10 Mpc z=1.2

BH growth and the impact of AGN feedback on galaxy evolution

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Collaborators:
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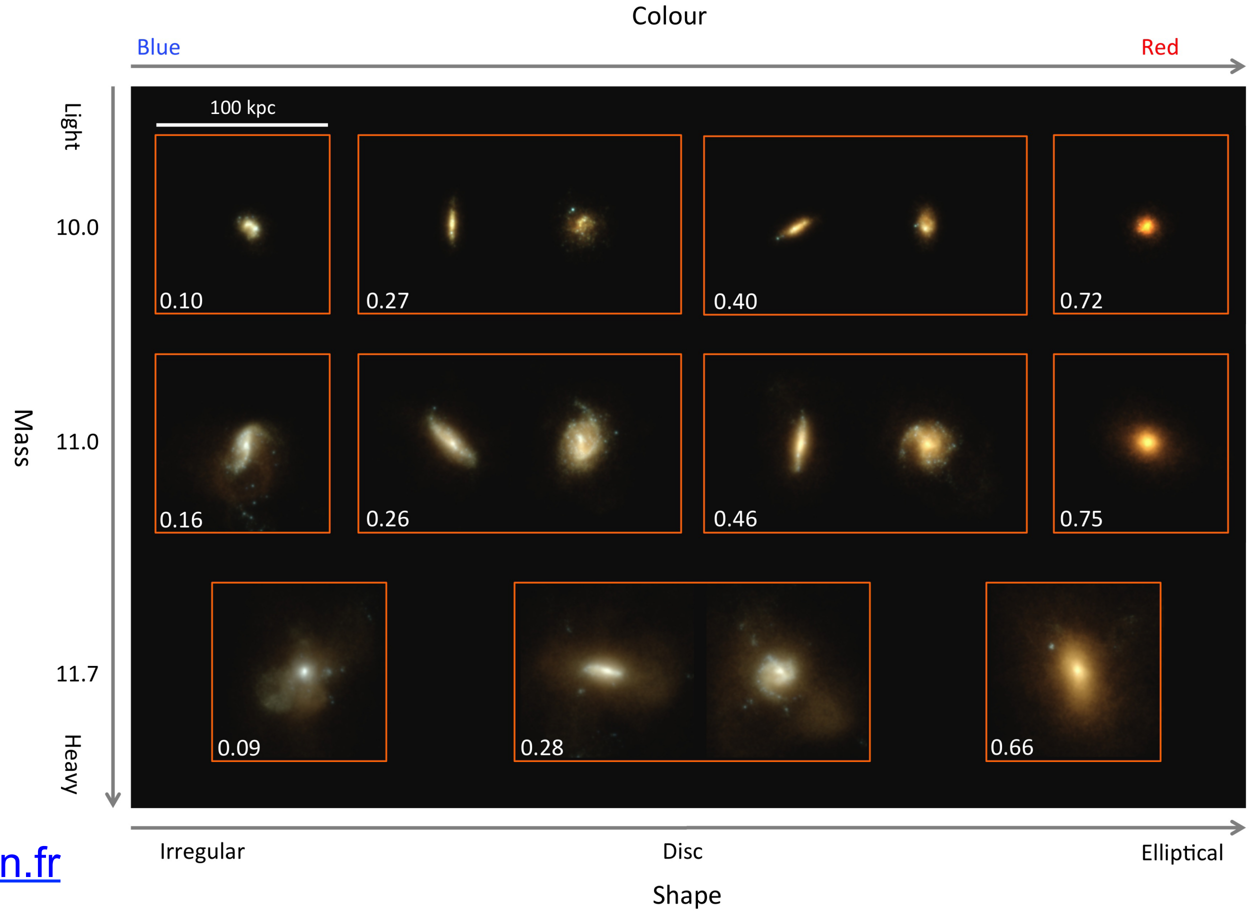
Horizon-AGN simulation
http://horizon-AGN.projet-horizon.fr

The Horizon-AGN simulation

- Ramses code (AMR) *Teyssier (2002)*
- L_{box}=100 Mpc/h
- 1024^3 DM particles
  $M_{DM,res}=8x10^7 M_{sun}$
- Finest cell resolution dx=1 kpc
- Gas cooling & UV background heating
- Low efficiency star formation
- Stellar winds + SNII + SNIa
- O, Fe, C, N, Si, Mg, H
- AGN feedback radio/quasar

- z=0.6 using 6.7 Mhours on 4096 cores
- 150 000 galaxies per snapshot (> 50 part.)
- 7 billions leaf cells (> Illustris or EAGLE)



– *Dubois et al, 2014*
– *Welker et al, 2014*
– *Codis et al, sub.*

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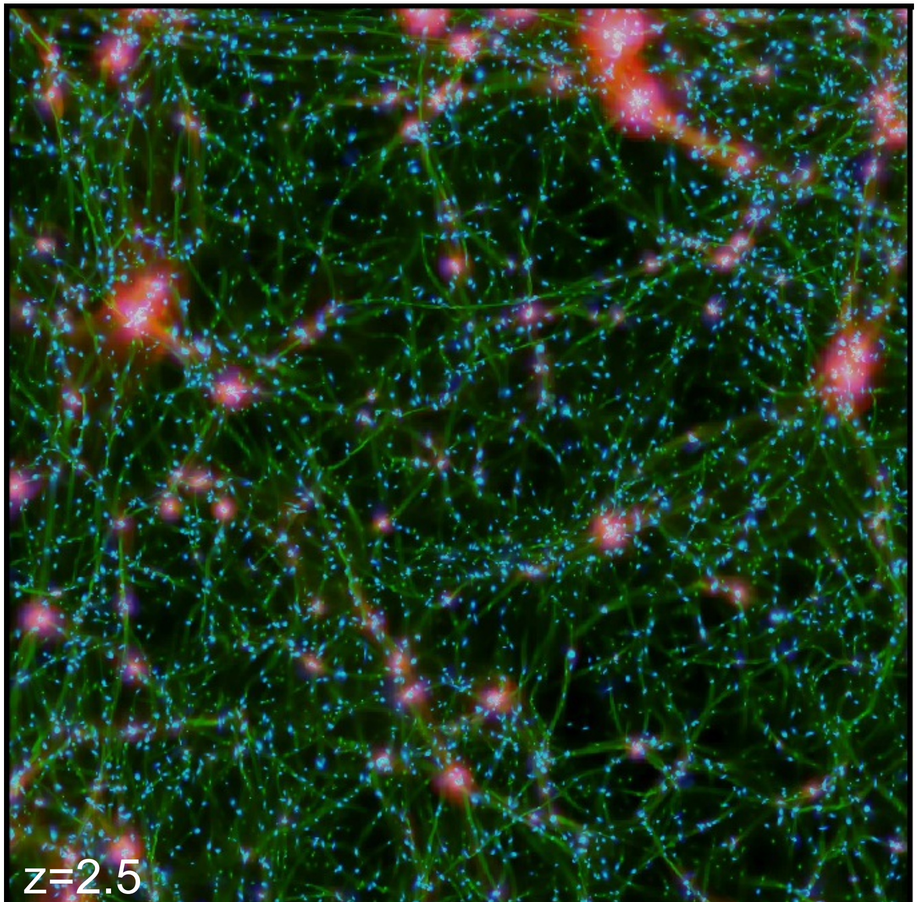
Green: gas density / Red: temperature / Blue: metallicity

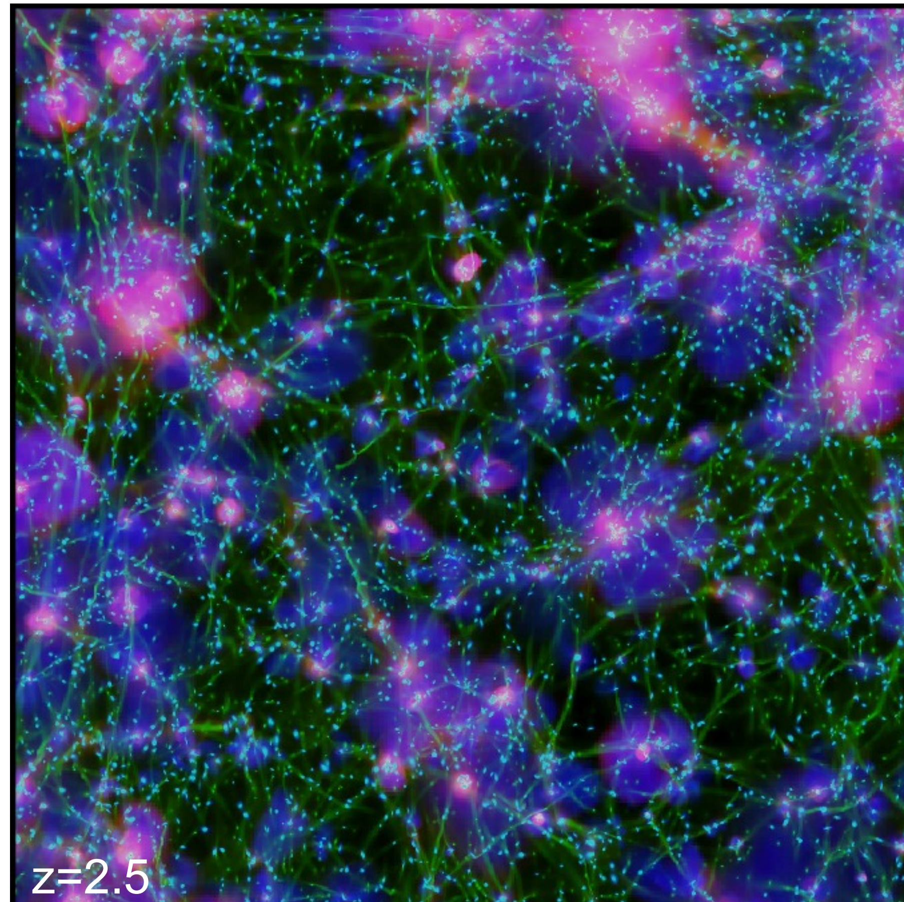
A visual inspection of the impact of AGN feedback on large-scale structures

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

Without AGN



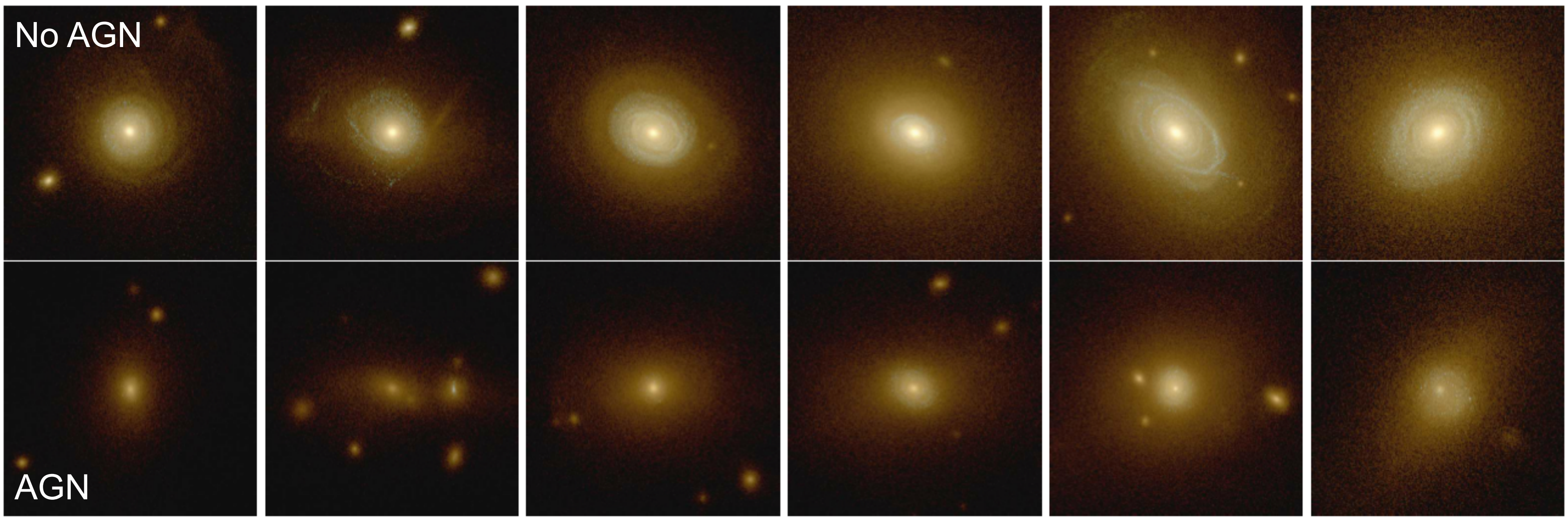
With AGN



AGN are responsible for turning discs into ellipticals

Central galaxies at z=0 in groups $10^{13} < M_{halo} < 10^{14}\ M_{sun}$

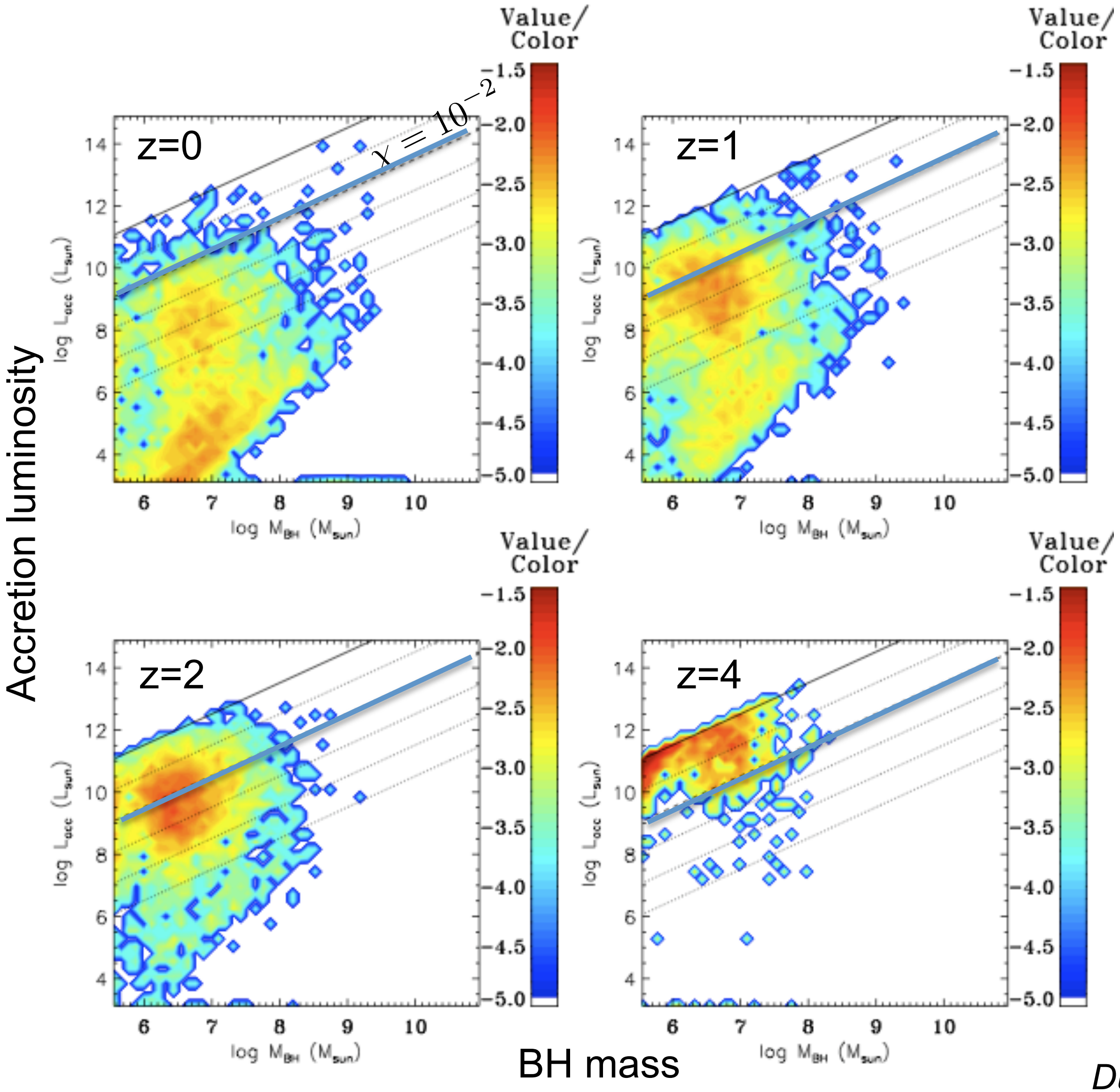
Increasing mass

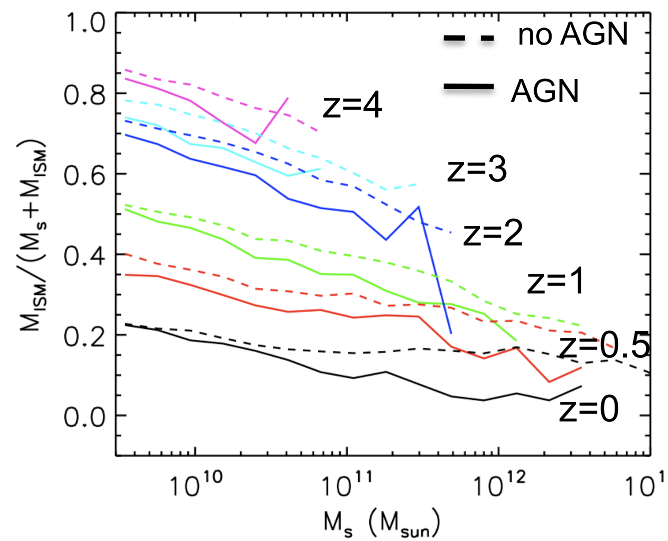


140 kpc

Dubois, Gavazzi, Peirani, Silk, 2013

Radio mode or quasar mode ?





Galaxies are gas-rich at high-redshift
Star formation and feedback consumes/removes/prevents from collapsing the gas

Dubois, Devriendt, Slyz, Teyssier, 2012

Growing the first bright quasars

<u>Observationnal facts</u>:

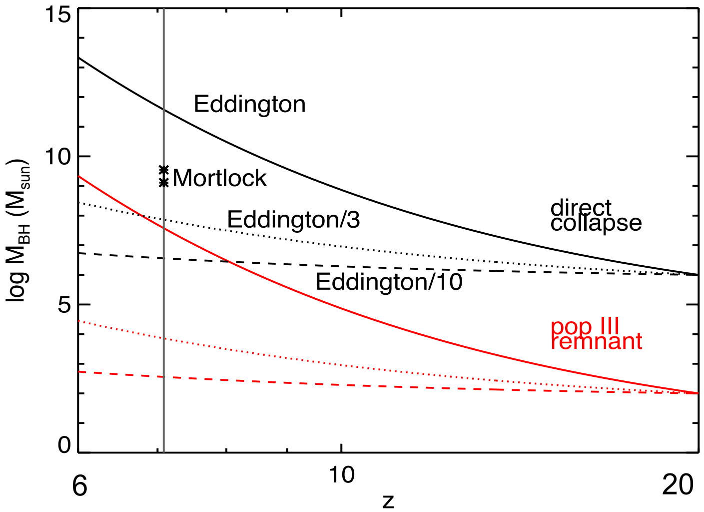
- Very bright quasars in the SDSS with z>6
(Willott et al., 2003; Fan et al., 2006; Jiang et al., 2009)
- Detection of a 2.10^9 M_{sun} BH at z=7
(Mortlock et al., 2011)

<u>Requirement</u>:

- Need to grow from 10^5-10^6 M_{sun} up to 10^9 M_{sun} in less than 700 Myrs ! Eddington limit provides an e-folding time = 45 Myr

<u>Question</u>:

- How to bring gas sufficiently rapidly into the bulge of the galaxy ?

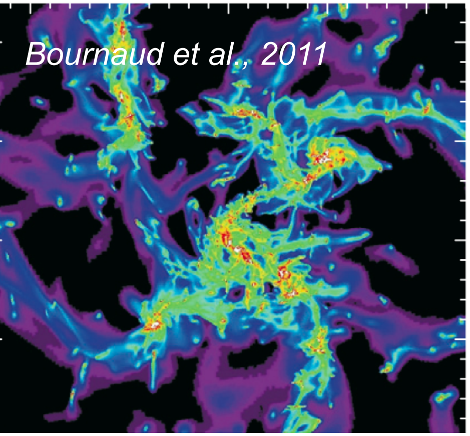


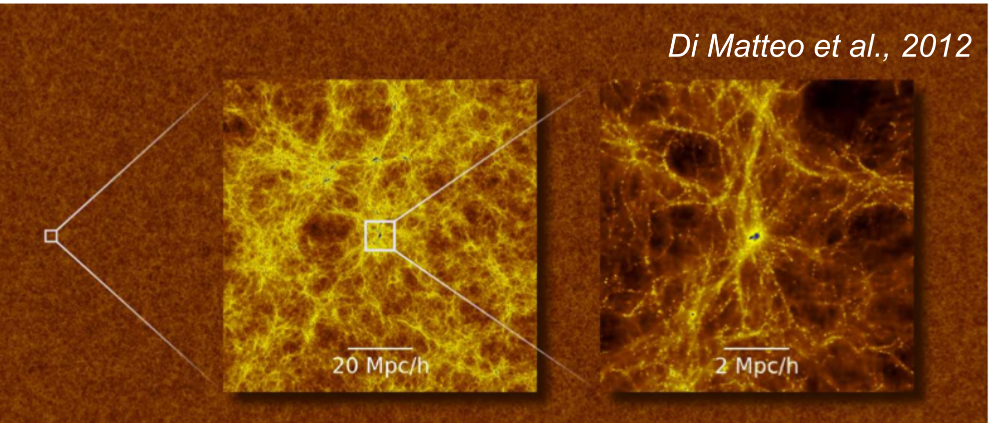
Growing the first bright quasars

- Direct accretion from the cosmic cold flows *(Di Matteo et al., 2012)*
Cosmological context with large statistics but low resolution (~1kpc)

Versus

- Violent disc instabilities *(Bournaud et al., 2011)*
High resolution (1pc) but isolated disc





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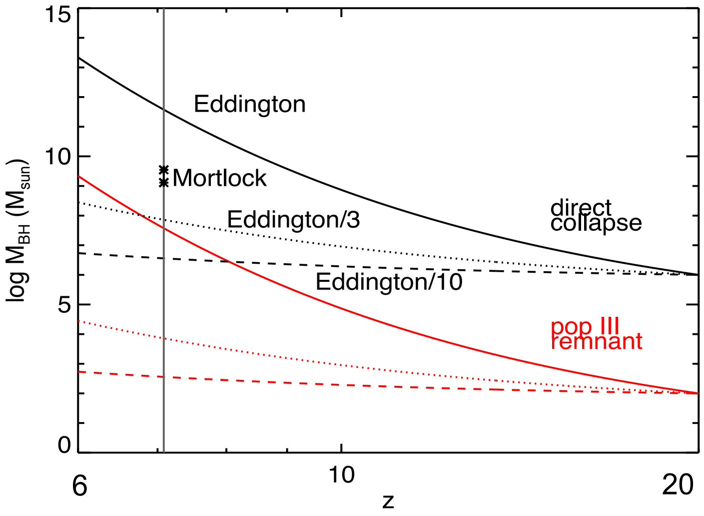

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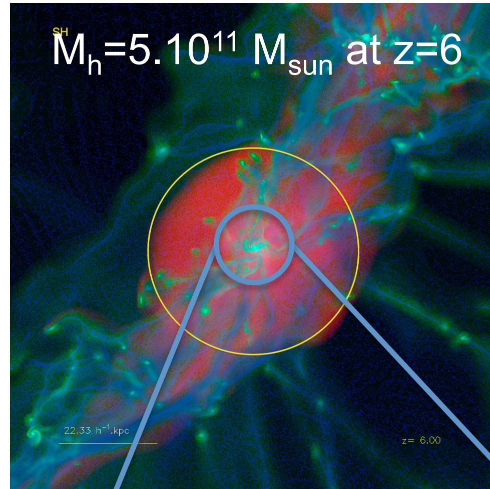
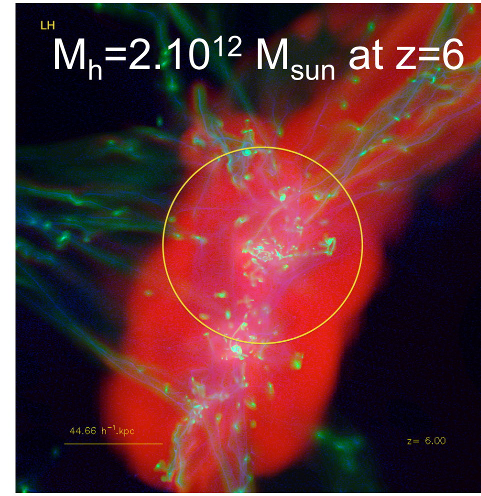
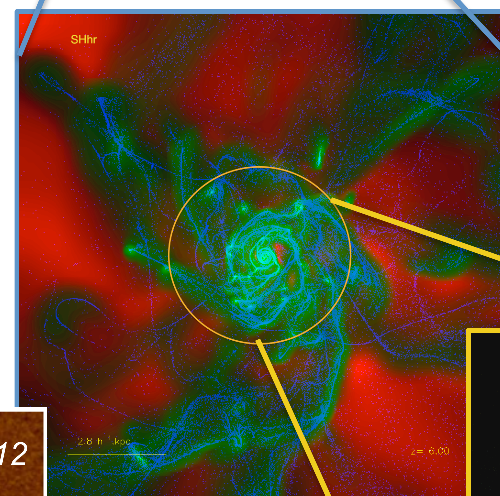
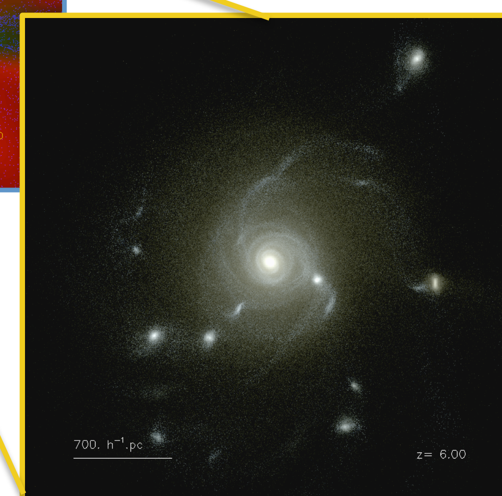


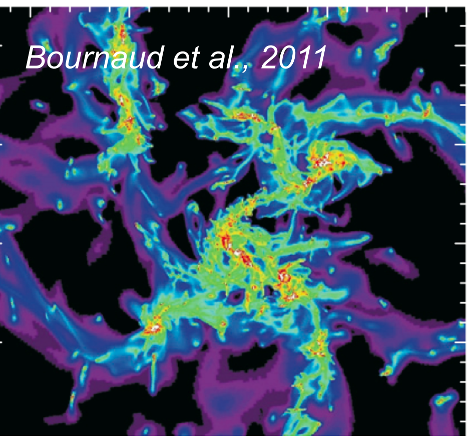


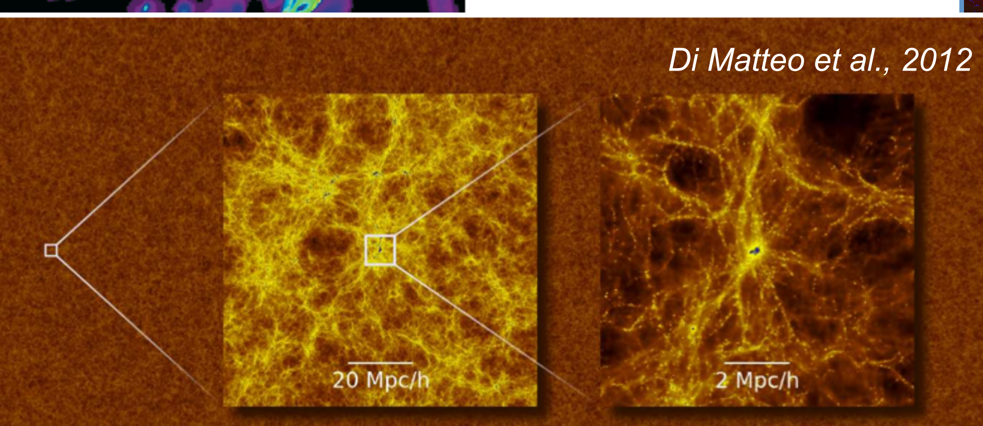


Cosmological zooms
10 pc resolution

Dubois, Pichon, Haehnelt et al., 2012




Bournaud et al., 2011



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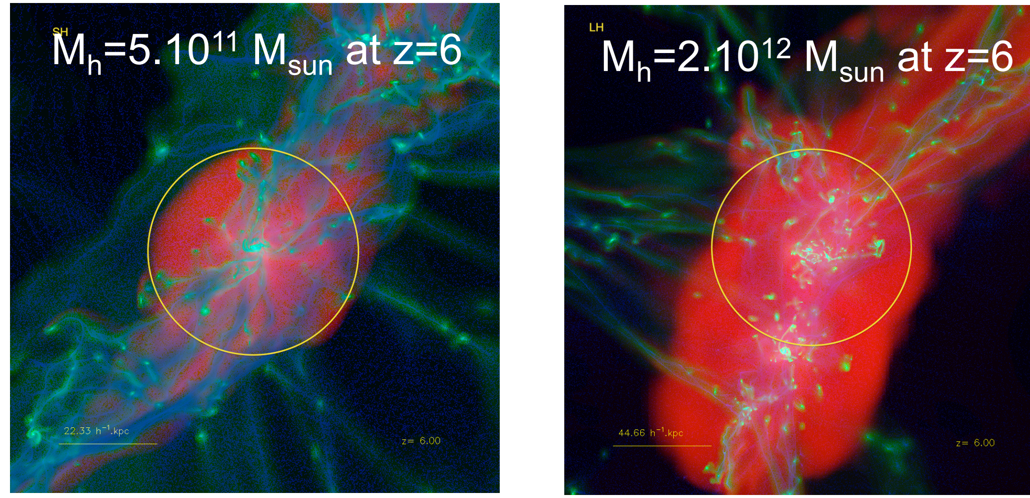
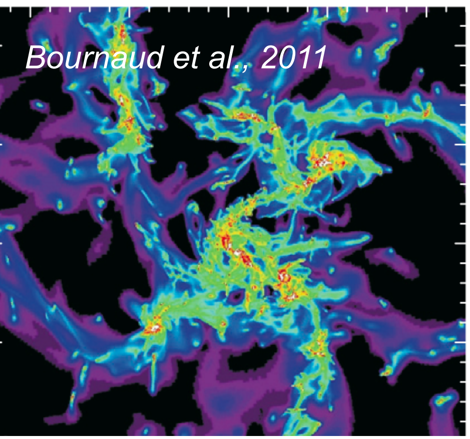
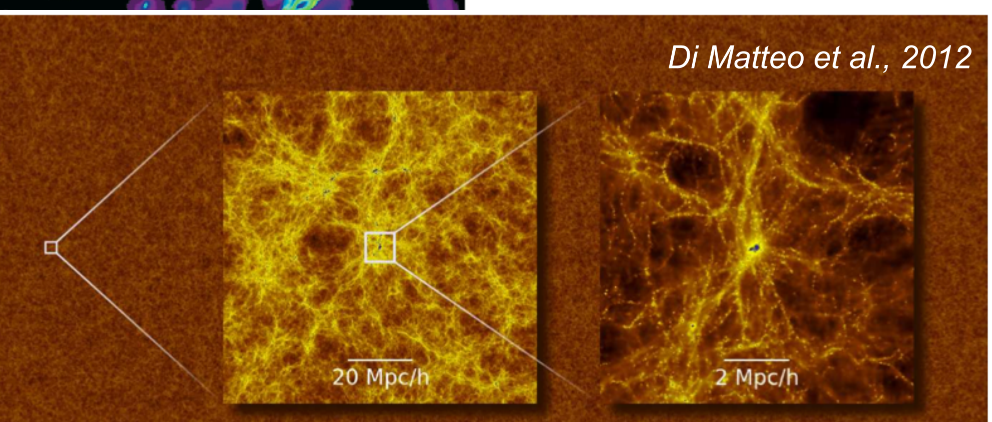
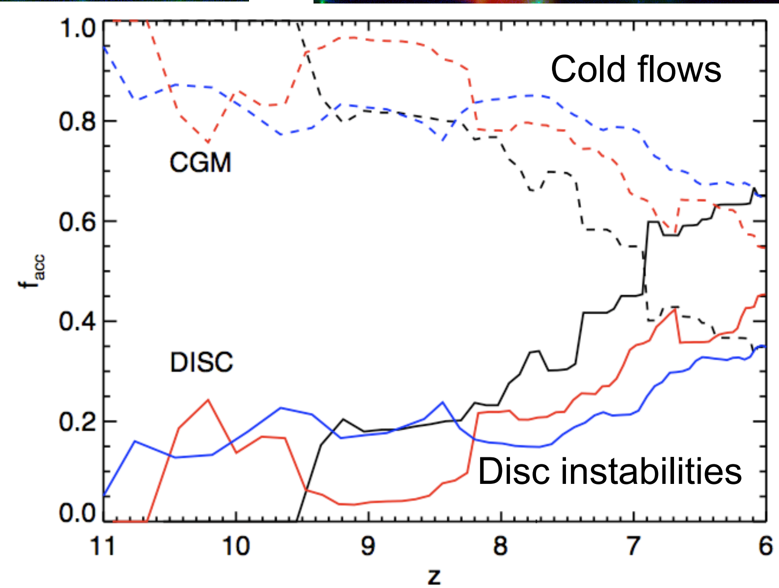


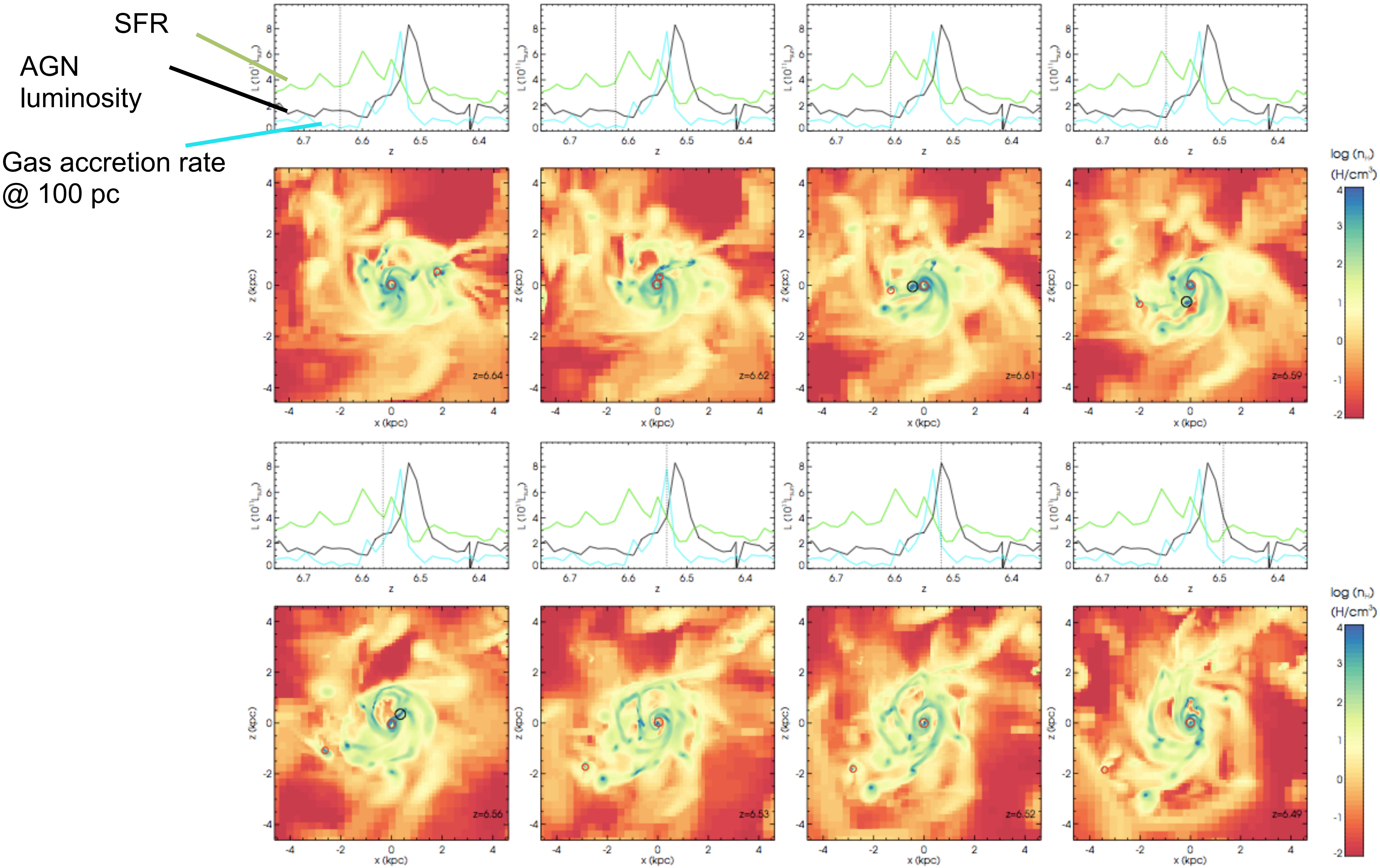






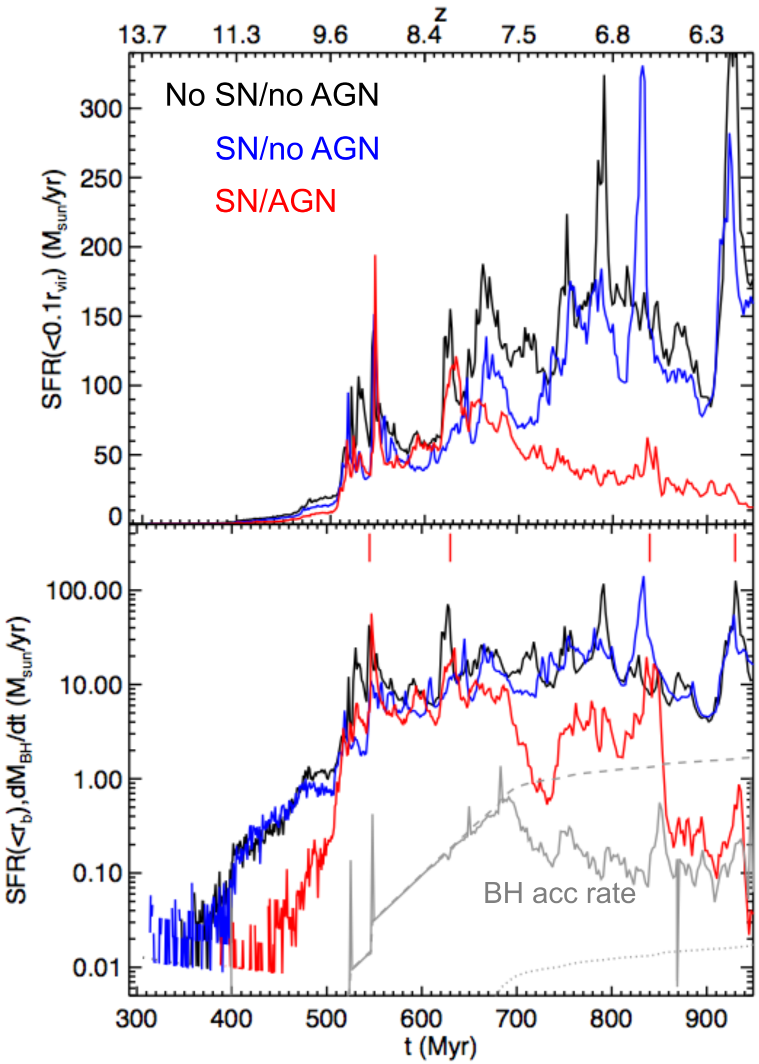
Dubois, Pichon, Haehnelt et al., 2012

A rapid clump migration to trigger « late-time » AGN bursts

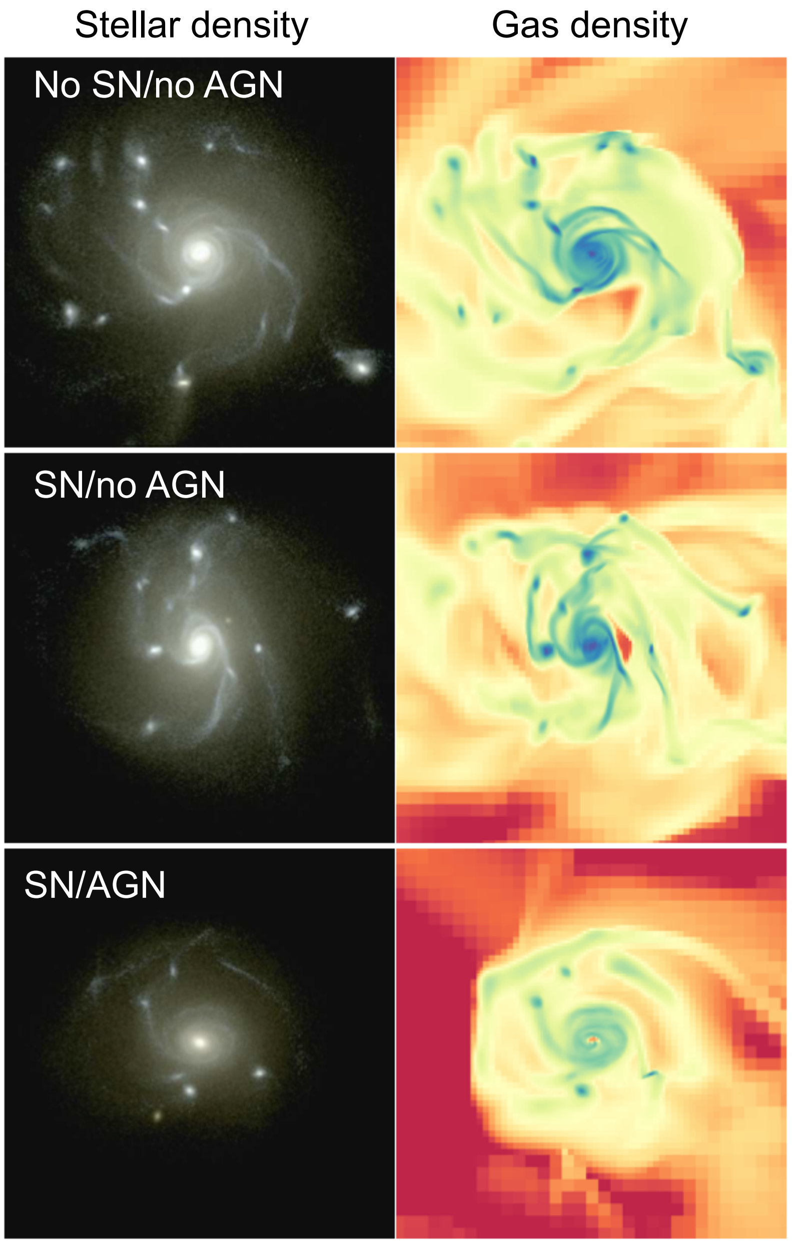


Dubois, Pichon et al., 2013

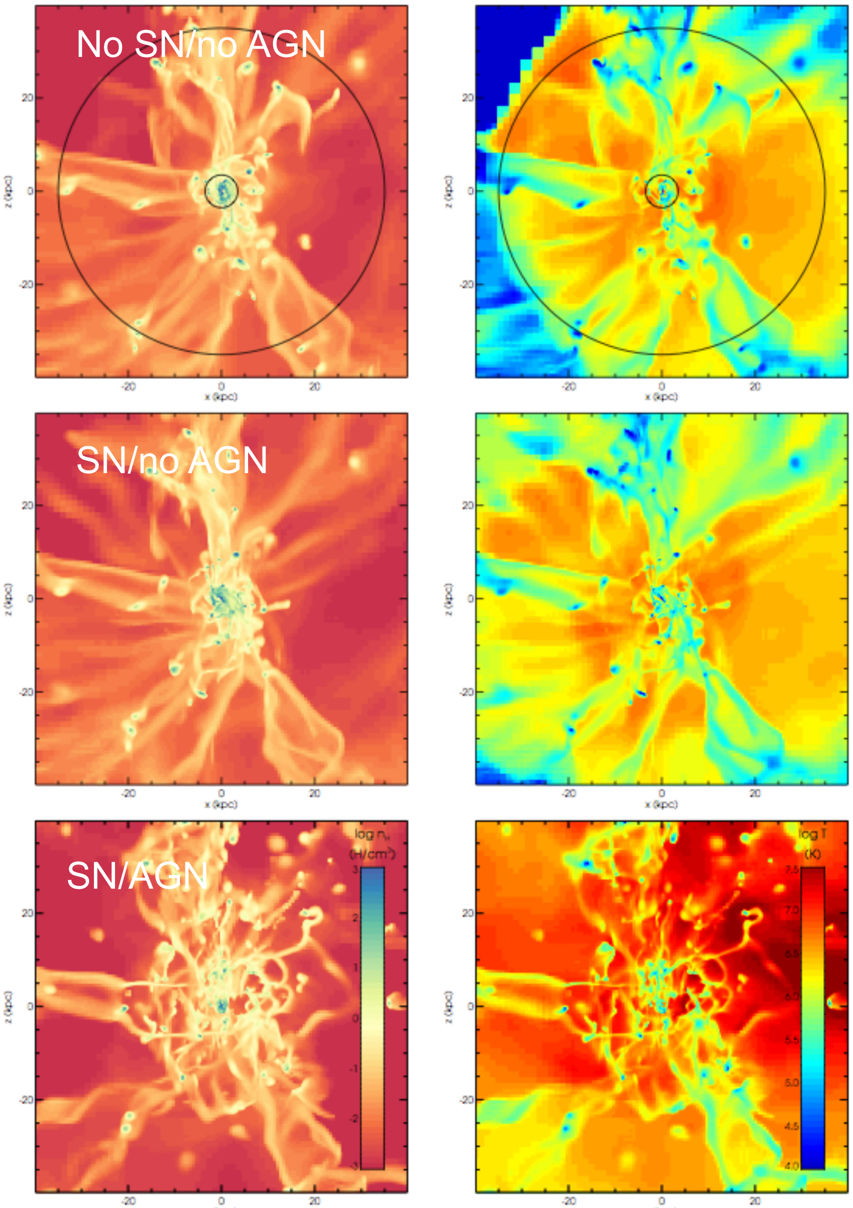
AGN quench star formation



Dubois, Pichon et al., 2013

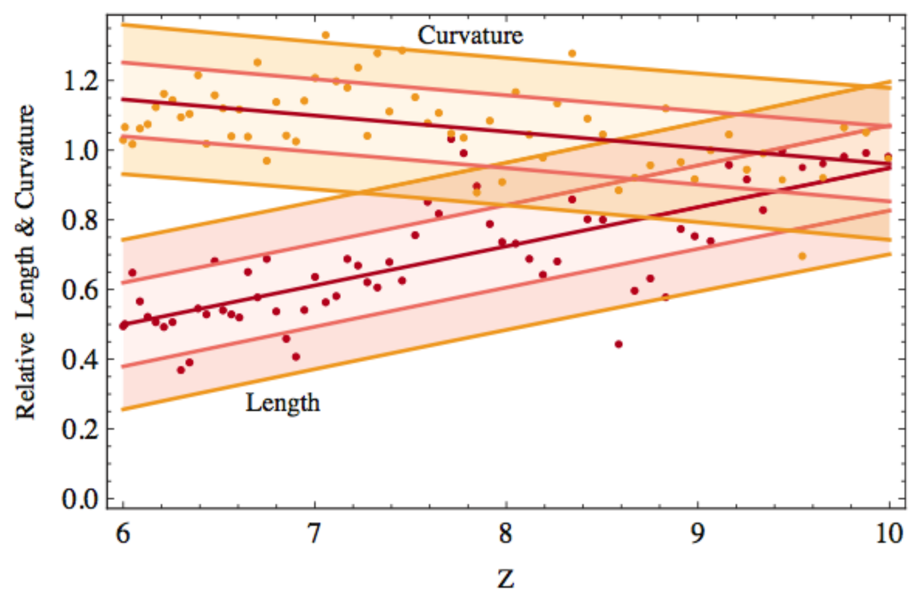


AGN blow cold flows away



Gas is driven out hot from the central galaxy due to AGN.

Cold filaments are repelled from the halo. Their structure is strongly perturbed

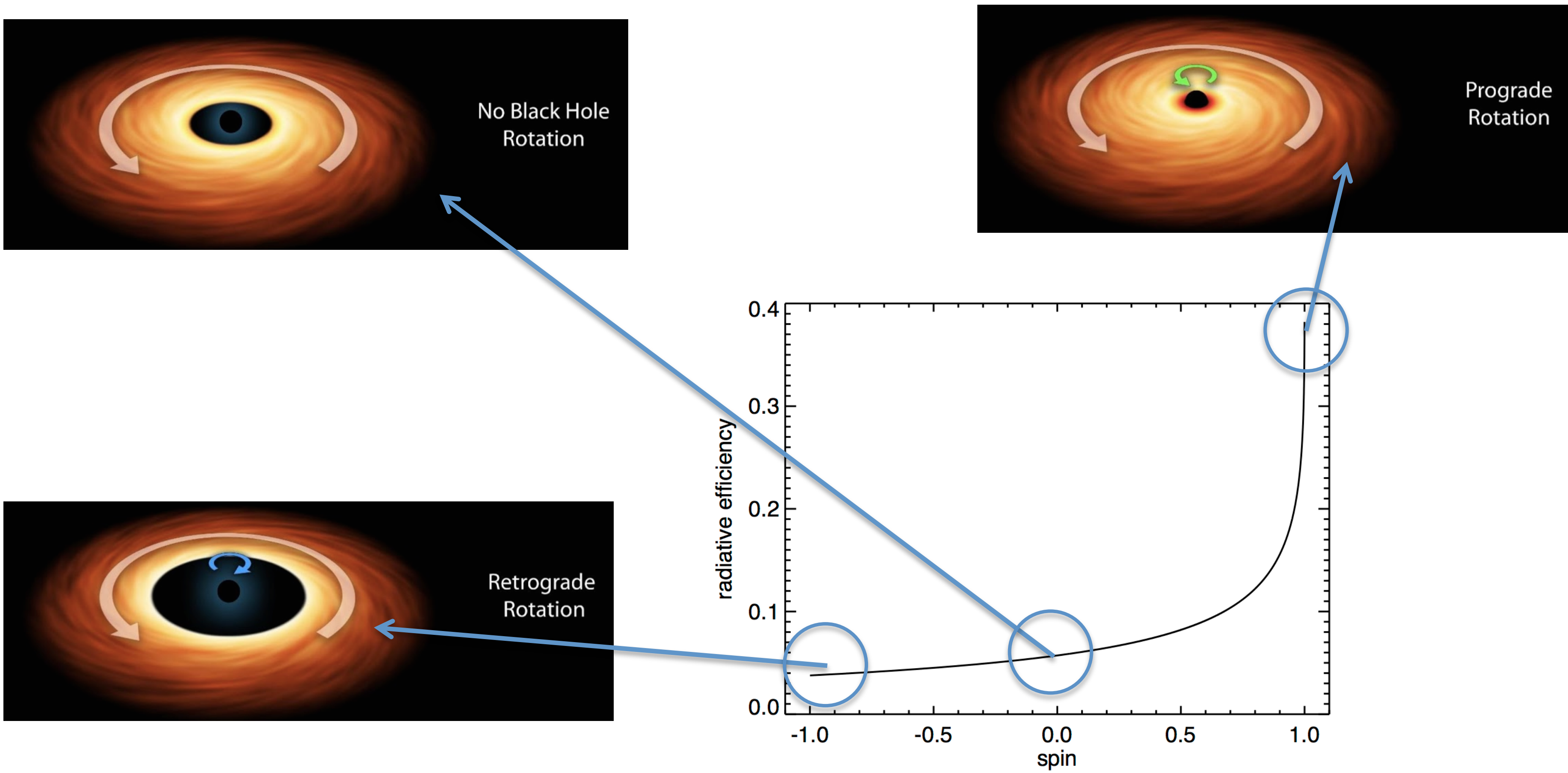


Dubois, Pichon et al., 2013

BH spin and its consequence on BH growth $spin = a = \frac{J_{\rm BH}}{(GM_{\rm BH}^2/c)}$

- Radiative efficiency depends on the BH spin parameter

- A non-spinning BH has a low radiative efficiency e_r=0.057. For a maximally spinning BH with a=0.998 e_r=0.321 (e_r=0.038 if a=-0.998)



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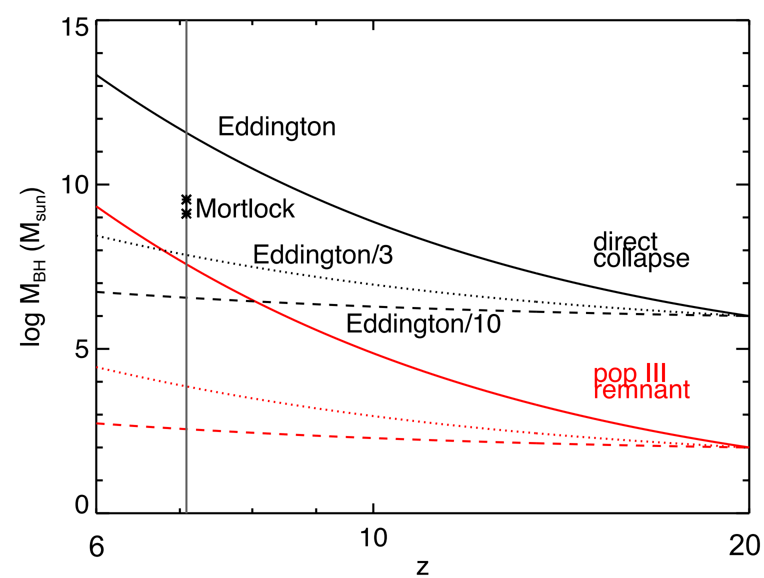
- The spin of BH is inherited from the history of gas accretion and successive mergers.

- Potential issue here: if BHs are maximally spinning then t_{Edd}(a=0.998)=144 Myr. Only possible to grow a 10^5 M_{sun} seed BH up to 10^8 M_{sun} in a Gyr (z=6)

$$t_{\rm Edd} = \frac{M_{\rm BH}}{\dot{M}_{\rm Edd}} = \frac{\epsilon_{\rm r}\sigma_{\rm T}c}{4\pi G m_{\rm p}}$$



BH spin evolution through accretion and binary coalescence (in a nutshell)

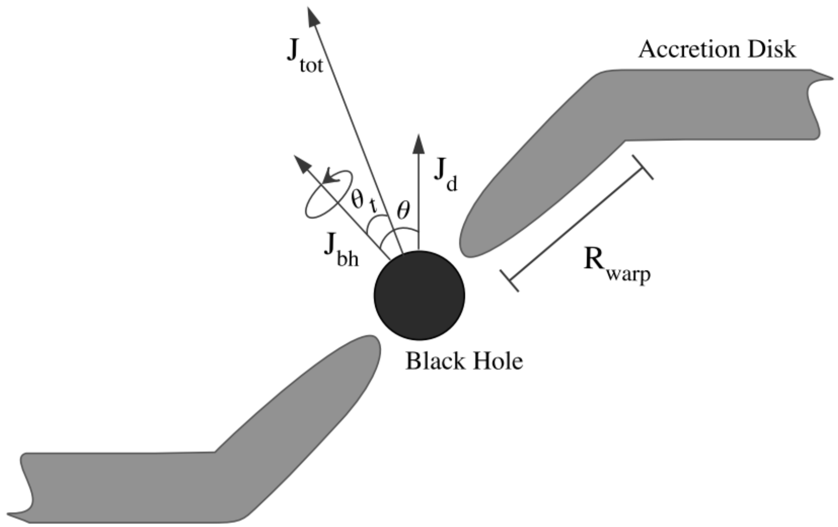
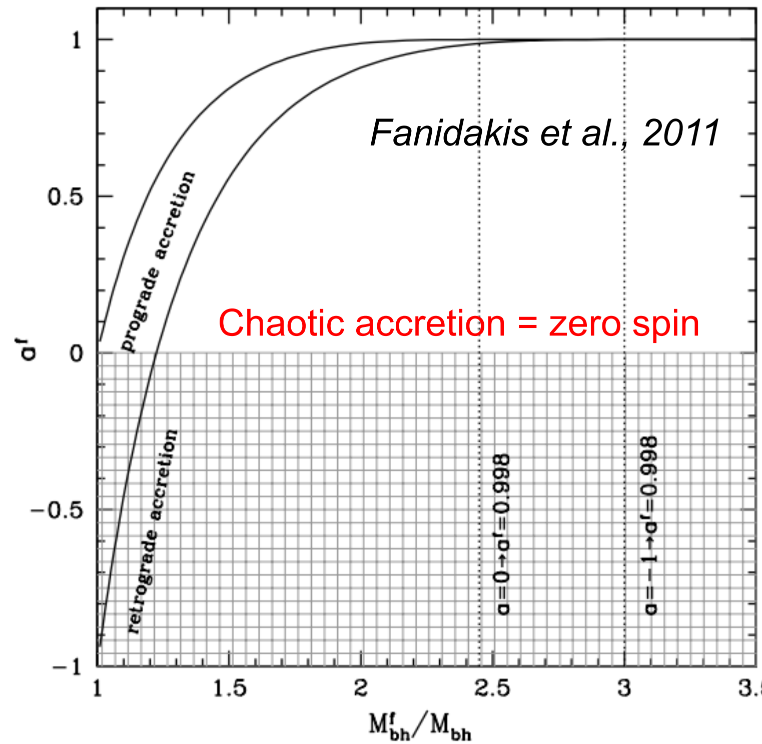


Figure 2. Schematic illustration of a warped accretion disc. $\boldsymbol{J}_{\rm bh}$ is the angular momentum of the BH ($|\boldsymbol{J}_{\rm bh}| = |a|GM_{\rm bh}^2/c$), $\boldsymbol{J}_{\rm d}$ is the angular momentum of the disc given by Eq. (20) and $\boldsymbol{J}_{\rm tot}$ represents the total angular momentum of the system, $\boldsymbol{J}_{\rm bh} + \boldsymbol{J}_{\rm d}$.

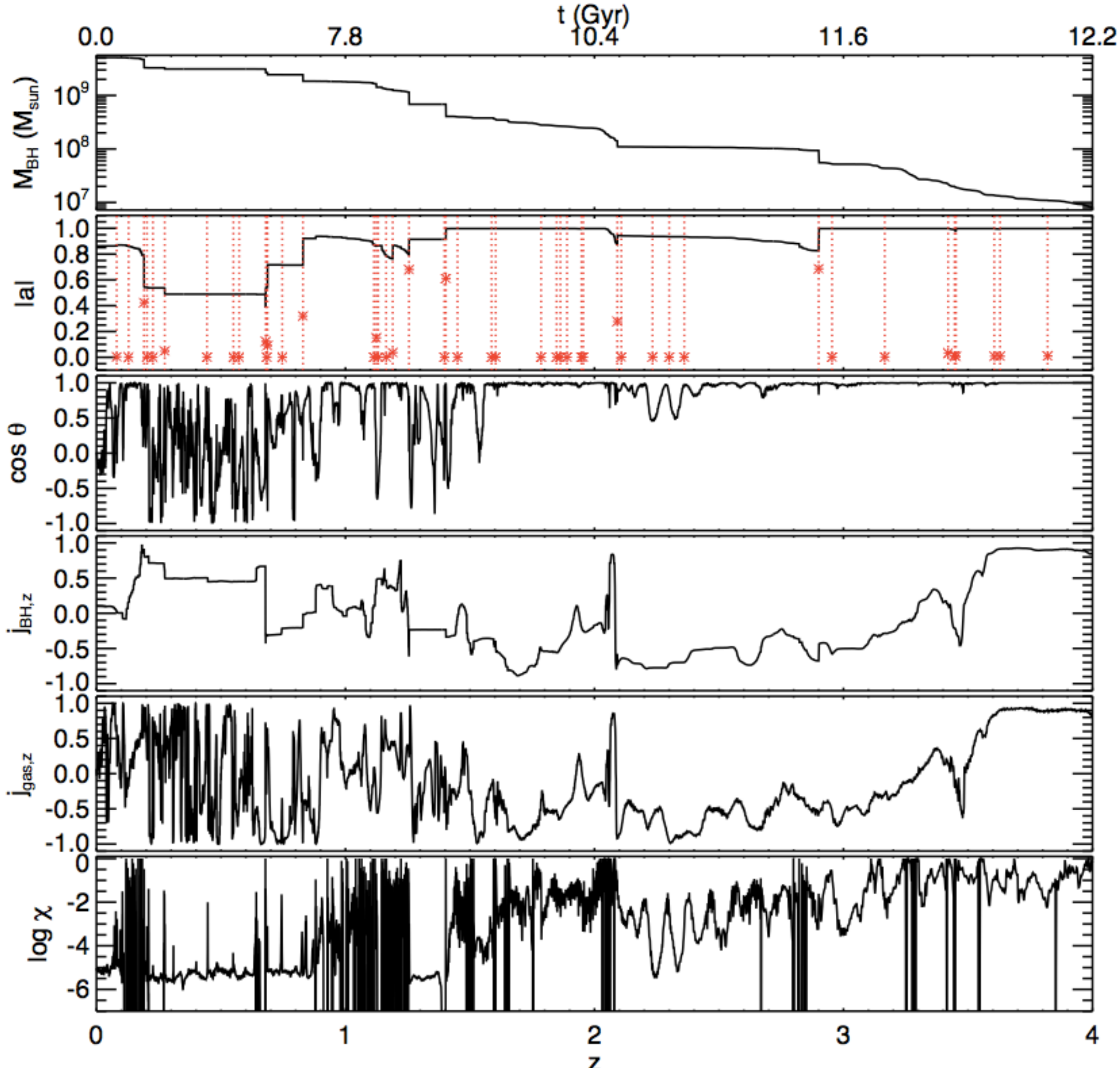


+

- BH-BH coalescence re-orientates the BH spin and change its amplitude if the mass ratio is large enough.
- The final value depends on the angle between the initial spin and orbital AM of the binary

Two types of evolution:
1- the typical SMBH in a BCG

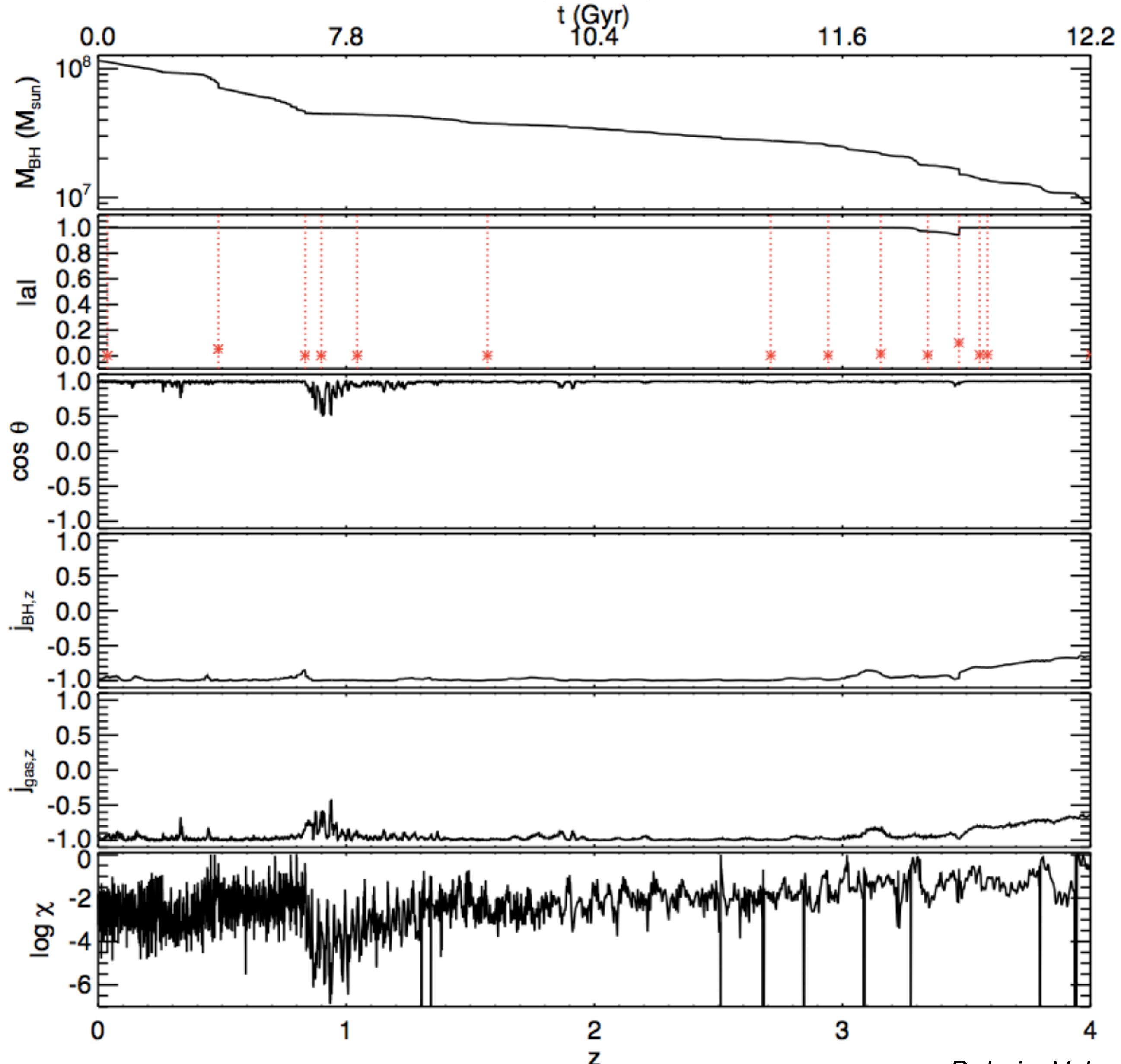
Large volume cosmological simulation
kpc resolution



Dubois, Volonteri, Silk, 2014

Two types of evolution:
2- the typical SMBH in a massive disc galaxy

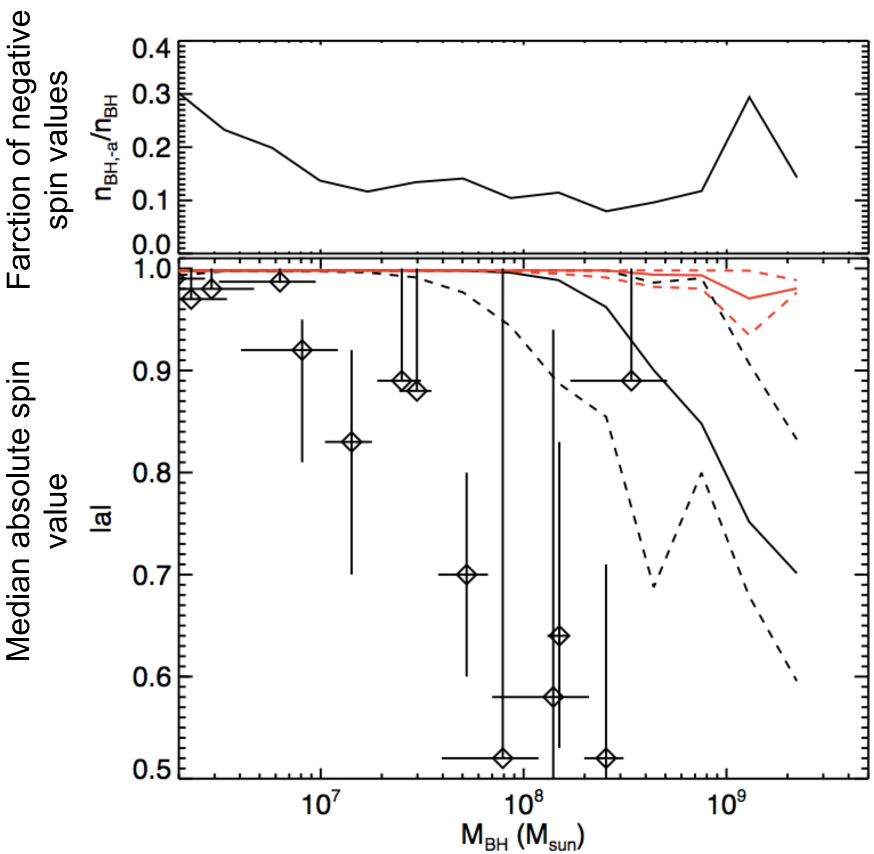
Large volume cosmological simulation
kpc resolution

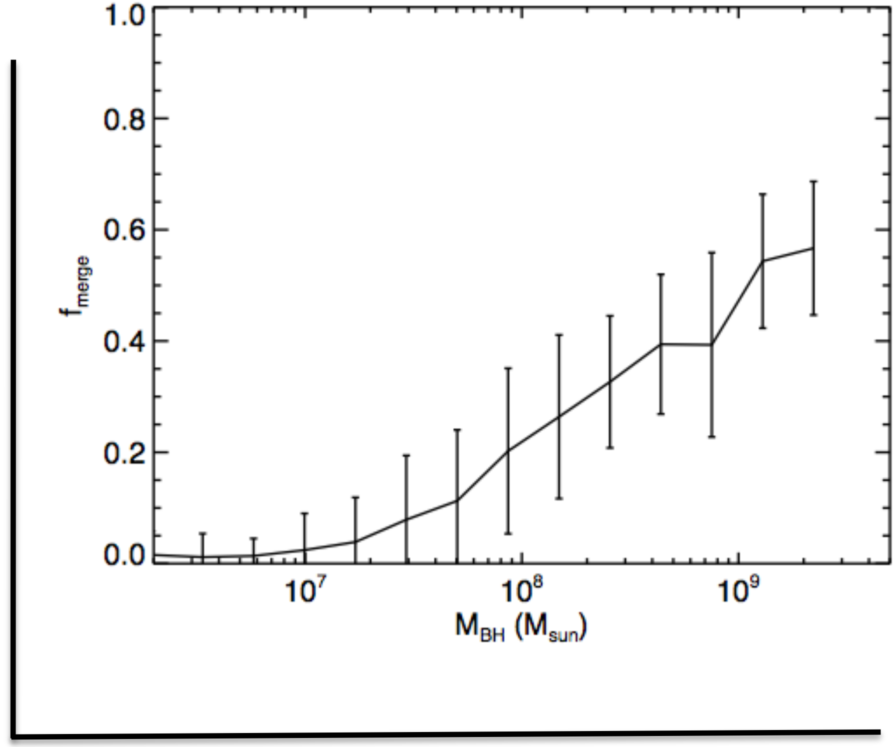


Dubois, Volonteri, Silk, 2014

Spins versus Masses and the role of mergers

Observations





Data *(Reynolds, 2013)*

Numerical simulation:

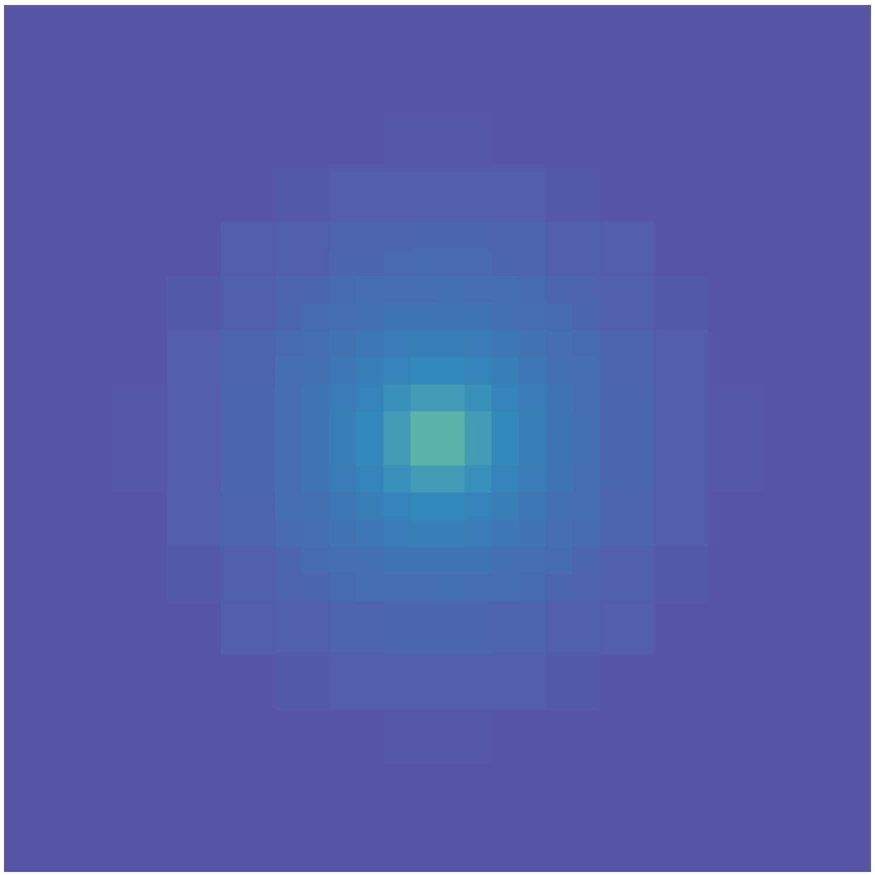
Fiducial model

Model w/o mergers to change spins

Cranking up the resolution

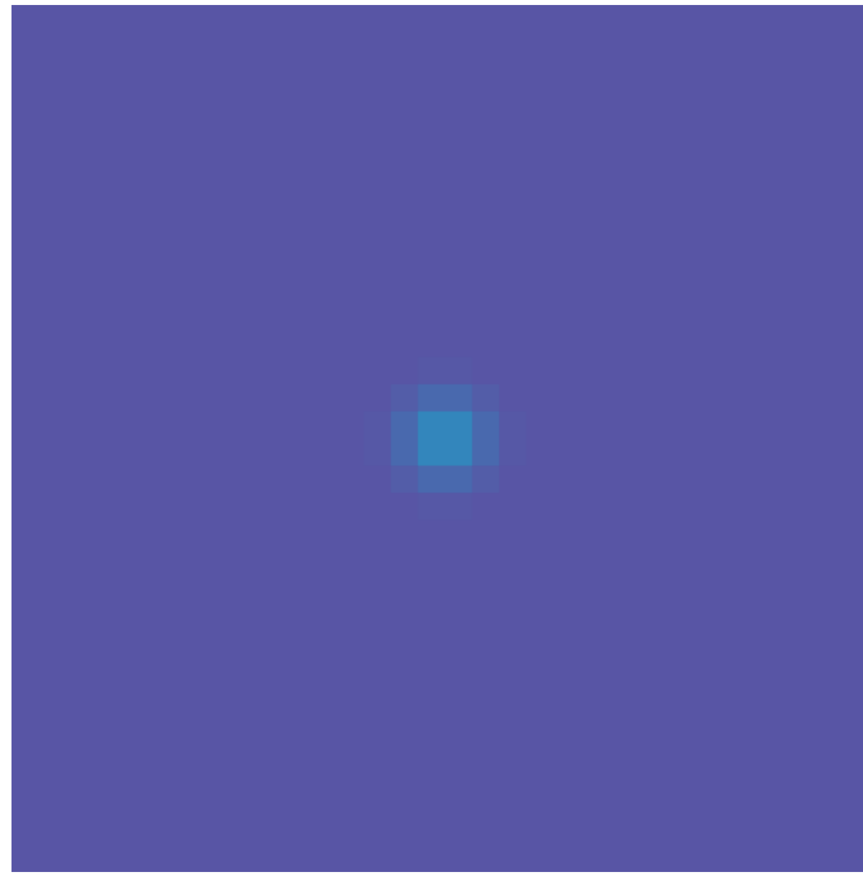
Isolated halo $M_{vir}=10^{12}$ M_{sun} & 10 pc resolution

Edge-on



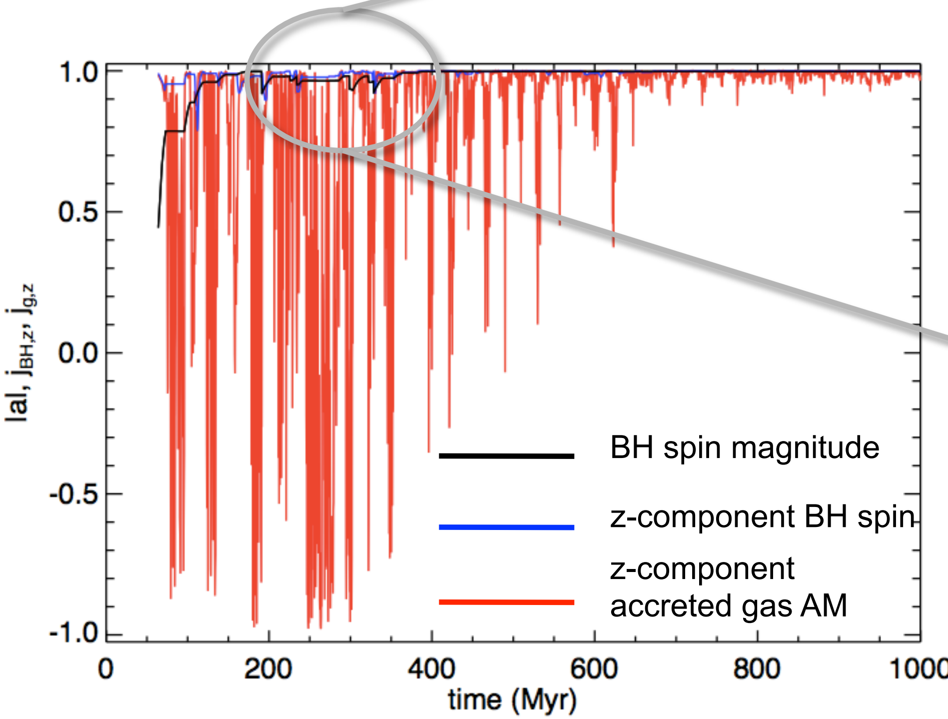
5 kpc

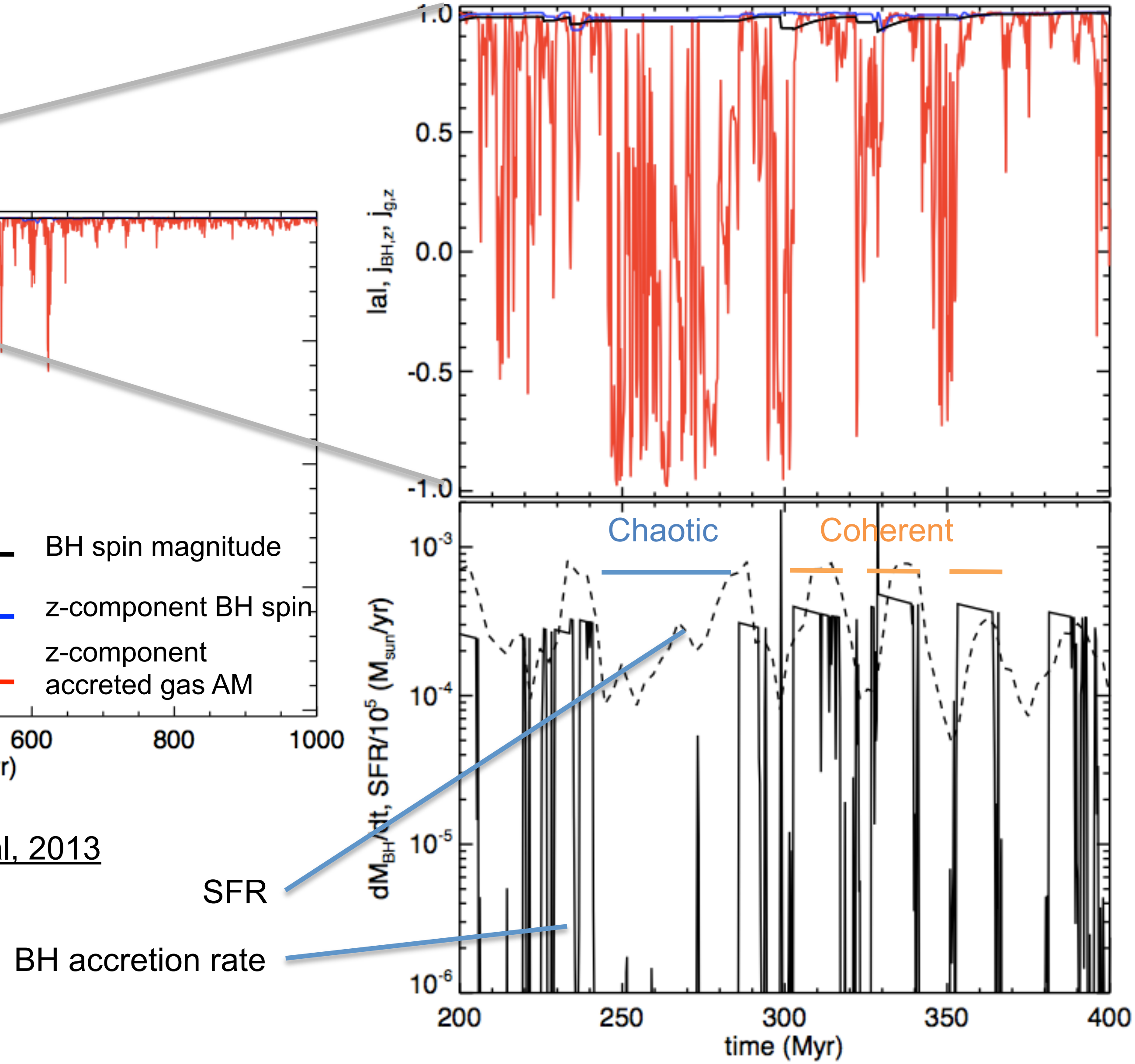
Face-on



5 kpc

Strong coherence of gas accretion



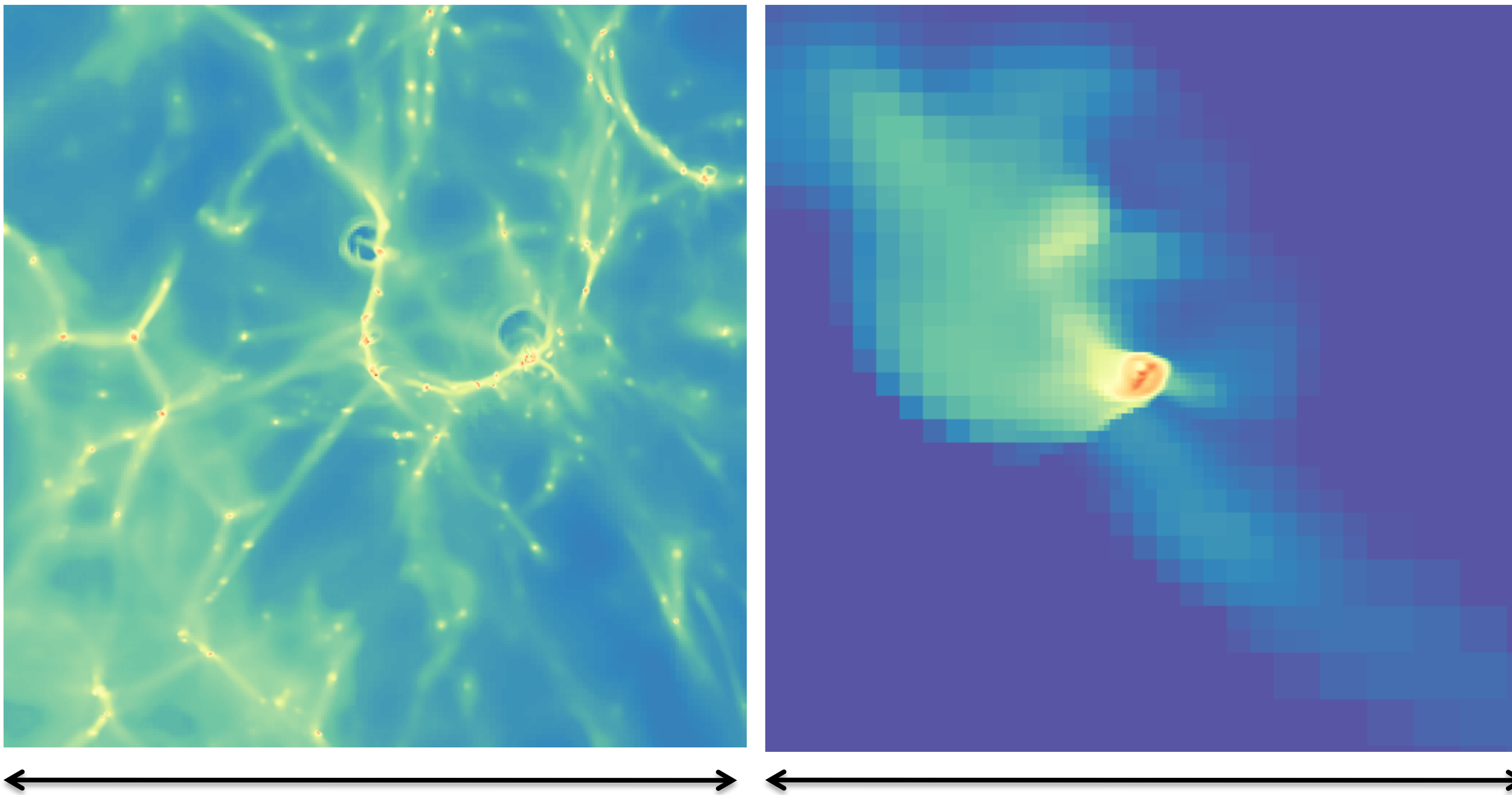


Consistent with Maio, Dotti et al, 2013

Dubois, Volonteri et al, 2014

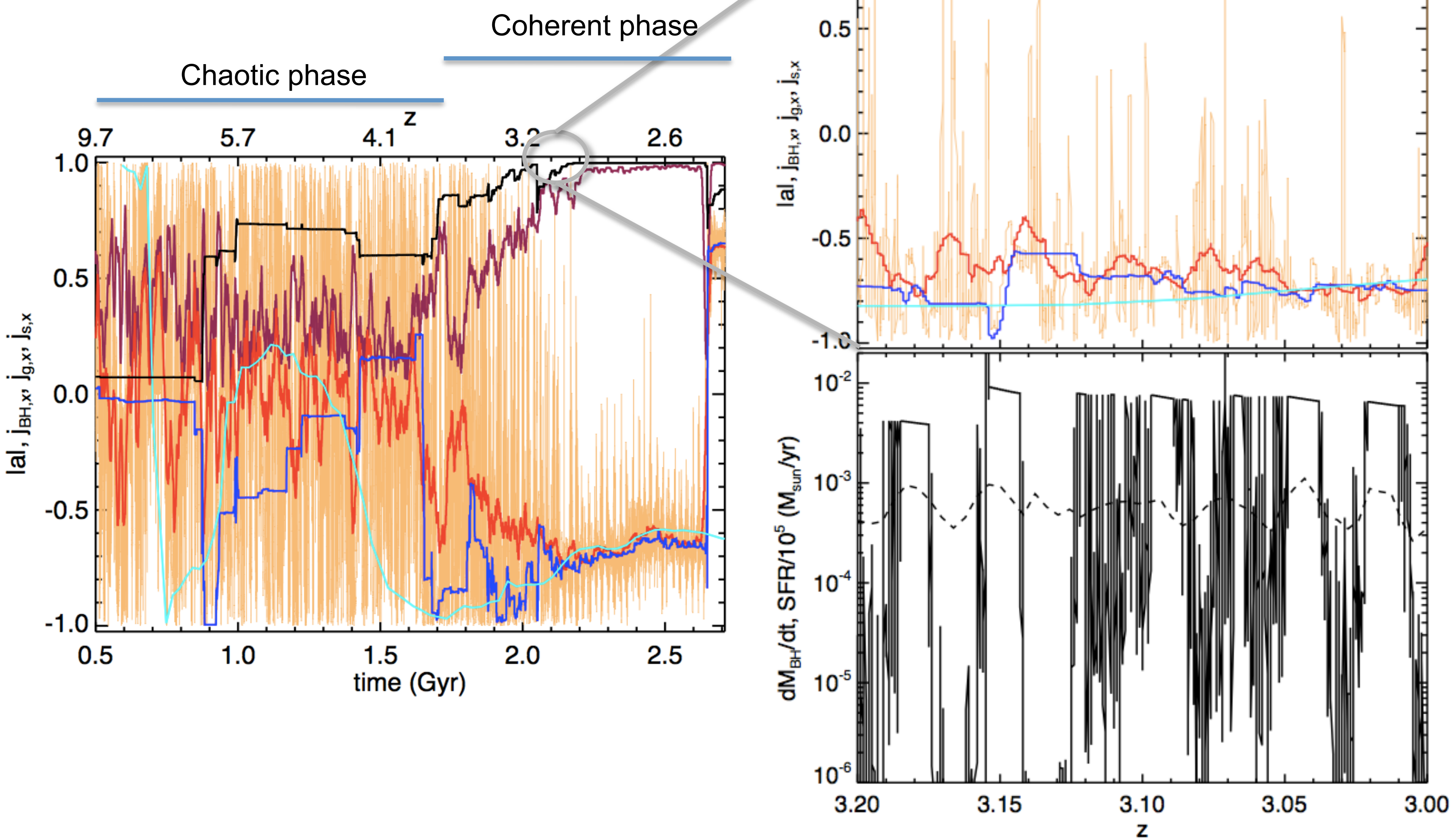
Going cosmological

$M_{vir}=10^{12}\ M_{sun}$ @ z=2 & 10 pc resolution



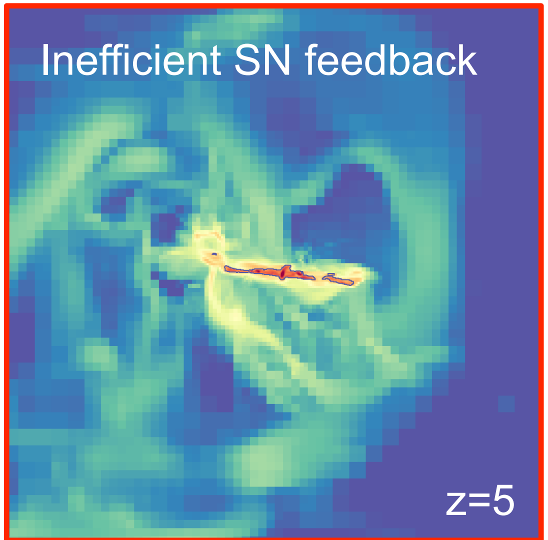
1 Mpc comoving 35 kpc comoving

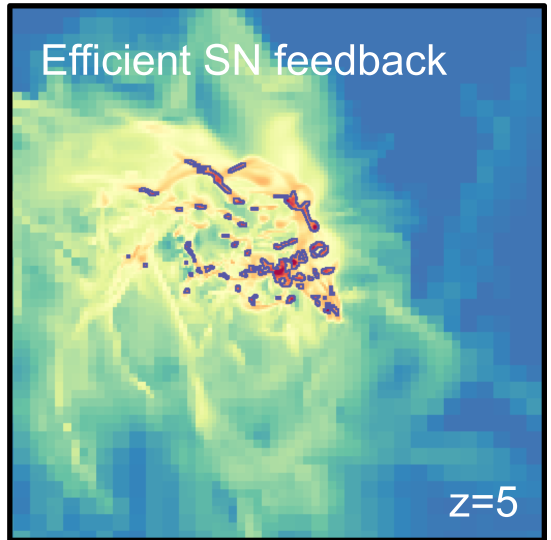
Going cosmological

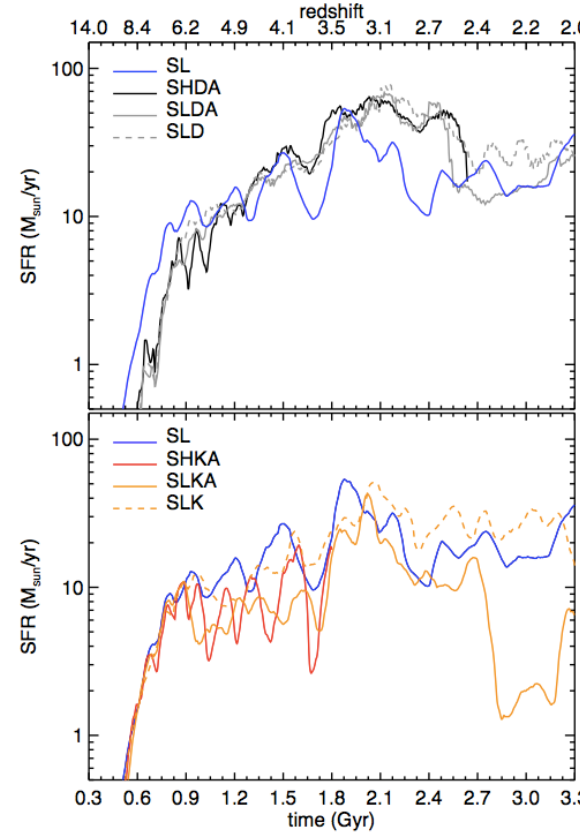


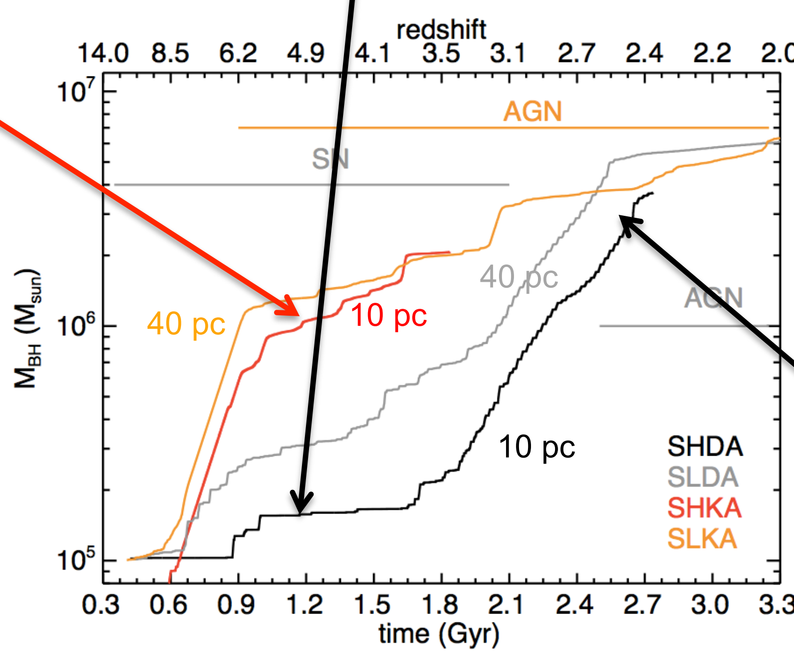
Dubois, Volonteri et al, 2014

BH growth delayed by (too?) efficient SN feedback



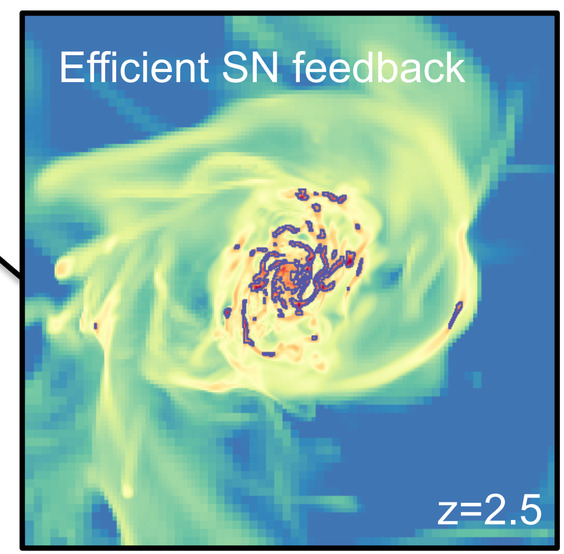


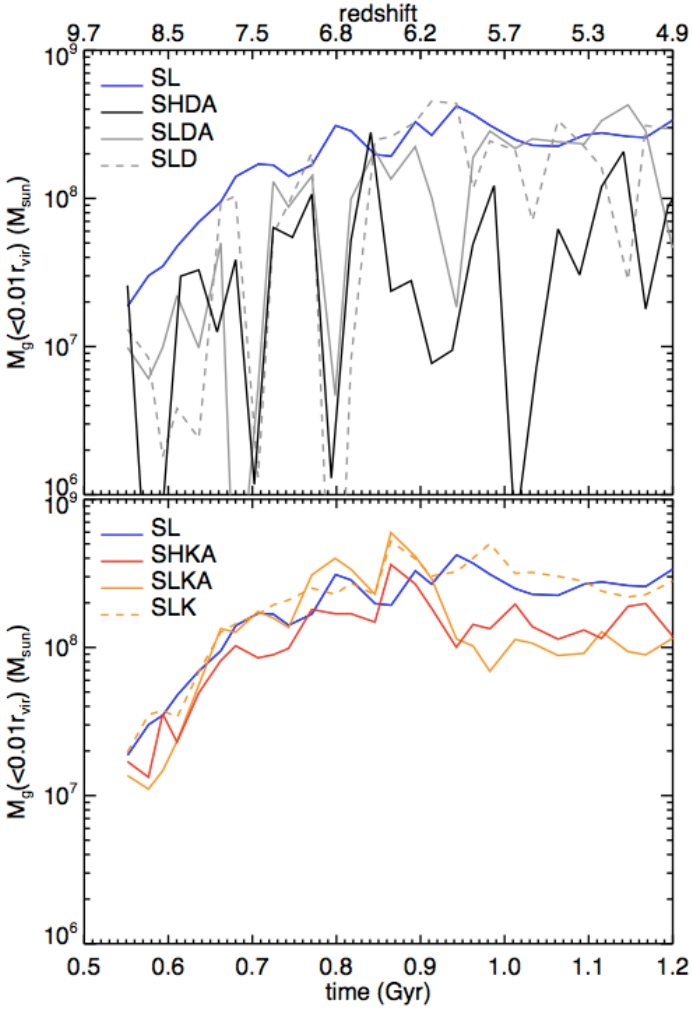




"Inefficient": kinetic blast wave model (Dubois & Teyssier, 2008)

"Efficient": non-thermal component (CR, turbulence, magnetic fields) that delays gas cooling (Teyssier et al, 2013)





$$u_{\rm SN} = 1.2\sqrt{\frac{m_{\rm new,s}\eta_{\rm SN}e_{\rm SN}}{m_{\rm g}}}$$

$$\simeq 270\sqrt{\frac{\eta_{\rm SN}}{0.1}}\sqrt{\frac{(m_{\rm new,s}/m_{\rm g})}{0.1}}\,{\rm km\,s^{-1}}$$

$$u_{\rm esc} = \sqrt{\frac{2Gm_{\rm cl}}{r_{\rm cl}}} \sim 300 \text{ km s}^{-1}$$

For $m_{cl}=10^9$ M_{sun} and $r_{cl}=100$ pc

Dubois et al., in prep

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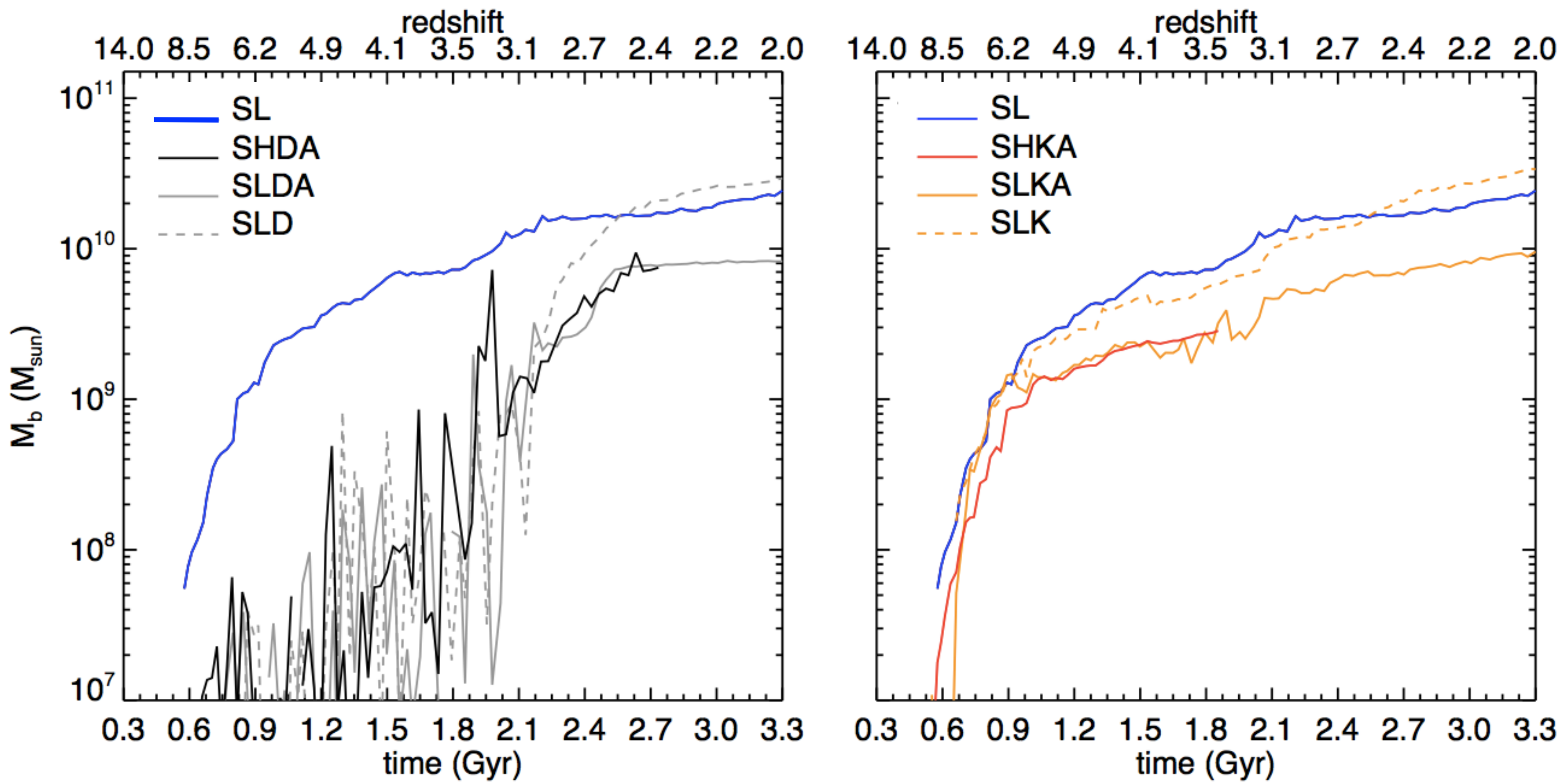

Dubois et al., in prep

Thank you for your attention