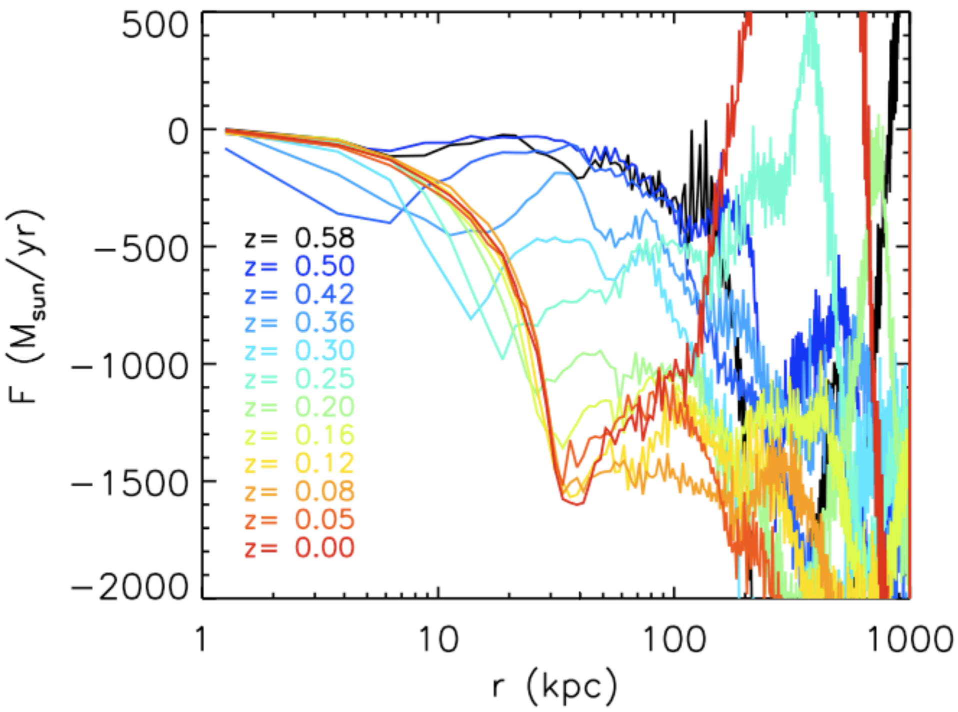
No gas cooling

Primordial gas cooling + SF
+ stop AGN feedback @ z=0.6



Some hints on the origin of entropy cores

Primordial gas cooling + SF
+ stop AGN feedback @ z=0.6

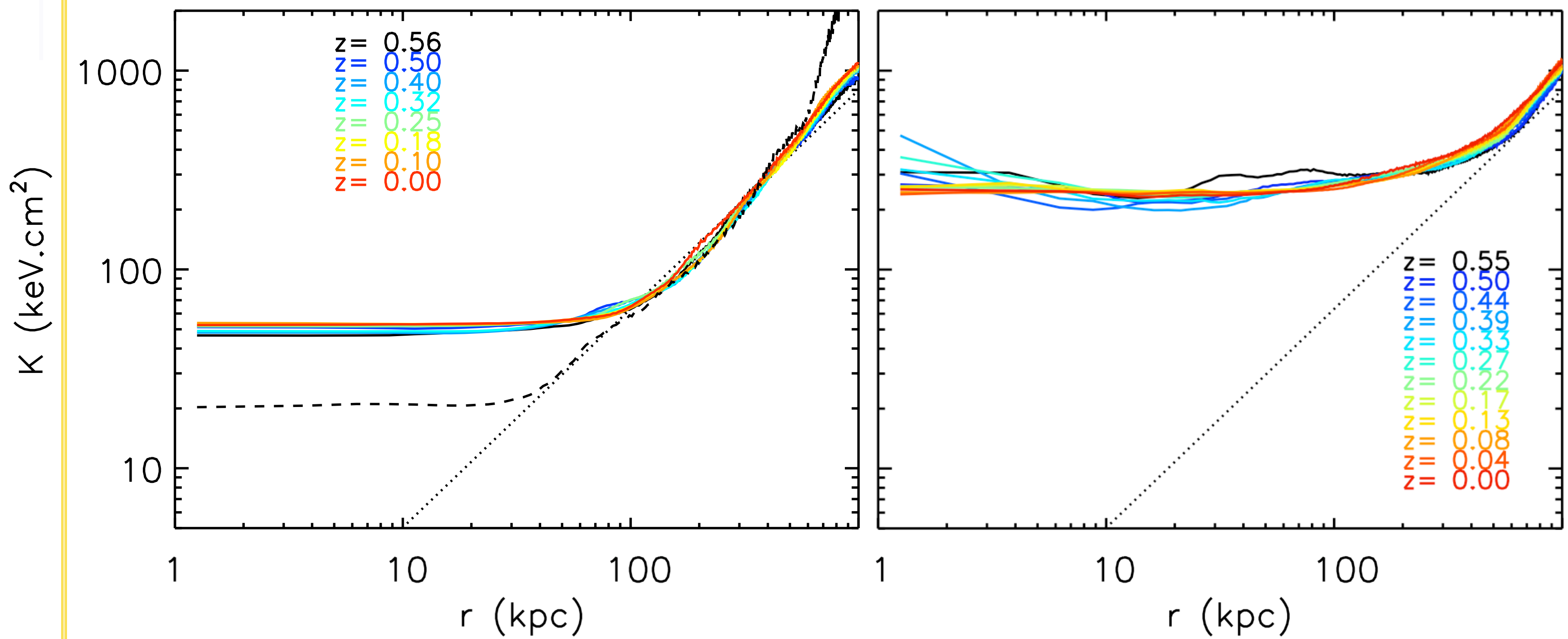


Cooling catastrophe !

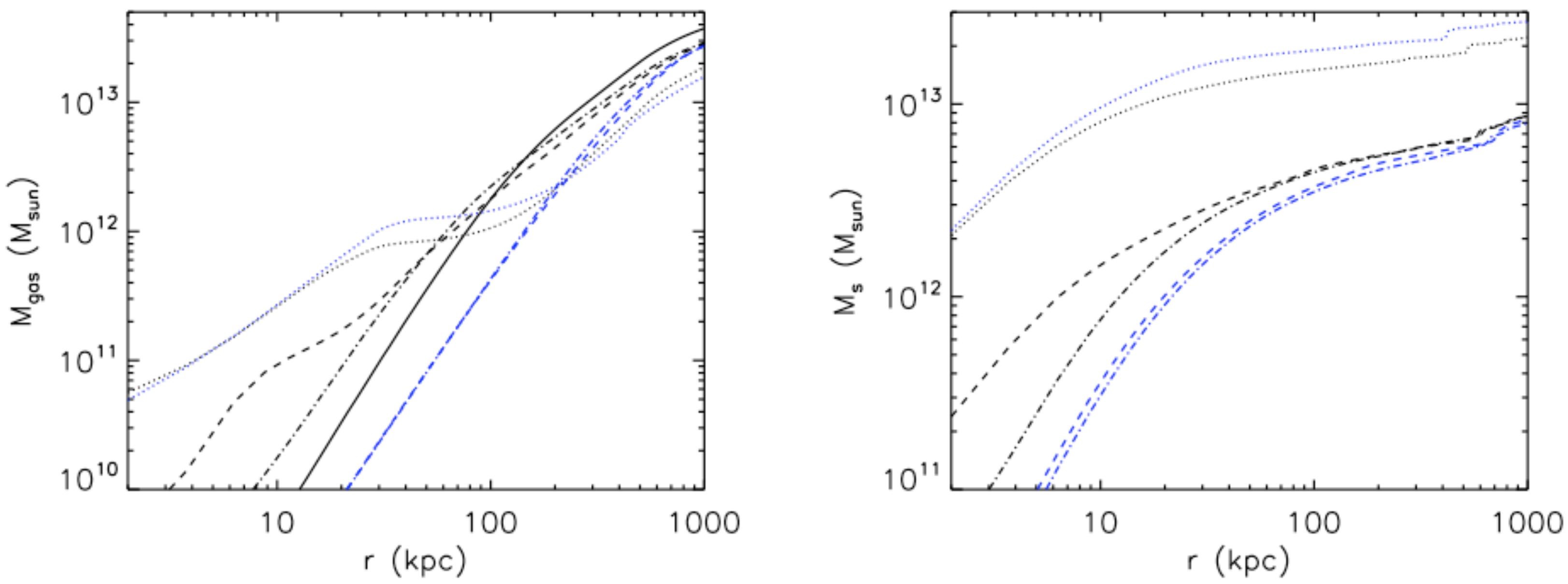
Some hints on the origin of entropy cores

No gas cooling

Primordial gas cooling + SF
+ AGN feedback
+ metal cooling



Some hints on the origin of entropy cores



Black: non-metal runs / Blue: metal runs

Dotted: no AGN / Dashed & Dot-dashed: AGN (different flavors)

Summary on AGN feedback

- AGN can reheat the core of groups and clusters and prevent cooling catastrophe
  - Efficiently suppresses star formation
  - Prevents high concentration of material
  - Powerful quasar modes are preferentially triggered at high redshift in gas rich systems (cold flows & wet mergers)
  - Quiescent radio modes are predominant at low redshift in massive structures (little cold material)

BUT

- Lot of free parameters (low predictive power)
  - Need constraints from GRMHD simulations or/and observations
- Do we get the right galaxy luminosity function ? Colors of galaxies ? Metallicities ? etc.
- Quasar mode is essentially a radiative mode => need proper RT
  - Some heating contribution (how much couples ?)
  - Shut-off gas colling