MassiveBlack

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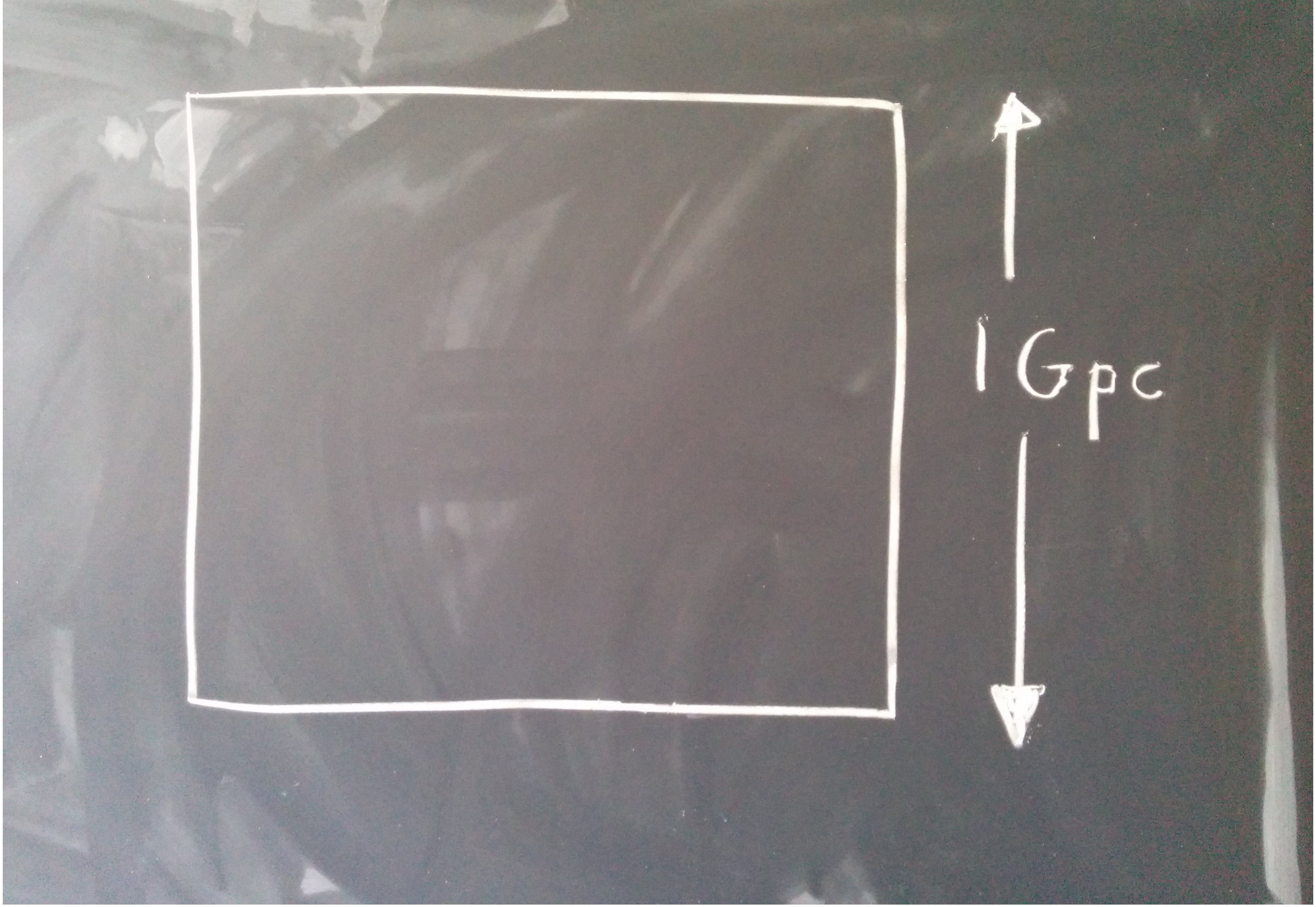
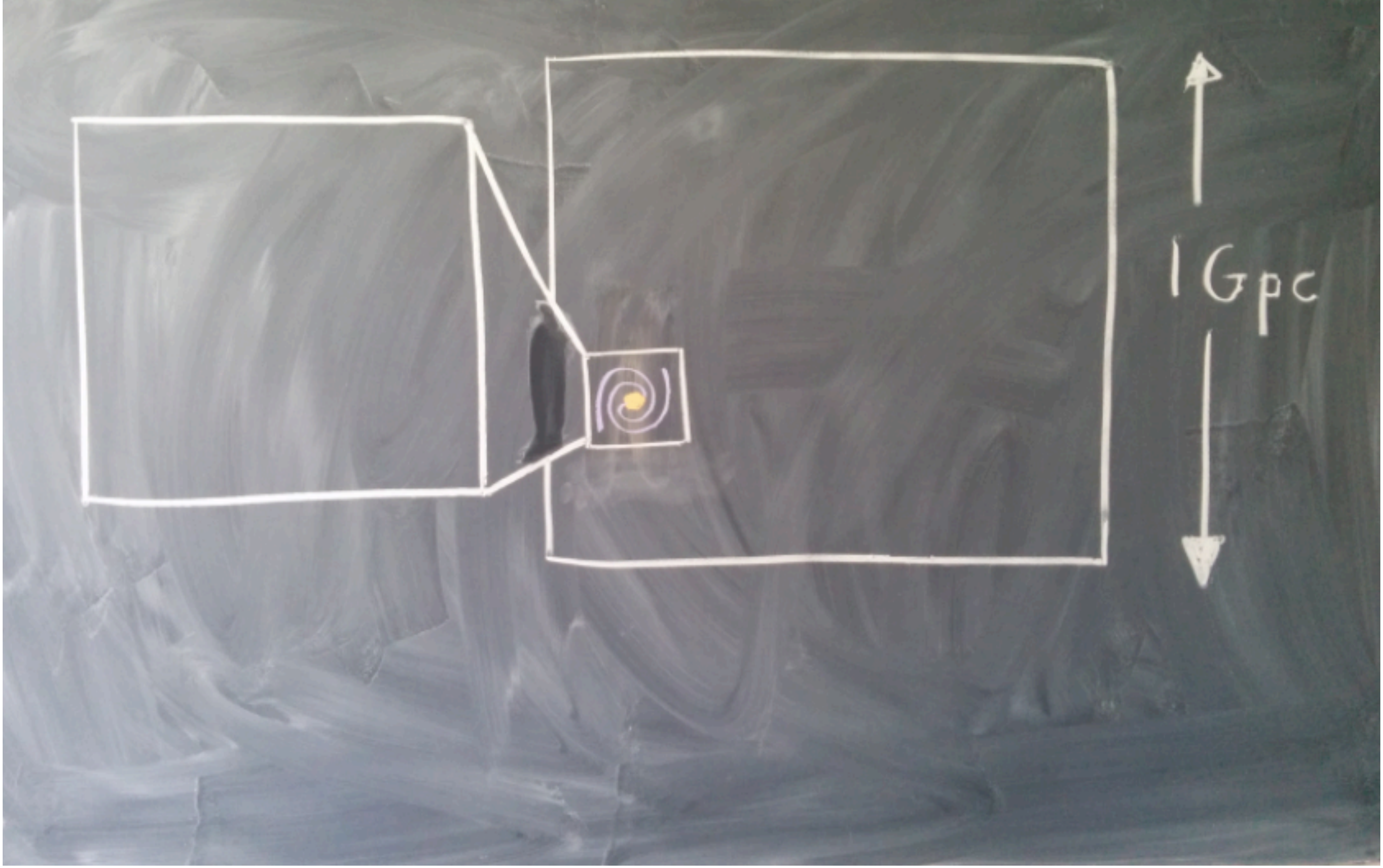
Public data store and simulation browser:

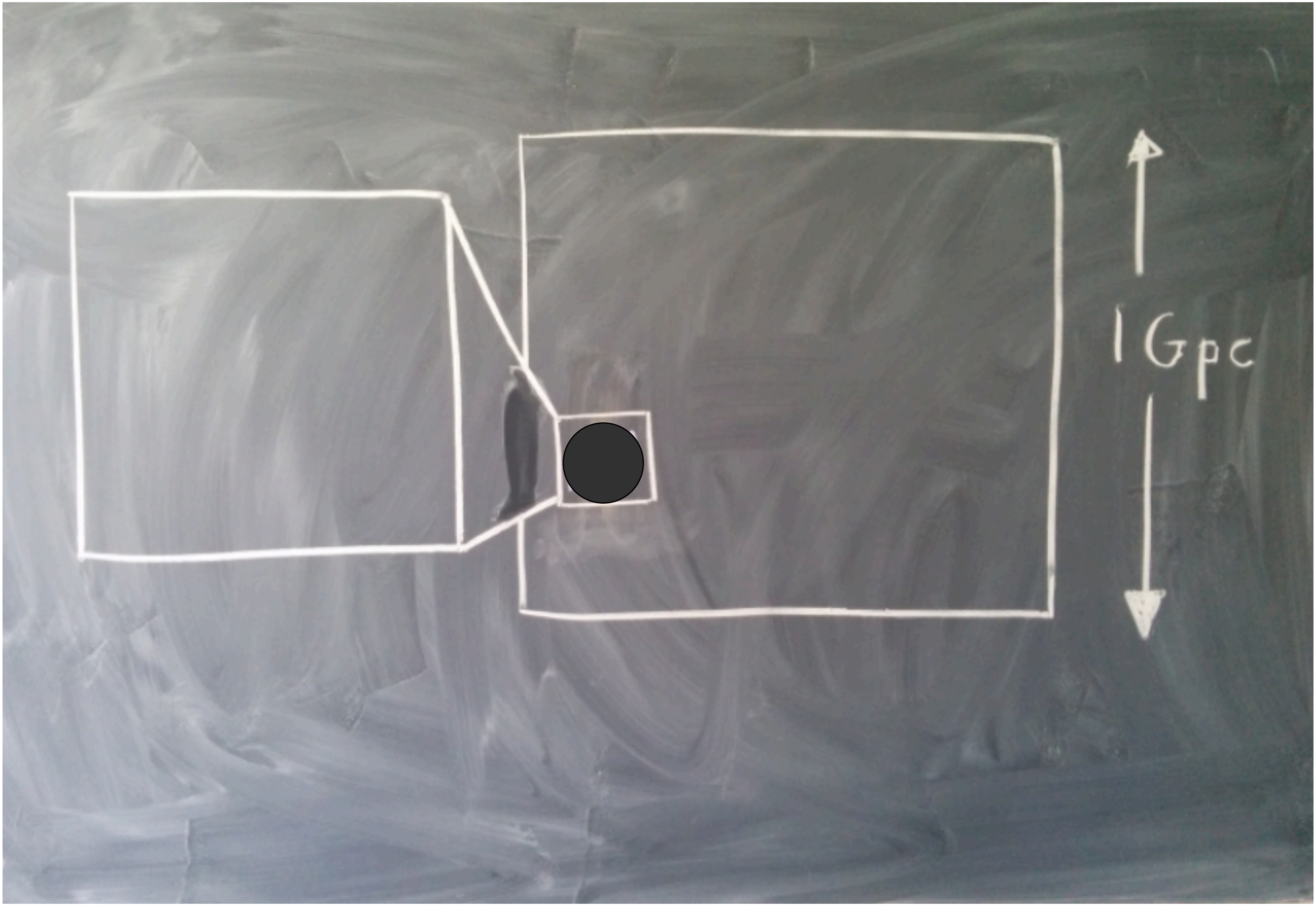
http://mbii.phys.cmu.edu

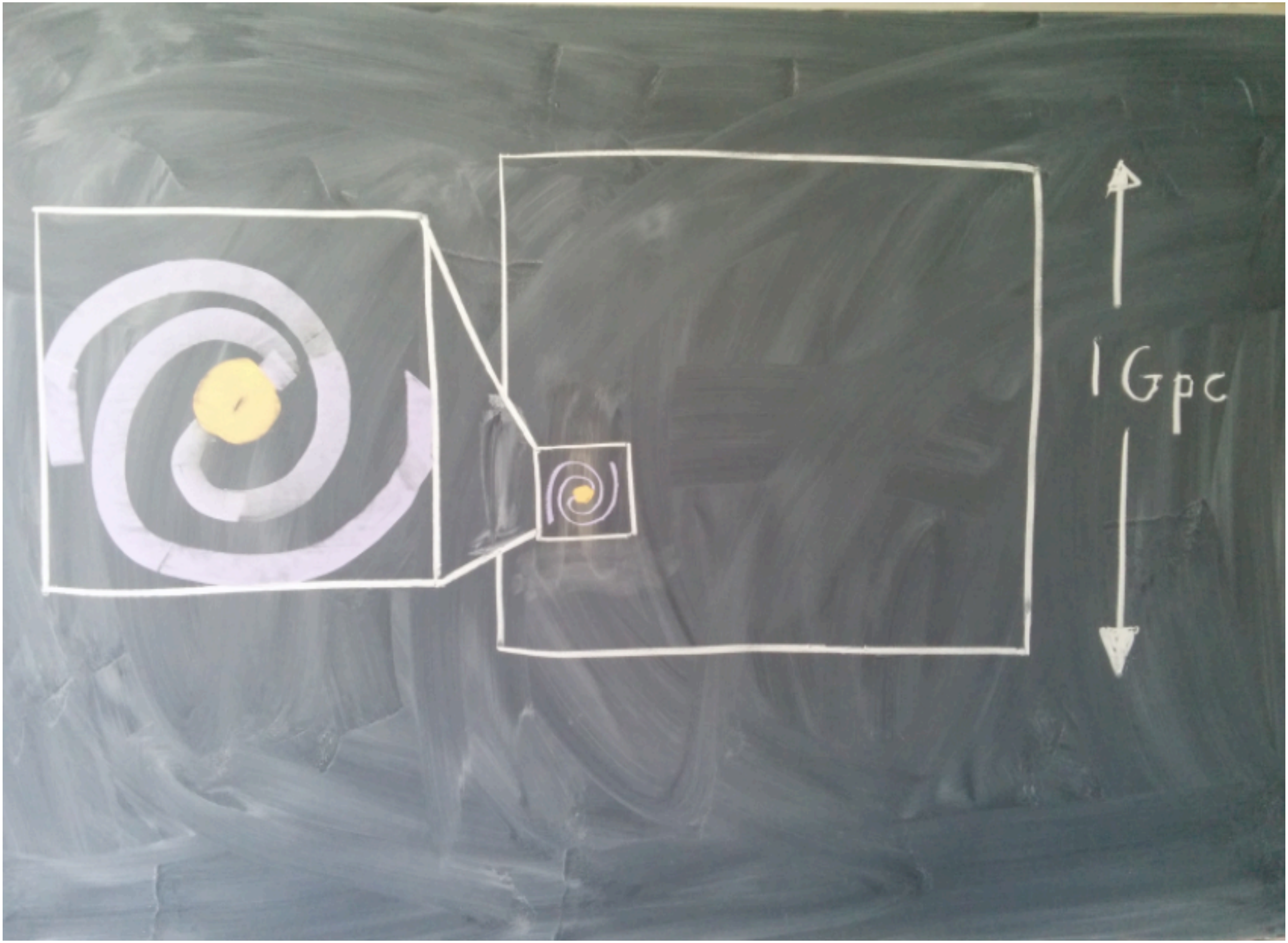
where do supermassive black holes form?



problems with usual zoom approach

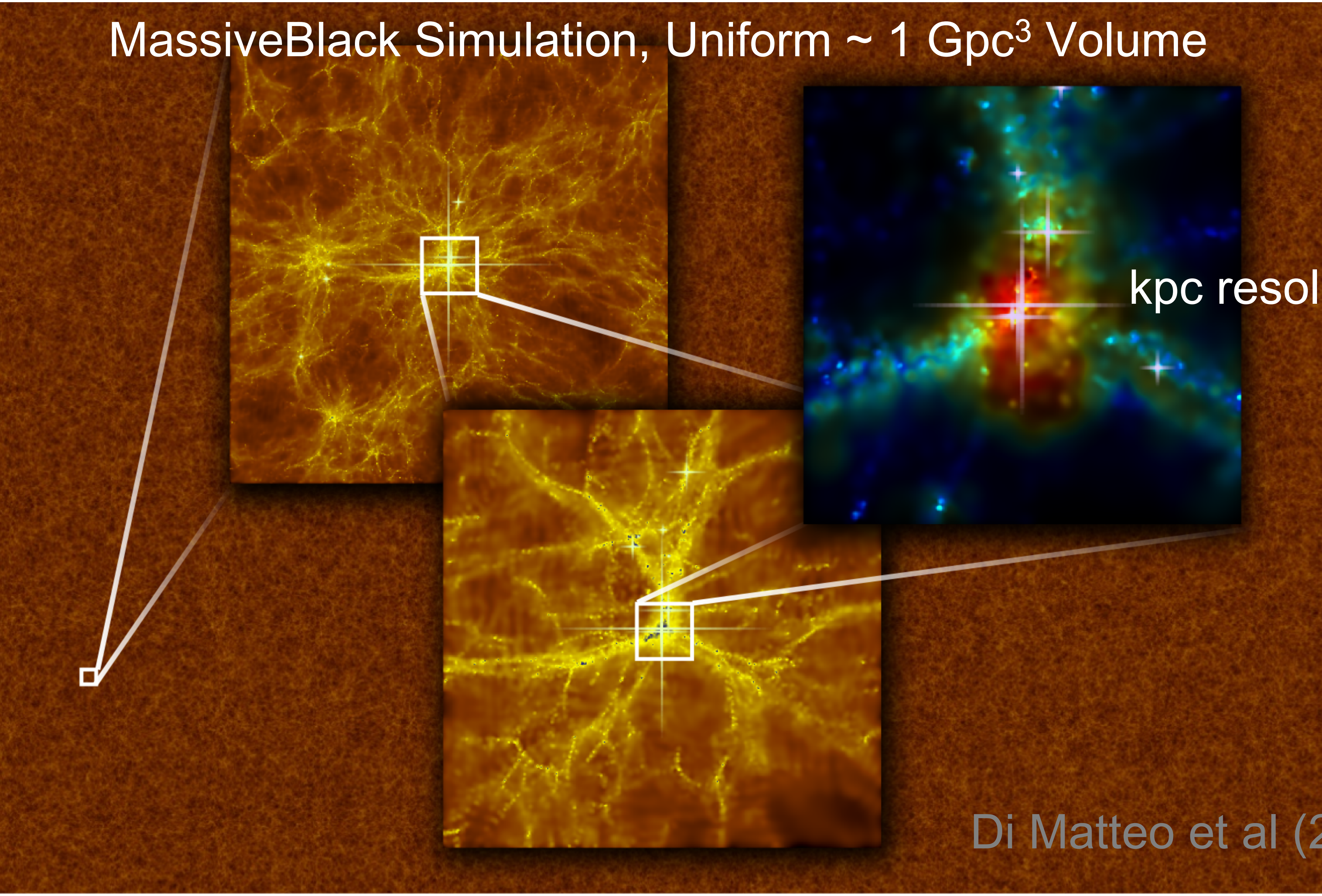



1 Gpc

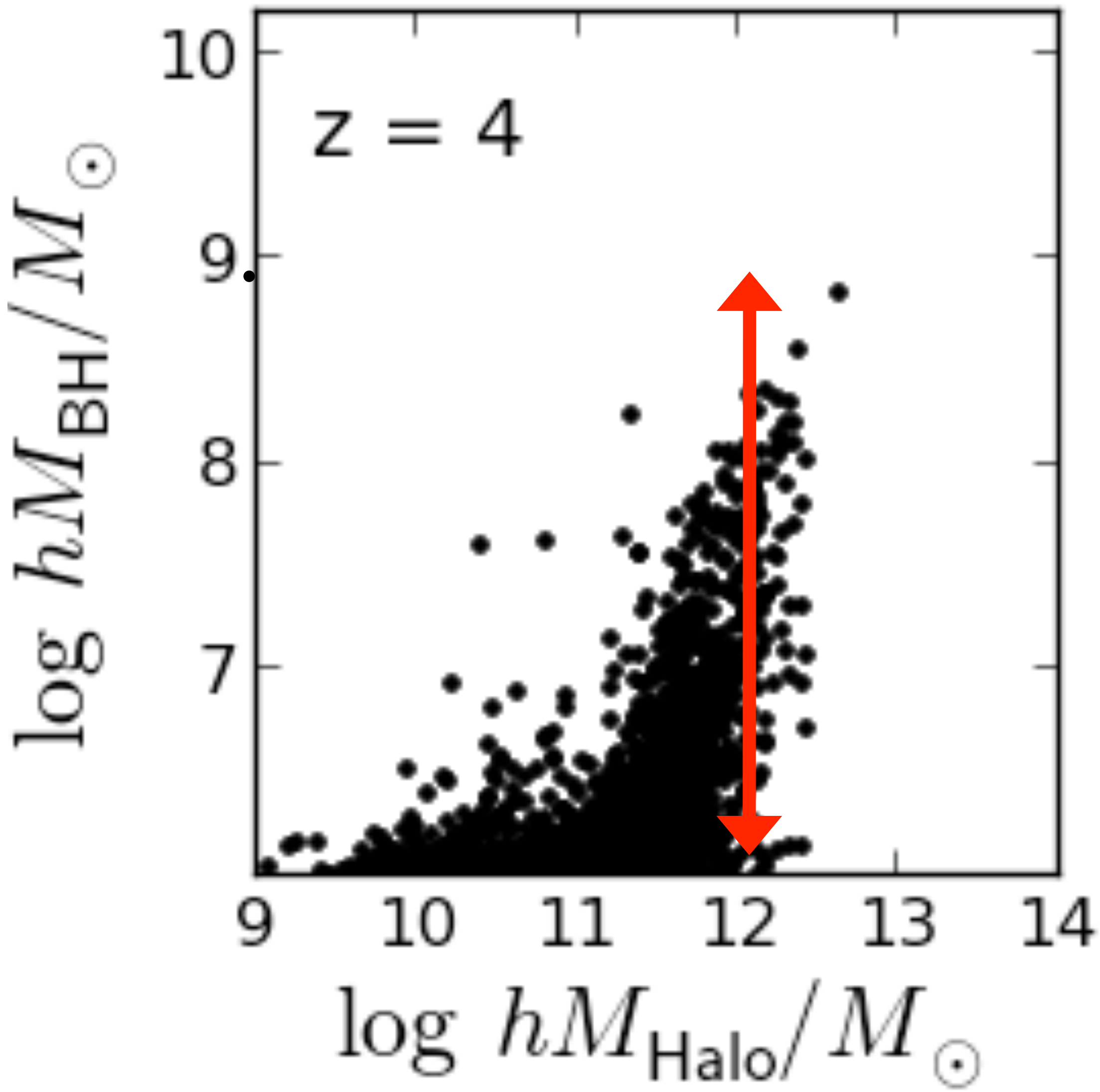

1 Gpc


1 Gpc

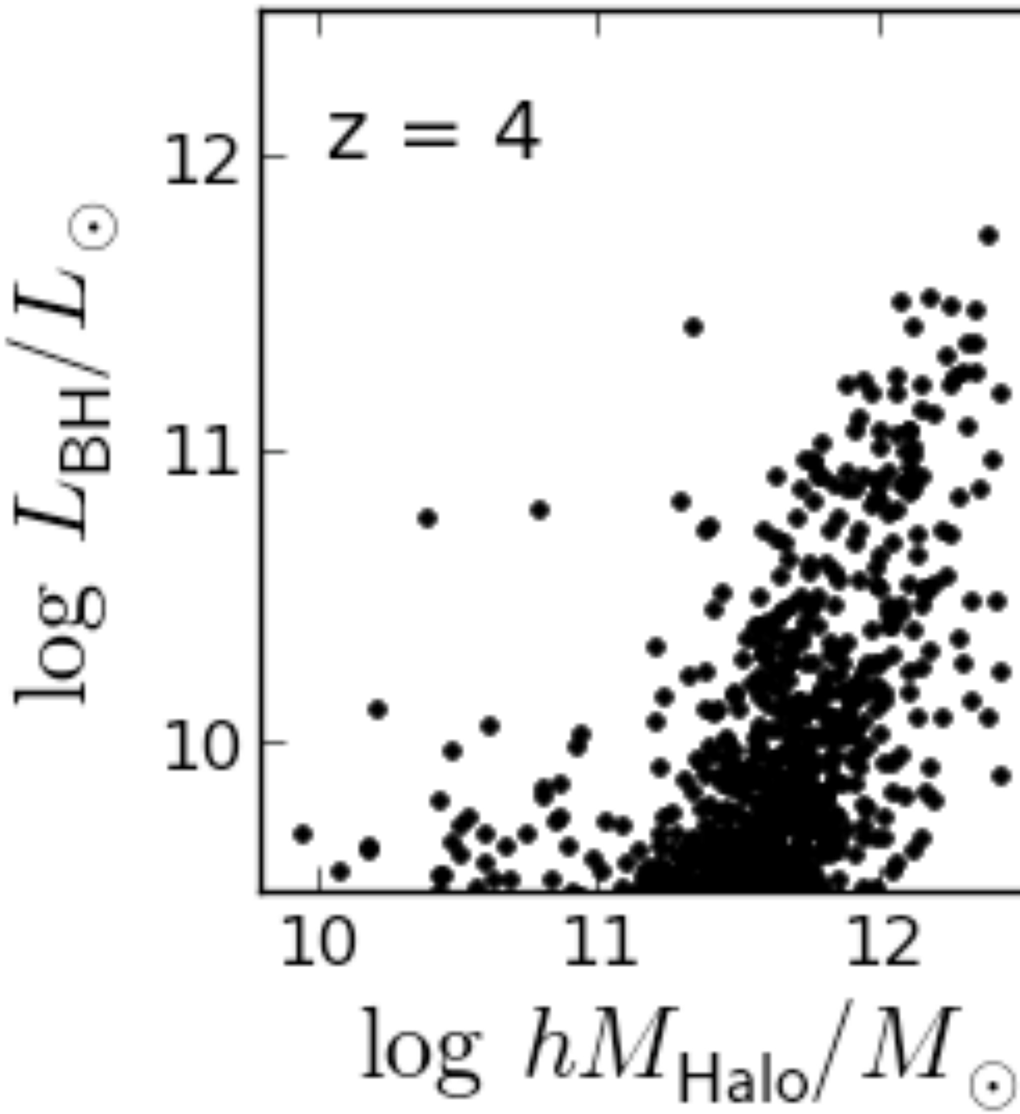

1 Gpc

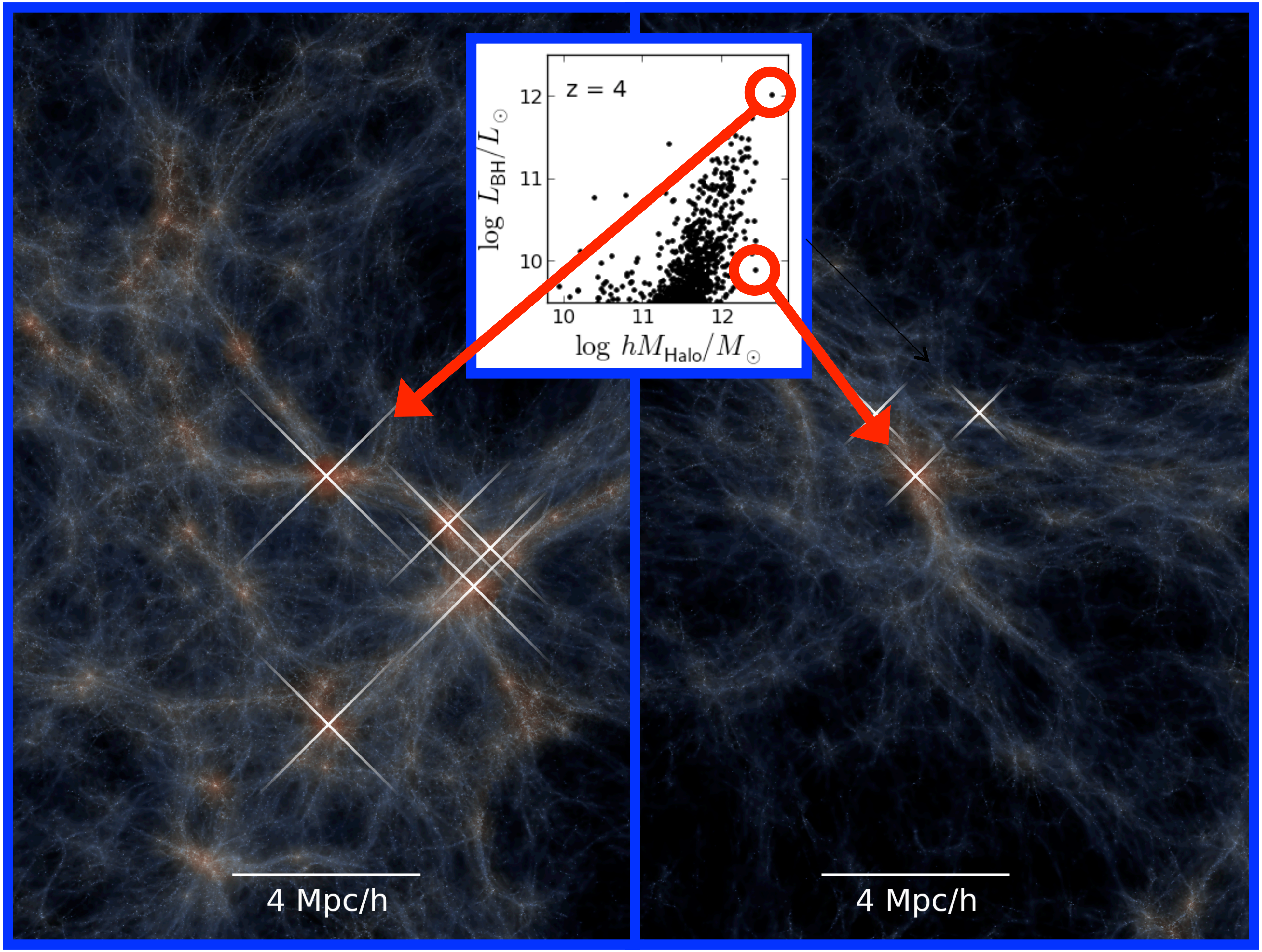

MassiveBlack Simulation, Uniform ~ 1 Gpc³ Volume
kpc resol
Di Matteo et al (2

Large-scale environment can cause black hole mass to vary by factor 1000 for 10^{12} solar mass halos



AGN luminosity vs halo mass




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

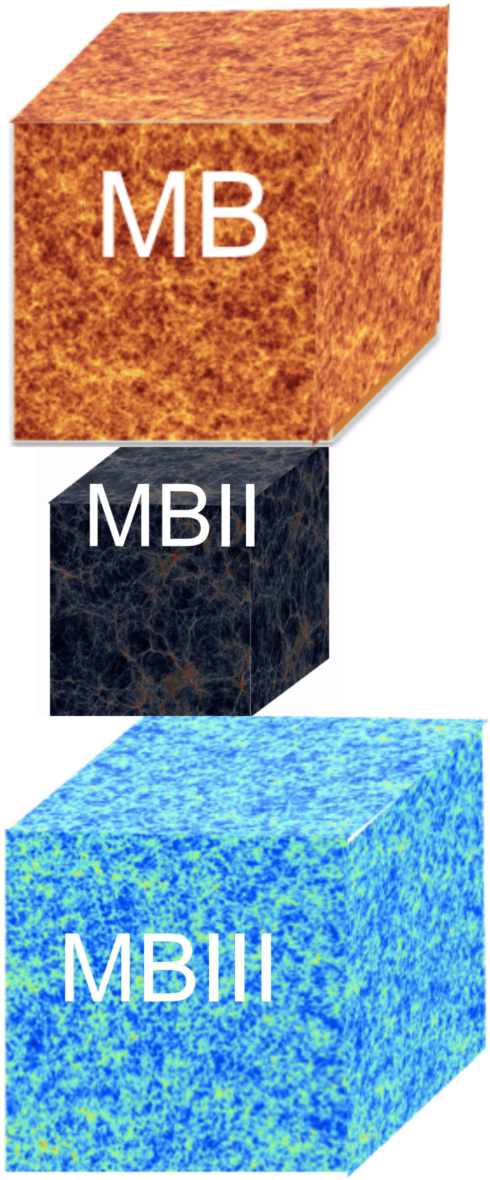
For statistics we need large volumes.

We can see what large scale physics does:

e.g. gas supply

MassiveBlack simulations: PetaGadget code

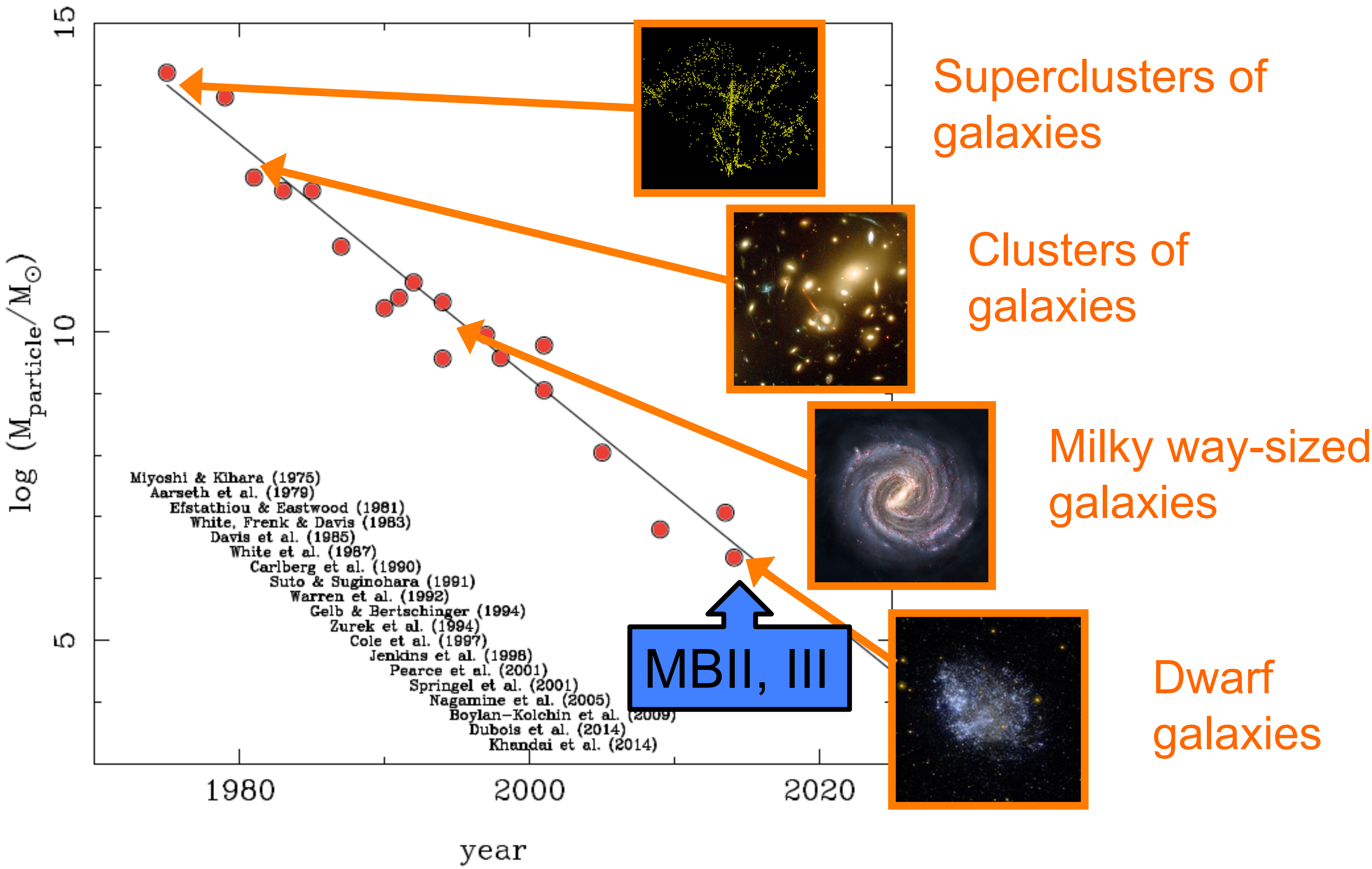
SPH, cooling, star formation, black holes.



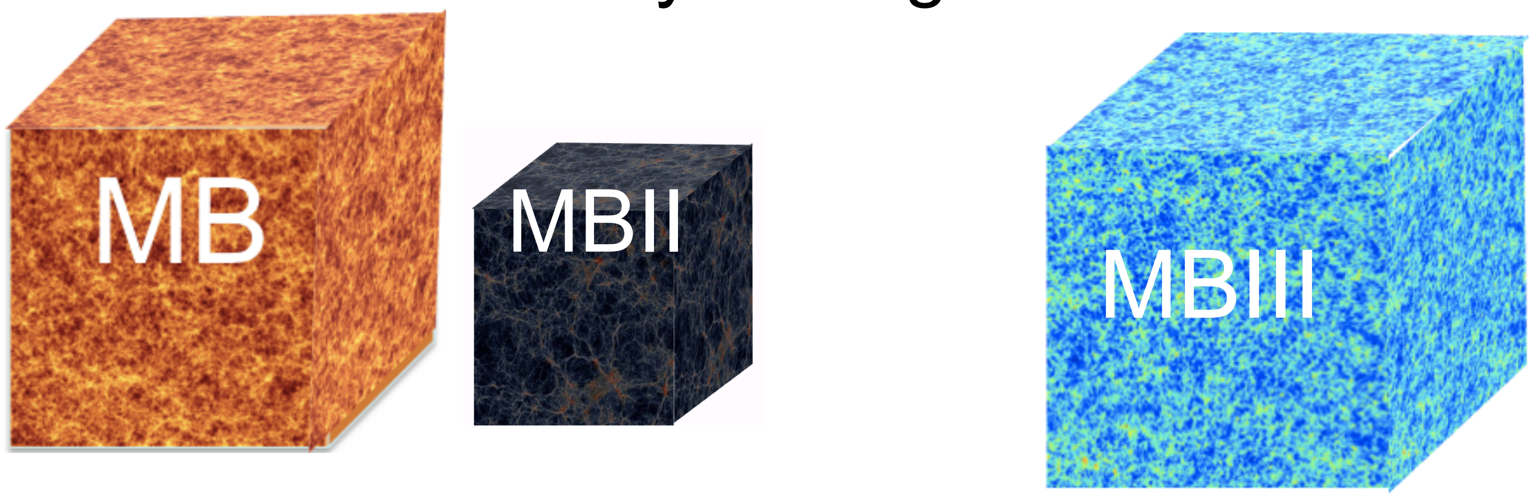
h^{-1}Mpc	z_{final}	$N_{particle}$	M_{res}/m_{sun}
533	4.75	64 billion	5×10^7
100	0	11.5 billion	2×10^6
400	?	0.7 trillion	2×10^6

Simulation particle mass vs year

What we can resolve with 100 particles:



Physics algorithms

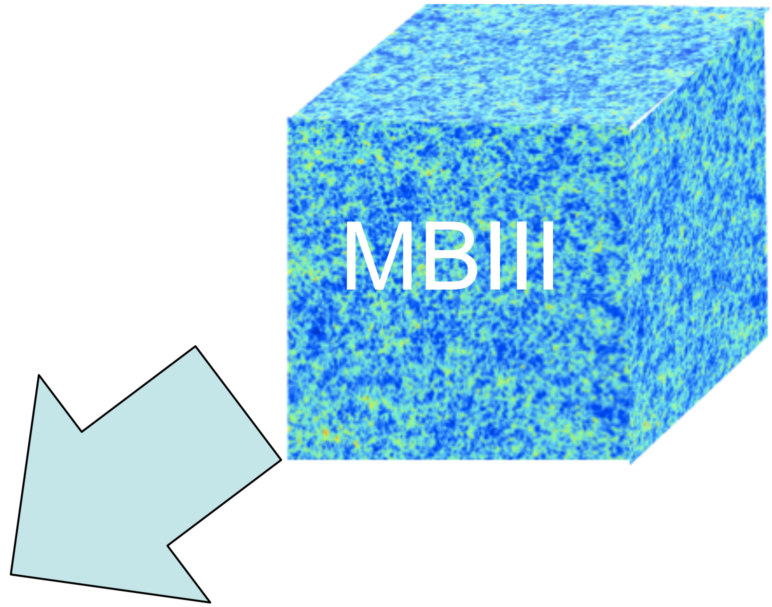


Springel & Hernquist 2002
Springel & Hernquist 2003
Haardt & Madau 1996

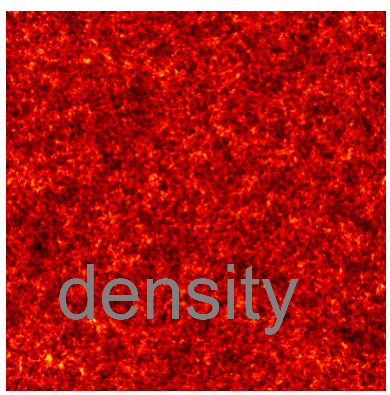
Hopkins 2013
Gnedin et al. 2009
Battaglia et al. 2014

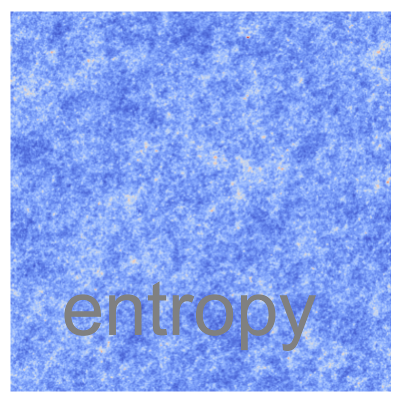
Density-entropy SPH
Multiphase star formation
Uniform UVBG

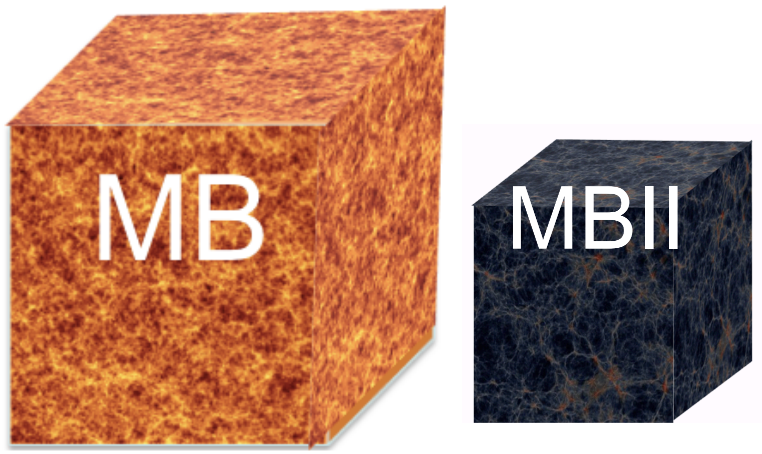
Pressure-entropy SPH
Molecular hydrogen
Patchy reionization



running,
reached z=16
(30 million particles in galaxies so far)





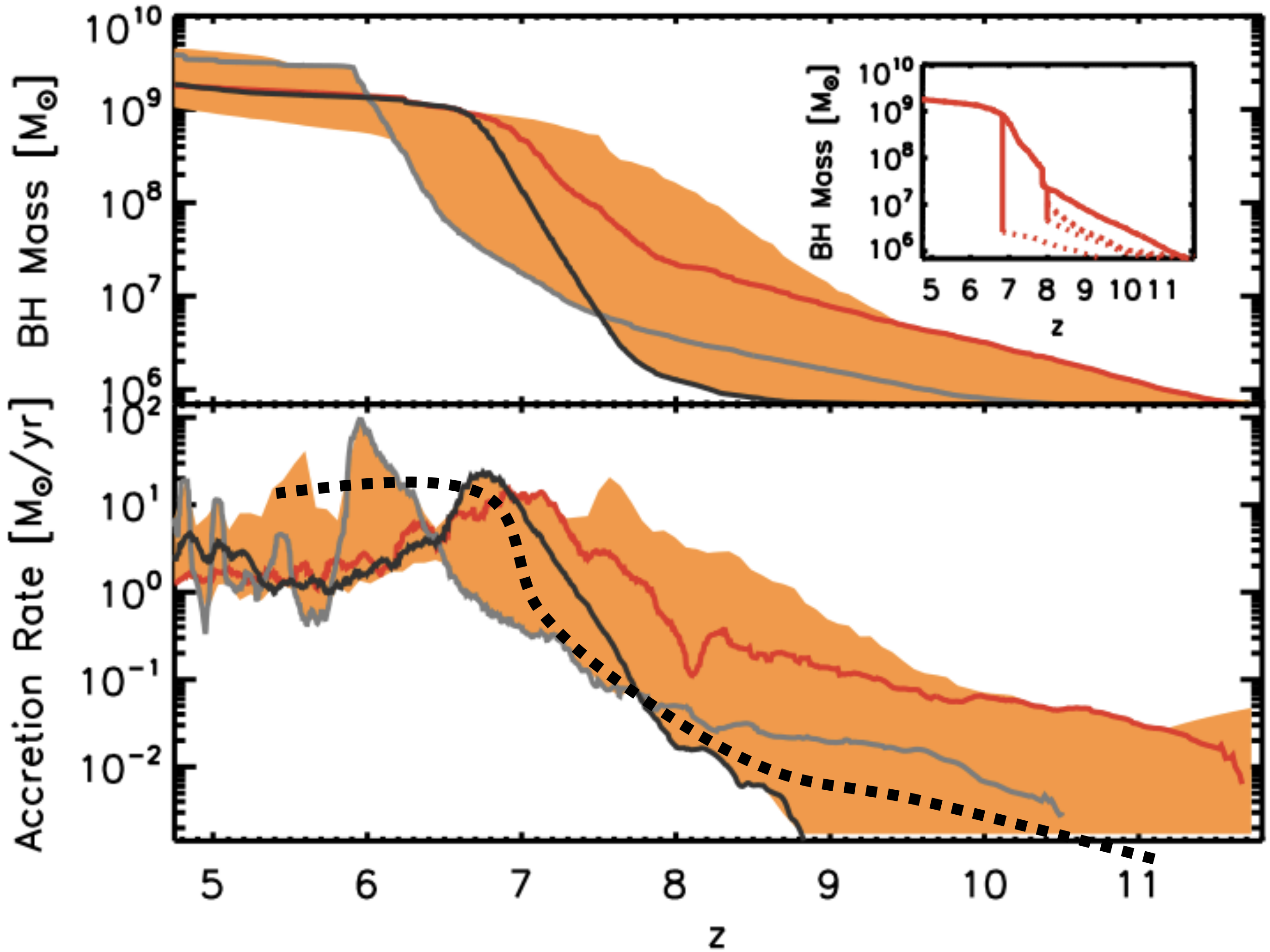


“old SPH”

Springel & Hernquist 2002
Springel & Hernquist 2003
Haardt & Madau 1996

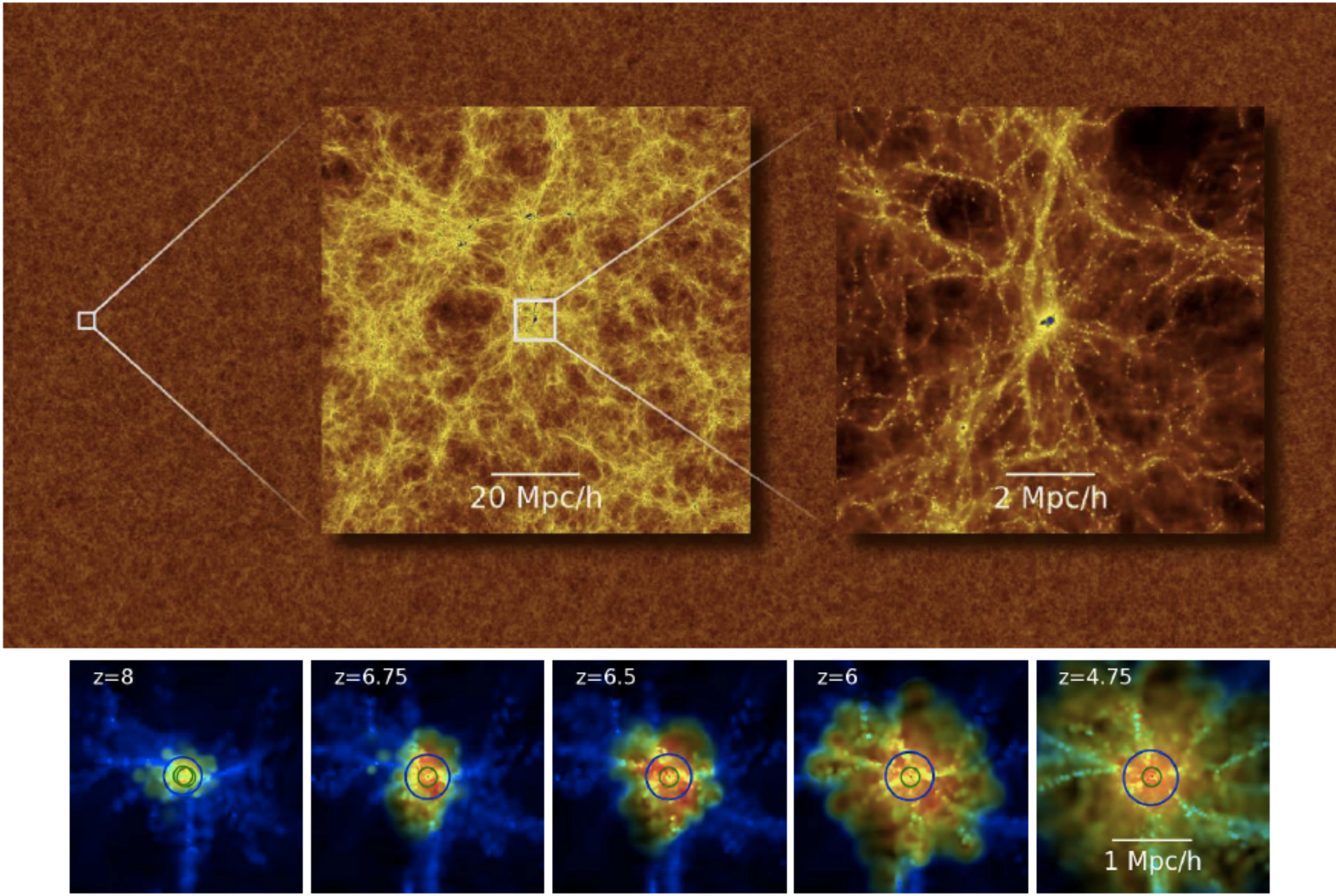
Density-entropy SPH
Multiphase star formation
Uniform UVBG

Some black holes grow to $10^9\,M_{sun}$ by z~6-7



Di Matteo et al . 2012

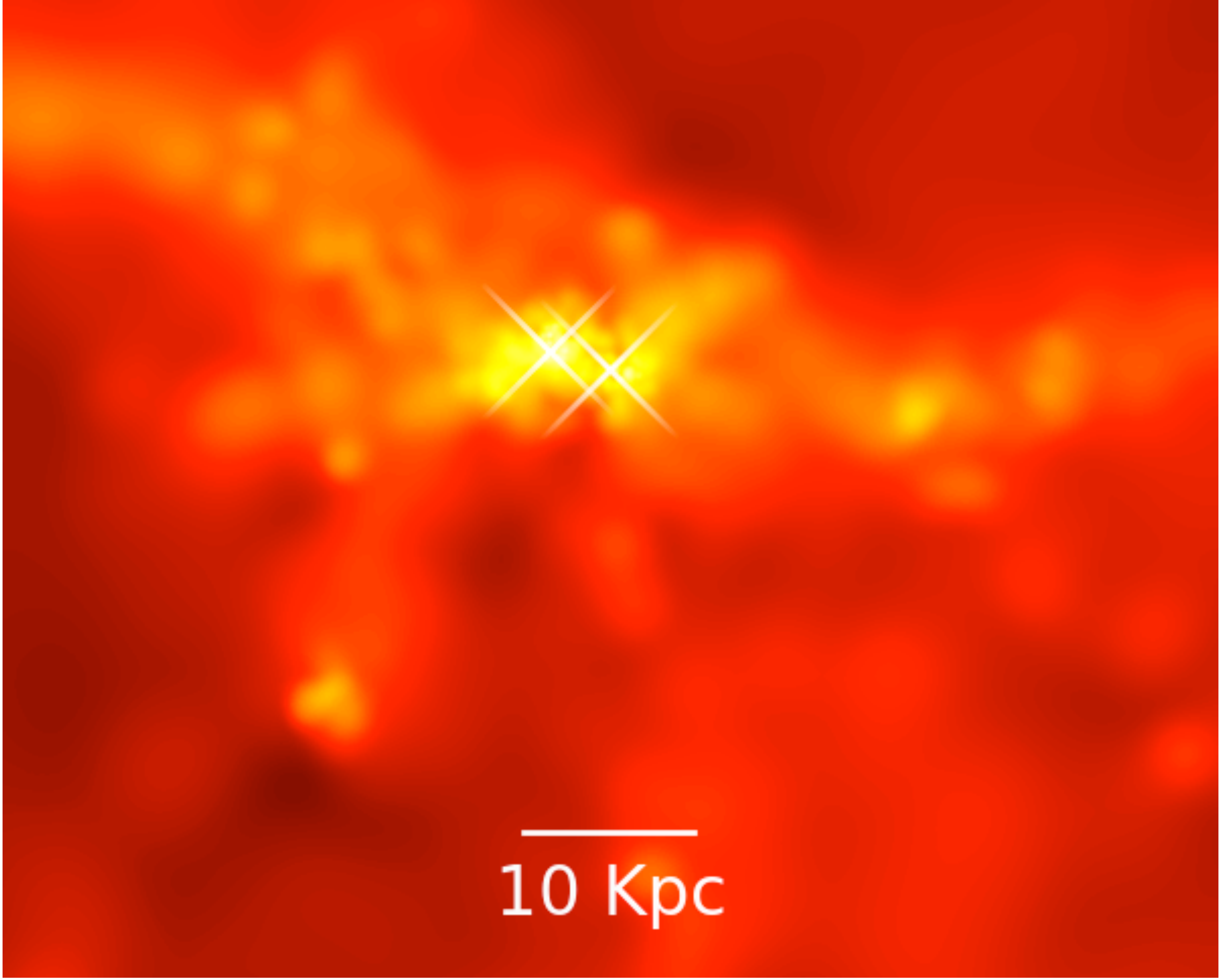
Eddington rates sustained long enough before AGN feedback able to act

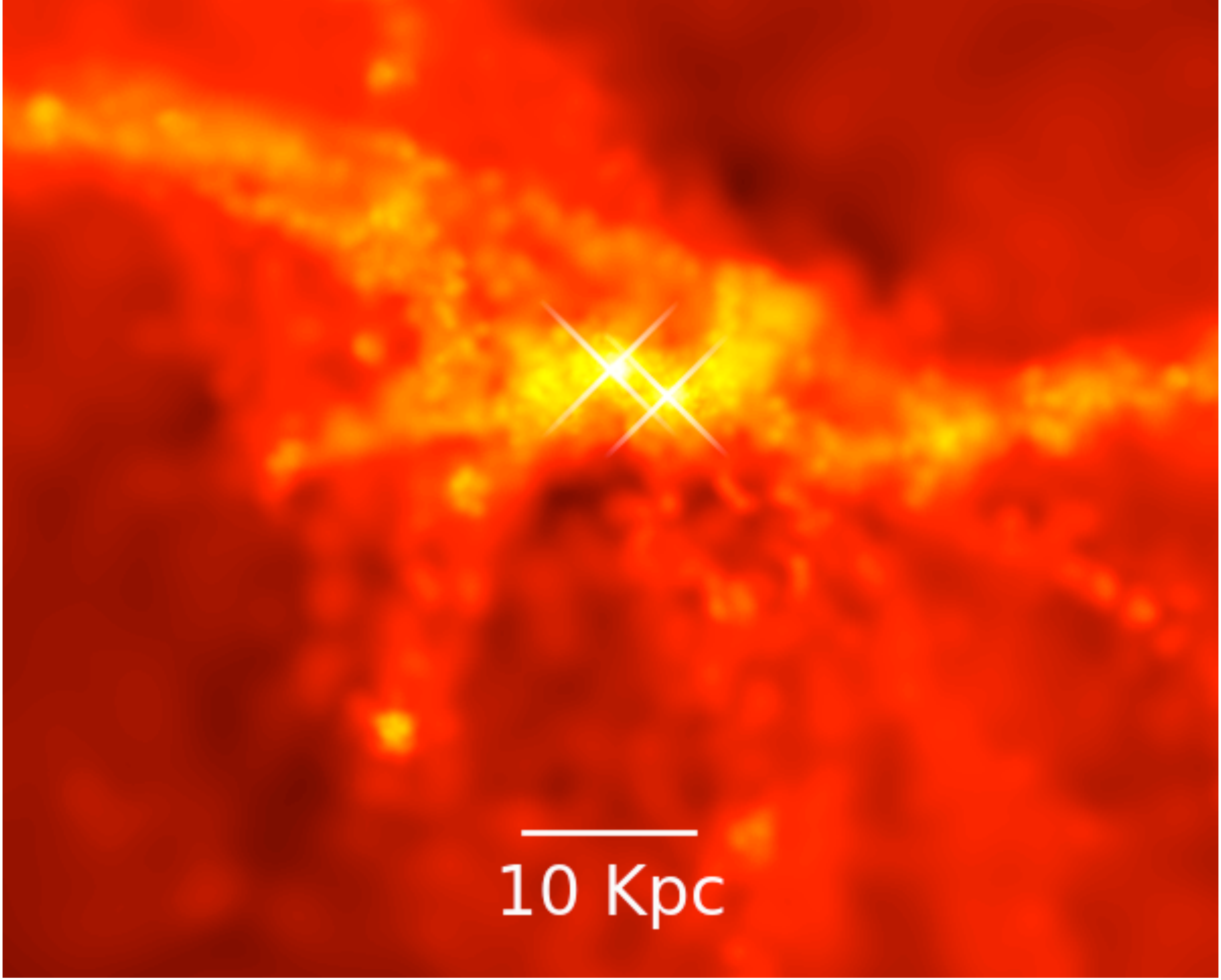


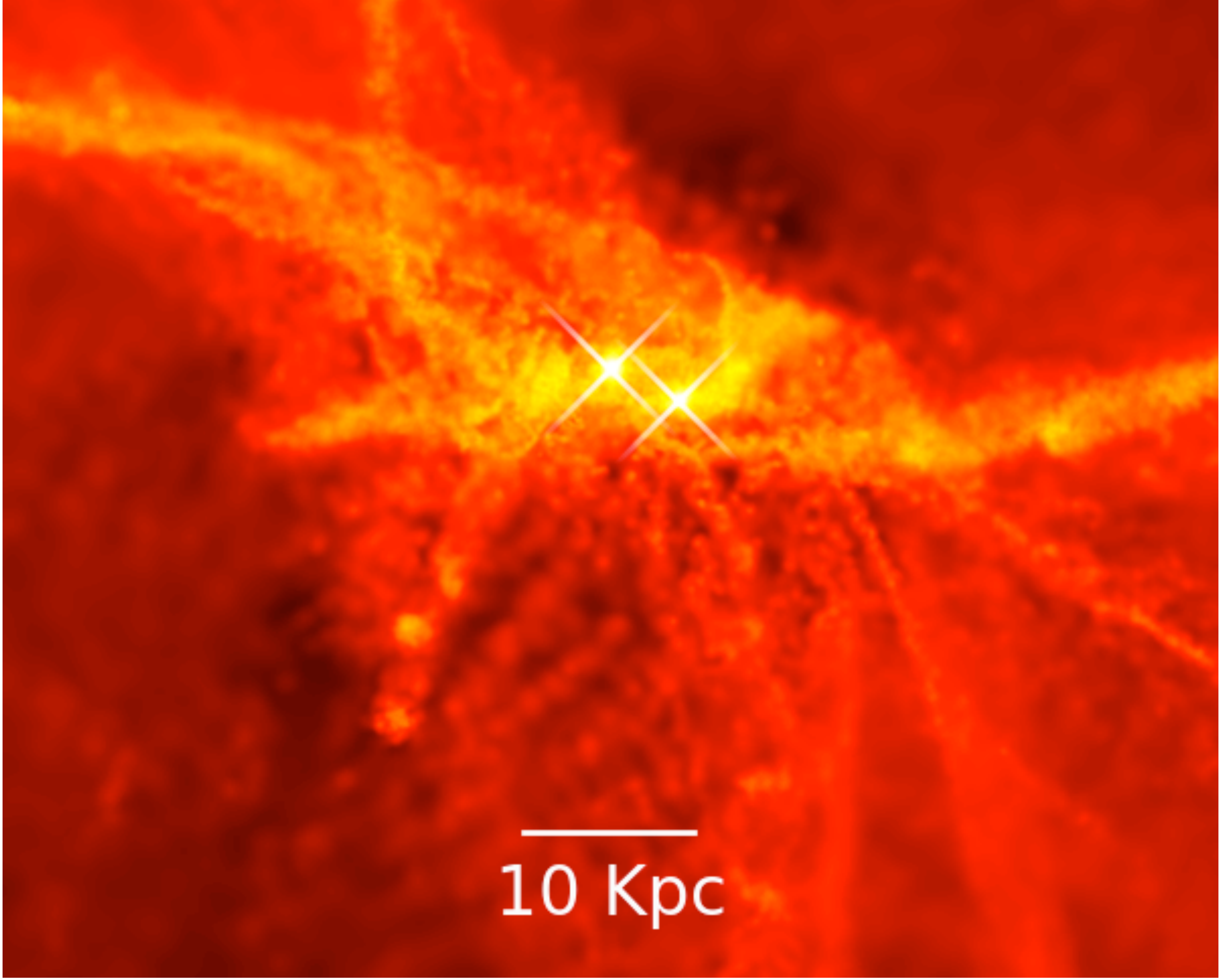
20 Mpc/h
2 Mpc/h
z=8
z=6.75
z=6.5
z=6
z=4.75
1 Mpc/h

Now we know where black holes form,
we can test resolutions, models, parameters using

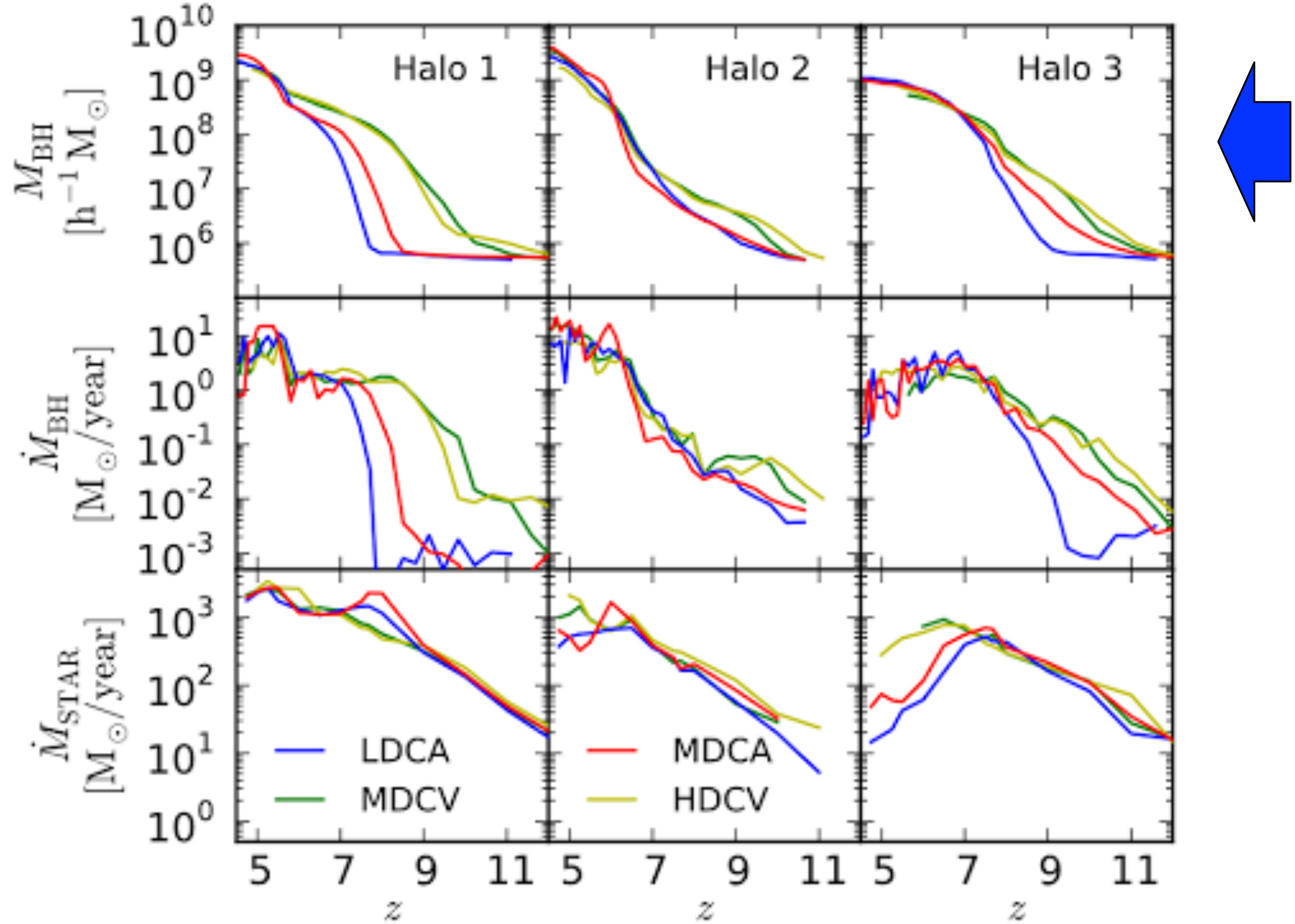
zoom from hydro (first)…


10 Kpc


10 Kpc


10 Kpc

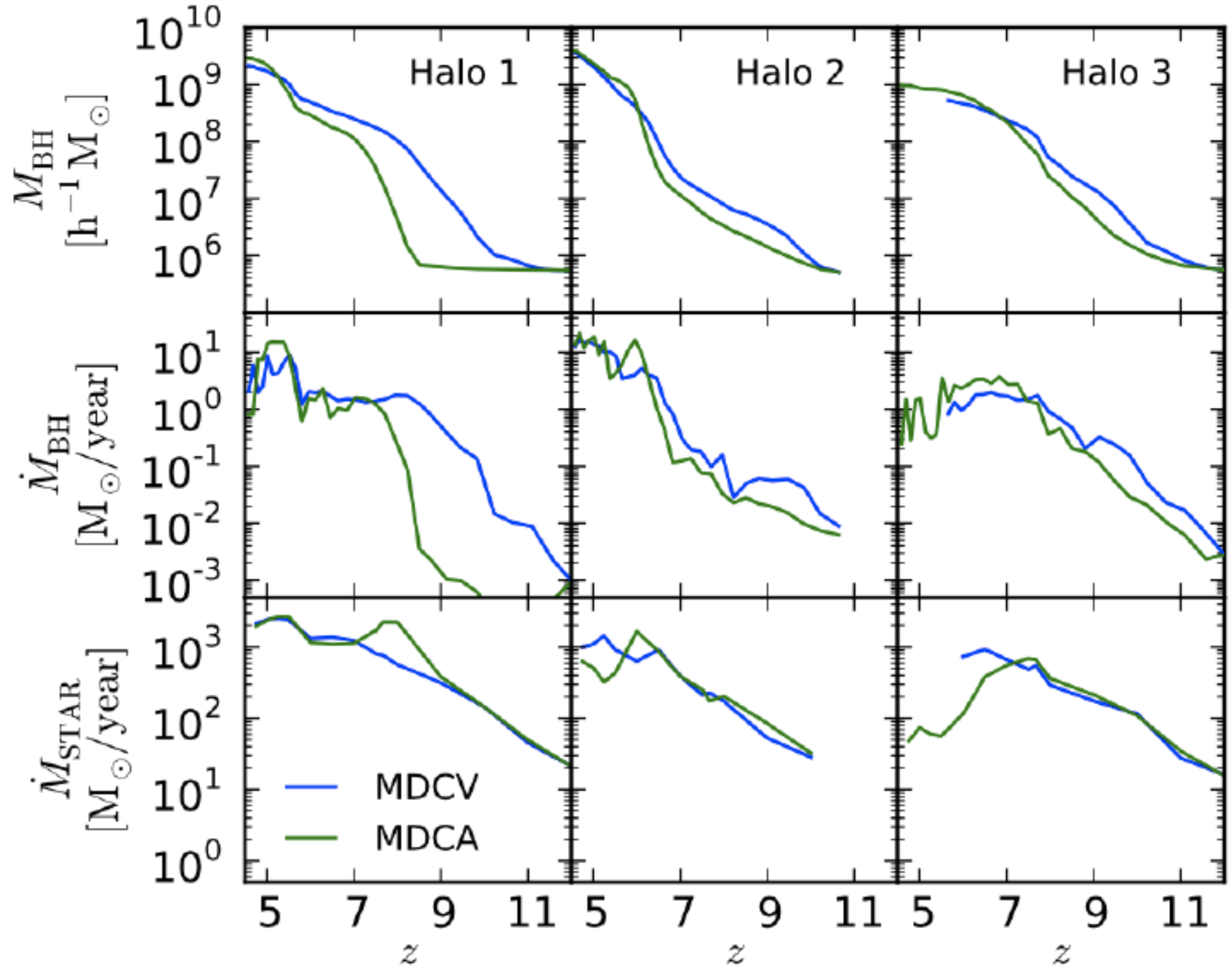
3 halos, 4 different resolutions:



final black hole mass insensitive to resolution

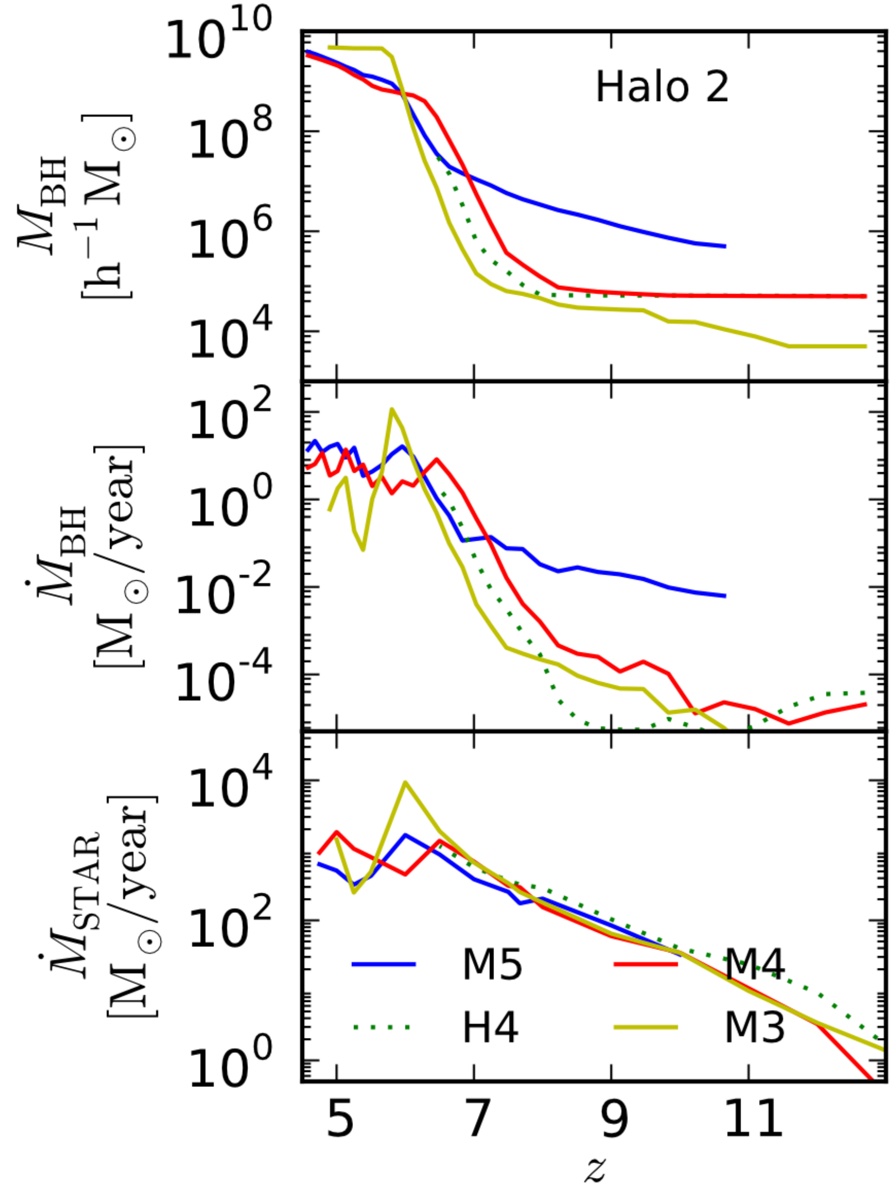
Feng et al. 2014

3 halos, 2 feedback depositions:
(constant volume or constant mass)



Feng et al. 2014

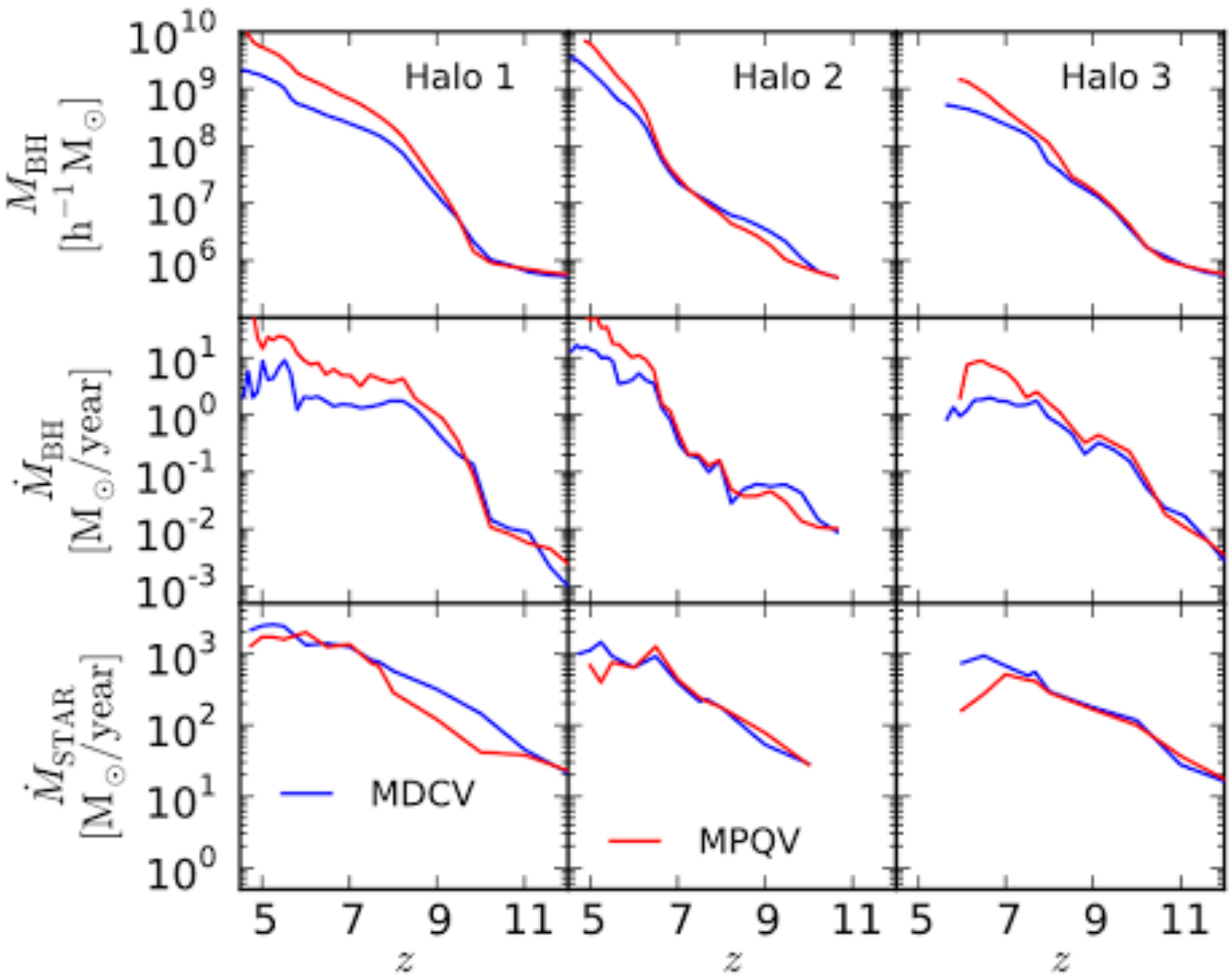
Final BH mass does not depend on BH seed mass



Lower mass seed
grows later
grows faster

$M_{seed}/M_{sun}=$
10^3
10^4
10^5

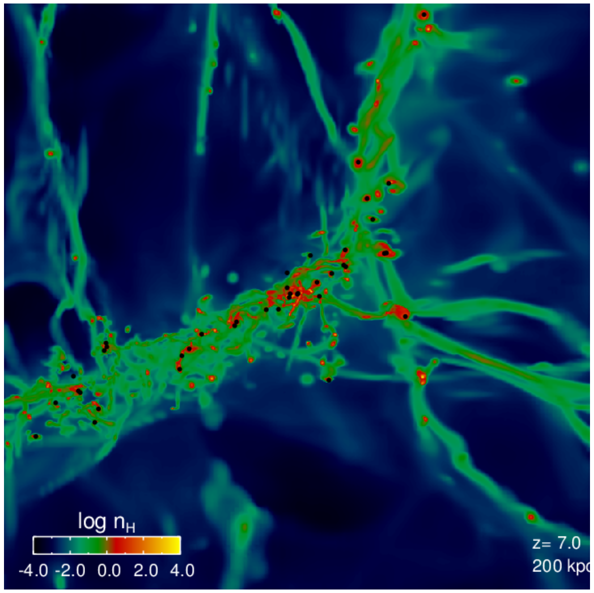
Zoom simulations varying Hydro Formulation (Sph/P-Sph) :
Black hole growth (and SF) histories remain mostly unchanged



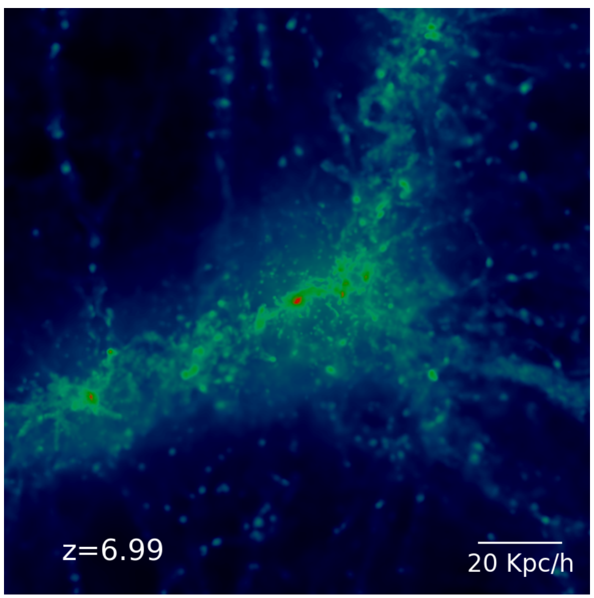
but:
bigger M_{BH}

Feng et al. 2014

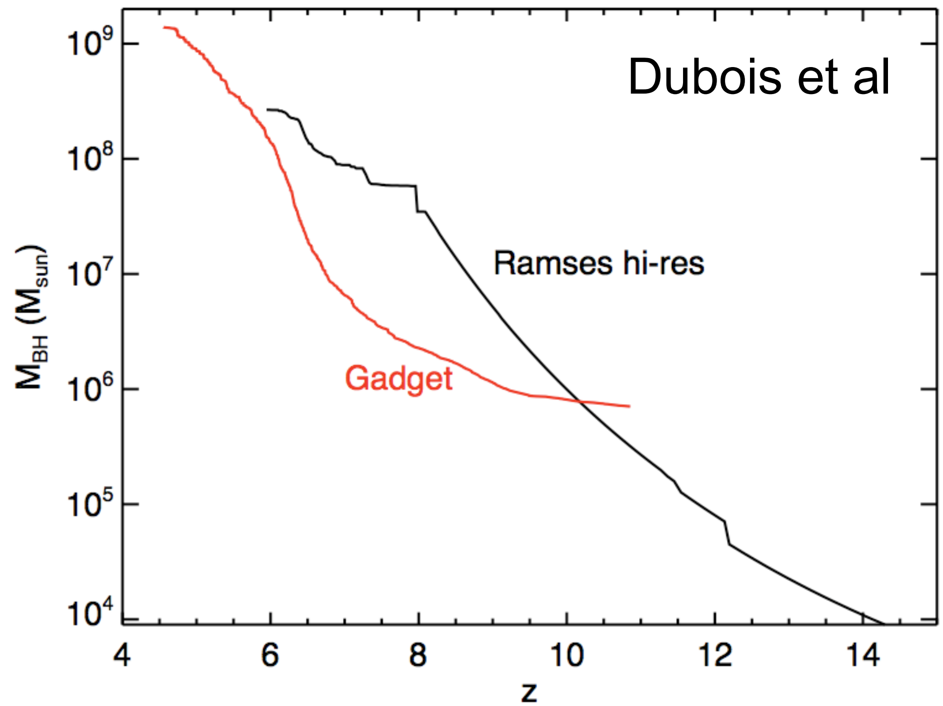
AMR (RAMSES) ZOOM vs



SPH (P-GADGET) ZOOM



RAMSES predicts similar black hole growth



High redshift conclusion:

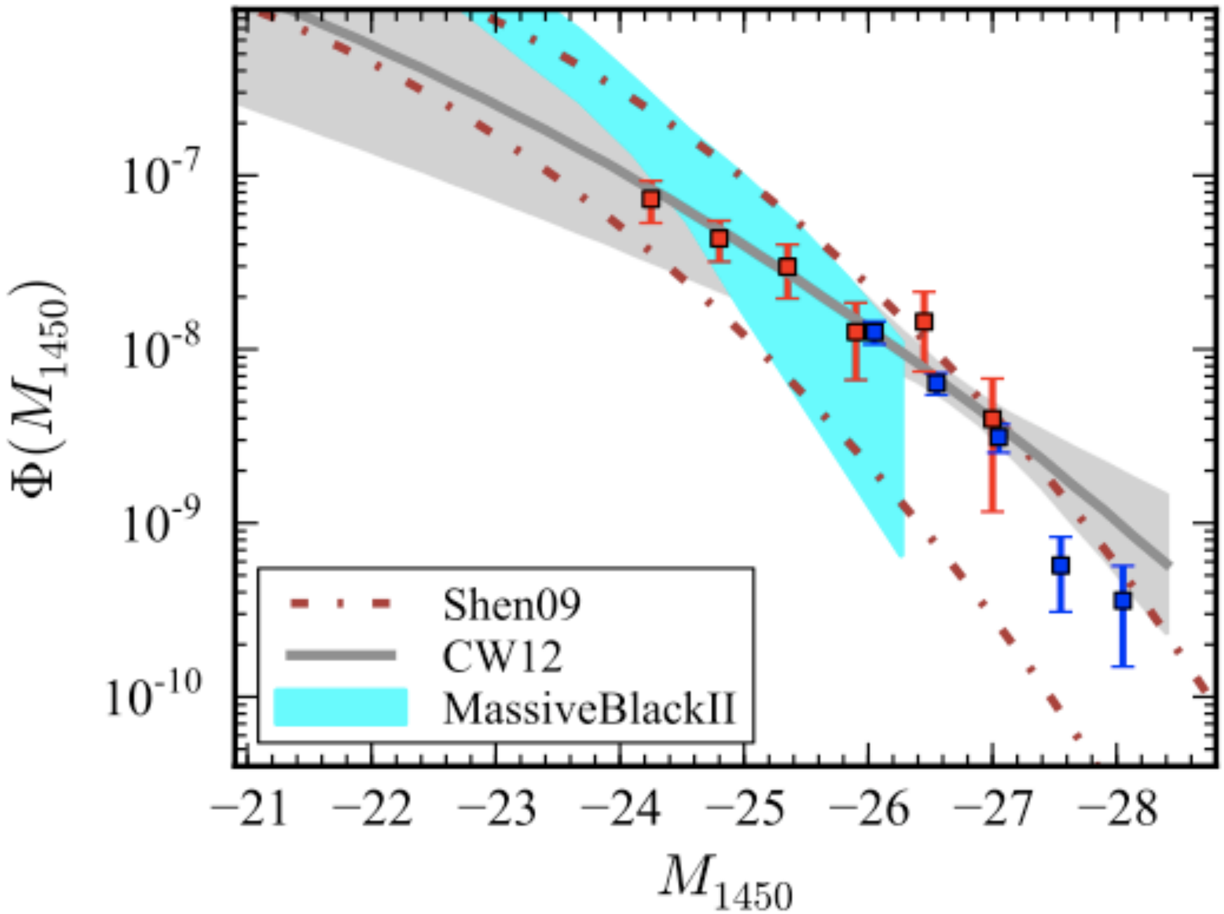
- large scale gas inflows govern black hole growth before onset of feedback

- black hole subgrid modelling not important

comparison to obs...

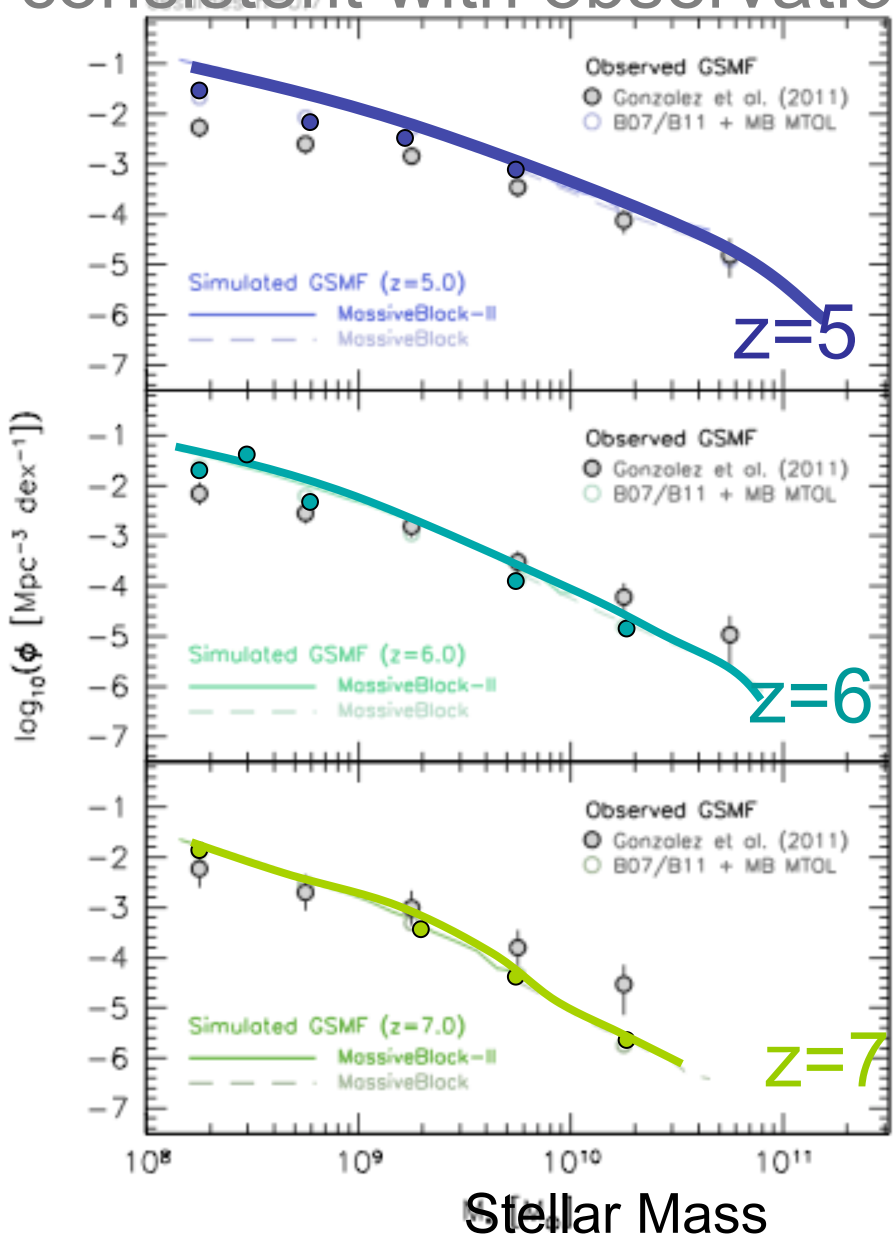
Quasar luminosity function

Sloan - Stripe 82 ‘faint’ z=5 quasars

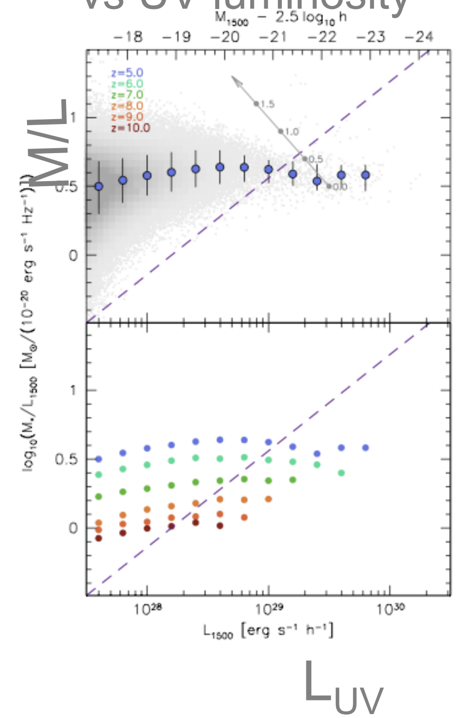


McGreer et al. 2013

MB and MBII predict a high-z Galaxy Stellar Mass Function consistent with observations



Mass to light Ratio vs UV luminosity



Wilkins et al 2013

at lower z:

gas supply limited → feedback limited

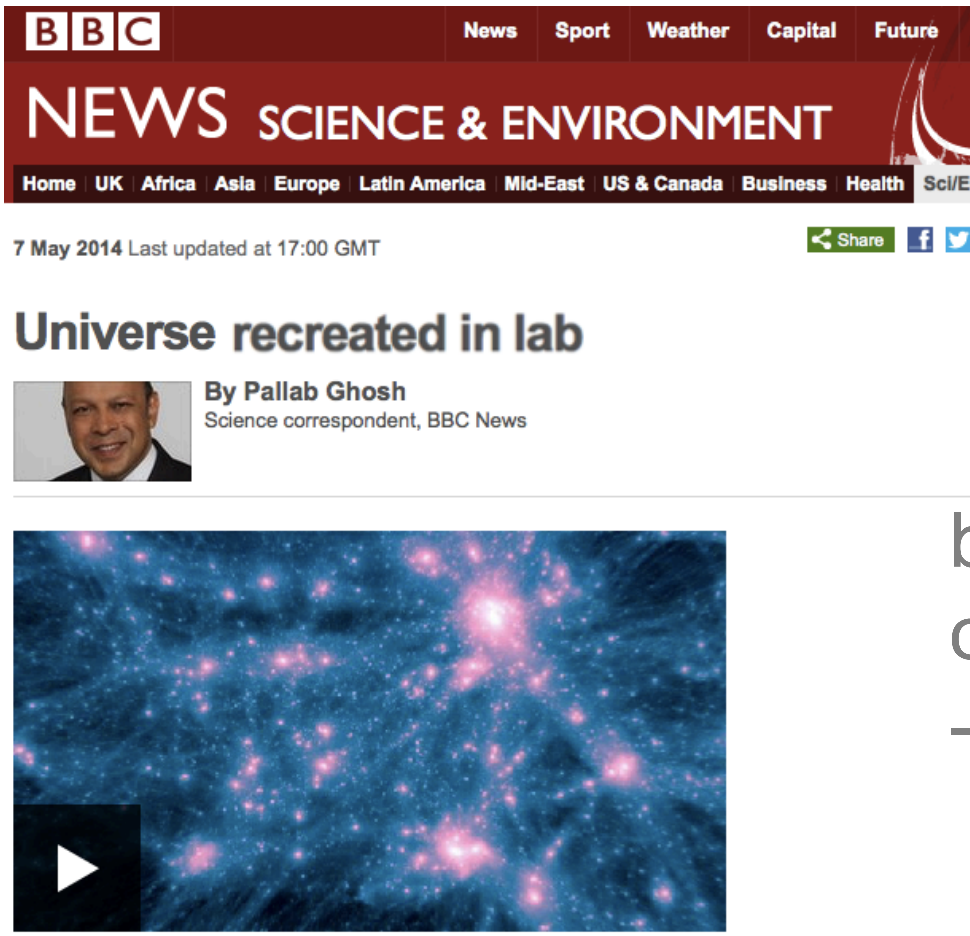
In context of stellar feedback,
Hopkins et al. 2013 show in cosmological simulations that feedback governs star formation.

We expect black hole accretion (scaling between accretion rate and local gas properties) to be governed by feedback too (and not black hole model).

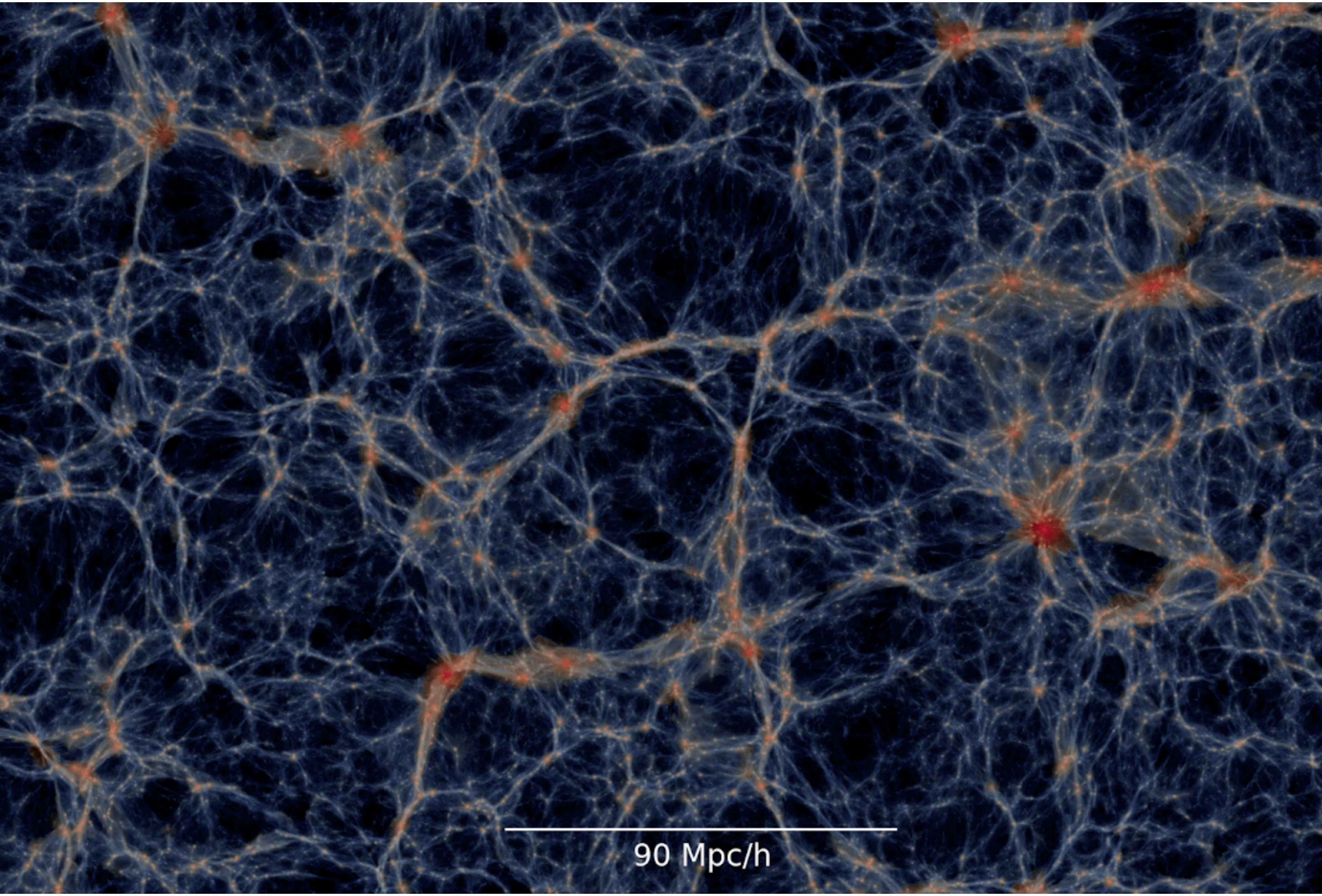
Let’s look at lower redshift galaxies in MBII…

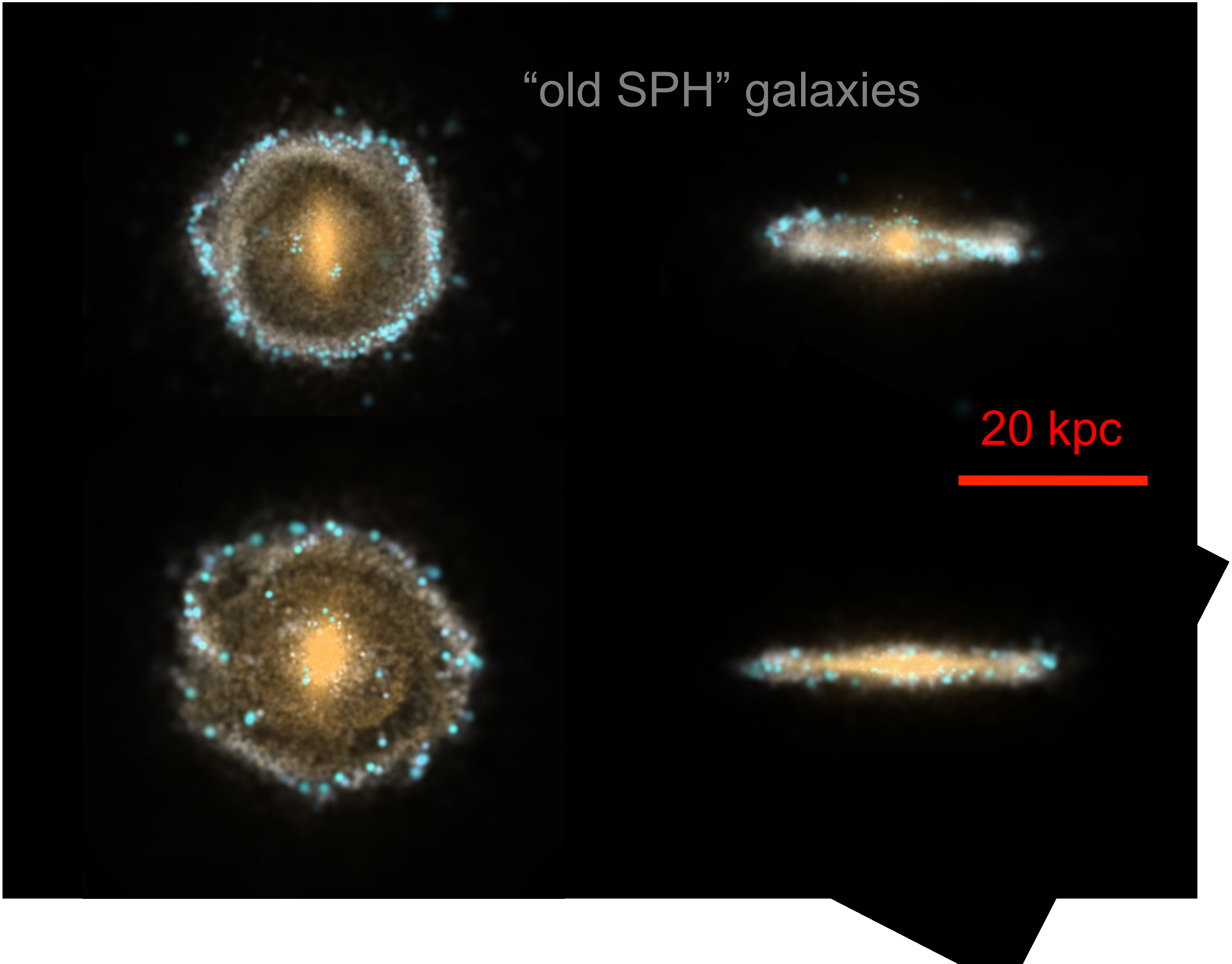
But first, we note that there is the famous

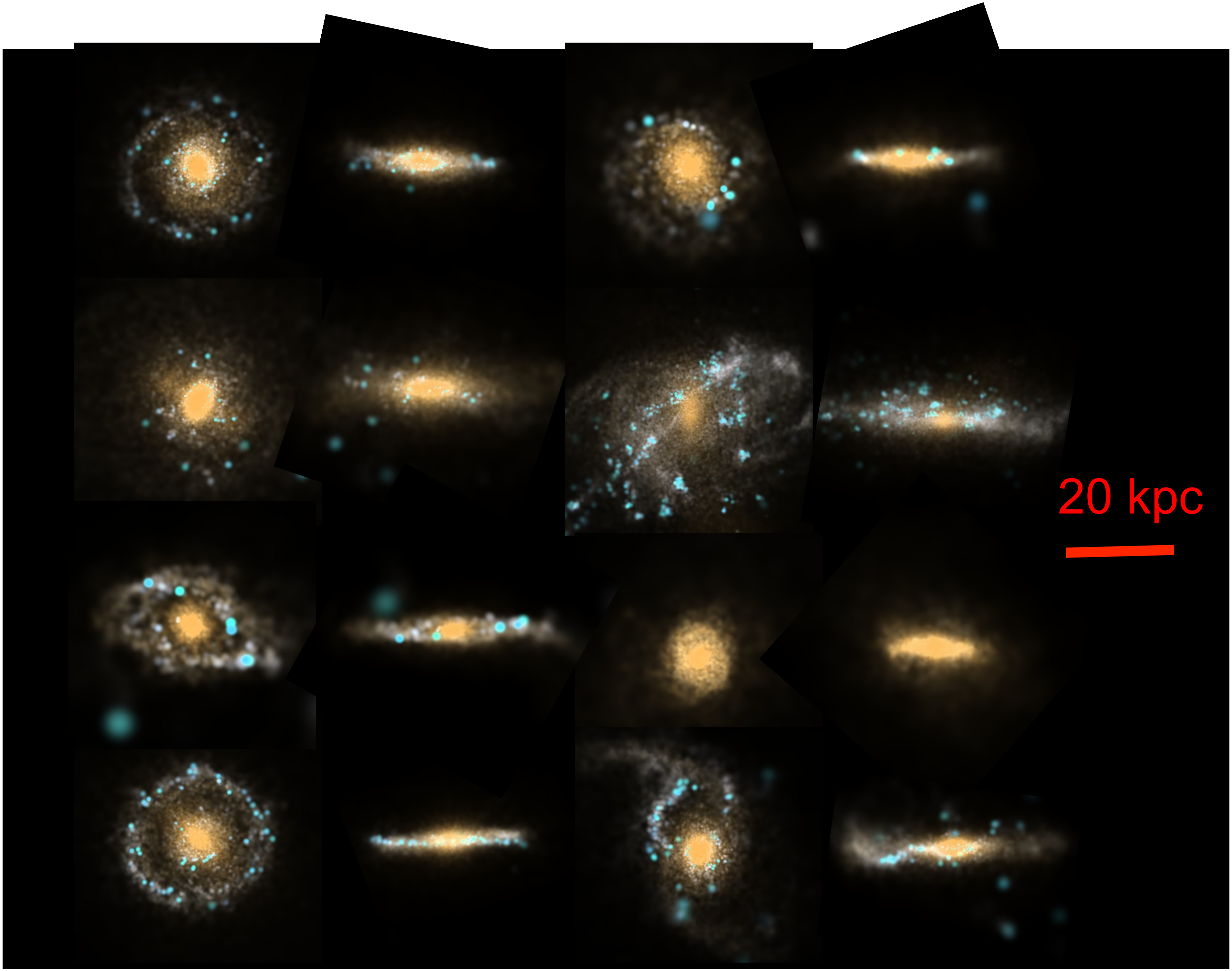
Illustris simulation (AREPO) –Springel, Vogelsberger et al.

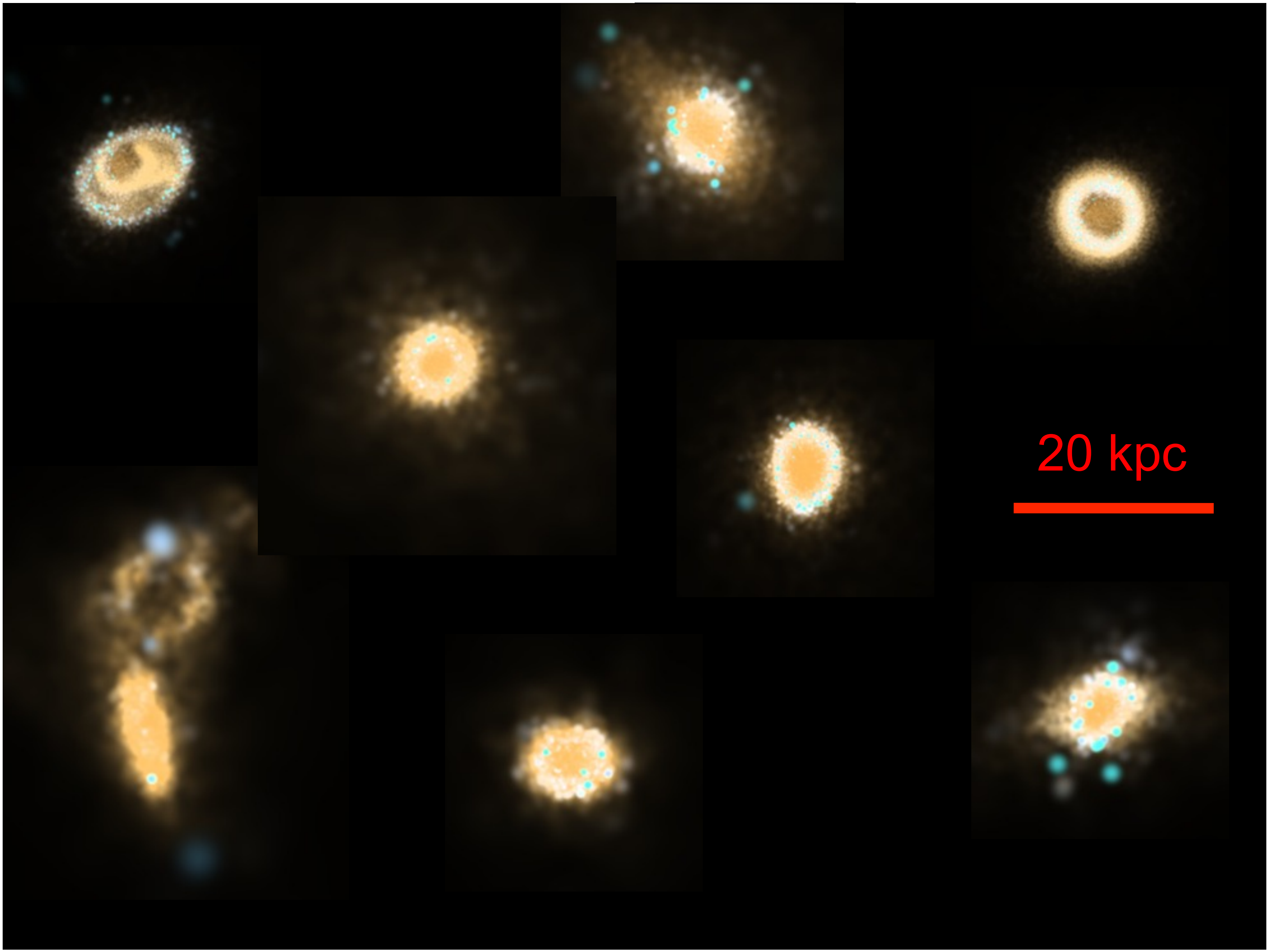


but our MBII sim is based on SPH from 2002
- how bad is it?

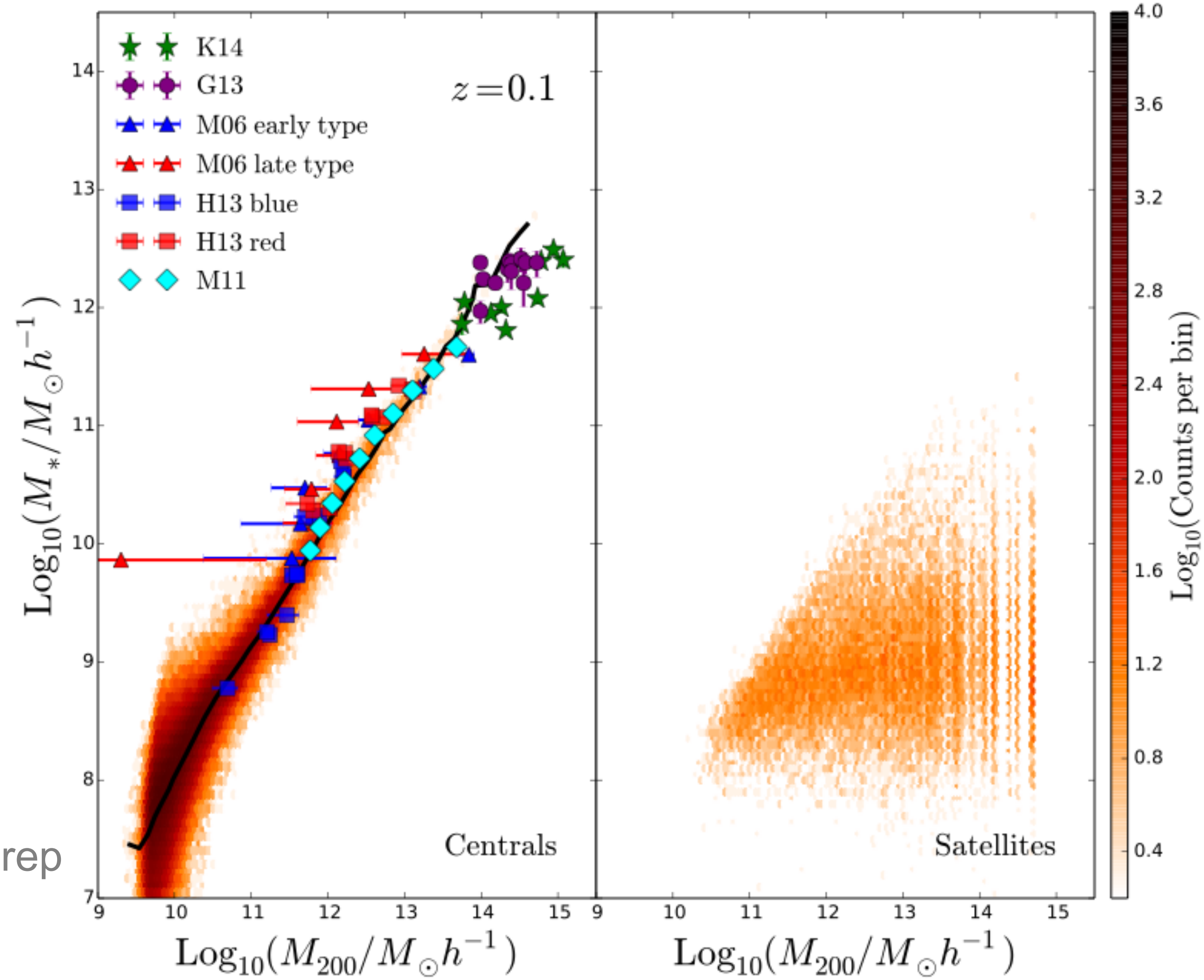

90 Mpc/h


“old SPH” galaxies
20 kpc


20 kpc

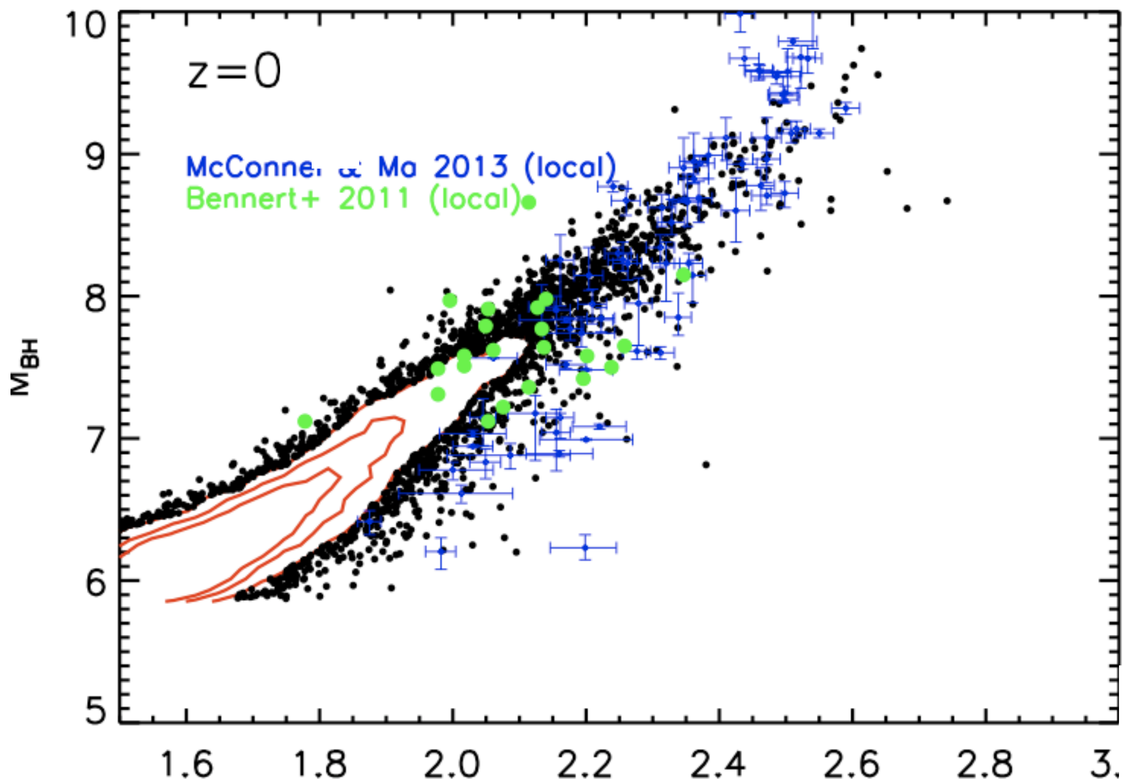

20 kpc

M* - M_{halo} relation in MBII simulation is consistent with observations.

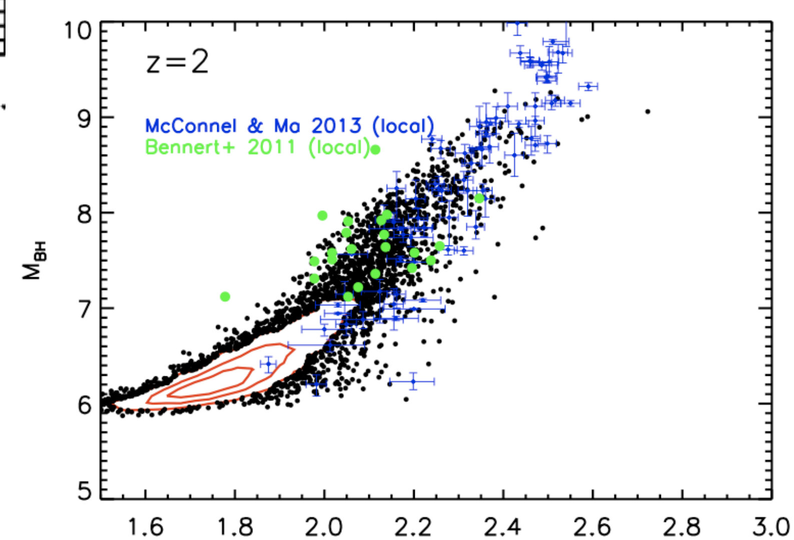


Tucker et al. in prep

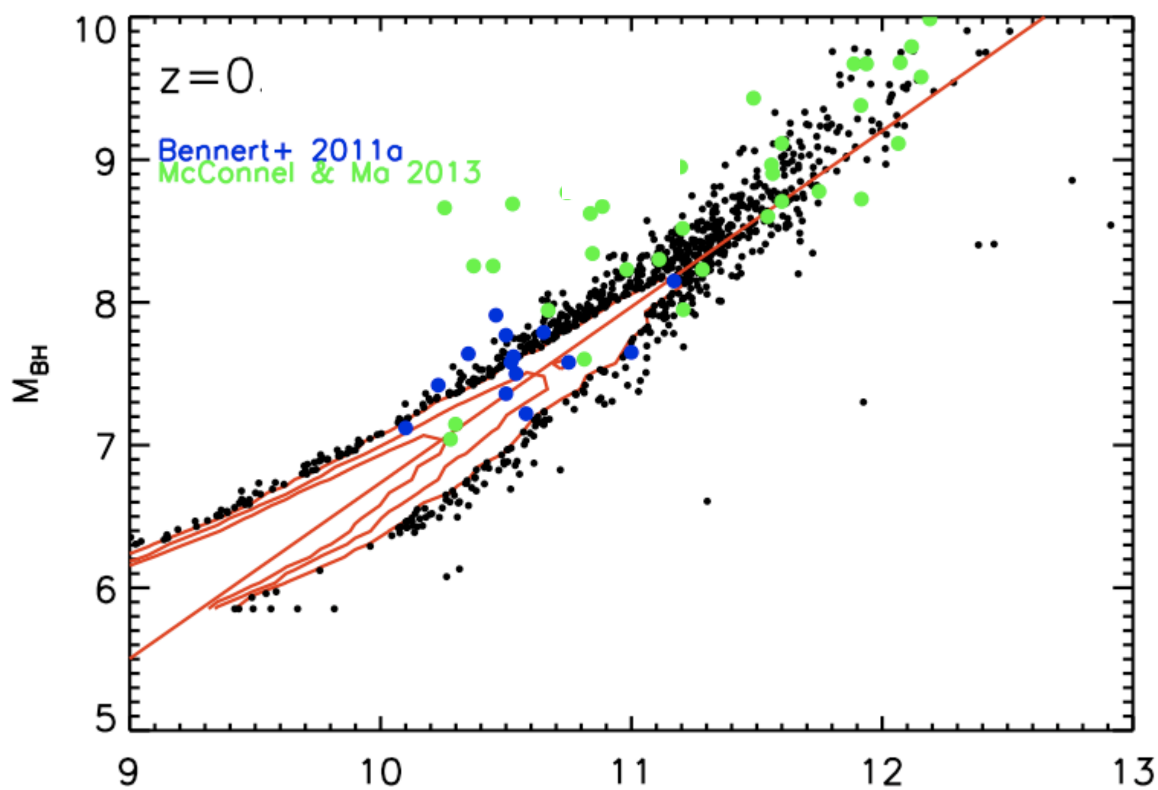
Black-hole mass vs σ



Log(Stellar velocity dispersion_[km/s],

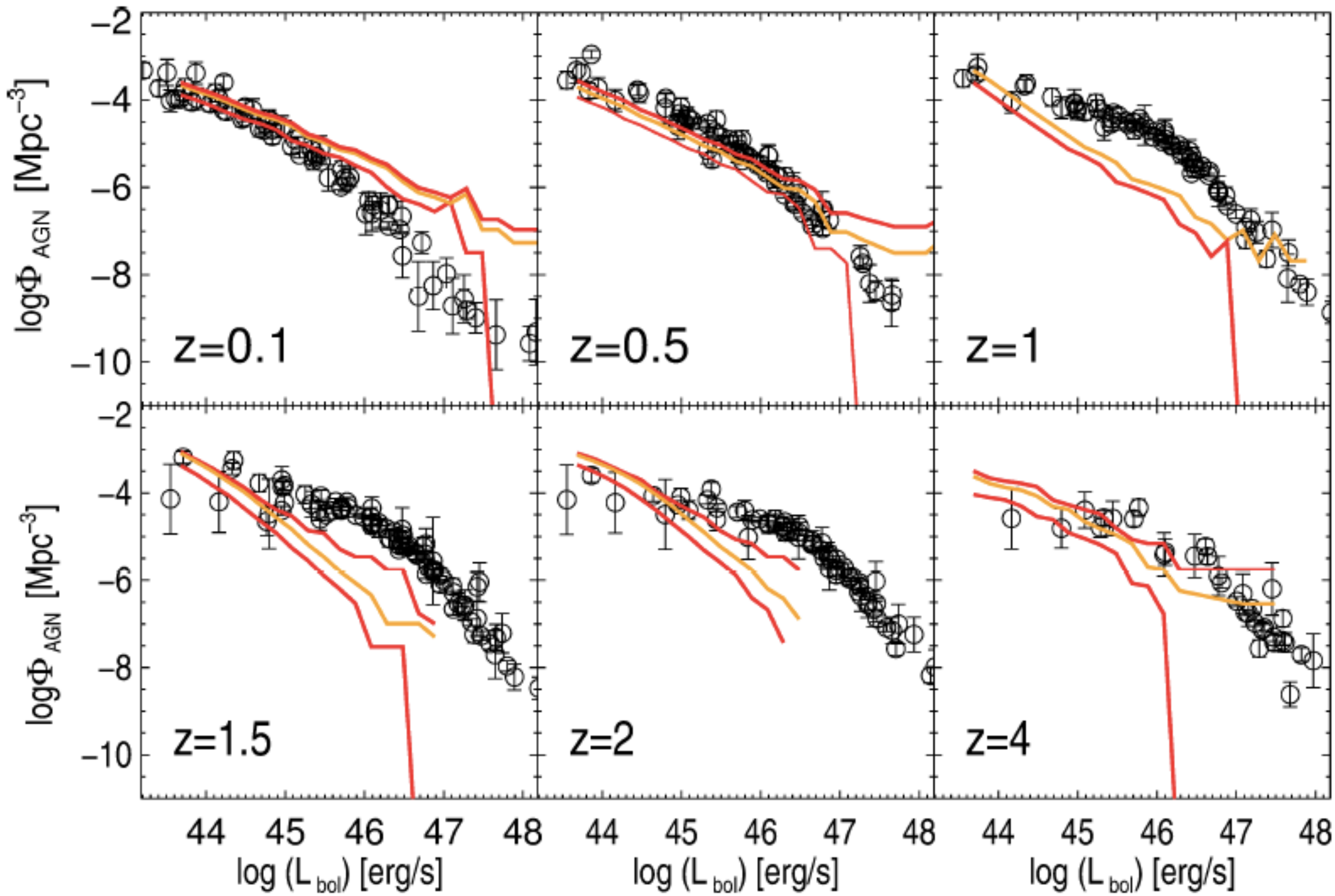


Black-hole mass vs galaxy stellar mass:

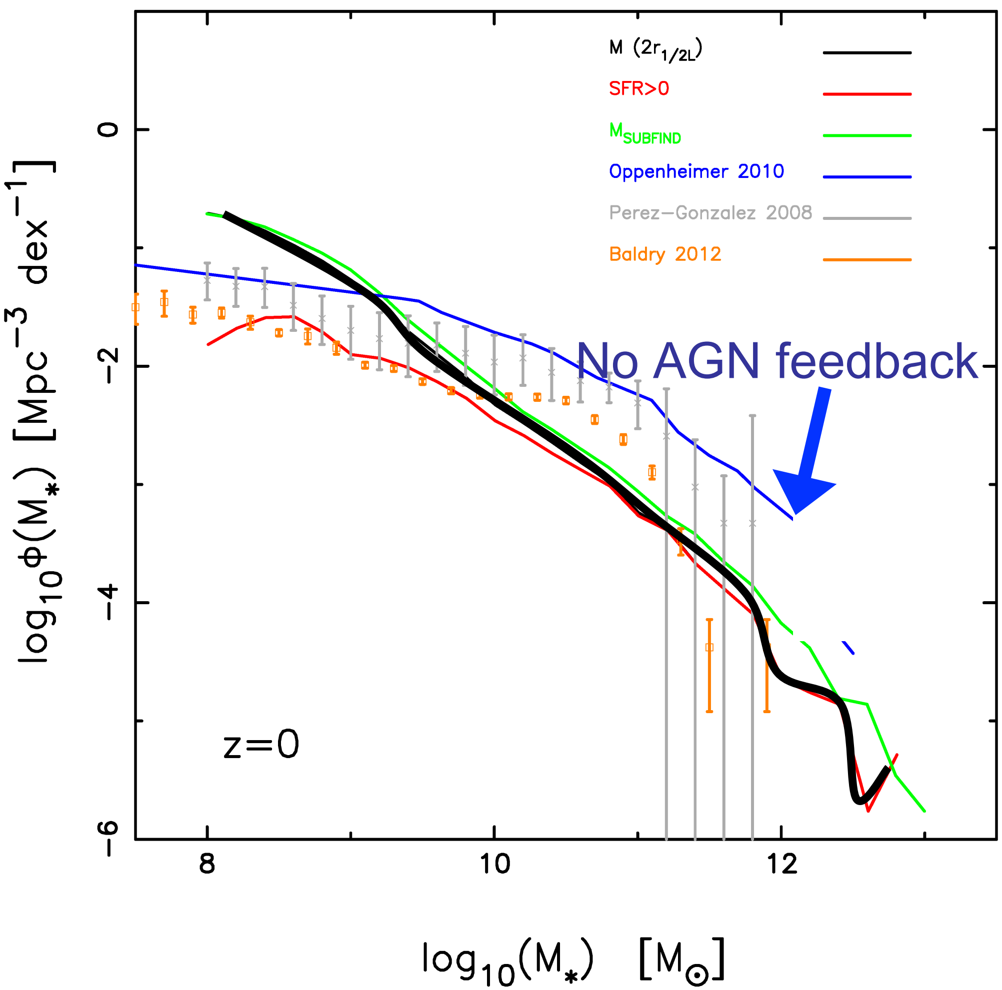


Log(stellar mass) [Msun]

AGN luminosity function at different redshifts



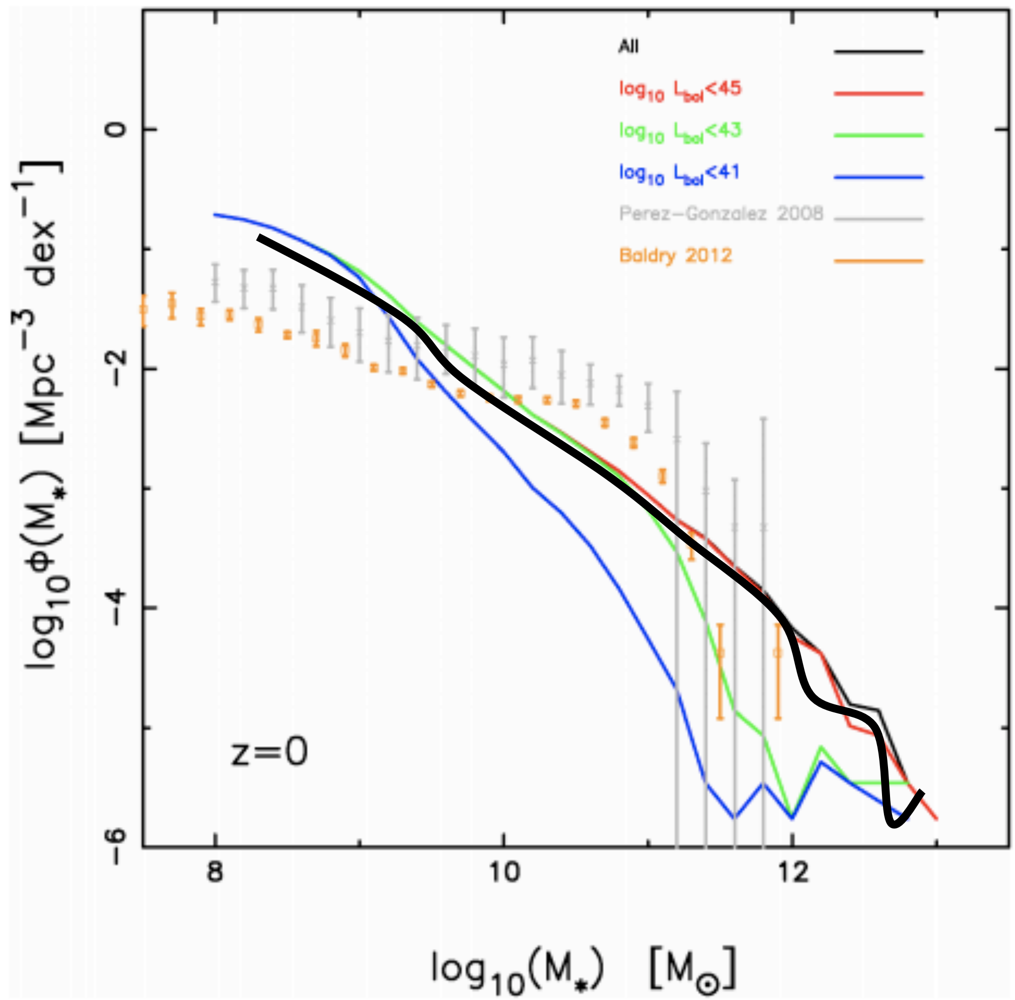
Present day galaxy stellar mass function compared to observations



AGN feedback helps reconciling high mass end (factor 10)

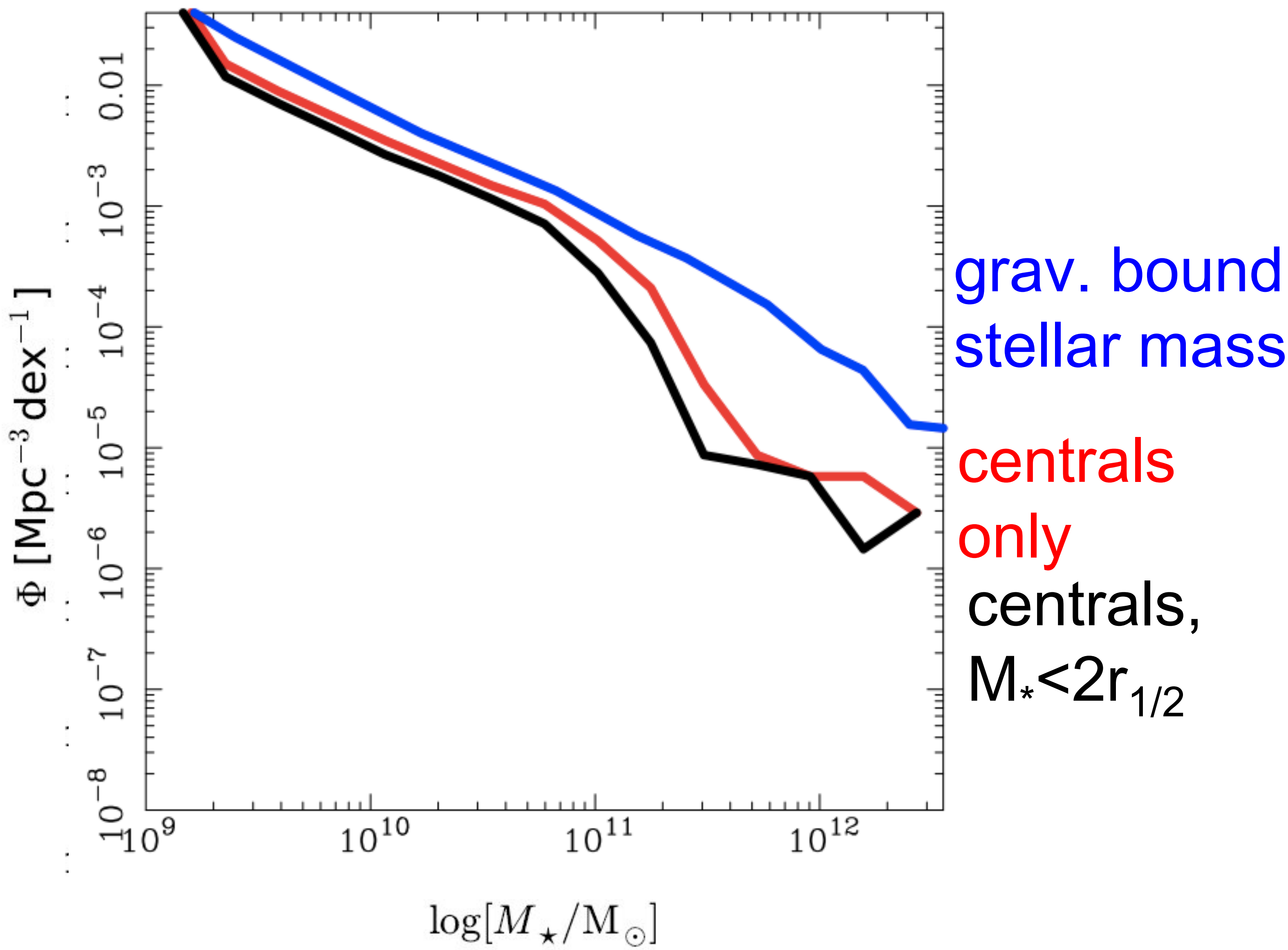
High mass end is very sensitive to how AGN are excised in observations

Log Number density of galaxies

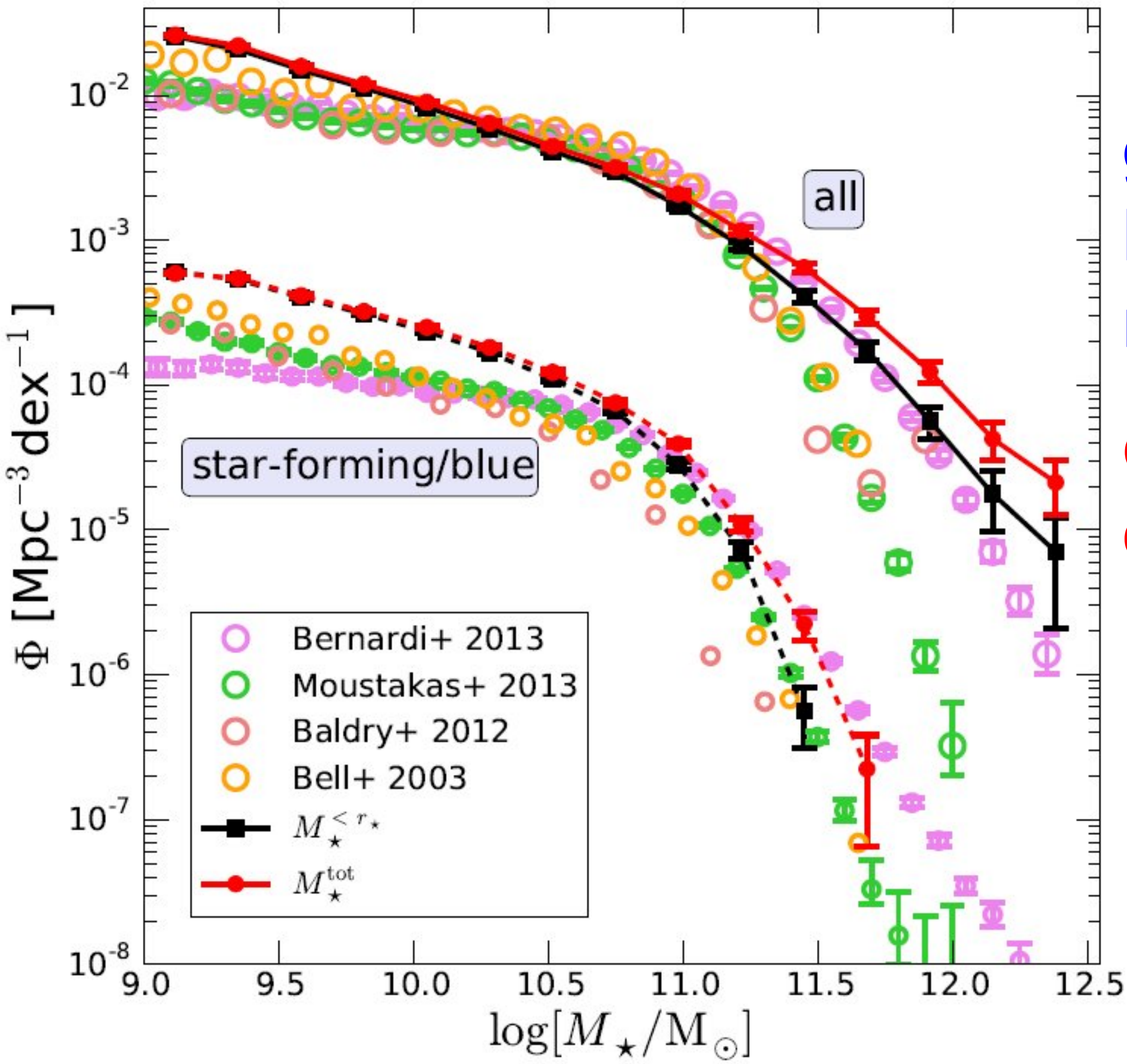


Mass of stars in each galaxy

But watch out: how stellar masses are measured in simulation affects GSMF:



Vogelsberger et al. 2014

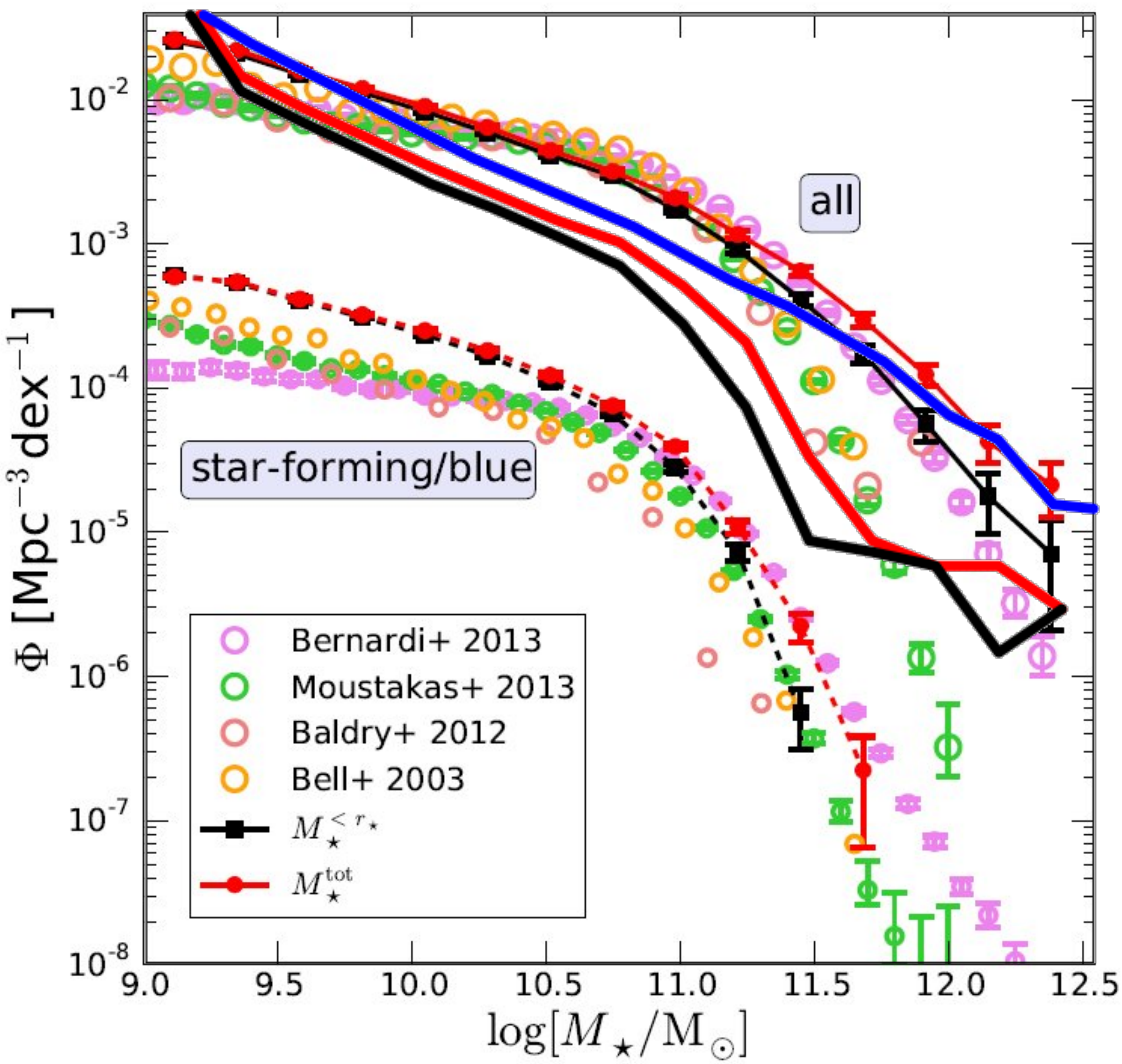


grav. bound mass?

centrals only

centrals, $M_*<2r_{1/2}$

put MB curves on top:



Summary

At high z, large-scale flows can grow black holes as observed, within standard cosmology.

At lower z, even "old" SPH galaxies & AGN look broadly OK (but GSMF too steep for $M_* < 10^9\ M_{sun}$)

Selection and measurement of L_* for galaxies in simulations (and observations) can easily change mass function by as much as AGN feedback