
THE SELF-REGULATED GROWTH OF BLACK HOLES DURING GALAXY MERGERS
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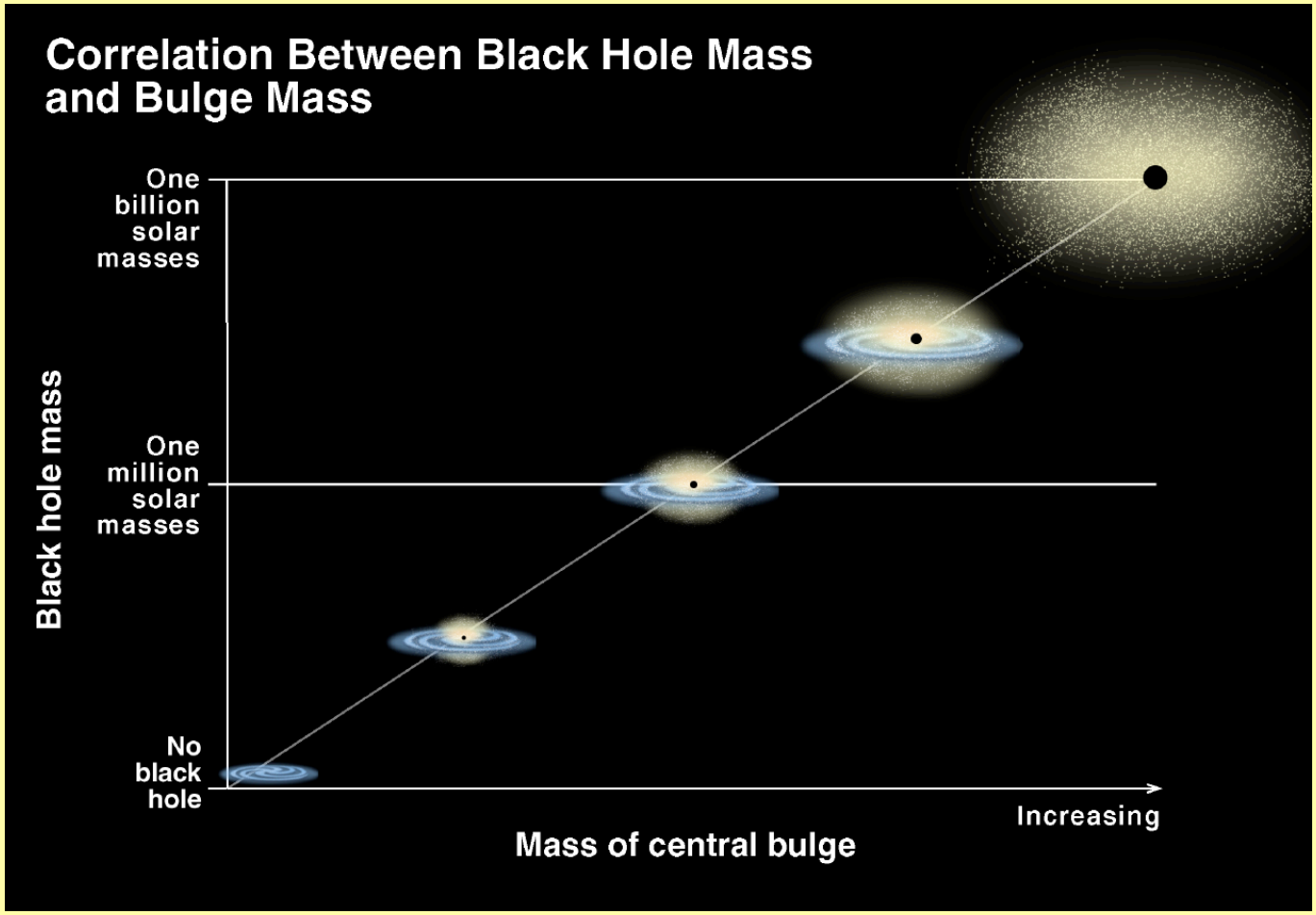
OUTLINE:

- INTRO: The black hole – galaxy connection
  The M - σ relation and the evolution of the QSO

- Self-consistent treatment of BHs in
  SpH Simulations of Galaxy Formation (Gadget)
  1. BHs in Isolated Galaxies & Mergers - BHs ⟷ galaxy formation
  2. BHs in Cosmological Simulations

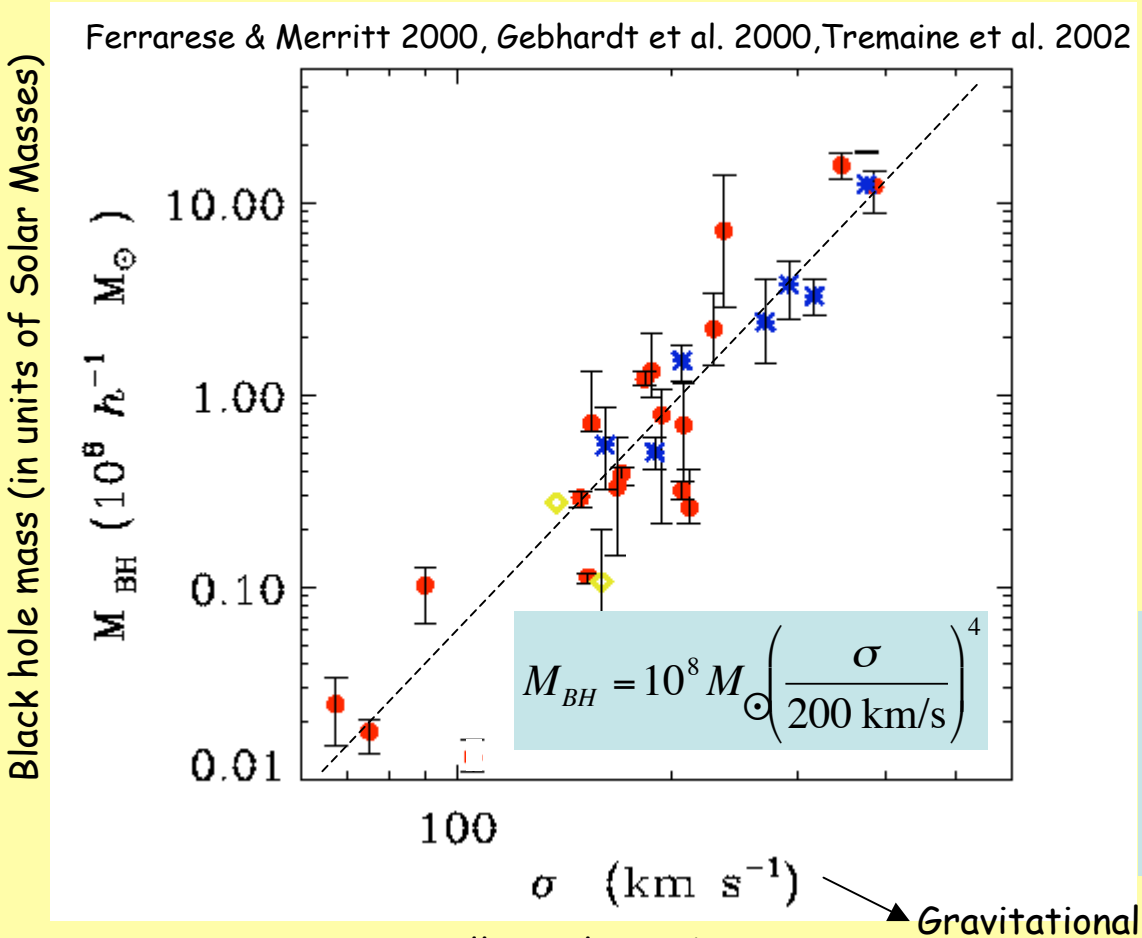
THE BLACK HOLE – GALAXY CONNECTION



Magorrian et al. 1998; Kormendy & Richstone 1995

THE BLACK HOLE – GALAXY CONNECTION

The M - σ relation for supermassive black holes



Gravitational potential of spheroid

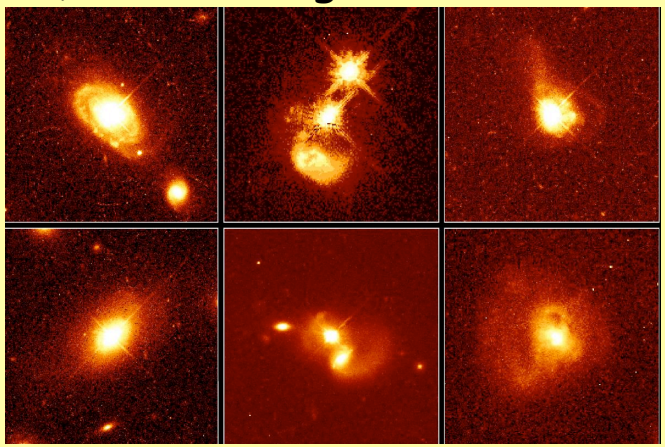
Black hole mass related to large scale properties of galaxies

fundamental link between assembly of black holes and galaxy formation

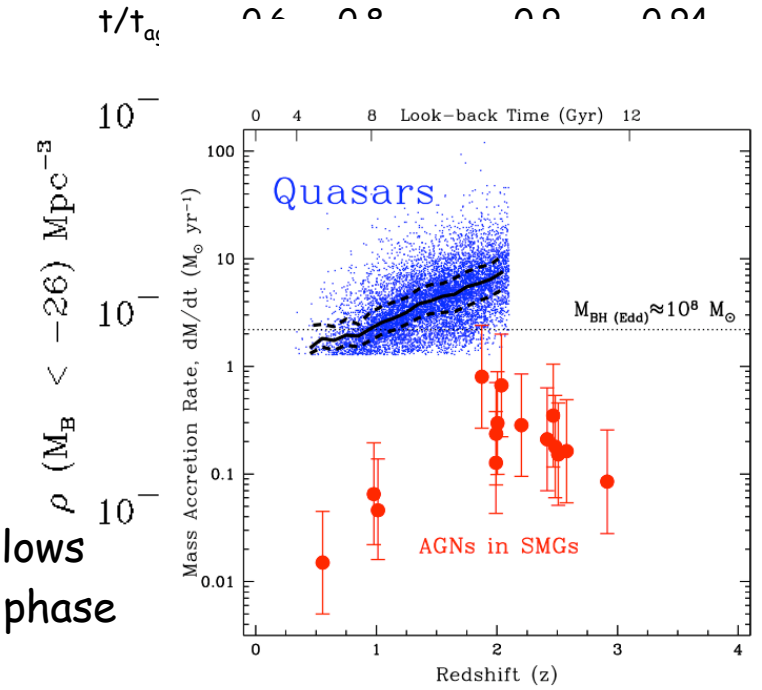
(Many) Theoretical models: BH growth regulated by Feedback (Silk&Rees98,Wythie&Loeb01 Fabian 99, King03)

THE BLACK HOLE – GALAXY CONNECTION

Quasar host galaxies



Quasars comoving space density



Alexander et al. 2005, Nature
Komossa et al. 2003

- Ultra deep X-ray obs. Of submm gal imply rapid black hole growth related to sites of intensive star fomation - hence massive gas flows SMG are roughly co-eval with peak of quasar phase

- Similar in local universe ULIRG - X-ray point sources - accreting BHs in intense nuclear starbursts.

Strong evolution of QSOs → **Evolution of the SFR density**

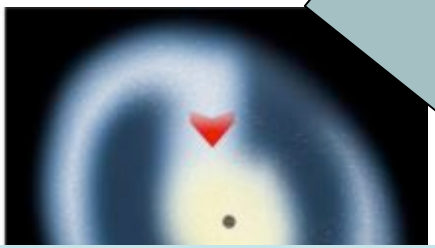
BH fuelling linked to spheroid star formation

Galaxy formation and accretion on supermassive black holes appears to be closely related →

BLACK HOLES MAY PLAY AN IMPORTANT ROLE IN THEORETICAL GALAXY FORMATION MODELS:

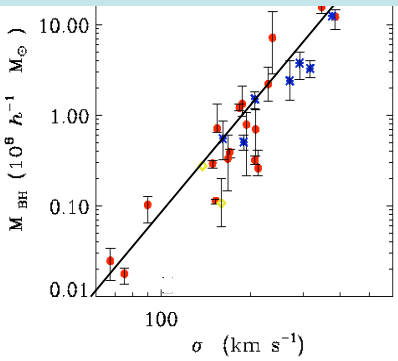
- Feedback important for solving entropy in clusters

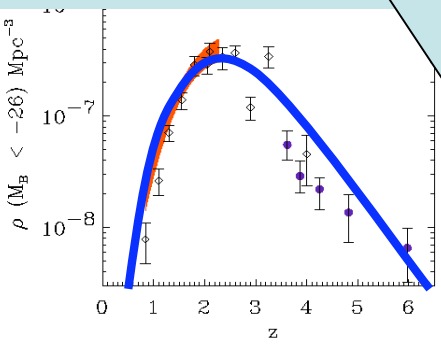
Galaxy formation models need to include the growth and feedback of black holes !



HYDRODYNAMICAL SPH SIMULATIONs of GALAXY FORMATION:

Model self-consistently star formation and gas accretion on BHs and feedback





SPH simulations of galaxy formation

(GADGET2 so far….)

DARK MATTER

GAS

STARS

N-body METHOD: mass dicretised in particles modeled as collisionless fluid governed by Boltzmann Eq. - grav potential solved with Poisson Eq.

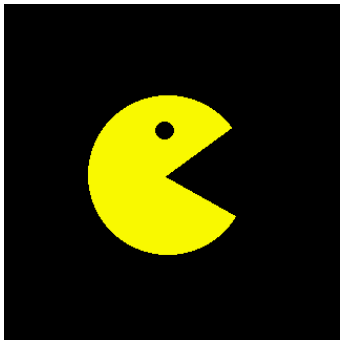
SPH Method: fluid represented by particles smoothed by local kernel averaging
Hydro eqns solved in its Galilean-invariant Lagrangian Formulation.

- Radiative cooling of gas within halos (dissipation)
- Star formation and feedback processes

(Springel & Hernquist 2003)

SUB-RESOLUTION multiphase MODEL for the ISM

BHs in SPH Simulations of Galaxy formation



- BH: collisionless "sink" particle in the centre of galaxies

- ACCRETION: relate (unresolved) accretion on BH to large scale (resolved) gas distribution

$$\dot{M}_B = \alpha 4\pi \frac{(GM_{BH})^2}{(c_s^{\,2} + V_{rel}^2)^{3/2}} \rho$$

$$\dot{M}_{BH} = \min(\dot{M}_{Edd}, \dot{M}_B)$$

- FEEDBACK: energy extracted from the black hole injected in the surrounding gas

$$\dot{E}_{feed} = f(\eta \dot{M} c^2) \qquad f \approx 0.5\%$$

0.1

BHs in Numerical Simulations

Implementation in SPH simulation code

Additions in the parallel GADGET-2 code:

- ✓ BH sink particle - only feel gravity- we compute,SPH Properties of local environment (T, rho, vel)
- ✓ BH particles swallow gas stochastically from their local neighbourhoods, in accordance with the estimated BH accretion rate •

$$p_j = w_j \dot{M}_{BH} \Delta t / \rho$$

- ✓ BH has additional internal degree of freedom:Variable described BH mass in smooth fashion
- ✓ Feedback energy is injected kernel-weighted into the thermal reservoir of gas in BH enviroment
- ✓ BHs are merged if they reach small separations (smoothing lengths) and low enough relative speeds
- ✓ On-the-fly FOF halo finder detects emerging galaxies and provides them with a seed black hole

We construct compound disk galaxies that are in dynamical equilibrium

Springel, Di Matteo & Hernquist, '05

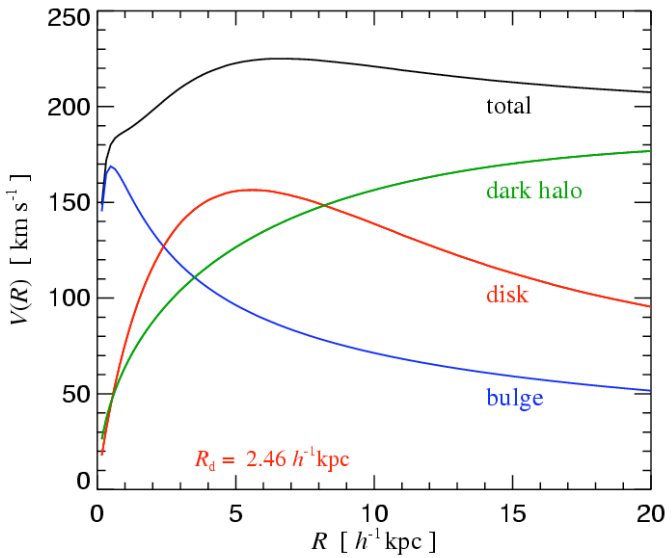
STRUCTURAL PROPERTIES OF MODEL GALAXIES

Components:

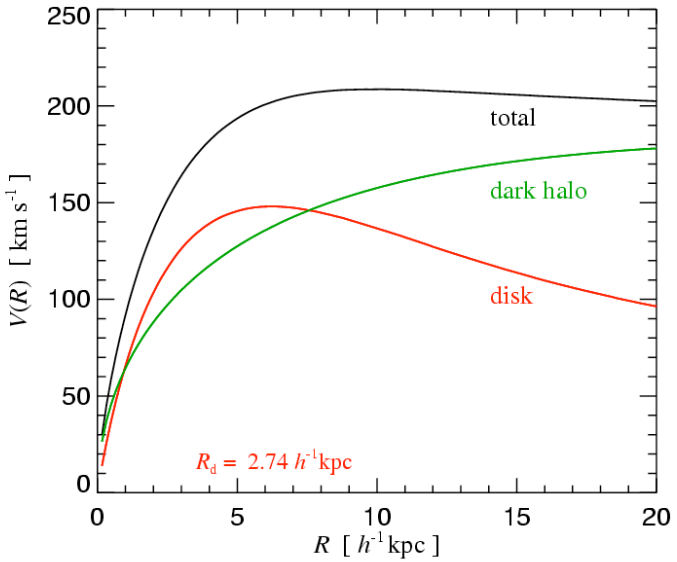
- Dark halo (Hernquist profile matched to NFW halo)
- Stellar disk (expontial)
- Stellar bulge
- Gaseous disk (expontial)
- Central supermassive black hole (small seed mass)

- We compute the exact gravitational potential for the axisymmetric mass distribution and solve the Jeans equations
- Gas pressure effects are included
- The gaseous scale-height is allowed to vary with radius

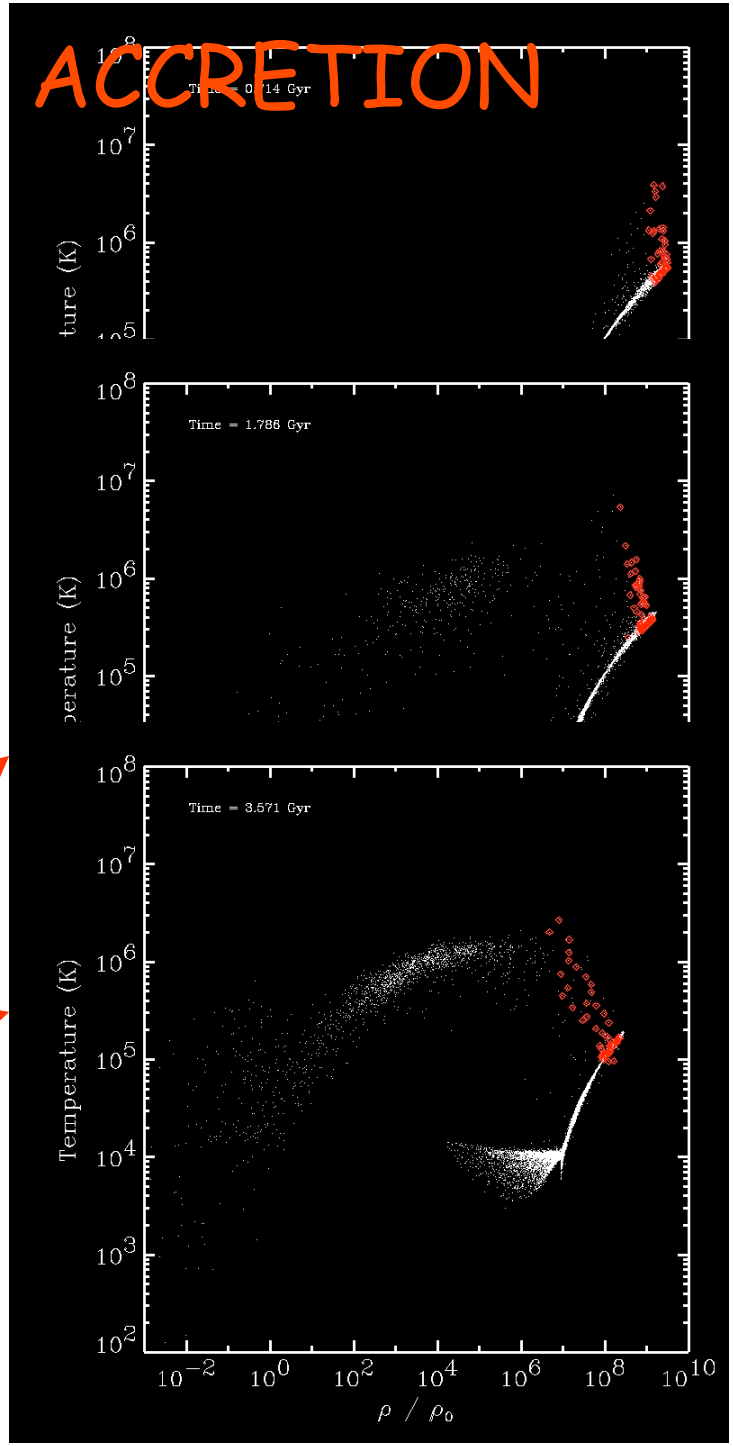
With Bulge



Without Bulge



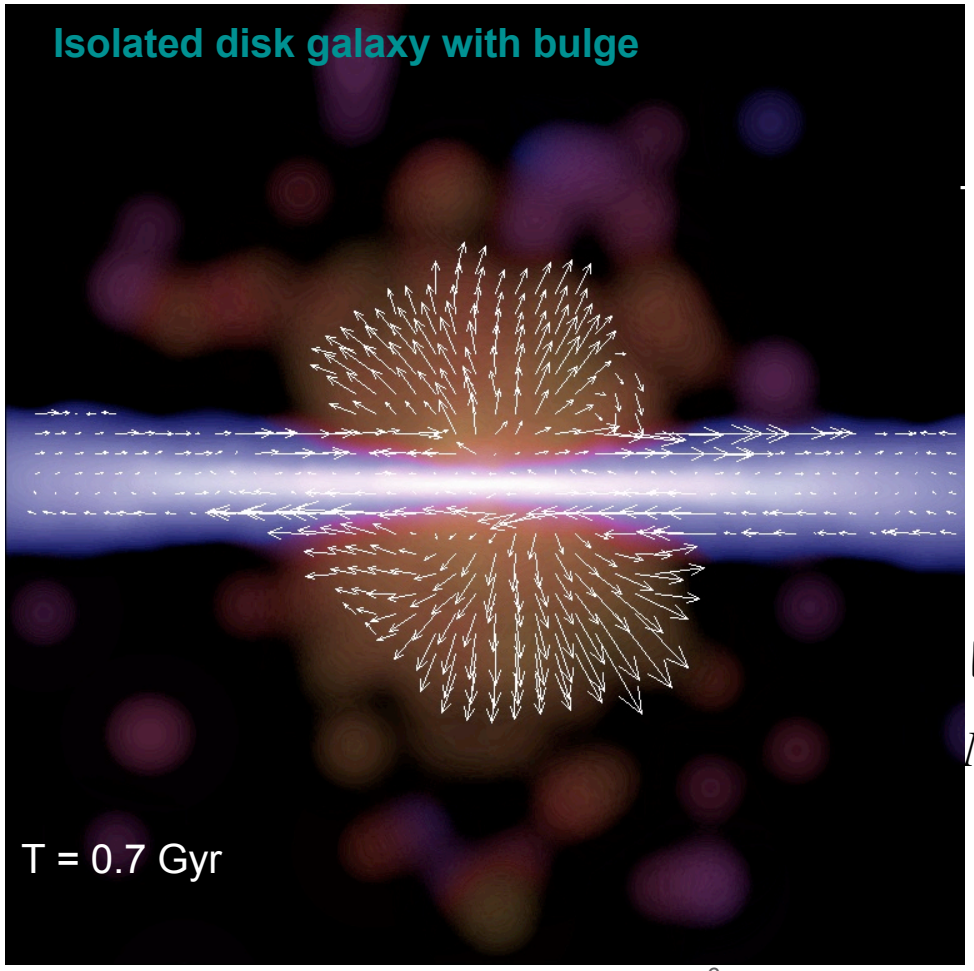
BH ACCRETION



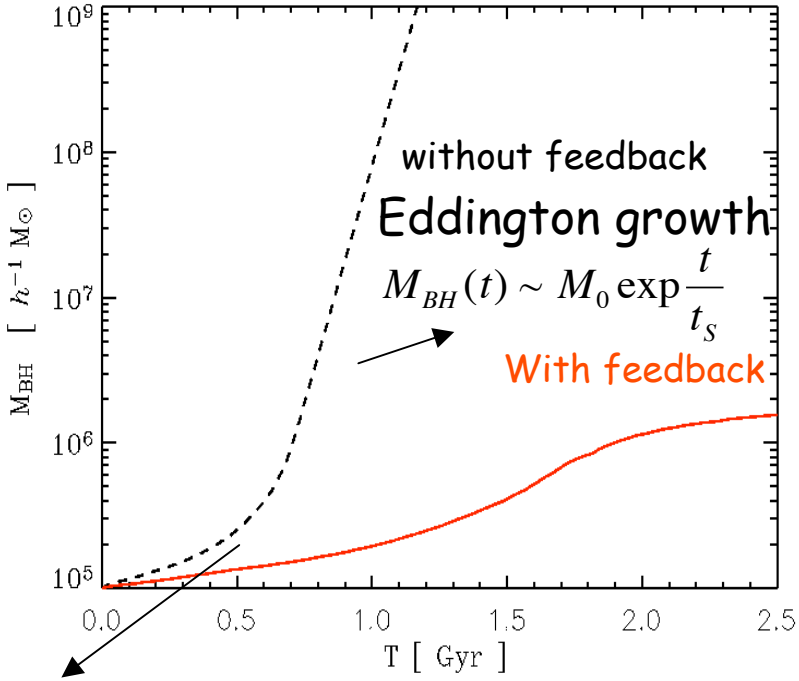
FEEDBACK

by the central black hole activity blows a weak wind into the halo

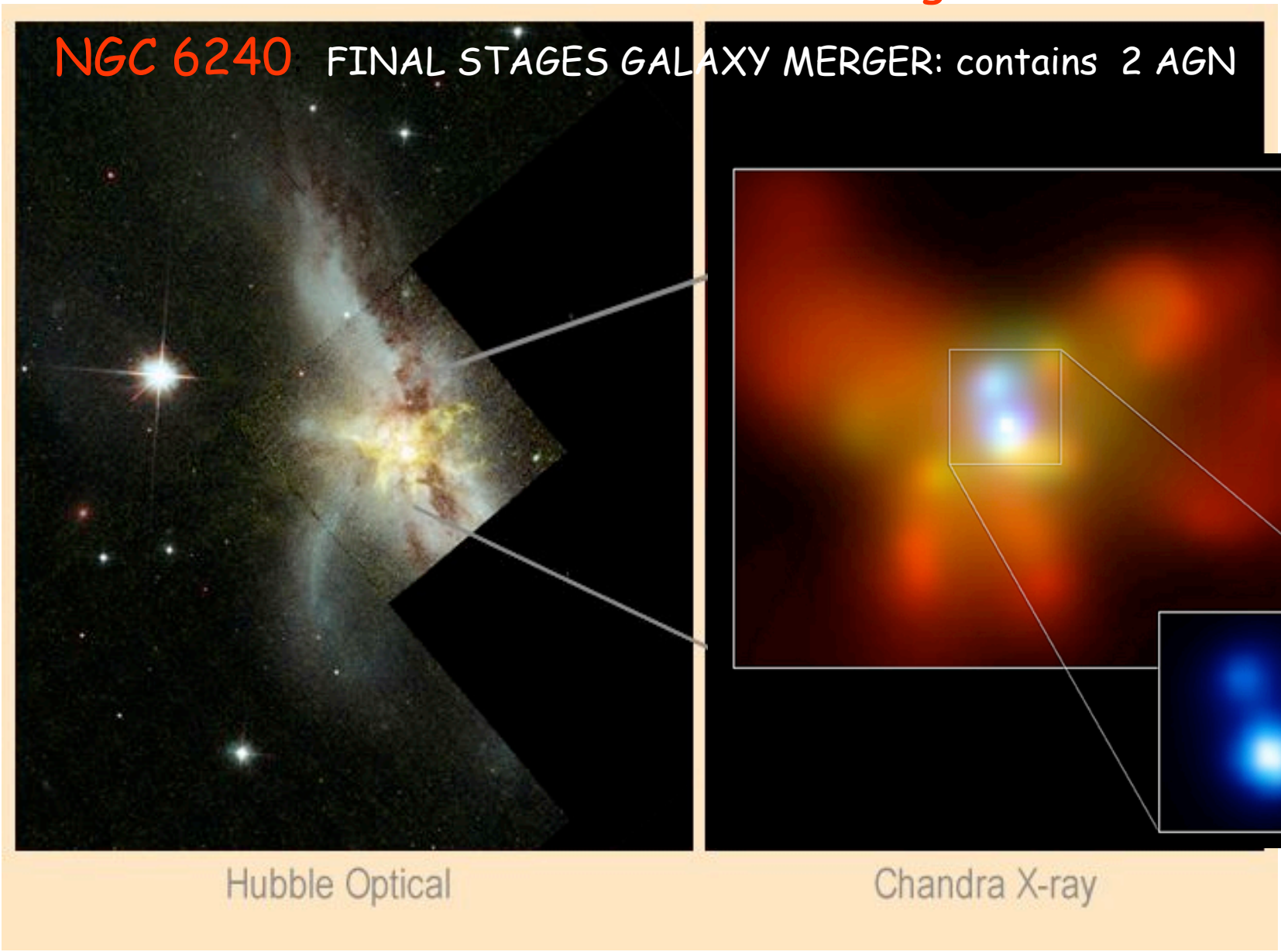
GAS FLOWs INTO THE HALO



(dynamic range in gas surface density ~10^6)



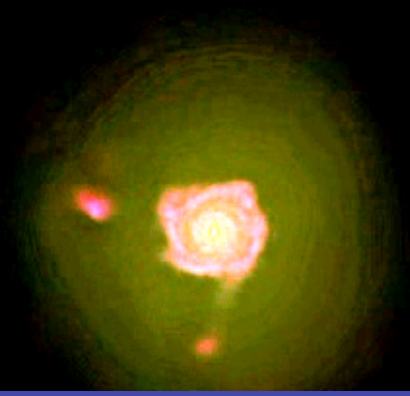
BH GROWTH and Fuelling of AGN :



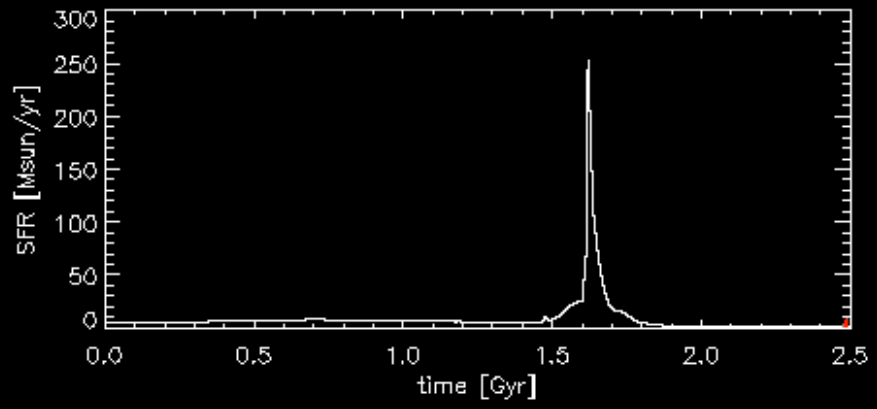
S.Komossa et al. 03 (MPE)

Time = 2.500 Gyr

no BH

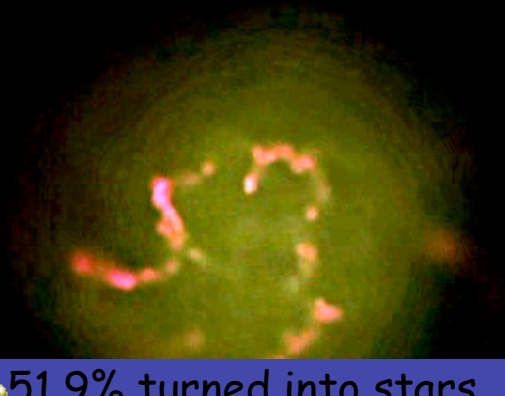


- 89.0% turned into stars
- 0.05% expelled from halo
- 1.2% cold, star forming gas
- 9.8% diffuse gas in halo

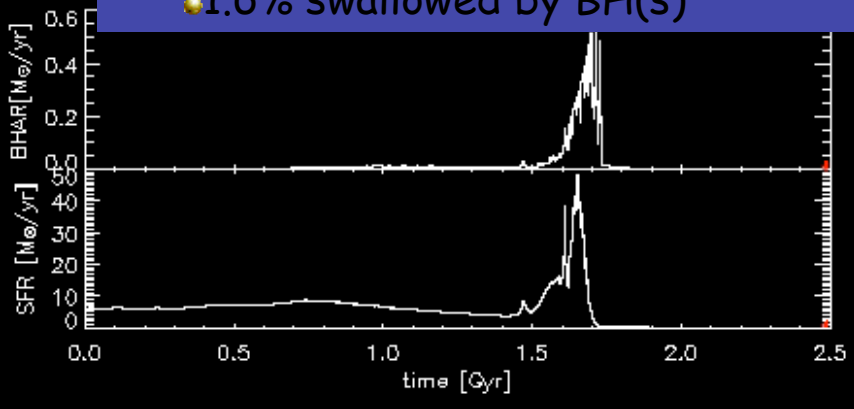


time = 2.500 Gyr

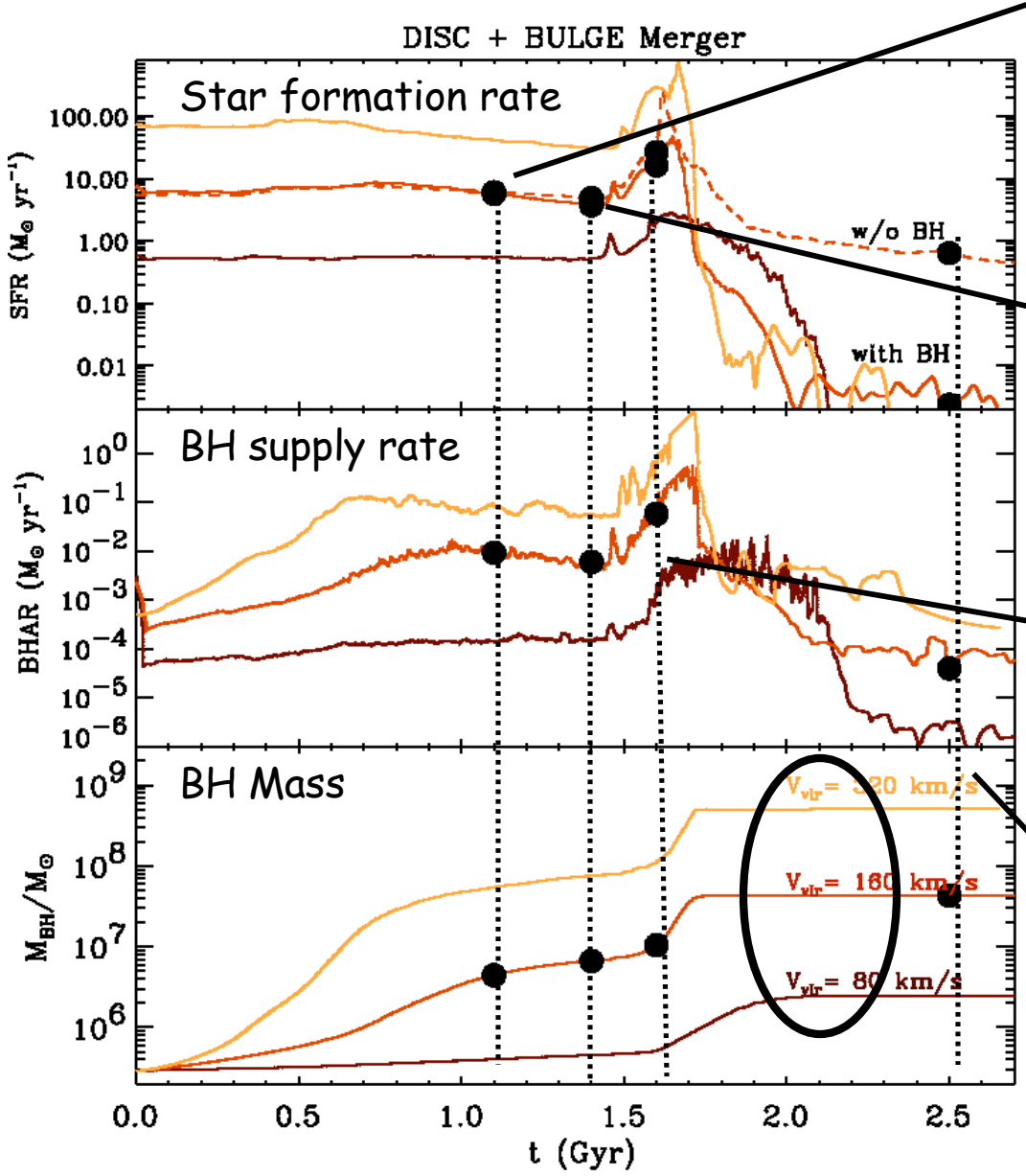
with BH

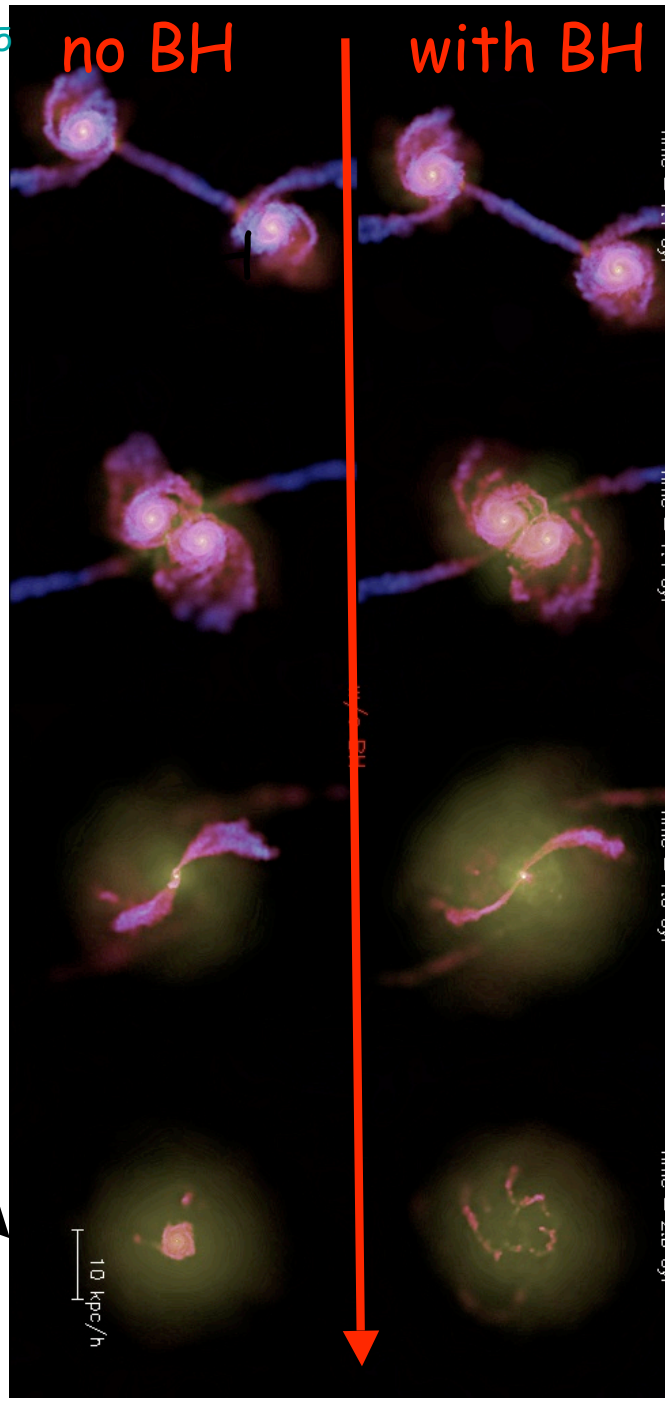


- 51.9% turned into stars
- 35.3% expelled from halo
- 0% cold, star forming gas
- 11.1% diffuse gas in halo
- 1.6% swallowed by BH(s)



Di Matteo, Springel & Hernquist 05

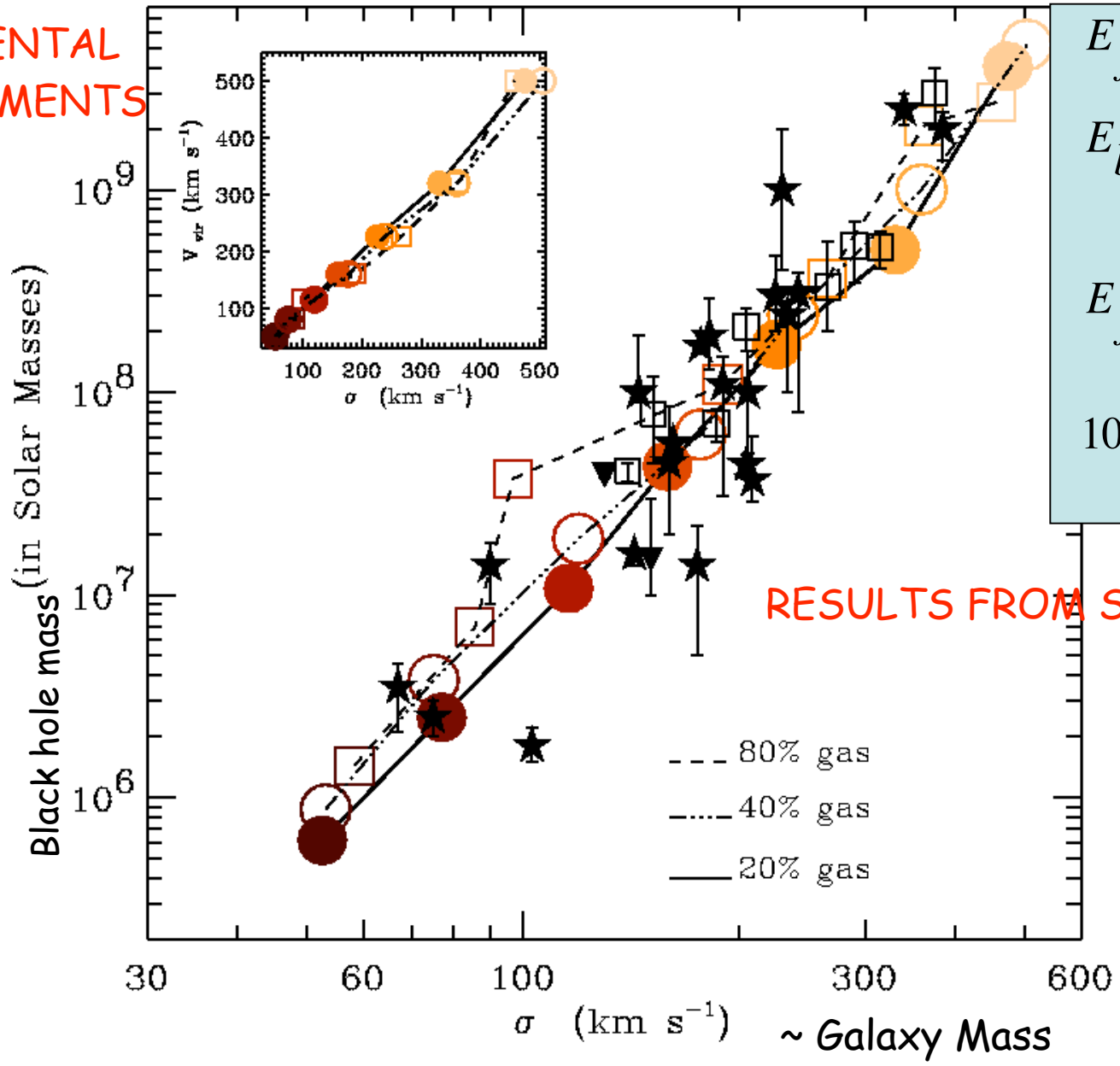




'DEAD' QUASARS: BH MASS AND GALAXY PROPERTIES:

Di Matteo, Springel & Hernquist 05

EXPERIMENTAL MEASUREMENTS



$$E_{fb} = \varepsilon_f M_{BH} c^2$$

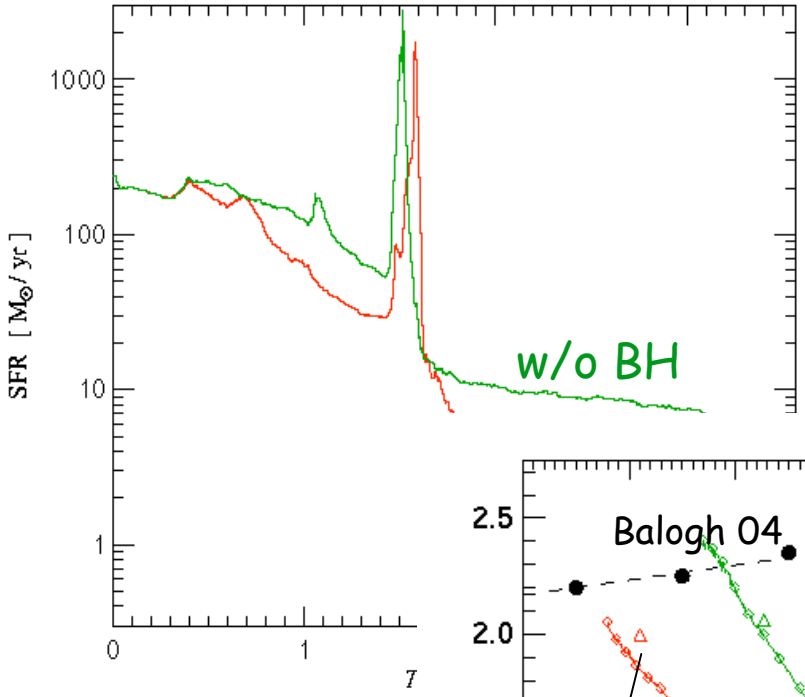
$$E_{bind} \sim M\sigma^2$$

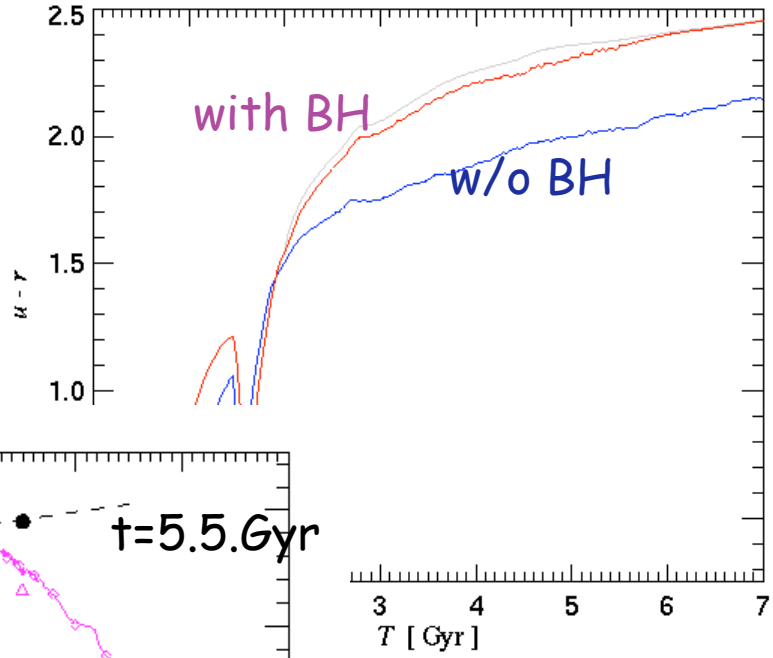
$$E_{fb}/E_{bind} \sim 10\left(\frac{\varepsilon_f}{0.005}\right)\left(\frac{\sigma}{300}\right)^{-2}$$

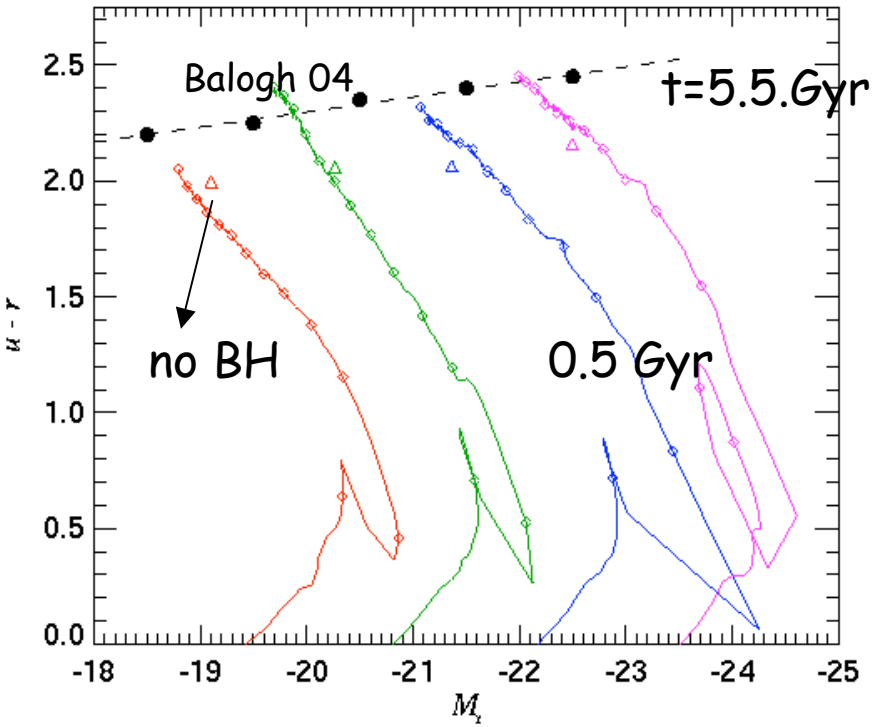
RESULTS FROM SIMULATIONS

'DEAD' ELLIPTICALS: BLACK HOLES: IMPACT ON GALAXY COLOURS: FORMATION OF RED ELLIPTICALS

Springel, Di Matteo & Hernquist 2005



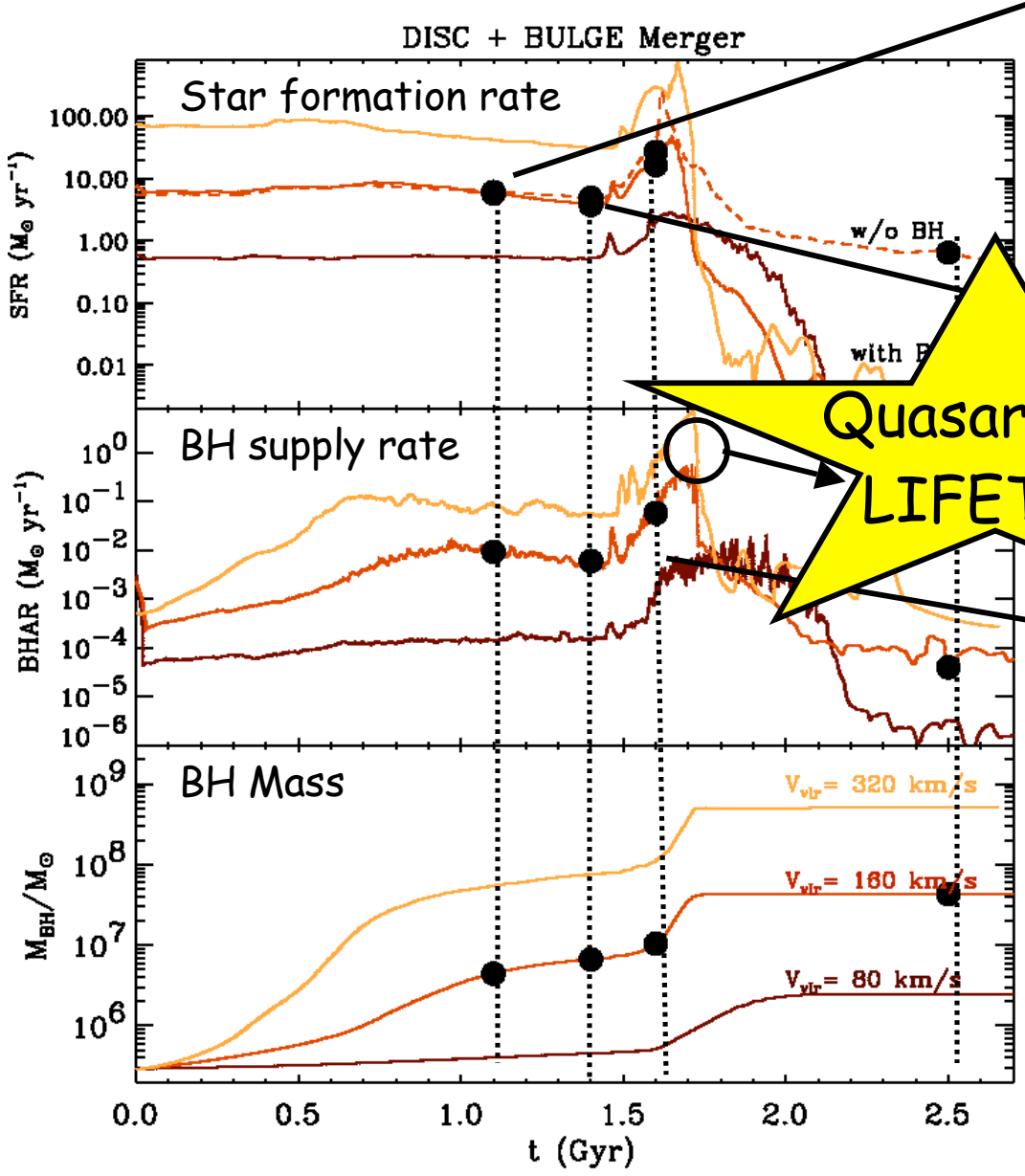




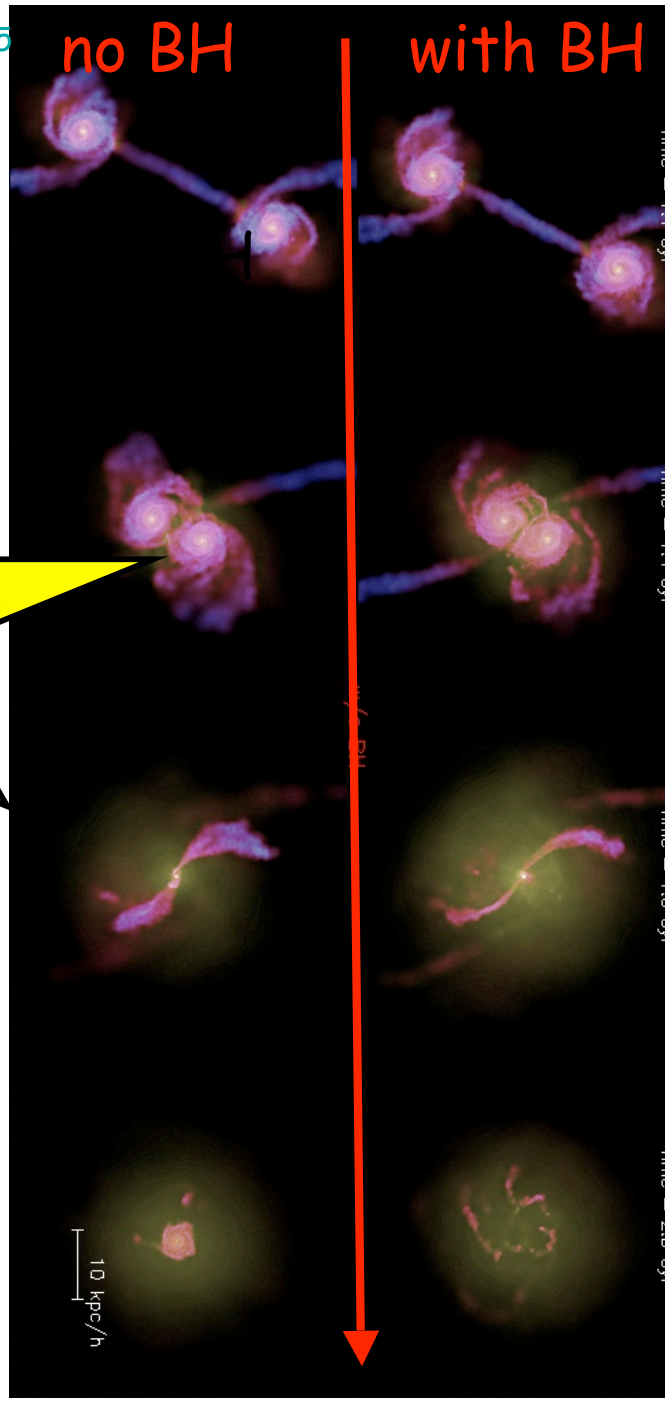
w/o BH - E fo
SF ov
- rem

N feedback quenches
over short timescale
ked difference in
r evolution of galaxies
, "dead" E forms

Di Matteo, Springel & Hernquist 05



Quasar phase
LIFETIME



'ACTIVE' QUASAR PHASE:

large fraction of the QUASAR phase is obscured

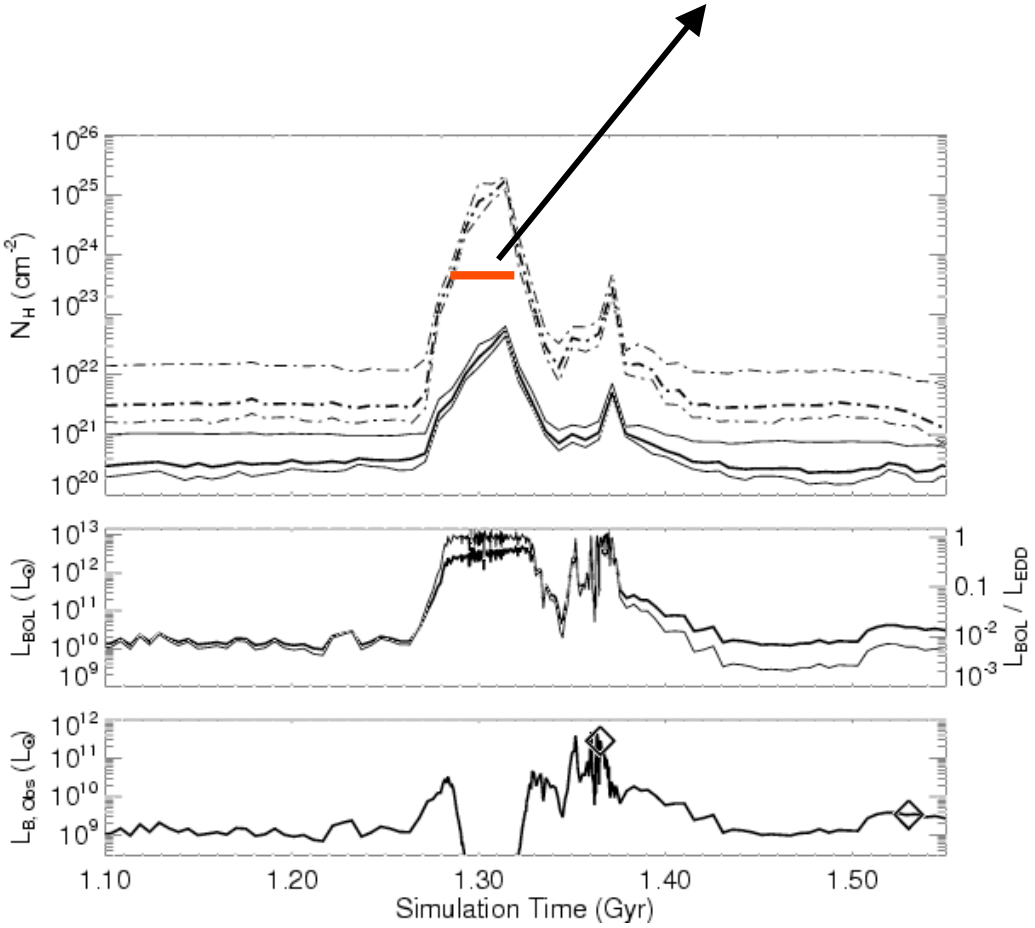
QSO obscured : time of the starburst

" " of BH growth

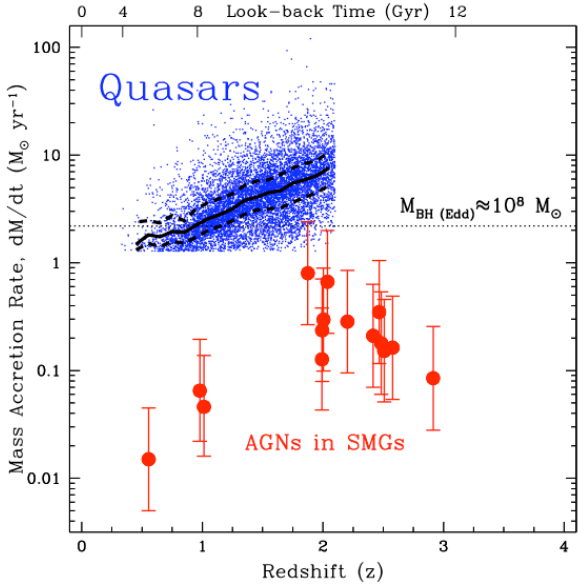
DO WE SEE THESE AGN?

Recent follow up of 20 SCUBA sources in CDFs:

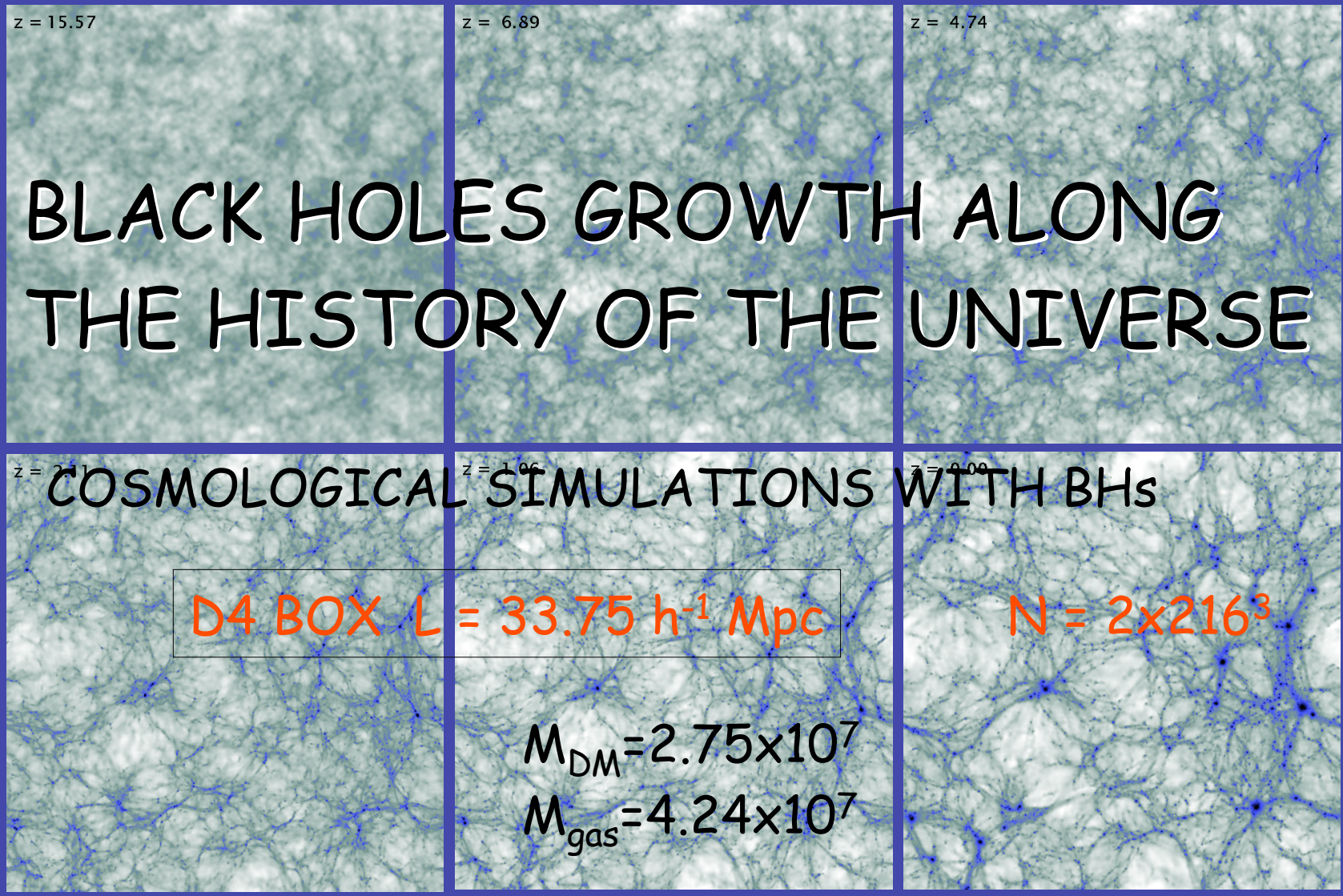
High SFR, obscured, MERGERS



Hopkins et al. 2005



Alexander et al.'05, Nature



BLACK HOLES GROWTH ALONG THE HISTORY OF THE UNIVERSE

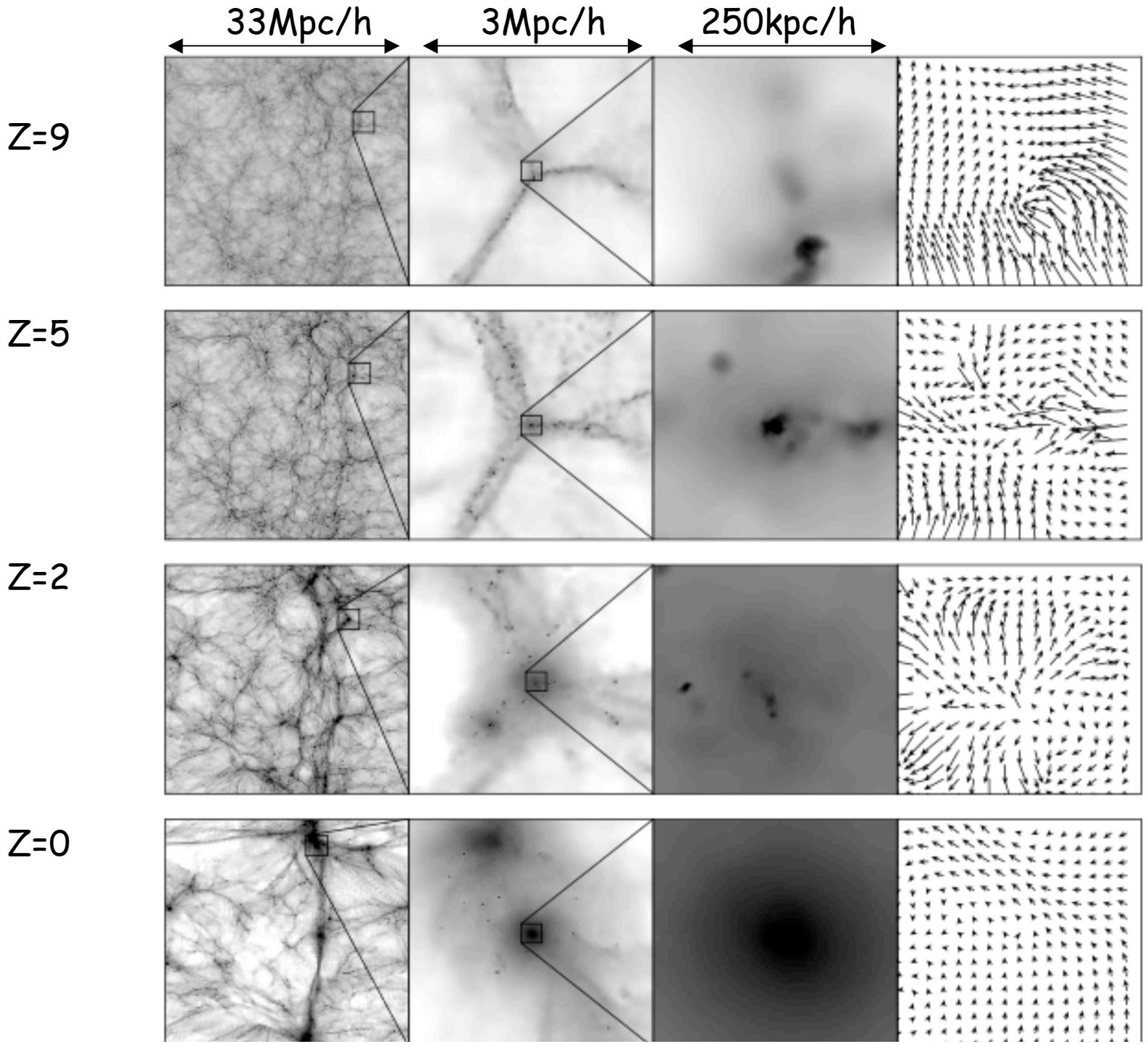
COSMOLOGICAL SIMULATIONS WITH BHs

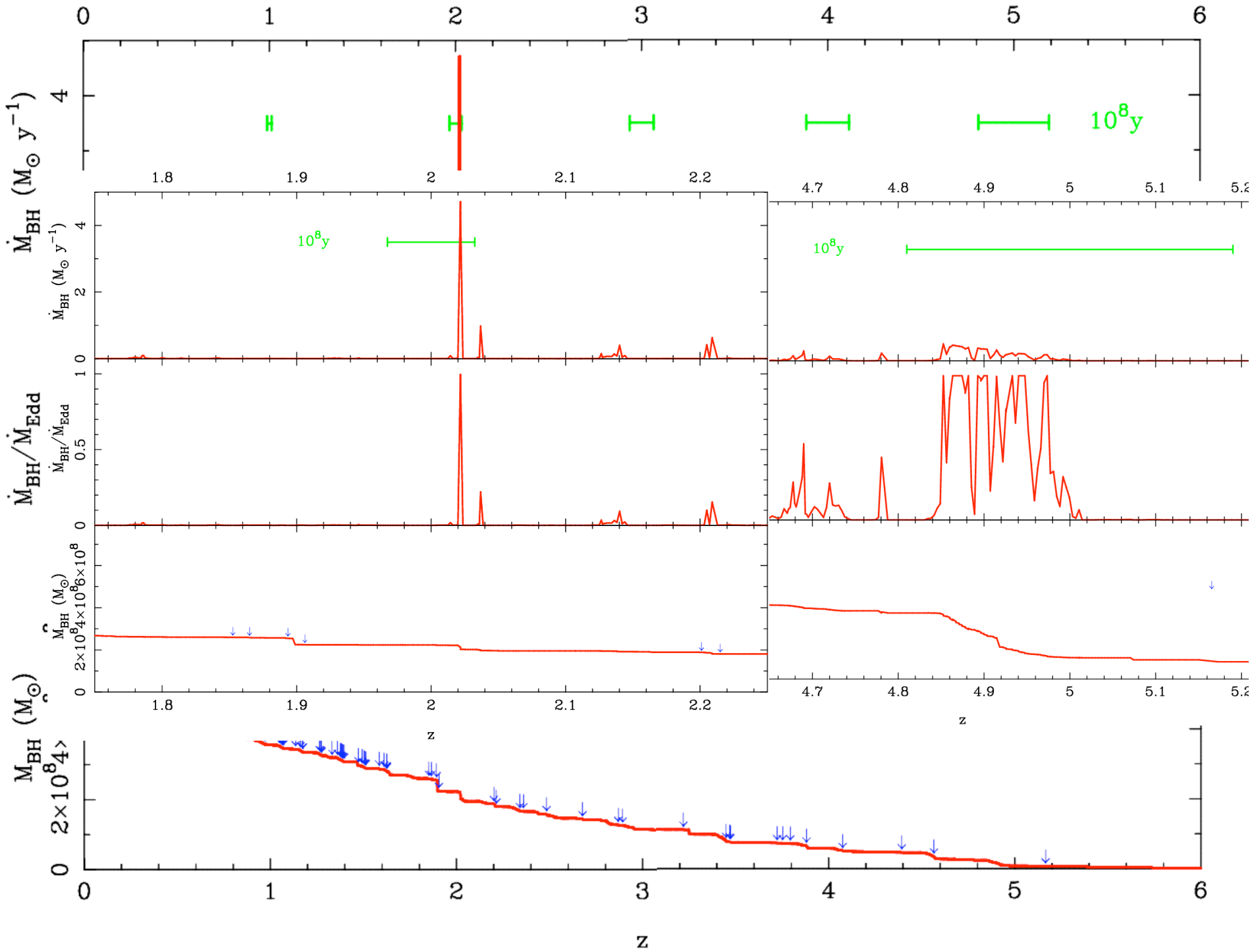
D4 BOX $L = 33.75\ h^{-1}$ Mpc

$N = 2 \times 216^3$

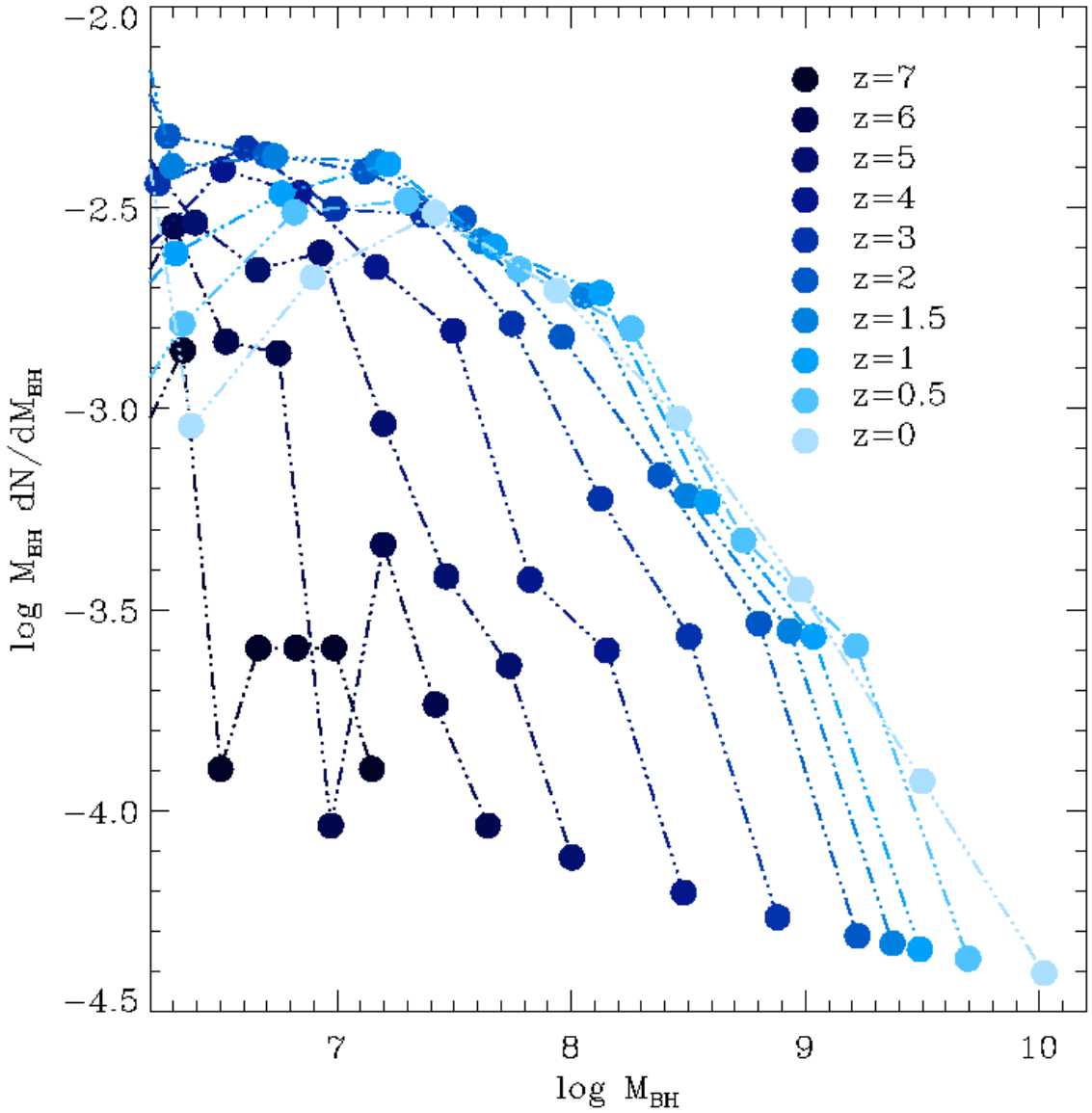
$M_{DM} = 2.75 \times 10^7$

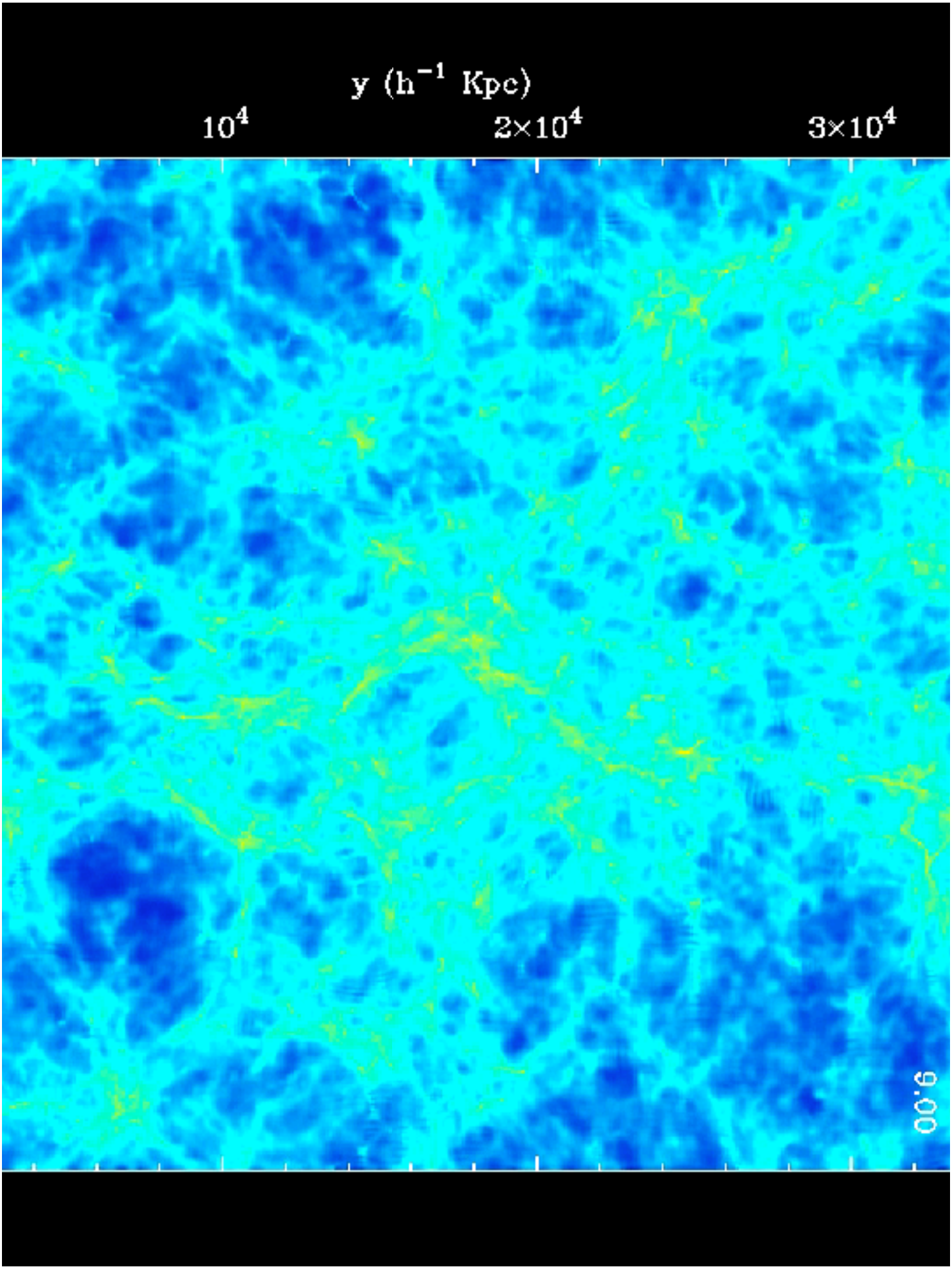
$M_{gas} = 4.24 \times 10^7$

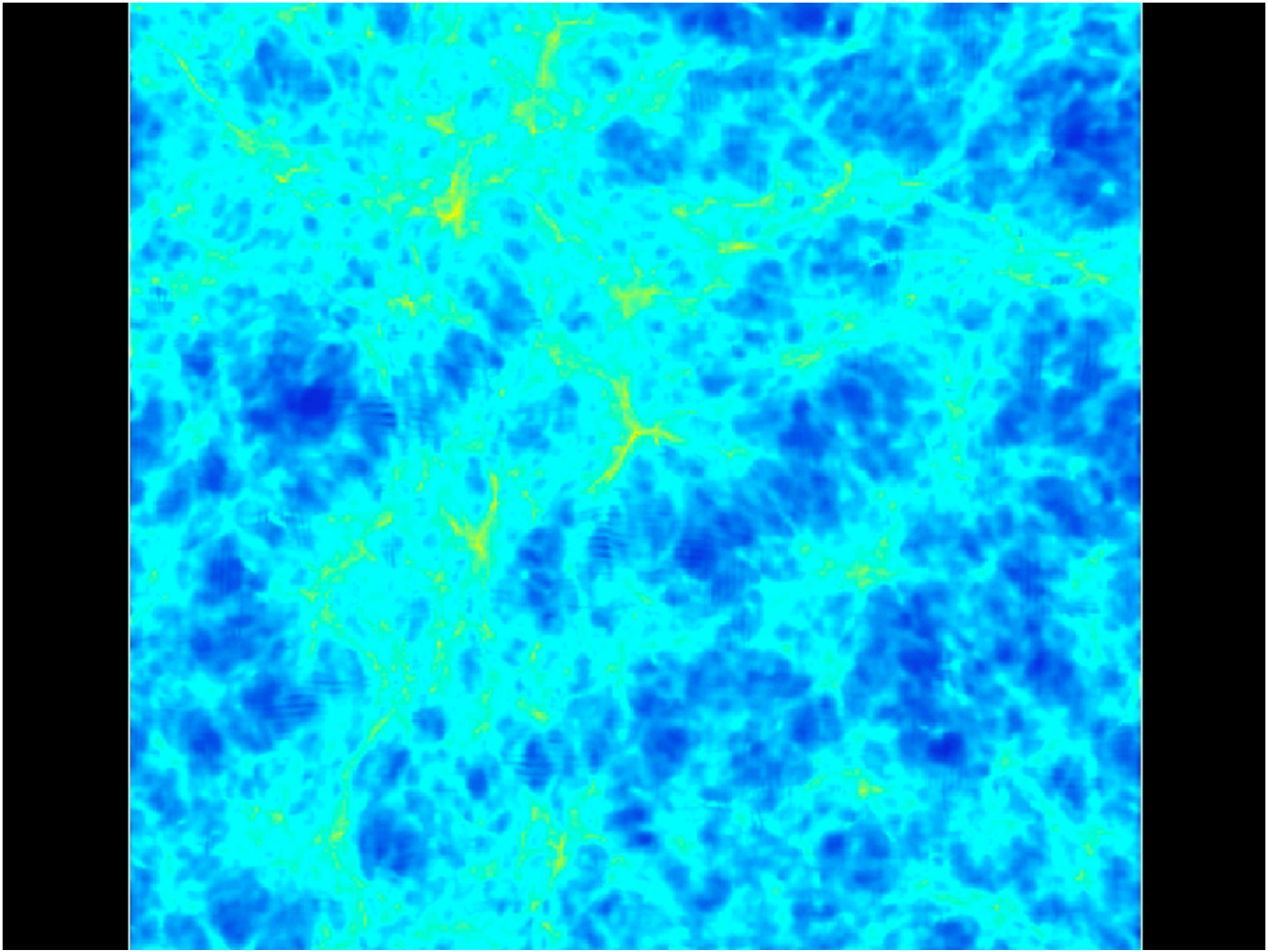

33Mpc/h
3Mpc/h
250kpc/h
Z=9
Z=5
Z=2
Z=0

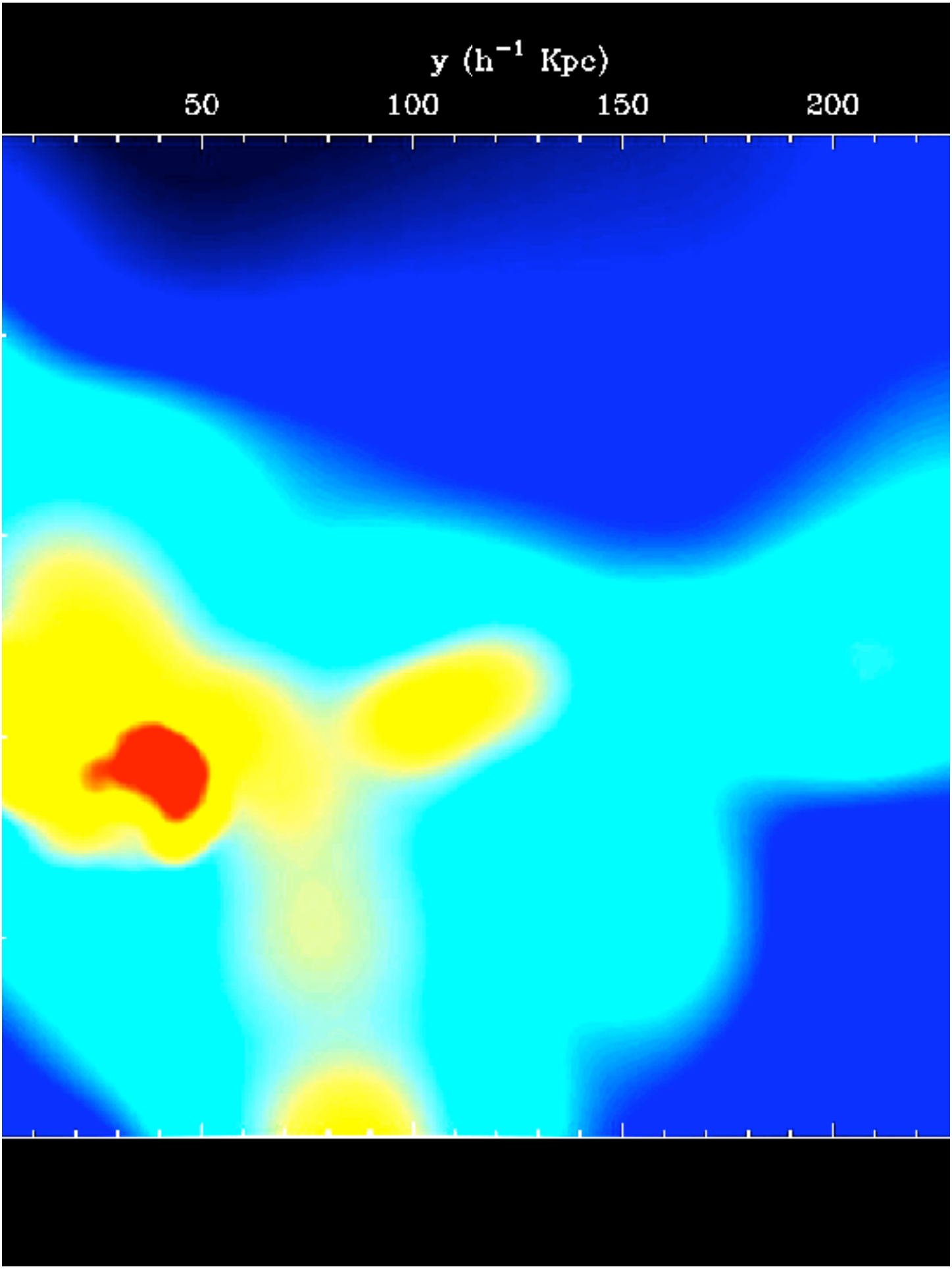

$\dot{M}_{BH}$ ($M_\odot$ y^{-1})
10^8y
$\dot{M}_{BH}/\dot{M}_{Edd}$
M_{BH} ($M_\odot$)
z

The evolution the black hole mass function




y (h^{-1} Kpc)
10^4
2×10^4
3×10^4
9.00




y (h^{-1} Kpc)
50
100
150
200

Conclusions:

- Self-Consistent treatment of BLACK HOLES IN NUMERICAL SIMULATIONS OF GALAXY FORMATION

- Self-Regulated Black hole growth and activity

GALAXY MERGERS:

- Black hole growth saturates in response to feedback

→ M- σ relation
IMPACT on galaxy COLOURS
OBSCURED QSOs phase, QUASAR lifetime, luminosity functions
…. Heating in clusters, ISM enrichment etc…..

COSMOLOGICAL RUNS

- Track the cosmic history of BH accretion and BH growth

→ follow growth black hole mass function
Constraints on t_Q duty cycle, and specific propeties of BH hosts
Impact on reinization etc…