SMBH in Large Scale Structure

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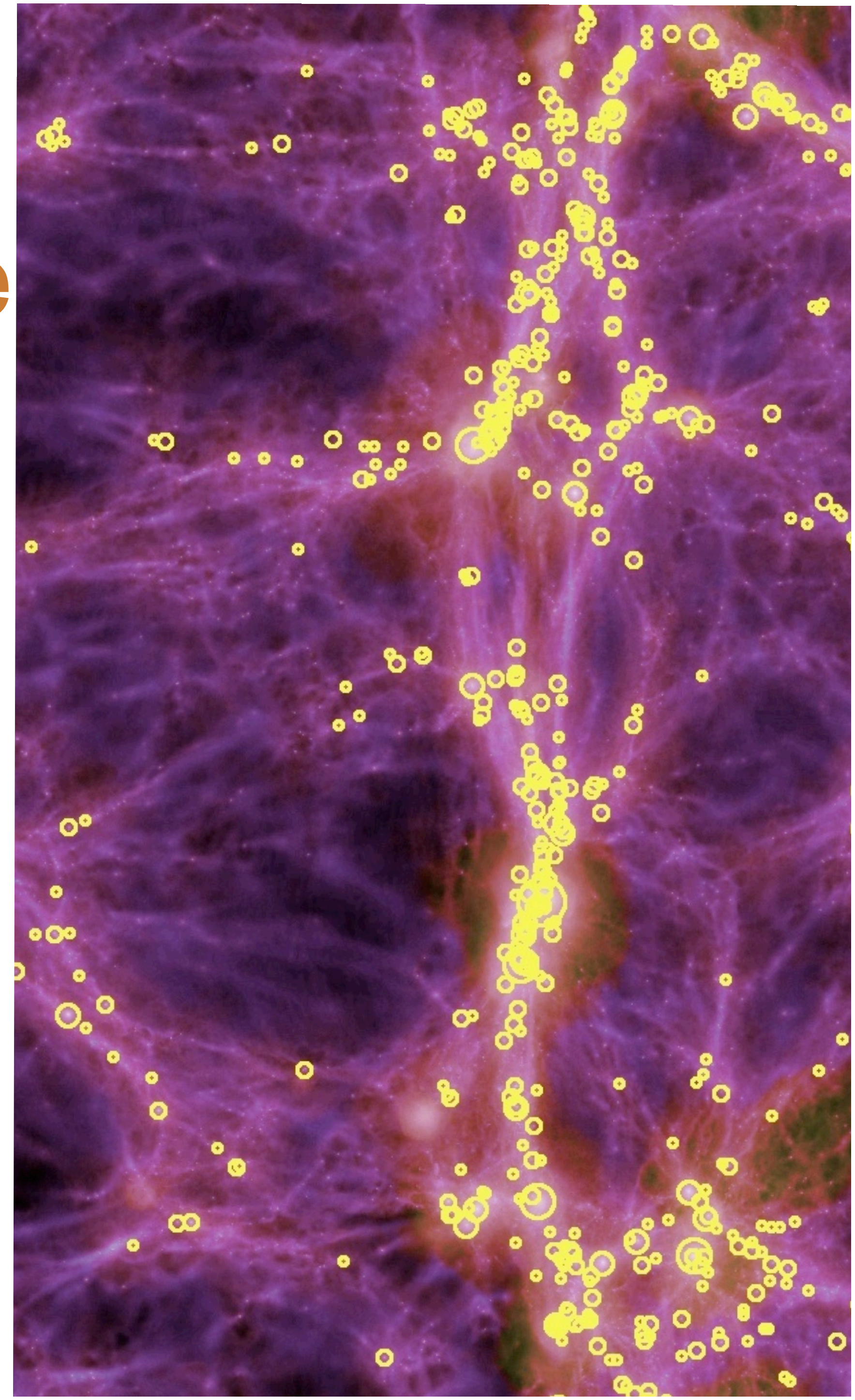


OUTLINE:

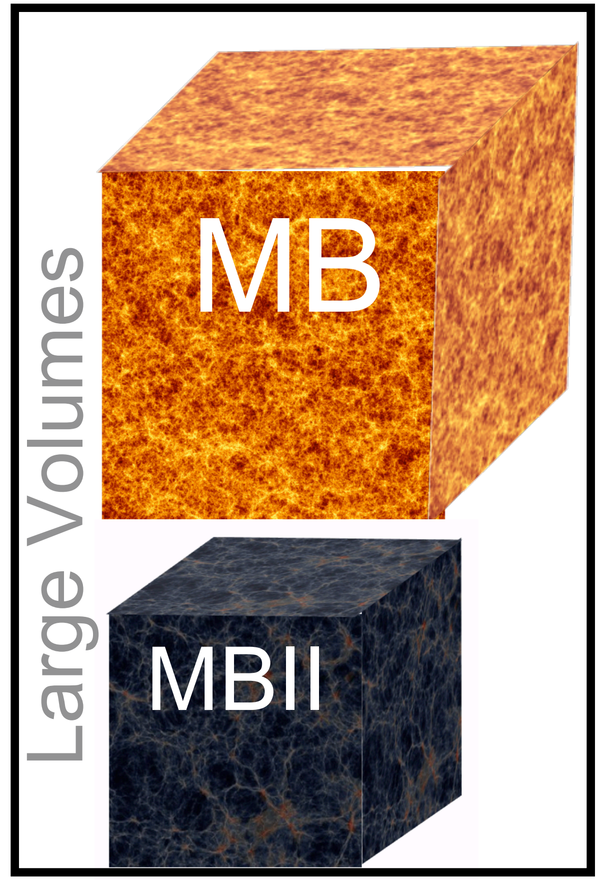
Black holes in cosmological simulations of structure formation

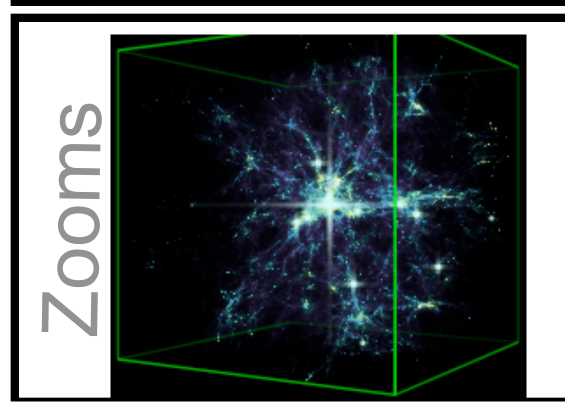
•Why?

•How?

•What can we learn?

first quasars
QLF, clustering, galaxies





BLACK HOLES and COSMOLGY

The formation, assembly history and impact of MBH - ubiquitous in the nuclei of galaxies - remain some of the main unsolved problems in cosmic structure formation studies

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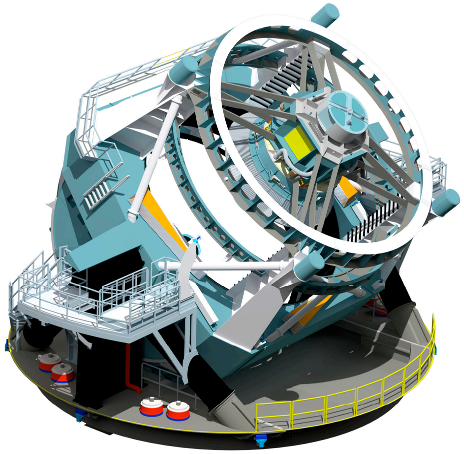
Key Questions in Galaxy evolution studies:

- When and how did the universe emerge from the dark ages
- How often galaxies merge and how do mergers shape the Hubble sequence /colors?
- How do “feedback” mechanisms influence galaxy formation ‘ (and cosmological parameters inferred from observations)?
- How do galaxy get their gas?

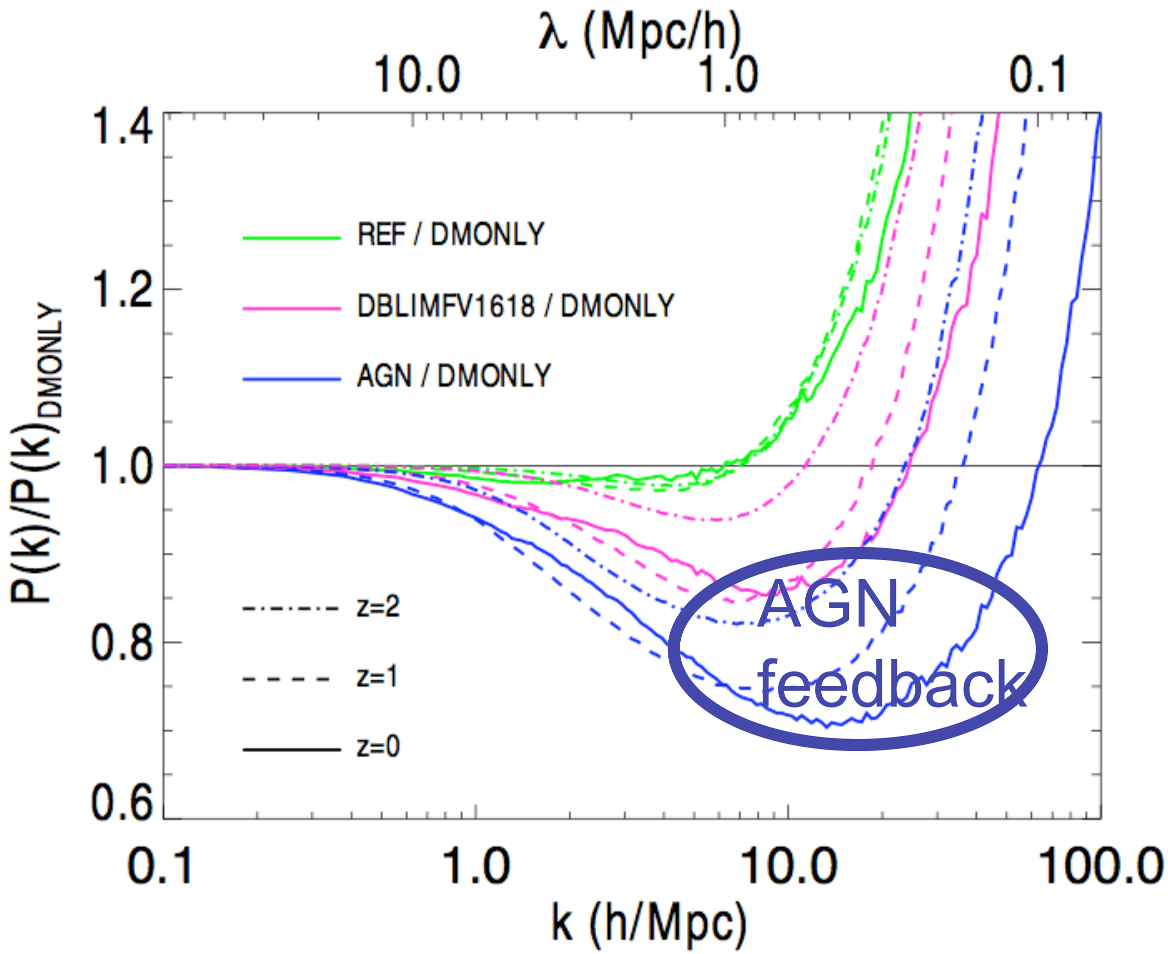
BHs enter into ‘real’ COSMOLOGY



- LSST and EUCLID aim to constrain DARK ENERGY by matter power spectrum with 1% accuracy.

- AGN feedback may bias results by up to 40%

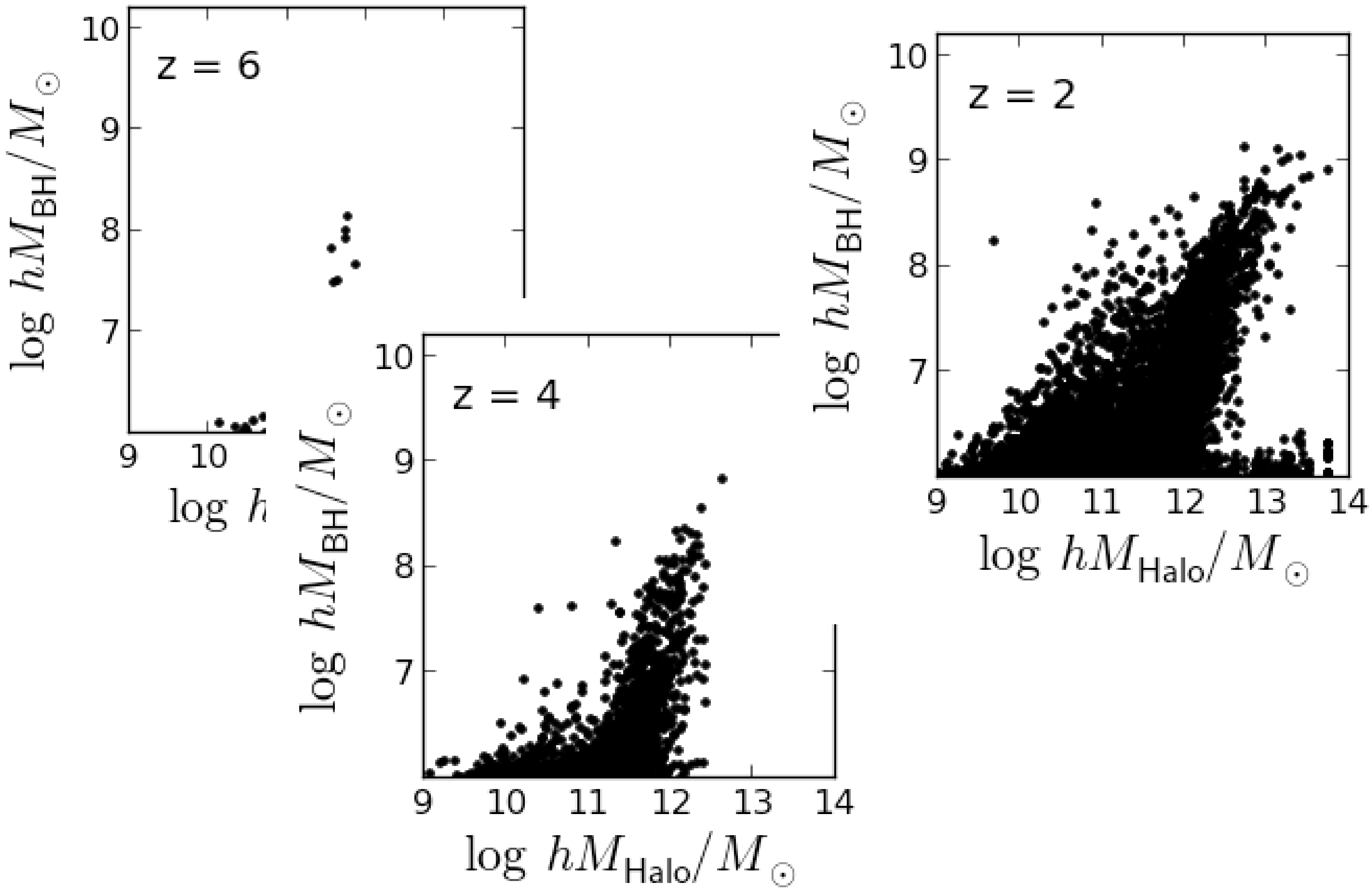
Matter power spectrum / DM only



Semboloni et al. 2011

Large Scale Structure influences BH properties

•variety of M_{BH} and L_{AGN} for a fixed DM halo



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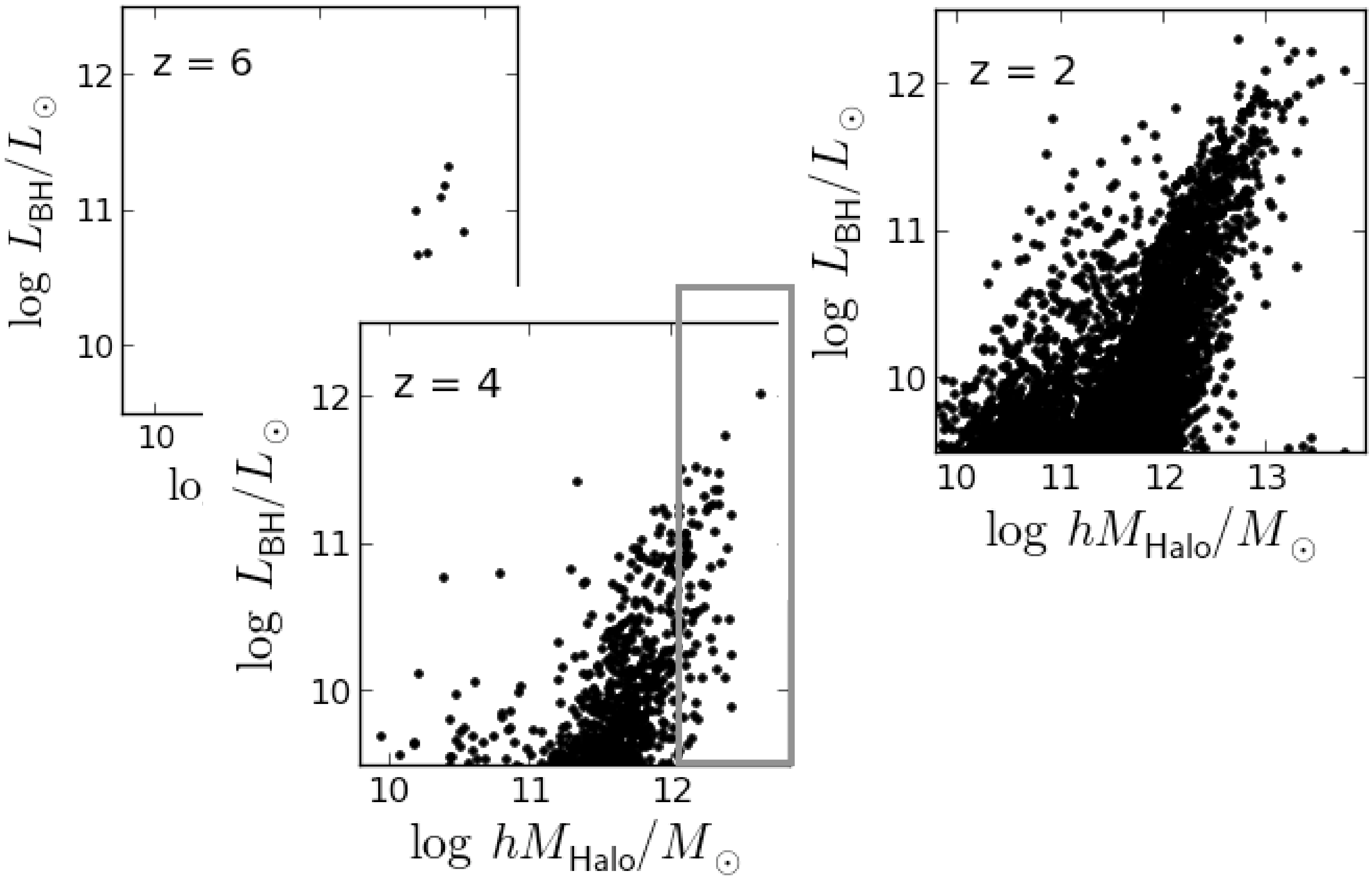
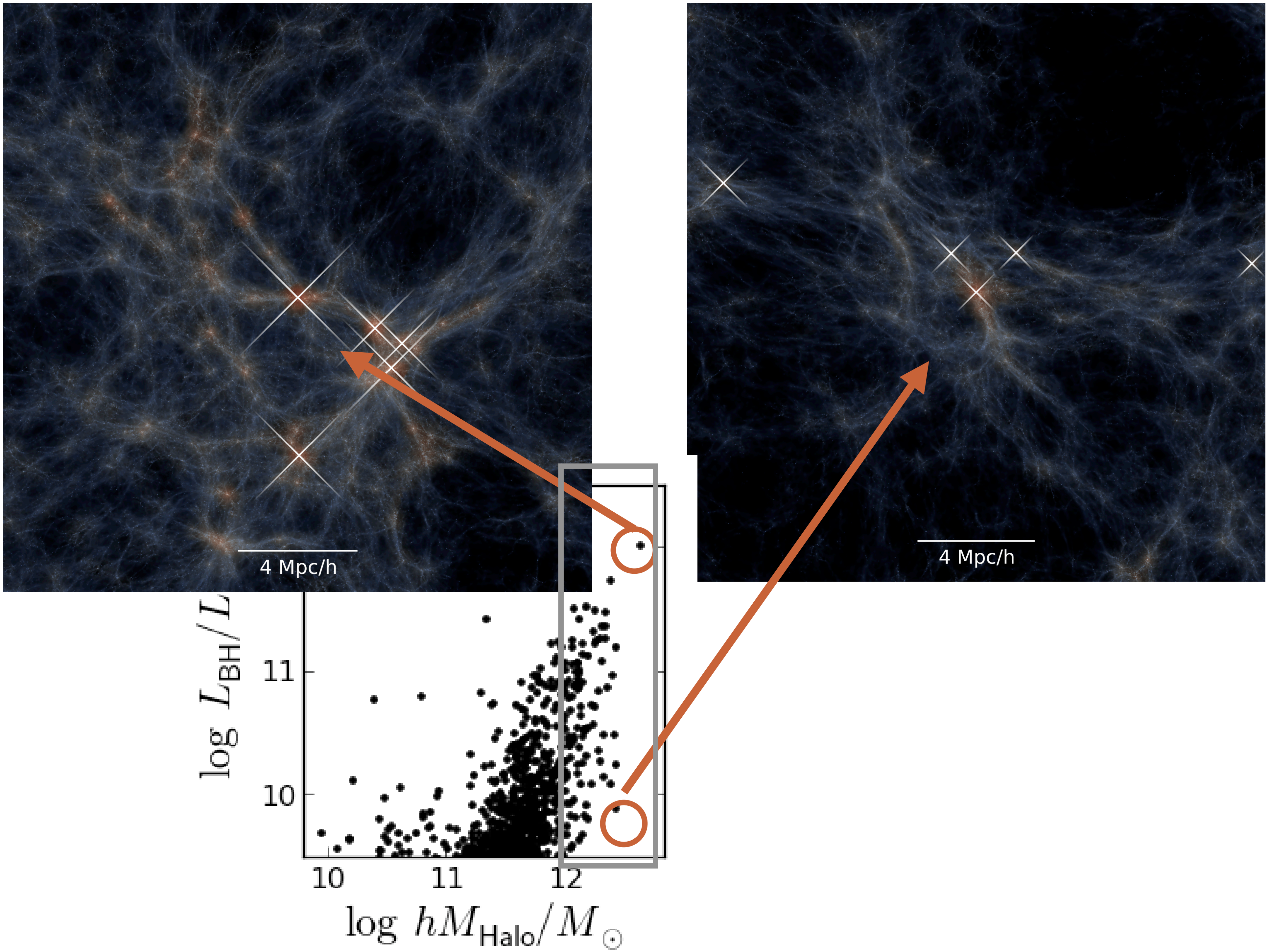
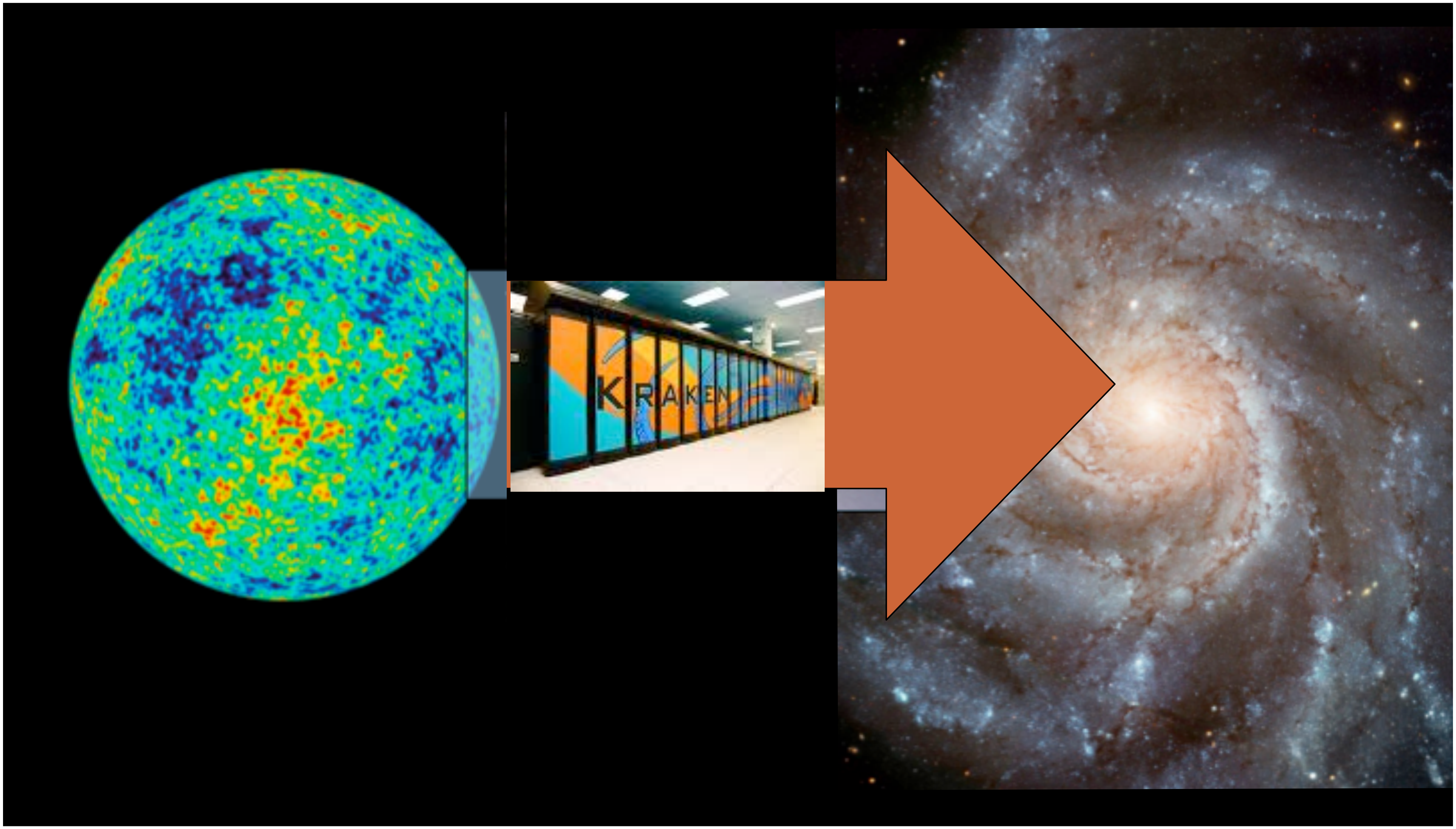




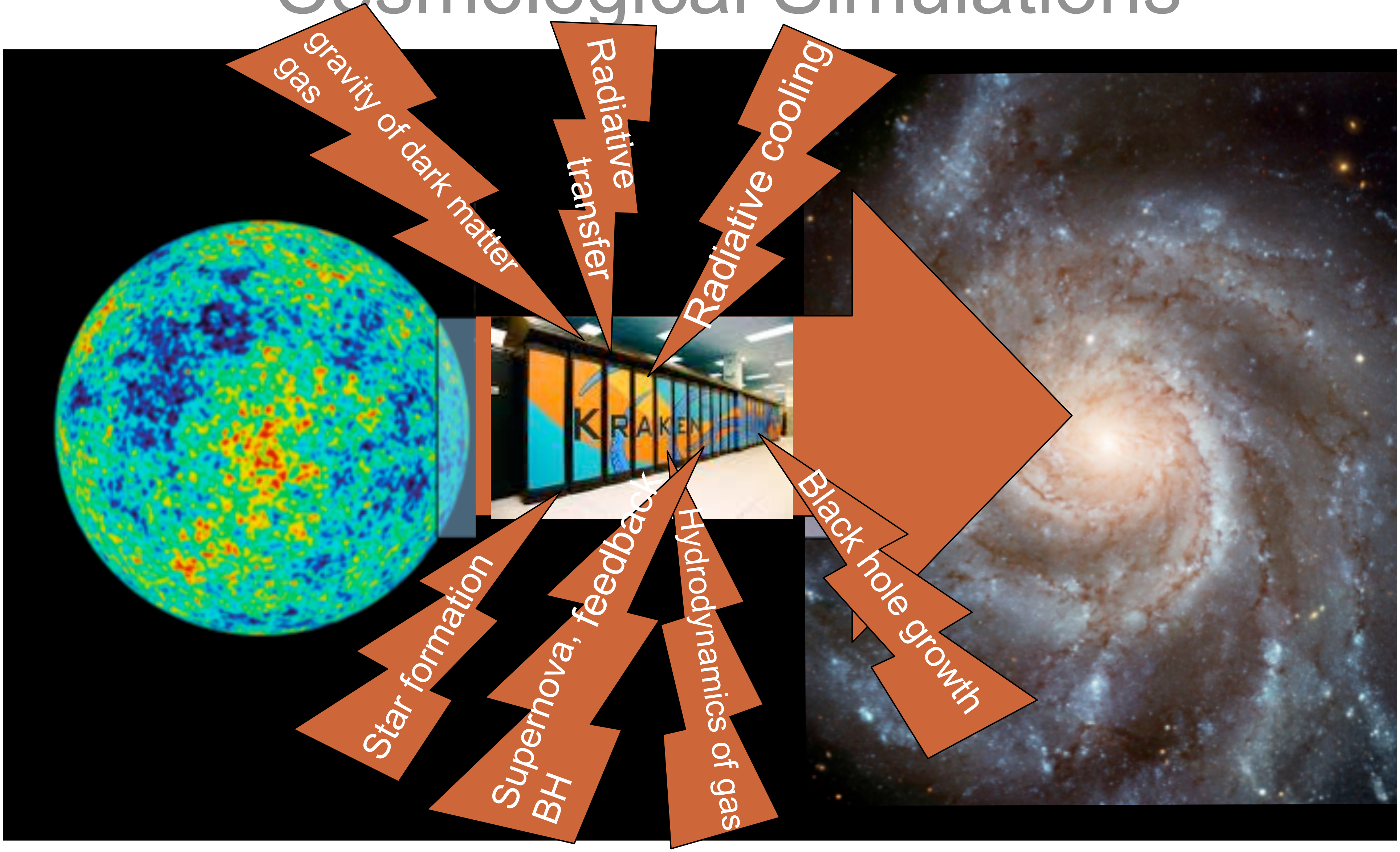
4 Mpc/h
4 Mpc/h
log L_{BH}/L
11
10
10
11
12
log $hM_{Halo}/M_\odot$

Cosmological Simulations



13.6 billion years of evolution

Cosmological Simulations

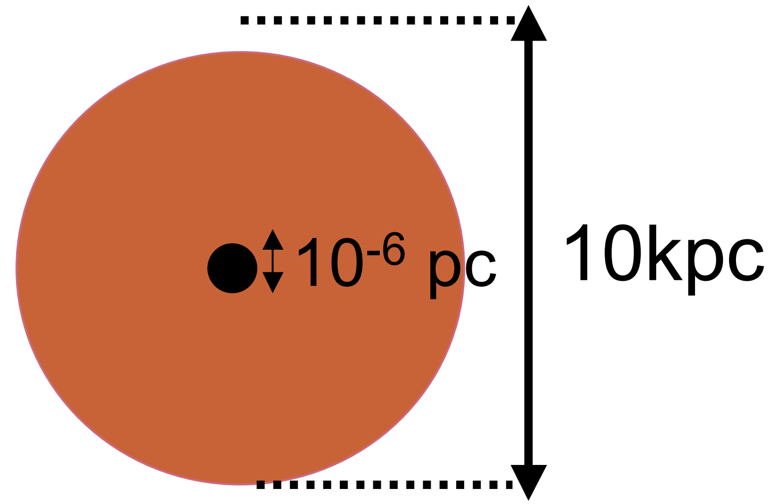


13.6 billion years of evolution

Galaxy formation - The dynamic range challenge

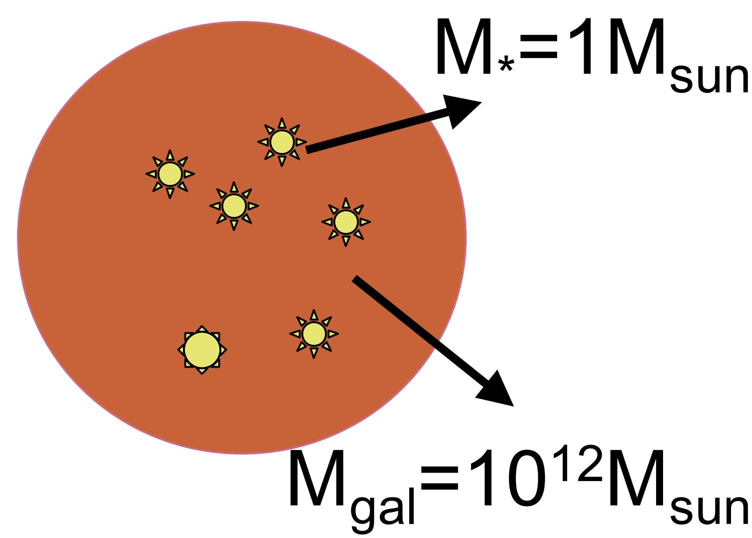
Supermassive BH
in a galaxy

- Dynamic range of 10^{10}



Stars in a normal galaxy

- Mass dynamic range of 10^{12}



Cosmological Simulations

What is the history of black hole formation and evolution?

What is the formation path of MBH seeds? When/where did they form?

How MBH seeds grow? How do they impact their environments?

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Journey into the growth of the first supermassive BHs

Checklist for Cosmological Simulations with BH

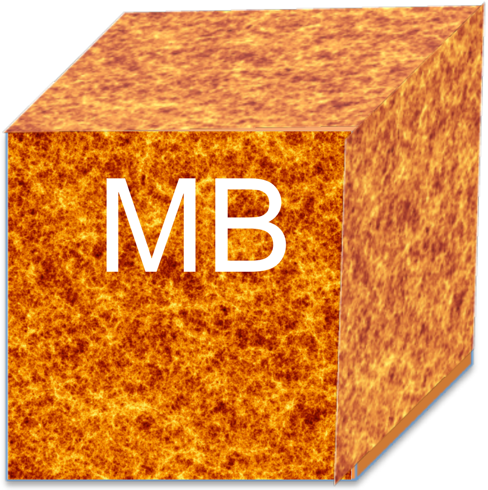
- ✓ biased regions → Large Volumes
- ✓ Galaxy scales → High Resolution
- ✓ Gas accretion → Hydrodynamics

…

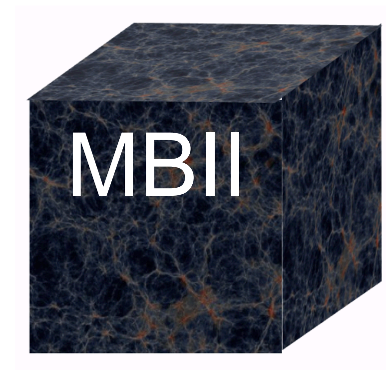
Cosmological Simulations with BH

	Zoomed halos	Uniform volumes
	Select rare peaks and re-simulate Li et al., Sijacki et al., Alvarez et al., Cattaneo et al., Bellovary et al. Teyssier et al,. Dubois et al., Devriendt , Slyz.	whole mass function Di Matteo et al, Booth & Shaye 09, Sijacki et al.,.
CONS:	Small vol.: 1 or small samples Hand 'picked' Quasar hosts based on DM mass	Never big enough vol.! Lower res.
PROs:	highest resolution: detailed studies of host and quasar more detailed modeling	direct investigation of quasars growth as a function of environment Direct statistics: M-sigma, BH mass functions, LFs, Correlation Functions etc..

Cosmological Simulations:



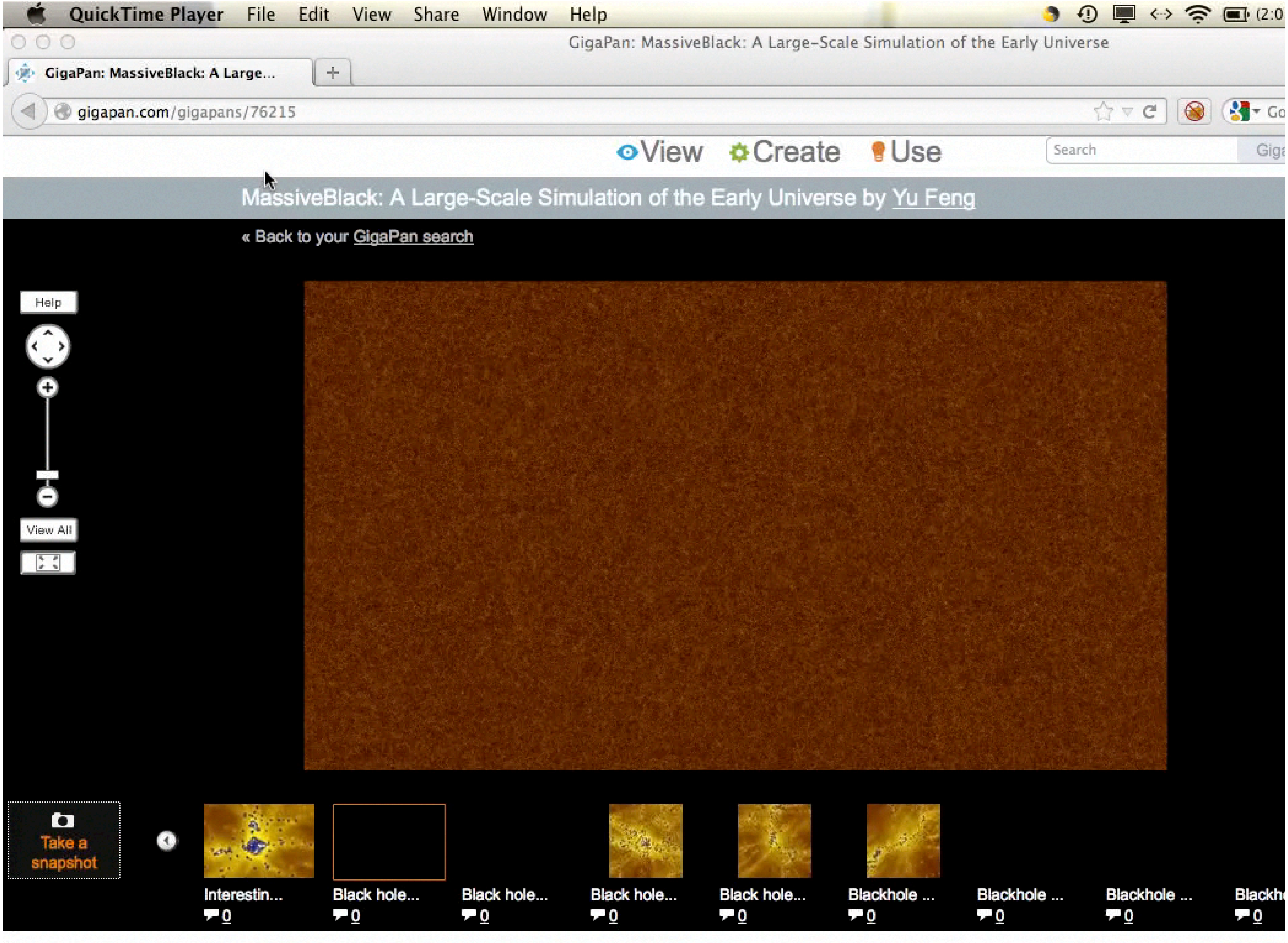
-Code used: PetaGadget (Petapps Cosmology)
-Physics: SPH,cooling, star formation, feedback, black holes.

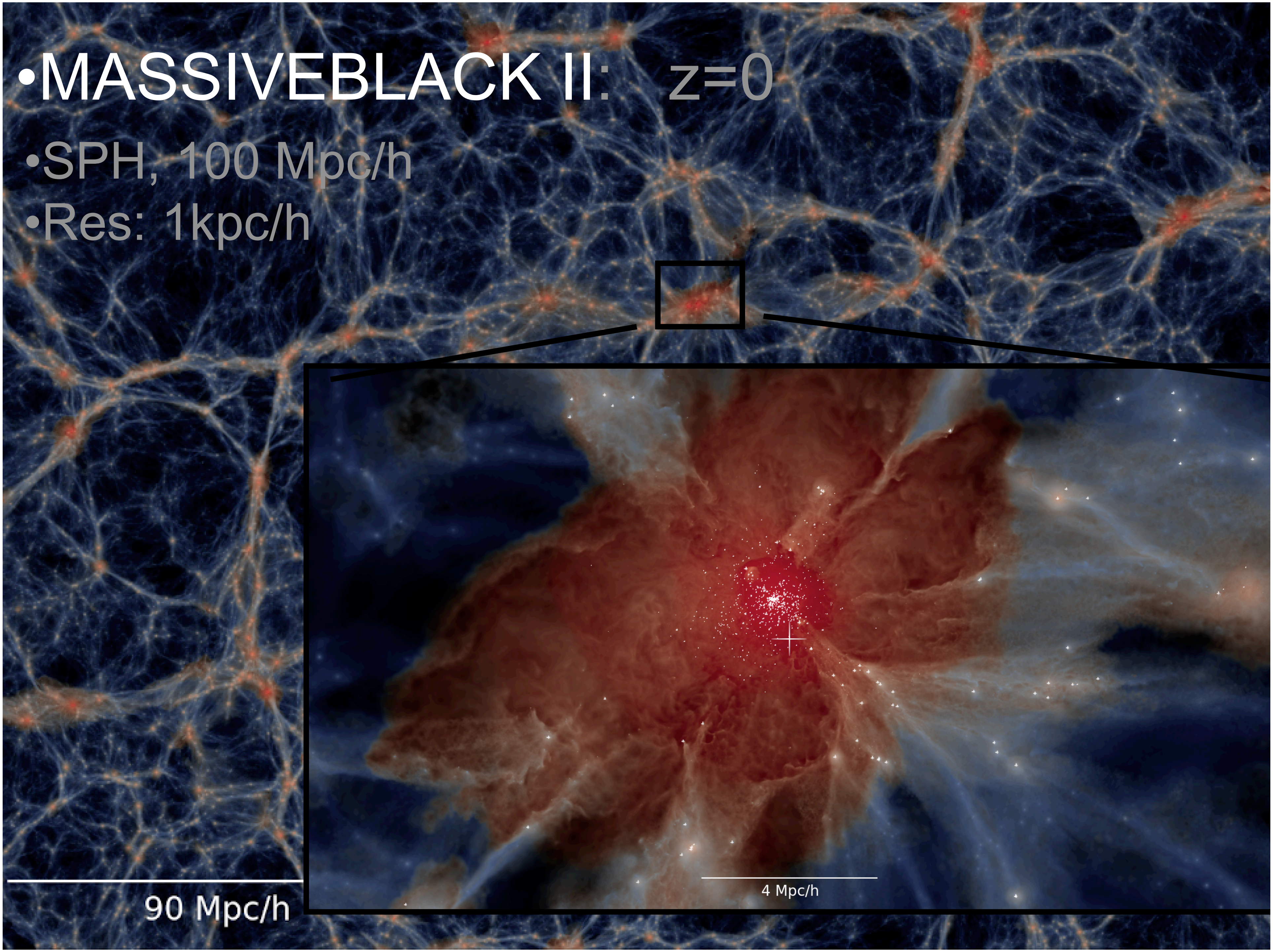


	MB	MBII
-Particle number:	$2\text{x}3200^3$ =64 billion	$2\text{x}1800^3$ =11.5 billion
-Box size:	533 h^{-1} Mpc	100 h^{-1} Mpc
- z_{final} =	4.75	- z_{final} = 0 (biggest SPH vol)

- Runs using Kraken at NICS (>100k compute cores).

Team: N. Khandai, C.DeGraf,Y. Feng, R. Croft, V. Springel, TDM

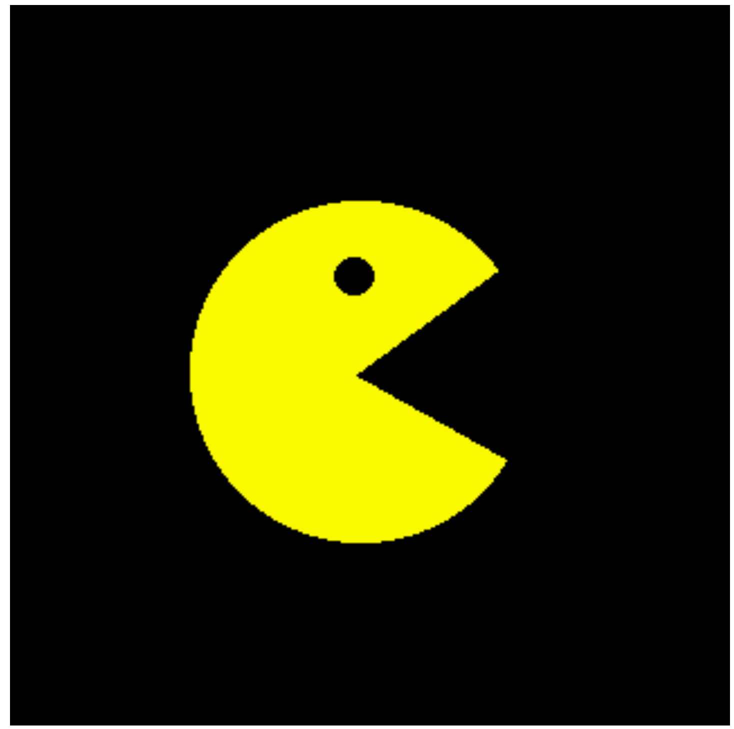

QuickTime Player File Edit View Share Window Help
GigaPan: MassiveBlack: A Large-Scale Simulation of the Early Universe
GigaPan: MassiveBlack: A Large...
gigapan.com/gigapans/76215
View Create Use
Search
MassiveBlack: A Large-Scale Simulation of the Early Universe by Yu Feng
« Back to your GigaPan search
Help
View All
Take a snapshot
Interestin...
Black hole...
Black hole...
Black hole...
Black hole...
Blackhole ...
Blackhole ...
Blackhole ...


•MASSIVEBLACK II: z=0
•SPH, 100 Mpc/h
•Res: 1kpc/h
90 Mpc/h
4 Mpc/h

BHs in Simulations of Galaxy formation
(subgrid)

BH Seed

BH accretion



BH feedback

BH mergers

BHs in Simulations of Galaxy formation
(subgrid)

Springel, DM, Hernquist 05

BH Seed

•IC collisionless “sink” particle in galaxies

$M_{BH(seed)} = 10^5 M_\odot$

Fixed

BH accretion

•Relate (unresolved) accretion to large scale (resolved) gas distribution

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

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

BH feedback

•Energy /momentum extracted from BH accretion injected in the surrounding gas

$$\dot{E}_{feed} = f(\varepsilon_r \dot{M} c^2)$$

$$f \approx 5\%, \varepsilon_r = 10\%$$

BH mergers

•When close and Low rel. vel.

BHs in Simulations of Galaxy formation
(subgrid)

Springel, DM, Hernquist 05

DeBuhr, Hopkins, Ma 11

BH Seed

•IC collisionless "sink" particle in galaxies

$M_{BH(seed)} = 10^5\ M_\odot$ Fixed

BH accretion

•Relate (unresolved) accretion to large scale (resolved) gas distribution

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

$$\dot{M}_{BH} = 3\pi\alpha\Sigma \frac{c_s^2}{\Omega}$$

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

BH feedback

•Energy /momentum extracted from BH accretion injected in the surrounding gas

$$\dot{E}_{feed} = f(\varepsilon_r \dot{M} c^2)$$

$$f \approx 5\%, \varepsilon_r = 10\%$$

$$\dot{p} = \frac{\tau}{c} \min(\varepsilon_r \dot{M}_{BH} c^2, L_{Edd})$$

$\tau = 30$

How/ where do MBH seeds grow at early time?

z=6 quasars imply
$M_{BH}=10^9\ M_{sun}$

First billion years
requires extremely
large accretion rates

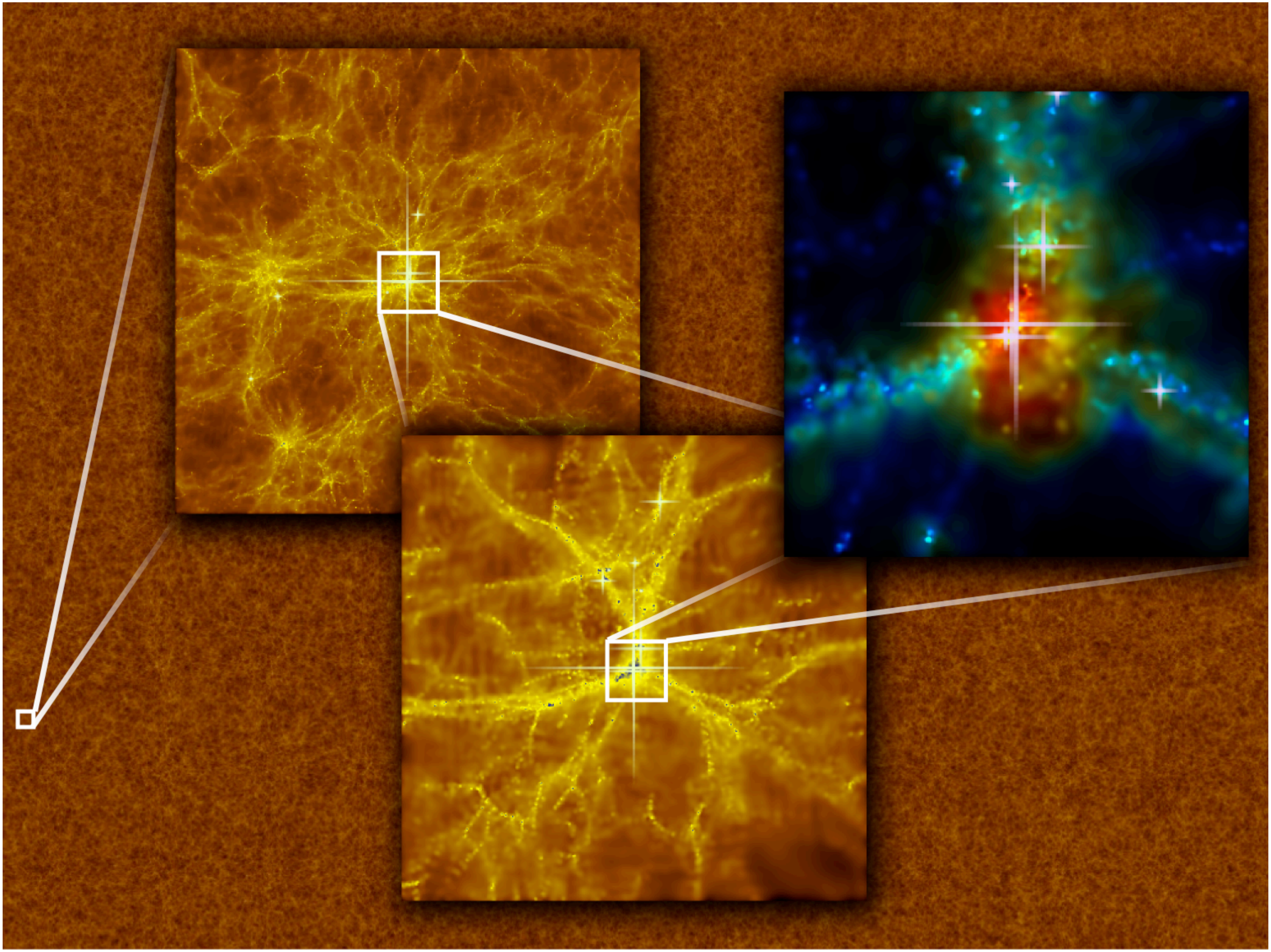
$$L_{Edd} = \frac{4\pi G c m_p}{\sigma_T} M_{BH} = \varepsilon\, \dot{M}\, c^2$$

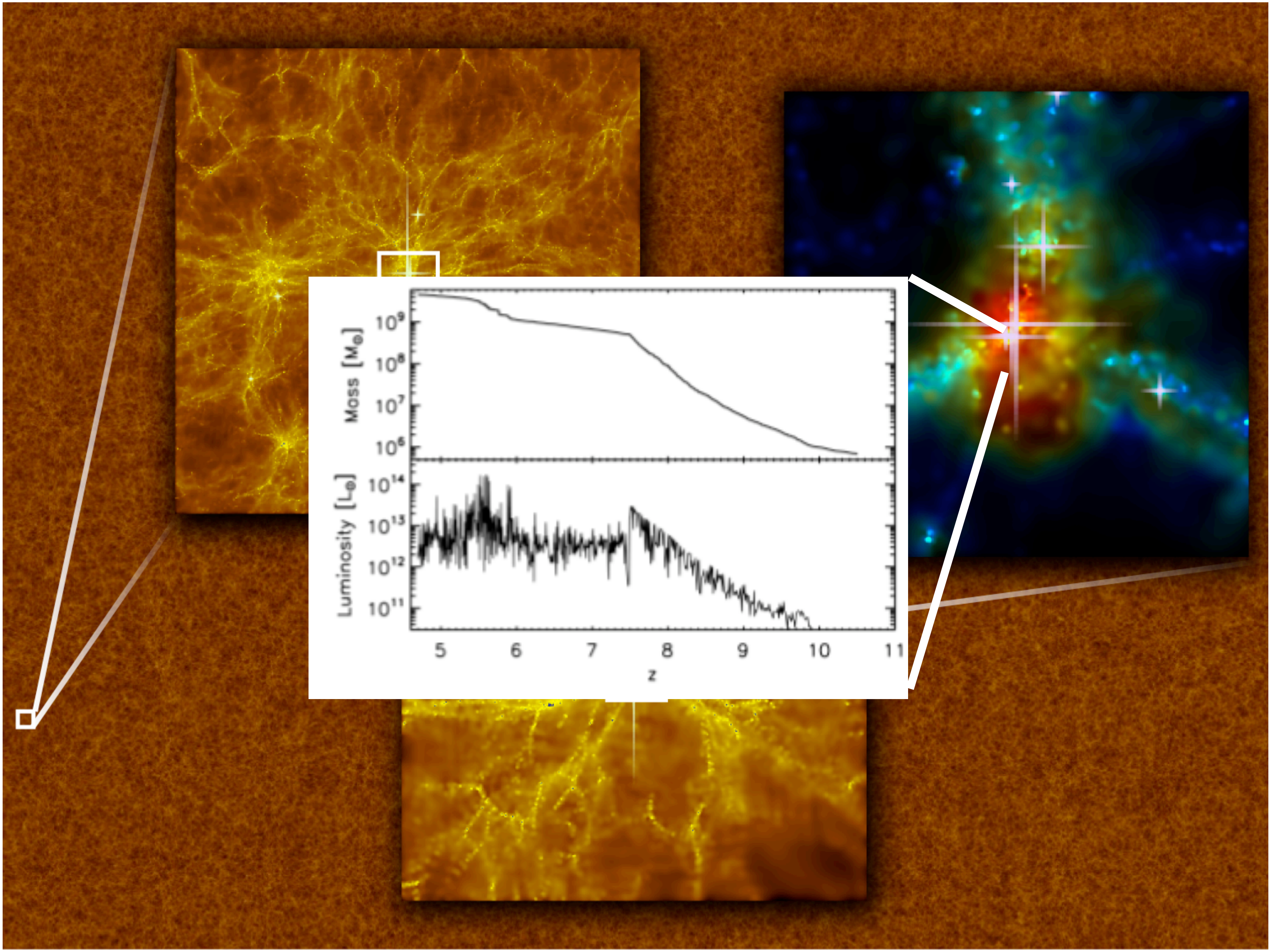
$$M_{BH} = M_{seed}\ e^{\frac{t}{t_{Edd}}}$$

$$t_{Edd} = 450\ Myr \frac{\varepsilon}{1-\varepsilon}$$

$$\ln(M_{BH}/M_{seed}) = \ln[10^9/(100 - 1e5)]$$
$$= 10 - 17\ \mathrm{e-foldings}$$

sustained accretion at Eddington rates in early growth

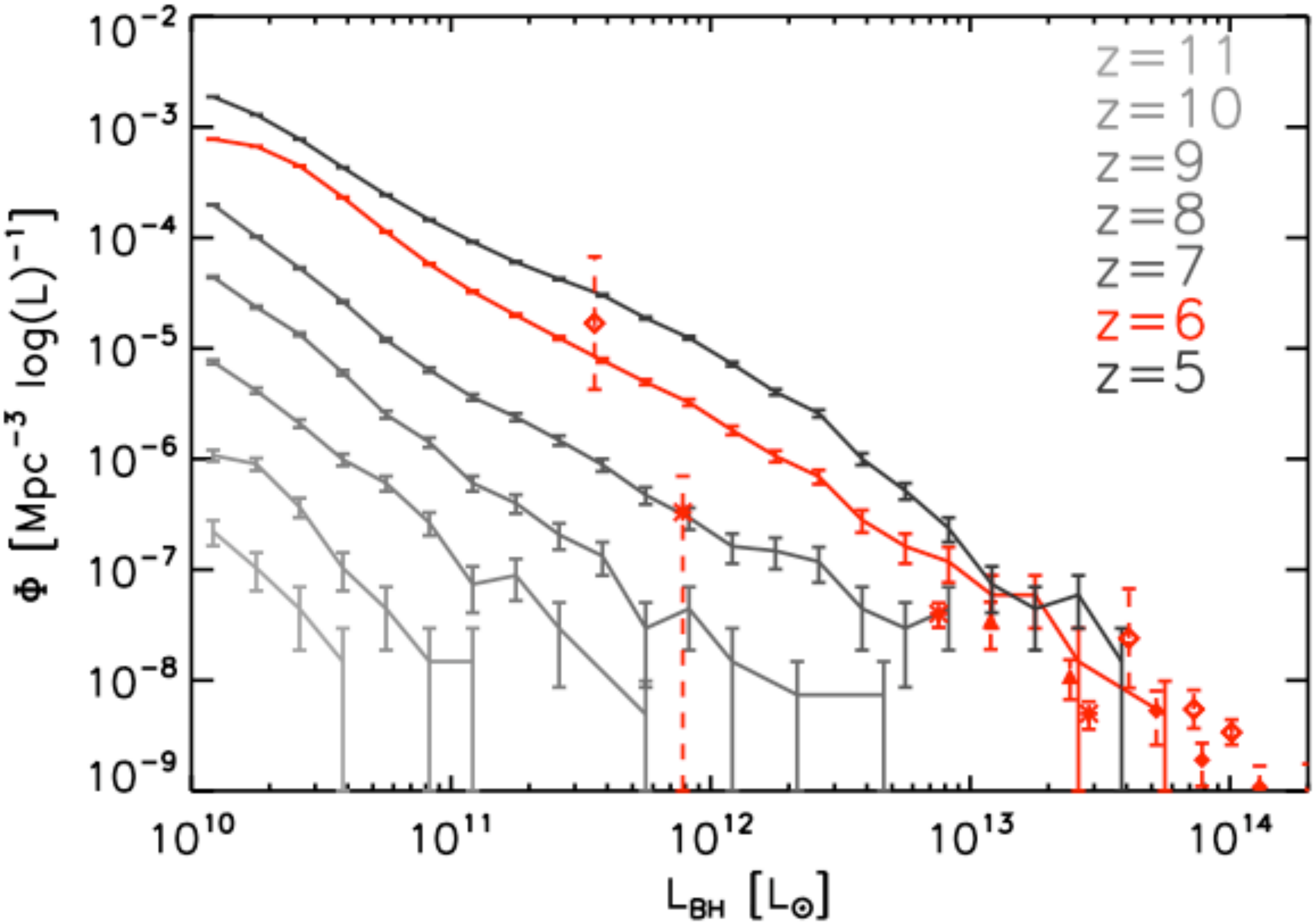




Mass [M⊙]
10^9
10^8
10^7
10^6
Luminosity [L⊙]
10^{14}
10^{13}
10^{12}
10^{11}
5
6
7
8
9
10
11
z

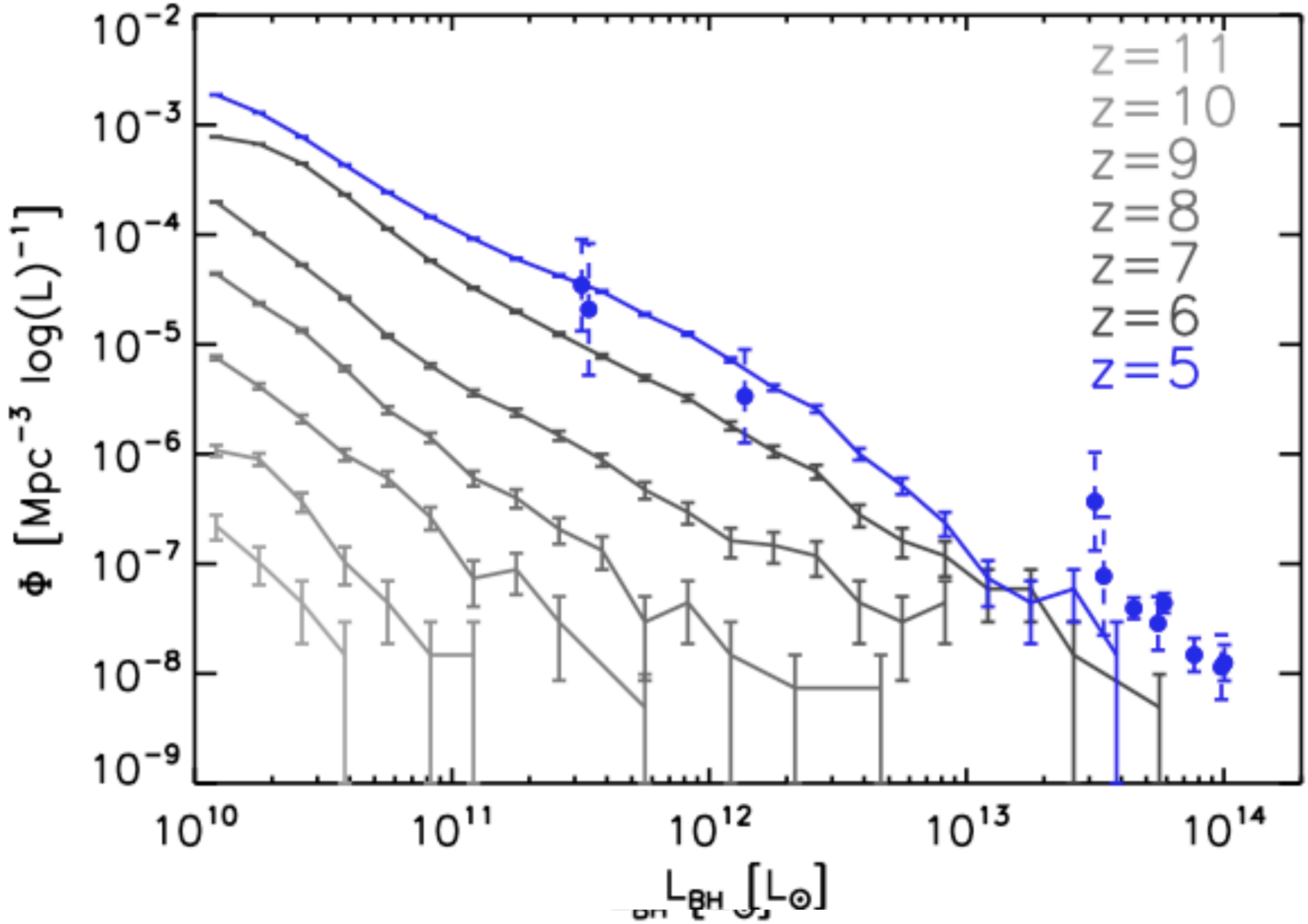
Quasar Luminosity Function

Degraf+12

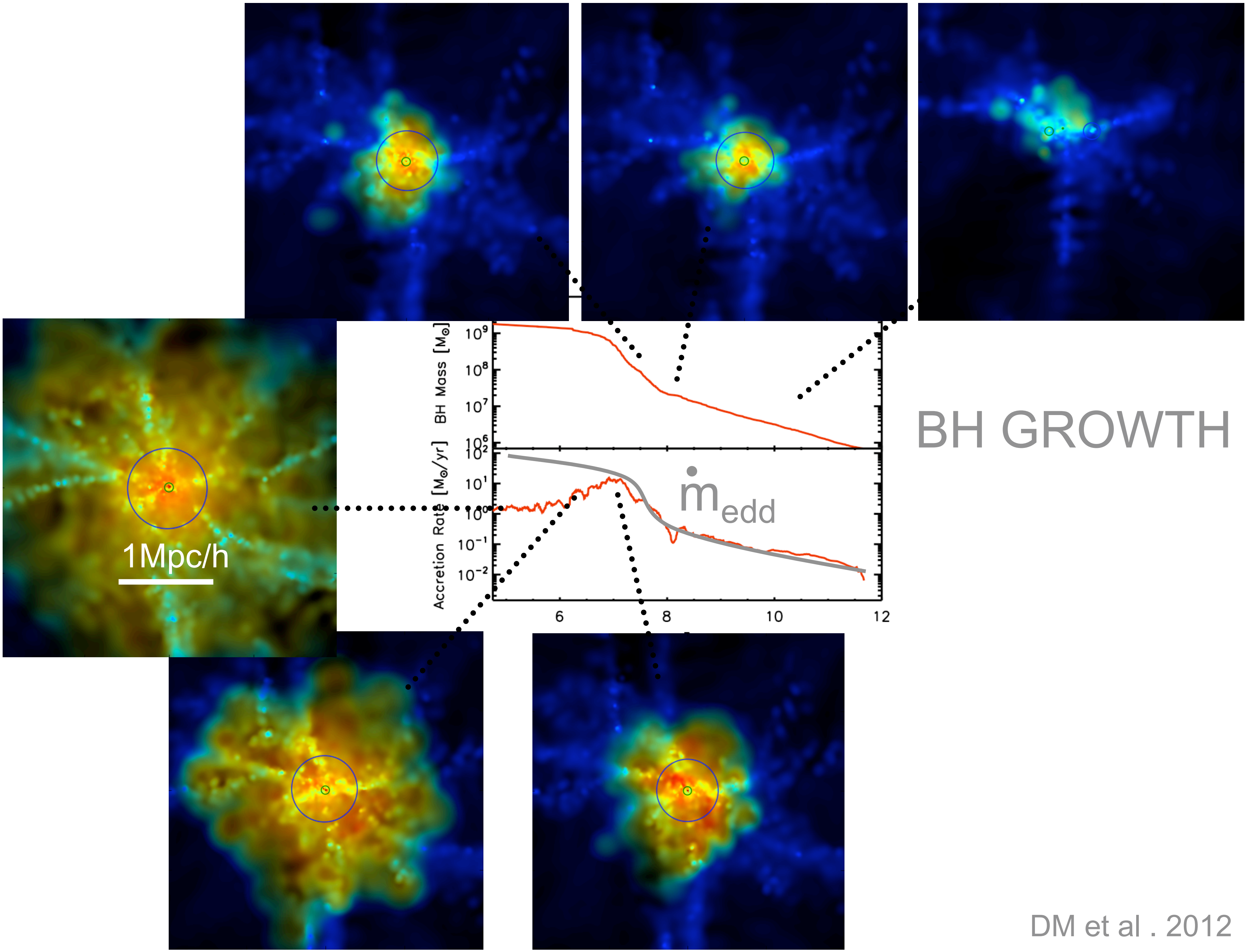


Quasar Luminosity Function

Degraf+12

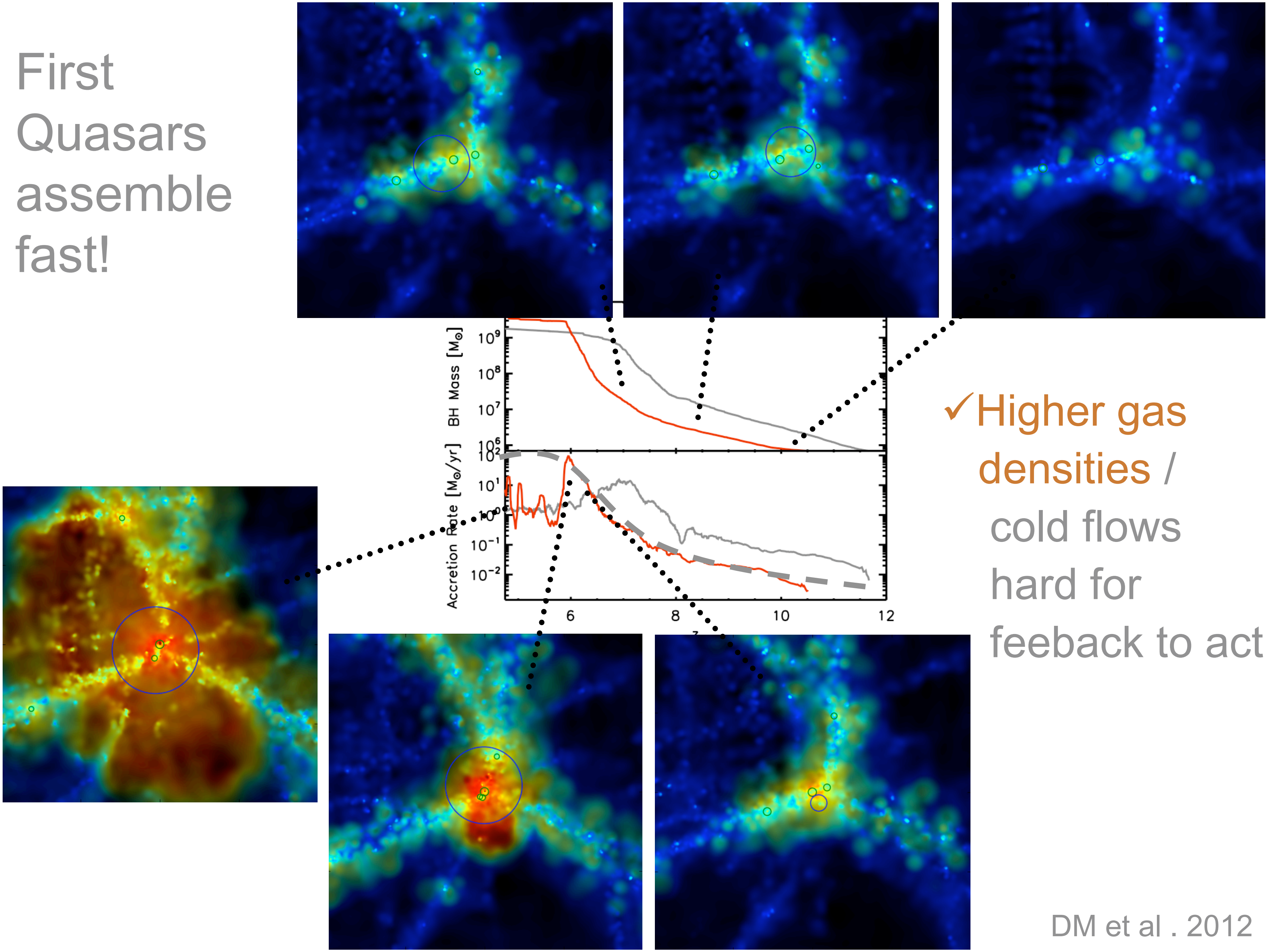


BH GROWTH



DM et al . 2012

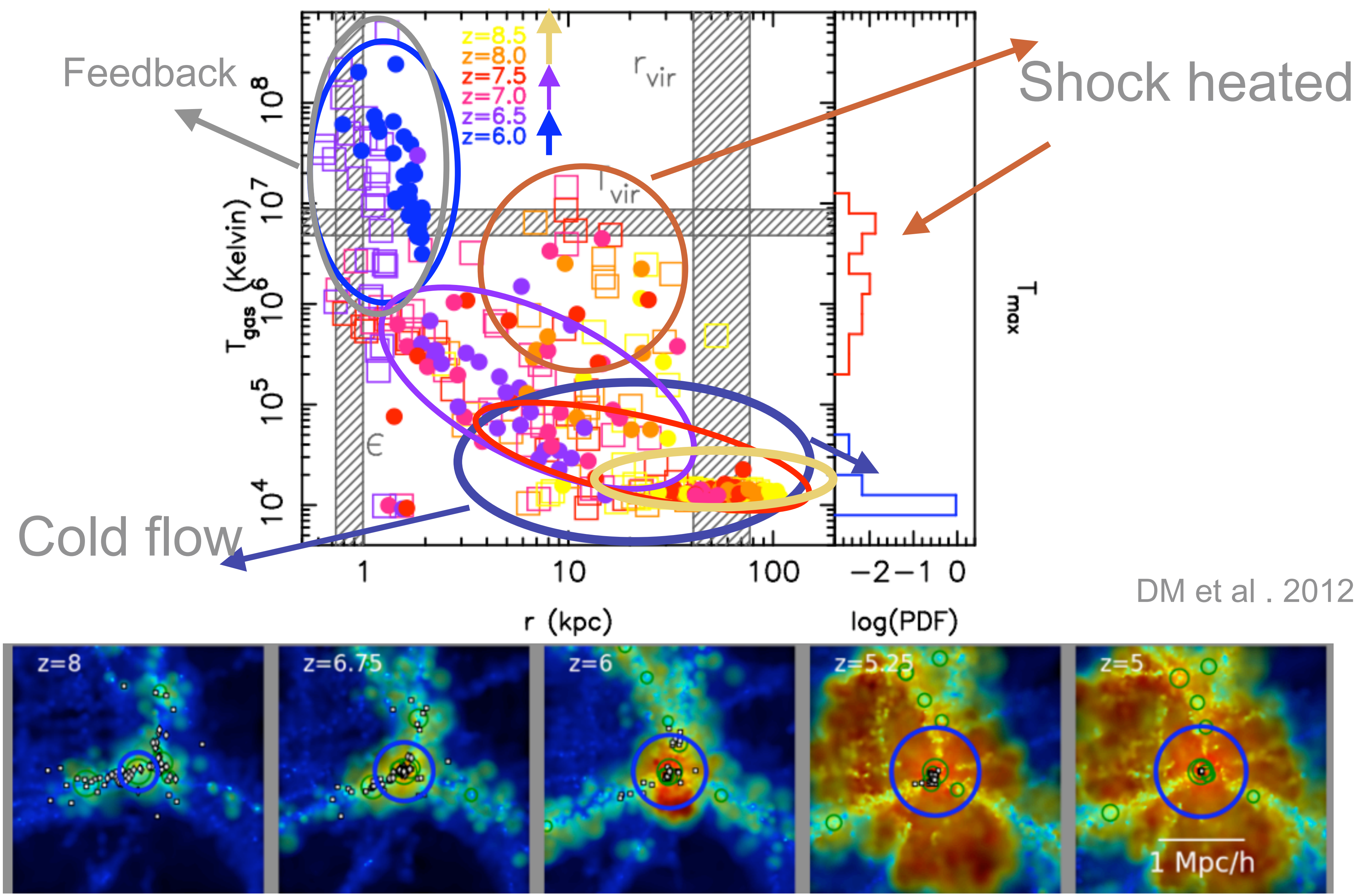
First Quasars assemble fast!



✓Higher gas densities / cold flows hard for feeback to act

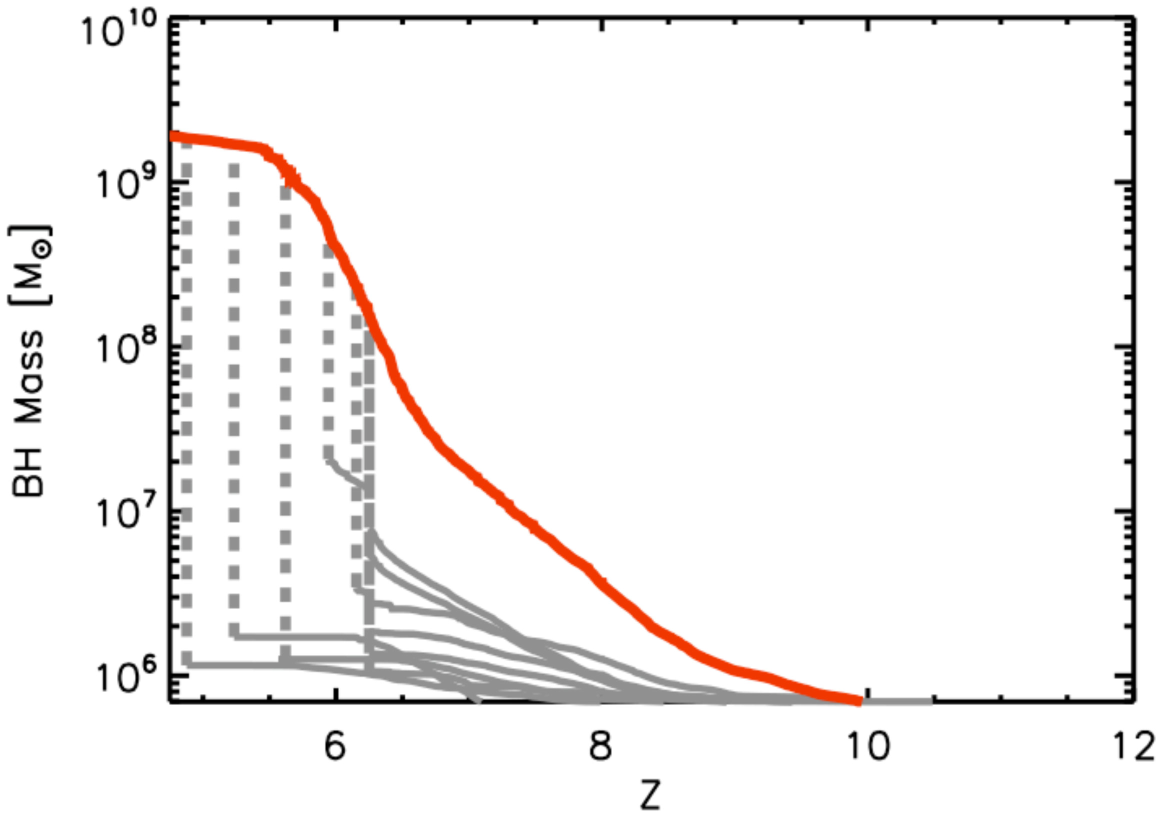
DM et al . 2012

The history of the gas: accretion from cold flows



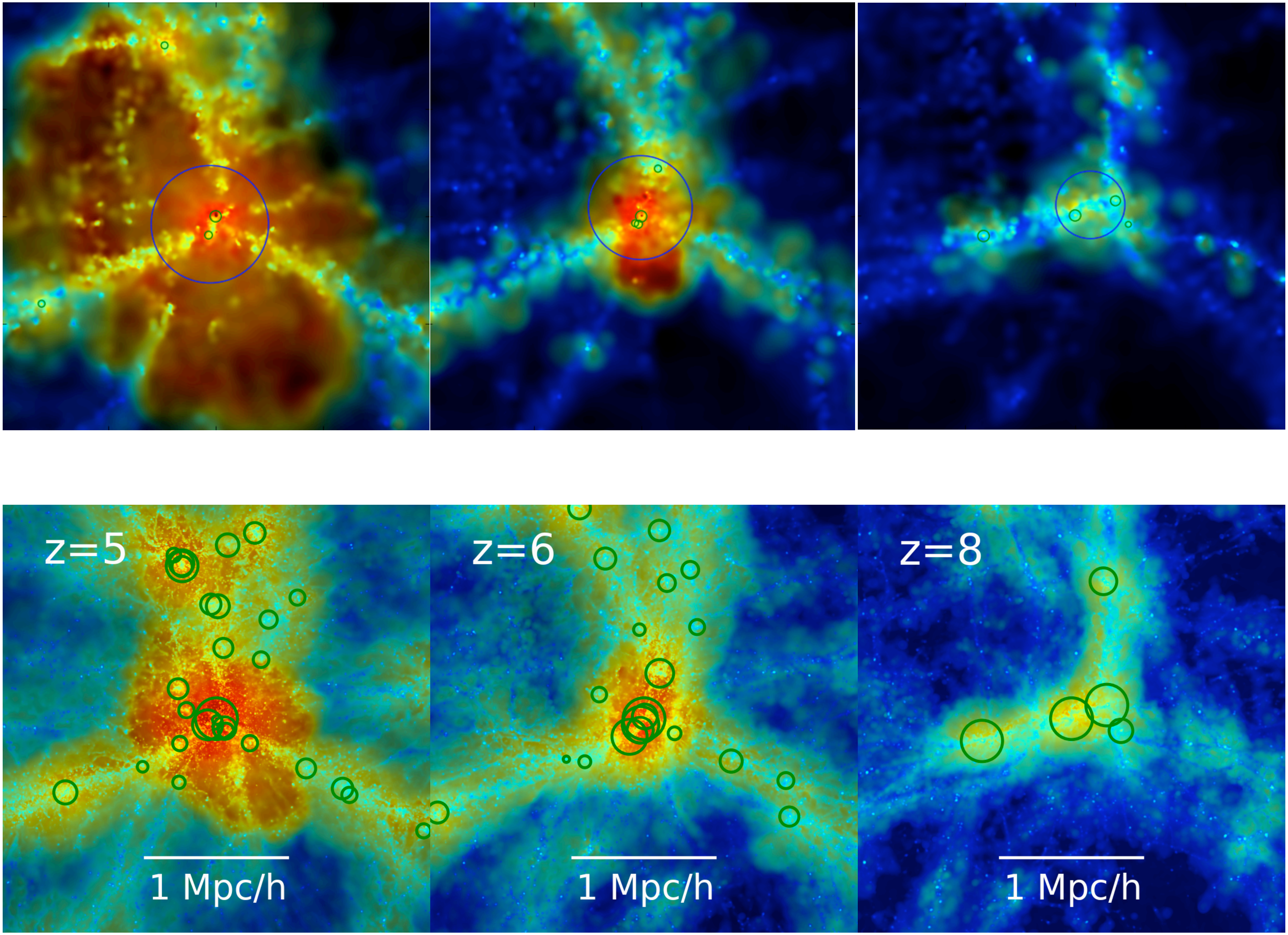
DM et al . 2012

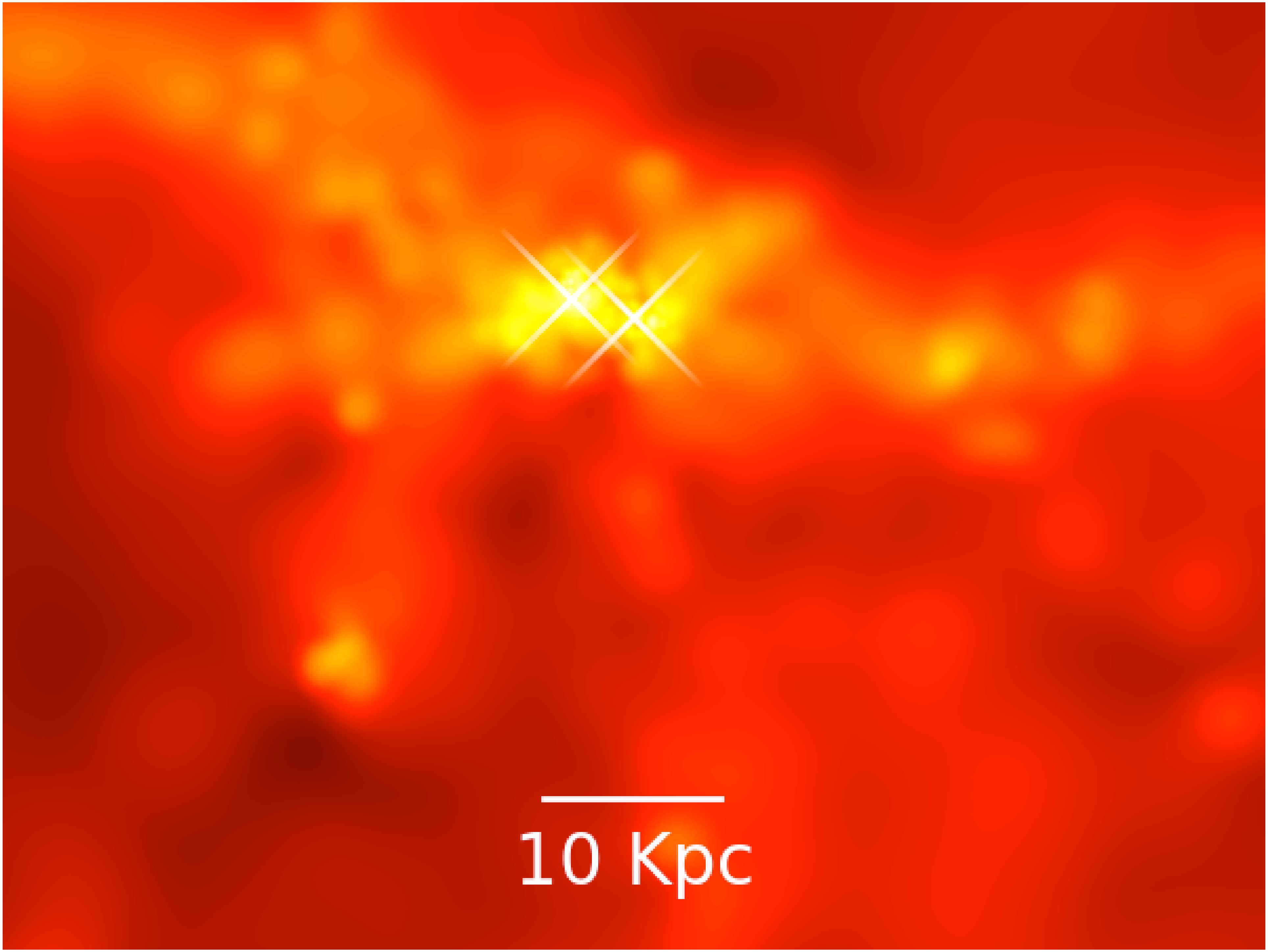
How/ where do MBHs grow?

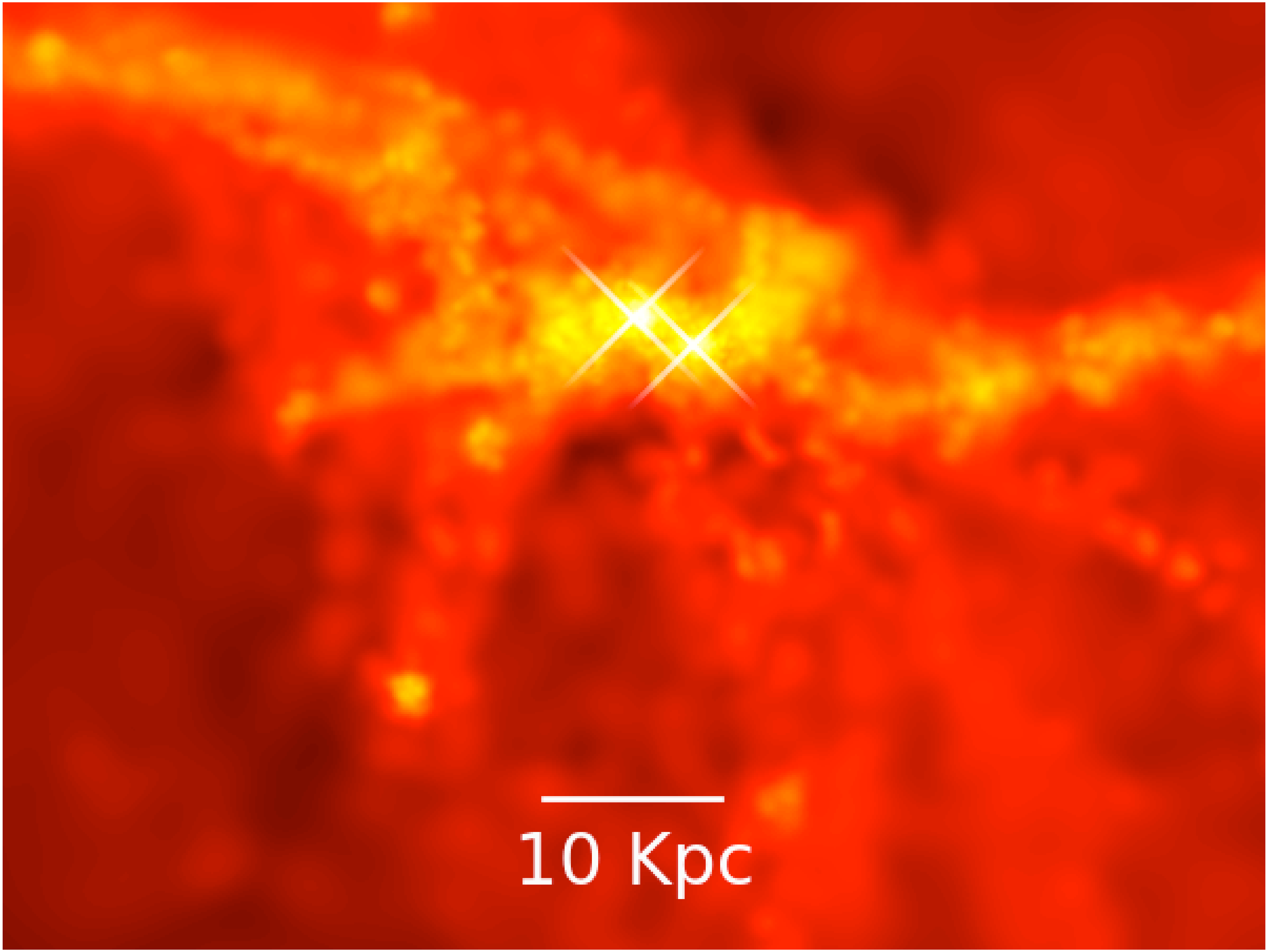


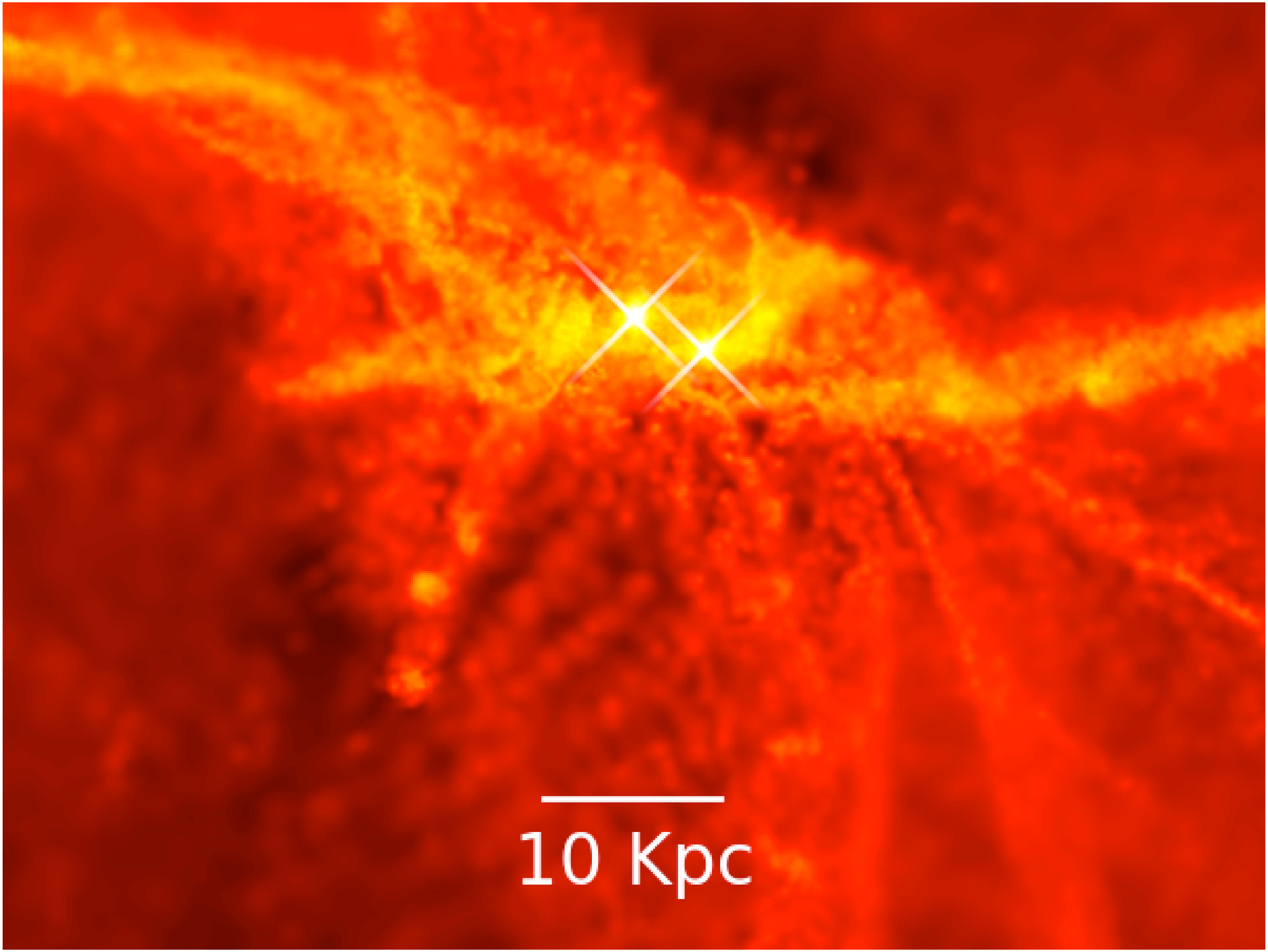
Journey into the growth
of the first supermassive BHs:

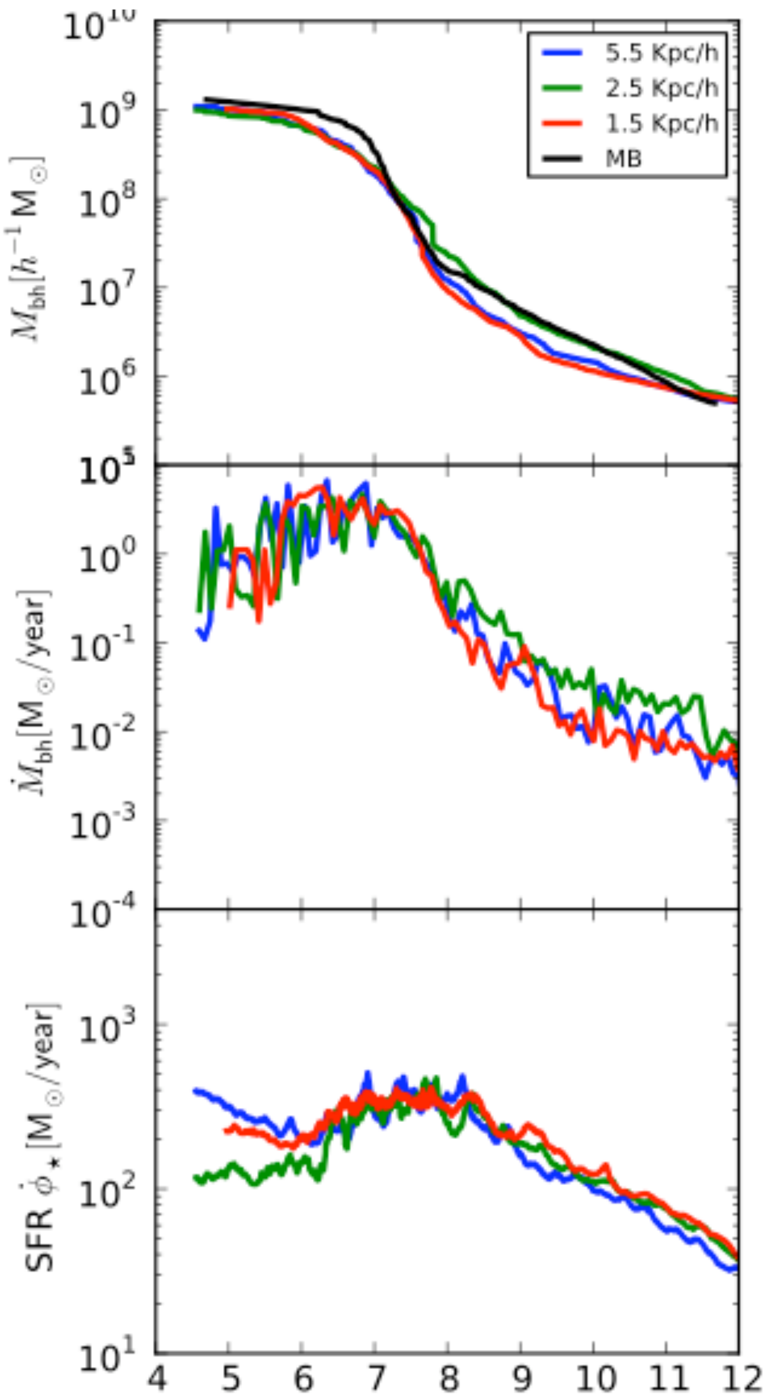
Zooming in


z=5
z=6
z=8
1 Mpc/h
1 Mpc/h
1 Mpc/h


10 Kpc


10 Kpc


10 Kpc

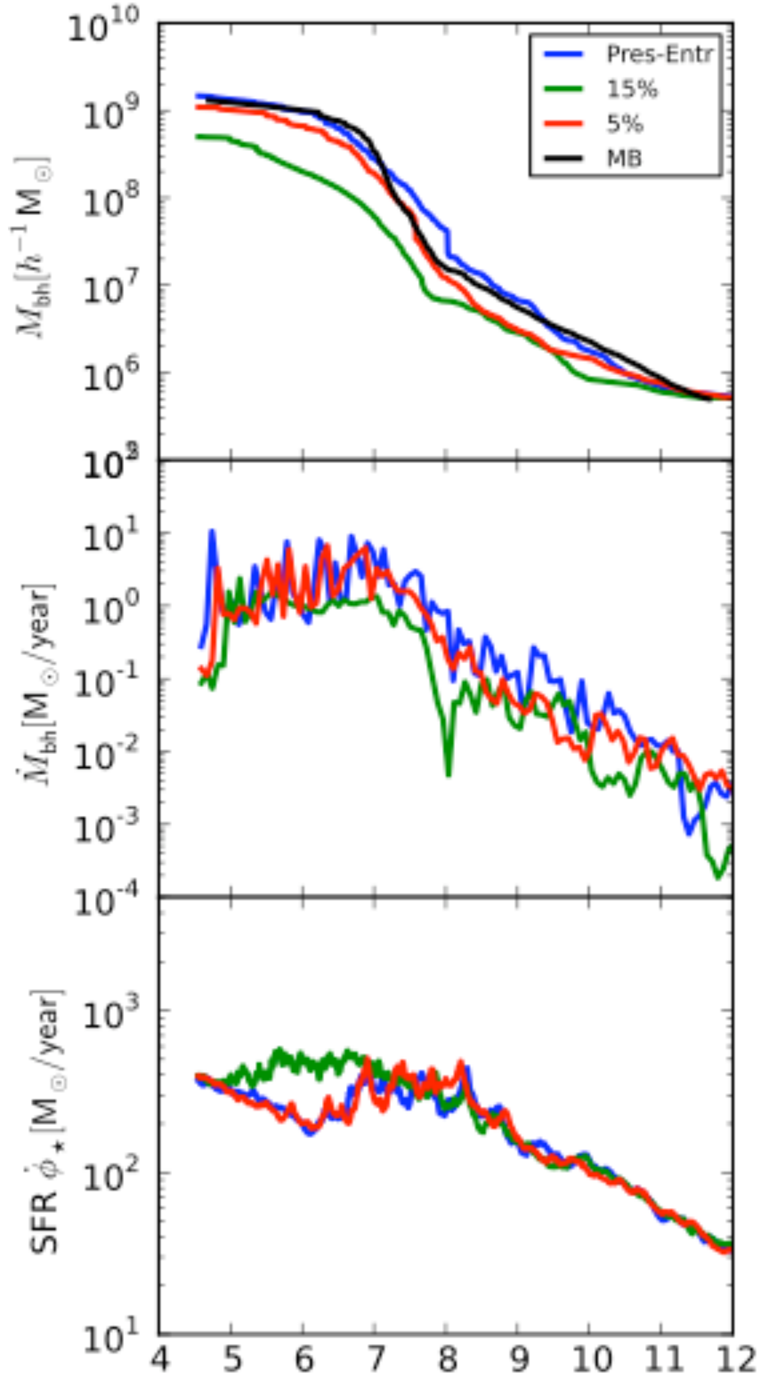


GADGET zooms

Convergence for BH properties for 3 resolutions

In physical units:
From few kpc to ~100pc

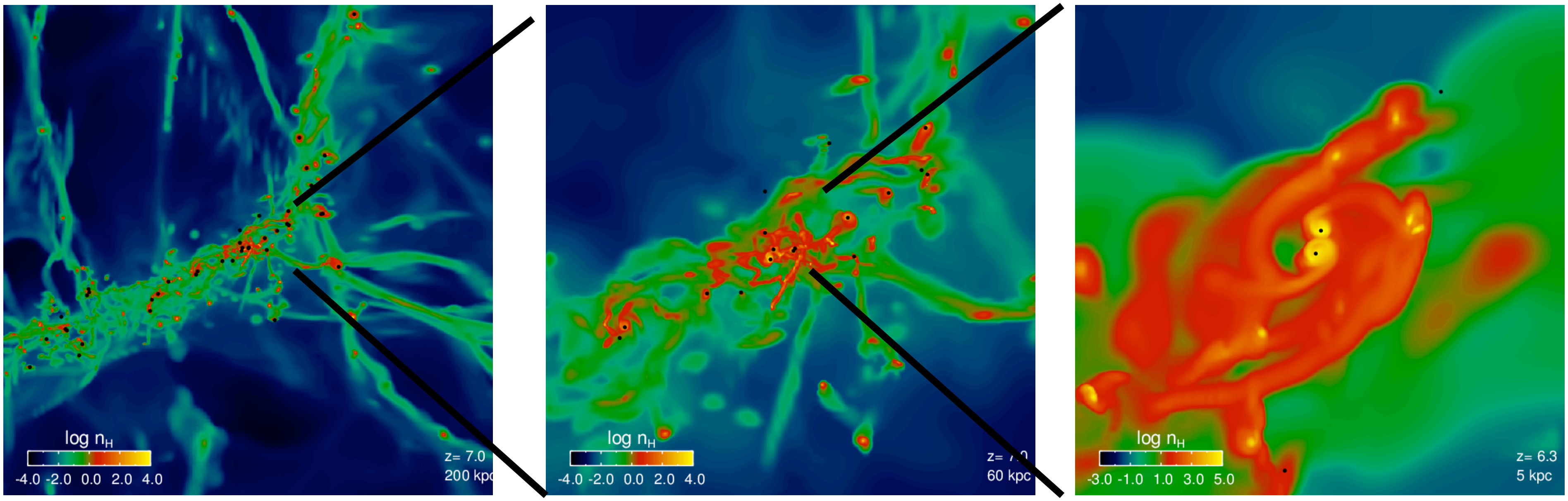
Feng et al. in prep



GADGET zooms

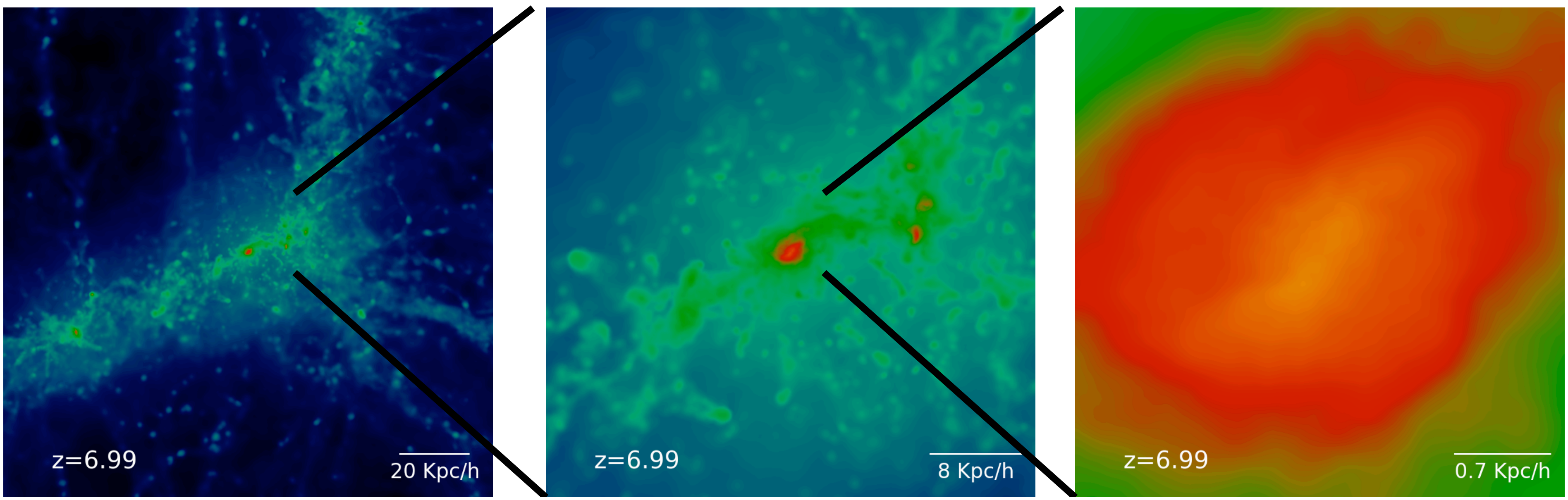
- Stronger dependence on feedback 'factor'
- No strong effects from SPH vs PSPH

AMR (RAMSES) ZOOM vs Dubois et al.

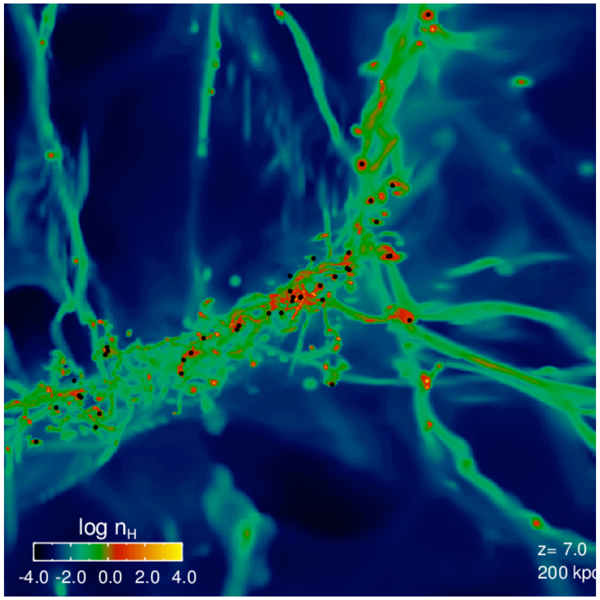


SPH (GADGET3) ZOOM

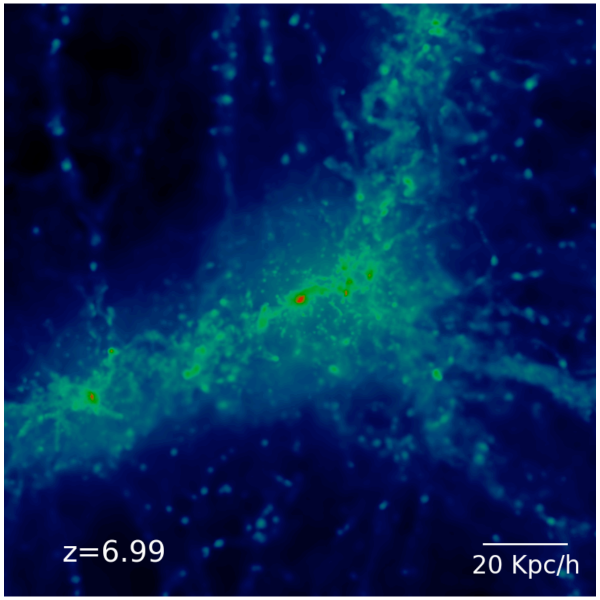
Feng et al

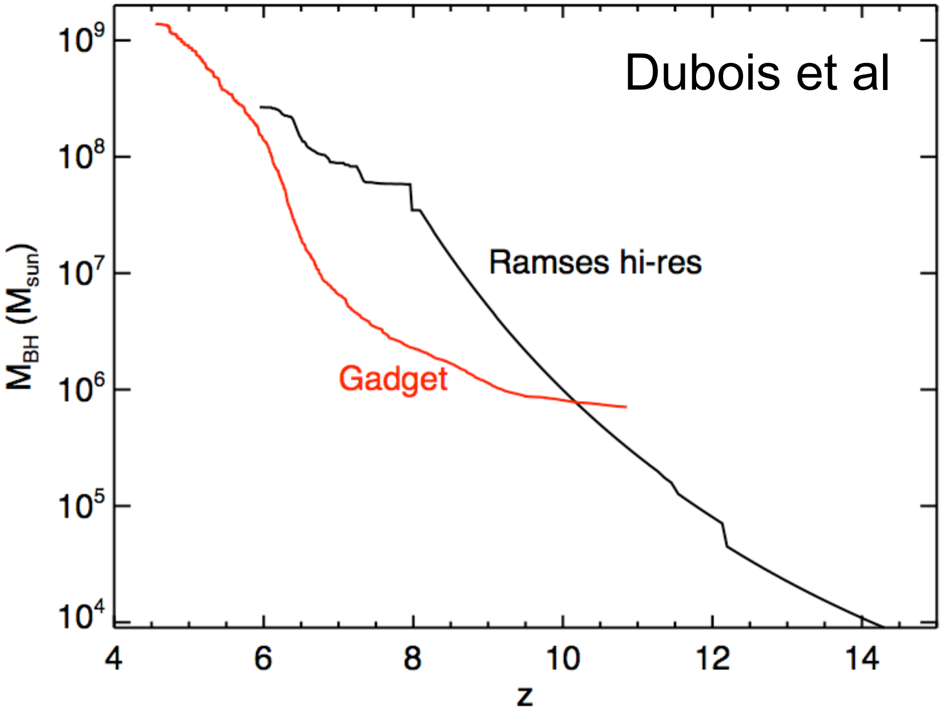


AMR (RAMSES) ZOOM vs



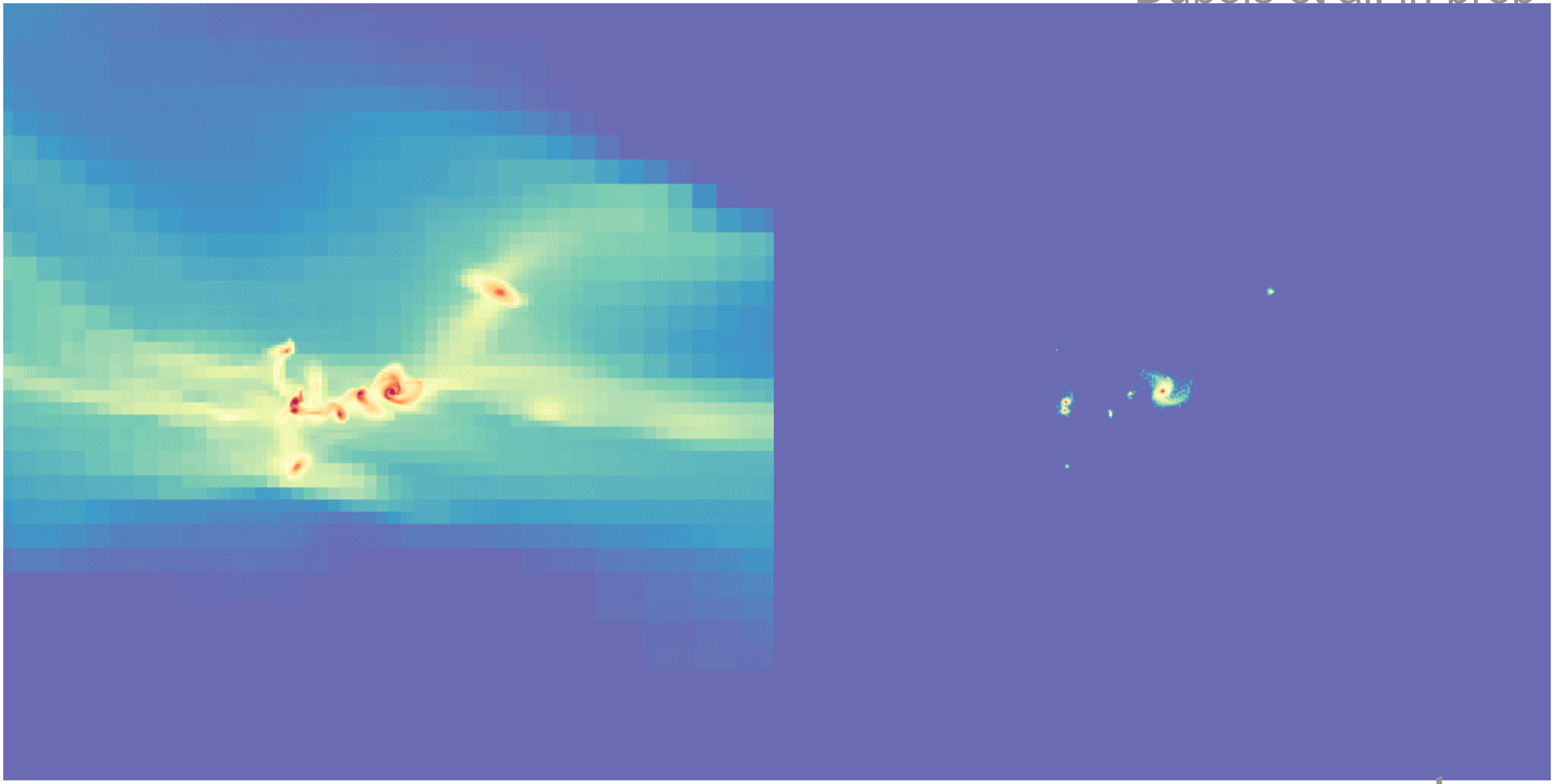
SPH (GADGET3) ZOOM





RAMSES Zoom - 10 parsec resolution

Dubois et al. in prep



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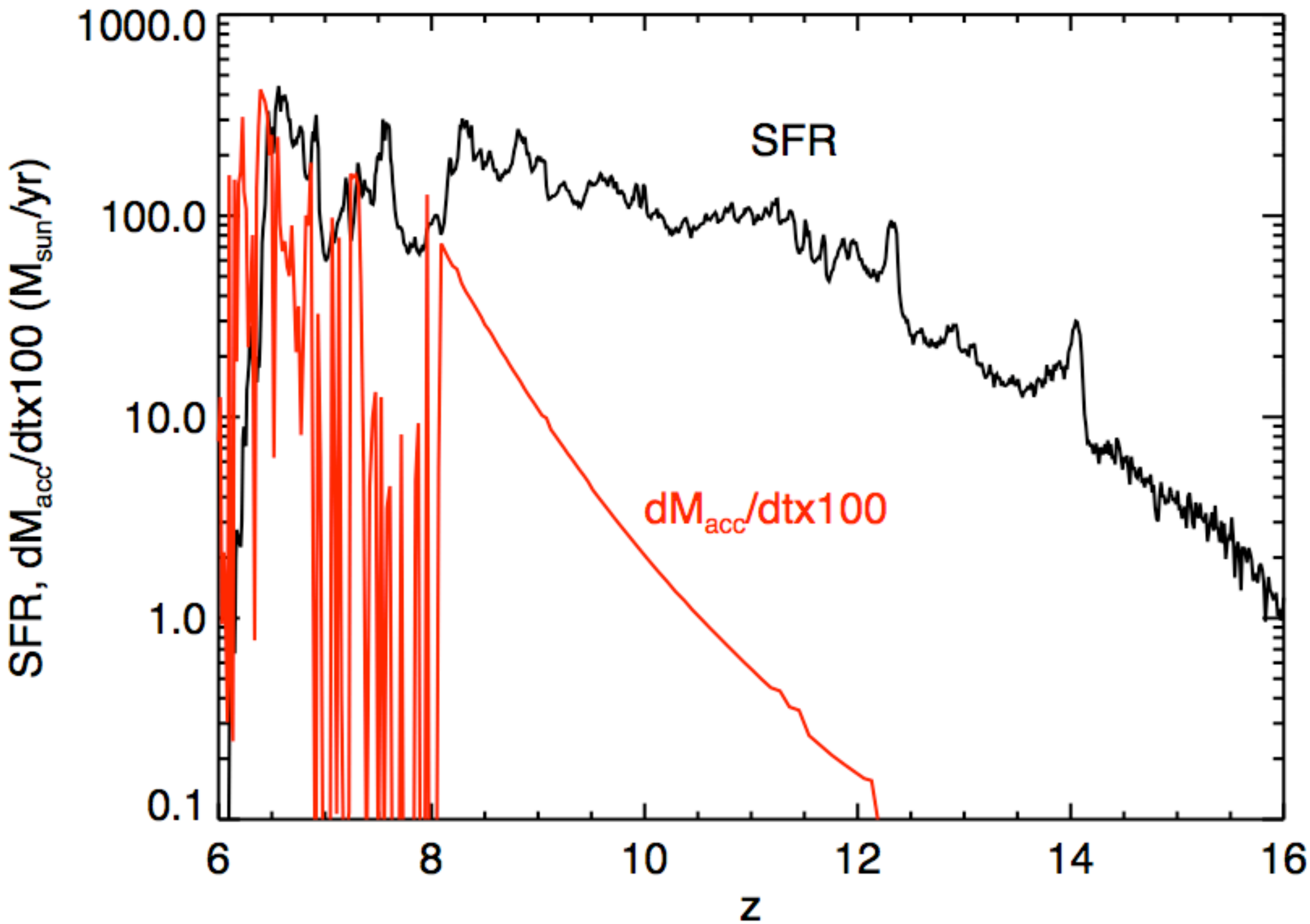
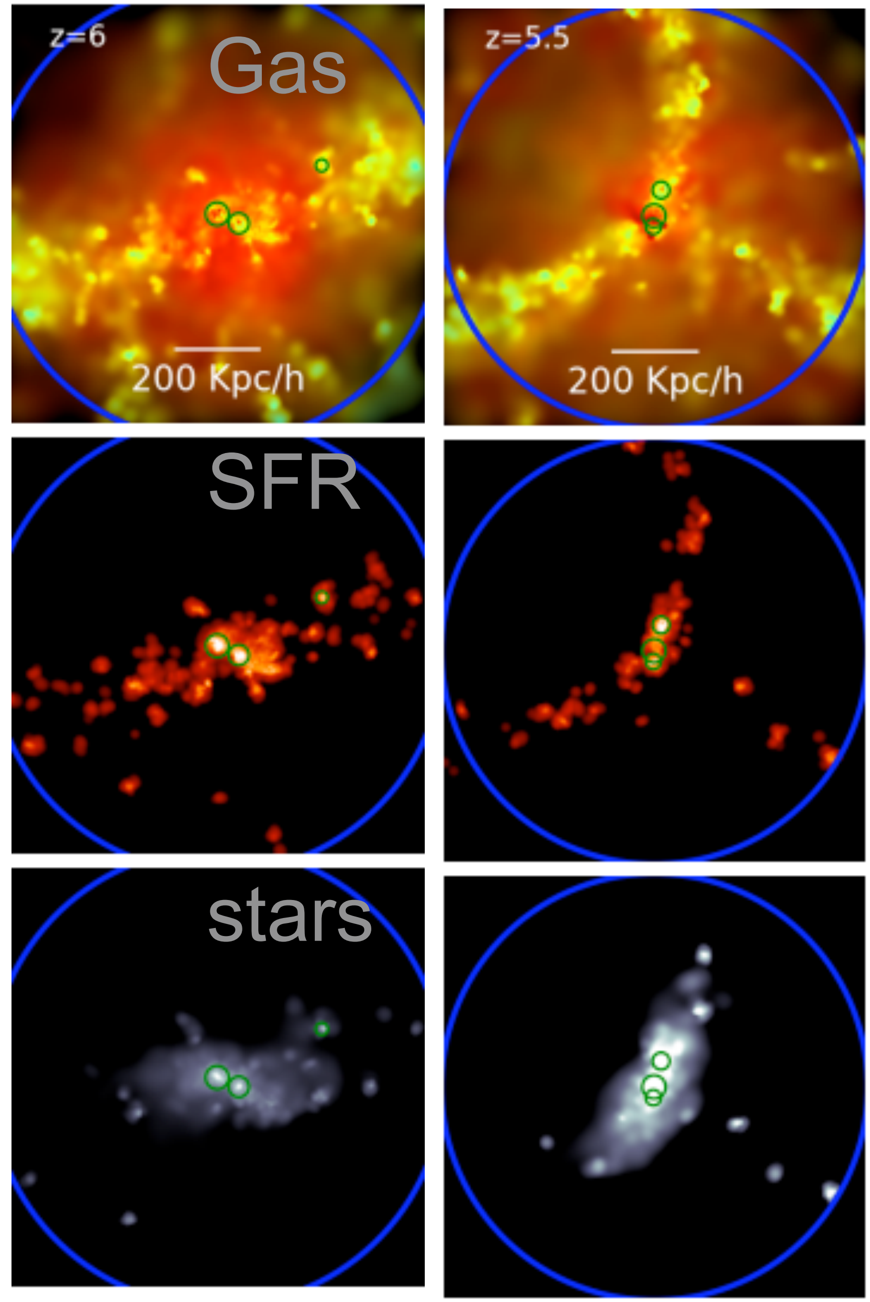
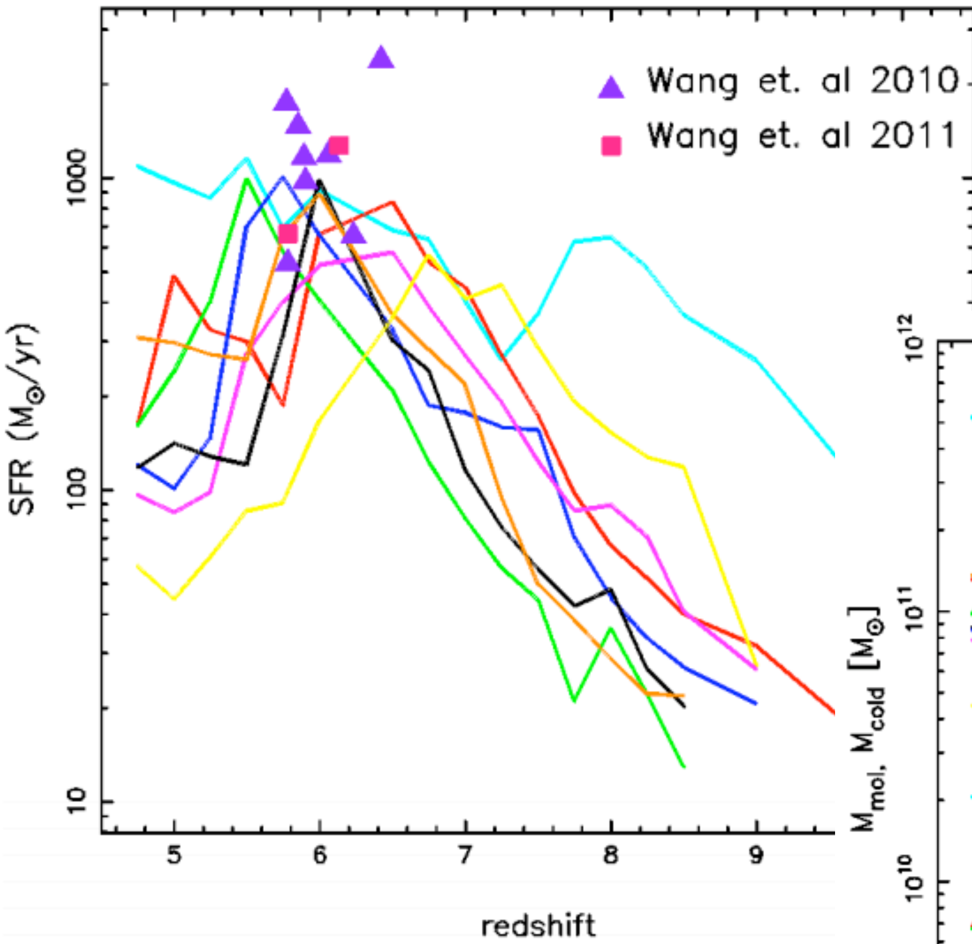


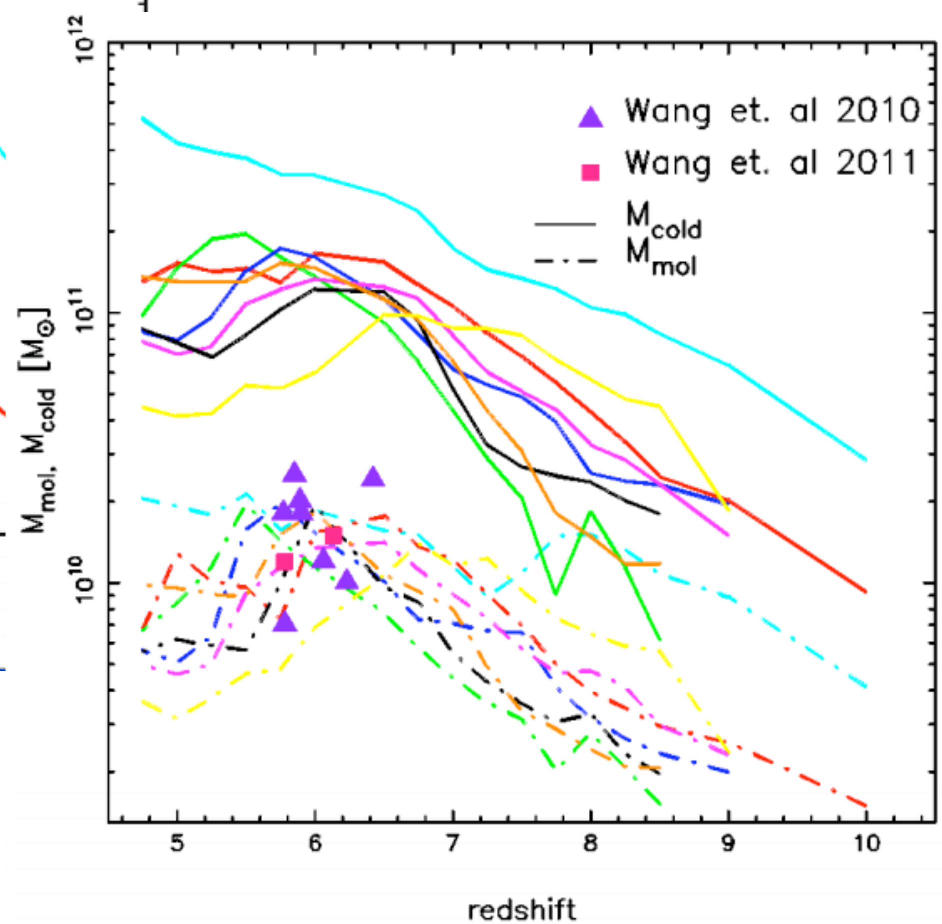
The first quasars and their hosts galaxies



Z=6 Quasar Hosts: The M_{BH}-sigma relation

Khandai et al. 2012





Z=6 Quasar Hosts: The M_{BH}-sigma relation

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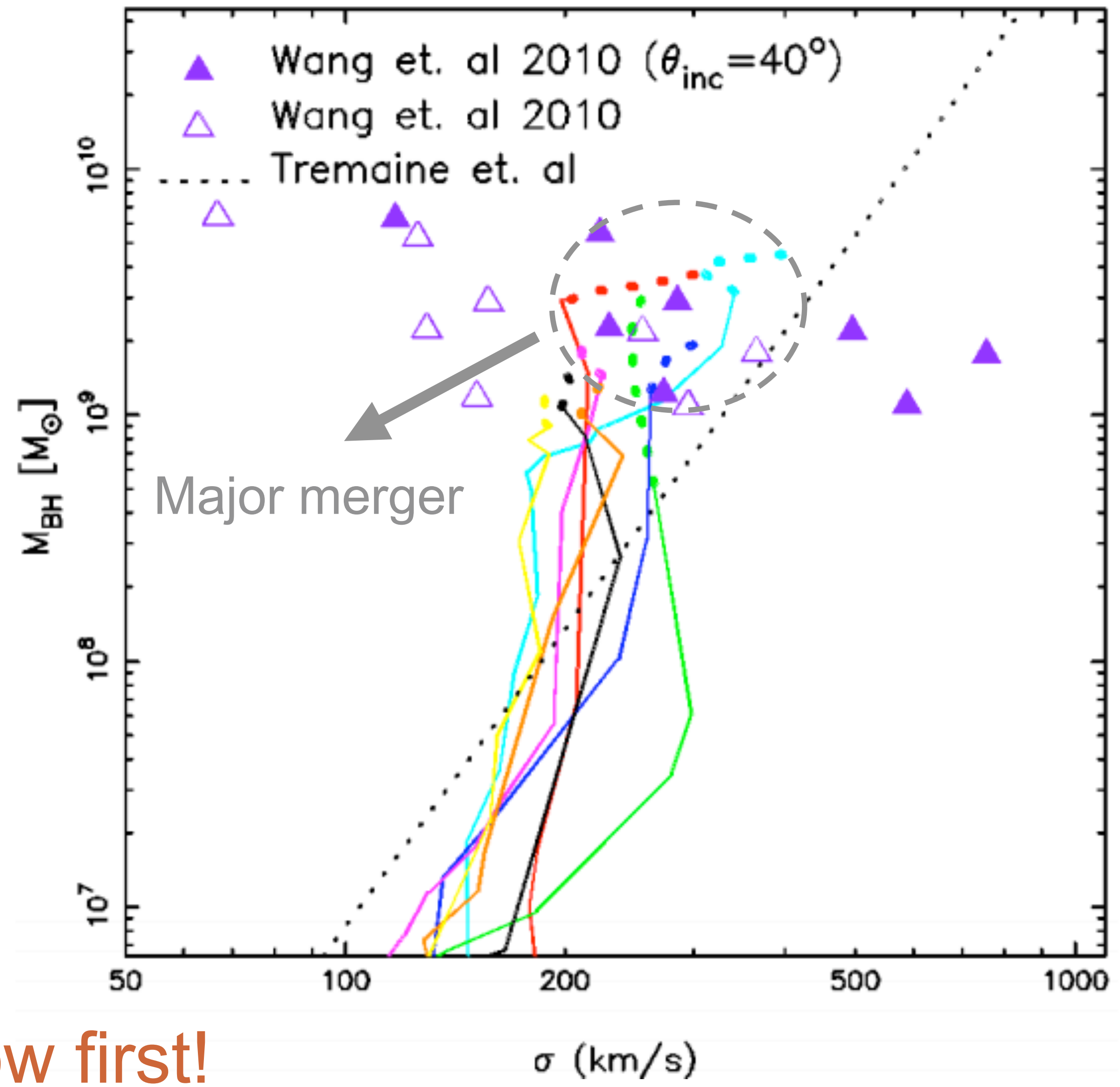
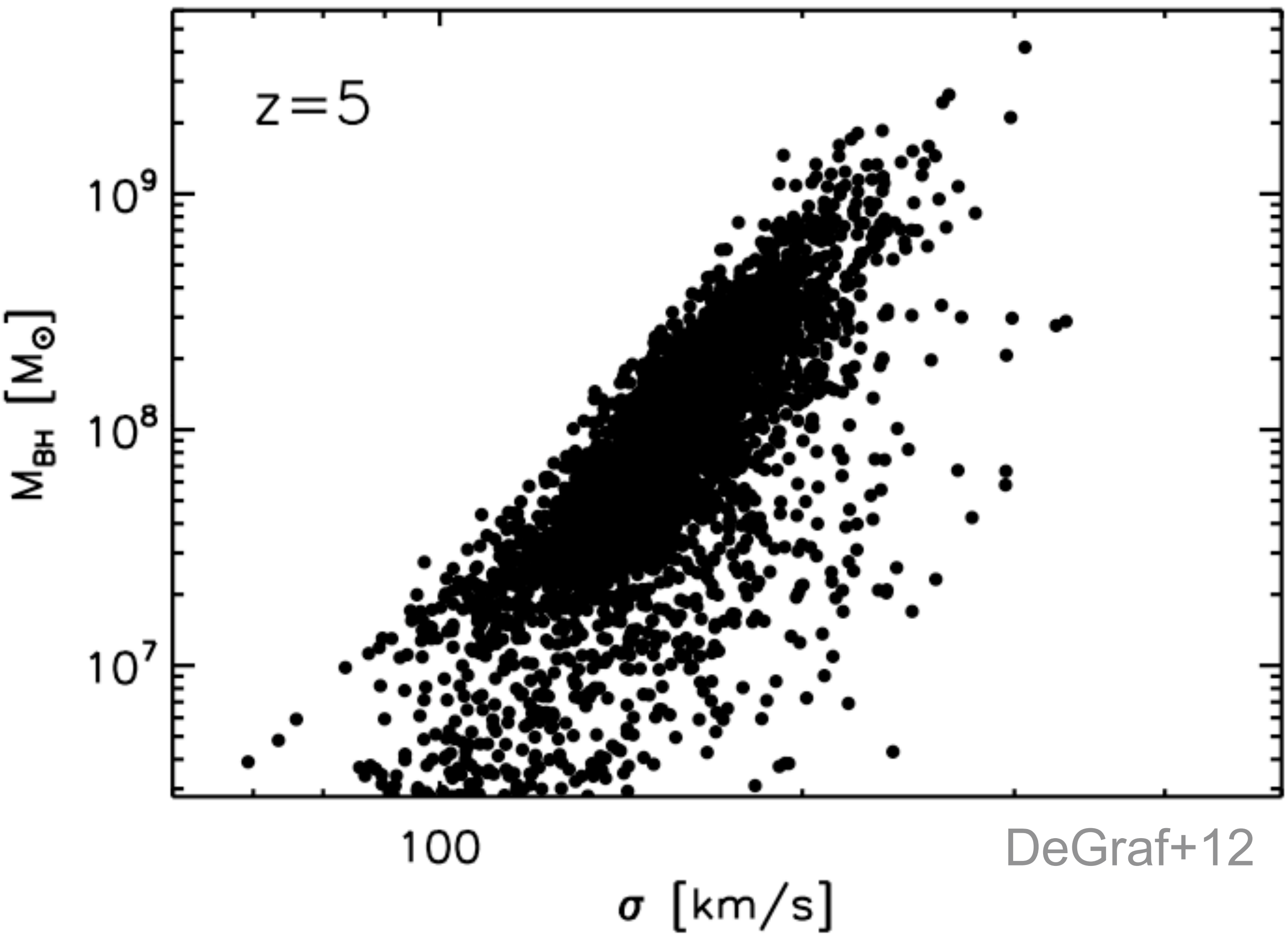


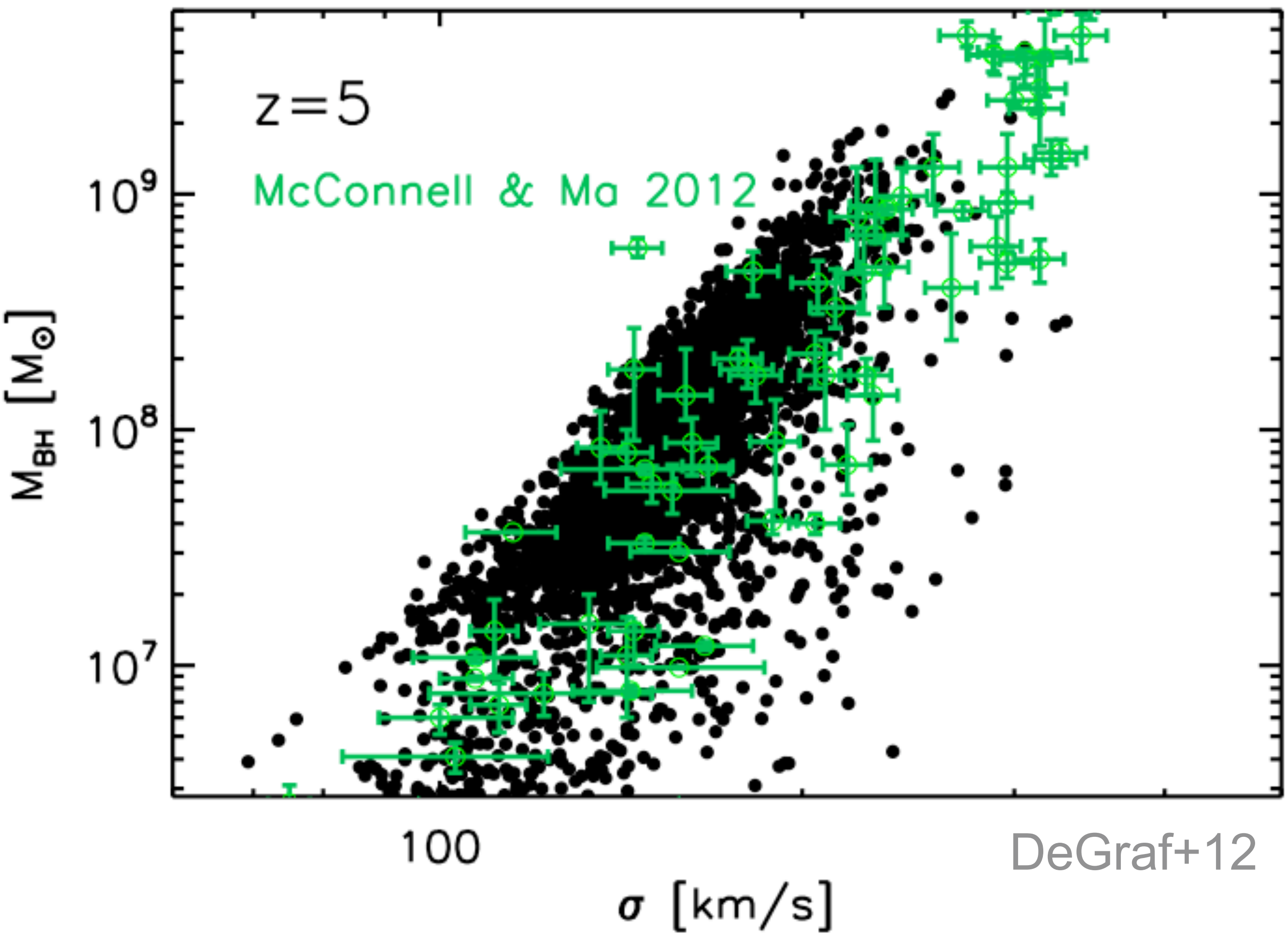
Black Holes grow first!

High-z M_{BH}-σ relation



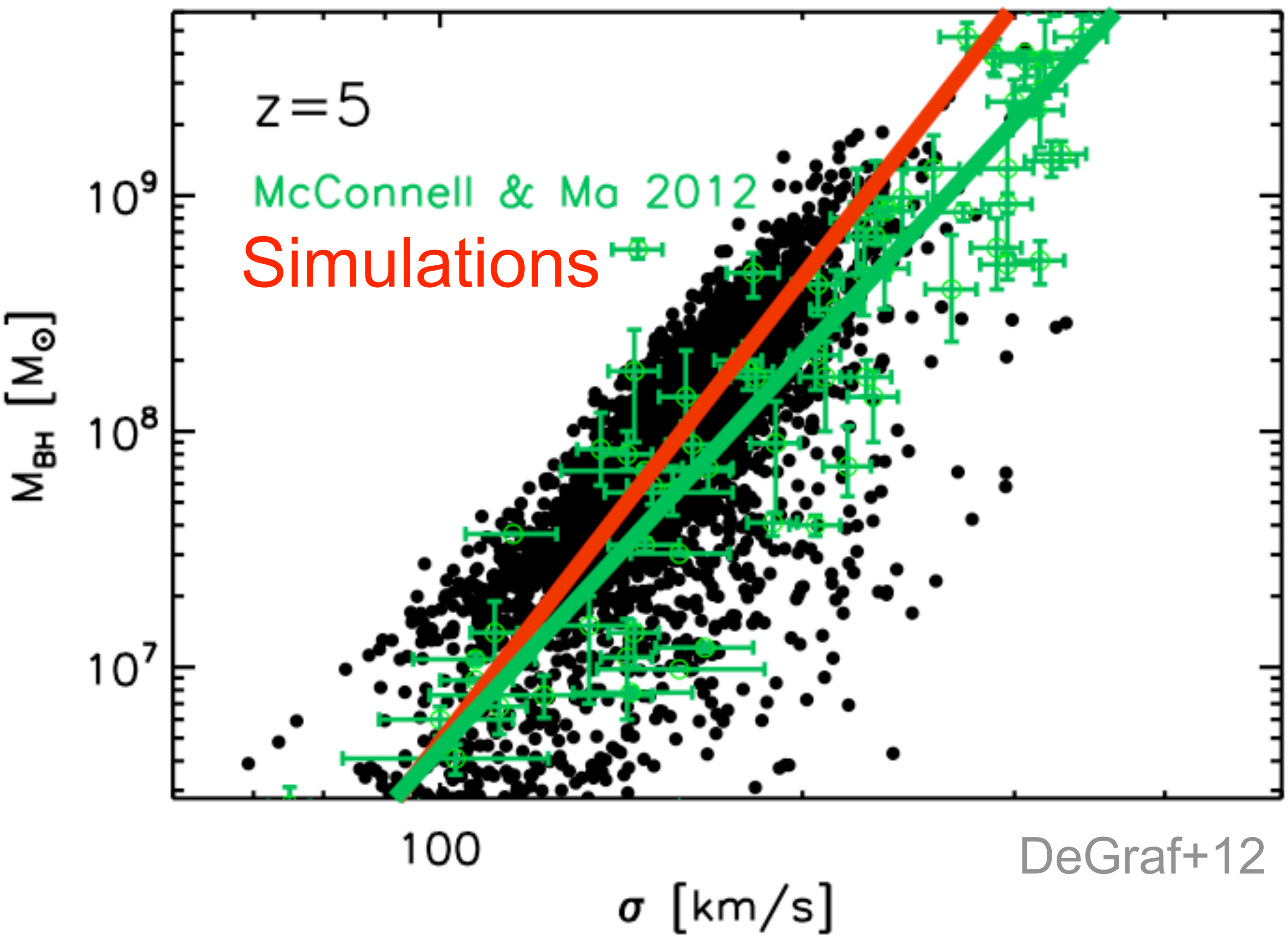
DeGraf+12

High-z M_{BH}-σ relation

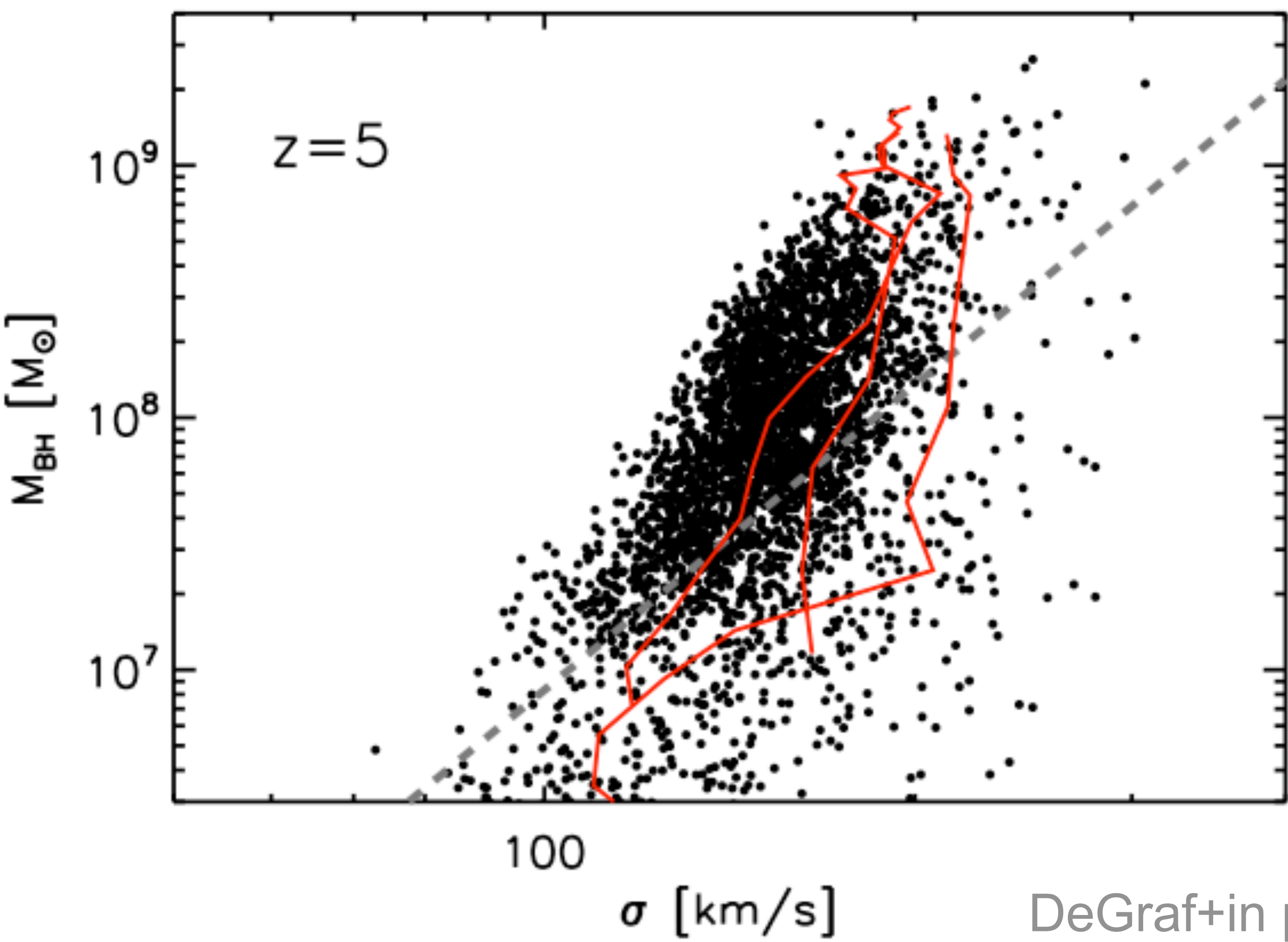


DeGraf+12

High-z M_{BH}-σ relation

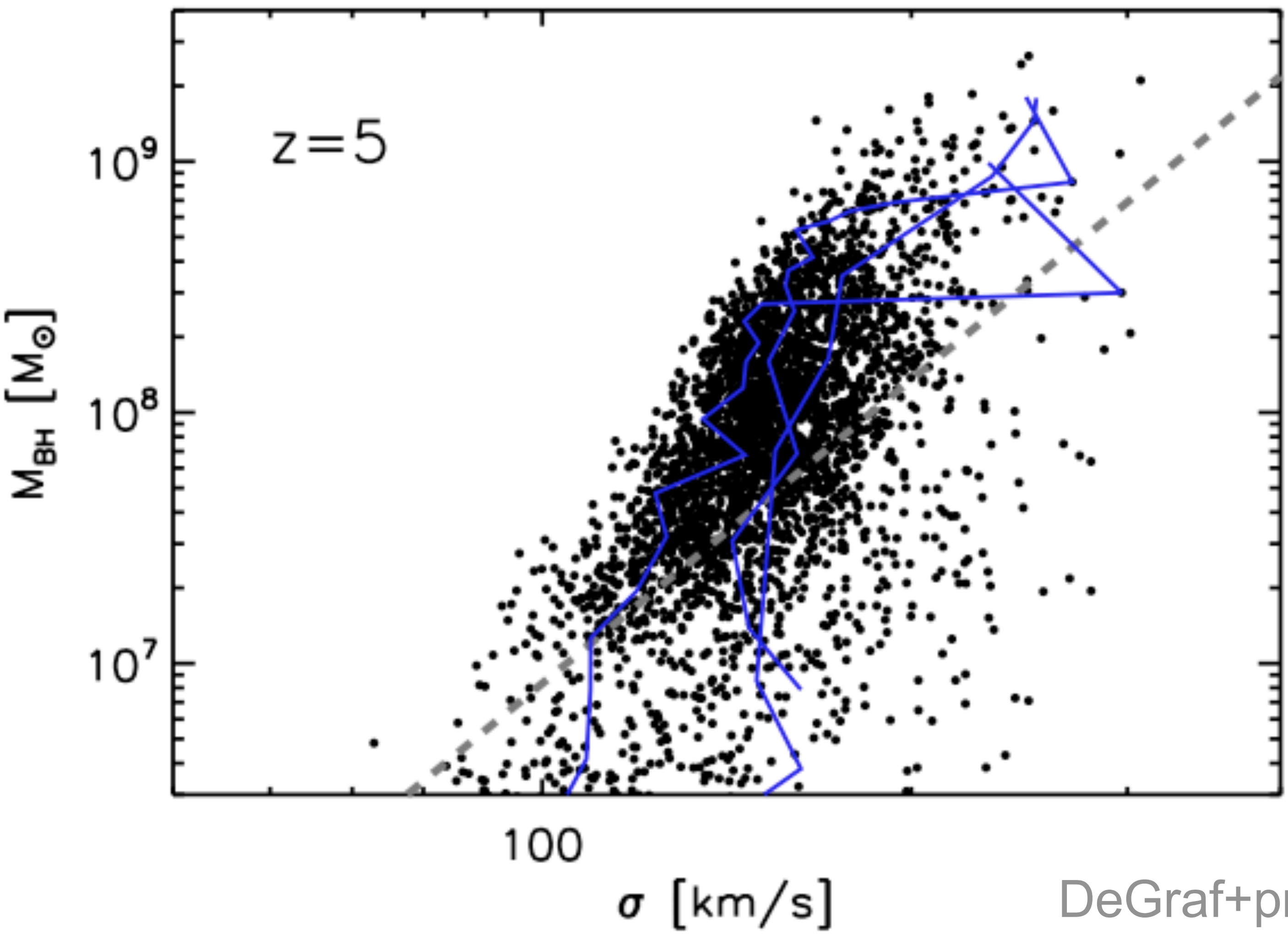


M_{BH}-σ relation: Galaxy mergers



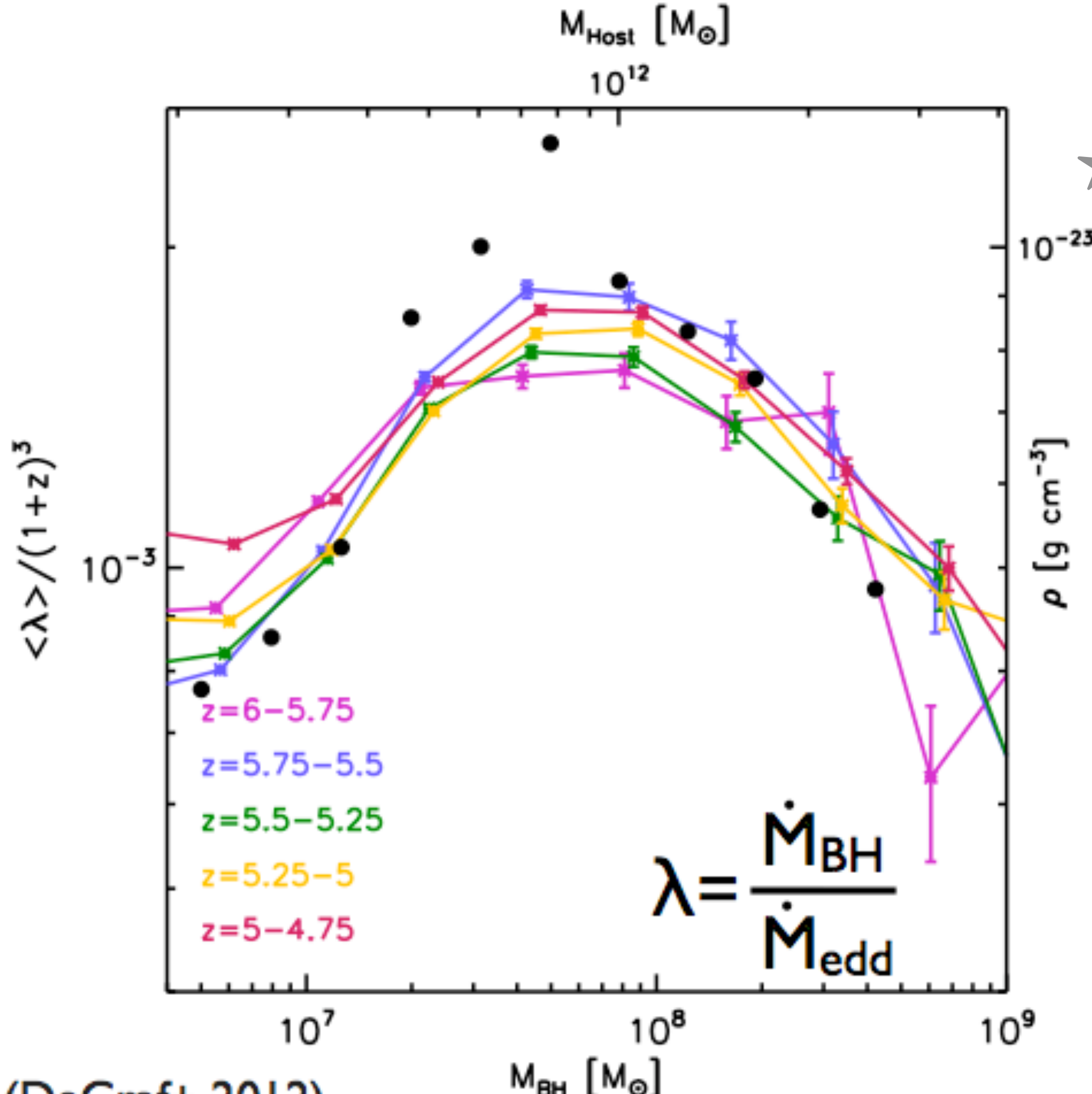
DeGraf+in prep

M_{BH}-σ relation: Galaxy mergers



DeGraf+prep

Black Hole Growth



(DeGraf+ 2012)

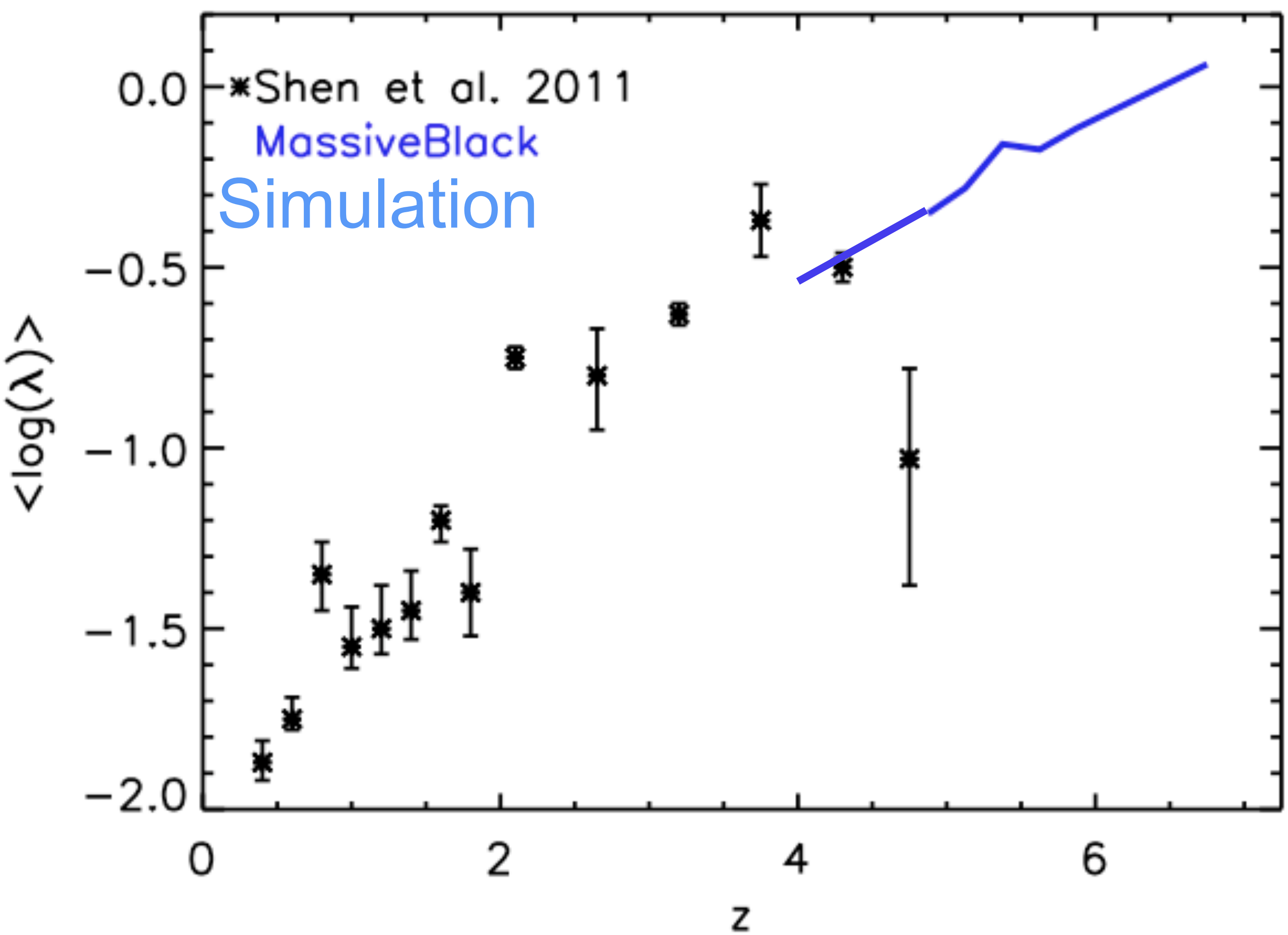
★ Peak in growth rate

★ Same peak in BH local gas density

Set by:

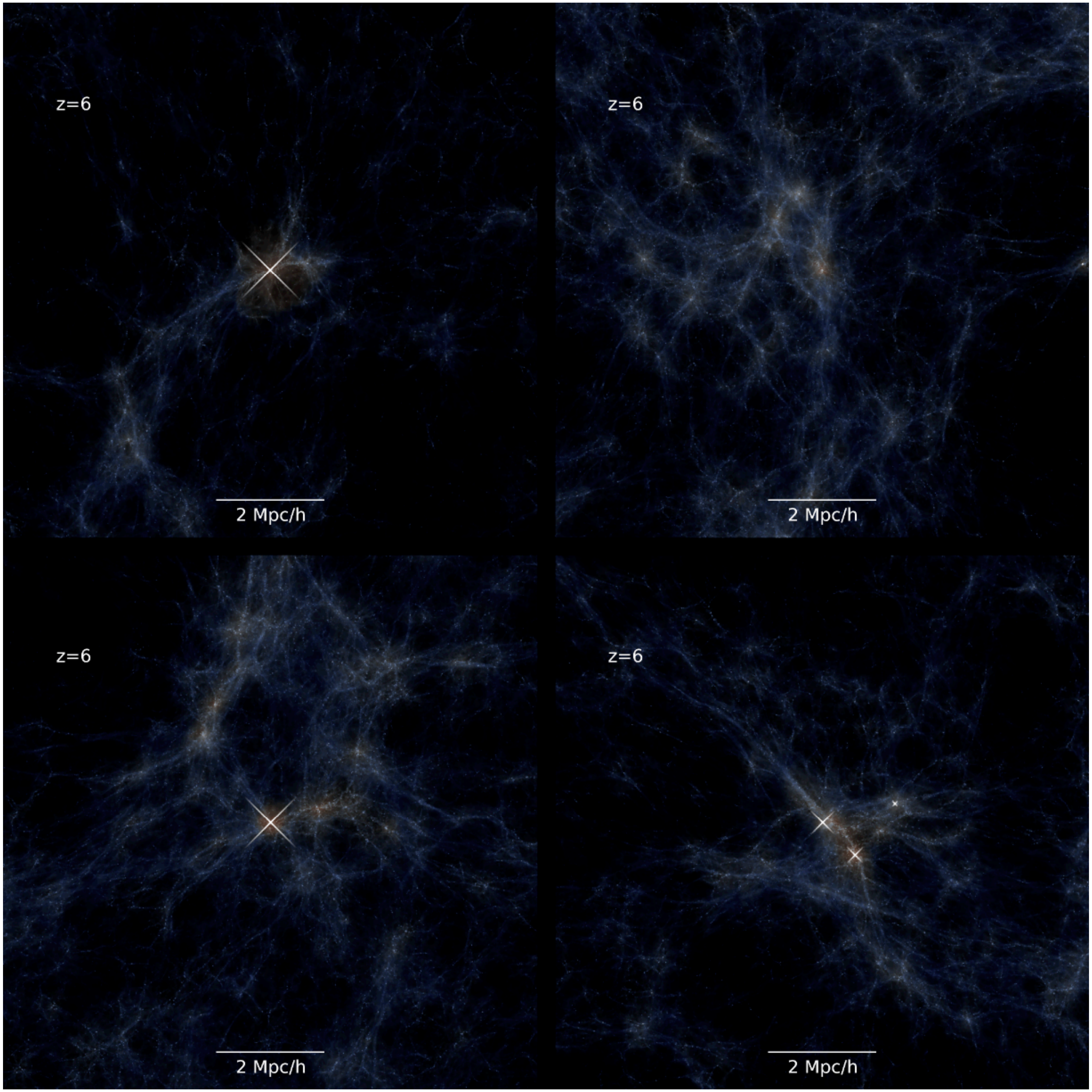
- High density gas inflows/ cold flows
- AGN feedback gas outflows

Black Hole Growth Evolution

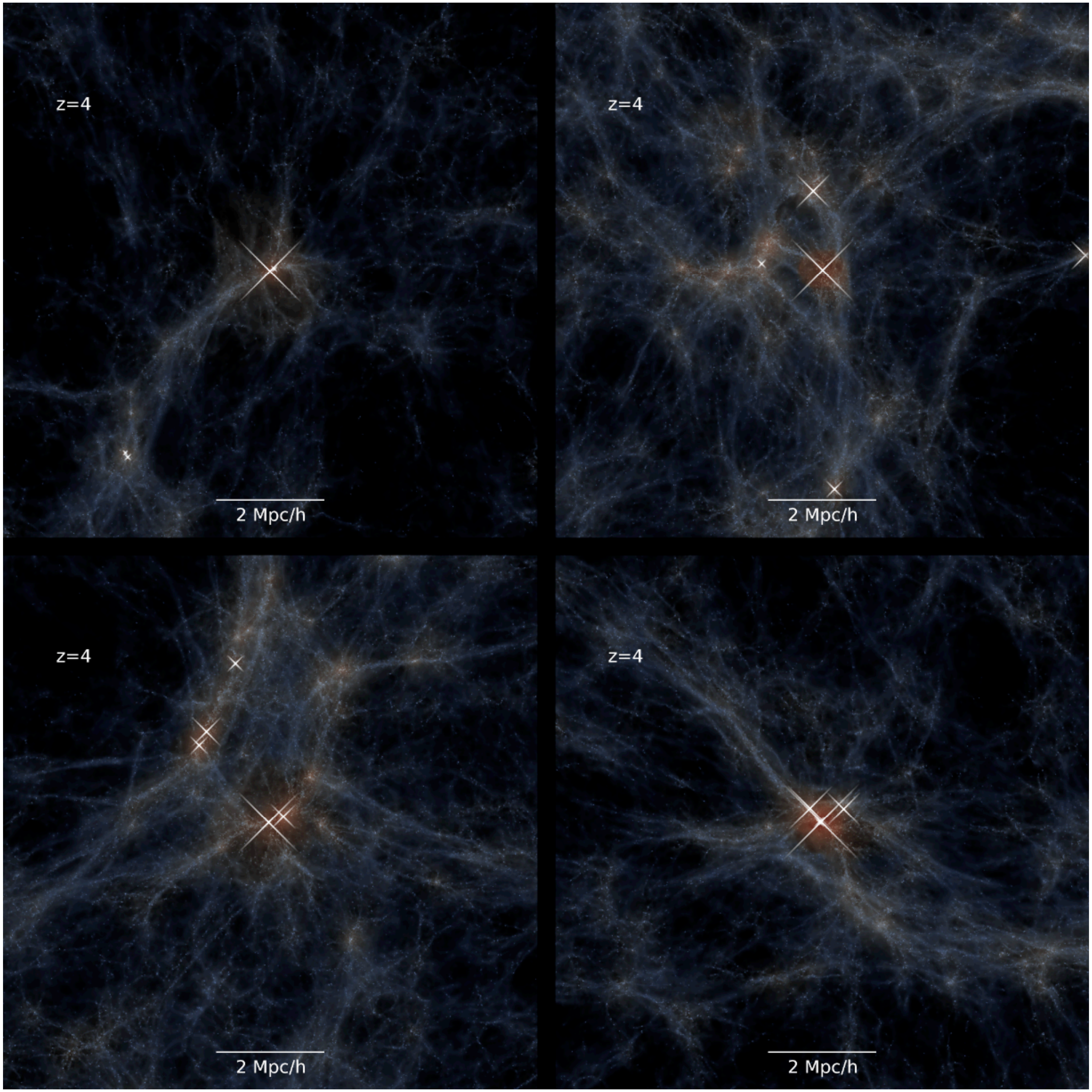


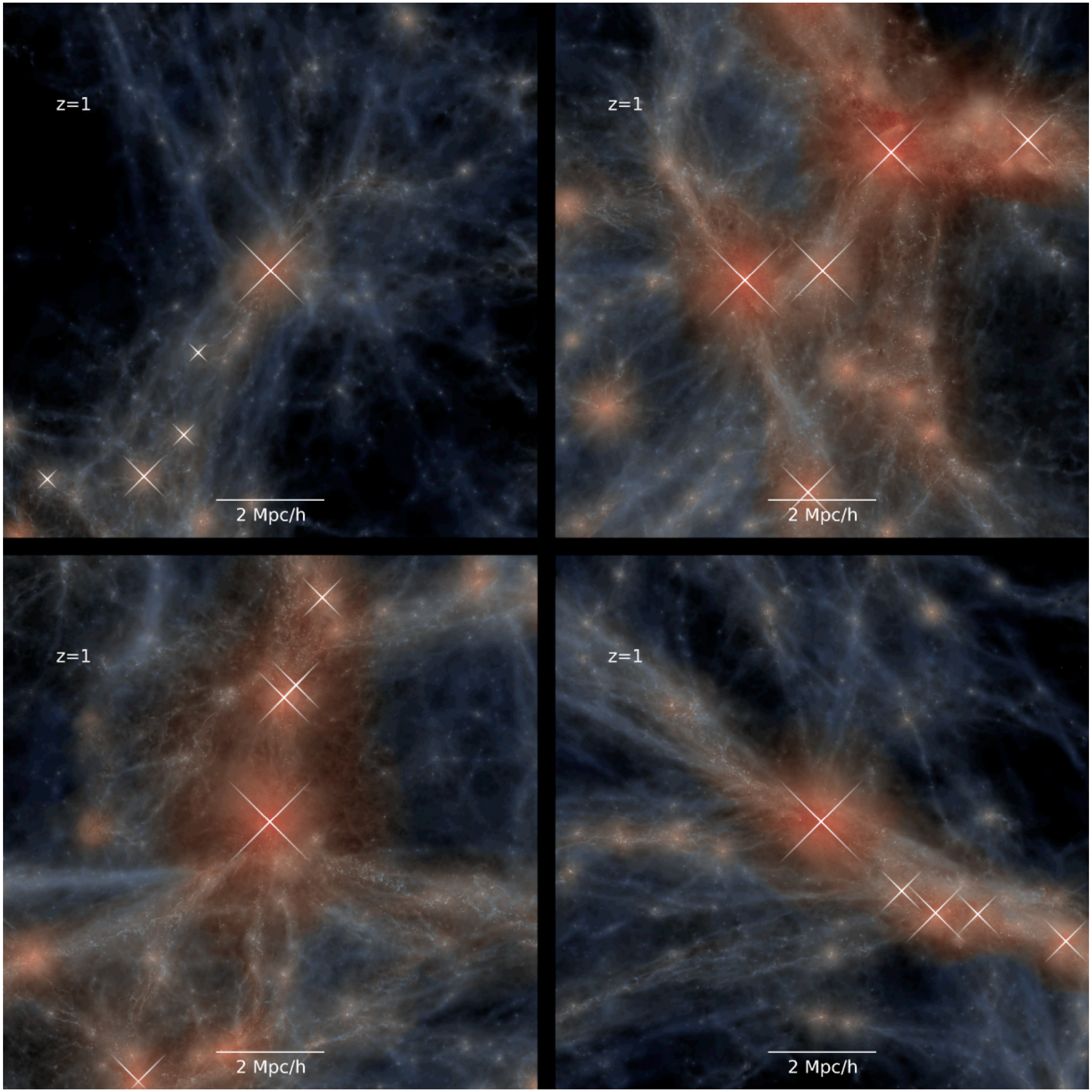
The history of massive black holes assembly, evolution, statistical properties..

do we get it right?



z=6
2 Mpc/h
z=6
2 Mpc/h
z=6
2 Mpc/h
z=6
2 Mpc/h


z=4
2 Mpc/h
z=4
2 Mpc/h
z=4
2 Mpc/h
z=4
2 Mpc/h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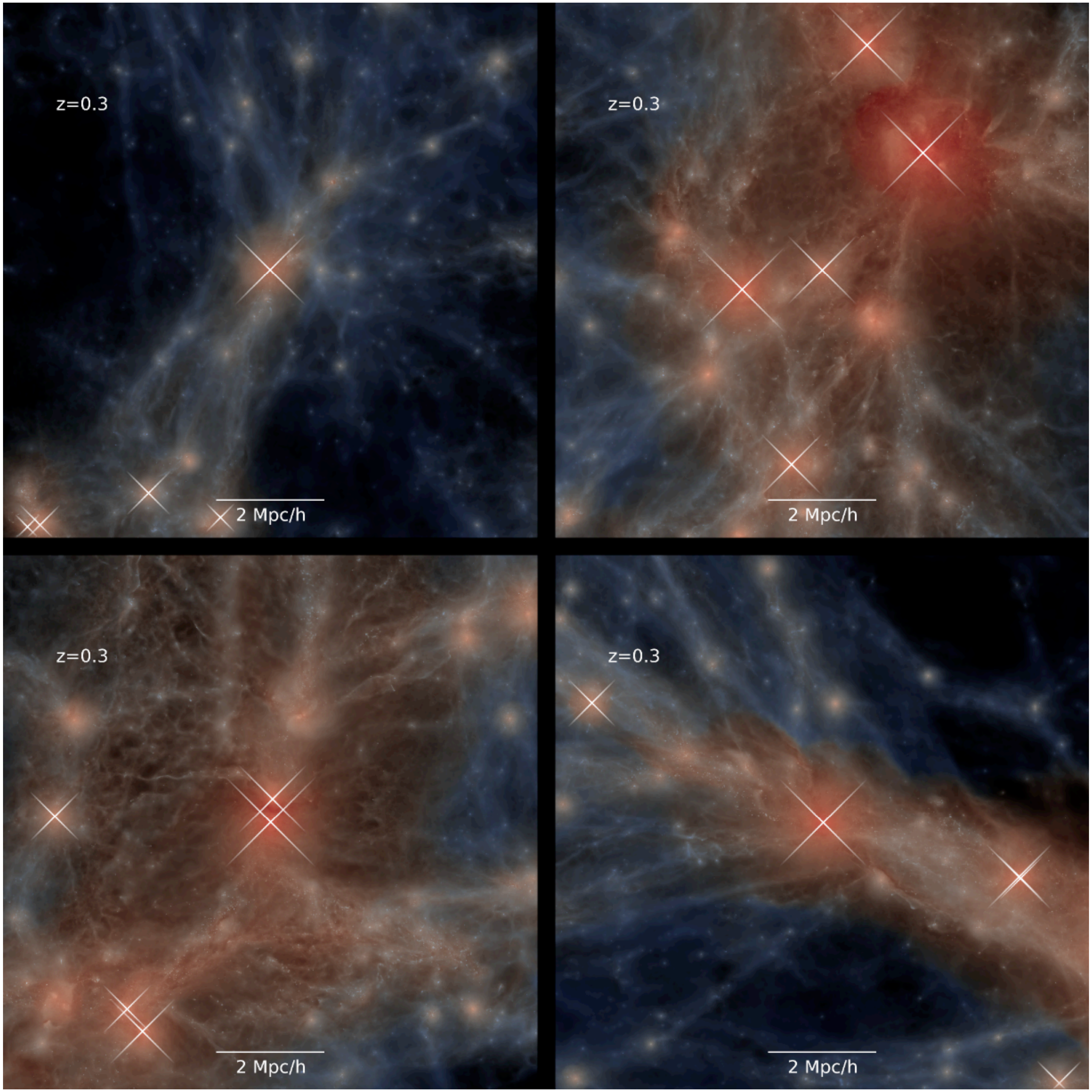
2 Mpc/h
z=1
2 Mpc/h
z=1
2 Mpc/h
z=1
2 Mpc/h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2 Mpc/h
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2 Mpc/h
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2 Mpc/h
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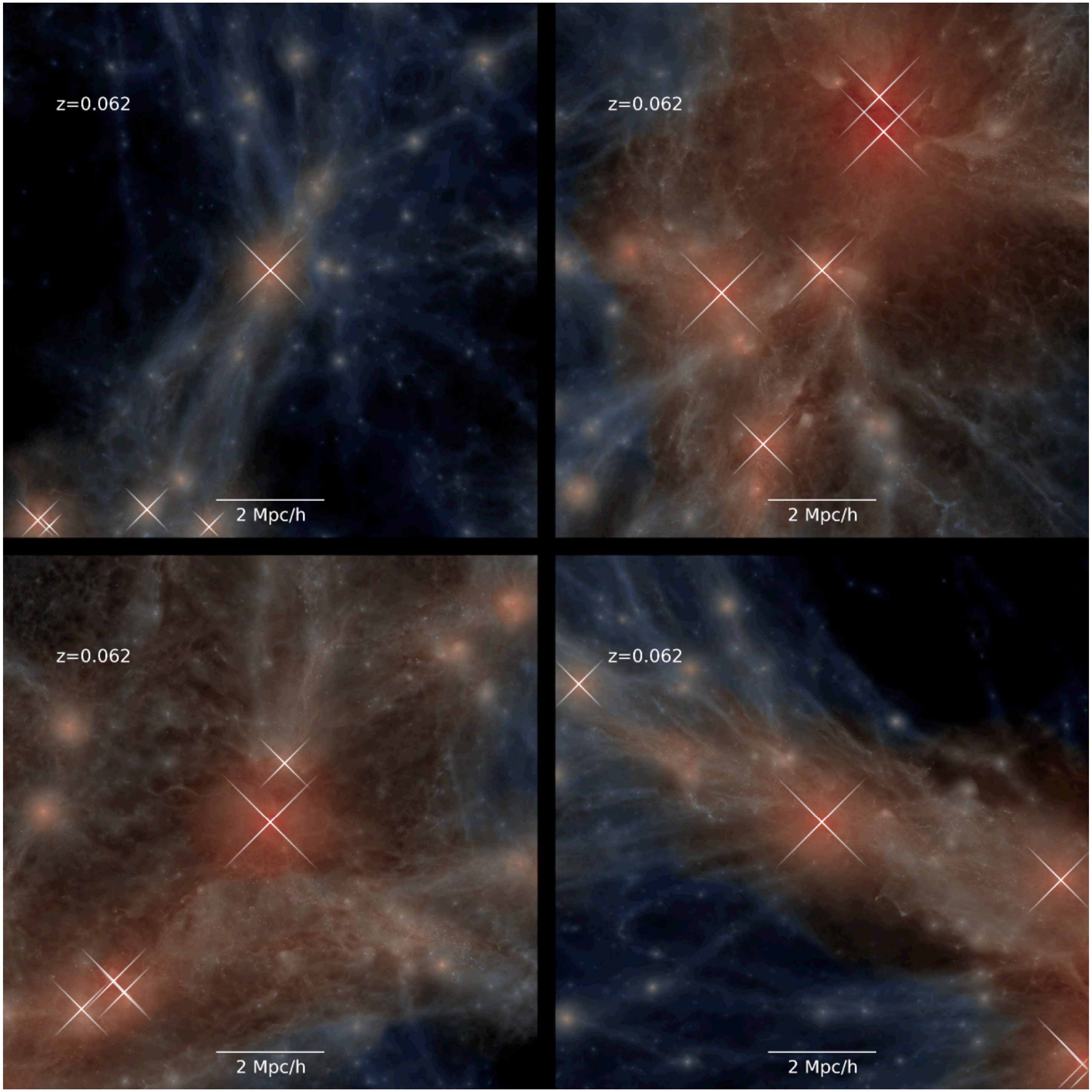
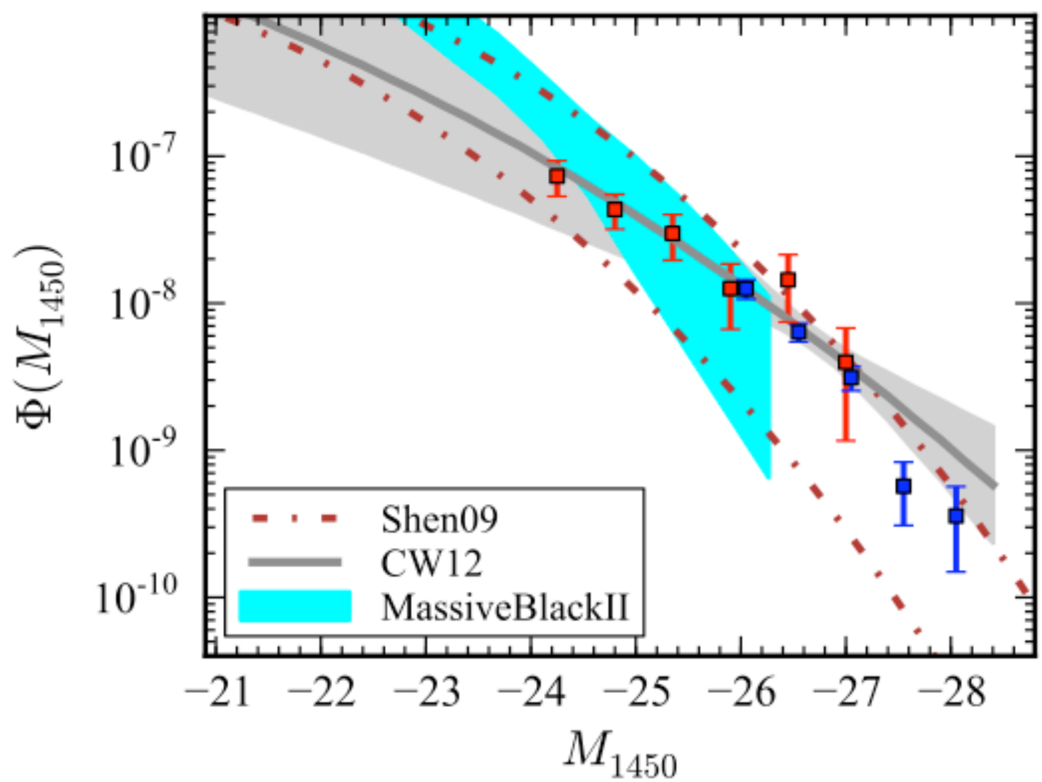
2 Mpc/h


z=0.062
2 Mpc/h
z=0.062
2 Mpc/h
z=0.062
2 Mpc/h
z=0.062
2 Mpc/h

Quasar Luminosity Function

"new" Sloan - Stripe 82 'faint' z=5 quasars

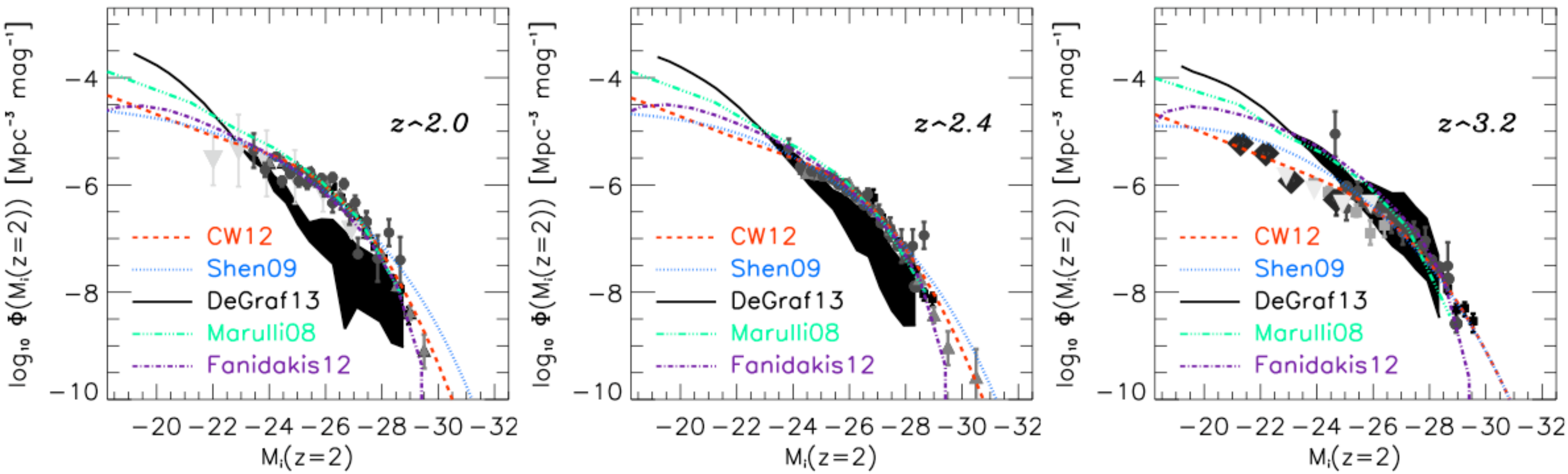


McGreer et al. 2013

Quasar Luminosity Function

- z = 2 - 4

Ross et al. '12

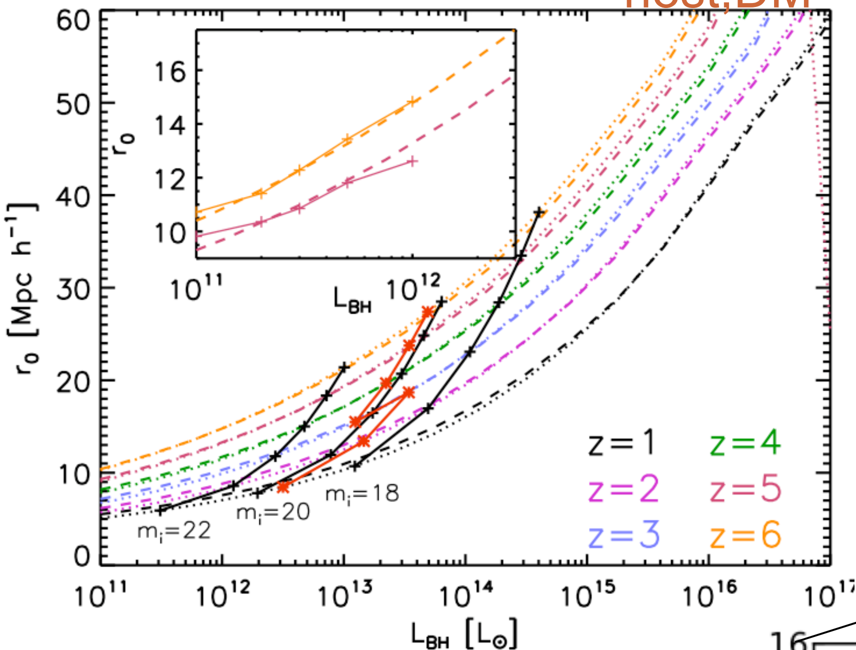


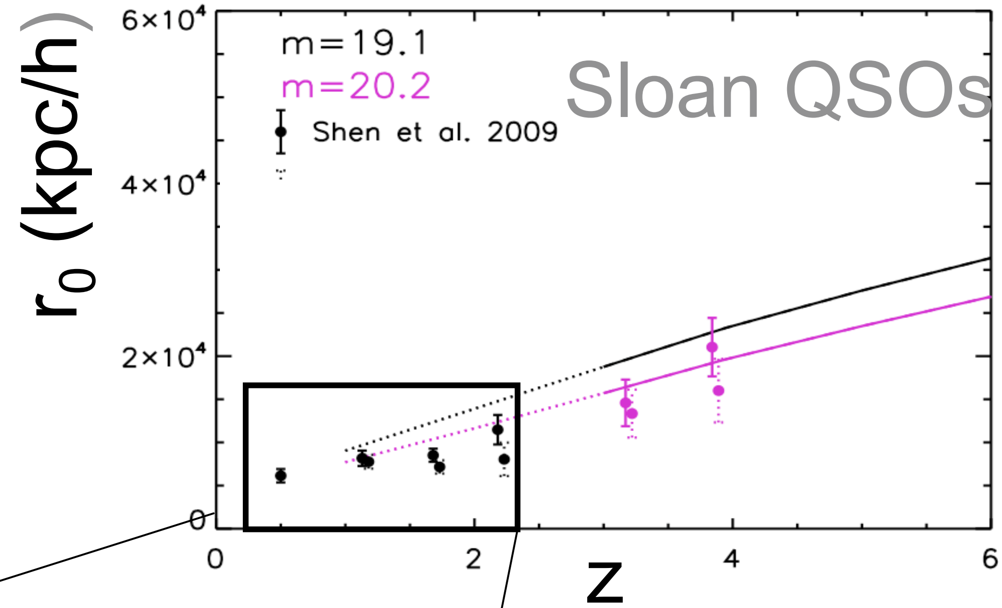
Simulations: confront BOSS (SDSS III)

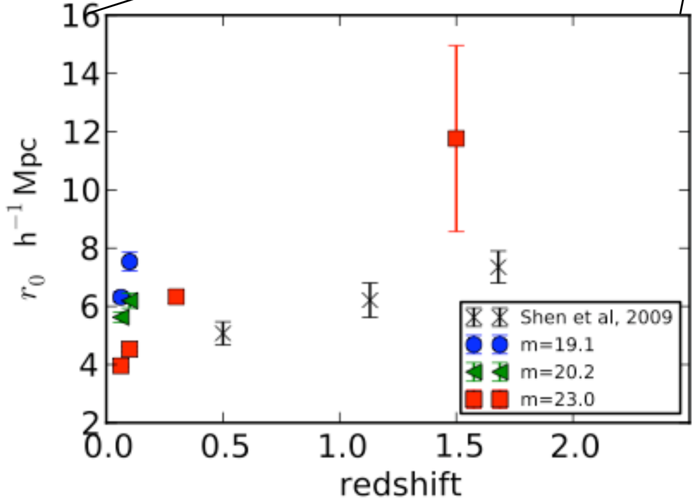
Quasar clustering: Large scales

$M_{host,DM} \sim 10^{12.5\text{-}13}\ M_{sun}$

DeGraf et al. 2012



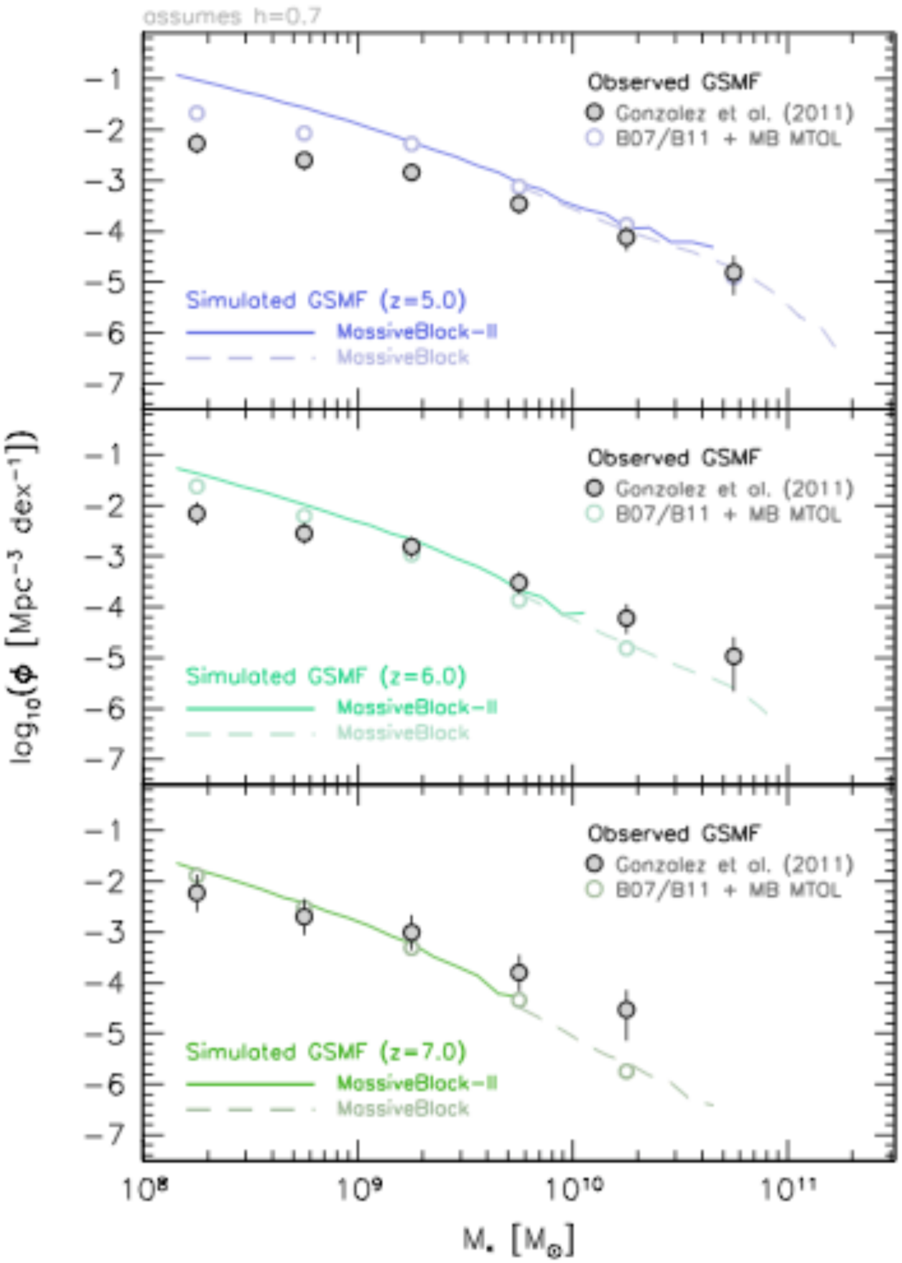




Preliminary MBII

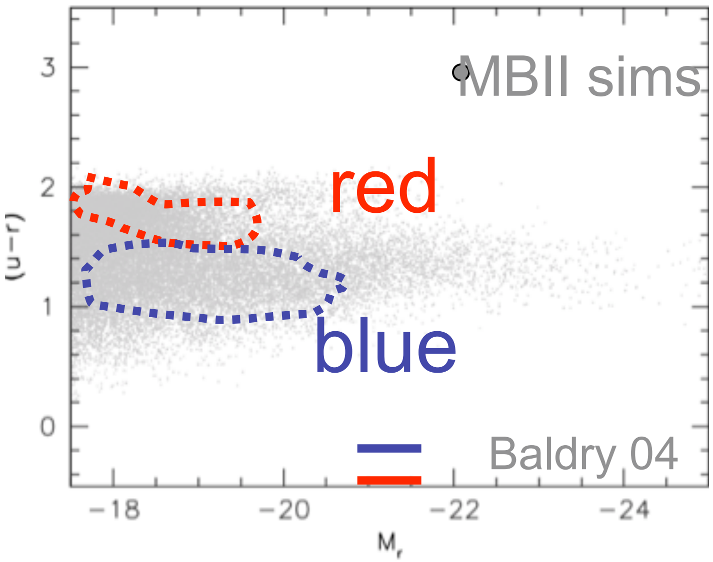
What about the galaxies?

The high-z Galaxy Stellar Mass finction

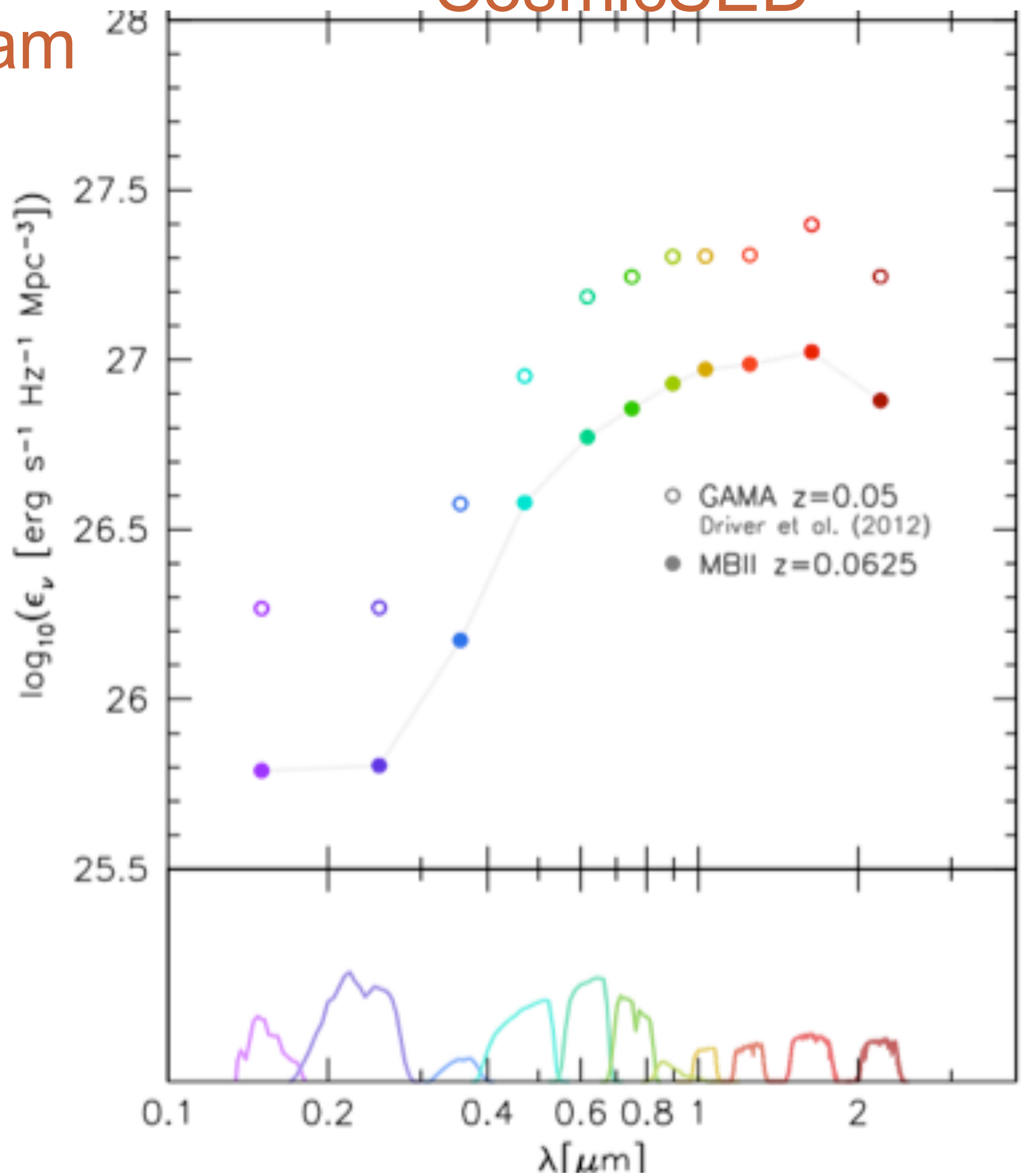


MBII galaxies

Color-Mag. Diagram



CosmicSED



Summary & Conclusions:

- BH growth and evolution = f (Galaxy formation)+
  Minimal assumptions

No major tension with the overall BH assembly history and structure/galaxy formation

- First quasars, the BH population, LFs, clustering and M-sigma relation all consistent with our standard structure formation.

- Eddington accretion can be sustained during first large halo formation.
- Highest BH accretion = high gas densities = high z
- MBHs grows 'first'

- BH Feedback crucial for self-regulation/M-sigma
  now need … now we need to understand more….