THE ROLE OF BLACK HOLES IN GALAXY EVOLUTION

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OUTLINE:

•INTRO: The black hole – galaxy connection
e.g.: The M -σ relation and the evolution of QSOs

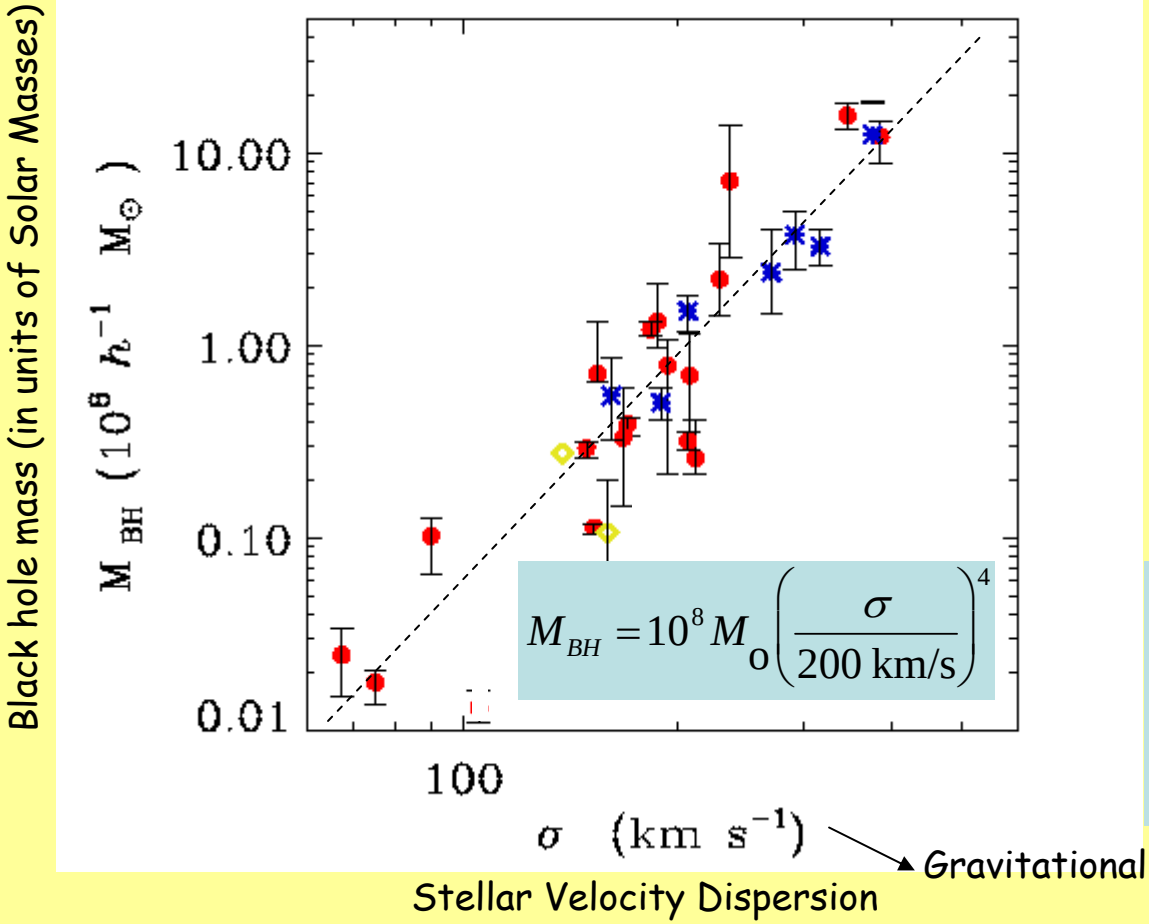
•Self-consistent treatment of BHs in
SPH Simulations of Galaxy Formation (Gadget)

1. BHs in Isolated Galaxies & Mergers - BHs ⟷ galaxy formation
   implications for QSO lifetime/ LFs
2. BHs in Cosmological Simulations
   - evolution of black hole mass density and M-sigma relation
   - accretion history
   - the quasar hosts from high to low z

THE BLACK HOLE – GALAXY CONNECTION

The M - σ relation for supermassive black holes

Ferrarese & Merritt 2000, Gebhardt et al. 2000, Tremaine et al. 2002



Stellar Velocity Dispersion

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)

SPH simulations of galaxy formation

(GADGET2 so far….)

DARK MATTER

GAS

STARS

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

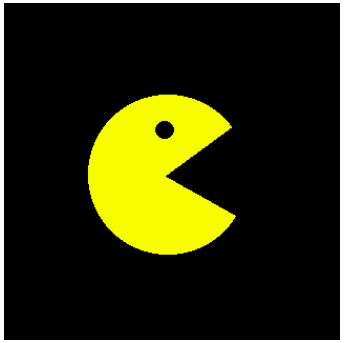
SPH Method: fluid represented by particles smoothed by local kernel averaging
Hydro eqns solved in its Galilean-invariant Lagrangian Formulation.

- 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 (accretion) injected in the s 0.1 ounding gas

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

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

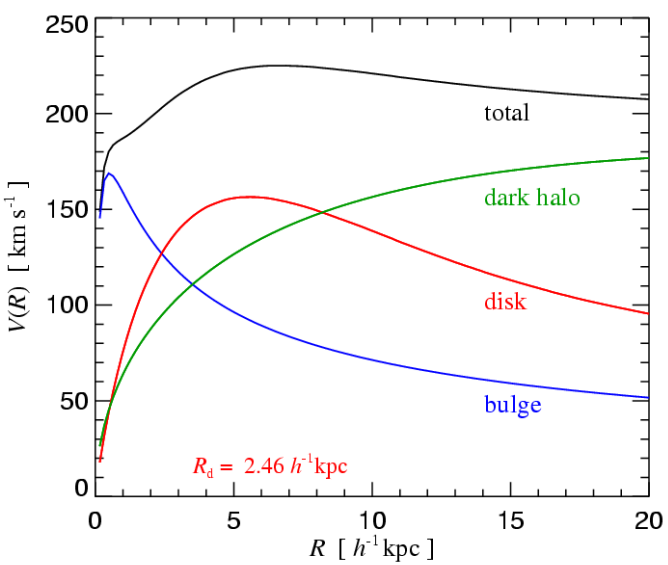
STRUCTURAL PROPERTIES OF MODEL GALAXIES

Components:

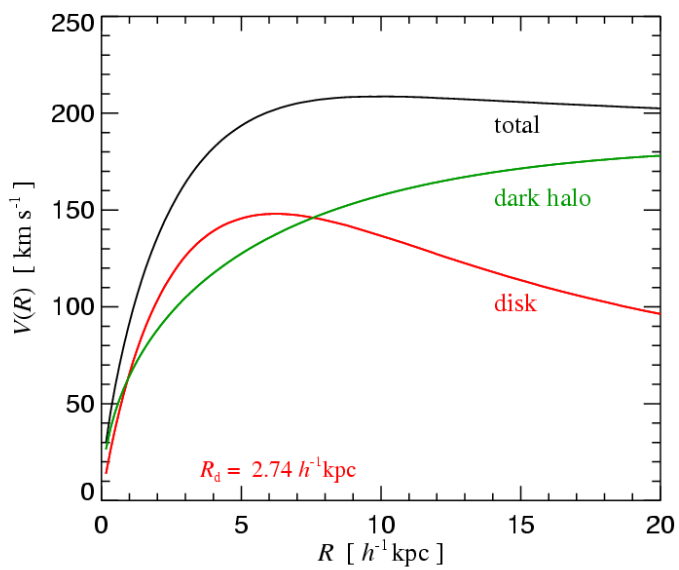
- Dark halo (Hernquist profile matched to NFW halo)
- Stellar disk (expontial)
- Stellar bulge
- Gaseous disk (expontial)
- Central supermassive black hole (small seed mass)

- 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



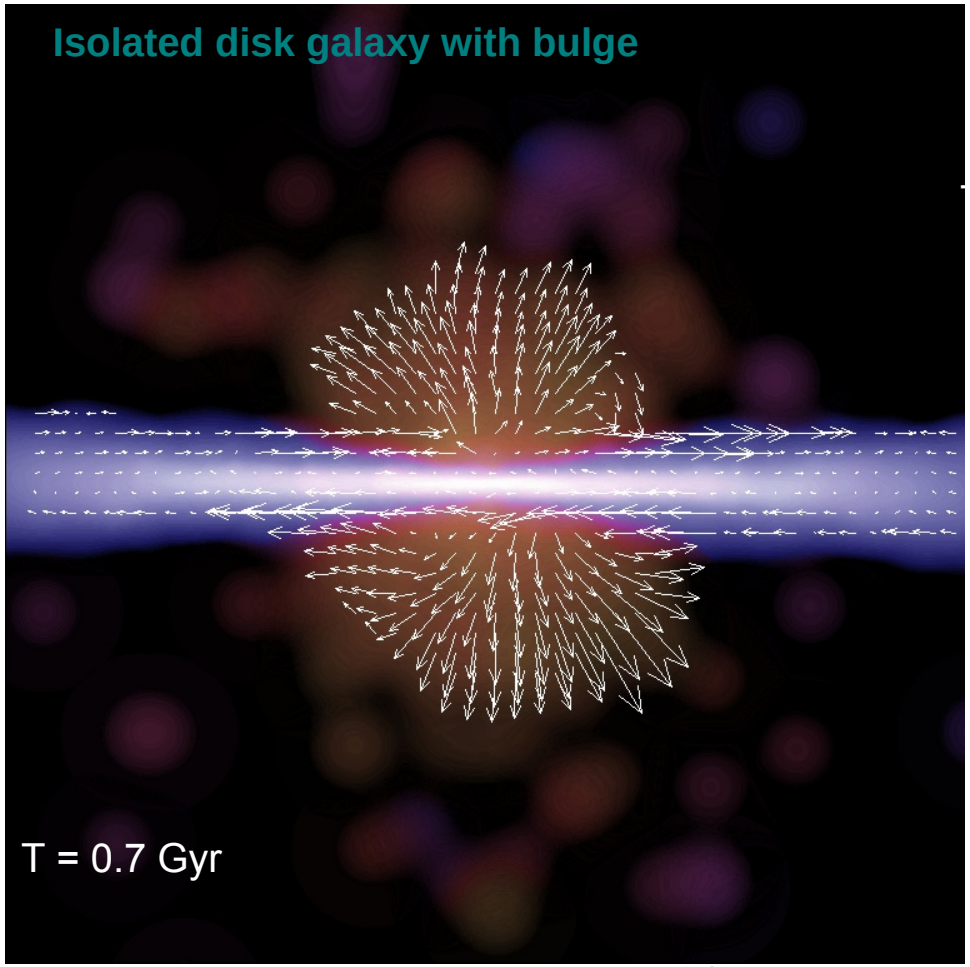
Without Bulge



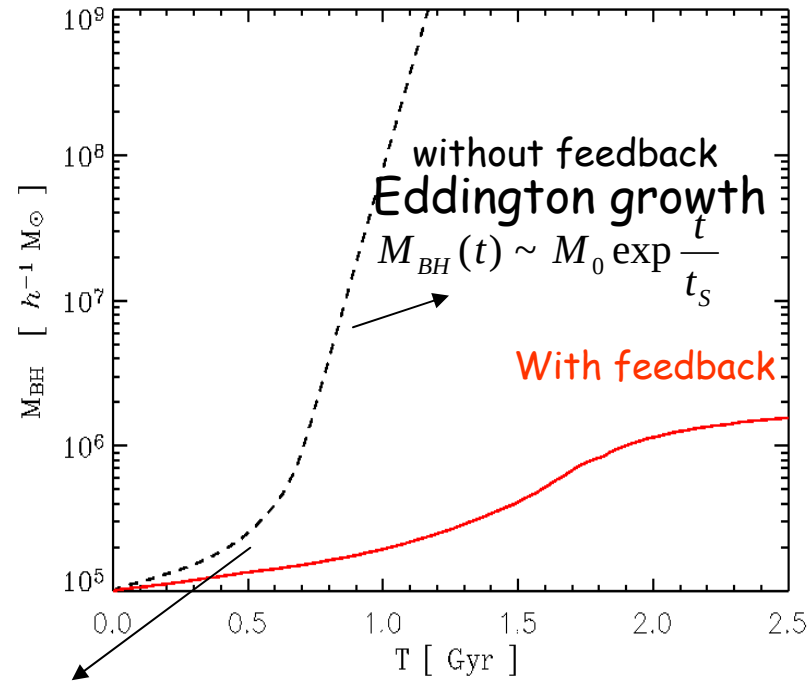
BH ACCRETION AND FEEDBACK

the central black hole activity blows a wind into the halo

GAS FLOWs INTO THE HALO



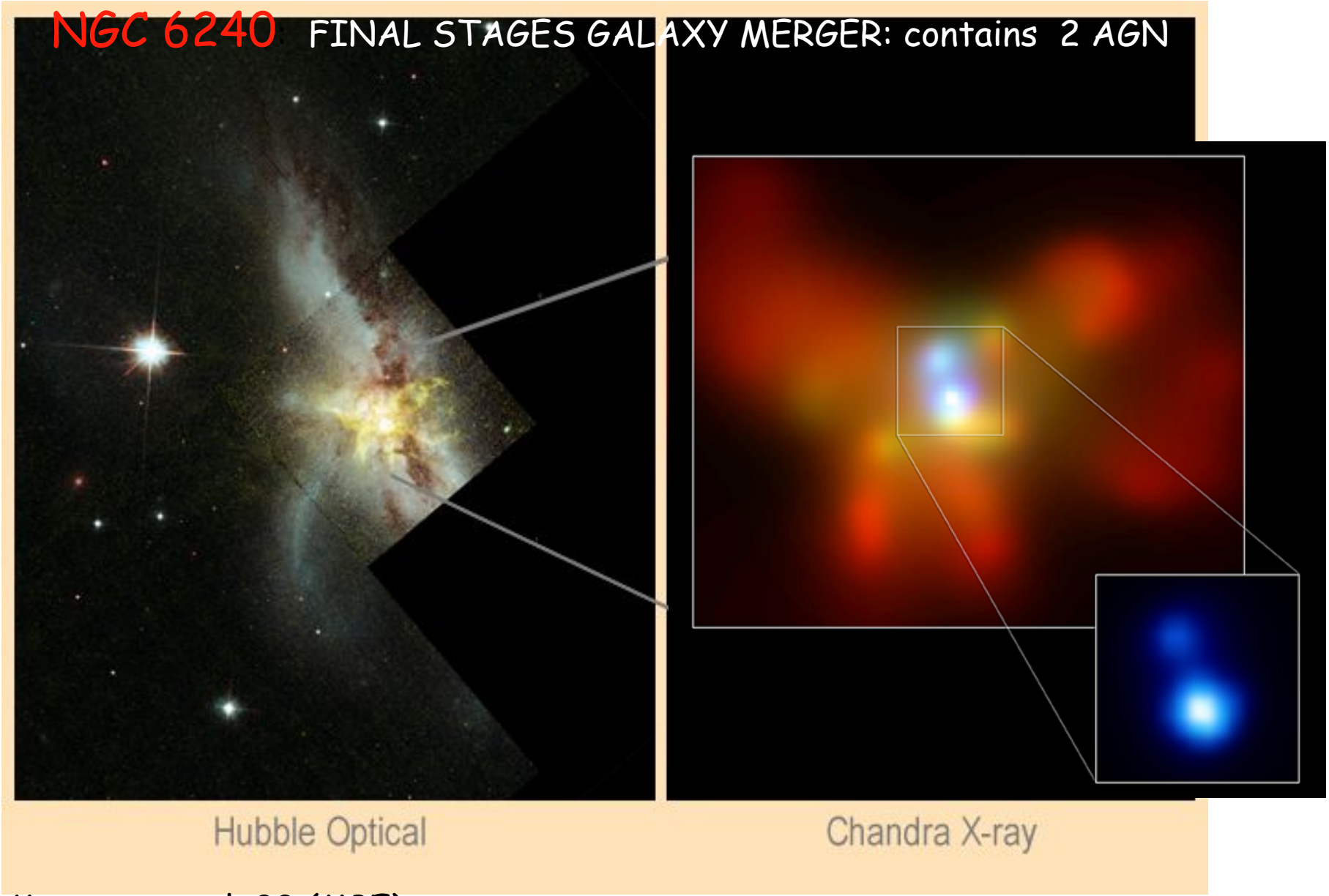
(dynamic range in gas surface density ~10^6)



Bondi growth

$$M_{BH}(t) \sim \frac{M_0}{1-\chi M_0 t}$$

BH GROWTH and Fuelling of AGN :



S.Komossa et al. 03 (MPE)

QuickTime™ and a
decompressor
are needed to see this picture.

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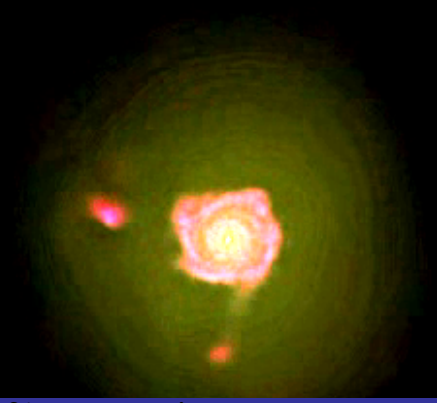
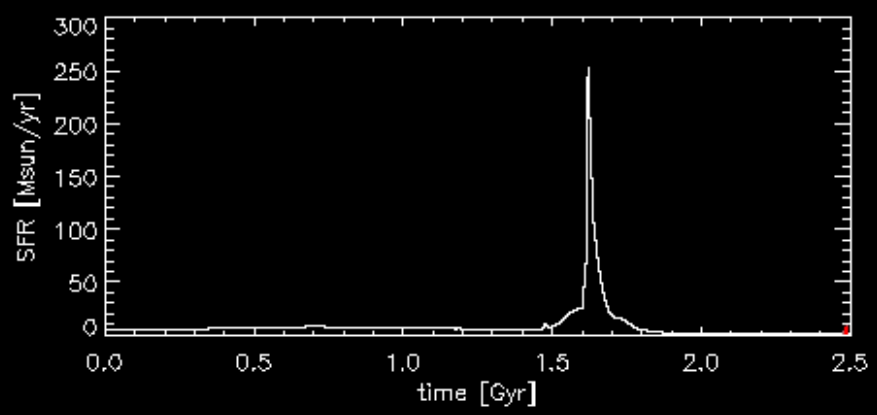
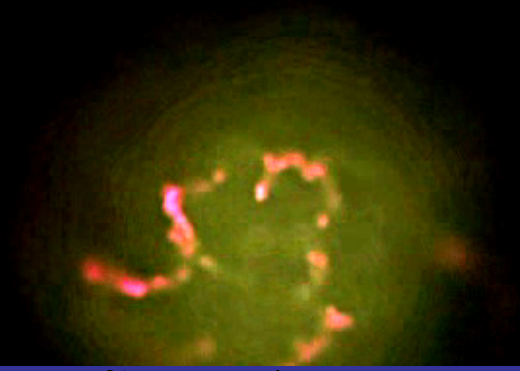
Time = 2.500 Gyr no BH



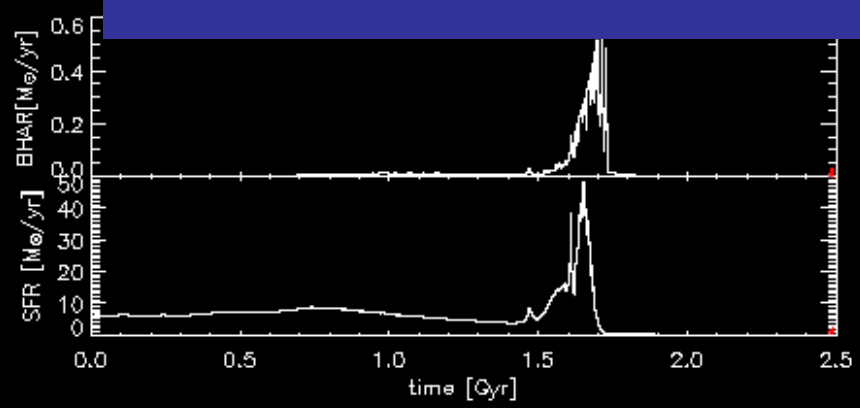
- 89.0% turned into stars
- 0.05% expelled from halo
- 1.2% cold, star forming gas
- 9.8% diffuse gas in halo



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)



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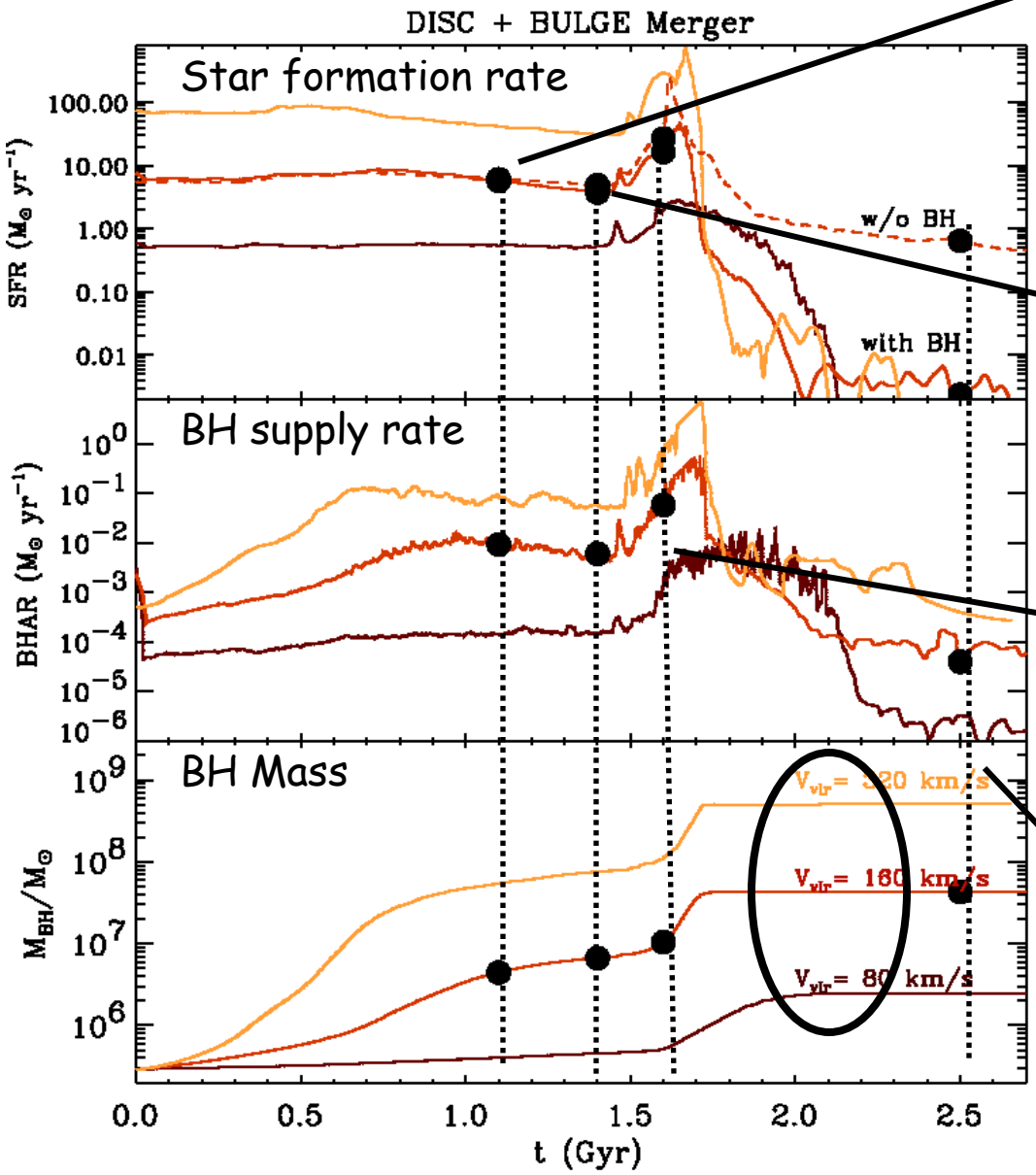
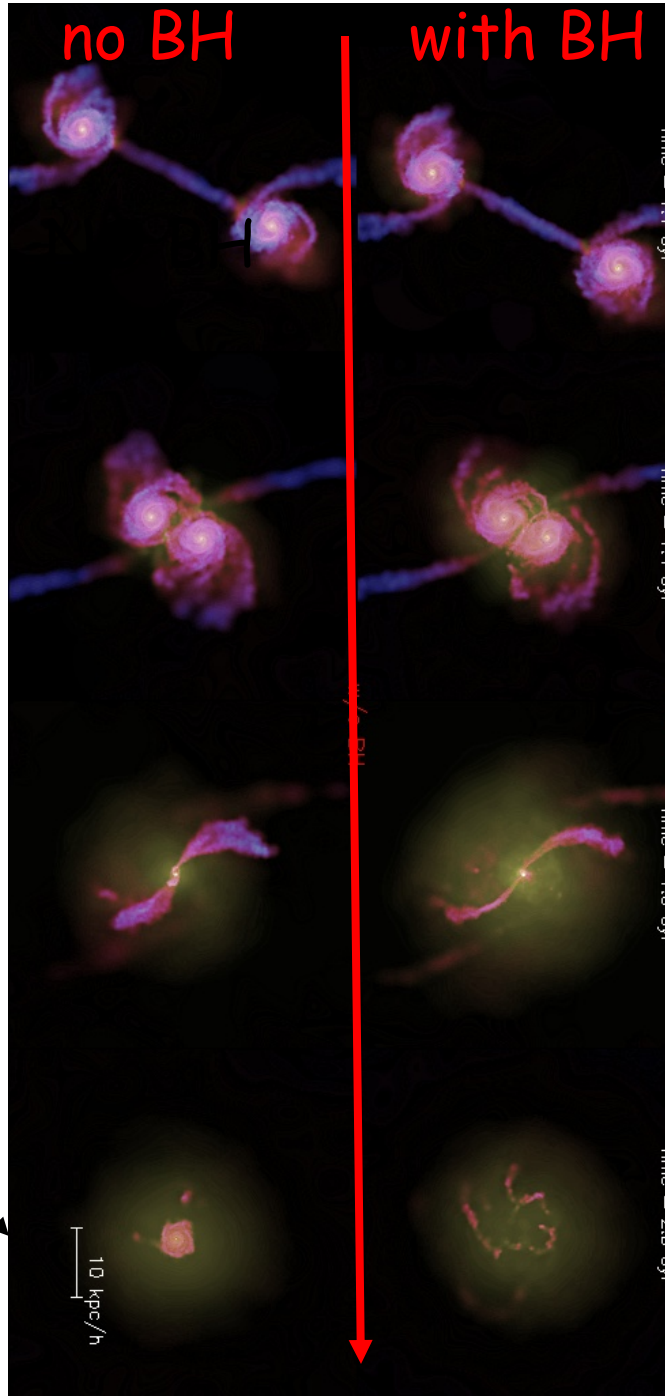
Di Matteo, Springel & Hernquist 05

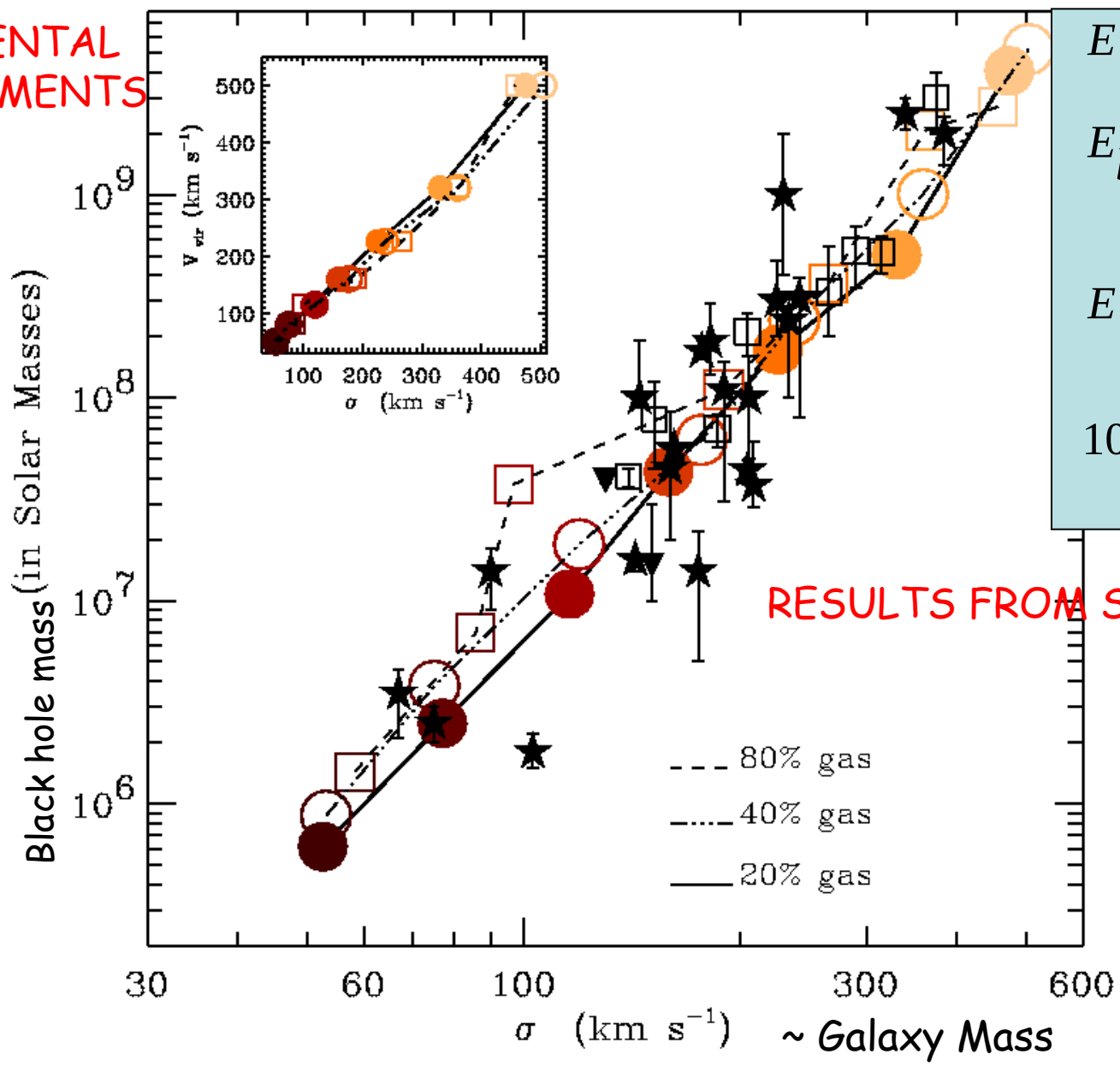




BLACK HOLE MASS AND GALAXY PROPERTIES:

Di Matteo, Springel & Hernquist 05

EXPERIMENTAL MEASUREMENTS



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

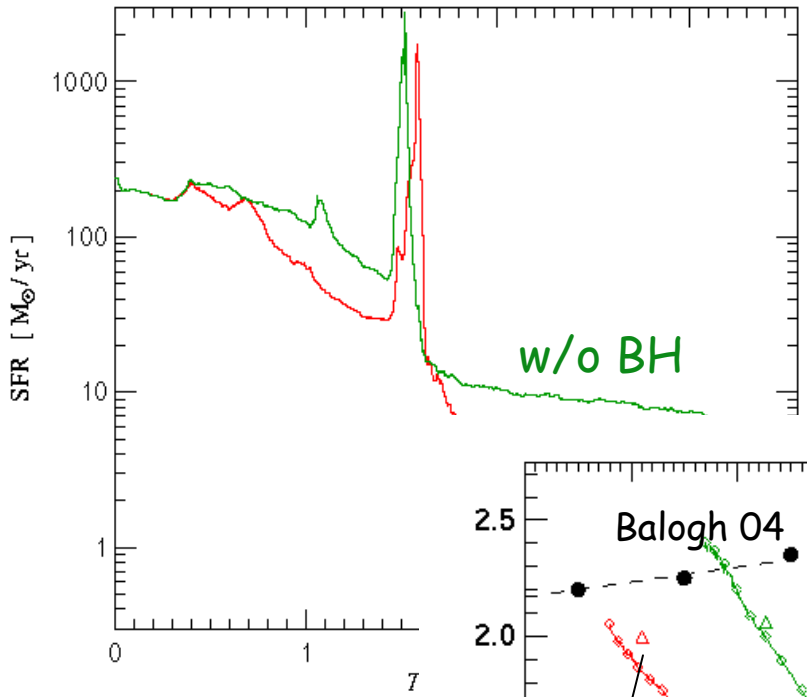
$$E_{bind} \sim M\sigma^2$$

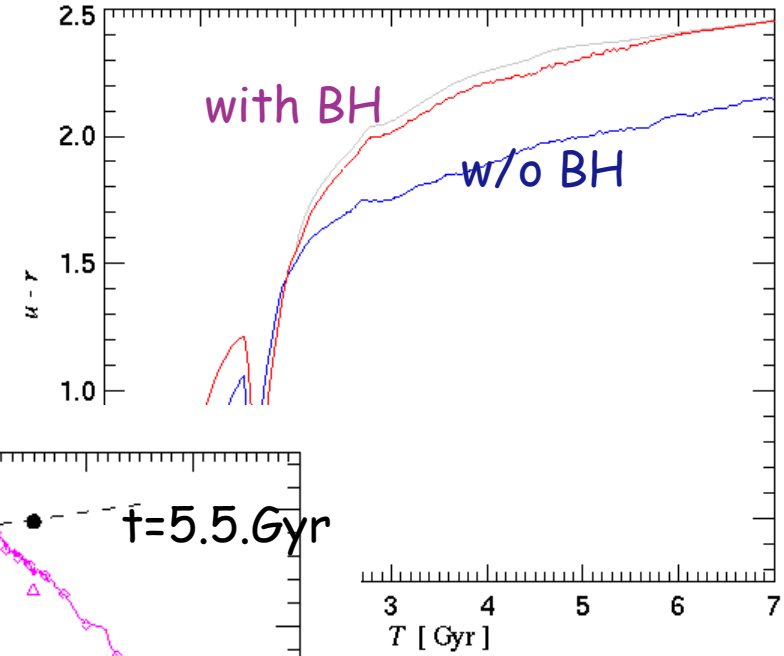
$$E_{fb}/E_{bind} \sim 10\left(\frac{\varepsilon_f}{0.005}\right)\left(\frac{\sigma}{300}\right)^{-2}$$

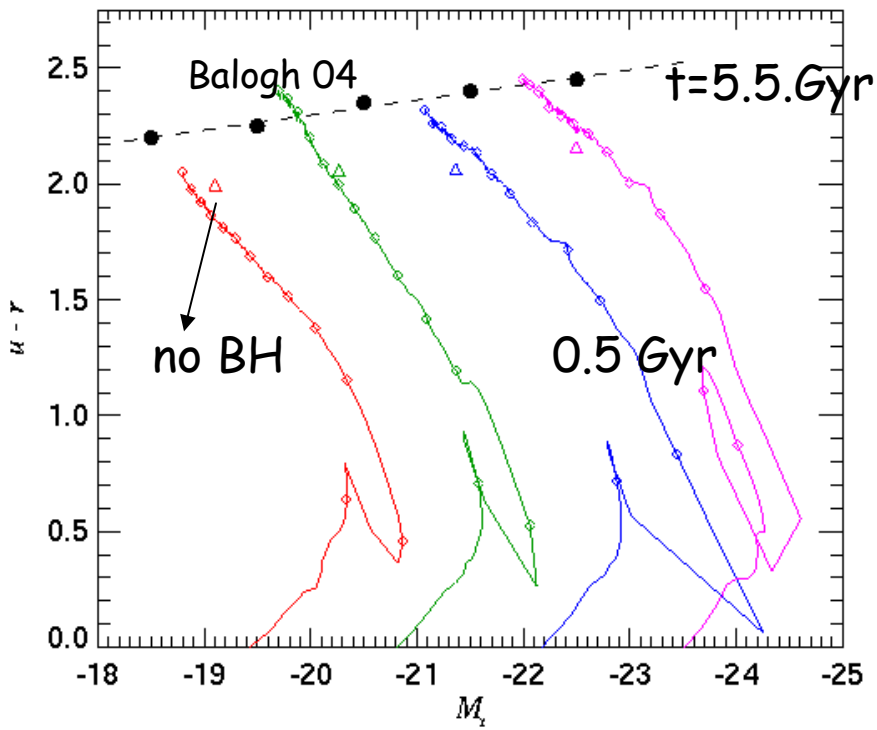
RESULTS FROM SIMULATIONS

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

Springel, Di Matteo & Hernquist 2005



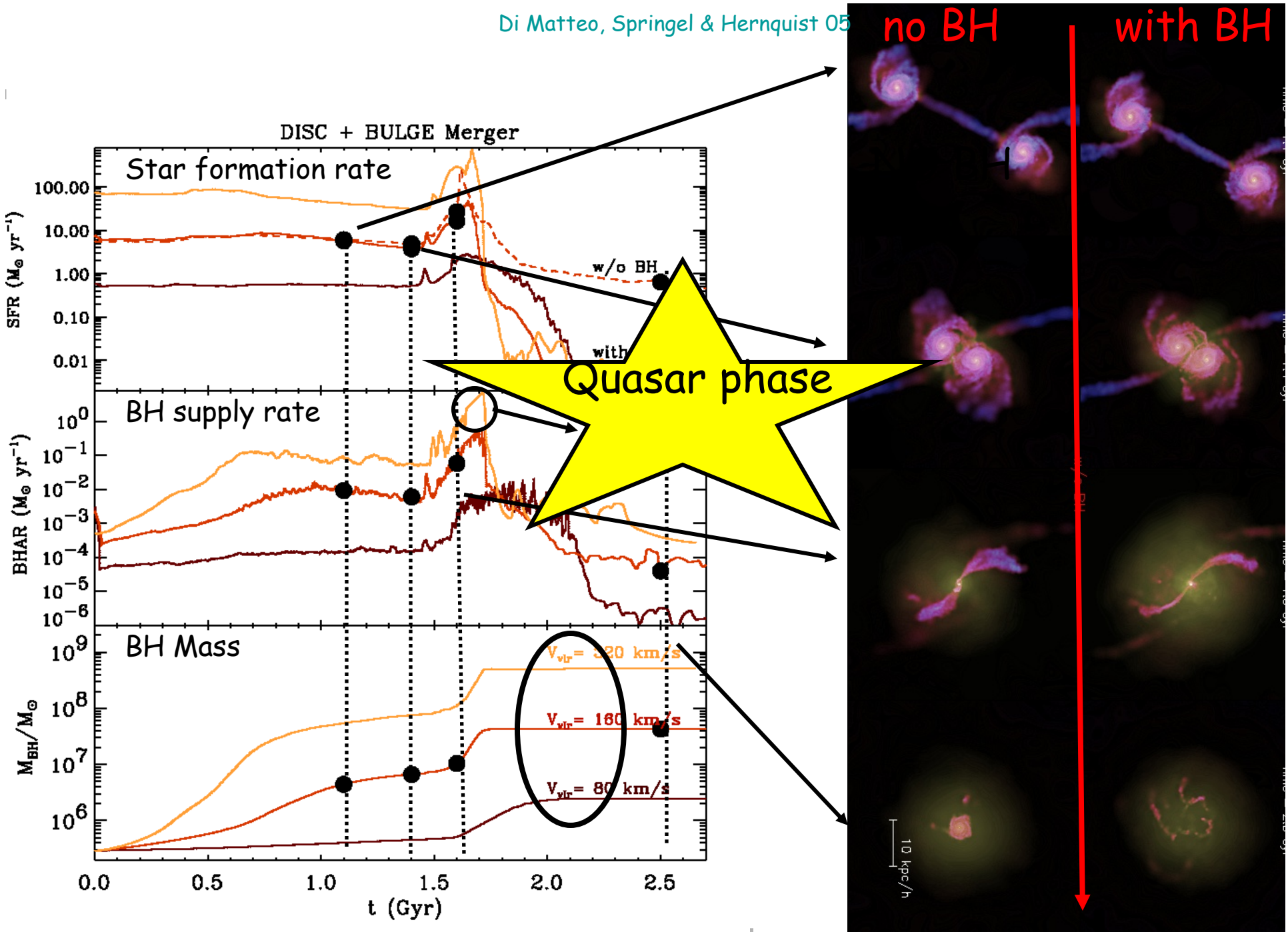




w/o BH - E fo
SF ov
- rem

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

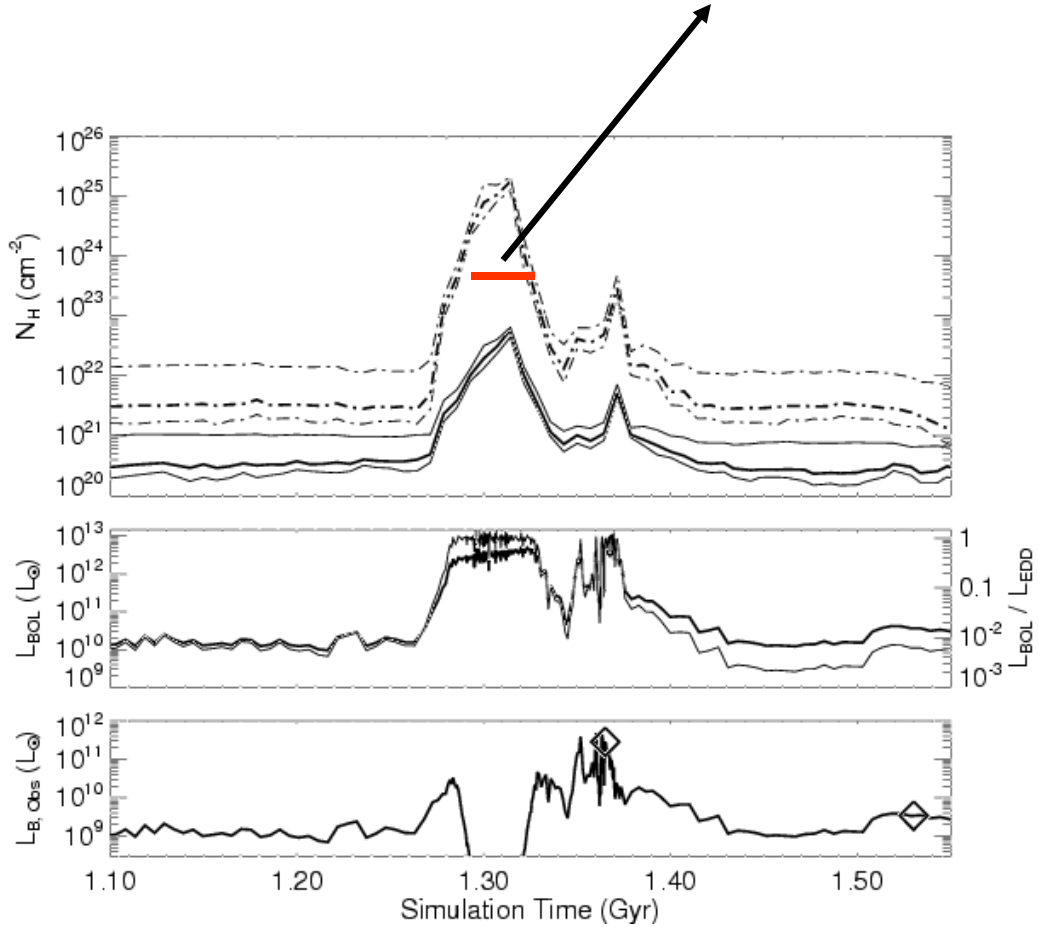
Di Matteo, Springel & Hernquist 05



PREDICTIONs FOR THE QUASAR PHASE:

large fraction of the QUASAR phase is obscured

QSO obscured : time of the starburst
" " of BH growth

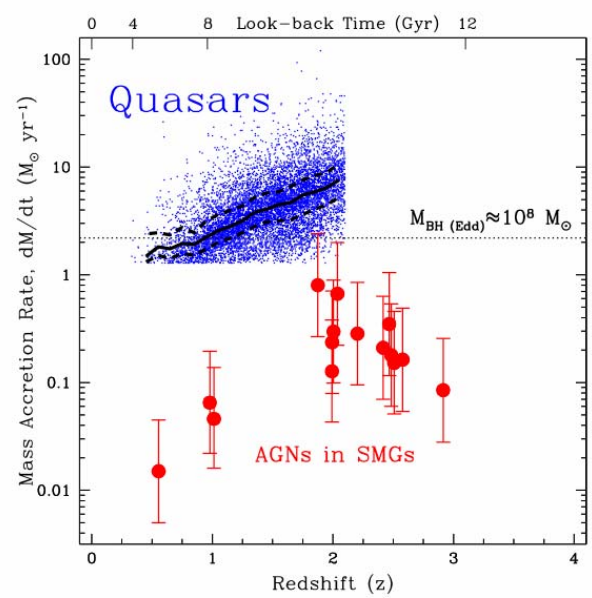


Hopkins et al. 2005

DO WE SEE THESE AGN?

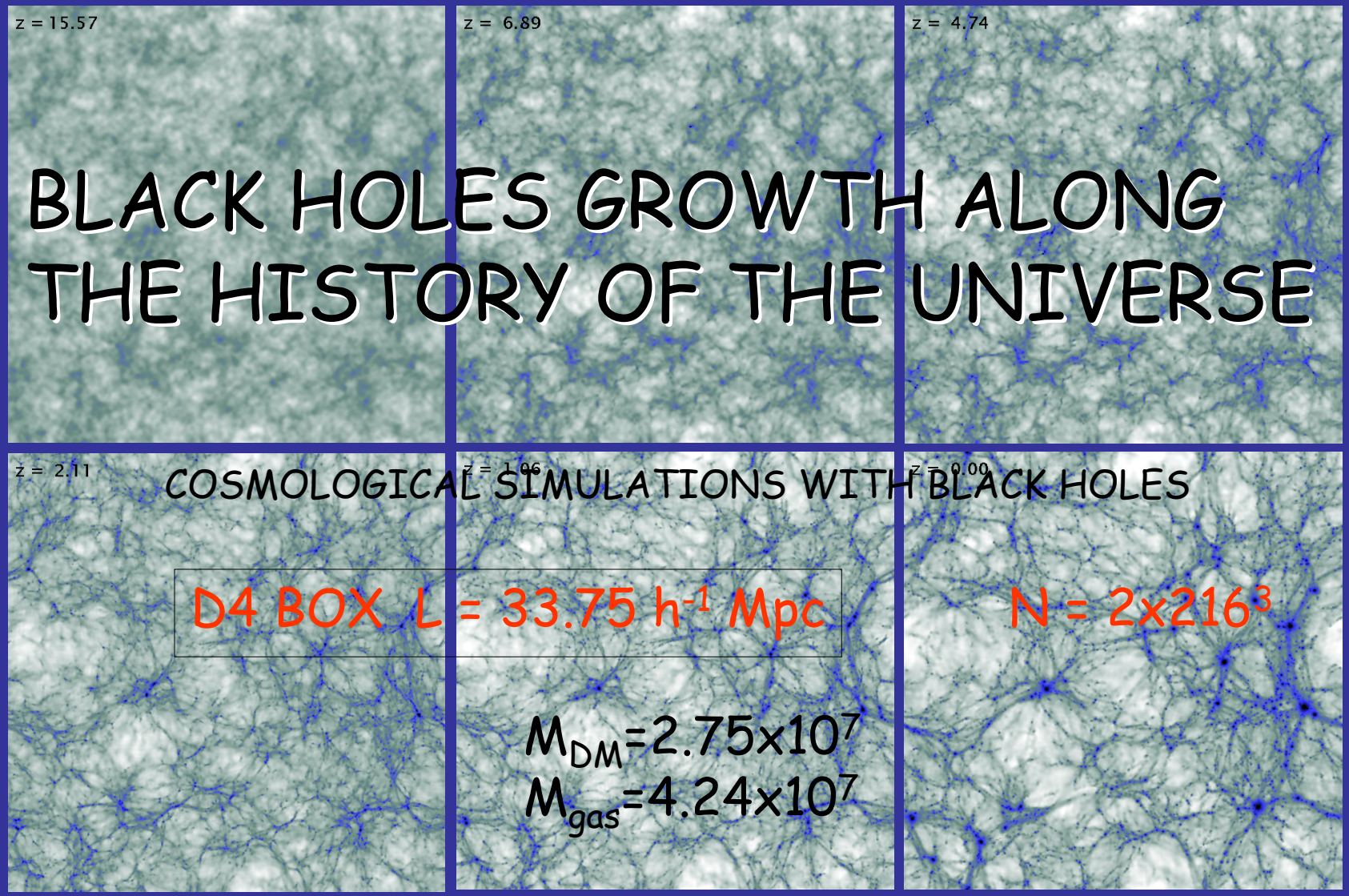
Recent follow up of 20 SCUBA sources in CDFs:

High SFR, obscured, MERGERS



Alexander et al.'05, Nature

BLACK HOLES GROWTH ALONG THE HISTORY OF THE UNIVERSE



COSMOLOGICAL SIMULATIONS WITH BLACK HOLES

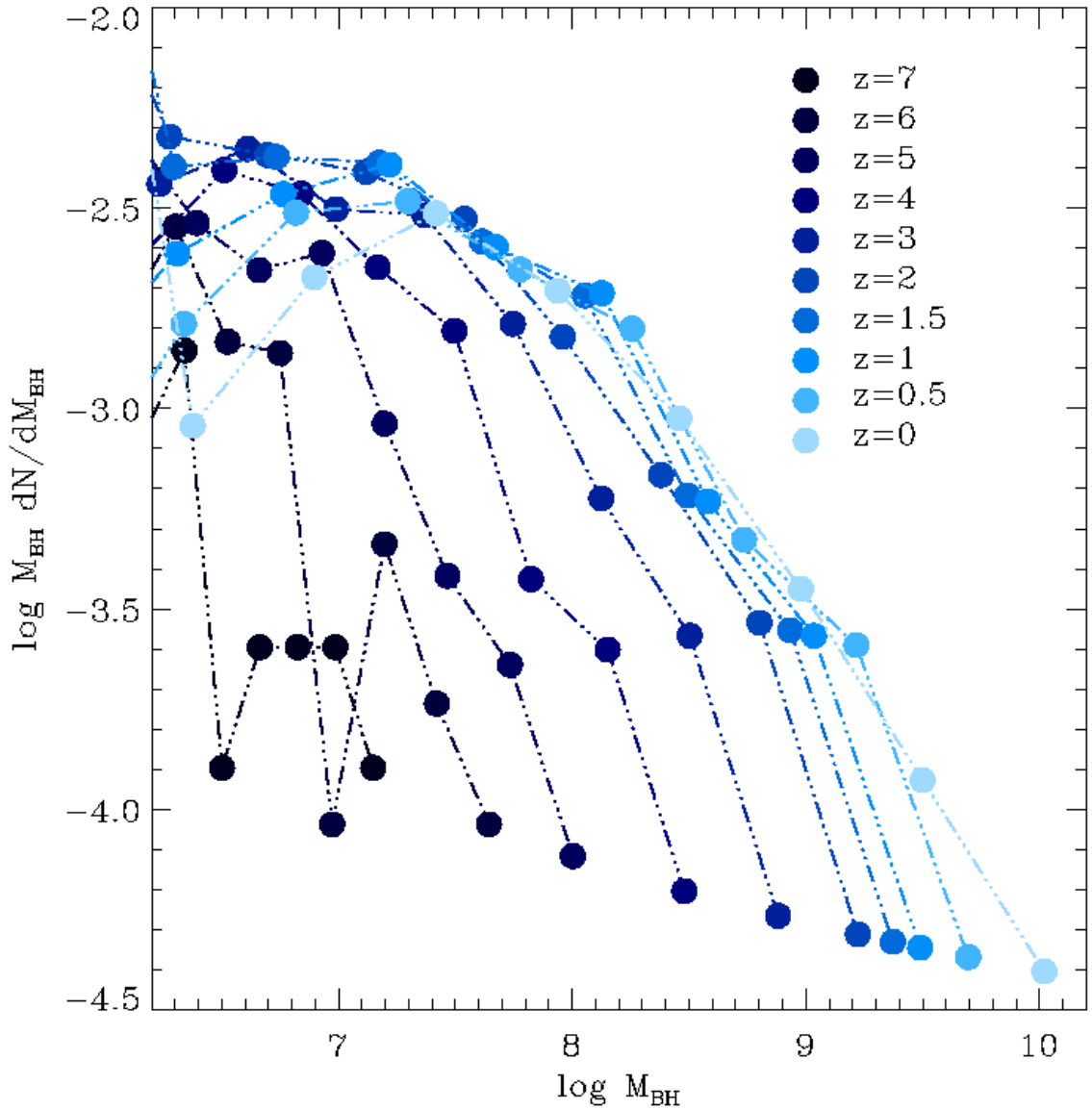
D4 BOX $L = 33.75\ h^{-1}$ Mpc

$N = 2 \times 216^3$

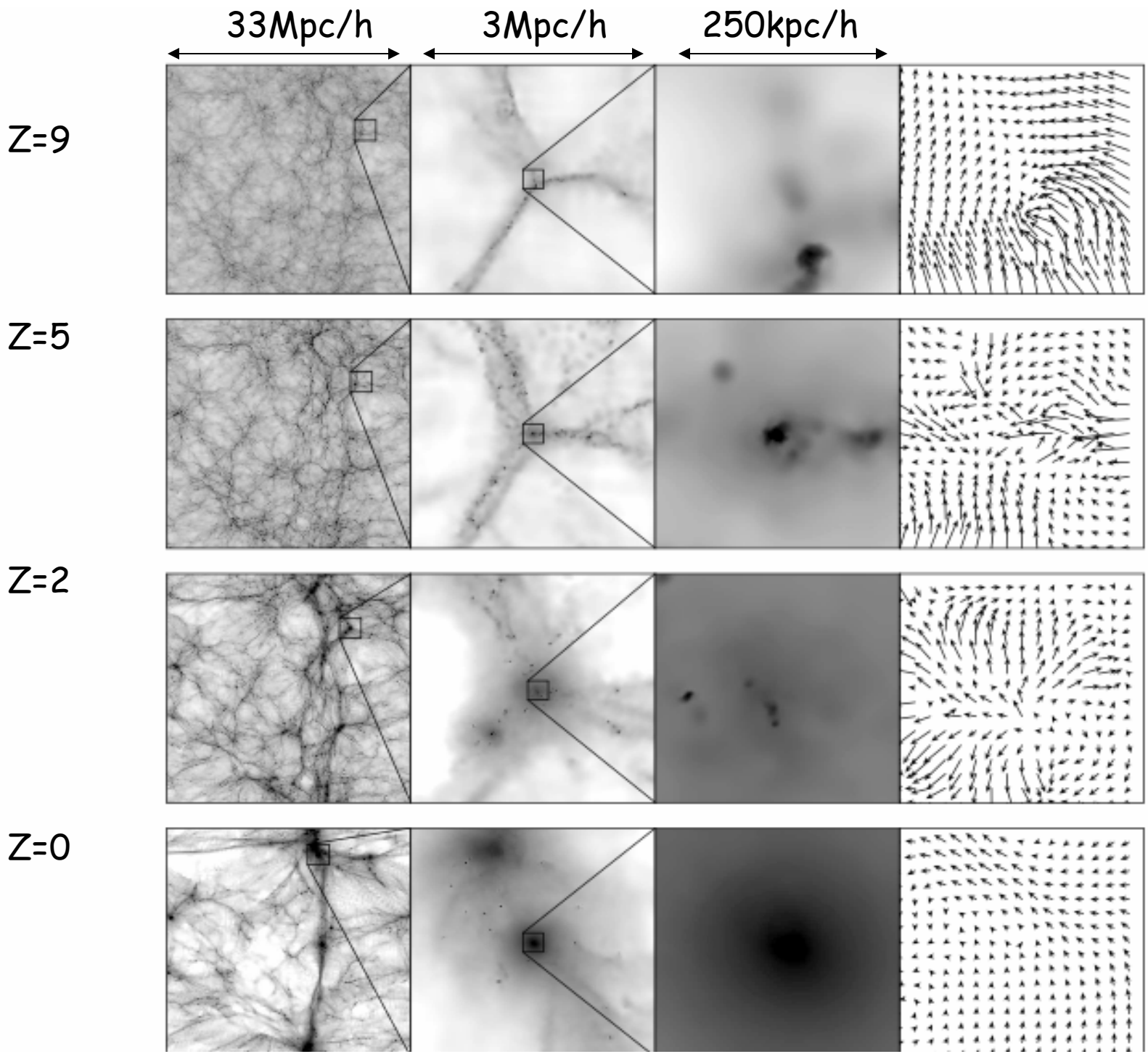
$M_{DM} = 2.75 \times 10^7$

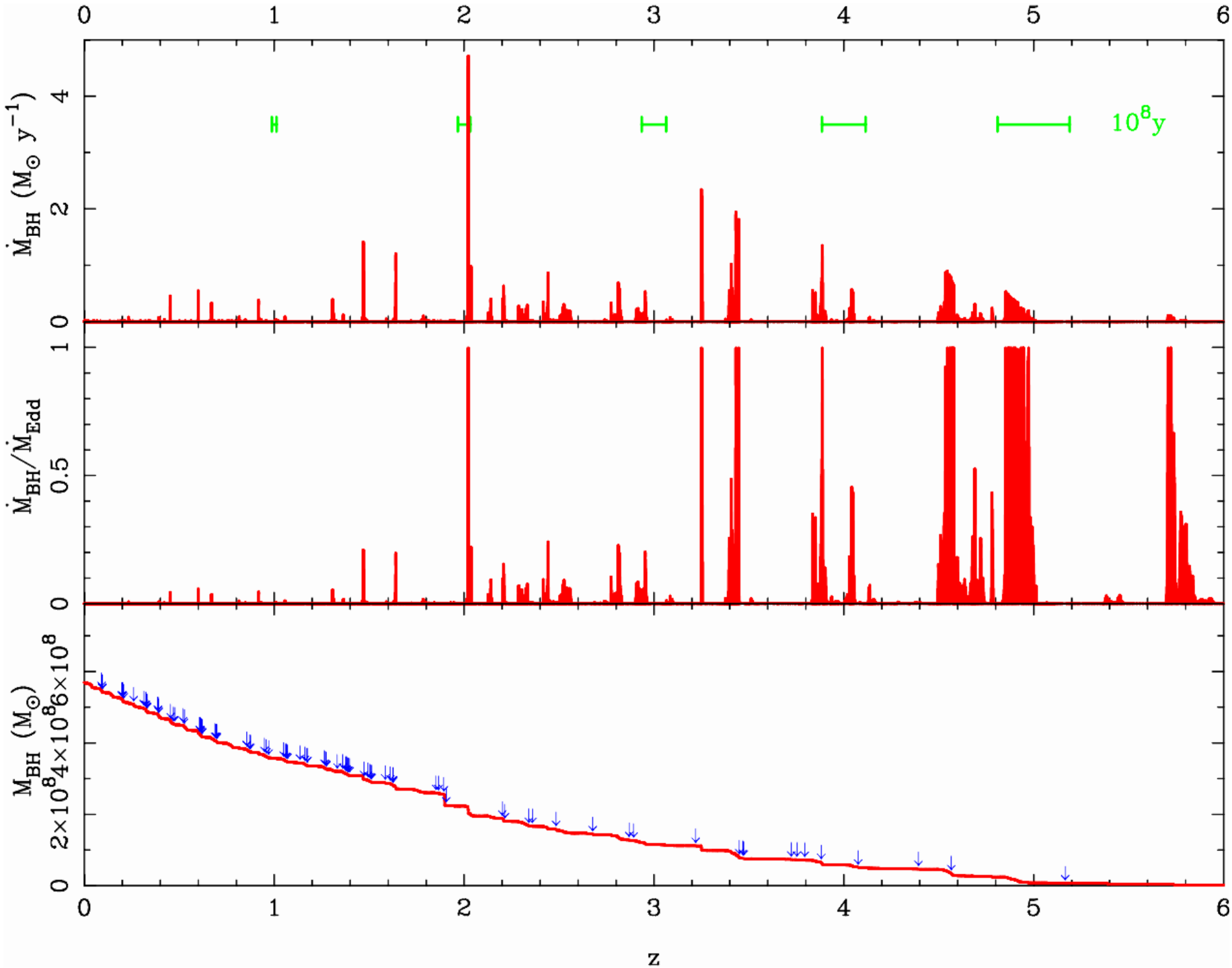
$M_{gas} = 4.24 \times 10^7$

The evolution the black hole mass function



QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.


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


0
1
2
3
4
5
6
$\dot{M}_{BH}$ ($M_\odot$ y^{-1})
10^8y
$\dot{M}_{BH}/\dot{M}_{Edd}$
M_{BH} ($M_\odot$)
2×10^8
4×10^8
6×10^8
z

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…