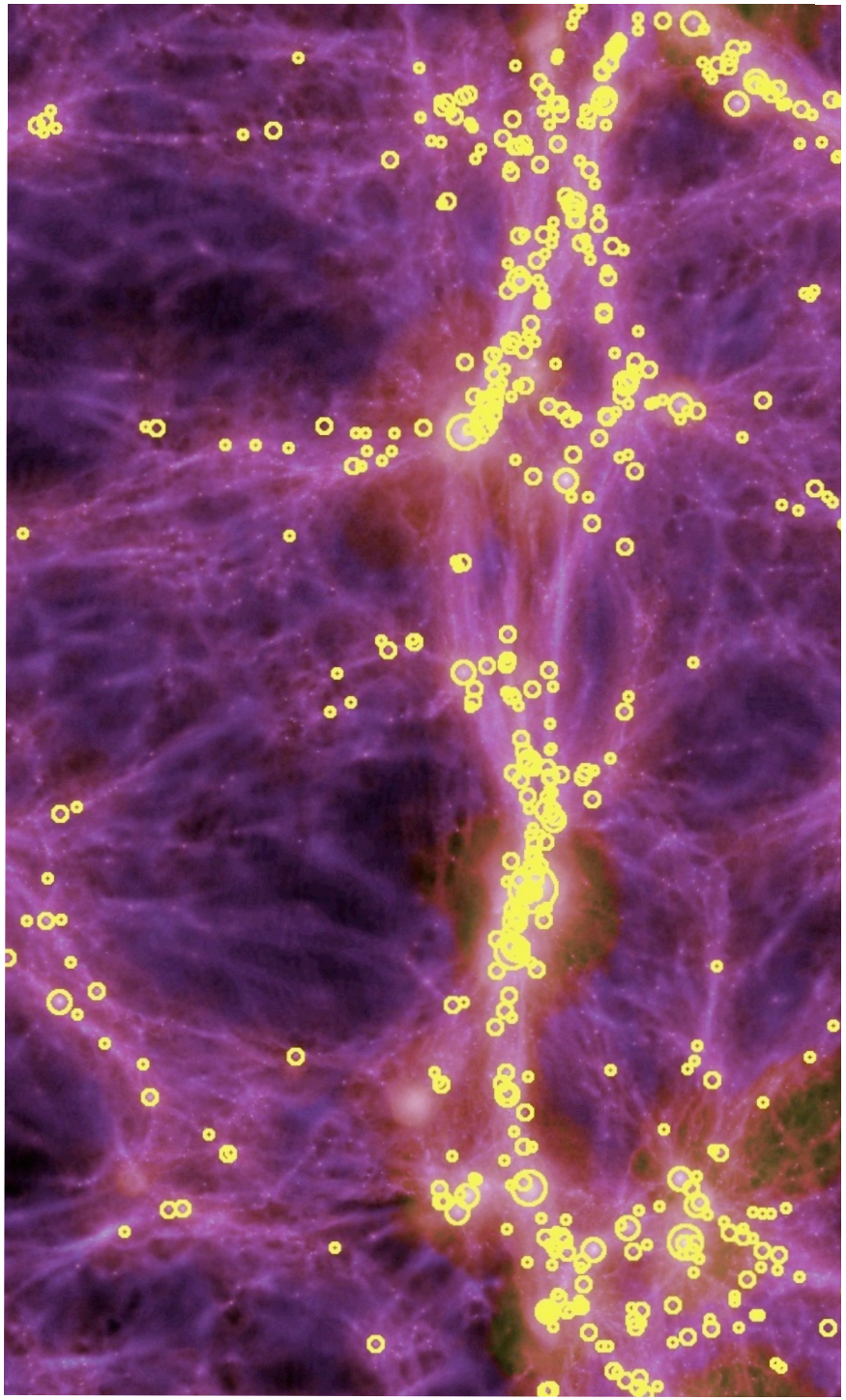
Cold Flows and the First quasars

Tiziana Di Matteo

BRUCE AND ASTRID MCWILLIAMS
Center for Cosmology
Carnegie Mellon

C. DeGraf, Y. Feng, N. Khandai,
R. Croft, (CMU), T. Kimm, Y. Dubois,
J. Devriendt, R. (Oxford),
V. Springel, R. Teyssier



SMBHs

Stars (bulges) /galaxies

DM halos?

$R_{Sch}=2GM_{BH}/c^2$

$R_{grav}=2GM_{BH}/\sigma^2$

microparsec/parsec

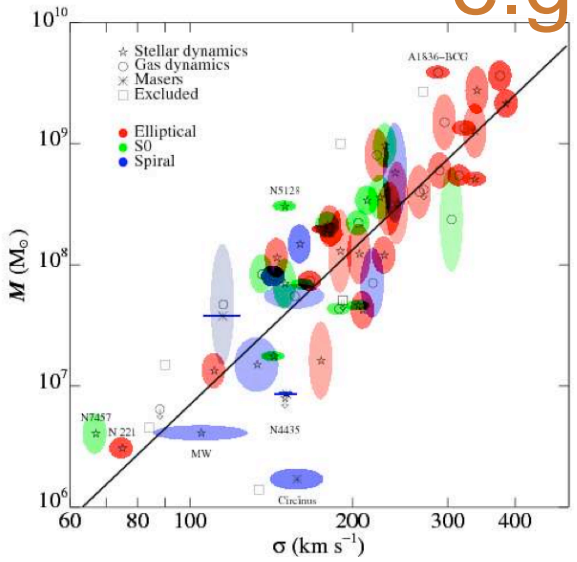
$R_{Sch}=2GM*/\sigma^2$

kiloparsec

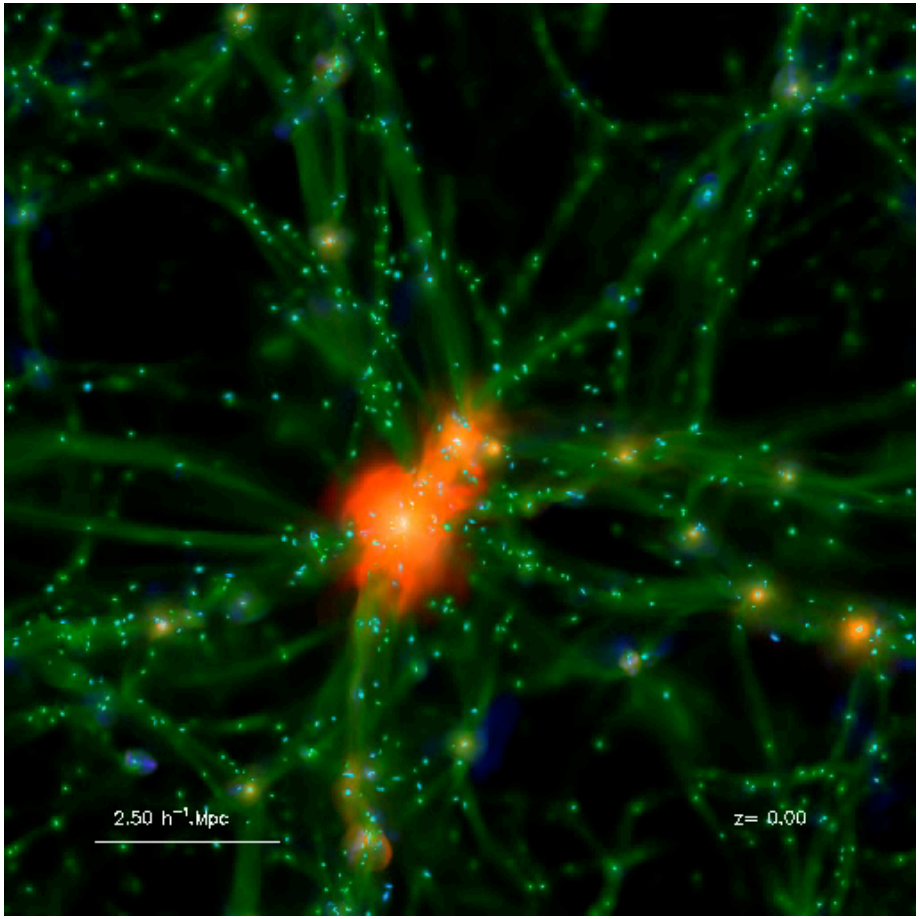
$R_{Sch}=2GM_{Halo}/\sigma^2$

megaparsec

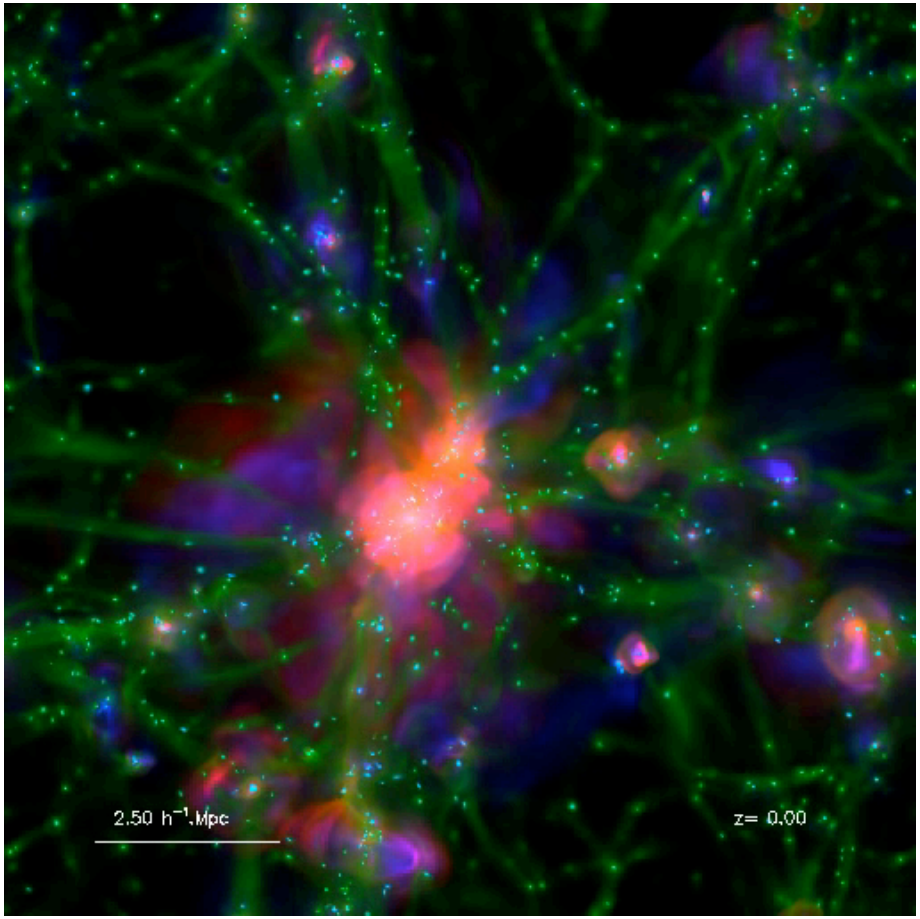
e.g.



Structure Formation Simulations…



W/o BHs



With BHs

Dubois, Teyssier
Devrient, Slyz et al.

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?

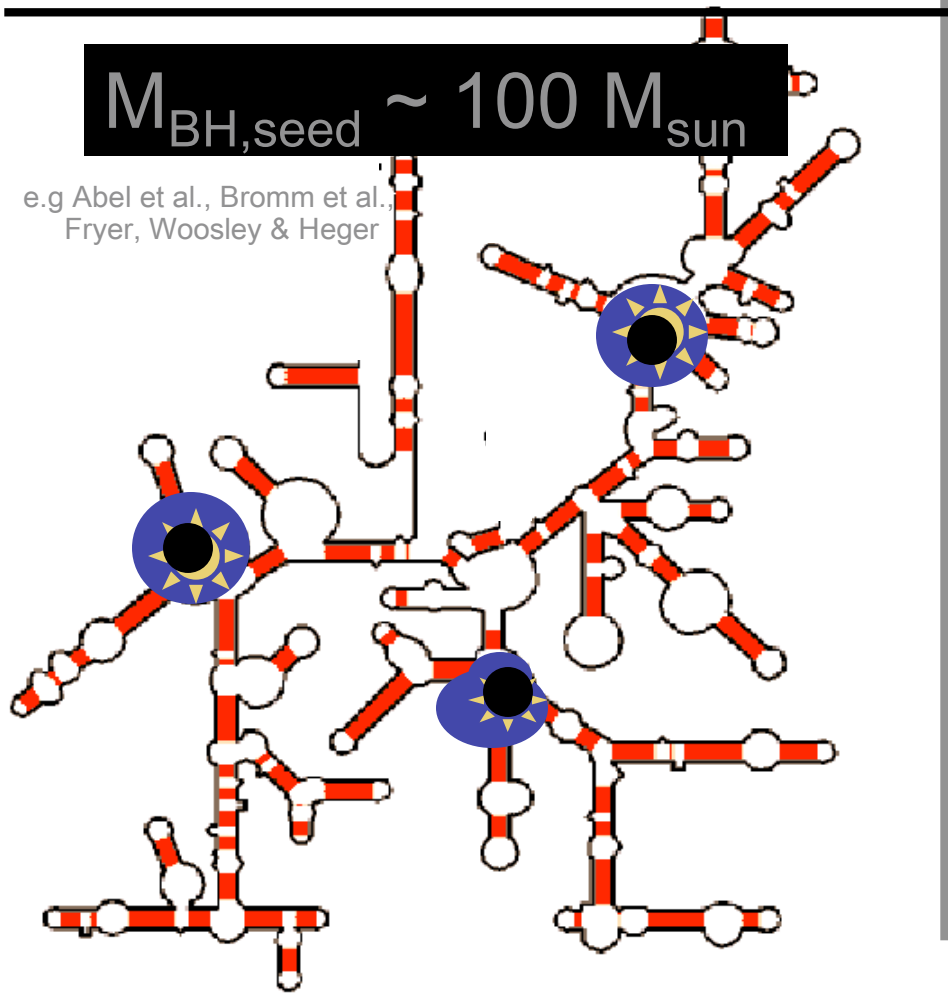
What is the formation path of MBH seeds?
When did they form? Where? Light or heavy?

PopIII stars remnants

e.g. Madau & Rees 01
Volonteri Haardt, Madau 03

$M_{BH,seed} \sim 100\ M_{sun}$

e.g Abel et al., Bromm et al.,
Fryer, Woosley & Heger



What is the formation path of MBH seeds?
When did they form? Where? Light or heavy?

PopIII stars remnants

e.g. Madau & Rees 01
Volonteri Haardt, Madau 03

Gas dynamical processes
Direct collapse

e.g Eisentein &Loeb 95, Bromm & Loeb 2003, Koushiappas etal 04, Begelman et al, 06, Natarajan 06

$M_{BH,seed} \sim 100\ M_{sun}$

e.g Abel et al., Bromm et al., Fryer, Woosley & Heger

$M_{BH,seed} \sim 10^3\text{-}10^5\ M_{sun}$

In biased protogalaxies

… this is all we have for the ICs for MBH in models of galaxy formation…

Key Questions:

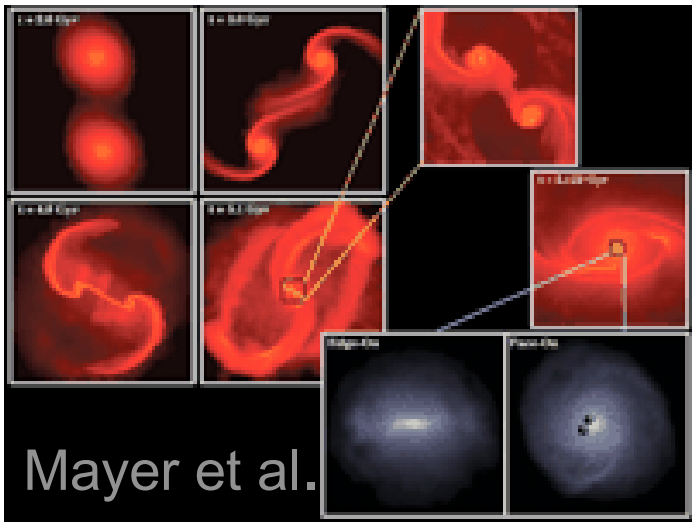
What is the formation path of MBH seeds?
When did they form? Where? Light or heavy?

How/ where do MBH grow and shine?

How/ where do MBHs seeds grow?

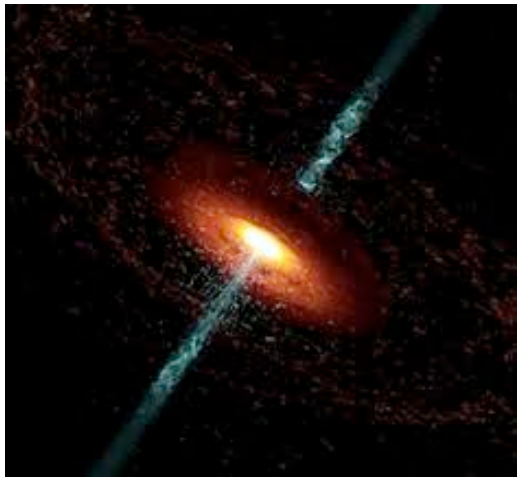
BH-BH mergers

BH mass density
almost constant with time
some reshuffle in the mass function..



Gas Accretion

Total mass density of BHs
grows with time.

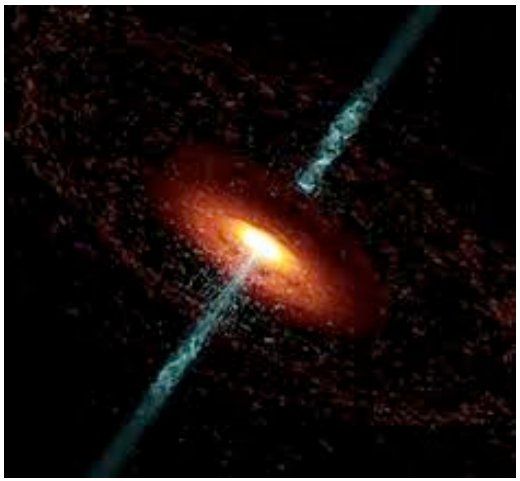


How/ where do MBHs seeds grow?

Gas Accretion

Total mass density of BHs grows with time.

L_{BH} = efficiency $\dot{M}_{acc}$ c^2



Black hole Growth = Gas Supply = Activity

AGN feedback

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

First billion years requires extremely large accretion rates

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

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

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

$$= 10.17 \text{ e foldings}$$

Can Eddington rates be sustained at early times?

Checklist for BH growth

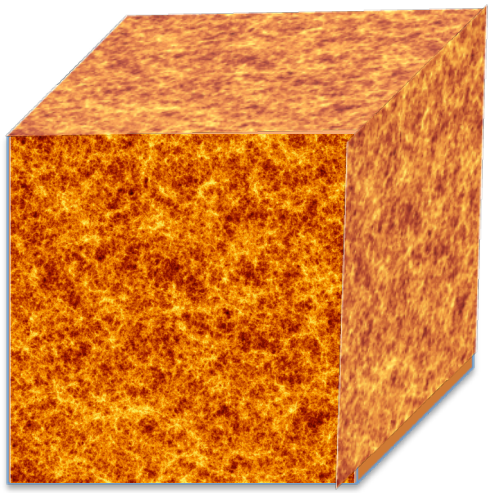
- ✓ biased regions → Large Volumes
- ✓ Galaxy scales → High Resolution
- ✓ Gas accretion → Hydrodynamics

…

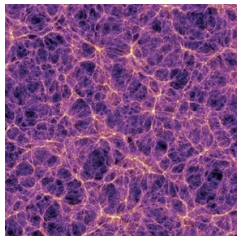
Cosmological Simulations with BH

	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..

Simulation: 'Massive Black' Run



-Code used: PetaGadget (Petapps Cosmology)
-Particle number: $2x3200^3$ = 64 billion
-Box size: 533 h^{-1} Mpc
-Physics: Smoothed Particle Hydrodynamics, cooling, star formation, feedback, black holes.



- Snapshots contain 12 times more data than the Millennium simulation.
- The simulation is >30 times larger than largest published SPH run.

- Run using the whole of Kraken at NICS (99072 compute cores).

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

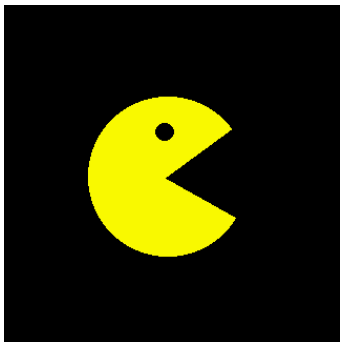
The MassiveBlack

visualization by Yu Feng

Our cosmological TimeMachine

BHs in SPH Simulations of Galaxy formation

DM, Springel, Herrnquist 05
Springel, DM, Hernquist 05



- **BH:** collisionless "sink" particle in the centre of galaxies $M_{BH(seed)}=10^5\ M_\odot$

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

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

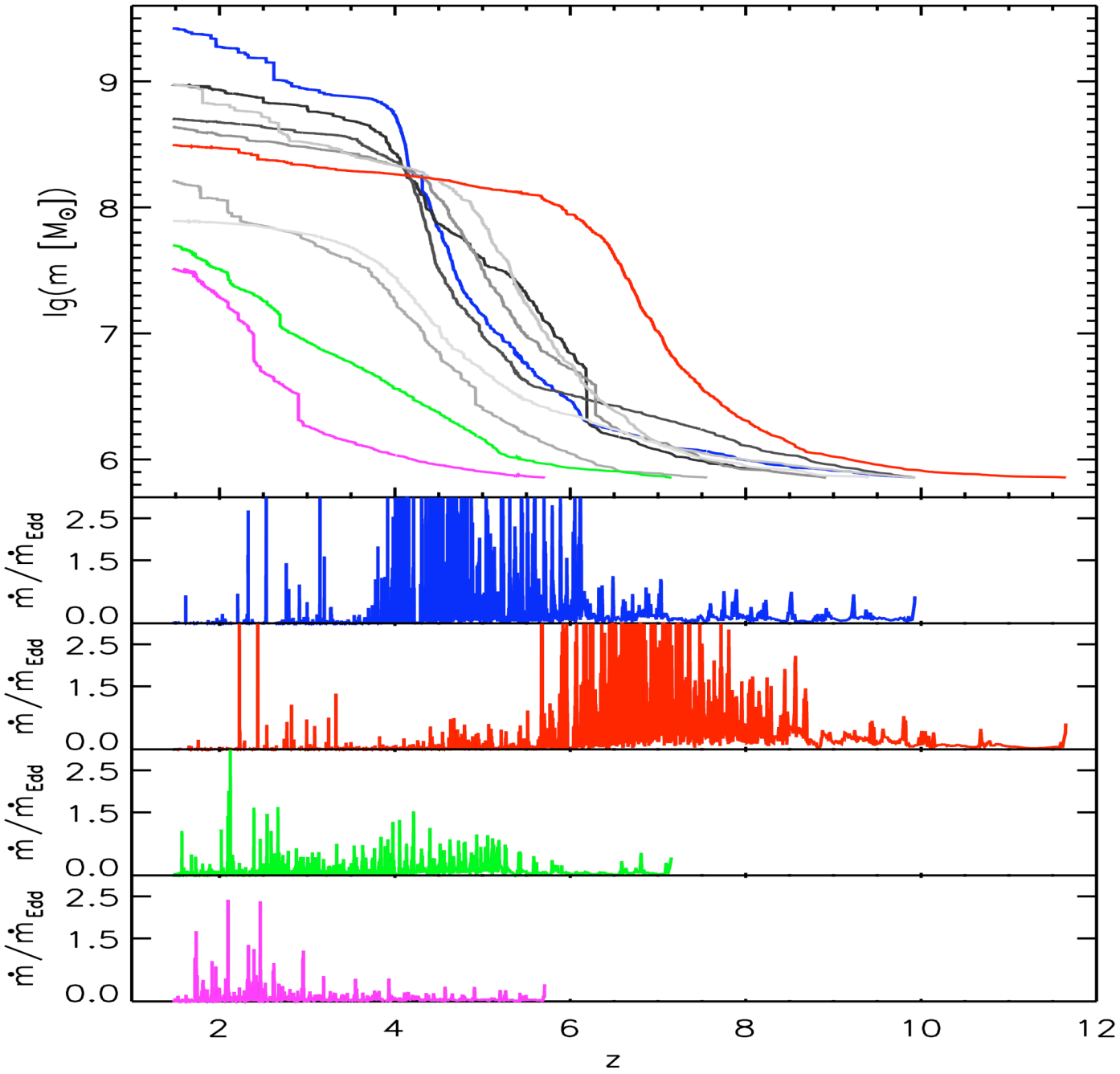
$$\dot{M}_{BH} = \min(\dot{M}_{Edd}, \dot{M}_B)$$

+ BH mergers

- **FEEDBACK:** energy extracted from the black hole (accretion) injected in the surrounding gas

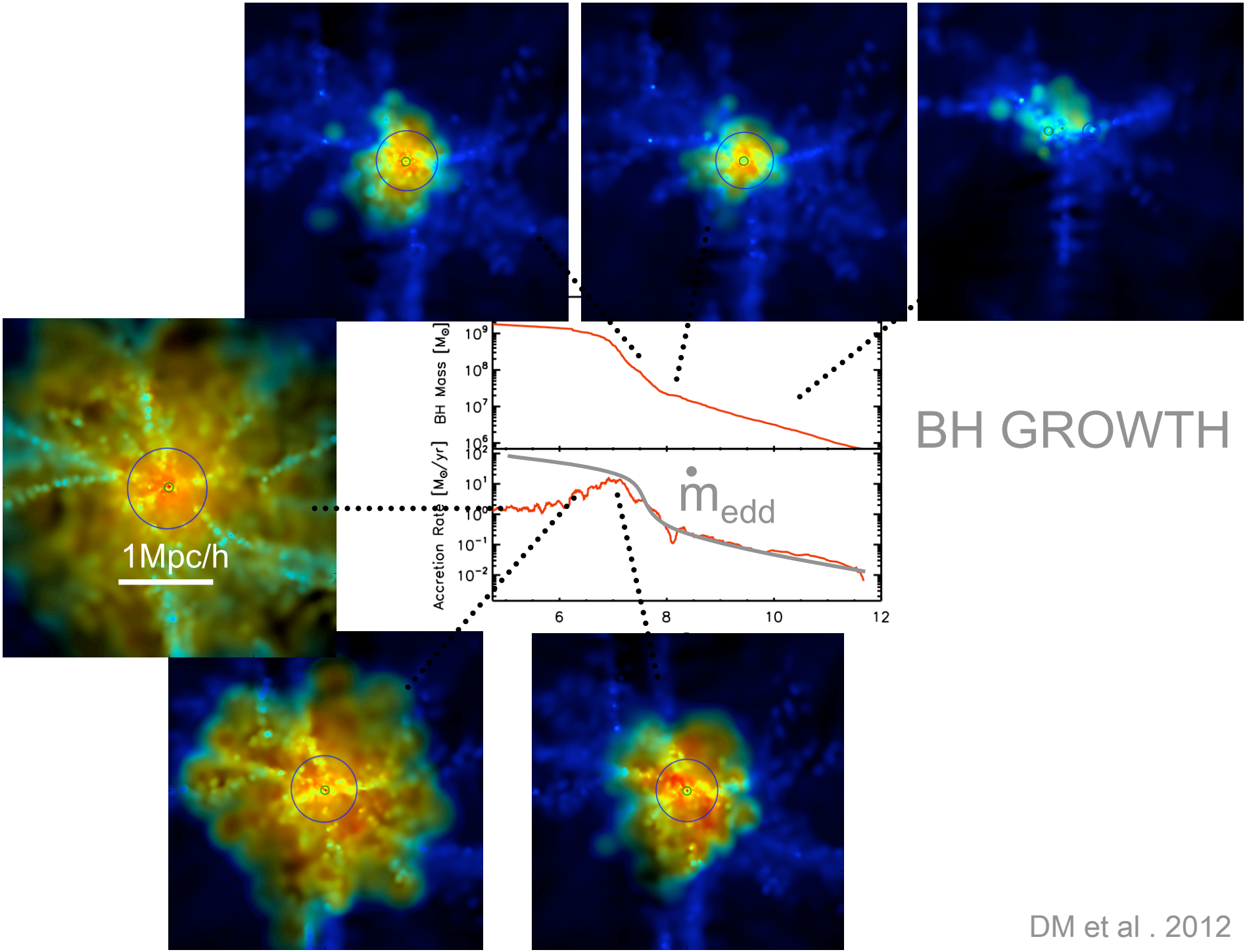
$$E_{feed} = f(\eta M c^2) \qquad f \approx 5\%$$

THE MASS ASSEMBLY HISTORY OF EACH BLACK HOLE



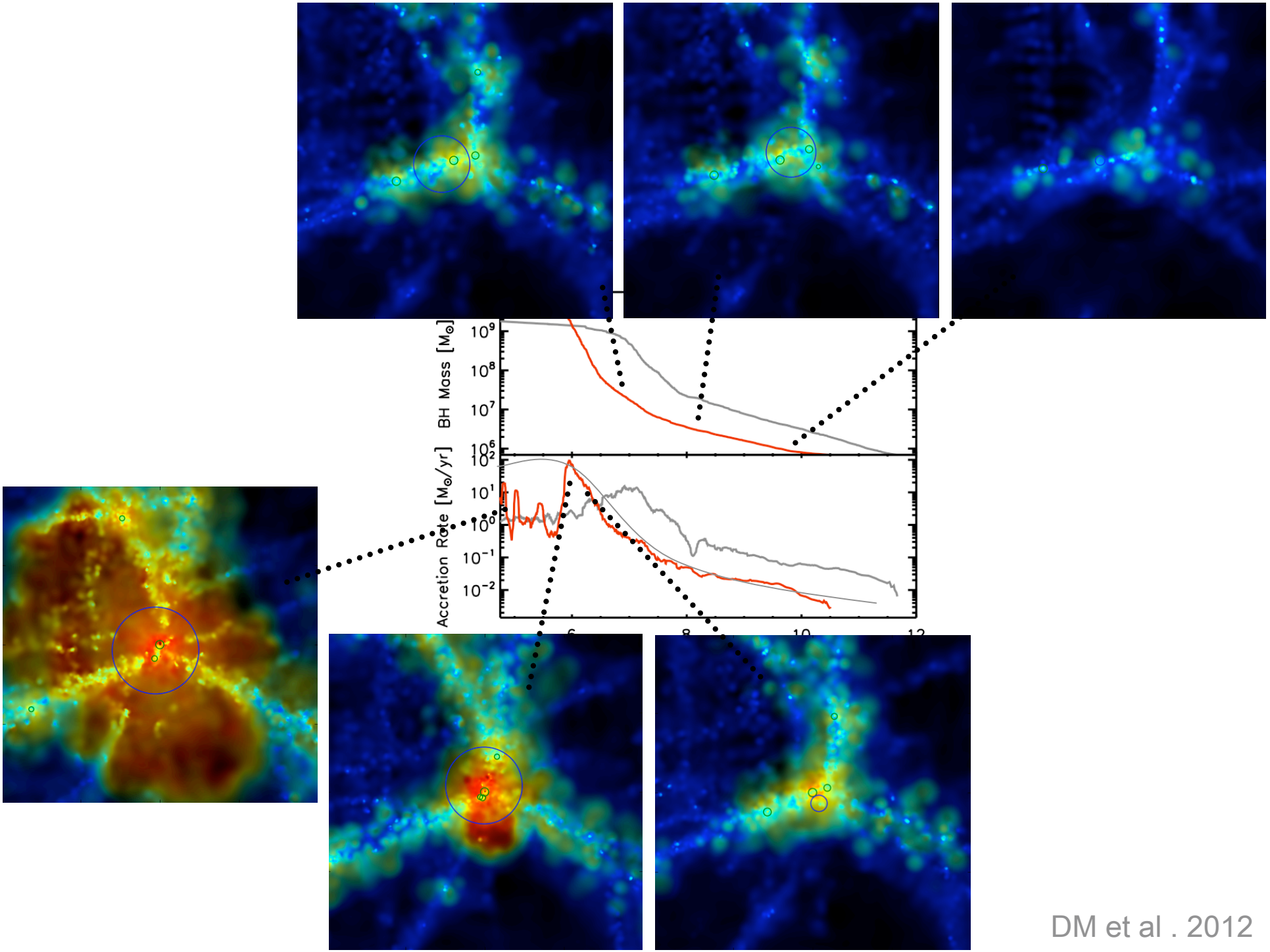
- Where are the descendants of early quasars today?
- What were they progenitors?

DM et al. 2008



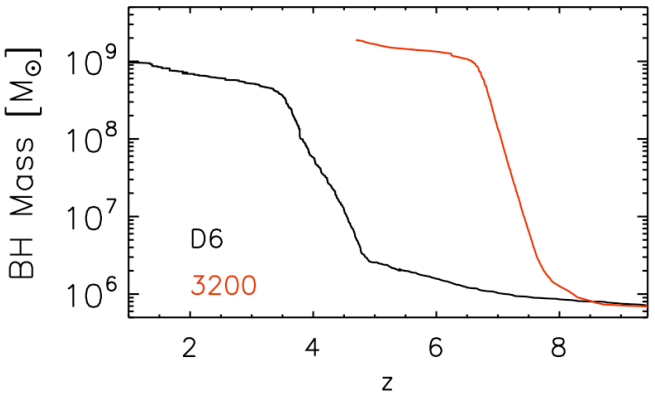
BH GROWTH

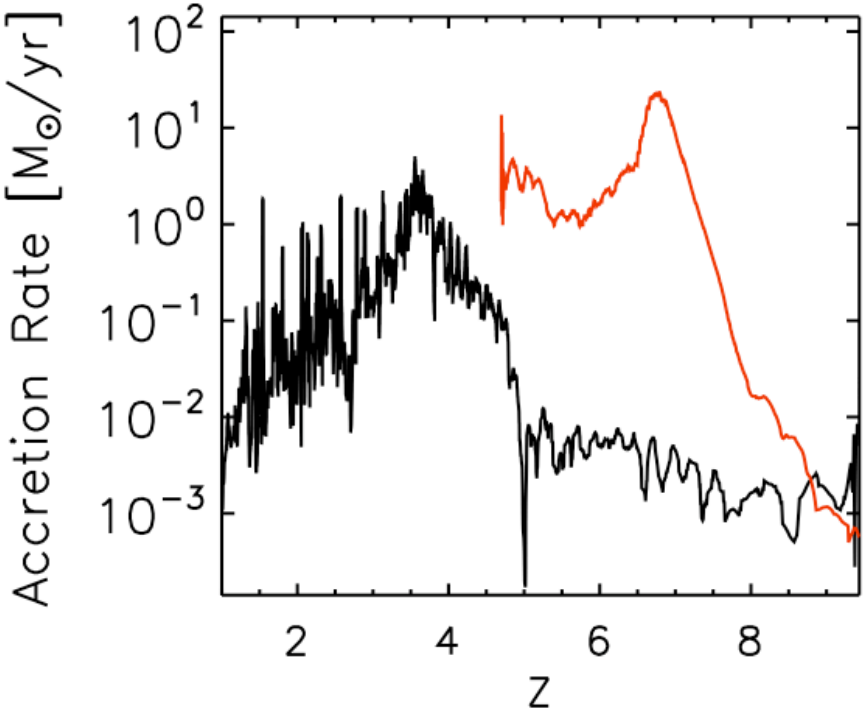
DM et al . 2012

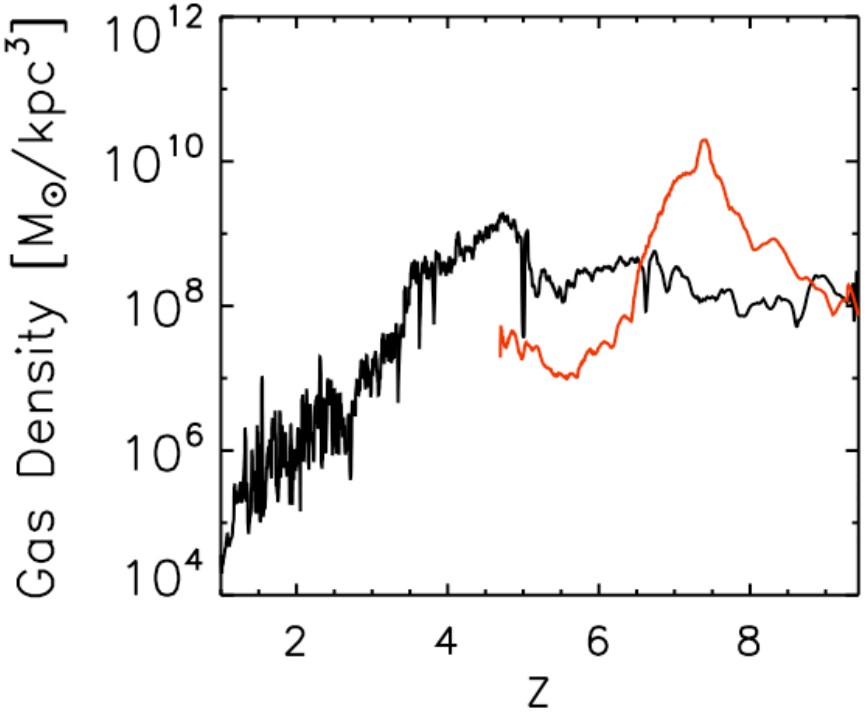


DM et al . 2012

First Quasars, MBHs assemble fast!



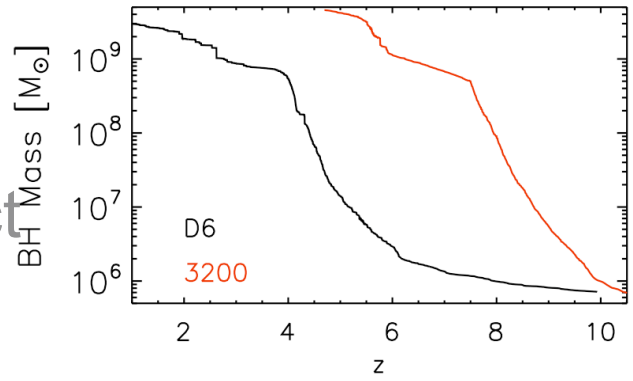


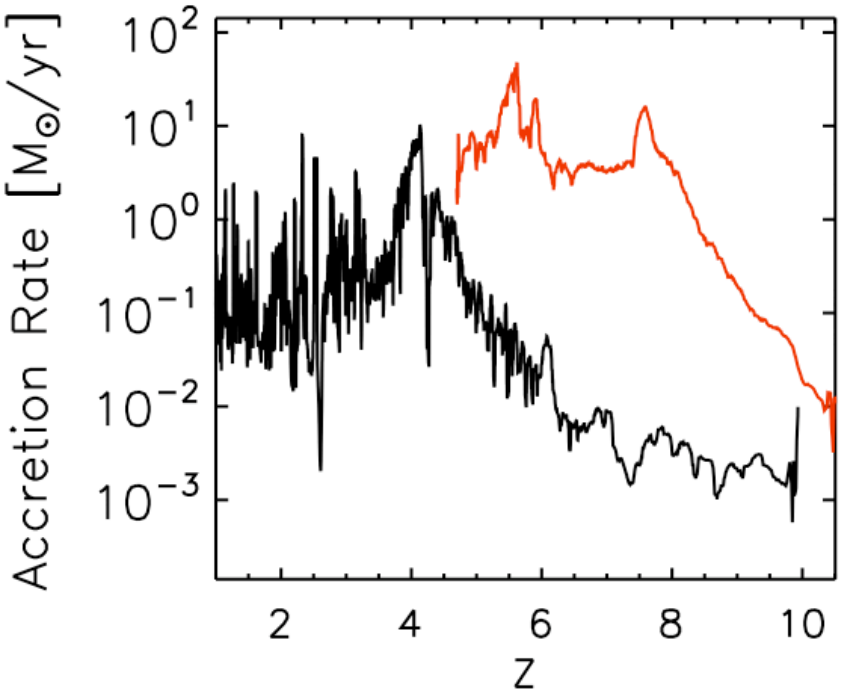


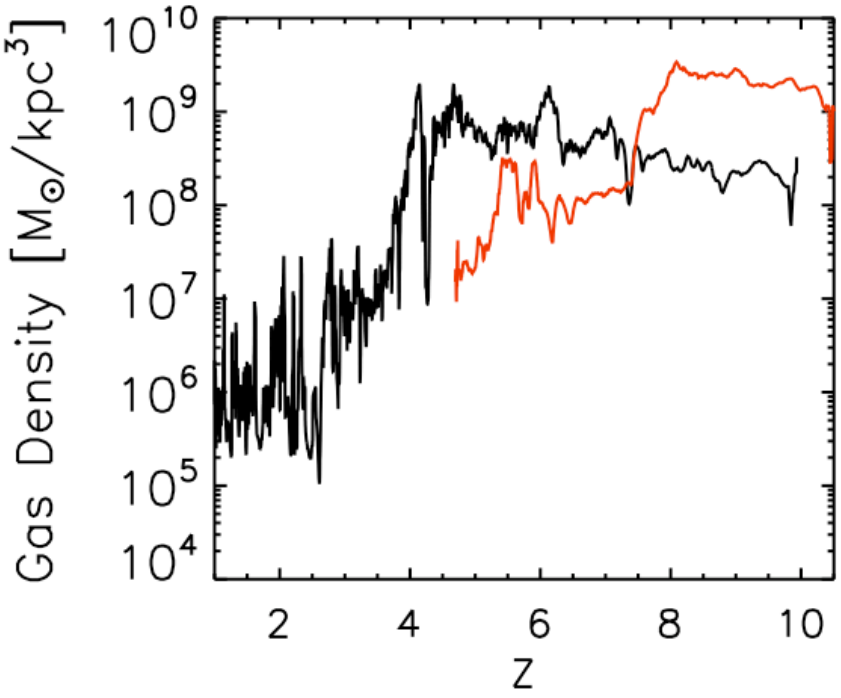
First Quasars, MBHs assemble fast!

- ✓Higher gas densities / cold flows
- ✓Steeper potentials for feeback to act

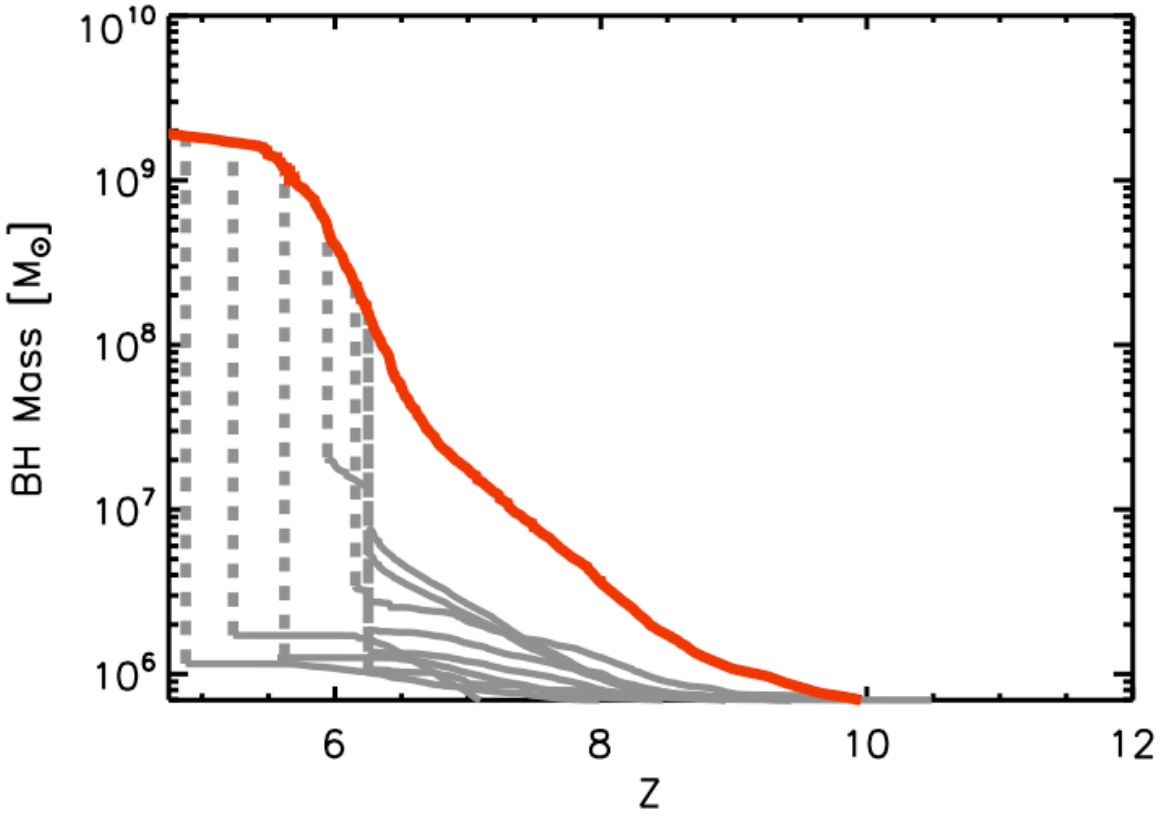
  - ➢ Z=6 quasars easy !







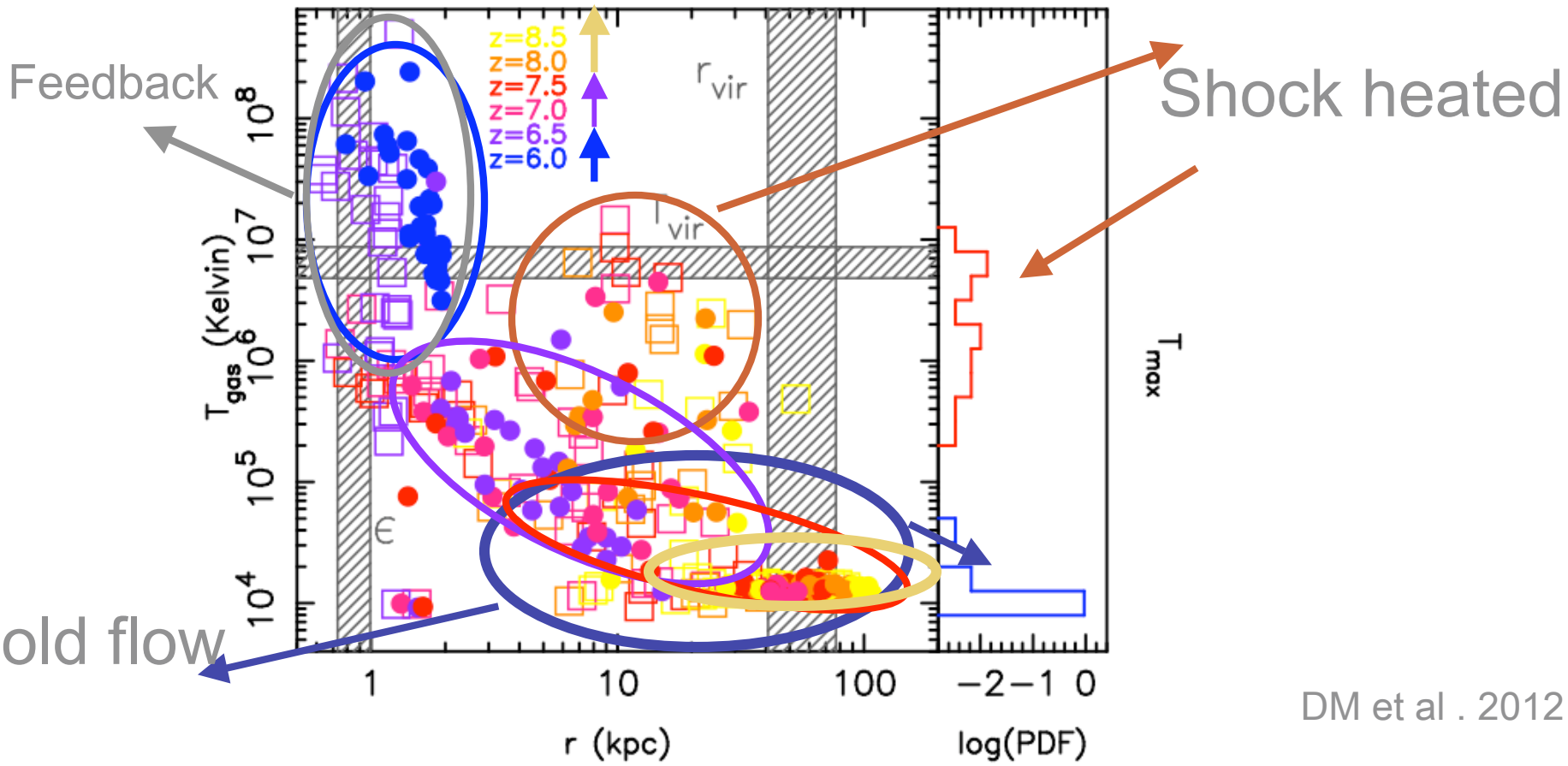
How/ where do MBHs grow?



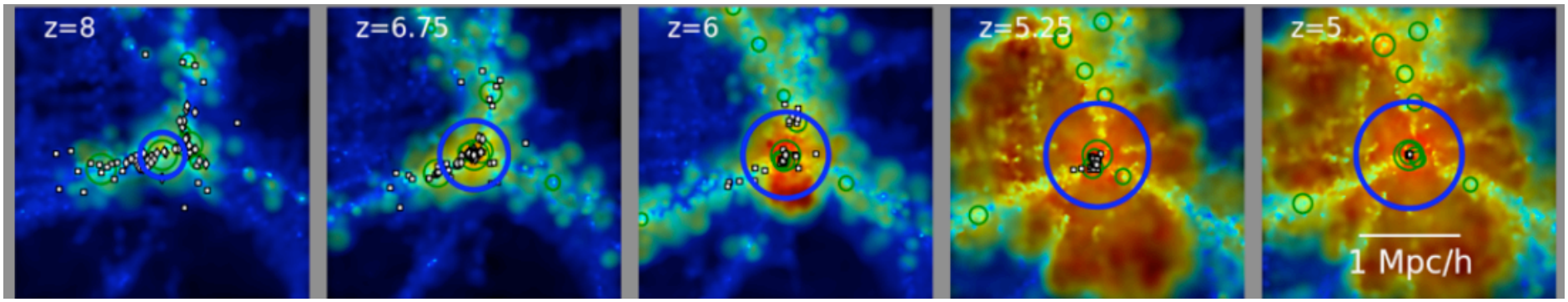
MBH mergers are rare events

Mass growth dominated by gas accretion (cf. Soltan's argument)

The history of the gas: accretion from cold flows

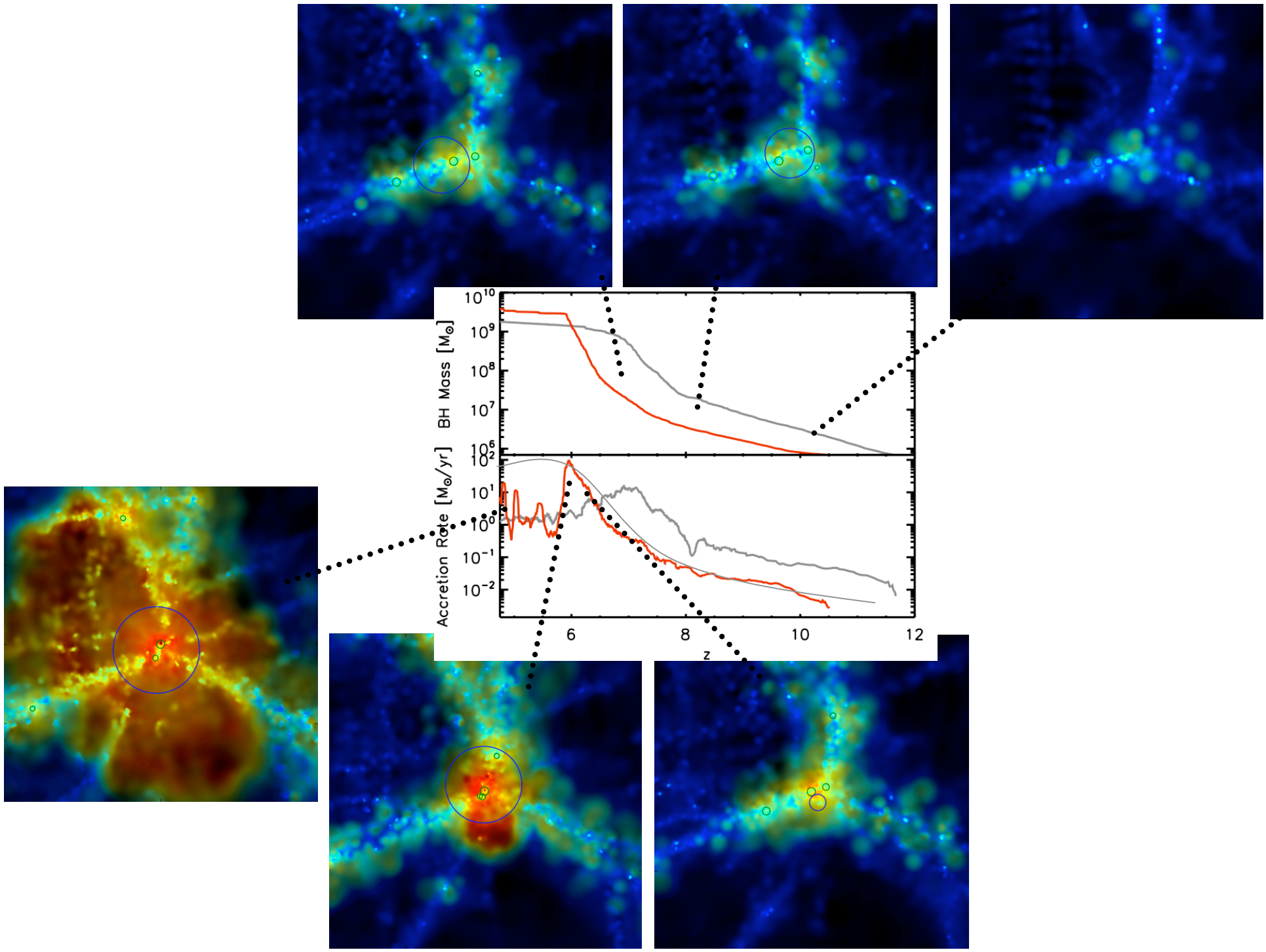


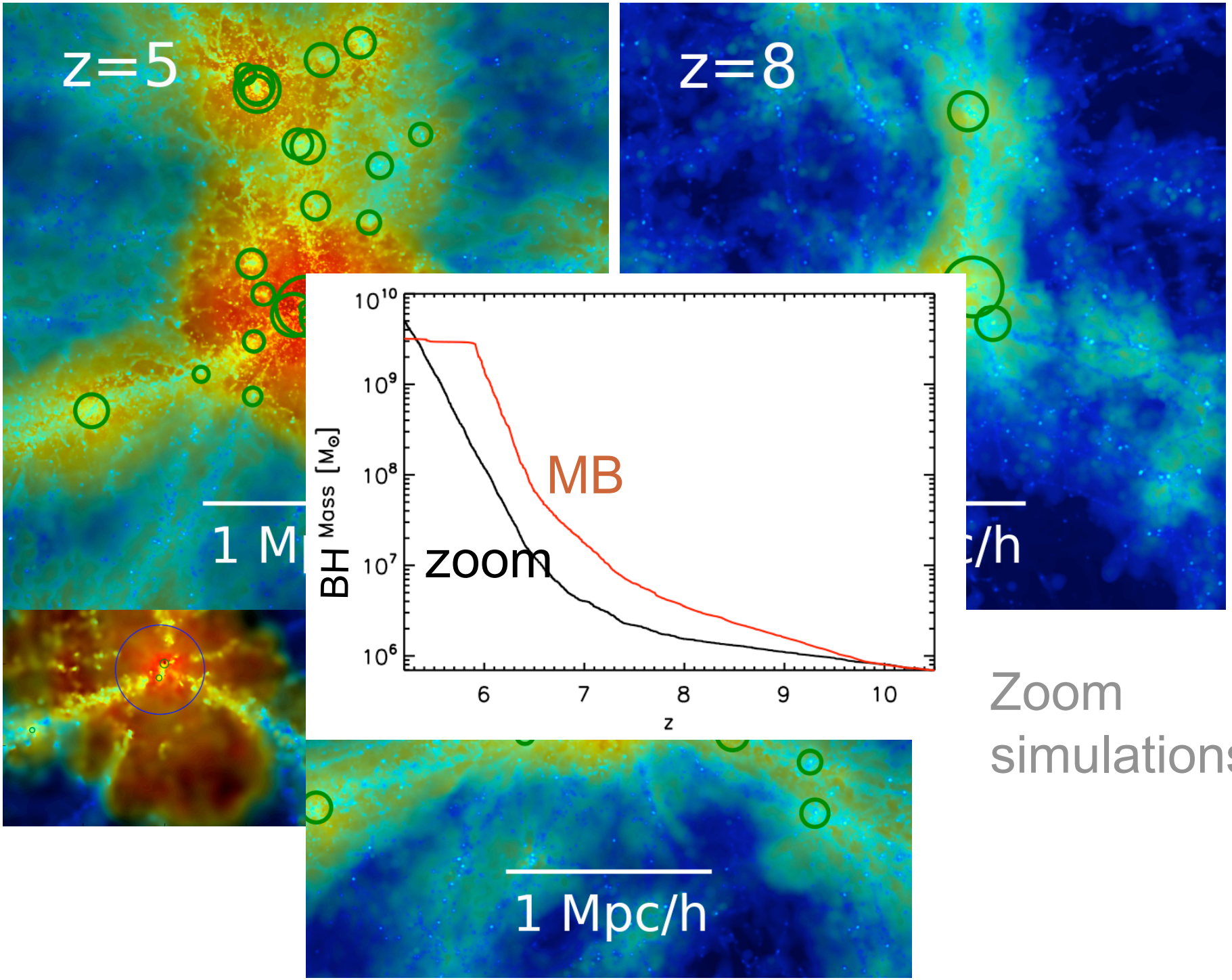
DM et al . 2012



Journey into the growth
of the first supermassive BHs:

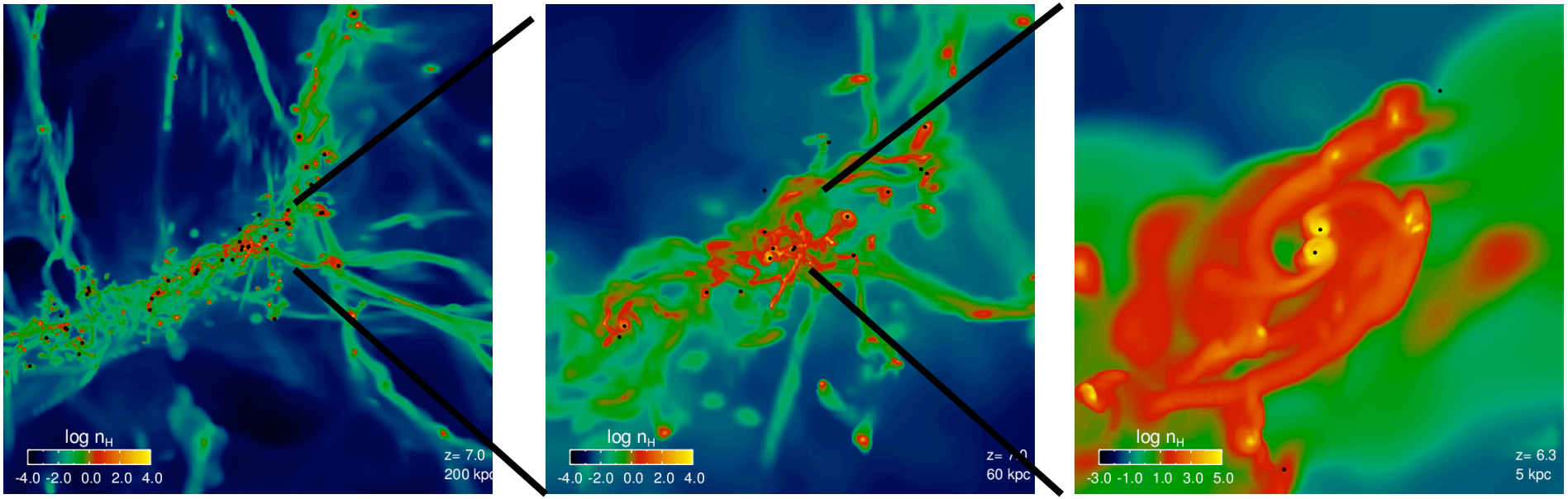
Zooming in


BH Mass [M⊙]
Accretion Rate [M⊙/yr]
z
6
8
10
12

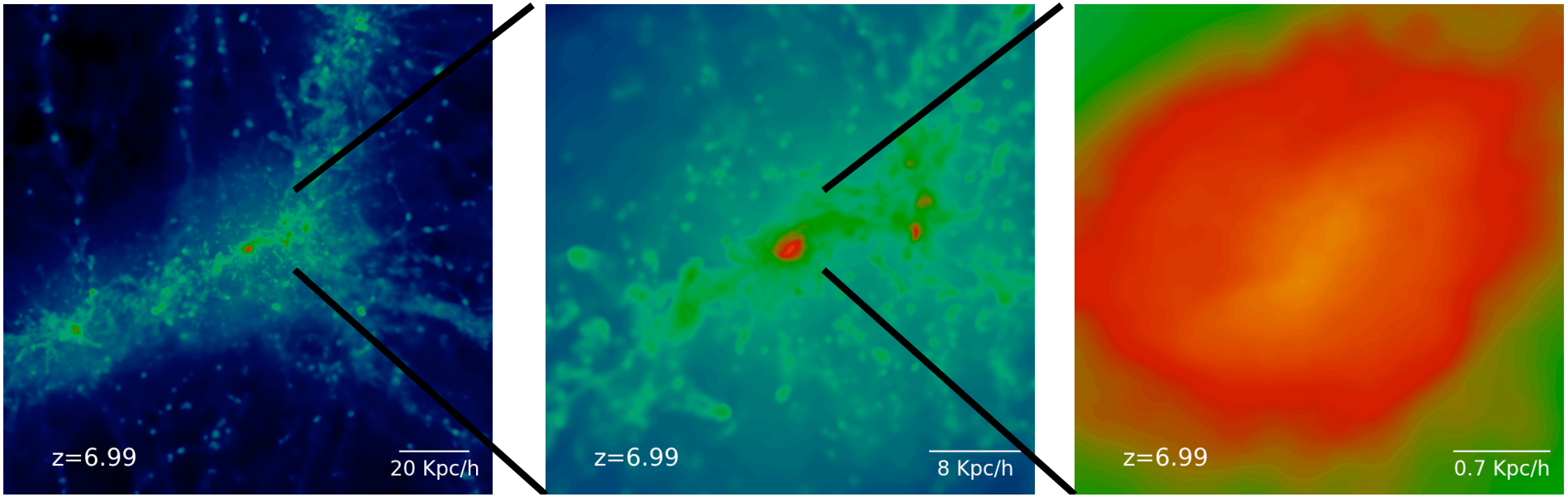


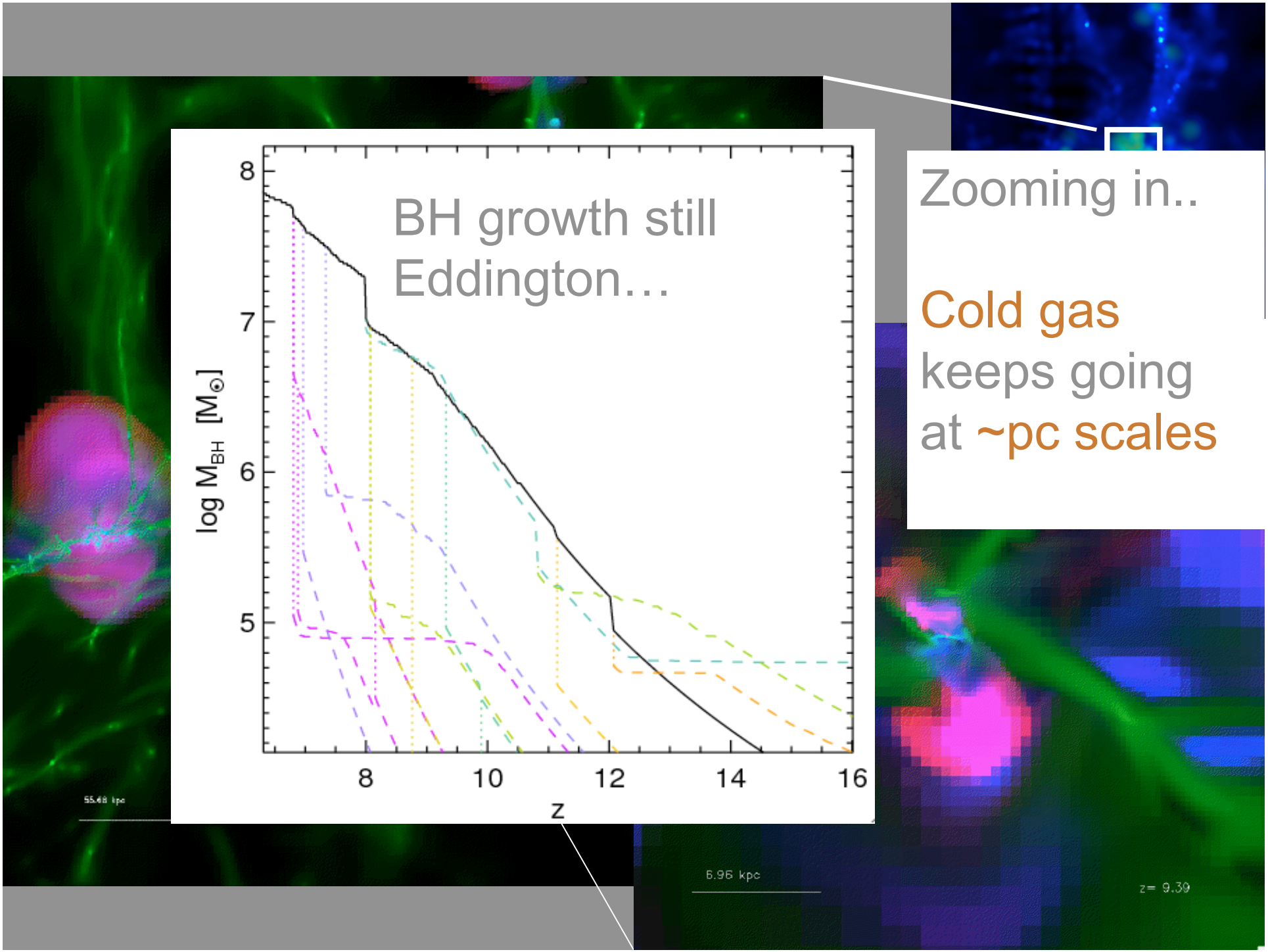
Zoom simulations

AMR (RAMSES) ZOOM vs

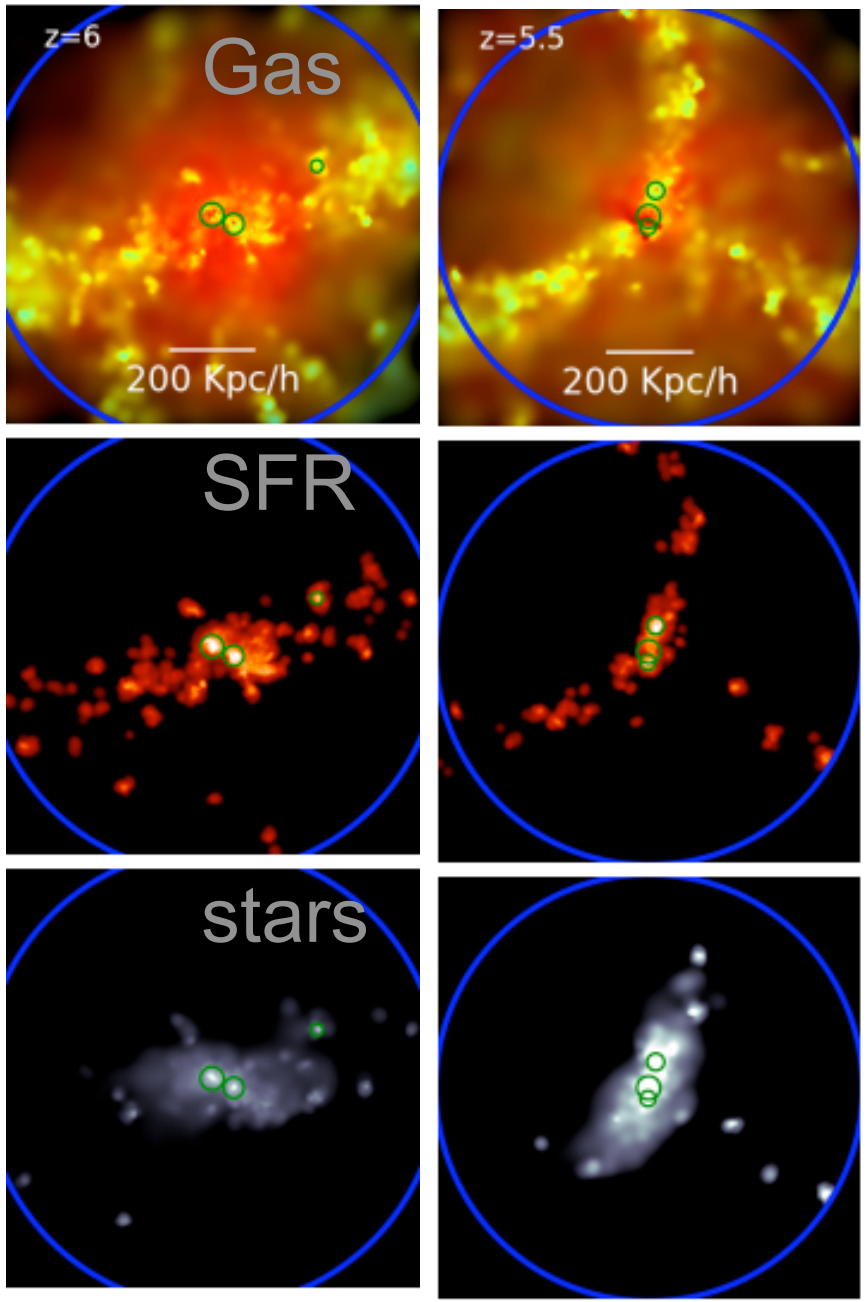


SPH (GADGET3) ZOOM



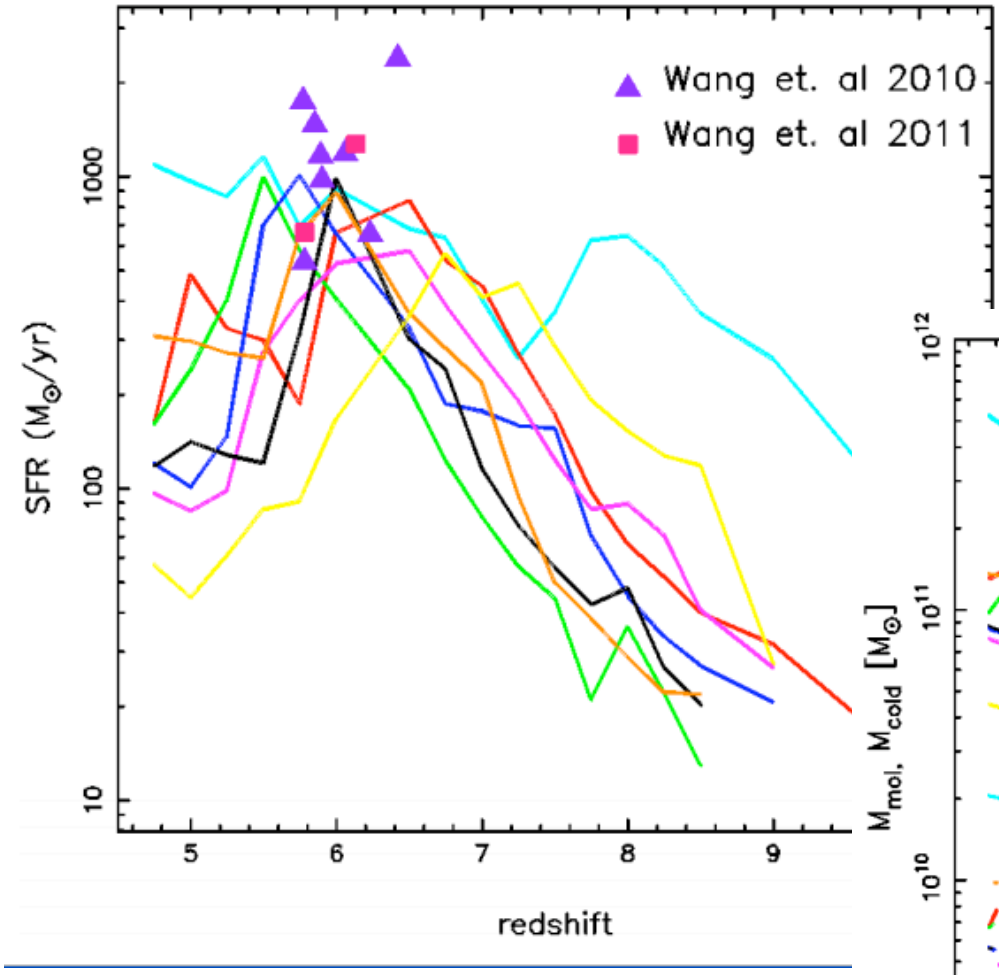

BH growth still Eddington…
log M_{BH} [$M_\odot$]
z
Zooming in..
Cold gas keeps going at ~pc scales
6.96 kpc
z= 9.39

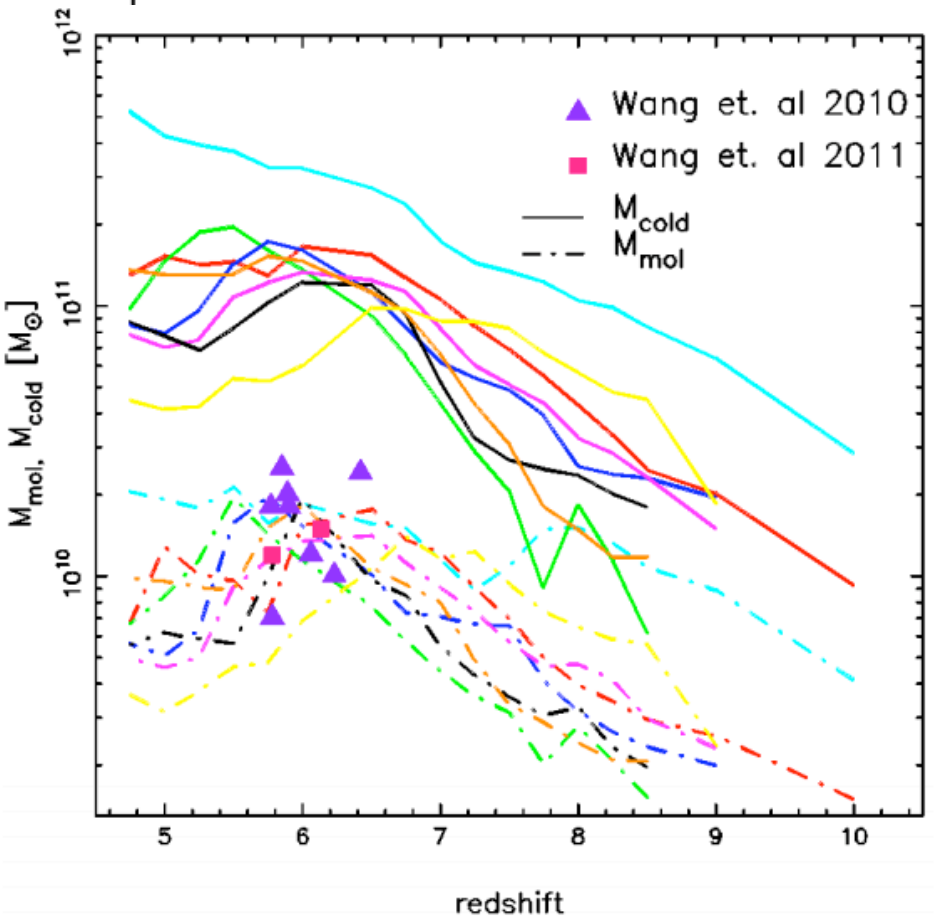
The first quasars and their hosts galaxies



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

Khandai et al. 2012





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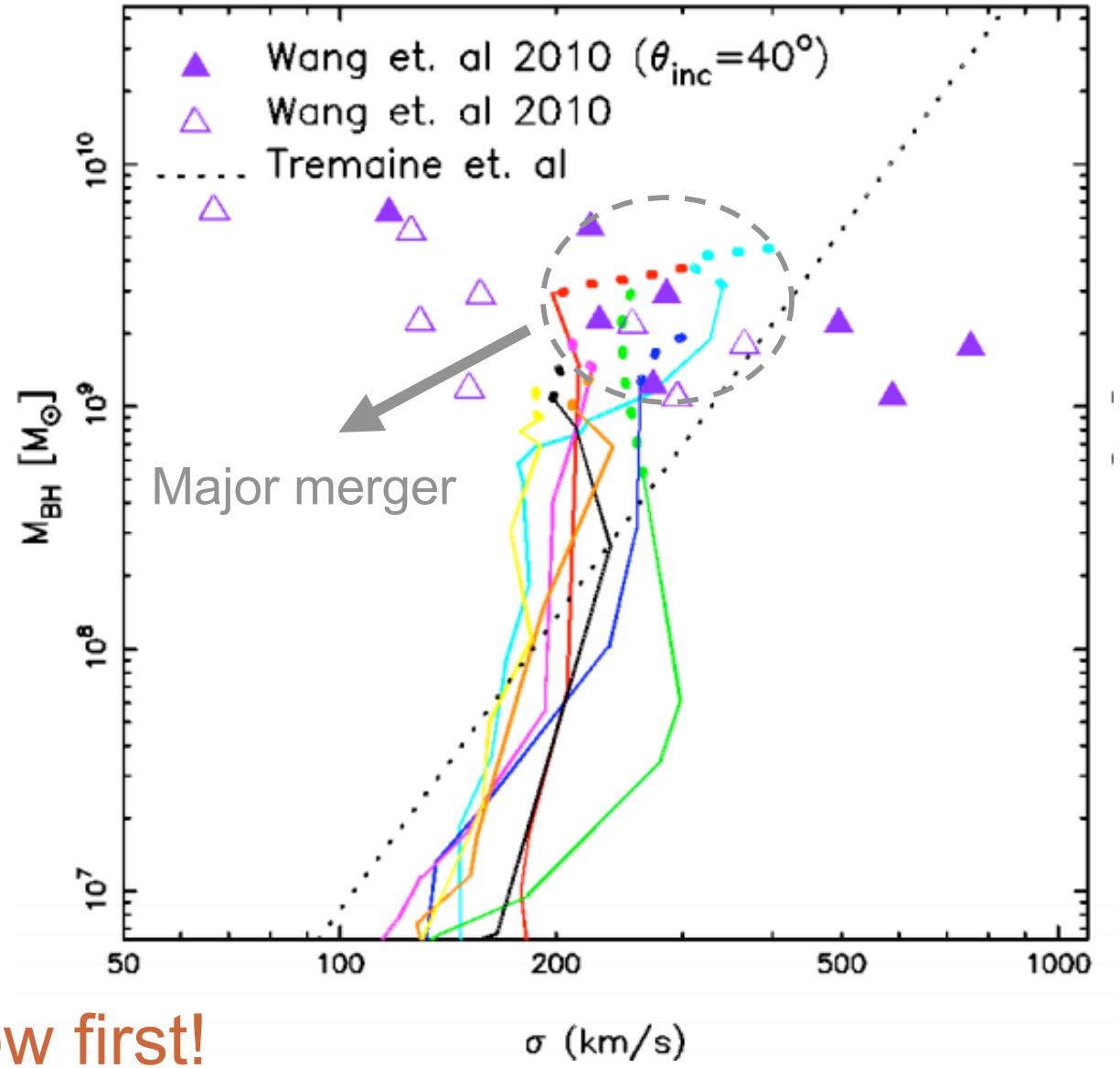

Black Holes grow first!

First Massive black holes, z=6 quasars

- where: first MBH grow in biased regions
- how: Critical accretion can be sustained due to cold gas accretion during first large halo formation
- MBHs grows ‘first’