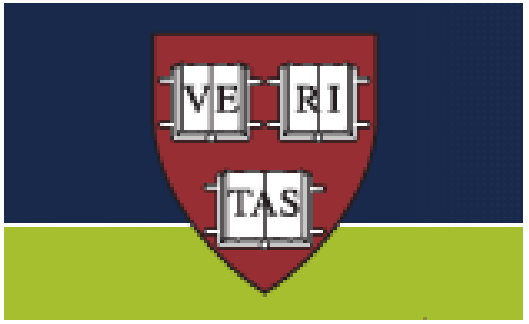
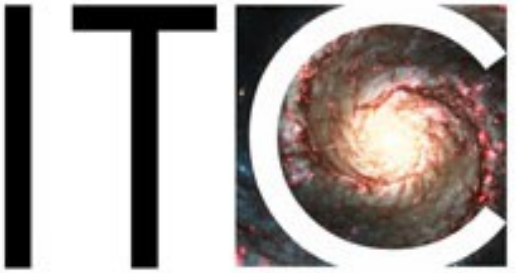




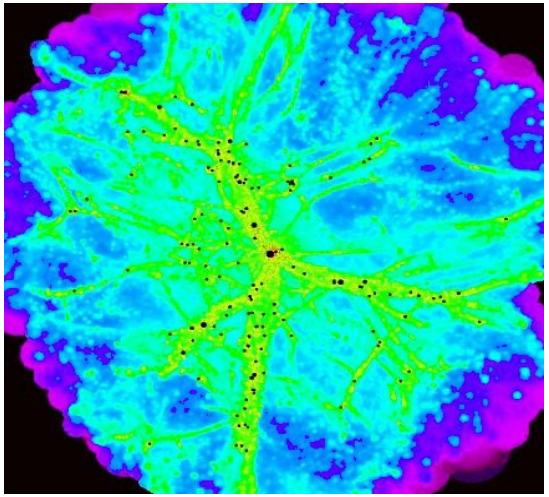
Merger driven BH accretion and QSOs

a cosmological perspective

Debora Sijacki
Hubble Fellow
CfA, Harvard University

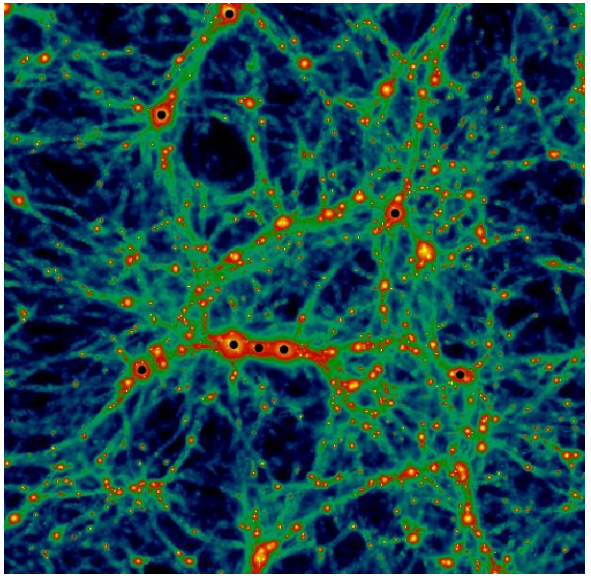
Single and double black holes in galaxies University of Michigan, August 22-25, 2011

Outline



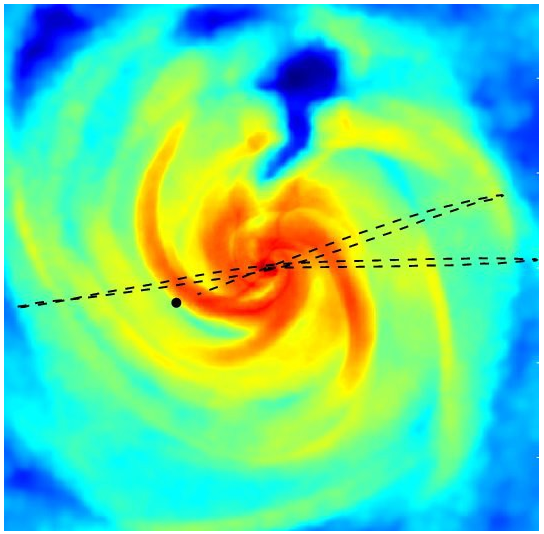
I Growth of the first bright QSOs

- how BHs grow in the highly biased regions in the early Universe?
- how is most of their mass assembled?
- how important are the mergers with other BHs?



II Co-evolution of galaxies and QSOs

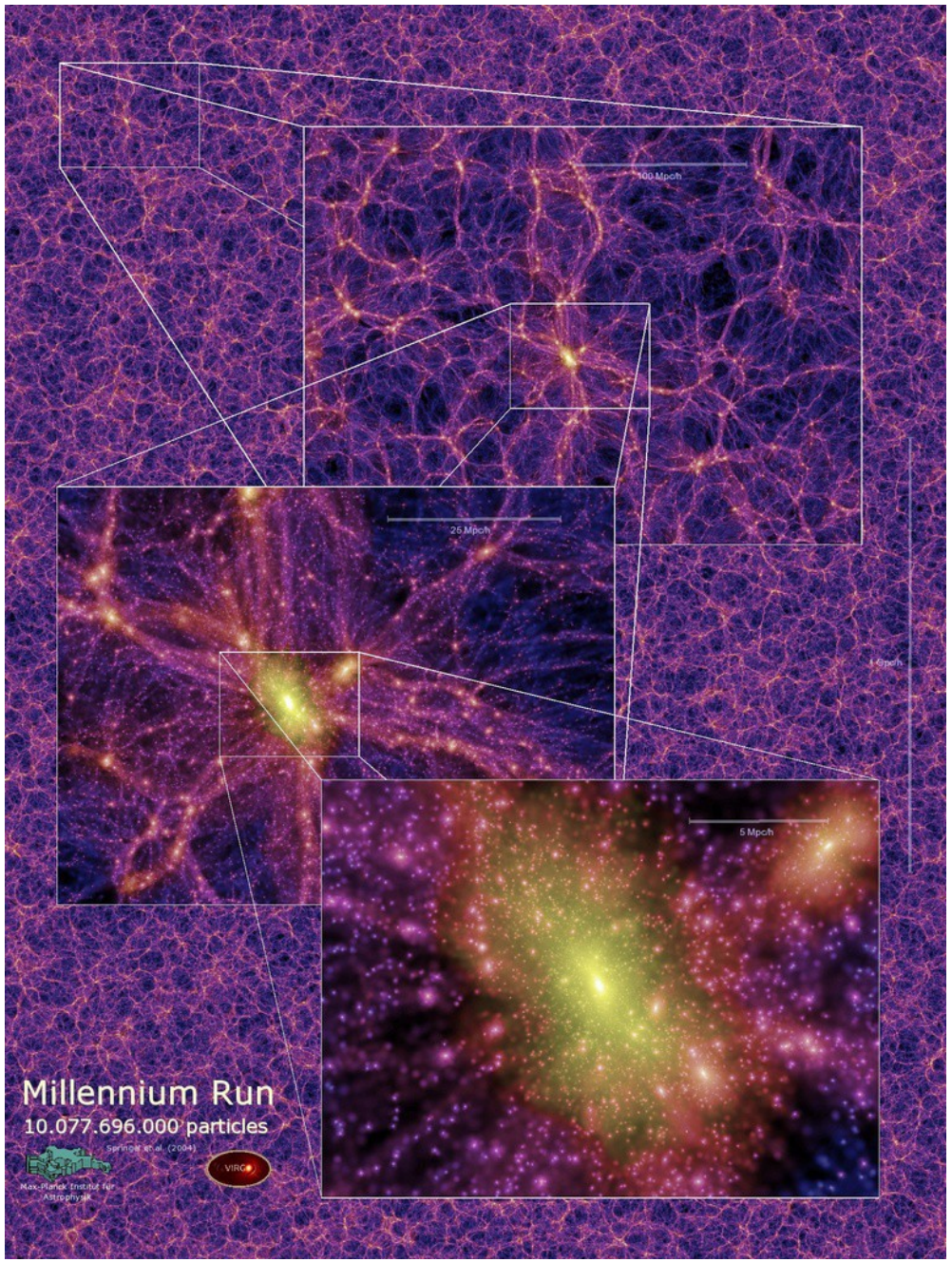
- how BHs grow at intermediate redshifts, i.e.3-1?
- how QSOs affect their hosts?

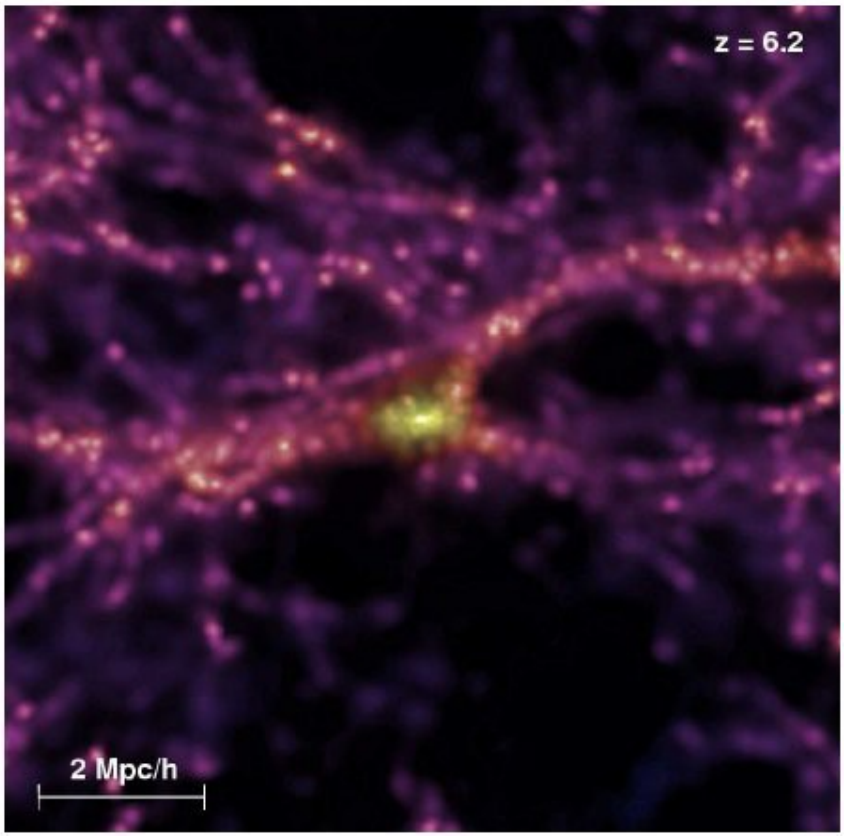


III Recoiling BH

- what is the role of AGN feedback?
- can this introduce significant scatter in BH-galaxy scaling laws?

Growing SMBHs in the Millennium simulation

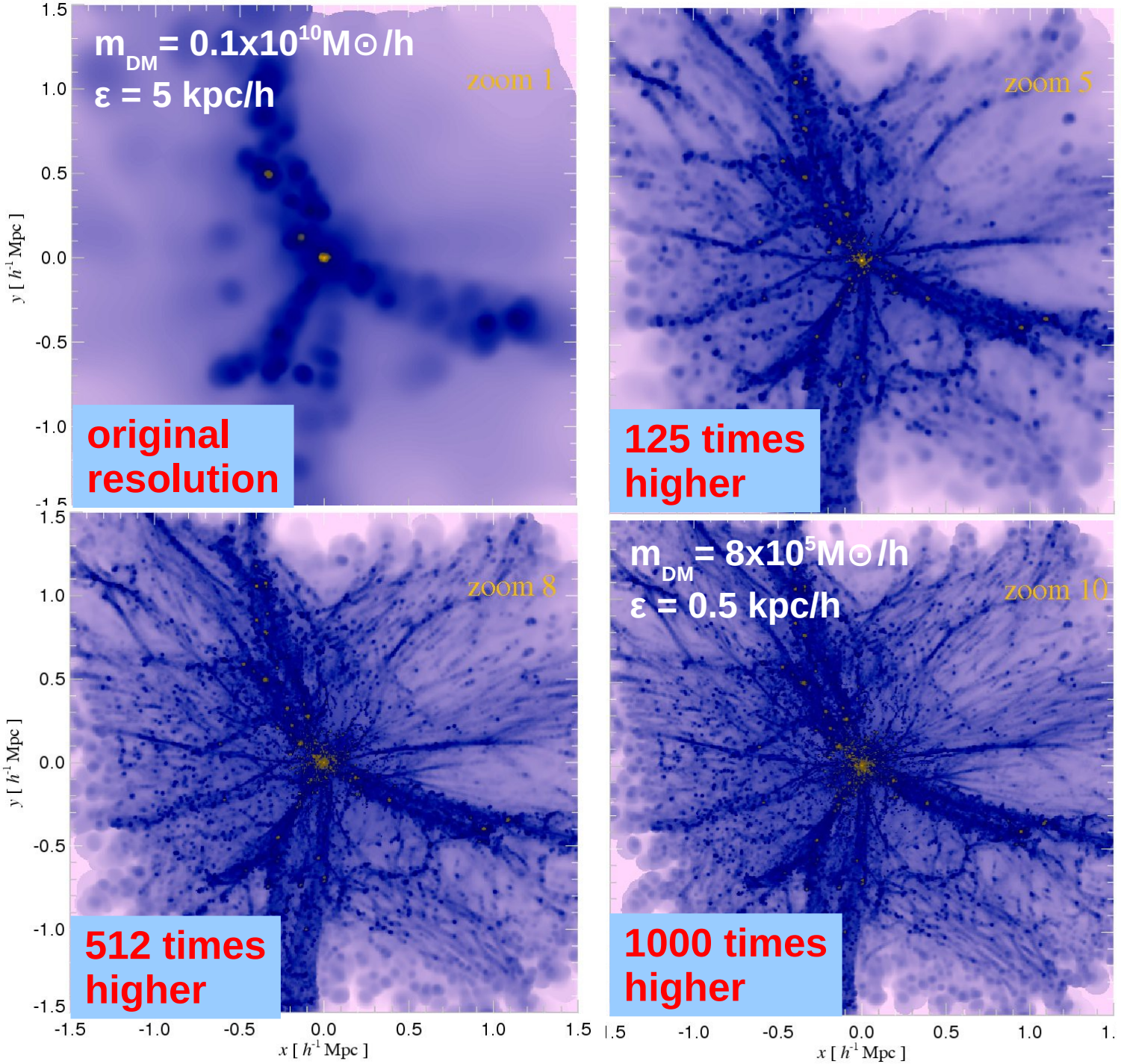




First QSO candidate: Millennium simulation volume should contain ~ ONE QSO

Springel et al, 2005, Nature

"Zooming" into the most massive cluster at z=6



Main properties

R_{vir} = 460kpc

M_{vir} = 5x10^{12}M⊙

$M_{gas,vir}$ = 3x10^{11}M⊙

$M_{star,vir}$ = 6x10^{11}M⊙

T_{vir} = 7x10^{6}K

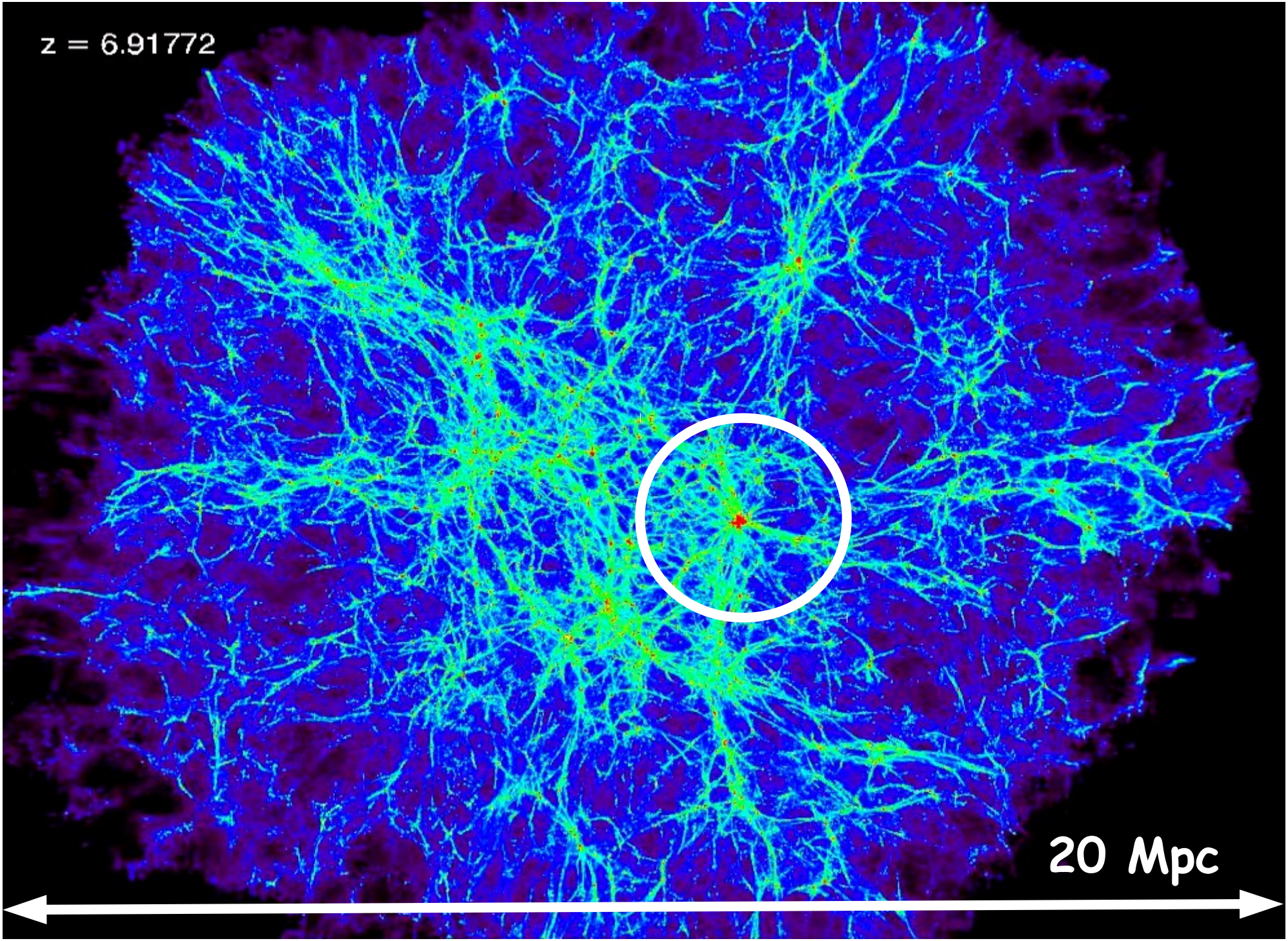
SFR_{vir} = 1000M⊙/yr

- **central gas collapse within protogalactic halos:**

10^{10} M⊙ or 10^{9}M⊙ halos seeded with 10^{5}M⊙ BHs

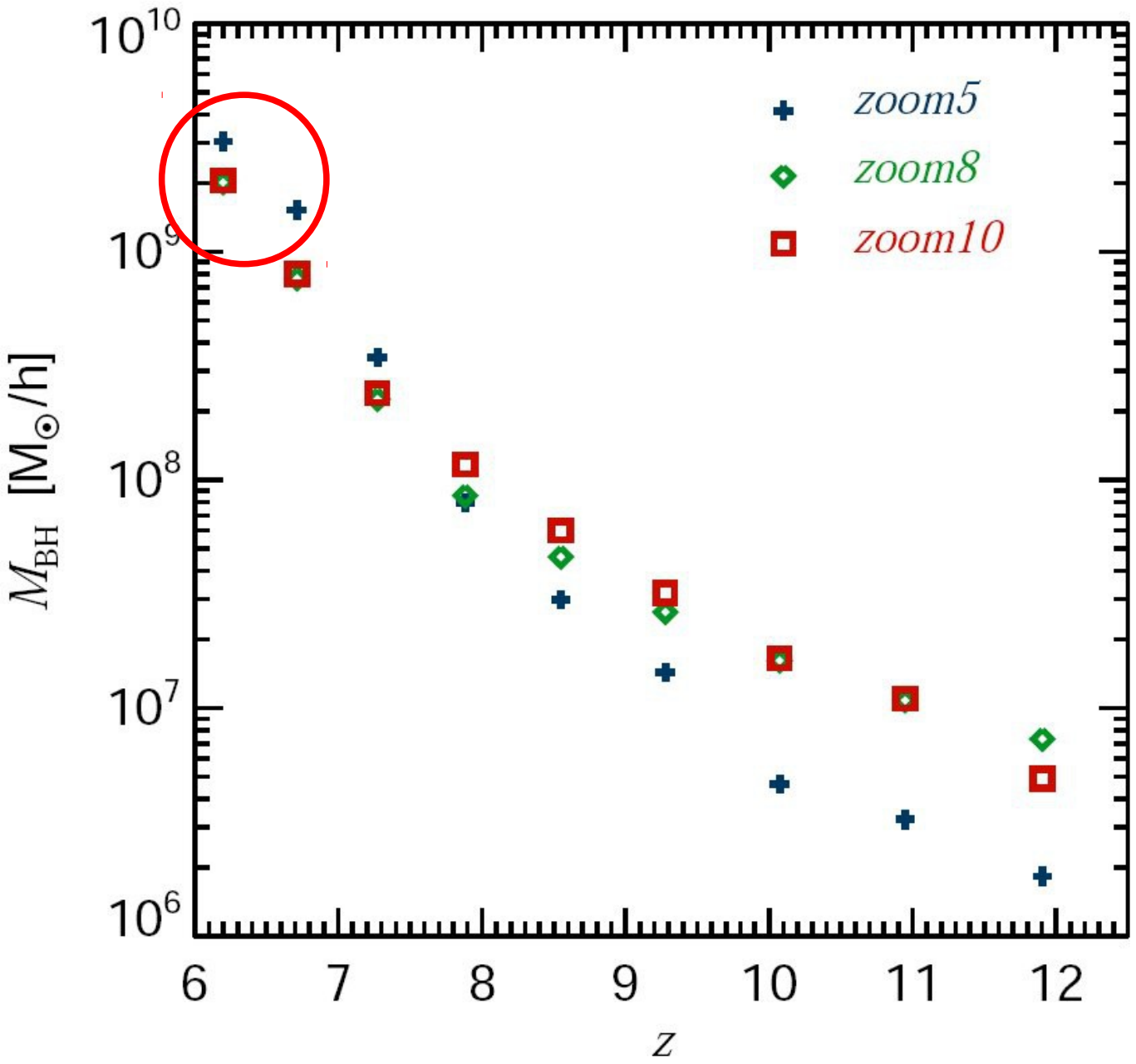
- **Eddington limited Bondi accretion**
- **QSO feedback**

Sijacki et al, 2009


z = 6.91772
20 Mpc

The mass growth of the most massive BH

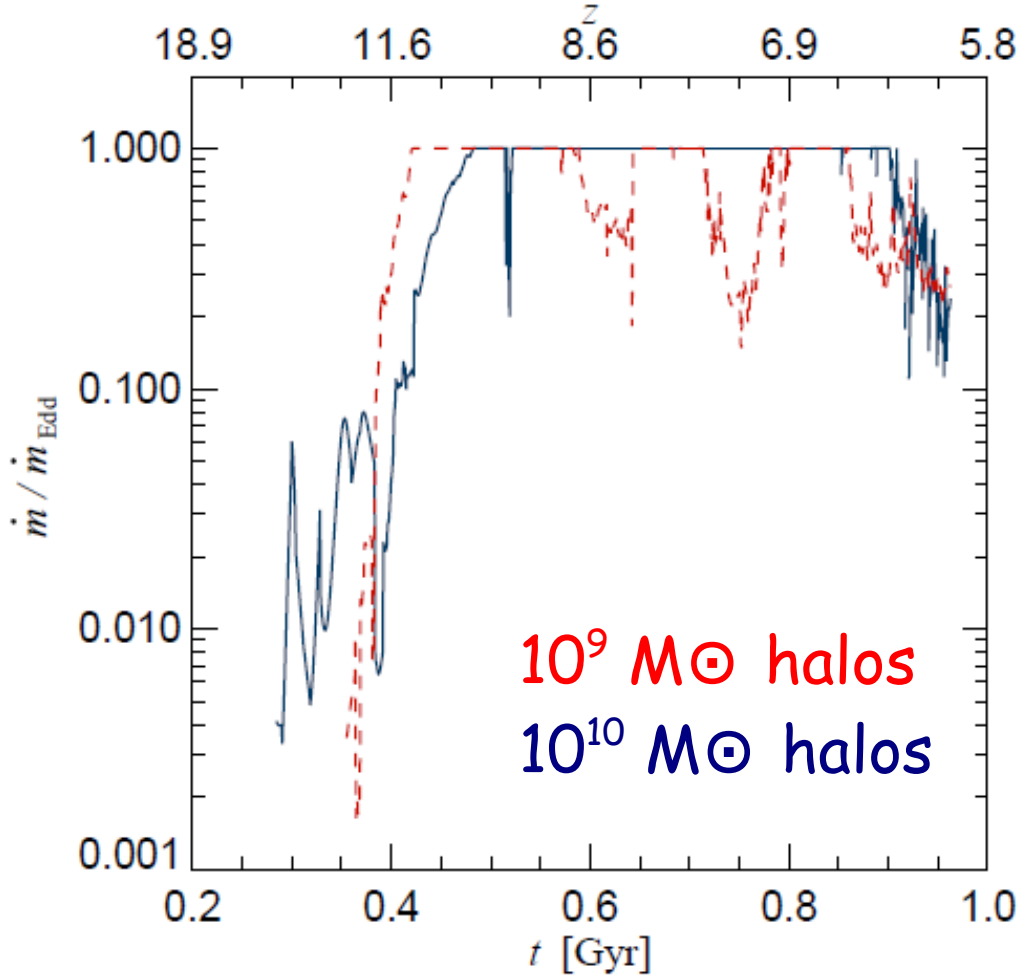
IN FULL COSMOLOGICAL SIMULATIONS IT IS POSSIBLE TO PRODUCE ~10^9 M⊙ BH AT Z = 6

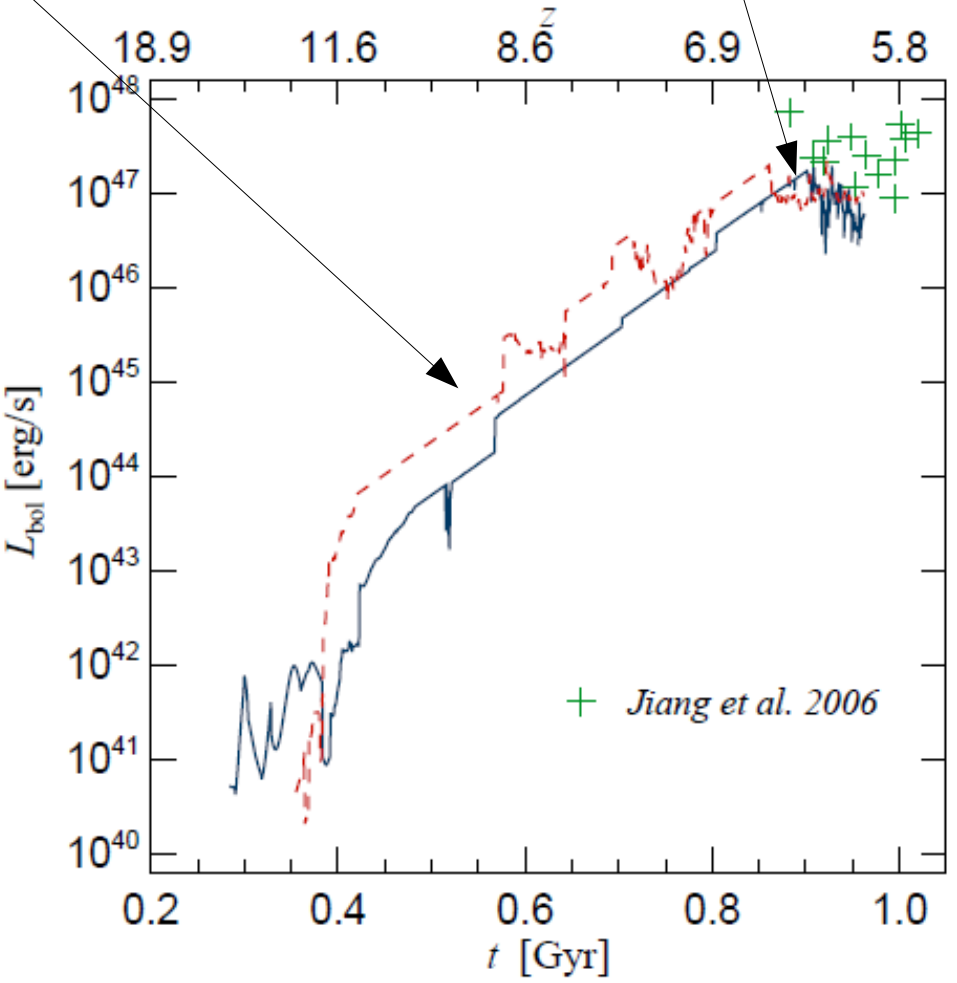


The accretion rate and Lbol of the most massive BH

Eddington limited growth
(+ gas starvation)

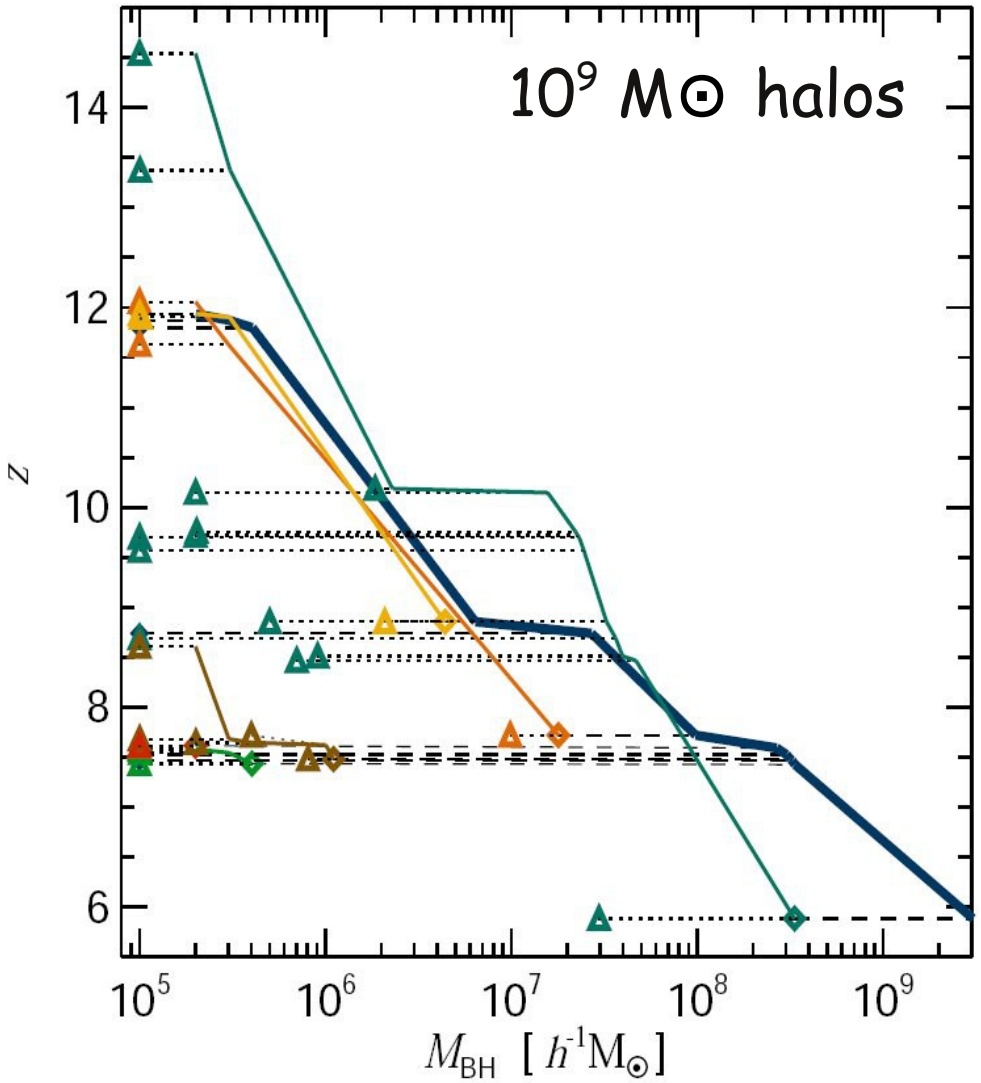
feedback regulated growth

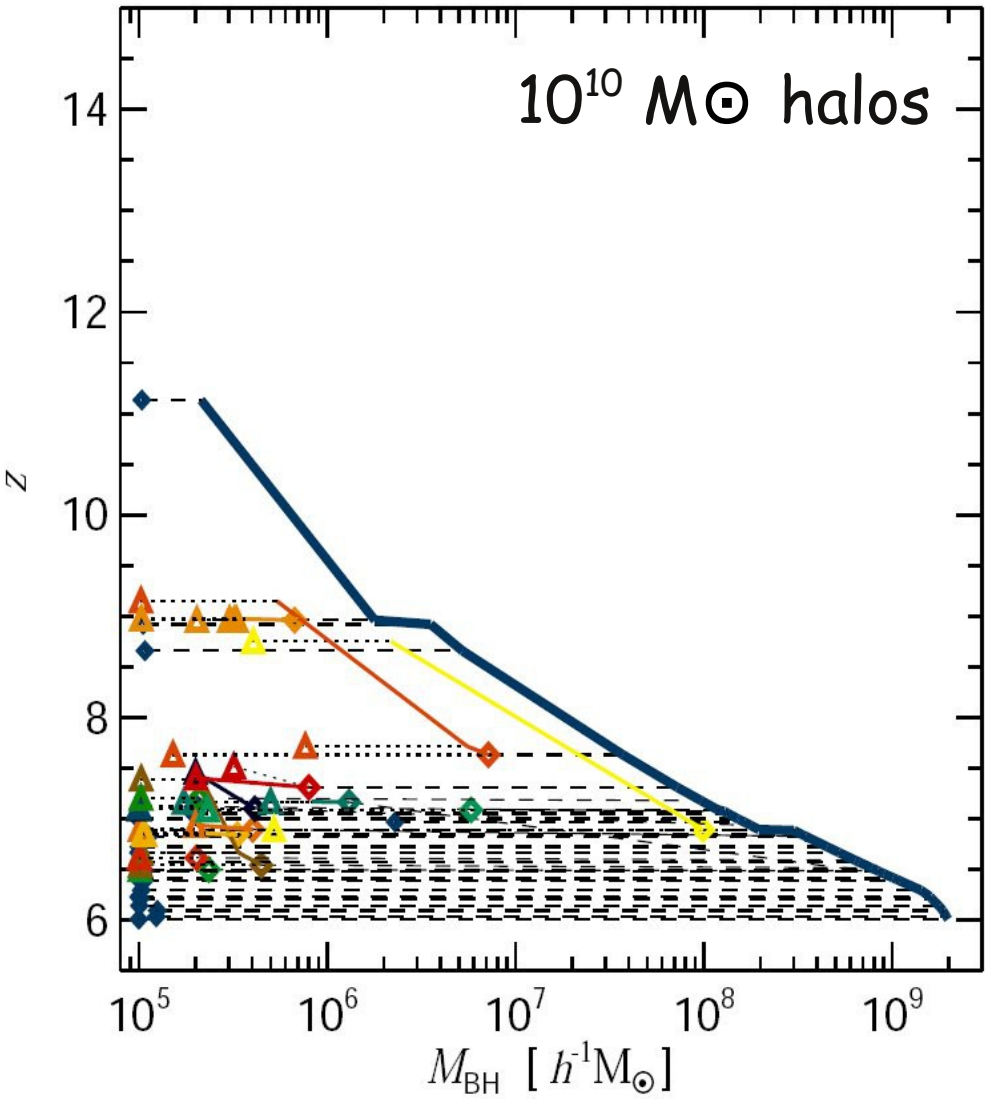




Seeding 10^9 vs. 10^{10} M⊙ halos

- BH mergers more important when BH seeded earlier, but final BH mass mostly due to the Eddington limited accretion



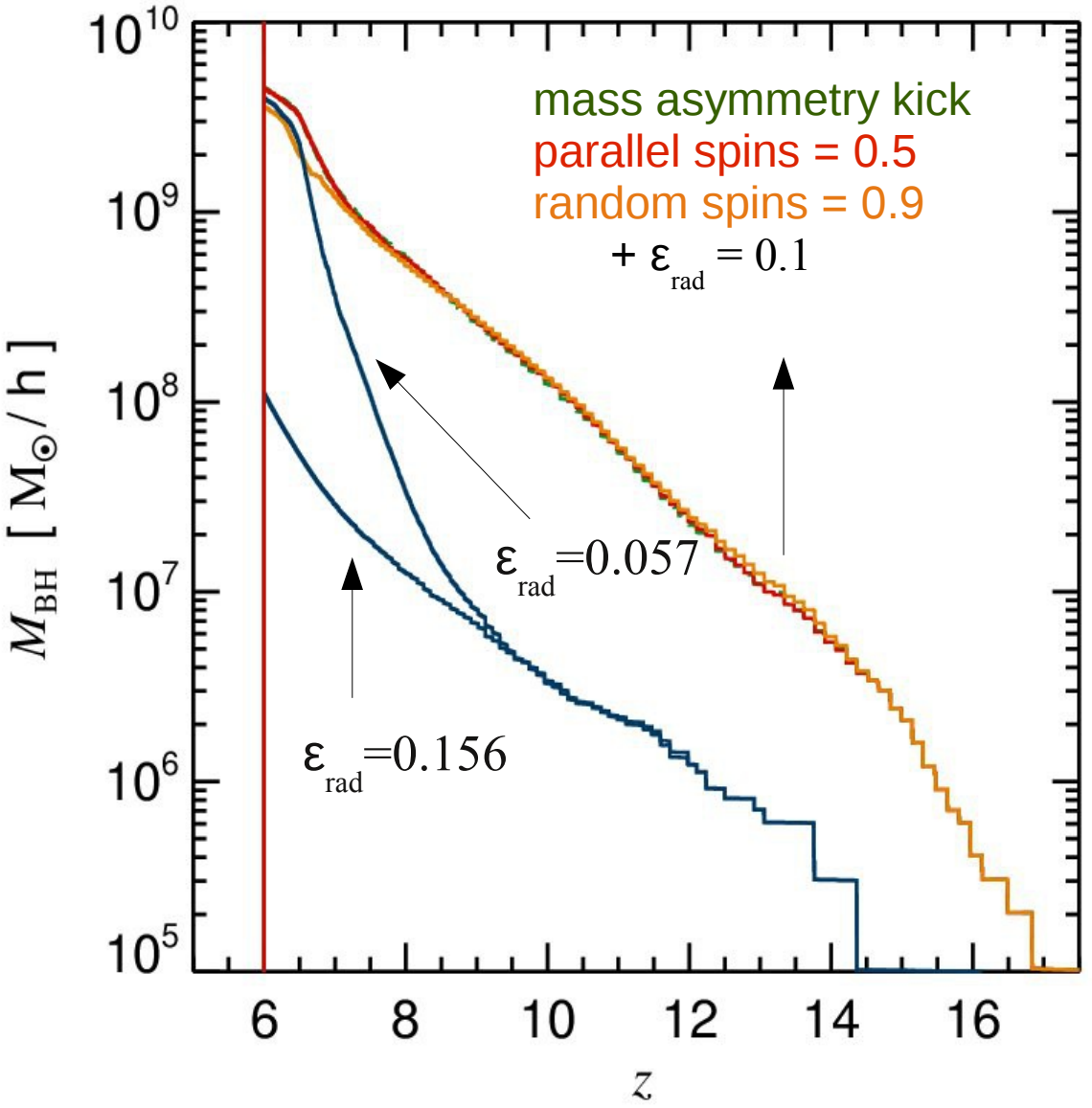


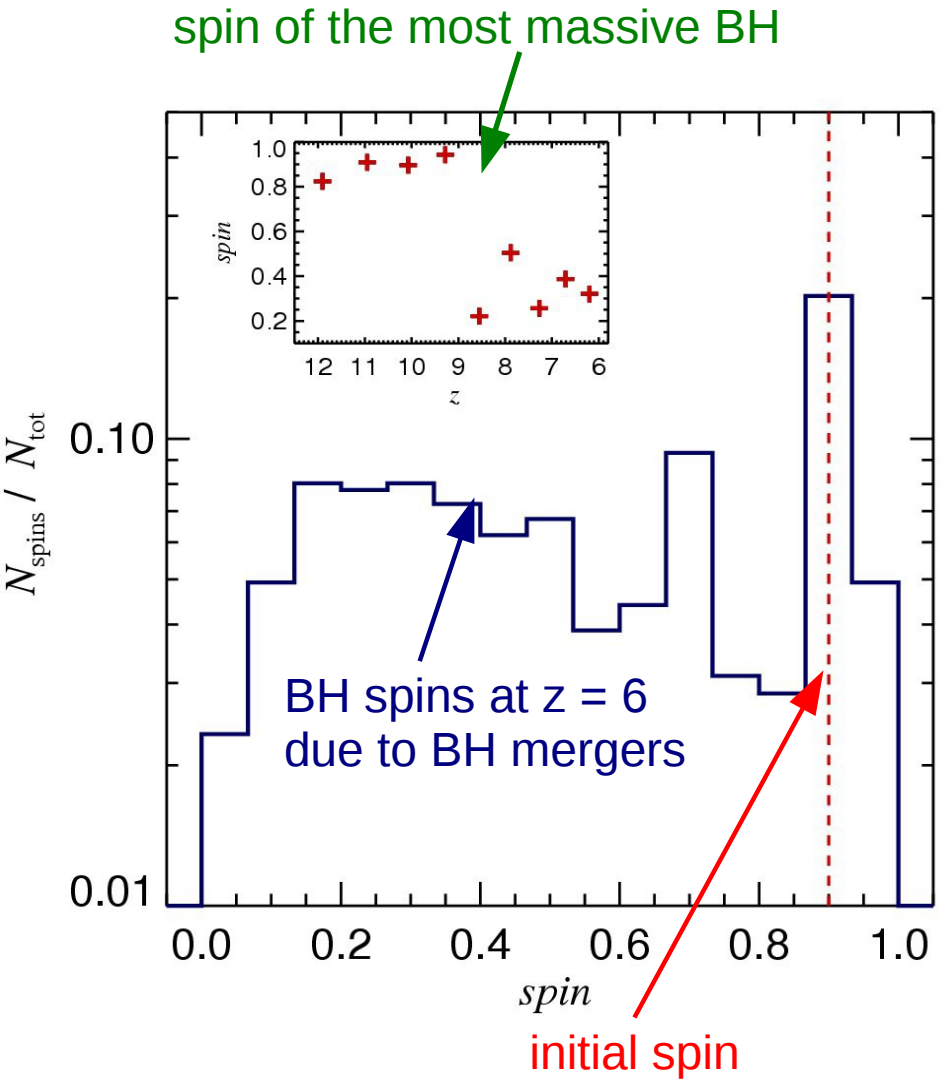
total mass of BHs that merge onto the main progenitor < 20% / 10%

What about BH kicks and rapidly spinning BHs?

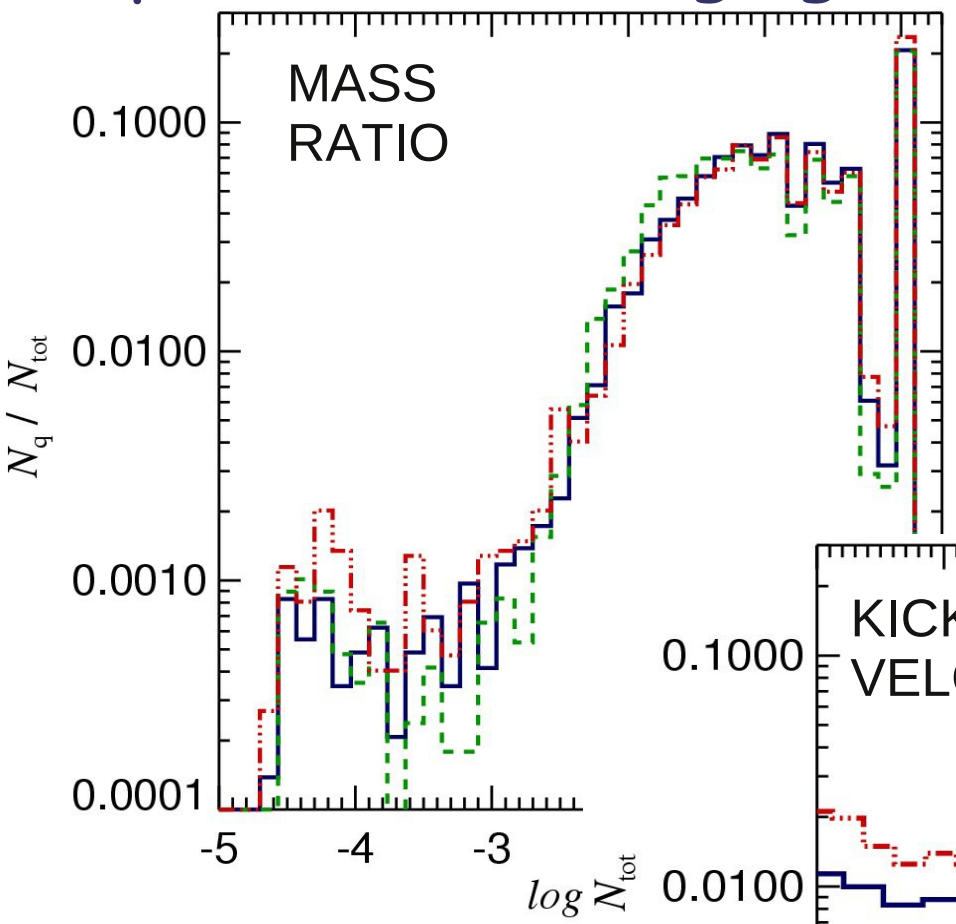
IF PROGENITOR OF SMBH AT Z=6 IS RAPIDLY SPINNING & NOT MERGING MUCH, DIFFICULT TO PRODUCE SMBH:
SUPER-EDDINGTON ACCRETION,...?

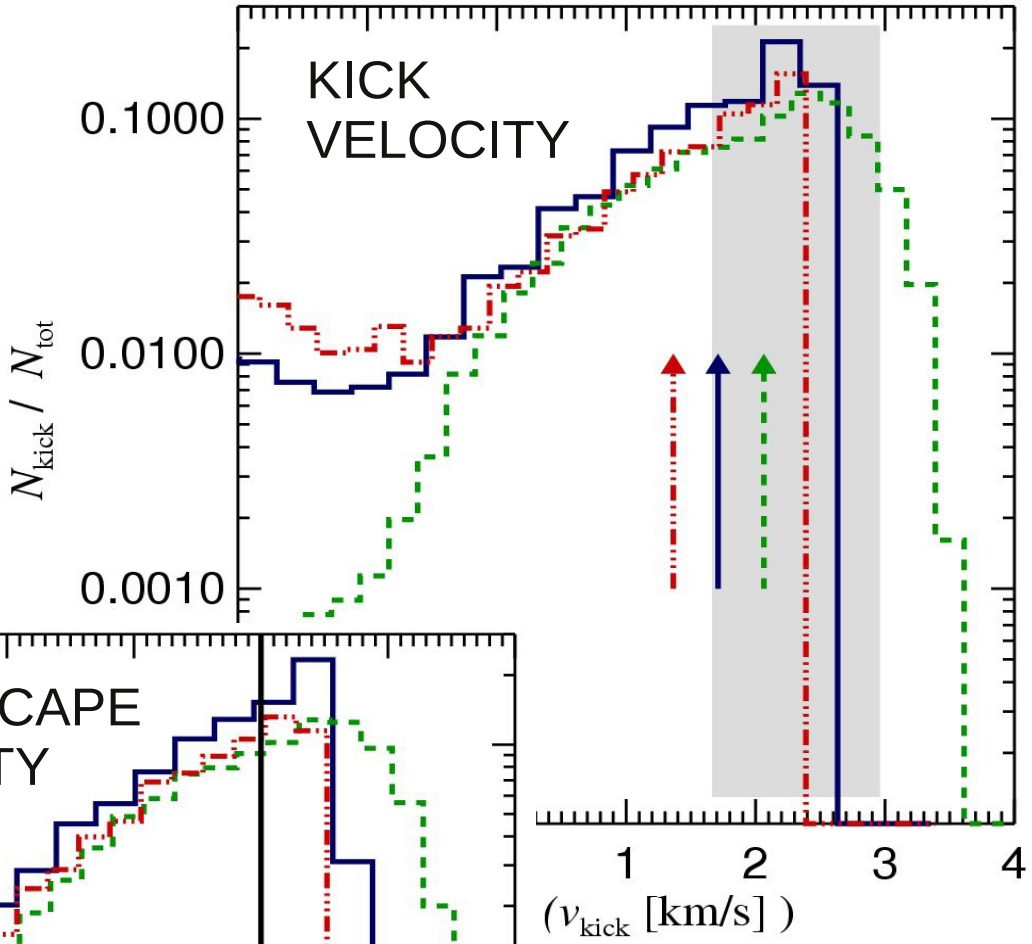
kicks not very important for the most massive BH

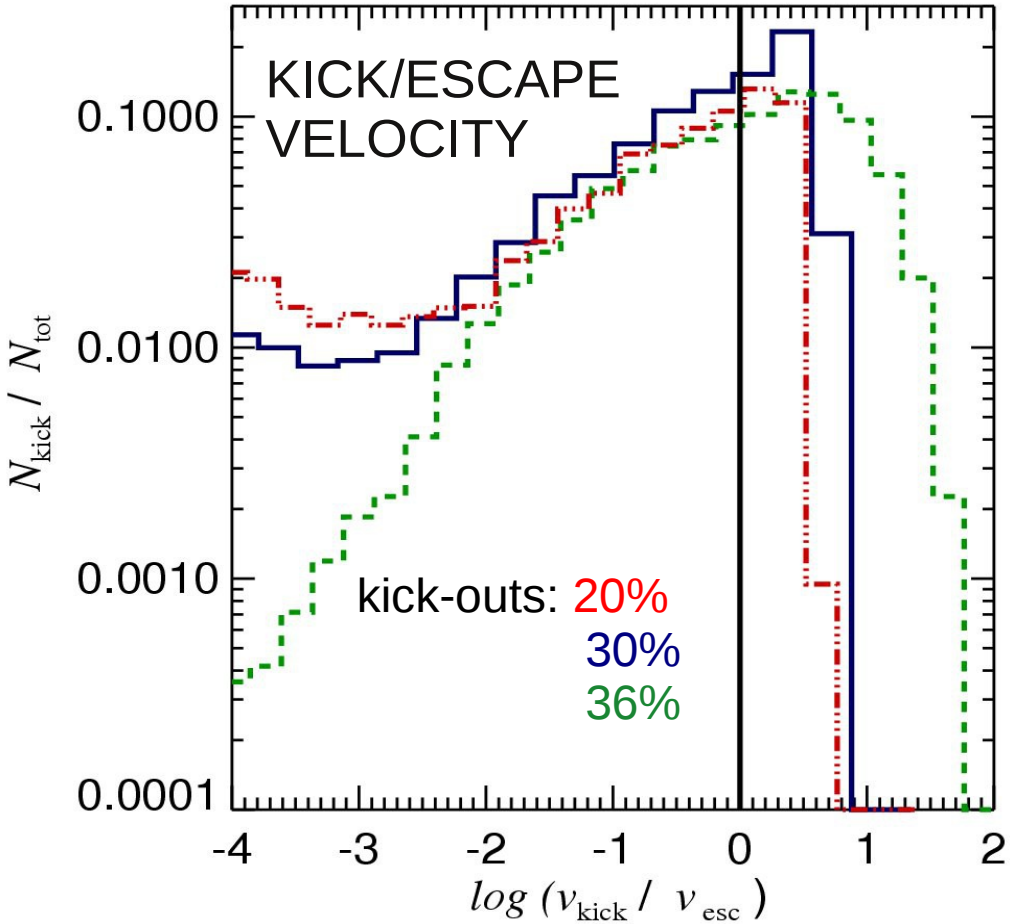




Population of merging BHs





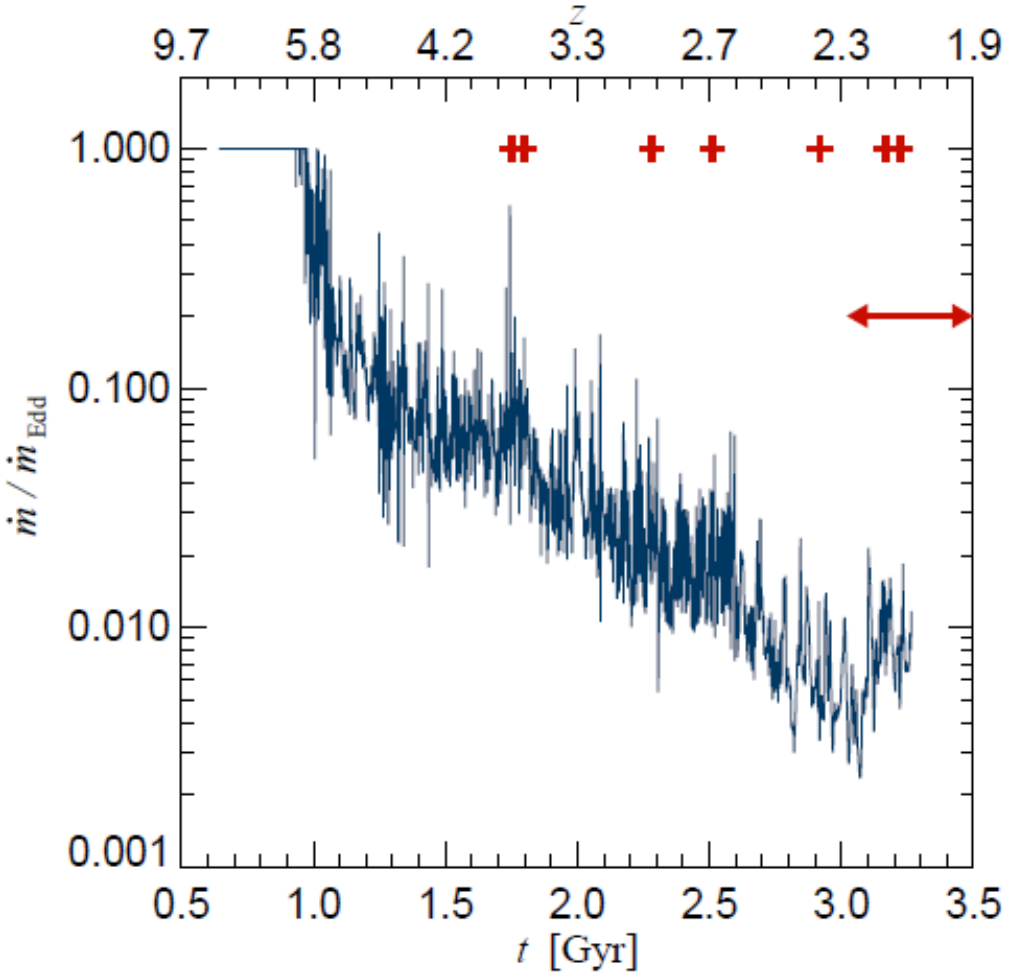


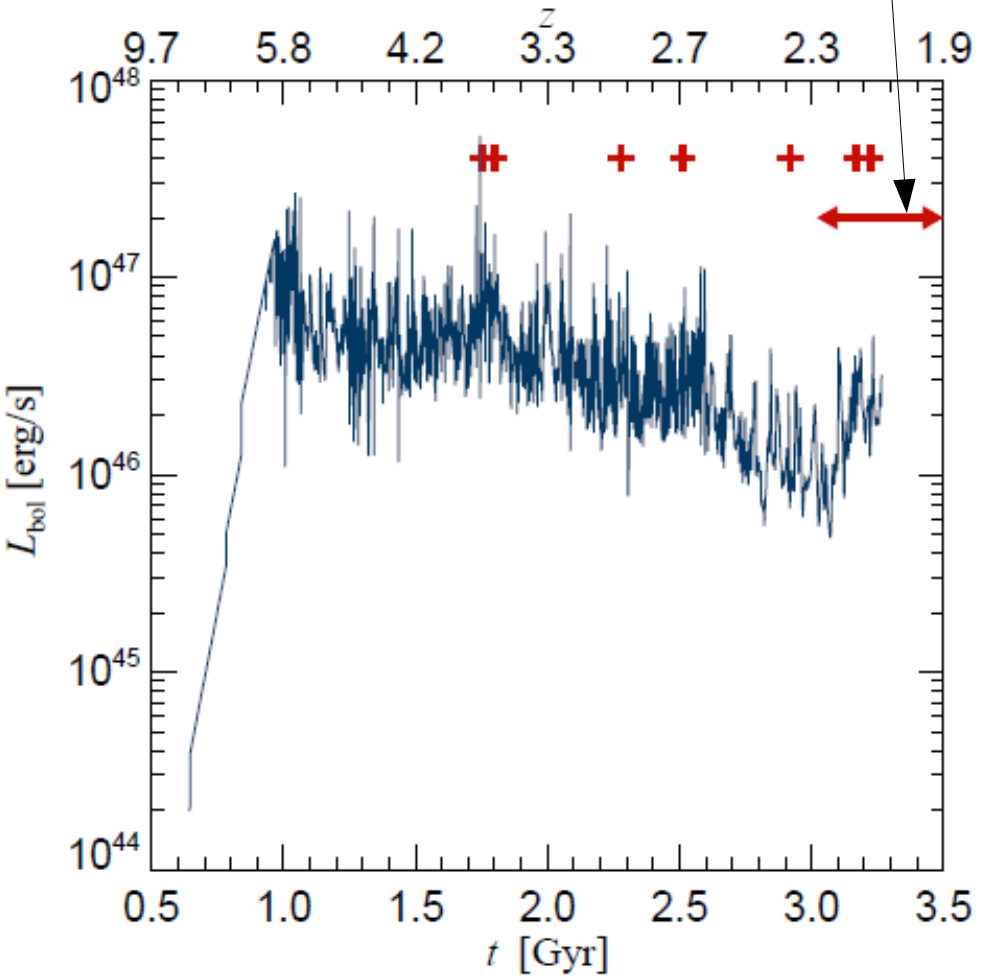
mass asymmetry kicks
parallel spins = 0.5
random spins = 0.9

Tracking mass assembly of SMBH and its host halo to low z

epoch of host halo major merger 1:1.2

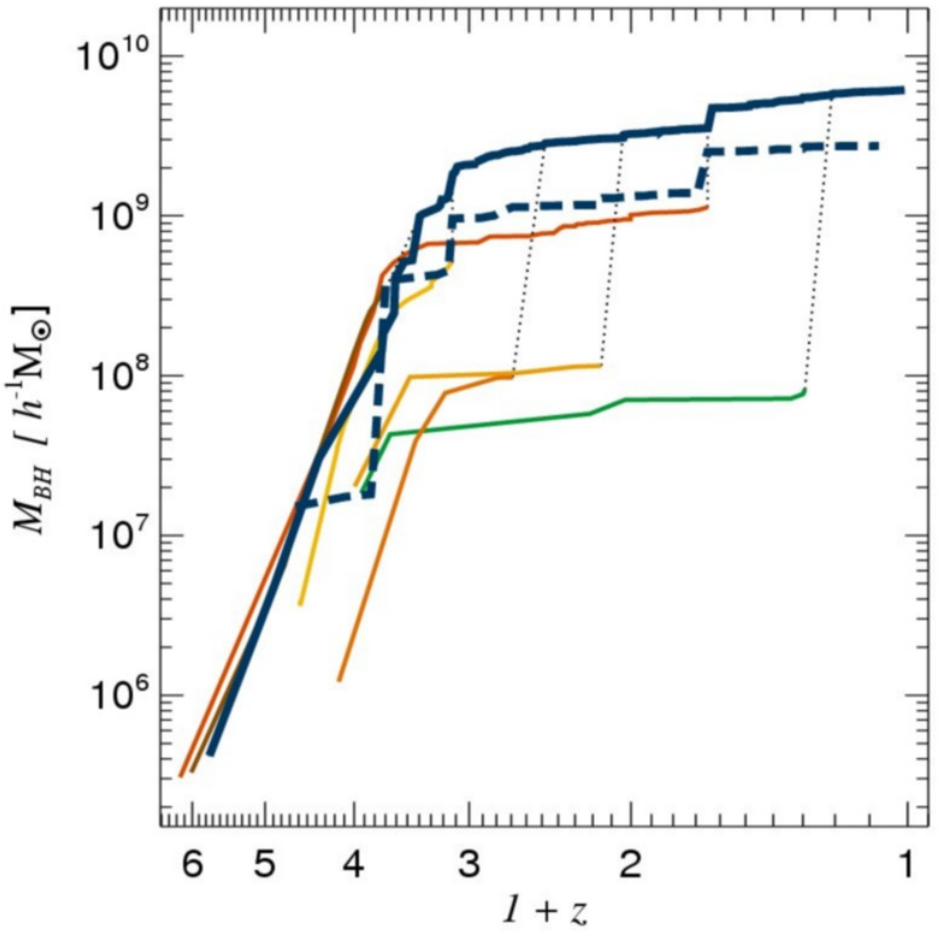
+ mergers of SMBH with at least $10^8 M\odot$ BH

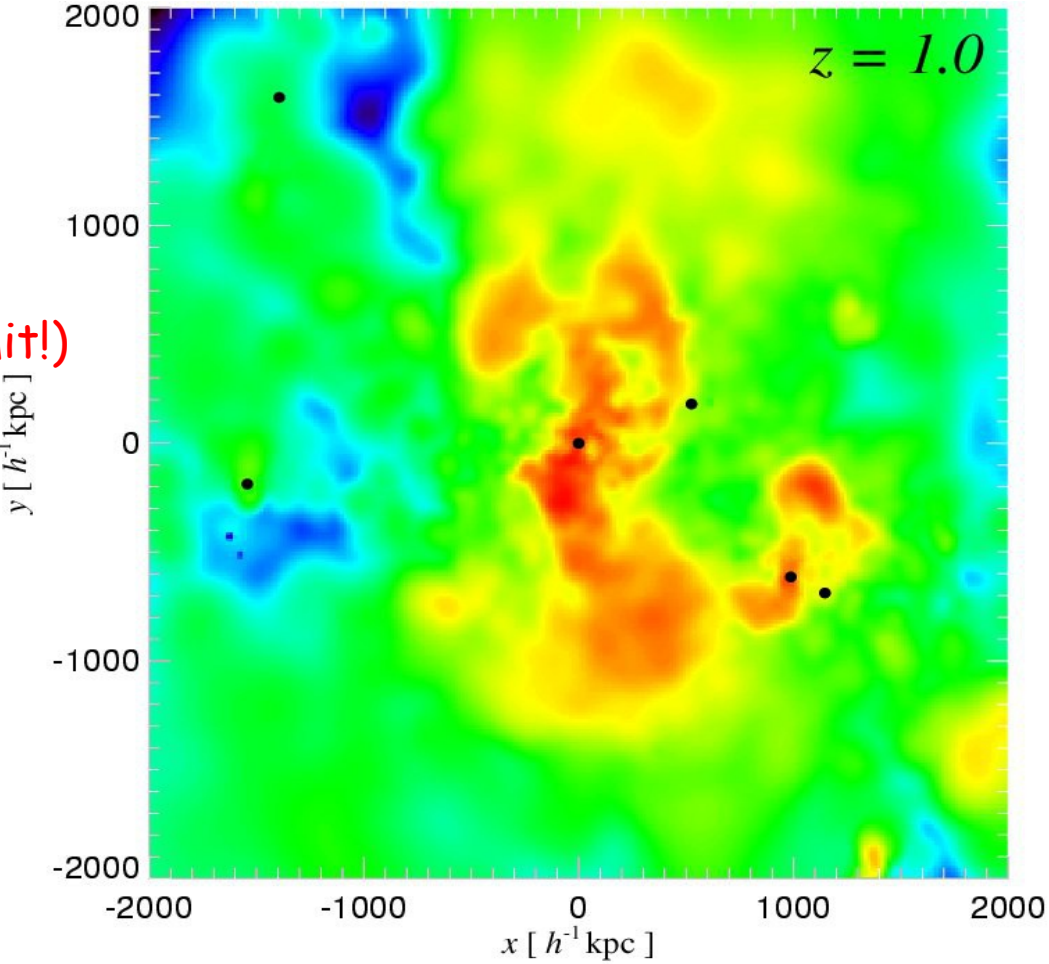




Tracking mass assembly of SMBH and its host halo to low z

MERGER TREE OF THE MOST MASSIVE BH AT Z = 0:
45% of mass due to BH mergers (upper limit!)
55% due to gas accretion

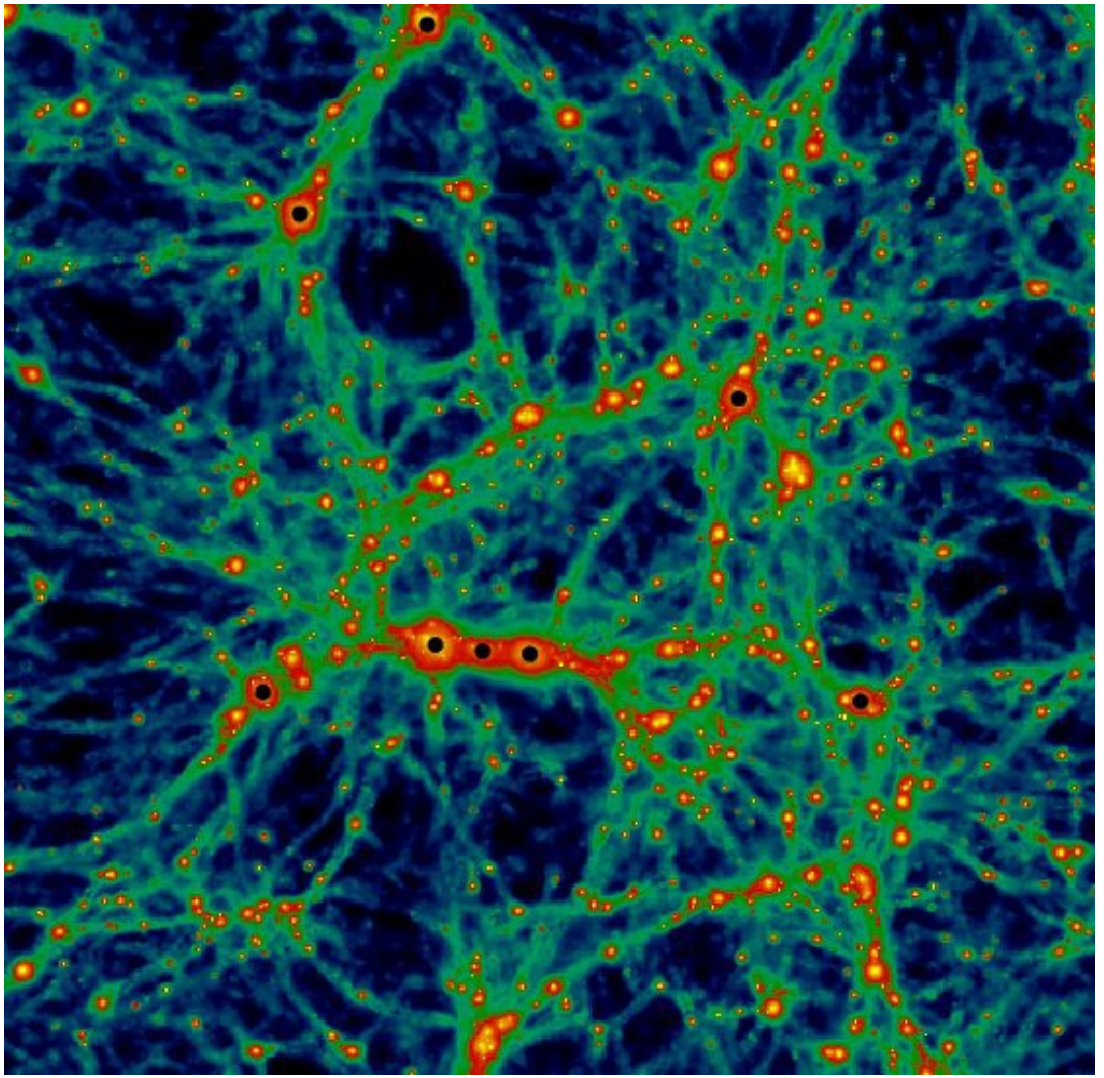




Sijacki et al, 2007, 2008, 2009
see also McCarthy et al. 2010
Teyssier et al. 2011

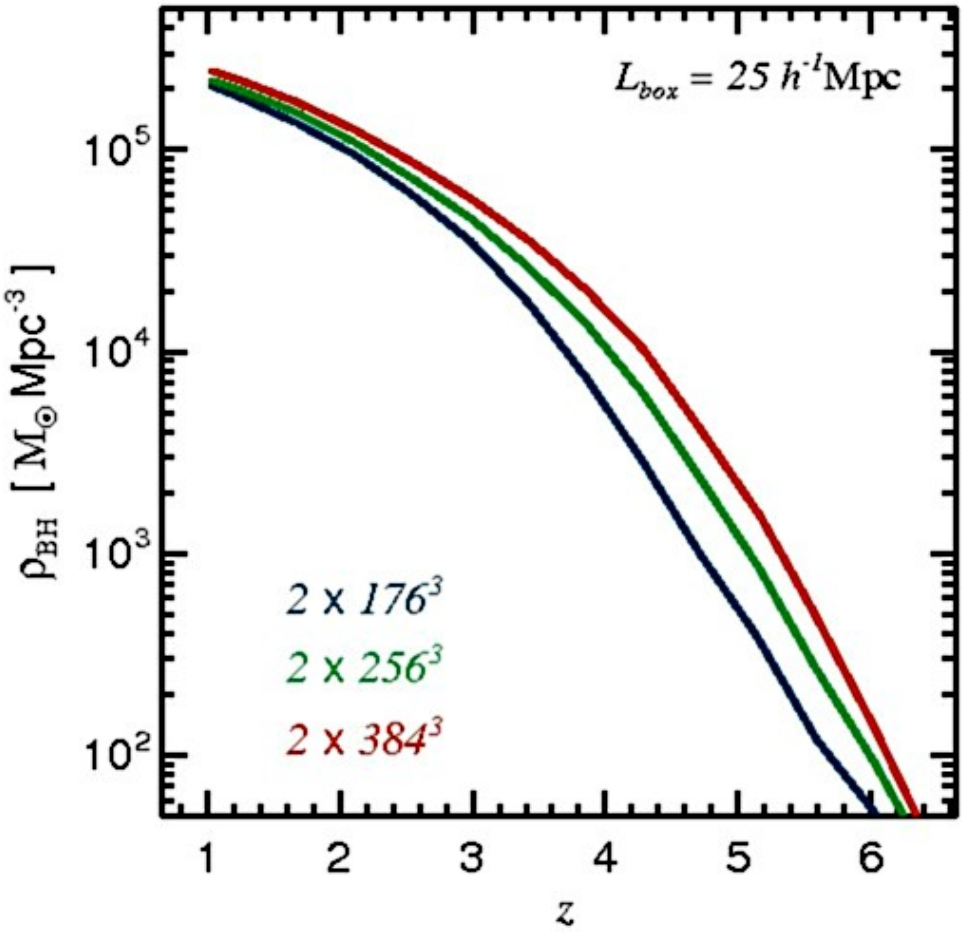
II Co-evolution of galaxies and QSOs

- how BHs grow at intermediate redshifts, i.e.3-1?
- how QSOs affect their hosts?

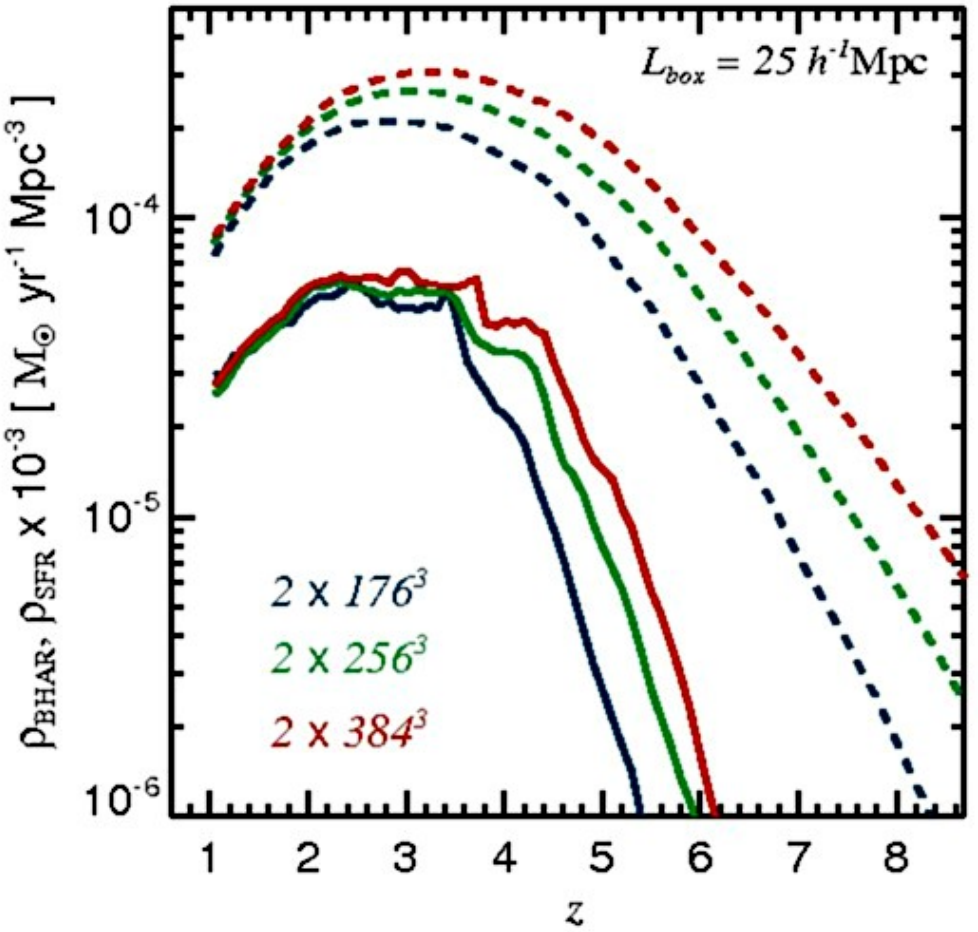


Galaxy formation with AGN feedback:

BH growth



COMOVING BH MASS DENSITY IN BROAD AGREEMENT WITH OBSERVATIONAL ESTIMATES



- BHAR PEAKS AT SOMEWHAT LOWER Z THAN SFR
- TOTAL SFR AT Z=1 REDUCED BY 20% DUE TO AGN FEEDBACK

Sijacki et al, 2007, Di Matteo et al, 2008

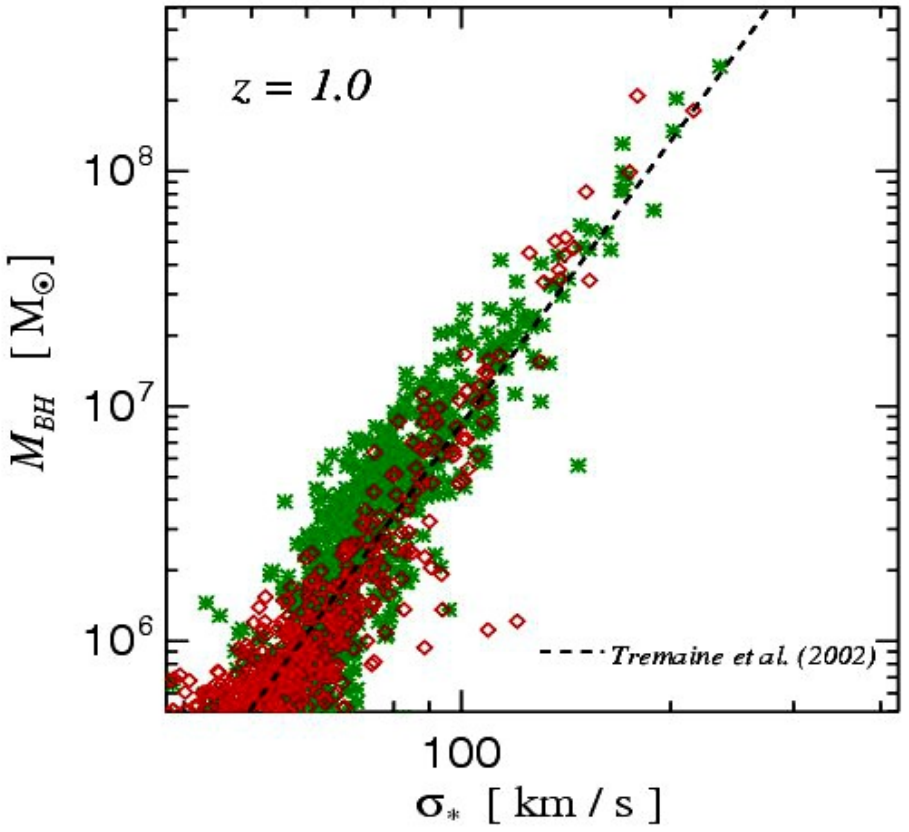
see also Booth & Schaye 2009

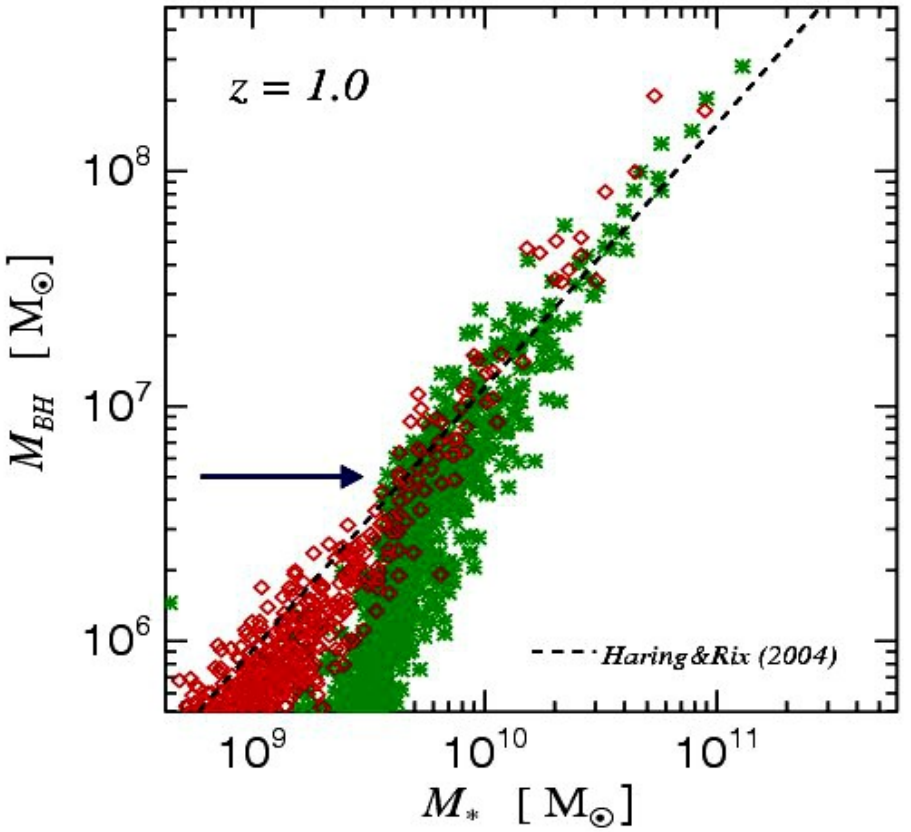
Galaxy formation with AGN feedback:

BH mass - host galaxy relations

no galactic winds

with galactic winds



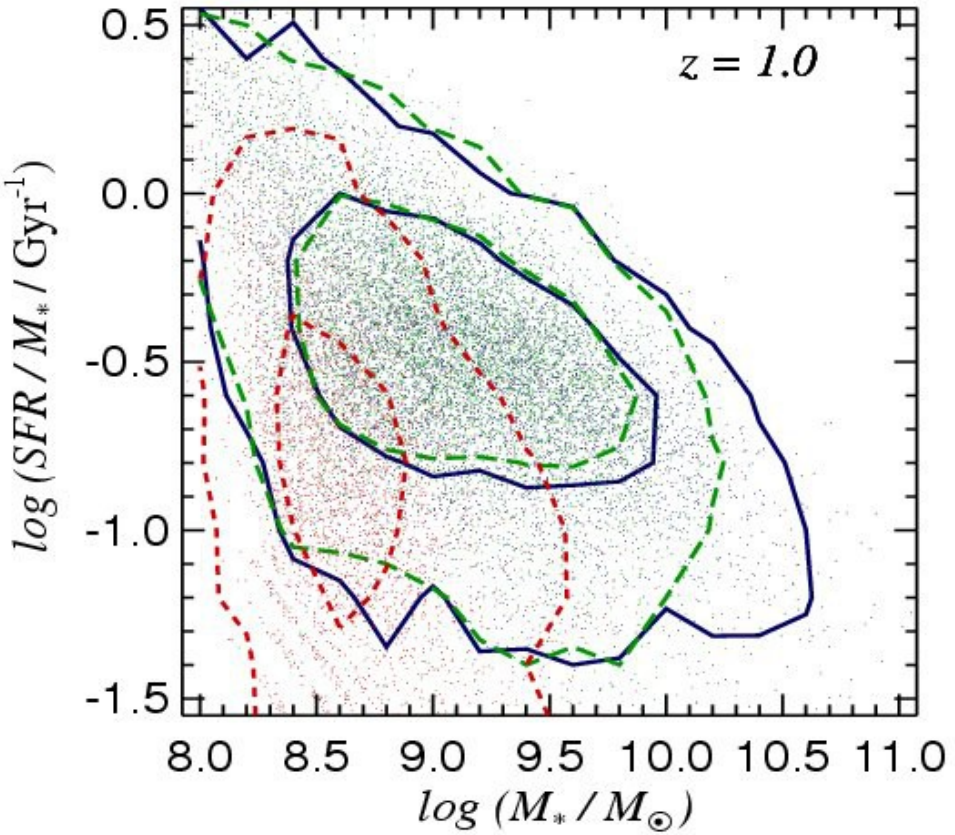


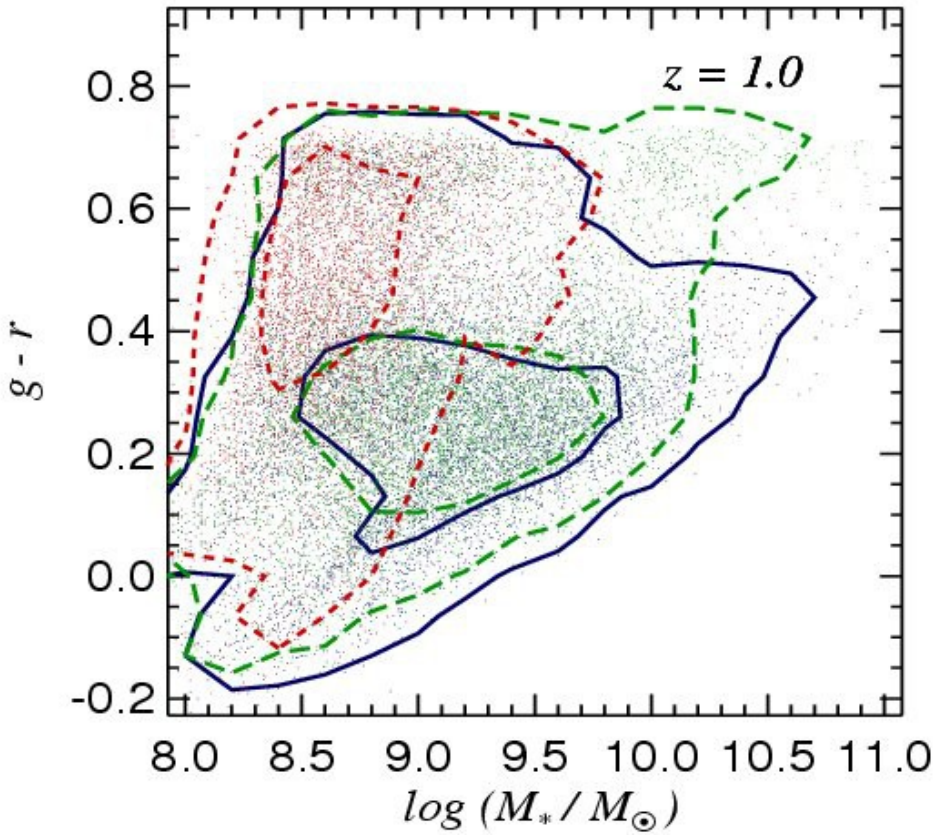
IN LOW MASS GALAXIES GALACTIC WINDS ARE MORE IMPORTANT THAN AGN FEEDBACK (modulo dependence on the seeding prescription)

Galaxy formation with AGN feedback:

host galaxy stellar properties

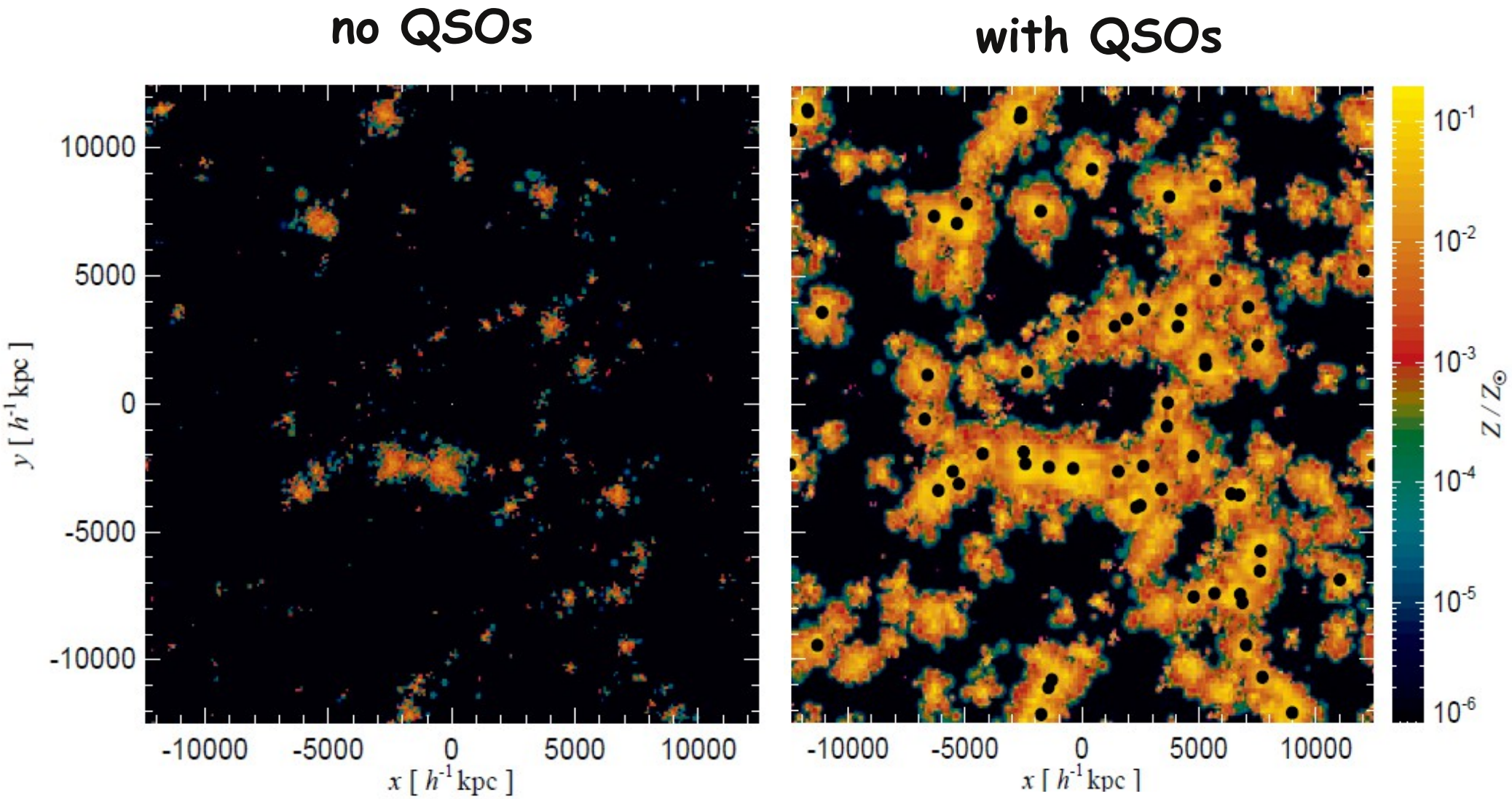
no AGN + no gal. winds
with AGN + no gal. winds
with AGN + gal. winds





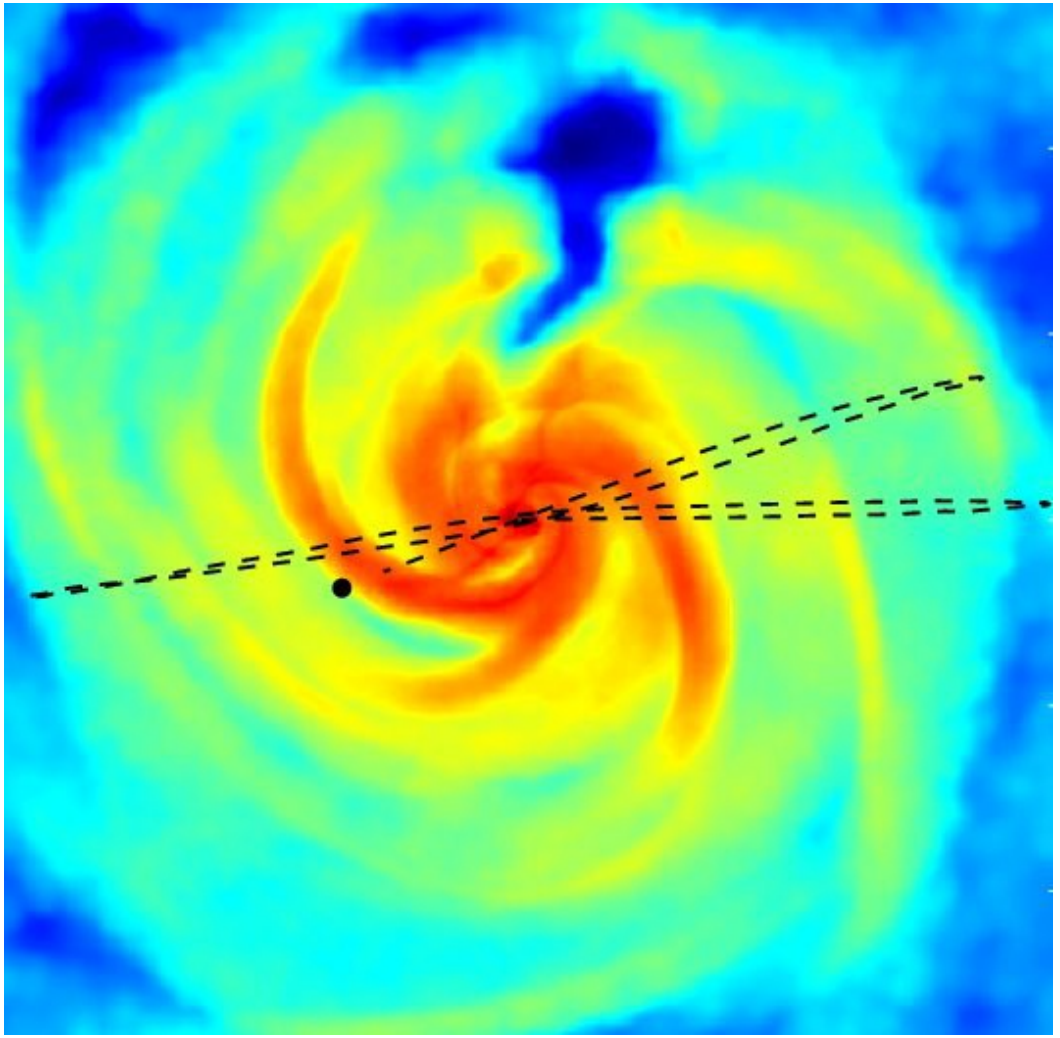
DUE TO THE AGN FEEDBACK SFR OF MOST MASSIVE GALAXIES IS REDUCED, AND COLOURS OF ARE MUCH REDDER

Galaxy formation with AGN feedback: metal rich outflows



III Recoiling BH

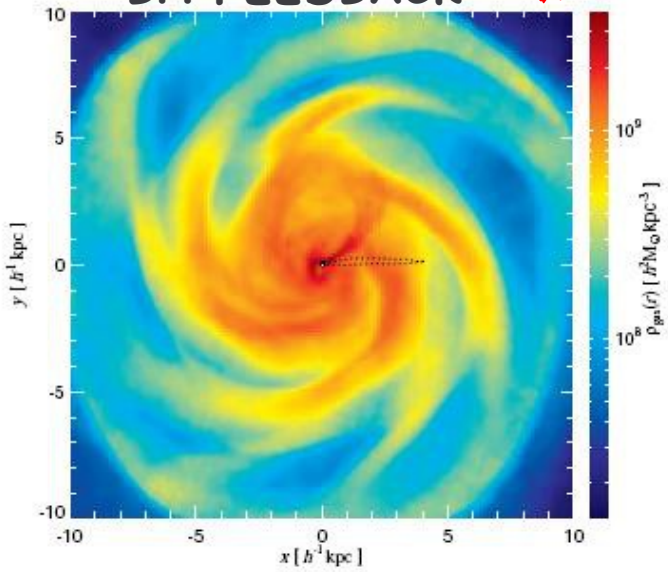
- what is the imprint of AGN feedback?
- can kicks introduce significant scatter in BH-galaxy scaling laws?

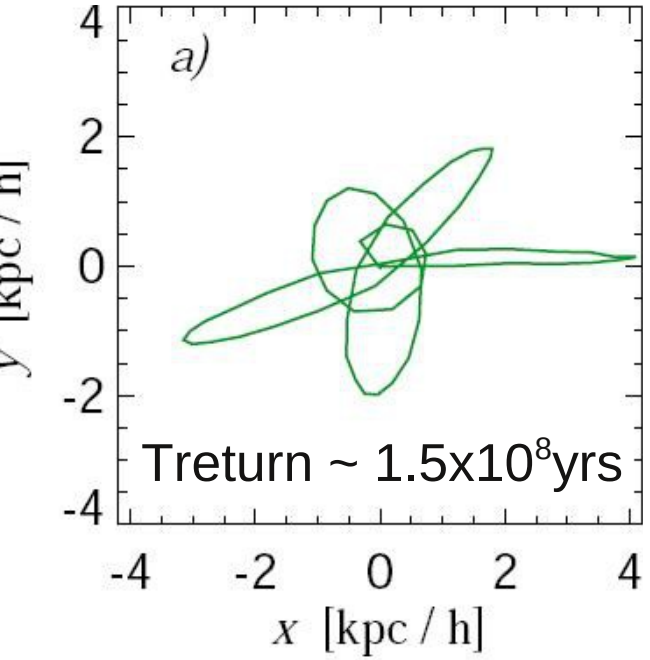


Sijacki et al, 2011
talk by Javiera Guedes

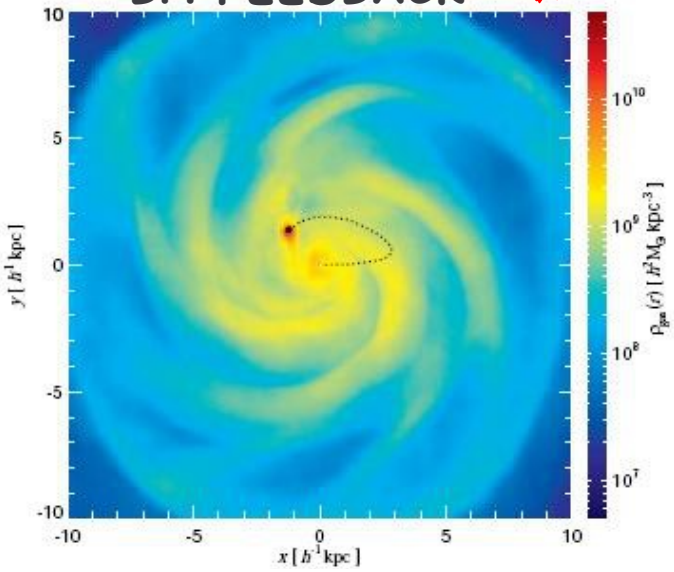
How recoiling BH trajectories depend on BH accretion and feedback?

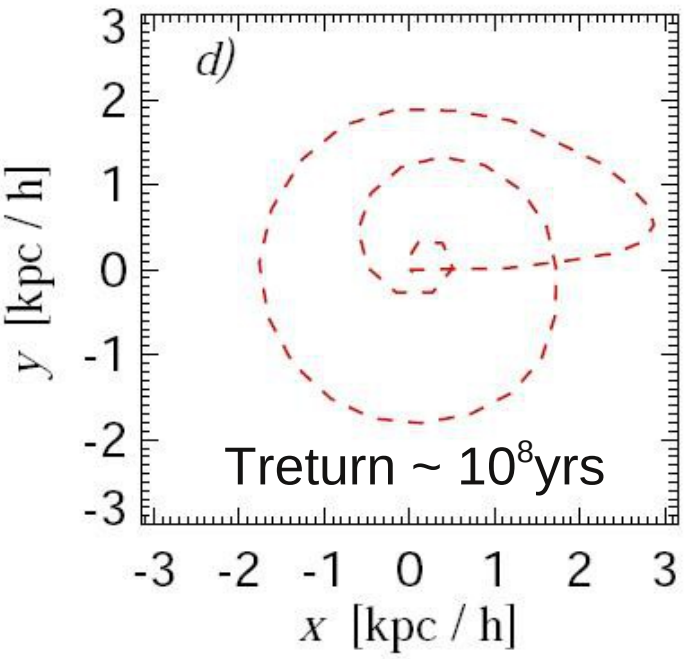
BH ACCRETION ✘
BH FEEDBACK ✘



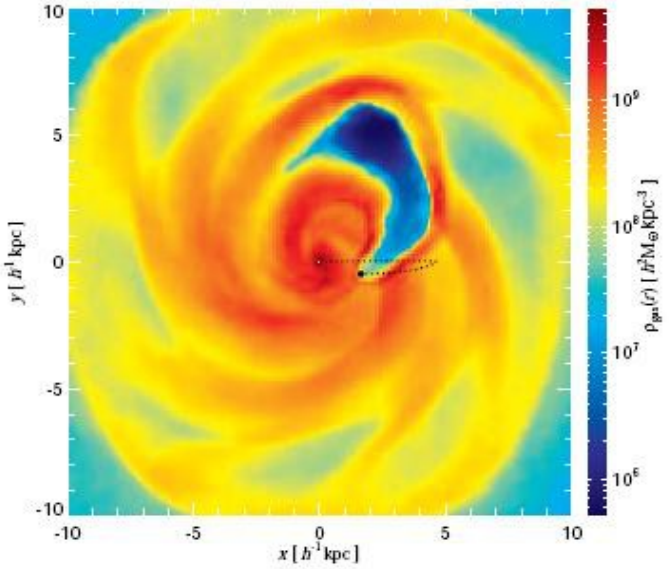


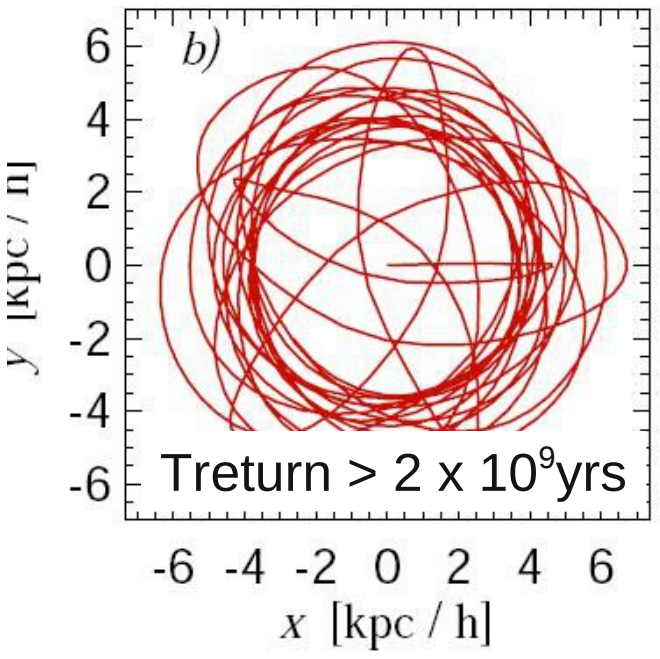
BH ACCRETION ✔
BH FEEDBACK ✘



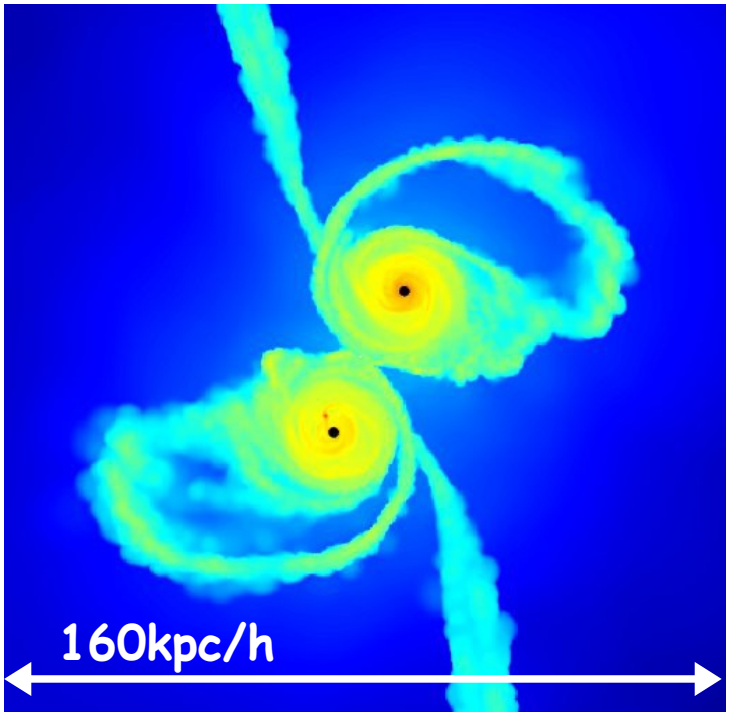


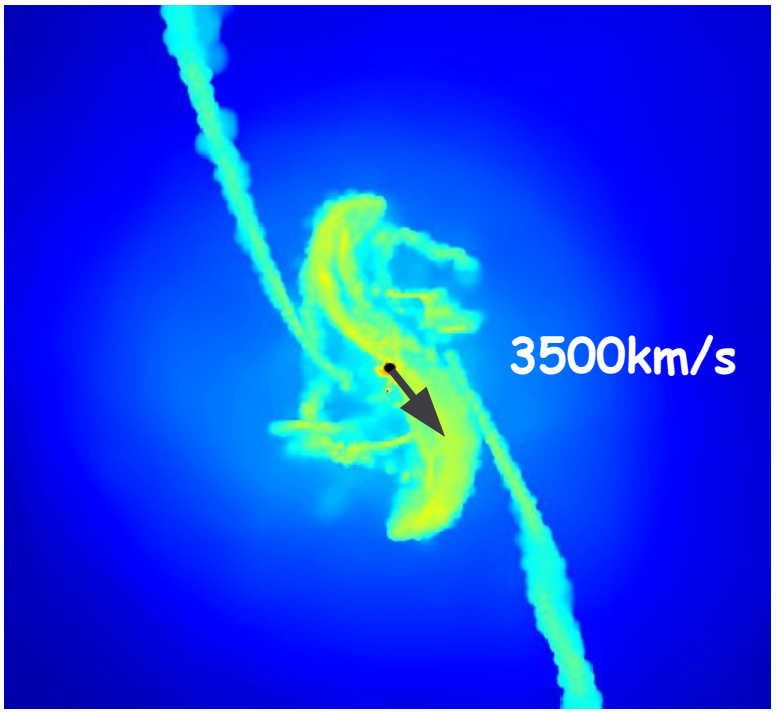
BH ACCRETION ✔
BH FEEDBACK ✔





Merging galaxies with SMBHs

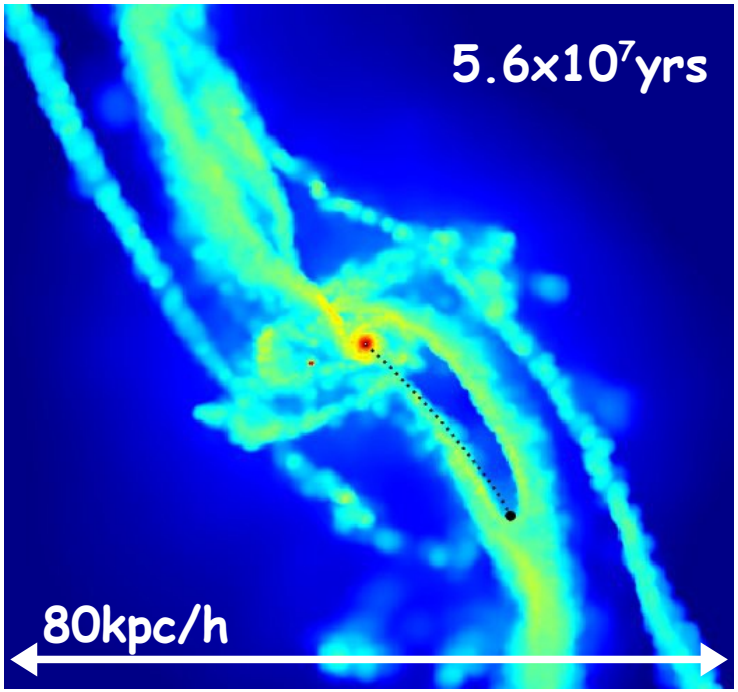


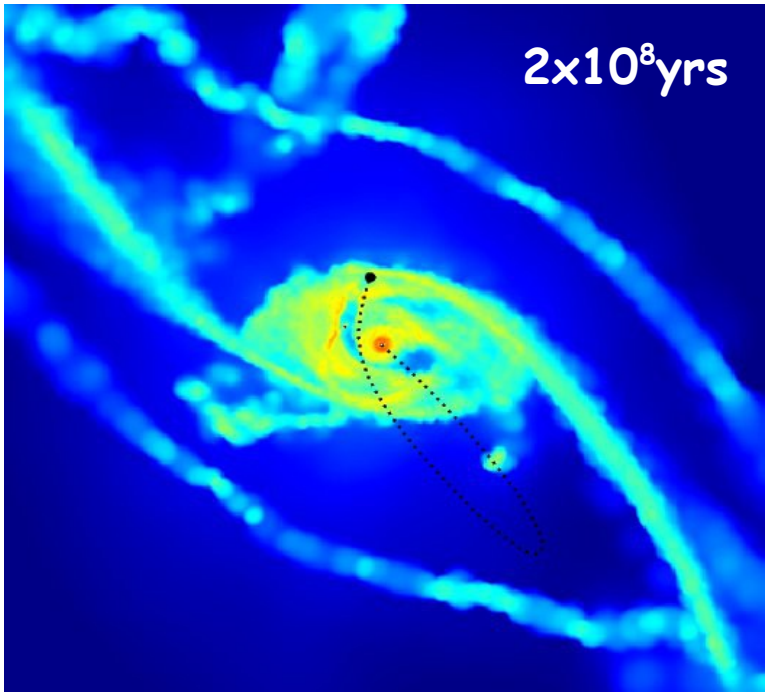


$M_{200}=6.3\times10^{12}M\odot$

$v_{200}=300km/s$

$M_{BH}=5\times10^{7}M\odot$





Merging galaxies with SMBHs

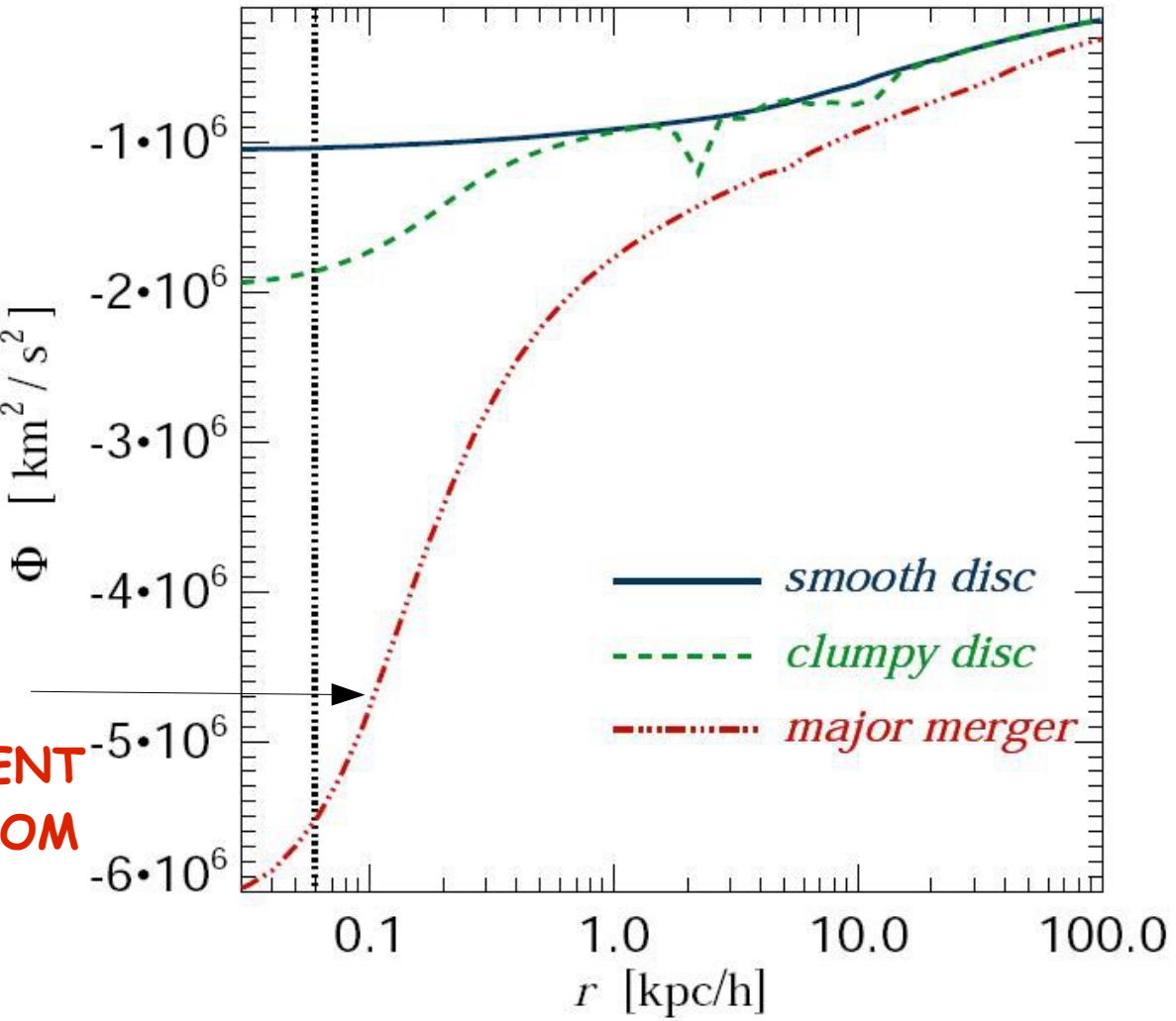
LEAVES THE CENTER:

$v_{esc}(0) = 1450 km/s \quad v_{kick} > 0.3\ v_{esc}(0)$

$v_{esc}(0) = 1980 km/s \quad v_{kick} > 0.5\ v_{esc}(0)$

$v_{esc}(0) = 3510 km/s \quad v_{kick} > 0.8\ v_{esc}(0)$

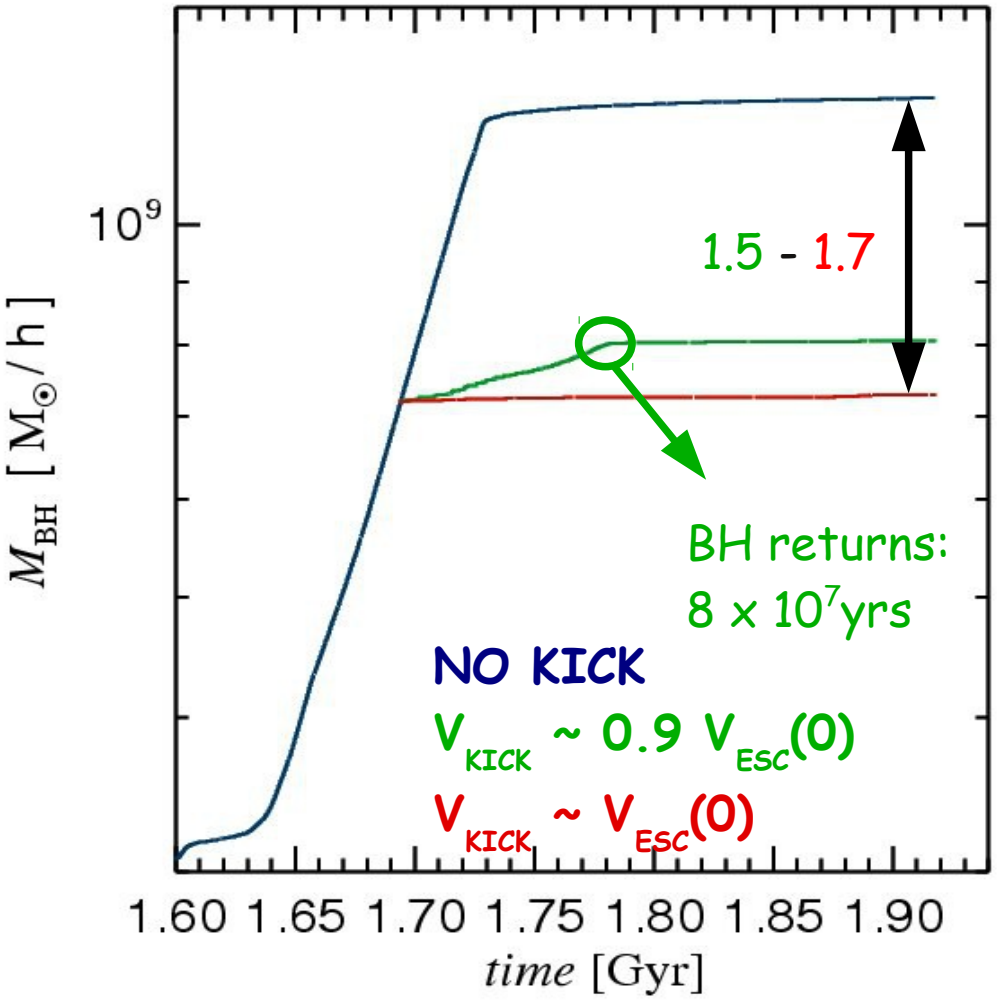
NOT EVEN MAXIMUM PREDICTED RECOIL VELOCITIES ARE SUFFICIENT TO COMPLETELY EJECT THE BH FROM THIS MERGING SYSTEM

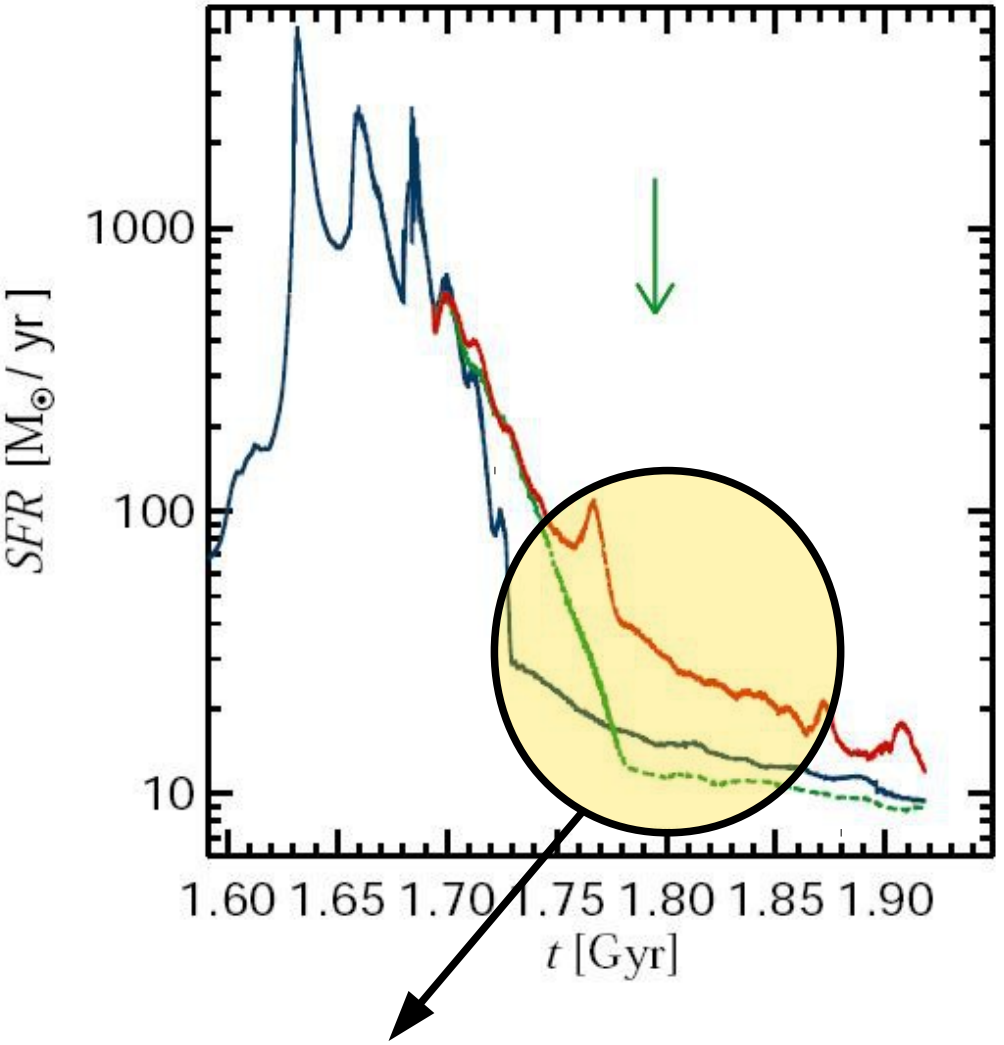


For centrally concentrated, clumpy galaxies or gas-rich merger remnants central potential might be deep enough to reduce substantially the fraction of ejected BHs

Merging galaxies with SMBHs

BH MASS REDUCED BY A FACTOR OF ~1.5-2:
IMPLICATIONS FOR BH - HOST GALAXY SCALING RELATIONS





PROLONGED STAR FORMATION RATE

Open questions

I Growth of the first bright QSOs

1. Are host halo properties even more hostile to the initial BH growth?
2. Does one need to invoke super-Eddington accretion after all?
3. What about smaller mass BH seeds? (hard problem for cosmo sims)
4. How to constrain spin histories of BHs? How BH spins change due to gas accretion (spin-ups, spin-downs)? (talk by M. Dotti)

II Co-evolution of galaxies and QSOs

1. What is the role of secular processes vs. mergers? (as a function of time, as a function of host halo mass,...)
2. Cosmological simulations of BHs in morphologically different galaxies?

III Recoiling BHs

1. Are kicks suppressed in majority of massive gas-rich galaxies?
2. How does the scatter in BH-galaxy scaling laws depend on:
   - the BH binary hardening time-scale? (talks by M. Preto & J. Cuadra)
   - on the efficiency of central star formation?