AGN feedback within AMR cosmological simulations

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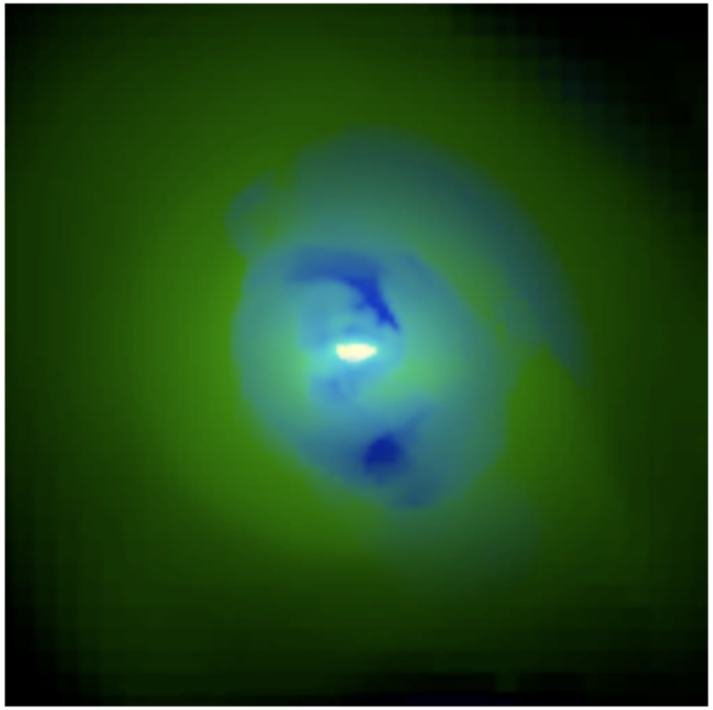


Teyssier et al., MNRAS, sub.
Dubois et al., 2010, MNRAS, in press
Dubois et al., 2009, MNRAS, 399, L49
Dubois & Teyssier, 2008, A&A, 482, L13

The missing baryons issue

- Observationnal fact: baryon fraction in galaxies < Universal baryon fraction $f_b=\Omega_b/\Omega_m \approx 15\%$

- Numerical simulations: vanilla models (gas cooling and star formation only) overpredict the baryon content in galaxies
  - Angular momentum deficit
  - Blue and active massive galaxies
  - Problem of the metal enrichment of the Inter-Galactic Medium (IGM)
  - Gas content in the Circum-Galactic Medium (CGM)

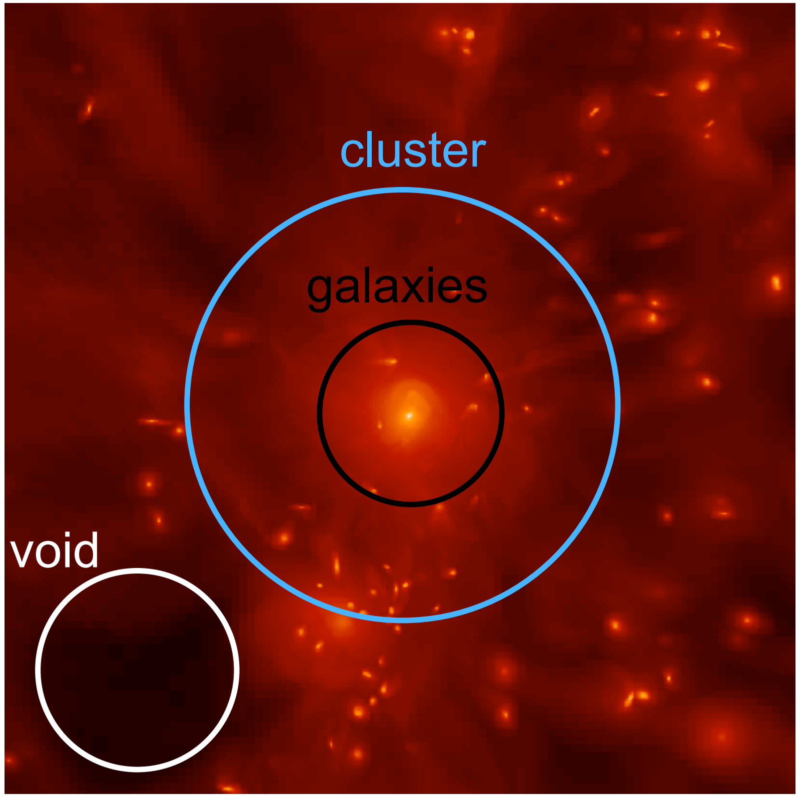
- Include more physics:
  - Supernovae feedback
  - Radiation pressure from OB associations (young stars)
  - Feedback from supermassive black holes
  - Thermal conduction
  - Cosmic ray pressure, magnetic fields, non-linear plasma physics

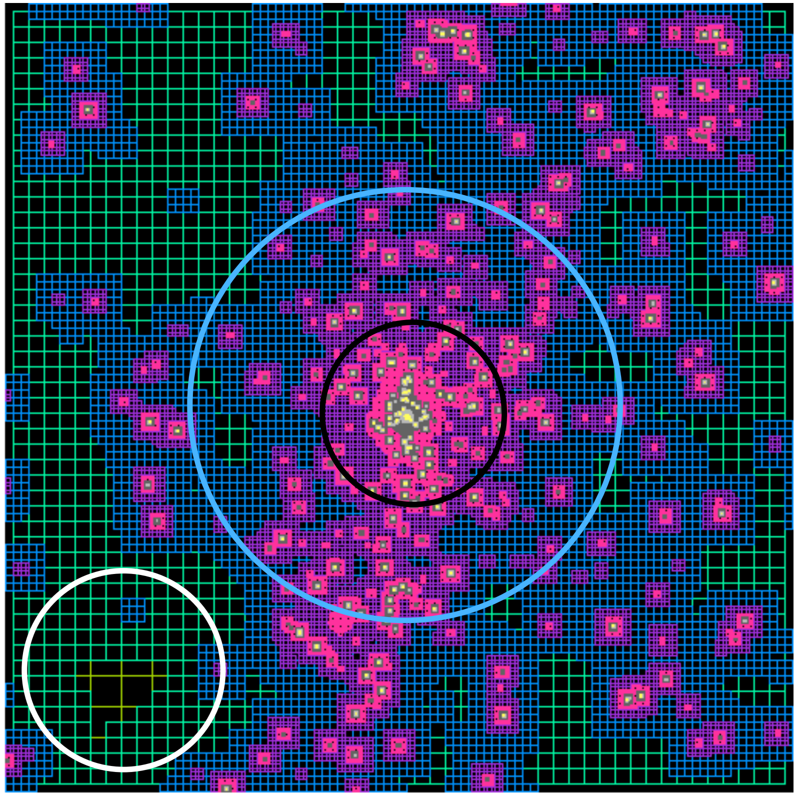
RAMSES : an Adaptive Mesh Refinement (AMR) code

- Language :
  - Fortran 90
  - MPI parallelization
- Method : adaptive grid refinement
- Equations :
  - Hydrodynamics
  - Magneto-hydrodynamics (Teyssier et al. 2006, Fromang et al . 2006)
  - Gravity
  - Atomic/Metal cooling + background UV-heating
  - Anisotropic thermal conduction (work in progress…)
- Sub-grid physics :
  - Star formation
  - Supernovae
  - <u>Active Galactic Nuclei</u> (AGN) (Dubois et al., 2010)
- Cosmology

See Teyssier 2002

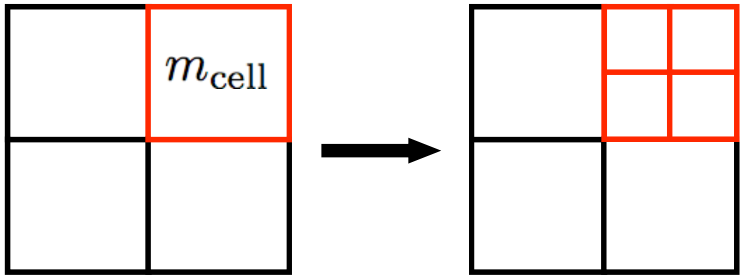
Adapting the grid resolution





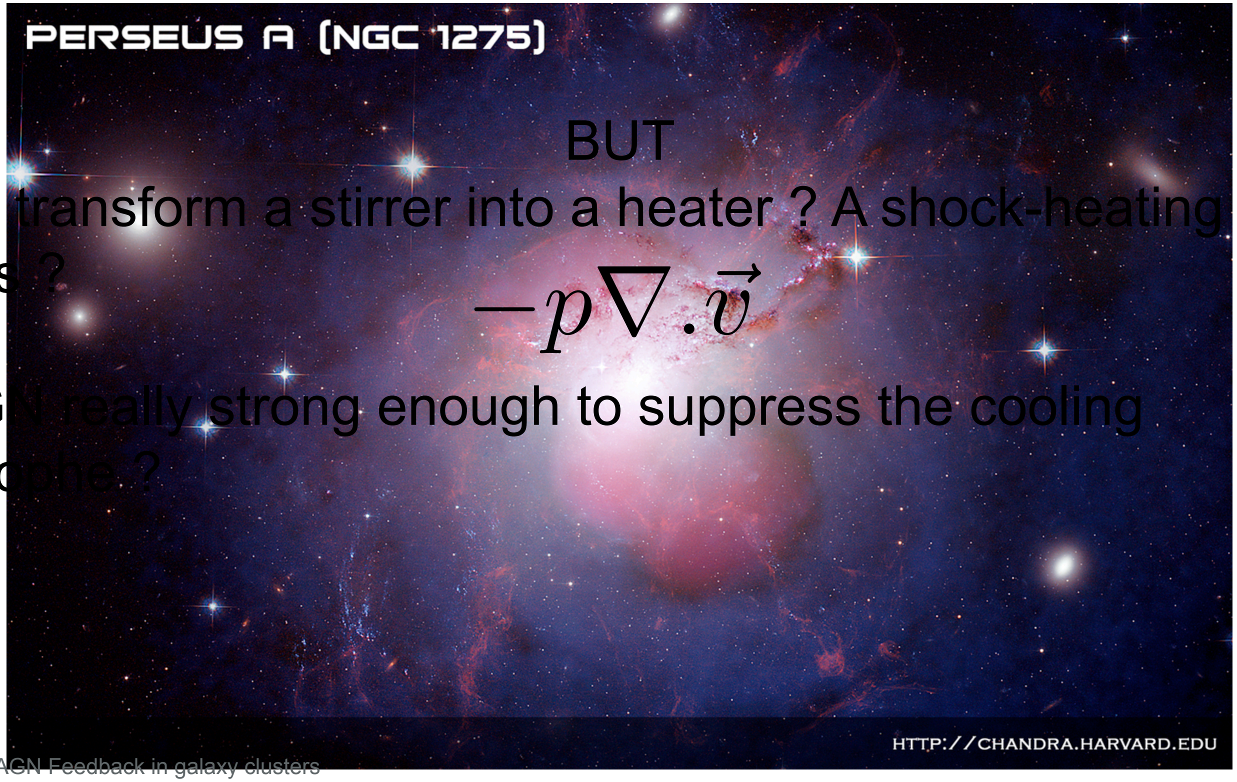
Local mass criterion :

if $m_{\mathrm{cell}} > m_0$ then



AGN feedback in massive galaxies

- Jets, radio lobes, cavities are commonly observed in cluster cores
- Massive galaxies host Supermassive Black Holes (SMBH) with $M_{BH}>10^8$-10^9 M_{sun}
- SMBHs accrete gas supersonically within accretion discs
- Strong emission of energy
  - $L_{AGN}>10^{45}$ erg/s (>> $L_{SN}=10^{43}$ erg/s)



BUT

How to transform a stirrer into a heater ? A shock-heating process ?

$$-p\nabla.\vec{v}$$

Are AGN really strong enough to suppress the cooling catastrophe ?

AGN in cosmological simulations

First simulations of self-consistent jet-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

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- 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

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

Bondi accretion rate

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

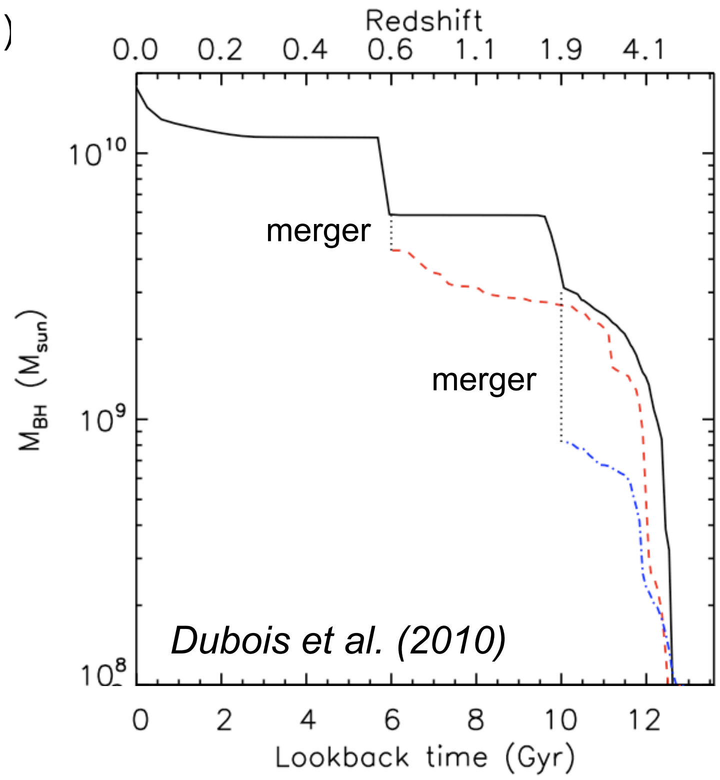
Fast accretion in dense and cold regions

AGN in cosmological simulations

First simulations of self-consistent jet-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)



AGN in cosmological simulations

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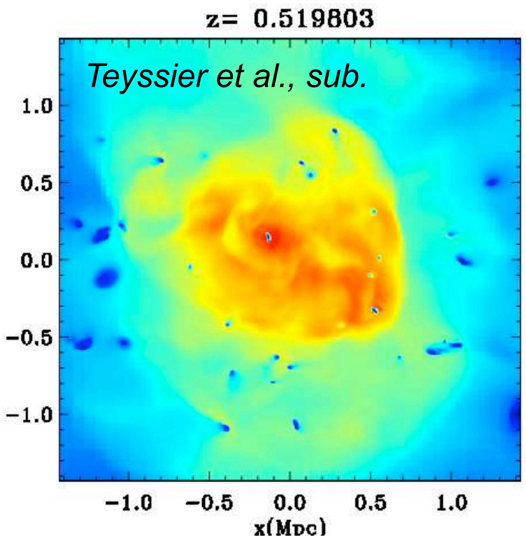
- Mimic the feedback from black holes (AGN)

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



Modification of the internal energy

-> increase the temperature

AGN in cosmological simulations

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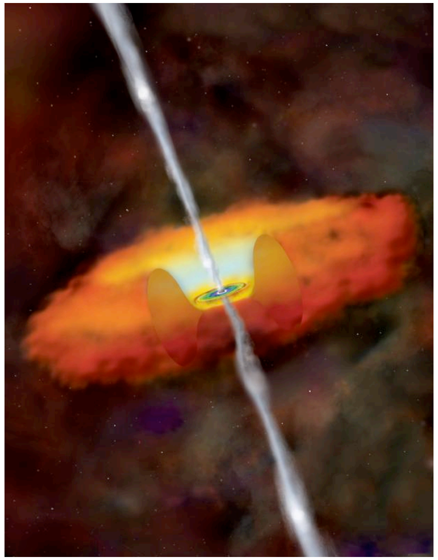
- Mimic the feedback from black holes (AGN)

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

$$\dot{E}_{\rm AGN} = 0.1 \dot{M}_{\rm BH} c^2$$



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)

AGN in cosmological simulations

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

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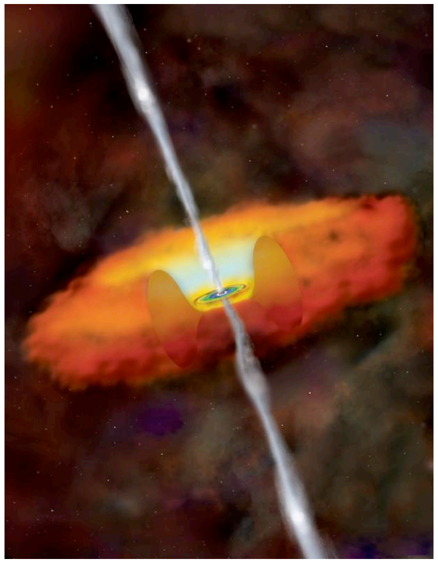
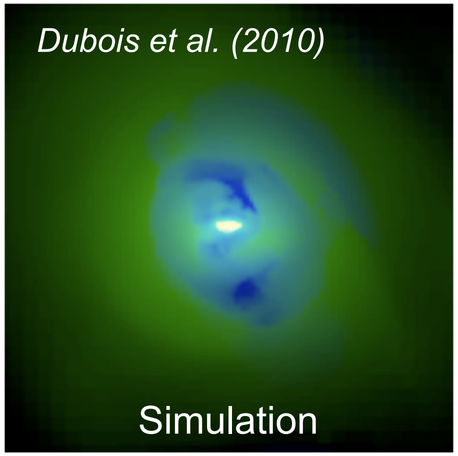
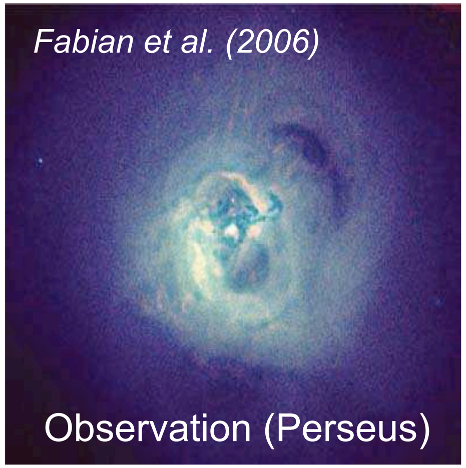


450 kpc





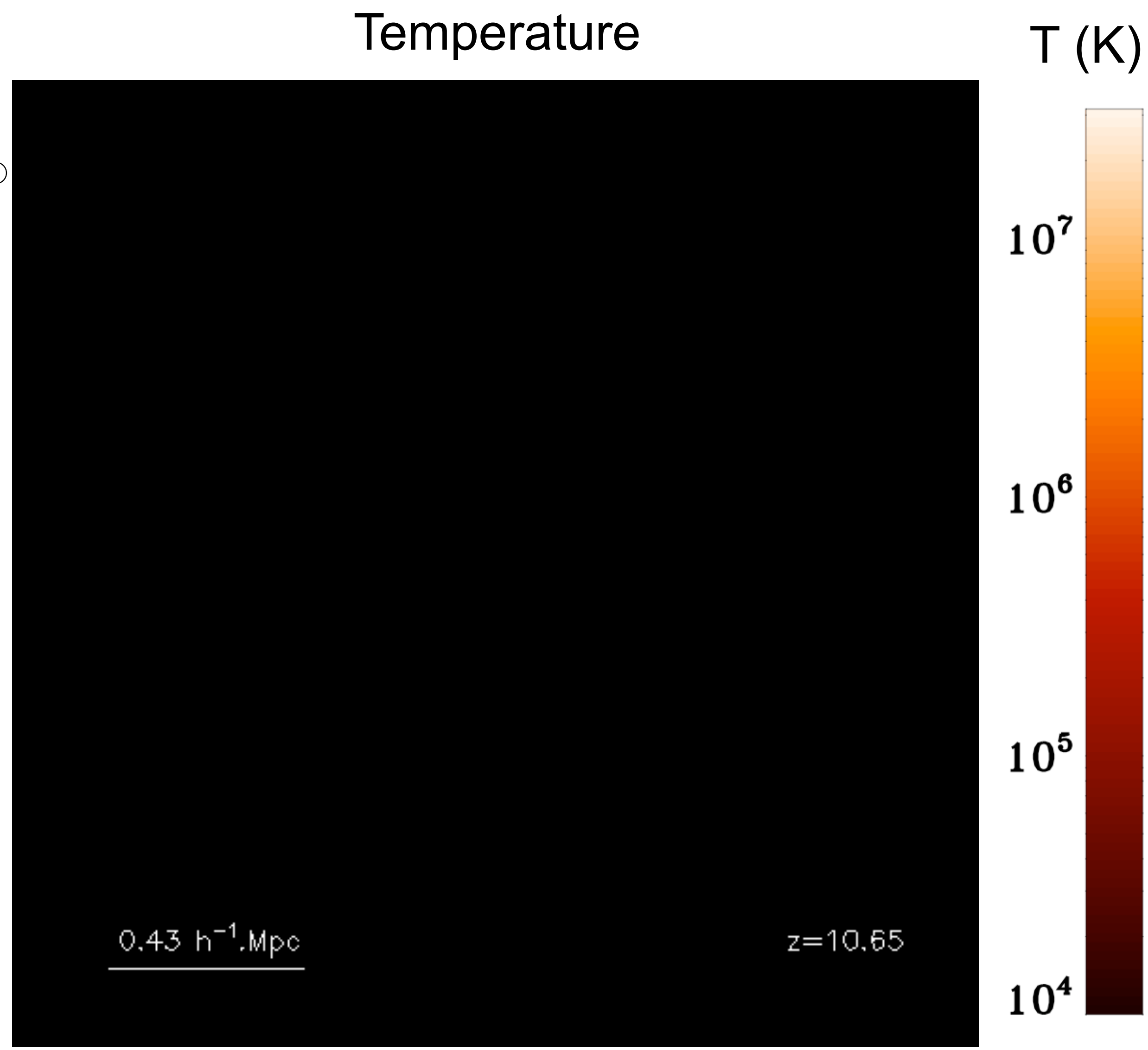
100 kpc

X-ray (3 bands)

AGN in action

WMAP-5 cosmology

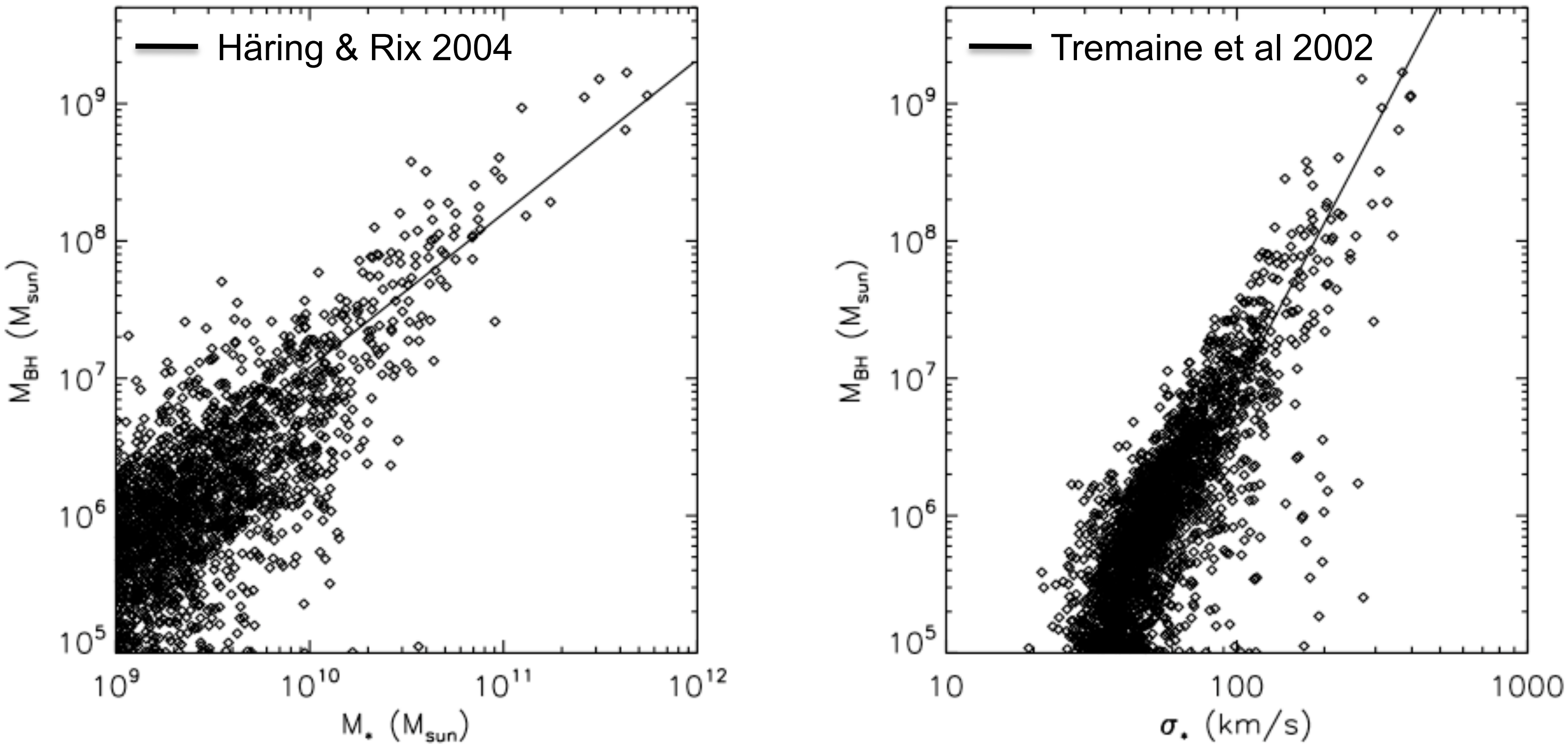
$$M_{\rm DM} = 5.5 \times 10^7\,{\rm h}^{-1}.{\rm M}_\odot$$
$$L_{\rm box} = 25\,{\rm h}^{-1}.{\rm Mpc}$$
$$\Delta x = 0.75\,{\rm h}^{-1}.{\rm kpc}$$
(comoving)



1.6 x 10^7 DM particles
@ z=0 :
- 10^7 star particles
- 1.5x10^8 gaz cells
- 2500 galaxies

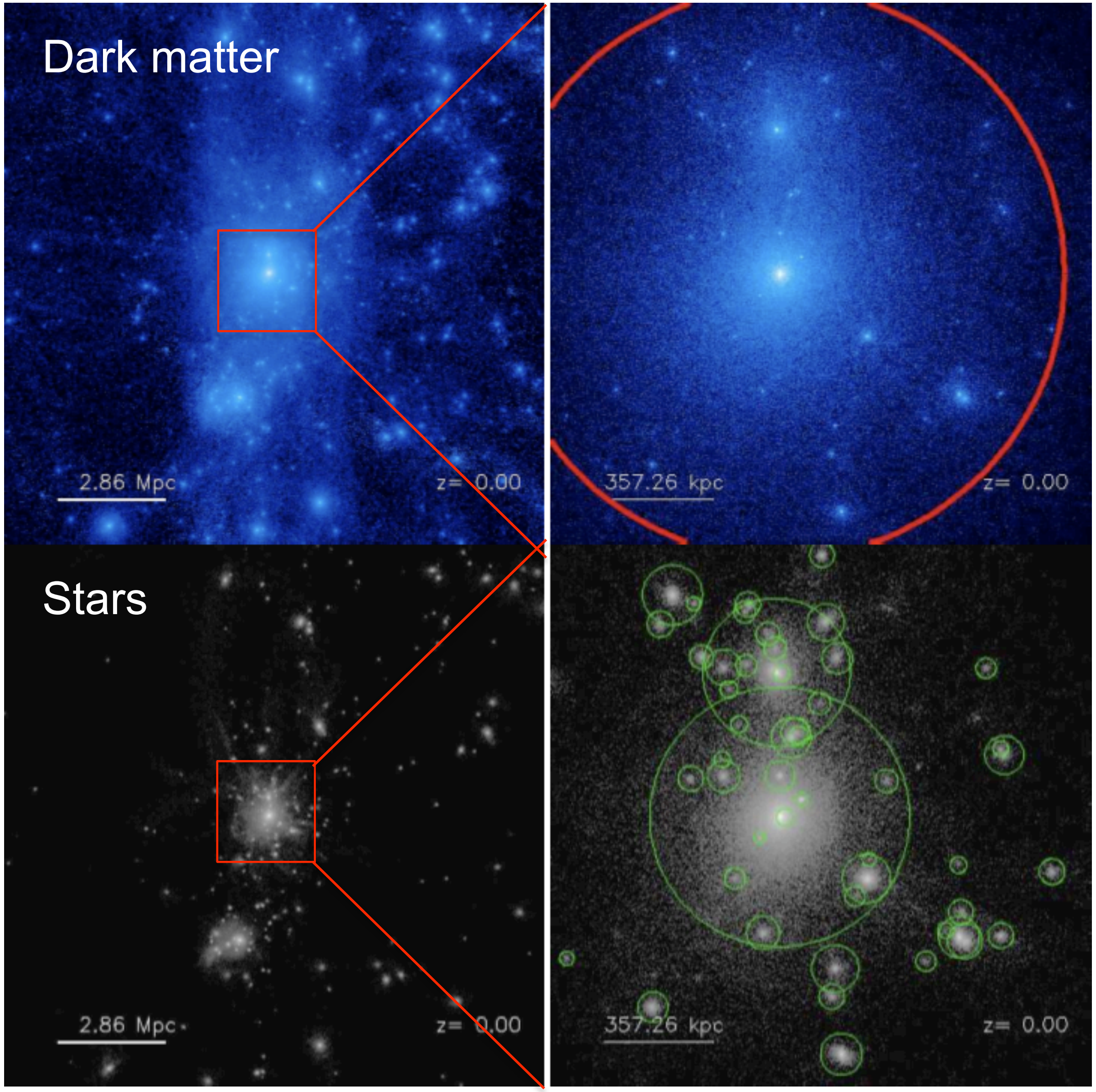
Fitting observationnal M_{BH}-M_* / M_{BH}-σ_* laws

z=0



Allows to calibrate the numerical model

Simulation of a galaxy cluster with AGN feedback



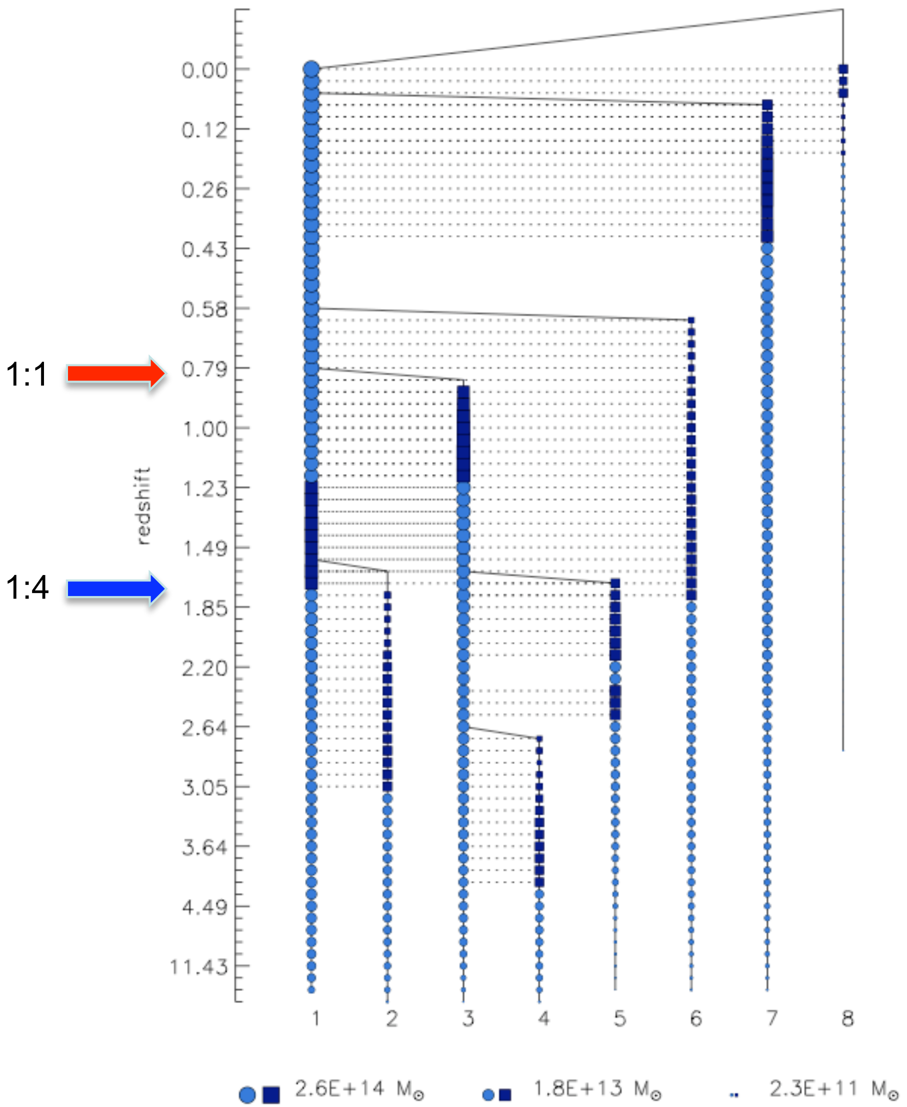
100 Mpc box

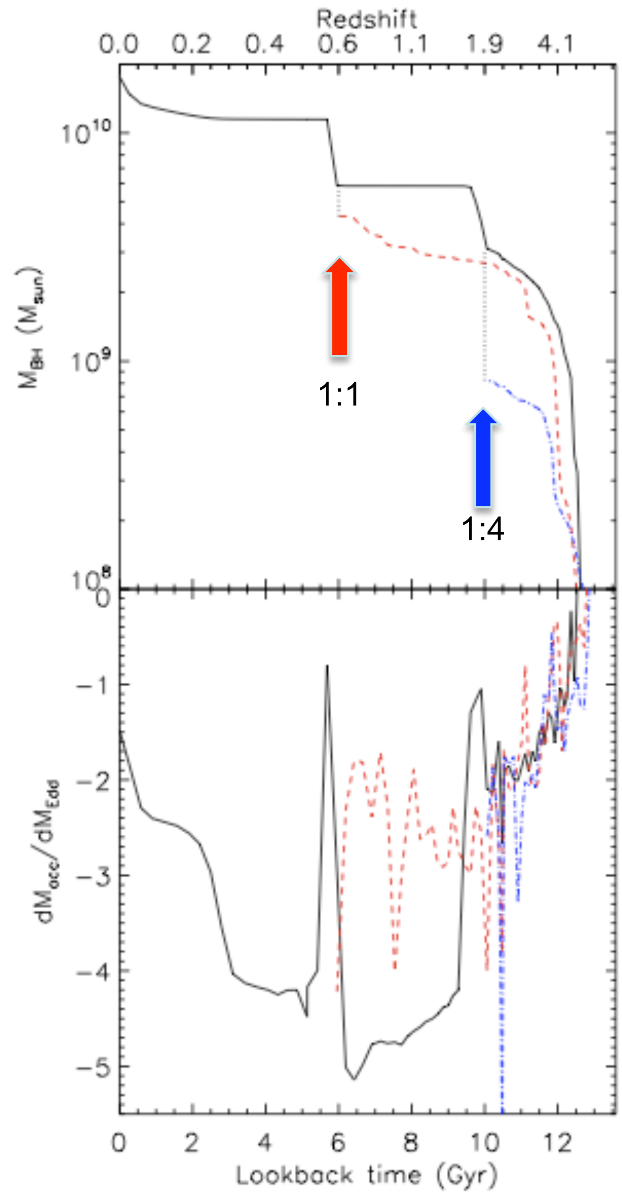
Zoom simulation
High resolution region 20 Mpc
M_{DM}=4.5 10^8 M_{sun}
Δx=1.5 kpc

@ z=0
M_{500}=2.4 10^{14} M_{sun}
R_{500}=940 kpc

Accretion onto the black hole

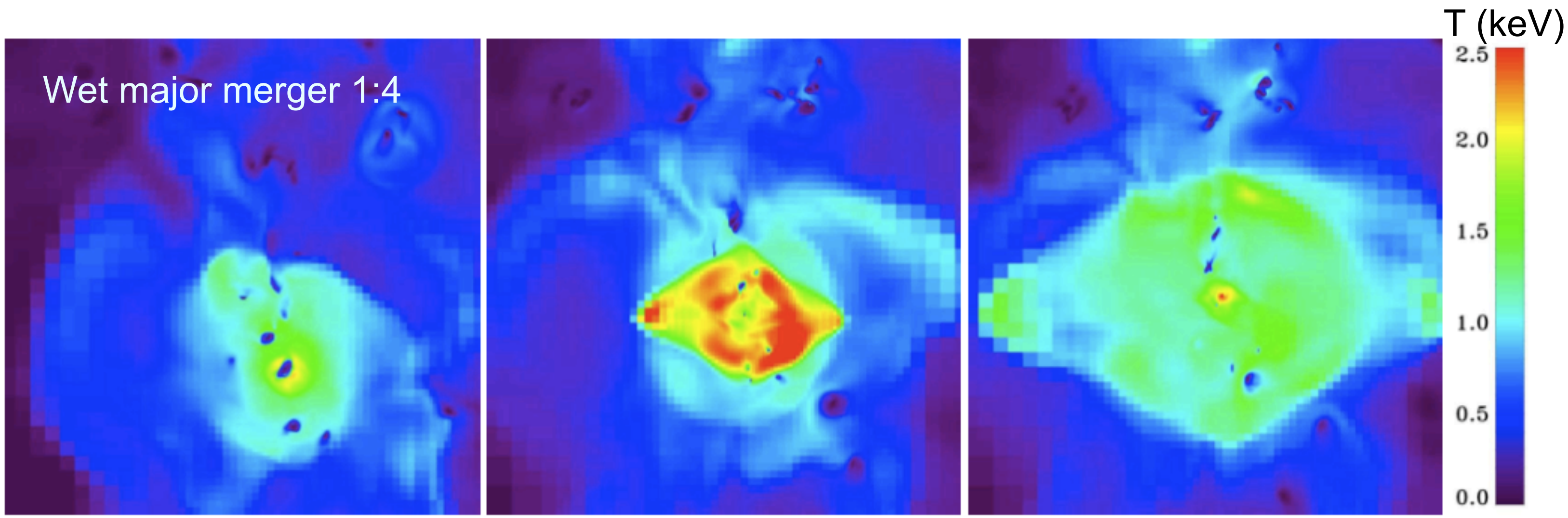
Dark Matter merger tree



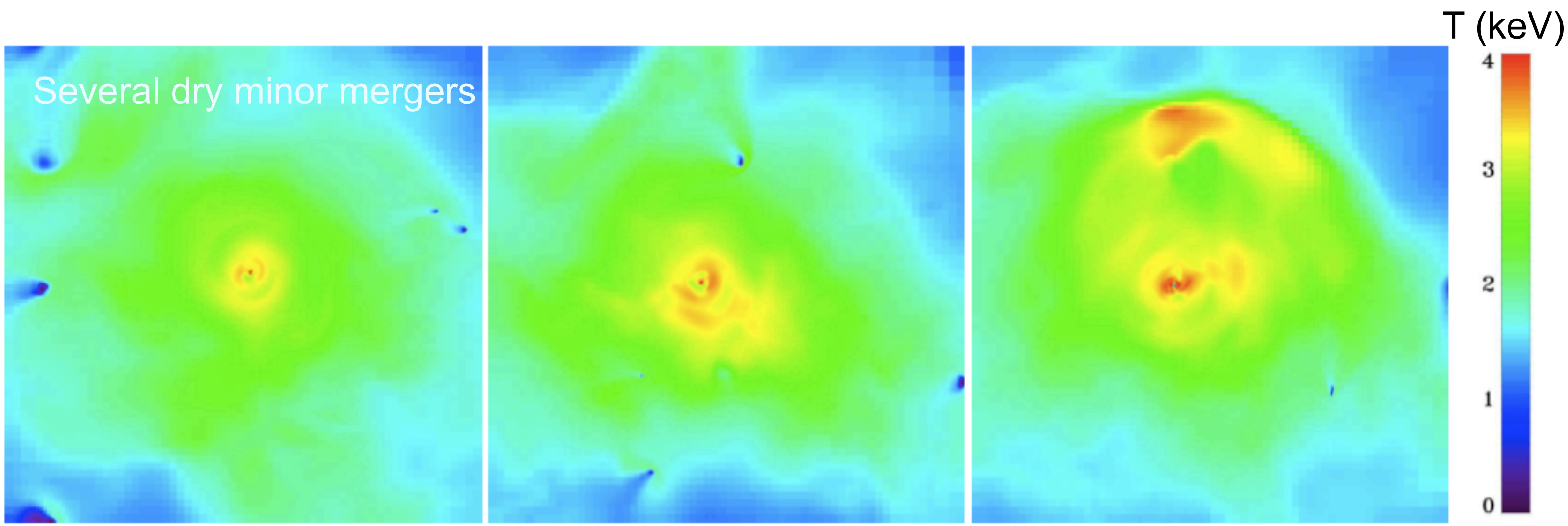


Quasar mode versus radio mode

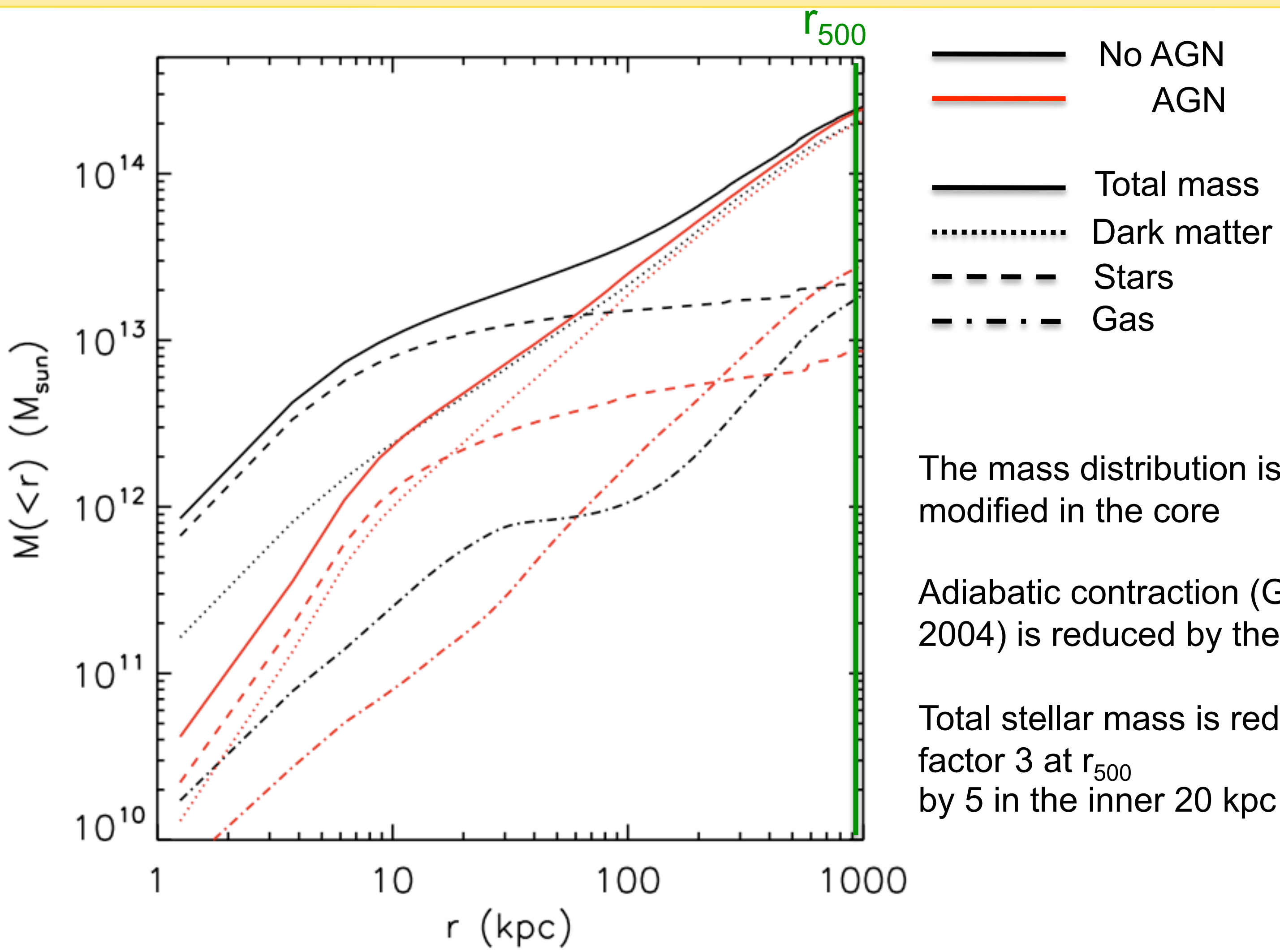
z=1.5
Quasar
mode



z=0
Radio
mode



Mass distribution

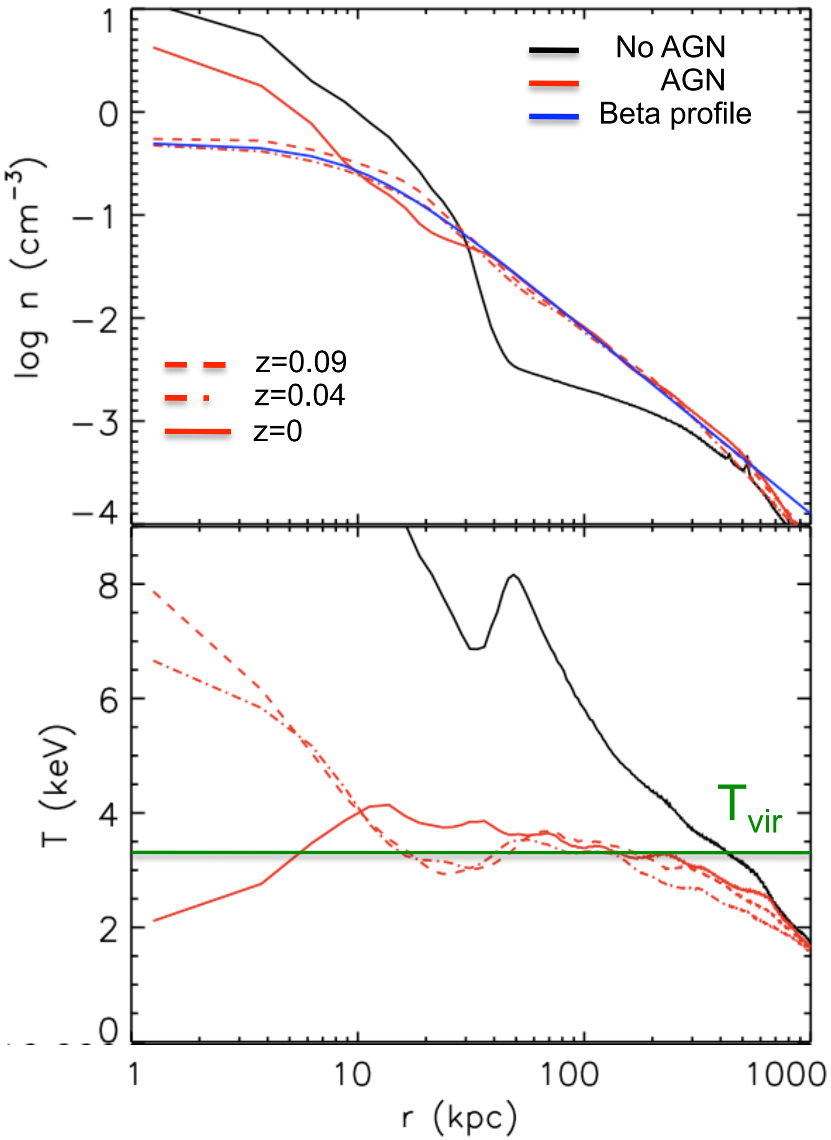


The mass distribution is significantly modified in the core

Adiabatic contraction (Gnedin et al. 2004) is reduced by the AGN

Total stellar mass is reduced by a factor 3 at r_{500}
by 5 in the inner 20 kpc of the cluster

Solving the cooling catastrophe



Beta profile $\rho = \rho_s \left(1 + (r/r_c)^2\right)^{-3\beta/2}$

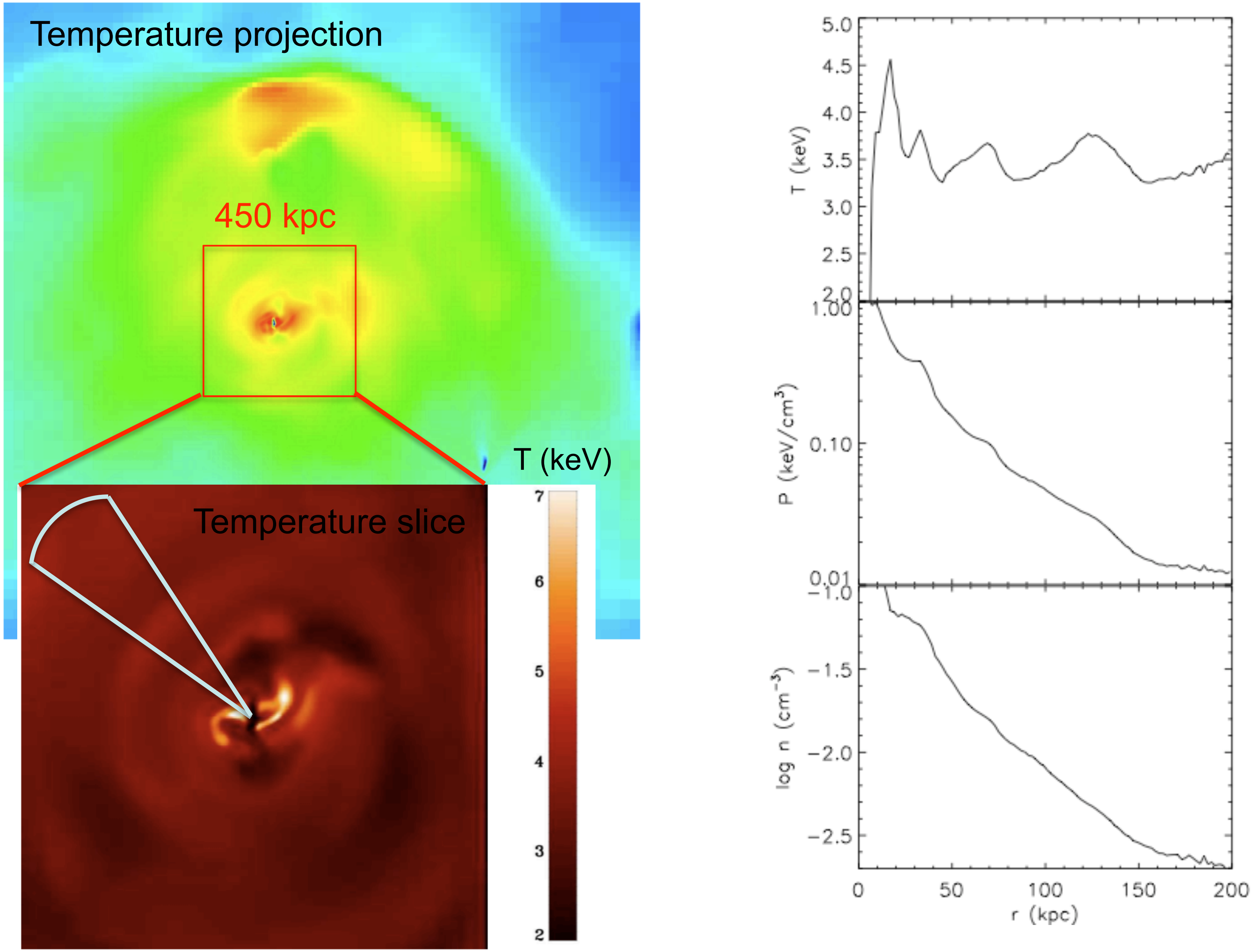
$\beta = 0.6$

$\beta \simeq 0.64$ In observed Xray clusters (Mohr et al 1999)

Without AGN:
- Strong core component
- Temperature rises because of adiabatic contraction

Cooling catastrophe !

Propagation of sound waves



Magnetic field in a cooling core cluster (turbulence)

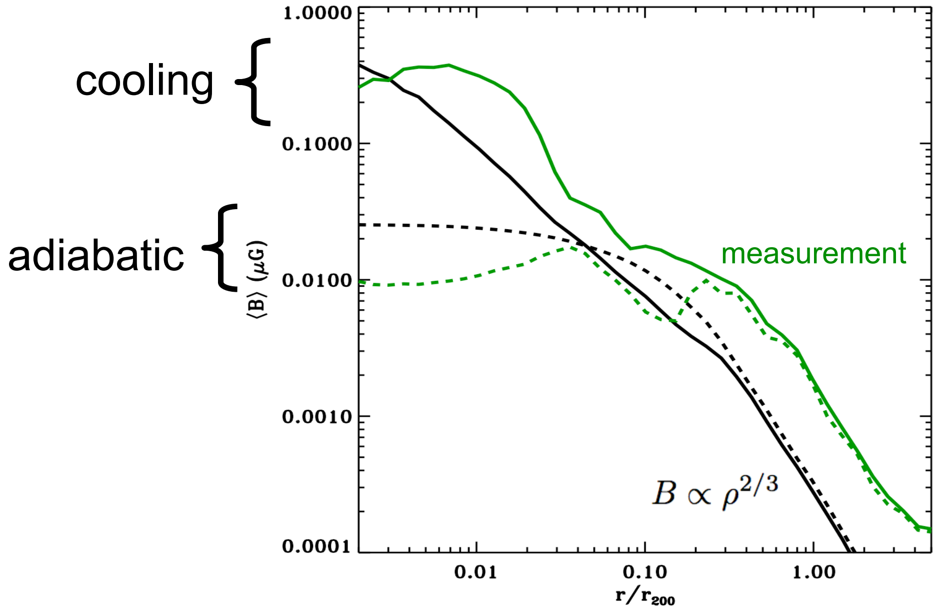
No AGN

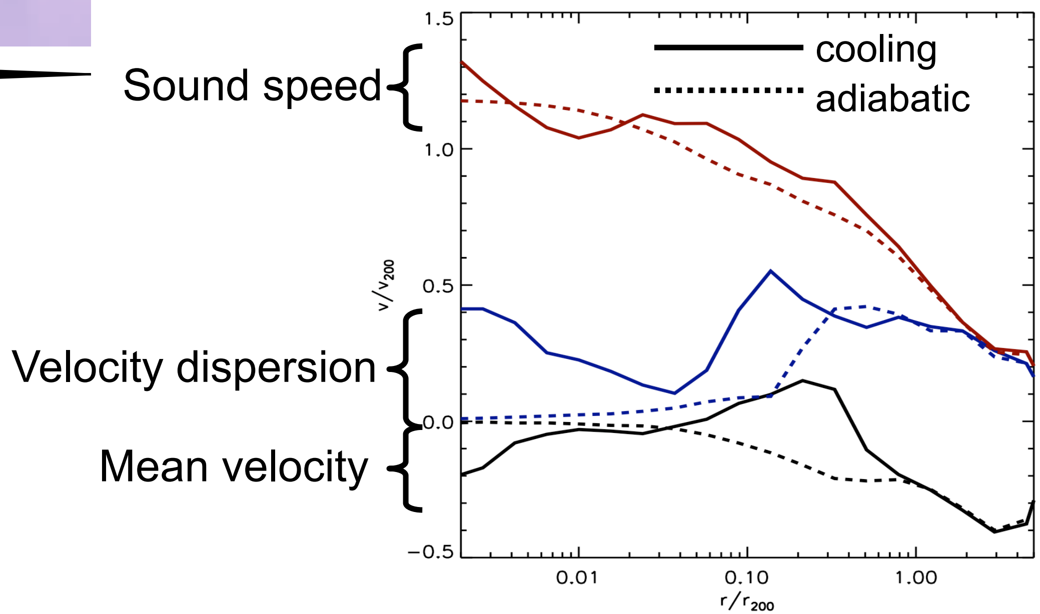
but

Cooling
+ star
formation

15 Mpc

Dubois & Teyssier (2008)





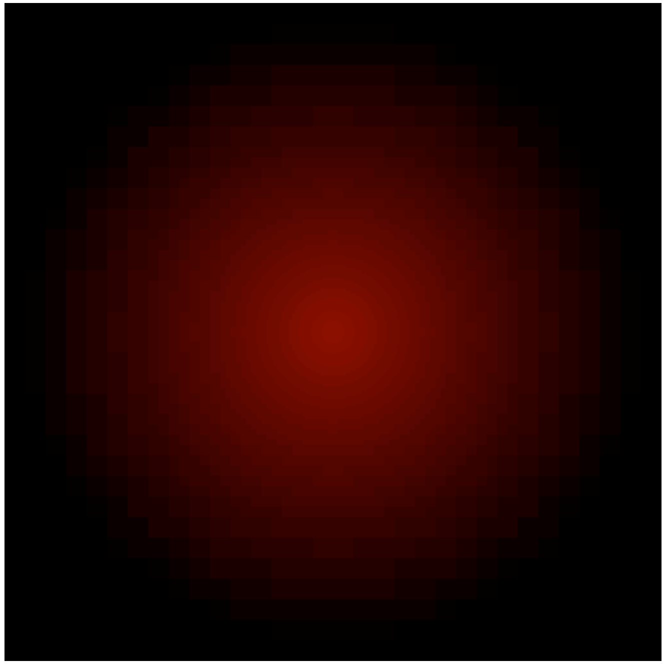
<u>Results from Ruszkowski's talk confirm this trend</u>

What about the magnetic field with AGN ?

Isolated NFW halo with (non cosmological)

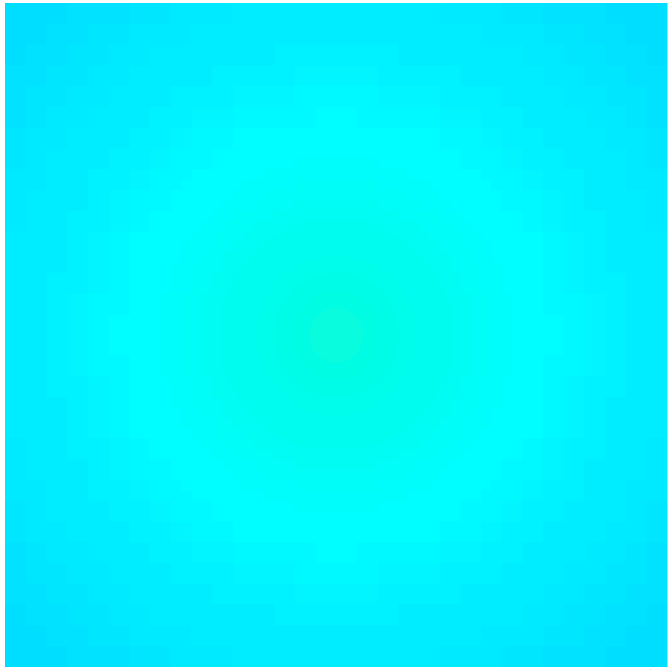
$$M_{200} = 1.5\,.\,10^{14} M_{\odot}$$
$$M_{SMBH} = 3\,.\,10^{9} M_{\odot}$$

density



325 kpc

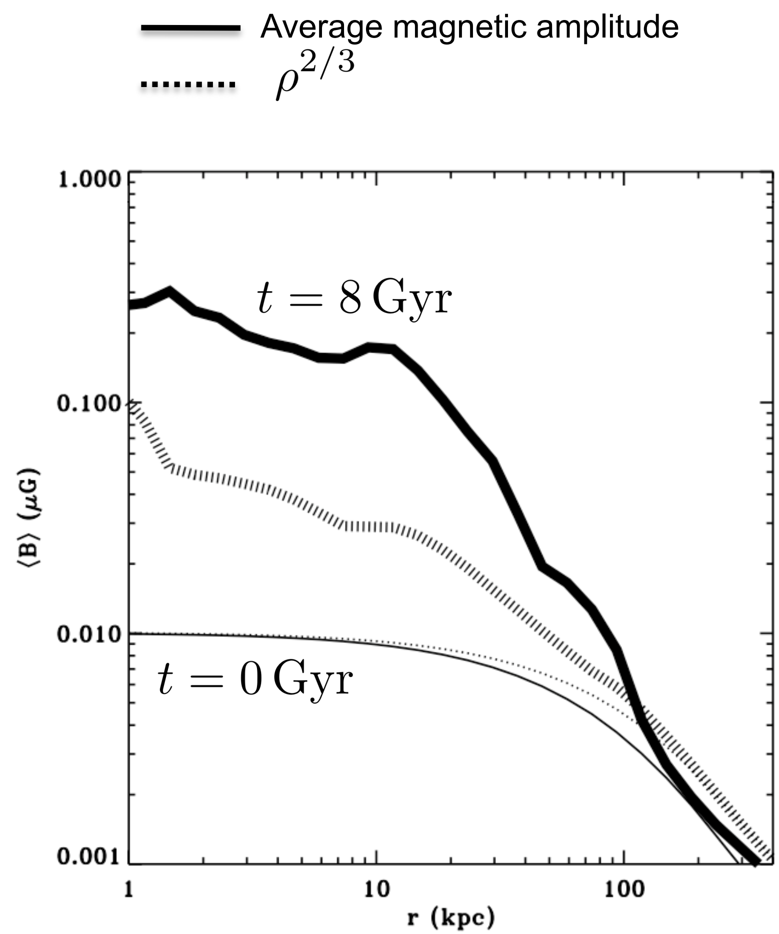
temperature



325 kpc

Dubois et al. (2009)

Magnetic field amplification by the AGN



Summary

- AGN jets can reheat the core of groups and clusters and prevent cooling catastrophe:
  - Efficient in massive galaxies
  - Powerful quasar modes are preferentially triggered at high redshift in gas rich systems
  - Quiescent radio modes are predominant at low redshift in massive structures
  - Xray cavities
  - Propagation of sound waves

- Turbulence drives some magnetic field amplification in the ICM
- AGN jets bring more turbulence and amplify the magnetic field in the ICM

Thank you for your attention