The co-evolution of galaxies and AGN, from voids to the field

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Punchline: halo mass is king

AGN, why we care ...

- we observe them
- do bad stuff to galaxies
- they sound cool in proposals

If we say AGN shuts down star formation, what do we mean ... ?

z>1: Quasar Epoch

quasar

infalling gas, hot halo build-up, cooling gas

z<1: hierarchical growth

If we say AGN shuts down star formation, what do we mean ... ?

z>1: Quasar Epoch

quasar

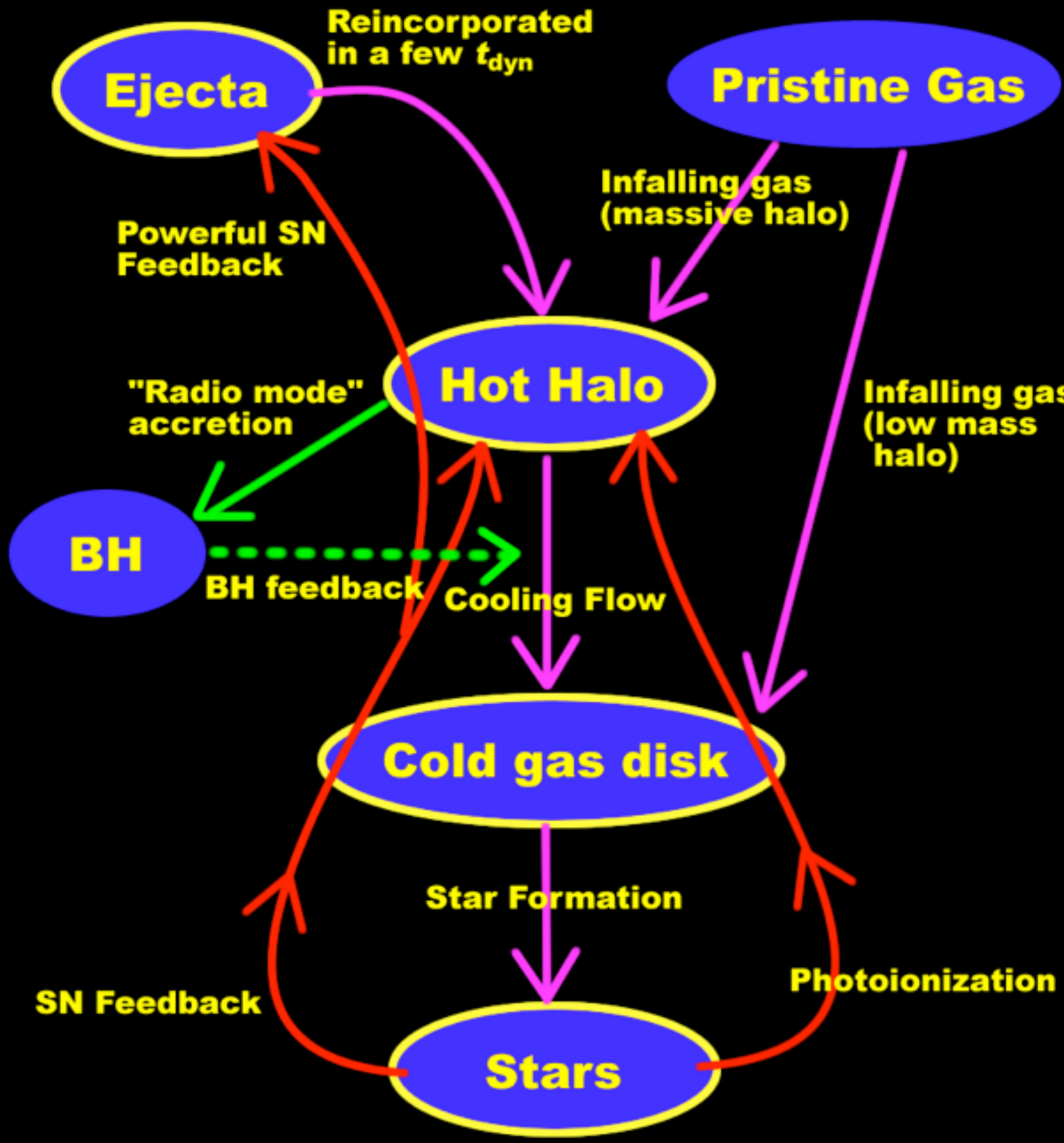
infalling gas, hot halo build-up

z<1: Radio Mode

If we say AGN shuts down star formation, what do we mean ... ?

	When?	Trigger?	Feeding?	Consequence?
Quasar Mode	at early times	gas rich mergers	cold gas	BH growth, sets properties of ellipticals
Radio Mode	at late times	BH & hot halo large enough?	hot gas? stellar winds?	suppresses cooling gas, shuts down SF

A complete picture of galaxy evolution probably needs both



- Schmidt law star formation
- SFR dependent SN winds
- satellite gas stripping
- morphological transformation
- assembly through mergers
- starbursts through mergers
- Magorrian relation BH growth
- jet & bubble AGN feedback

[schematic by Jenny Graves]

The AGN "radio-mode"

Sub-Eddington accretion from hot gas onto black hole

Efficient at late times, ongoing heating source

$$\dot{m}_{\rm BH} \sim m_{\rm BH} V_{\rm vir}^3$$

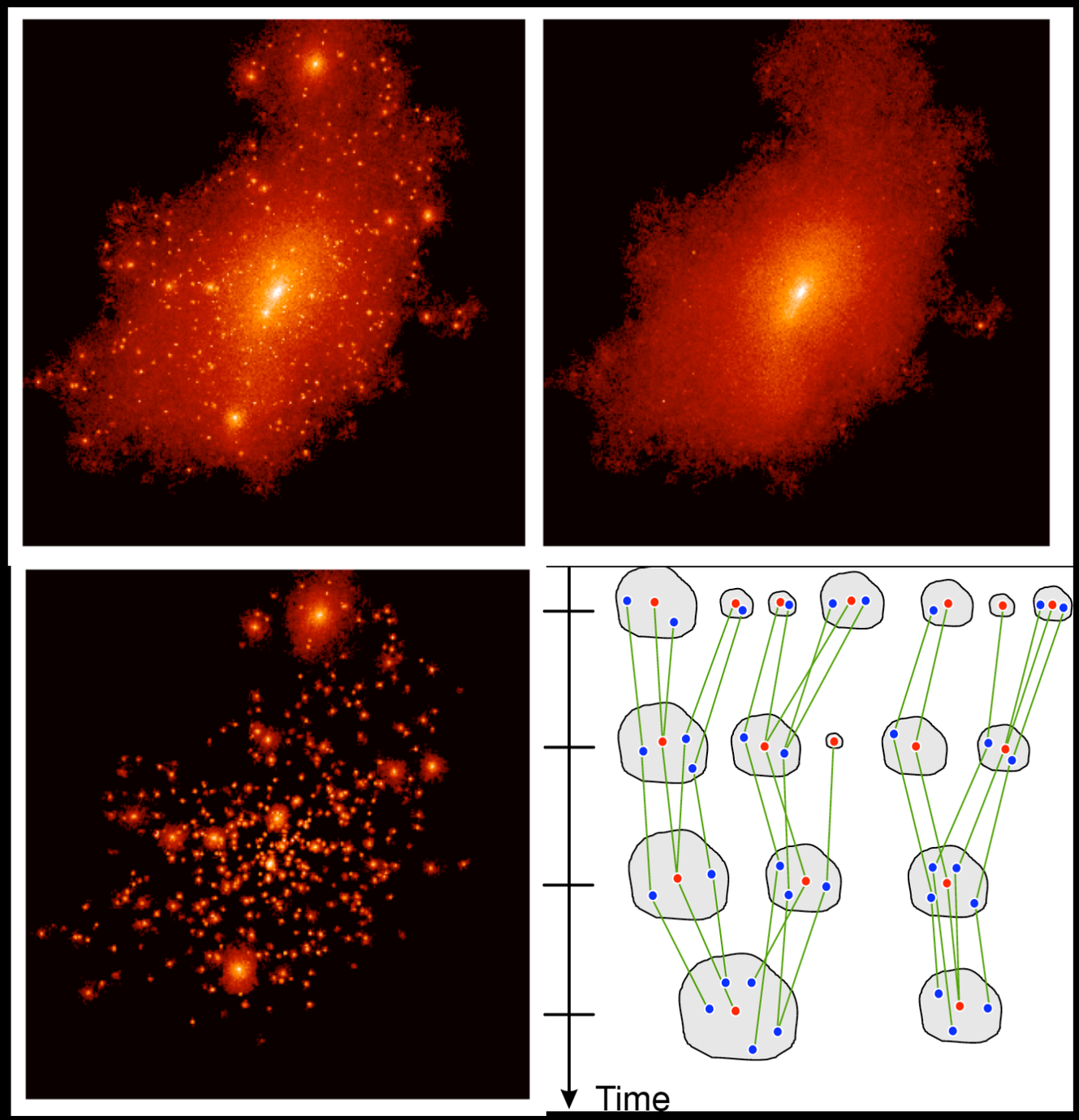
black hole accretion rate

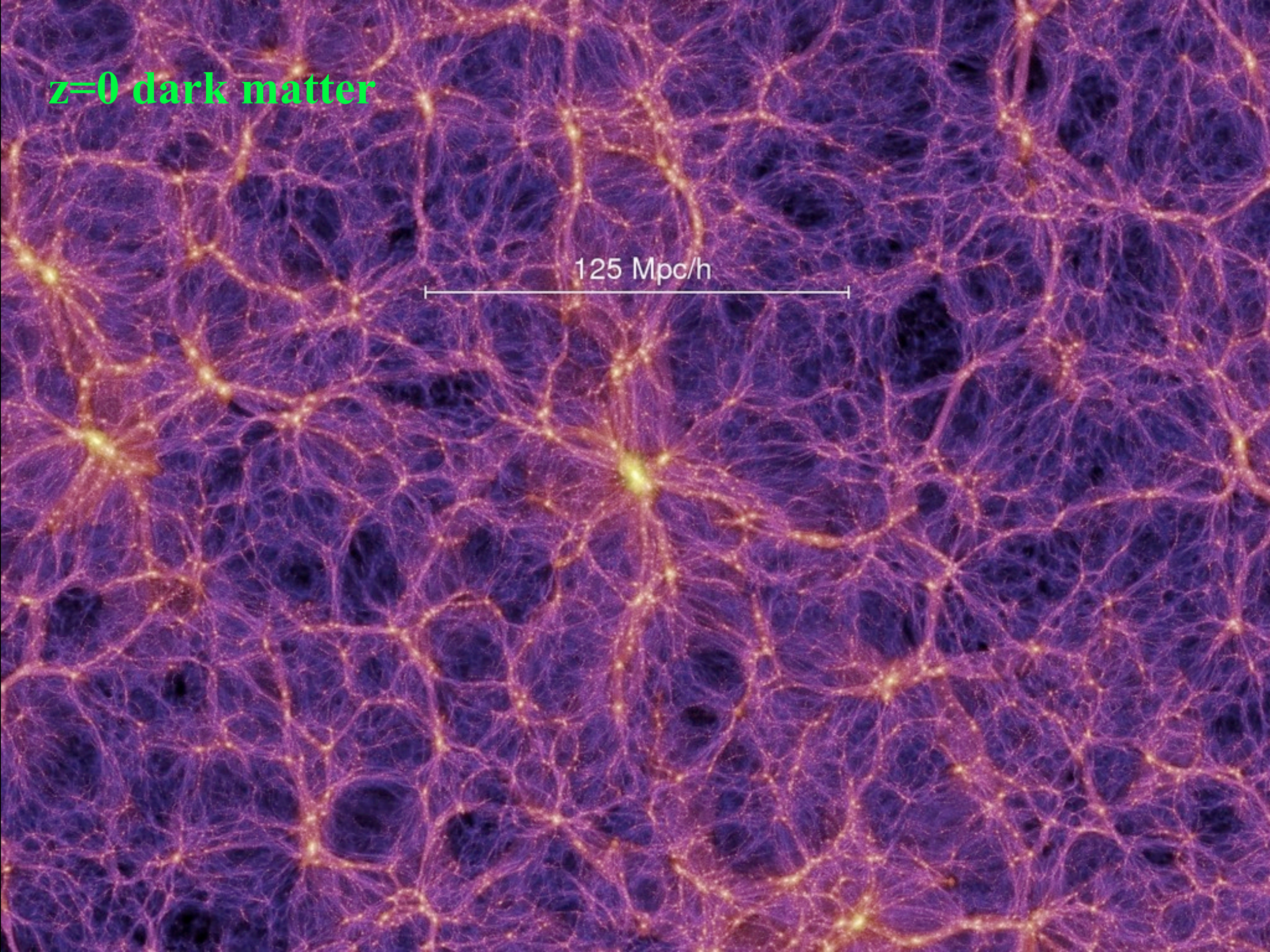
$$L_{\rm BH} = \eta \, \dot{m}_{\rm BH} \, c^2$$

radio-mode AGN luminosity

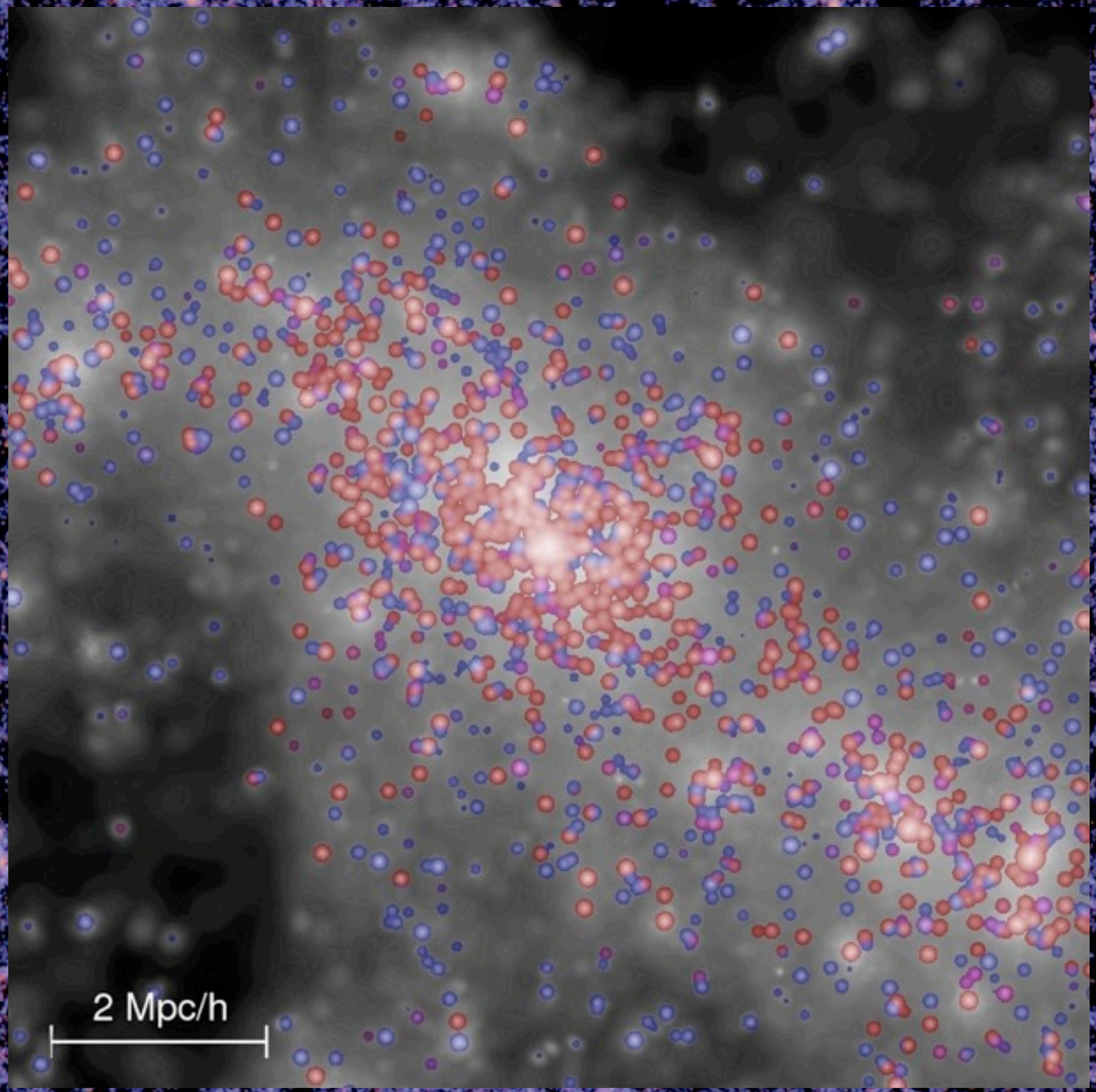
Croton et al. 2006

Placing Galaxies in Halos




z=0 dark matter
125 Mpc/h

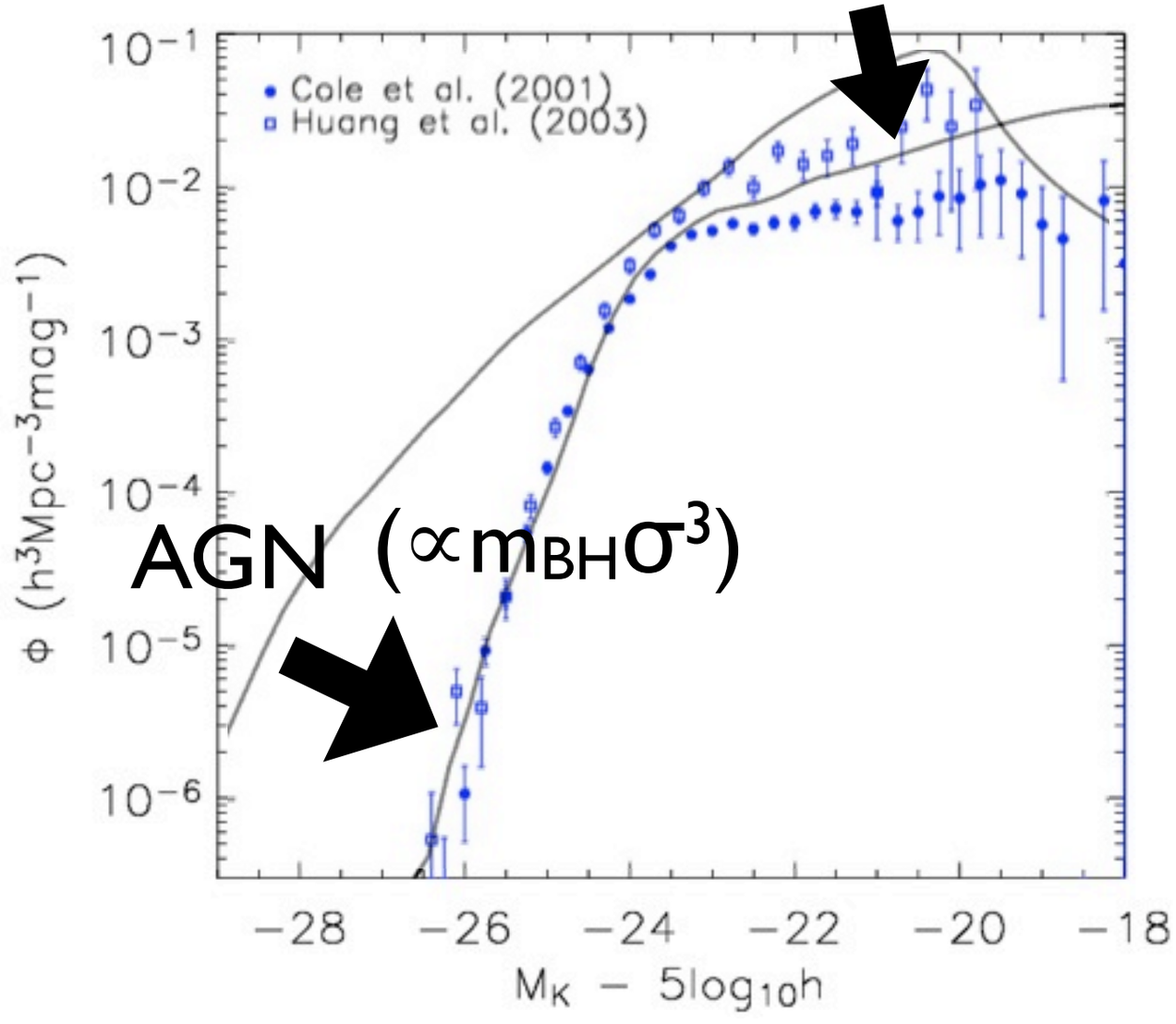
z=0 galaxy light

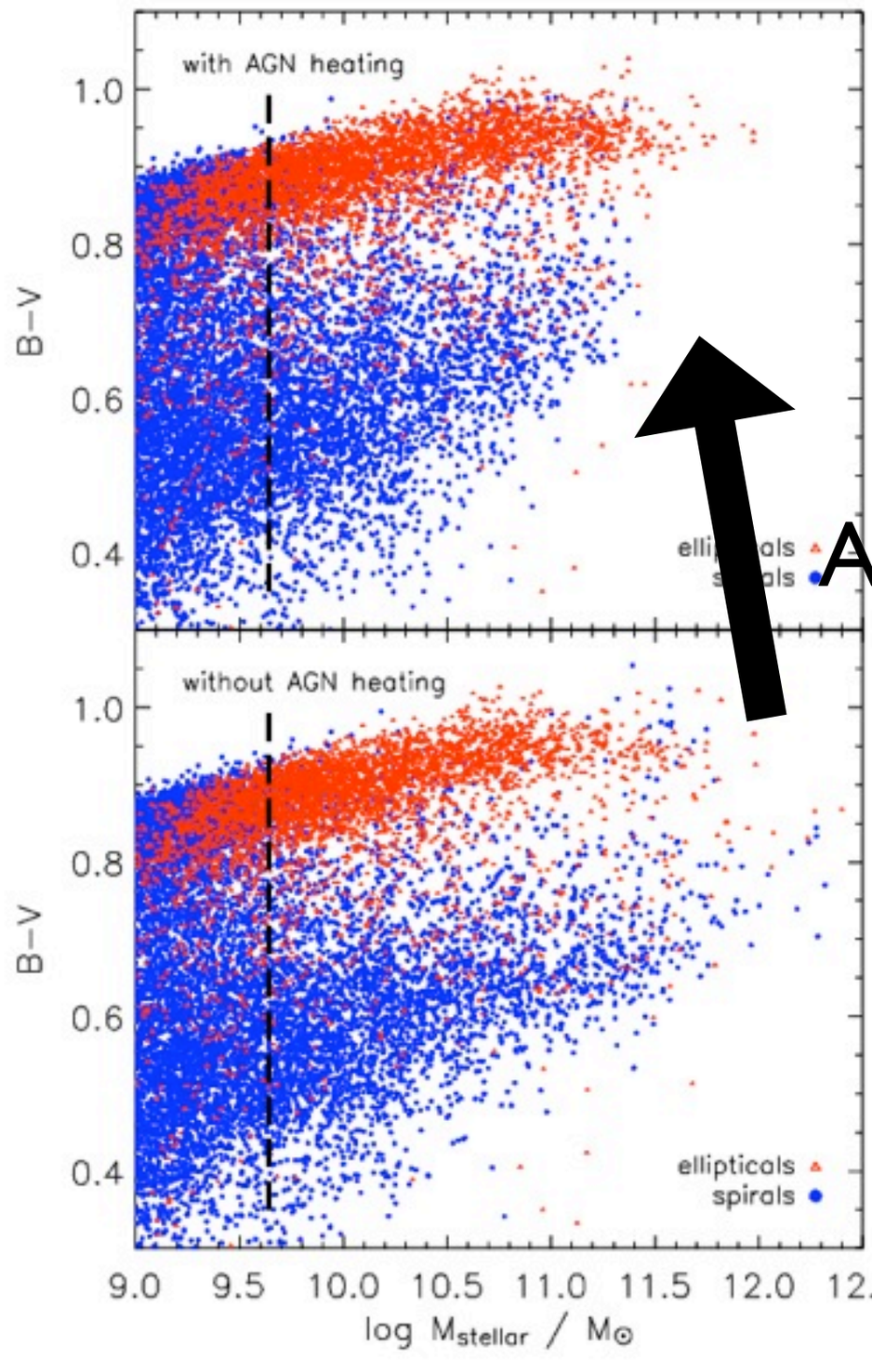


Physical consequences

SN (∝SFR)

AGN ($\propto m_{BH}\sigma^3$)



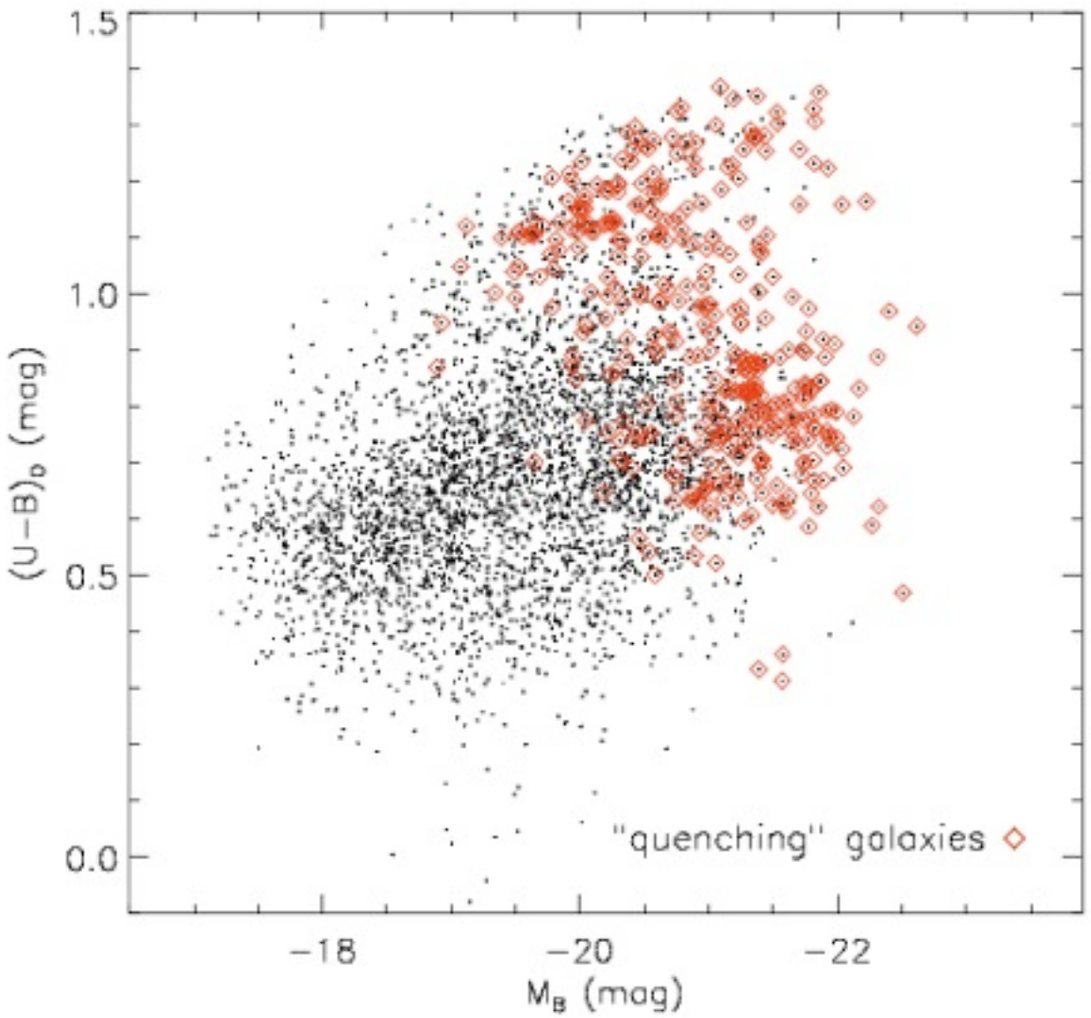


AGN

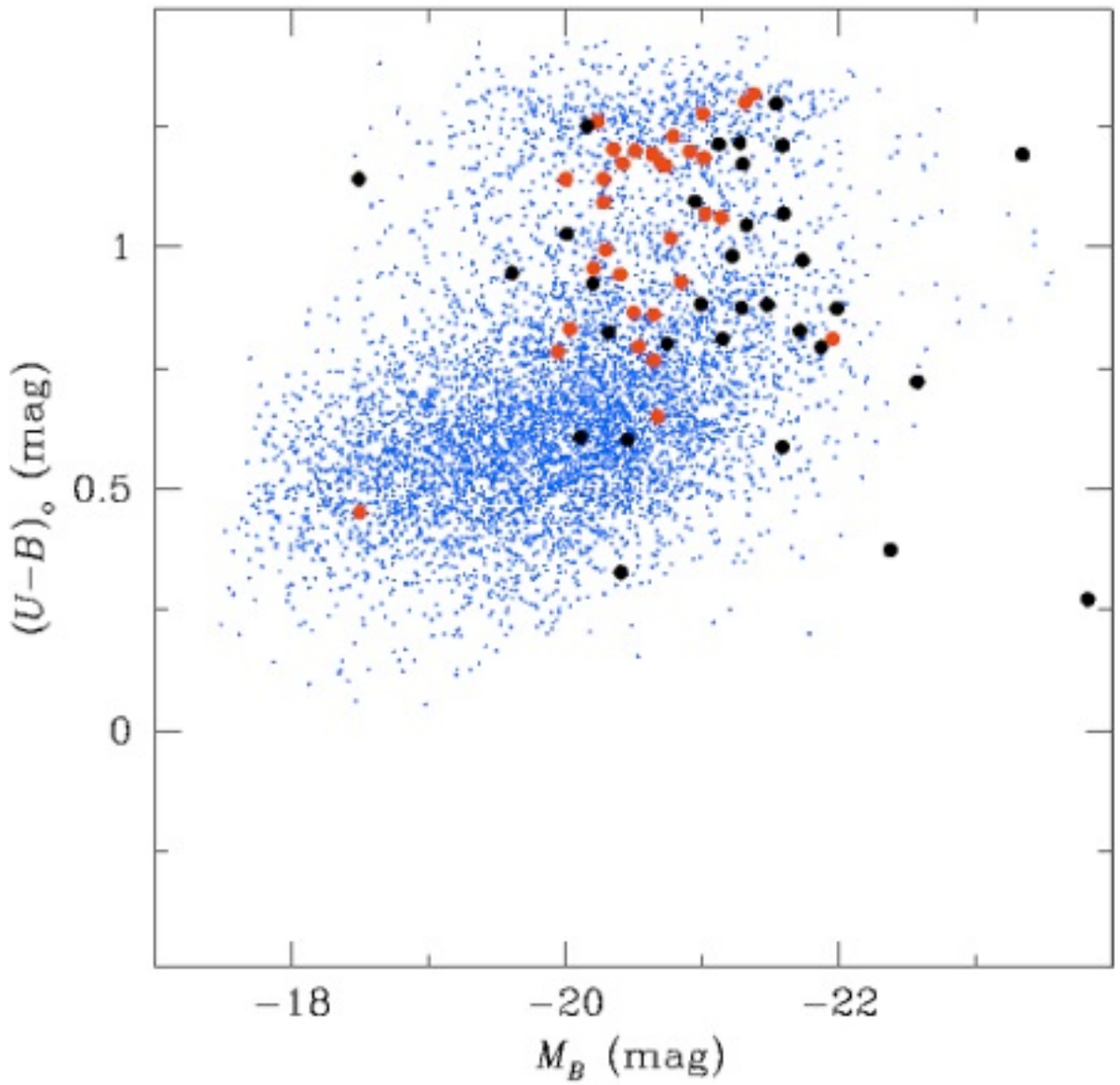
Croton et al. 2006

AGN in the AEGIS survey at z~1

Nandra et al. (2007)



DEEP2 semi-analytic mock



Chandra x-ray AGN in the EGS

Energy Considerations

Total cooling energy

vs.

Total heating energy

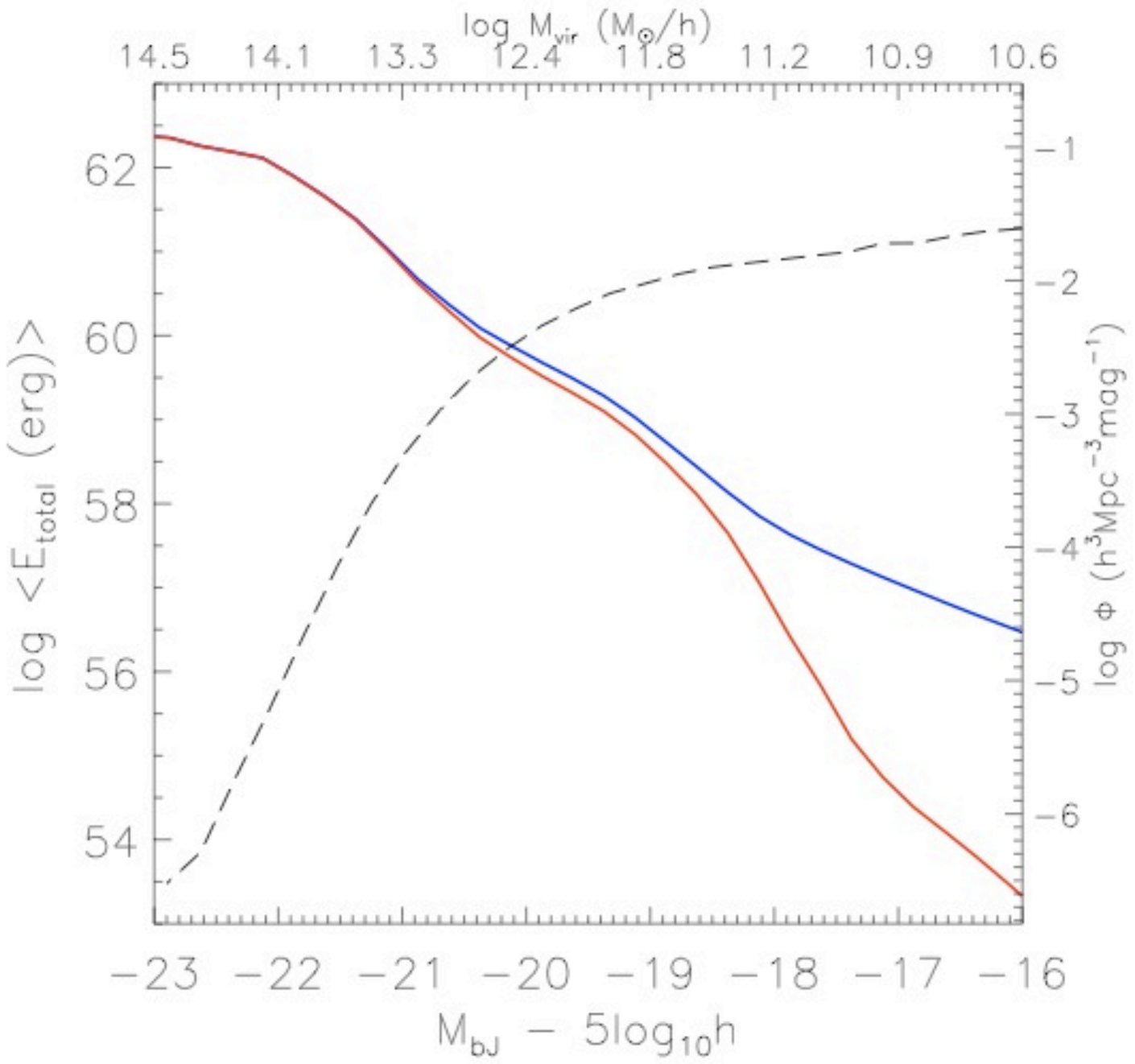
by z=0

LF knee corresponds to:

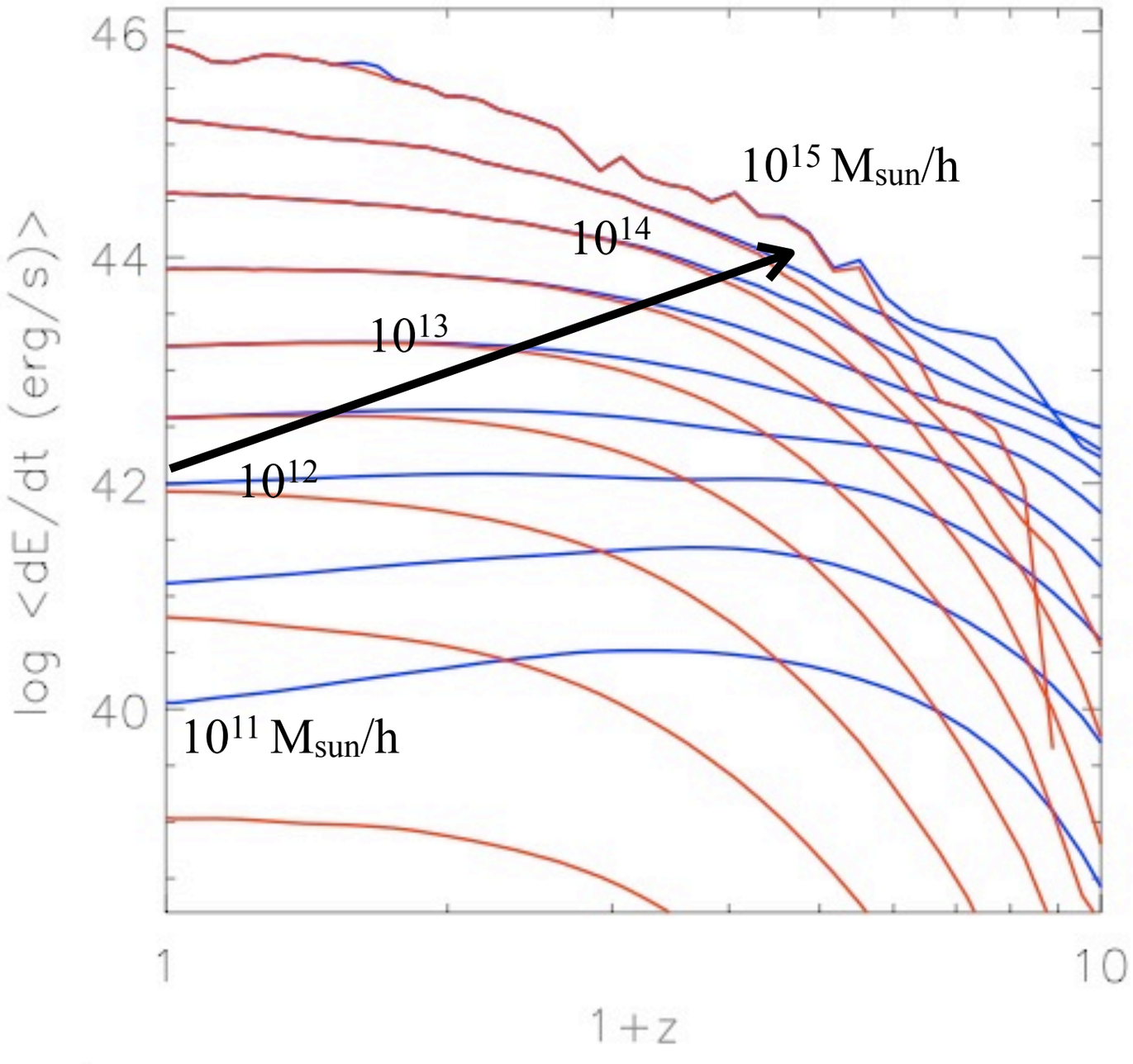
$E_{cool} \sim E_{heat}$

$M_{bJ} \sim -19 \,..\, -20$

$M_{vir} \sim 10^{11.5\text{-}12.5} M_{sun}/h$



Quenching vs. Halo Mass

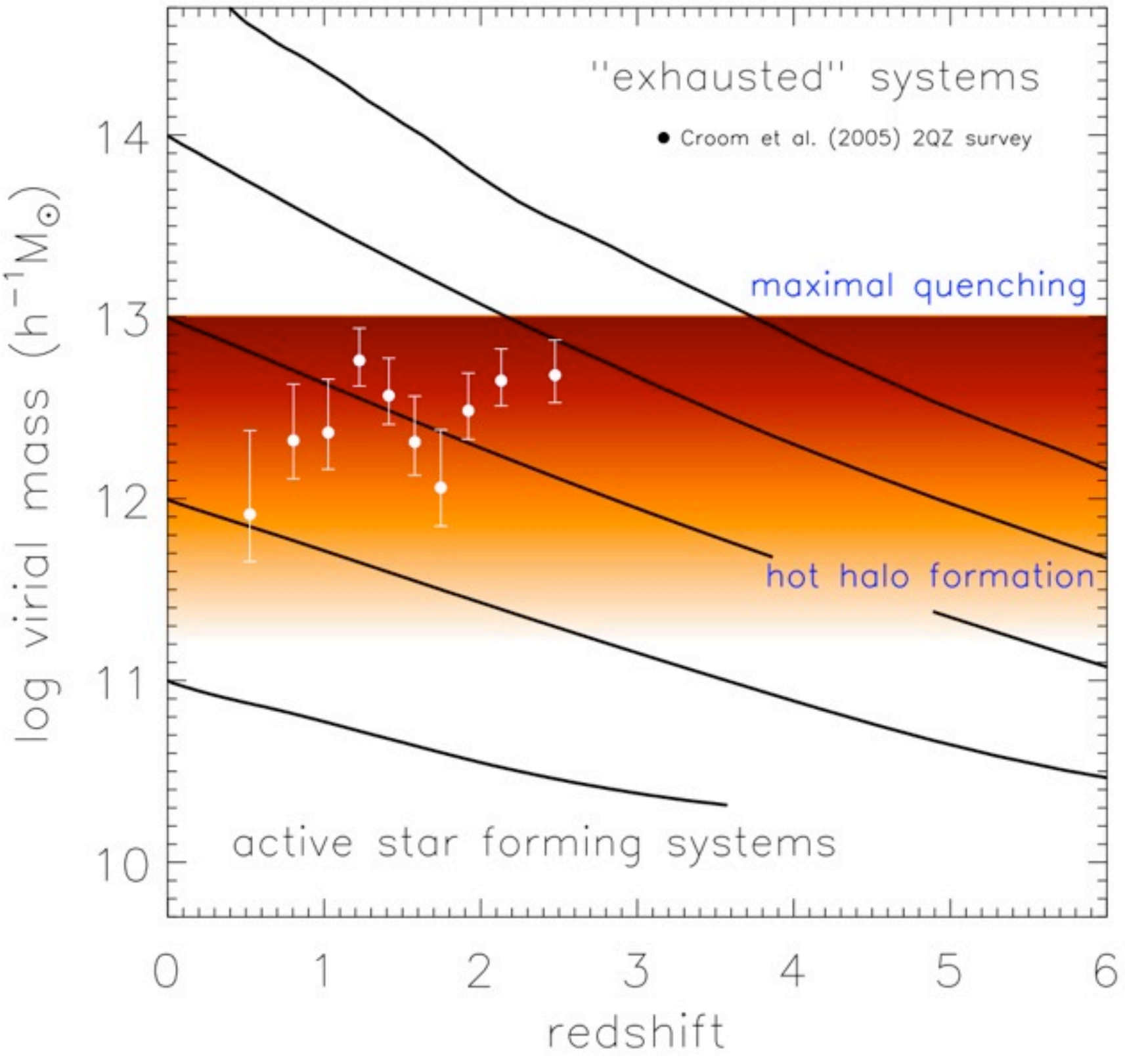


Cooling Rates

vs.

Heating Rates

currently
$M_{vir} \sim 10^{12} M_{sun}/h$ halos
are initiating quenching


"exhausted" systems
Croom et al. (2005) 2QZ survey
maximal quenching
hot halo formation
active star forming systems
log virial mass ($h^{-1}M_\odot$)
14
13
12
11
10
0
1
2
3
4
5
6
redshift

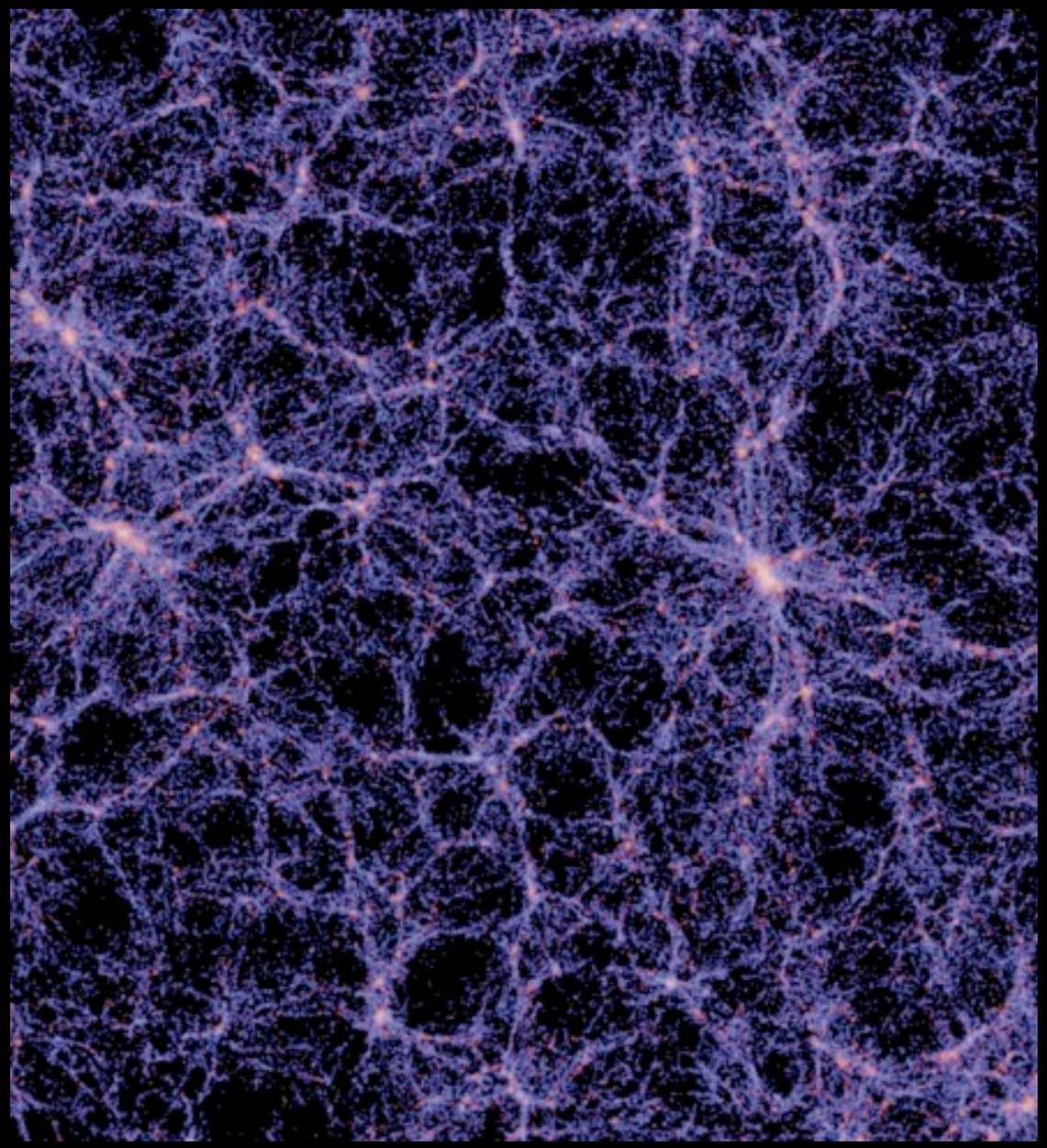
Environment dependent quenching?

When I s
is

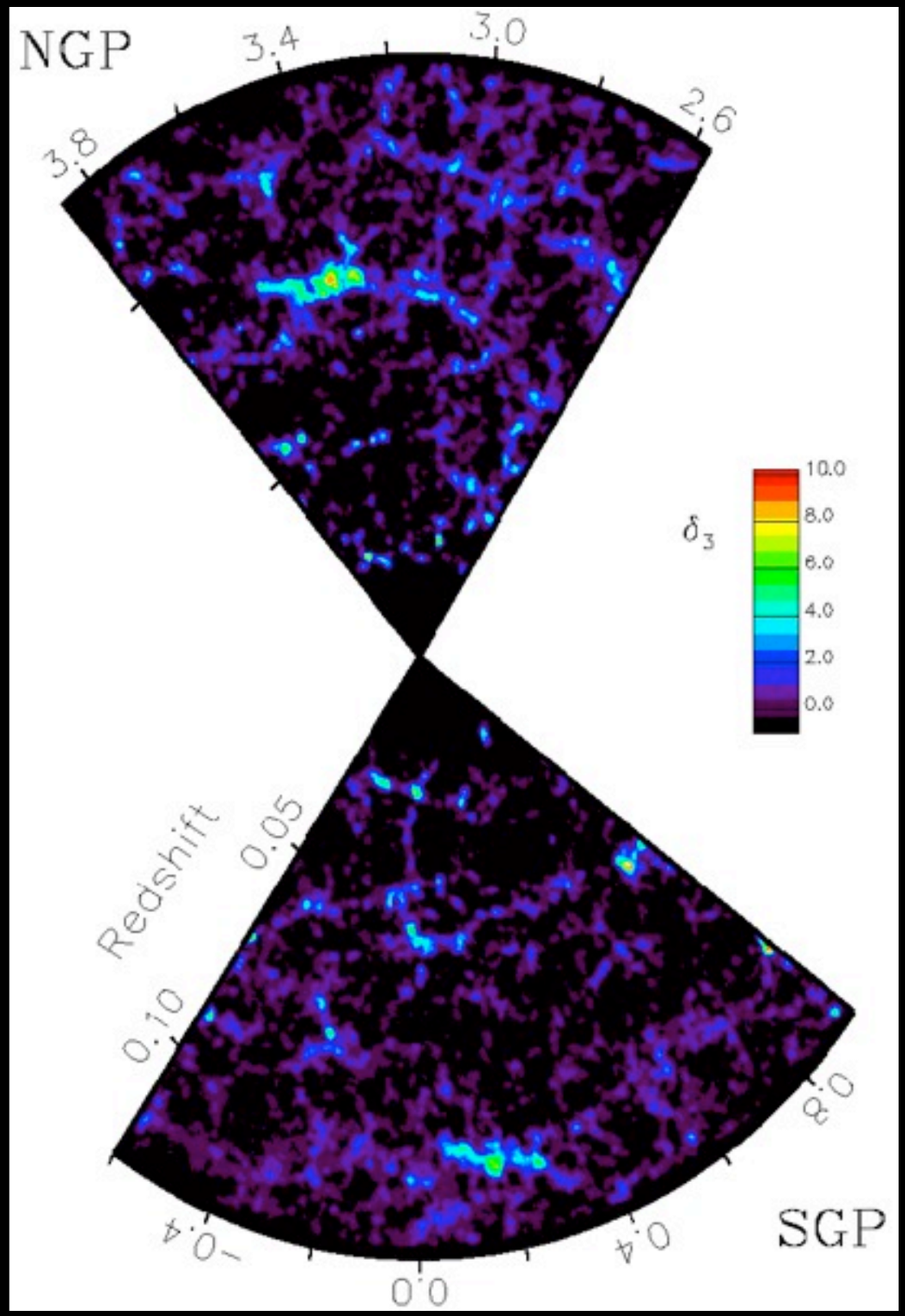
Munich

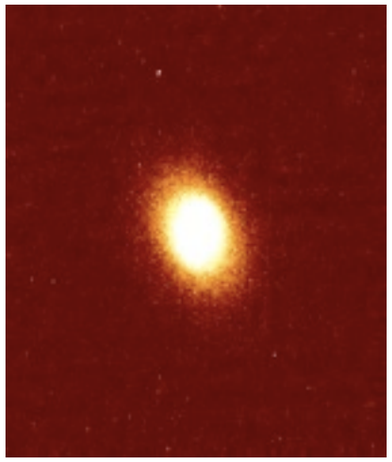
When I say "environment", this is what I mean ...

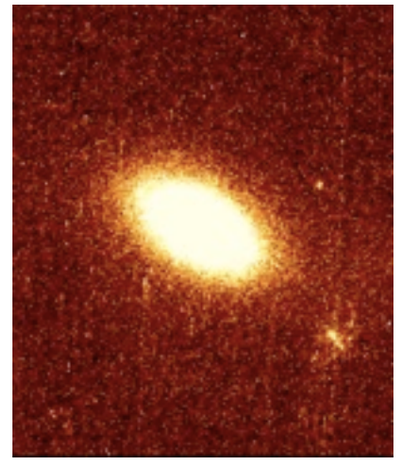
Millennium Simulation
semi-analytic model



2dFGRS







Croton et al. 2005

2dFGRS

late types
early types

cluster (δ_8>6.0)

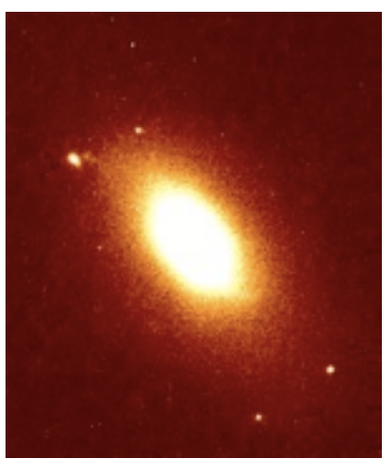
void (δ_8<−0.75)

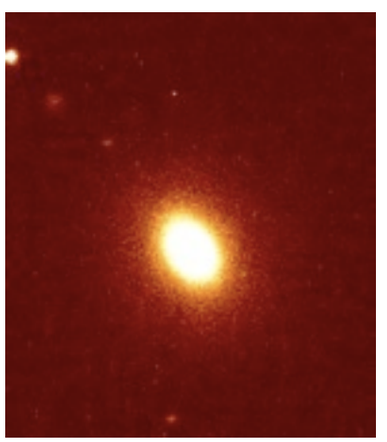
Φ (h^3Mpc^{-3} mag^{-1})

10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

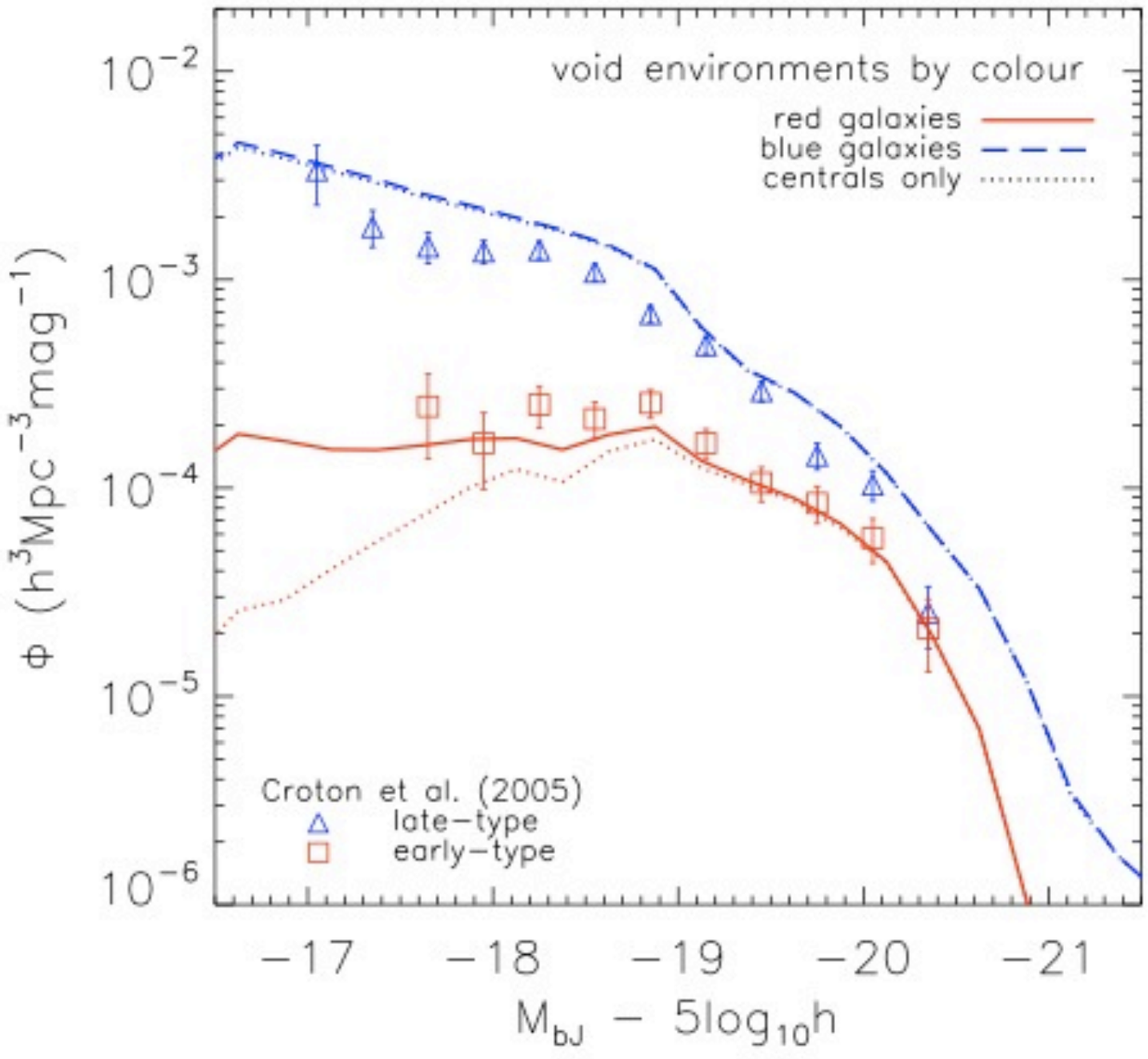
−17 −18 −19 −20 −21 −22

$M_{bJ} - 5\log_{10}h$





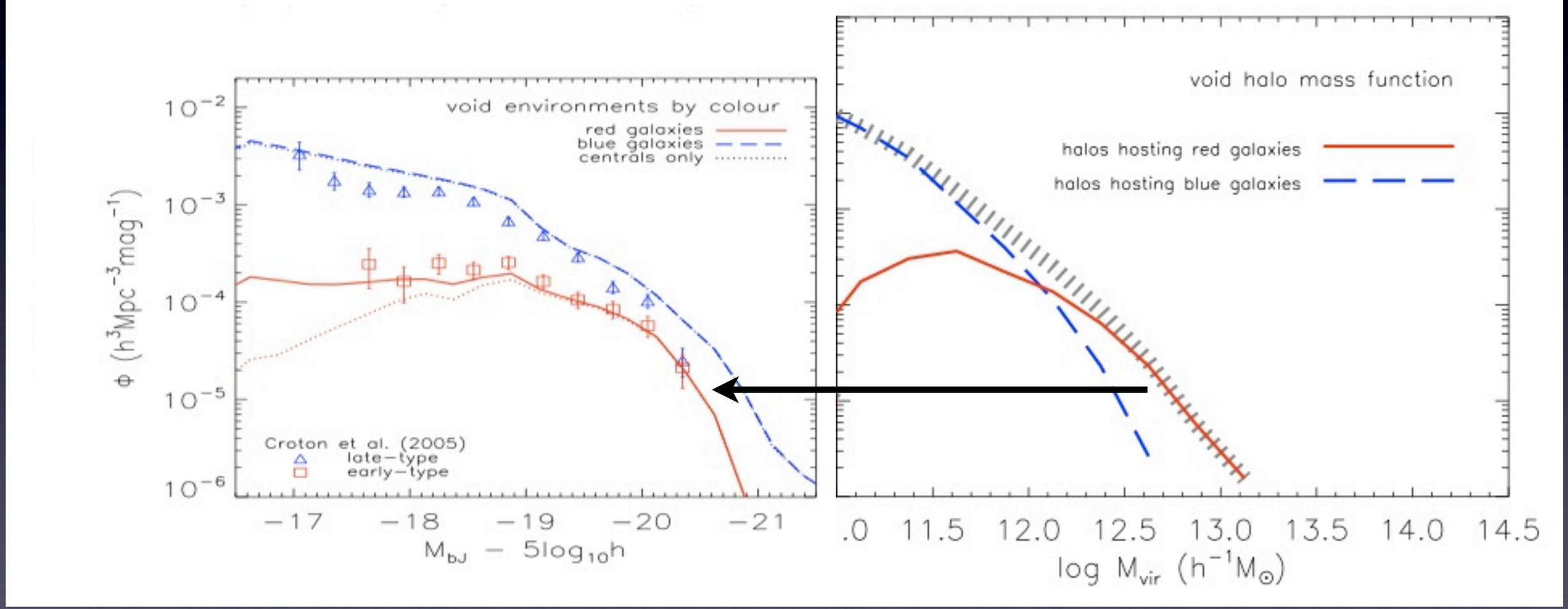
Croton & Farrar (2008)



The Millennium Simulation semi-analytic galaxy formation model

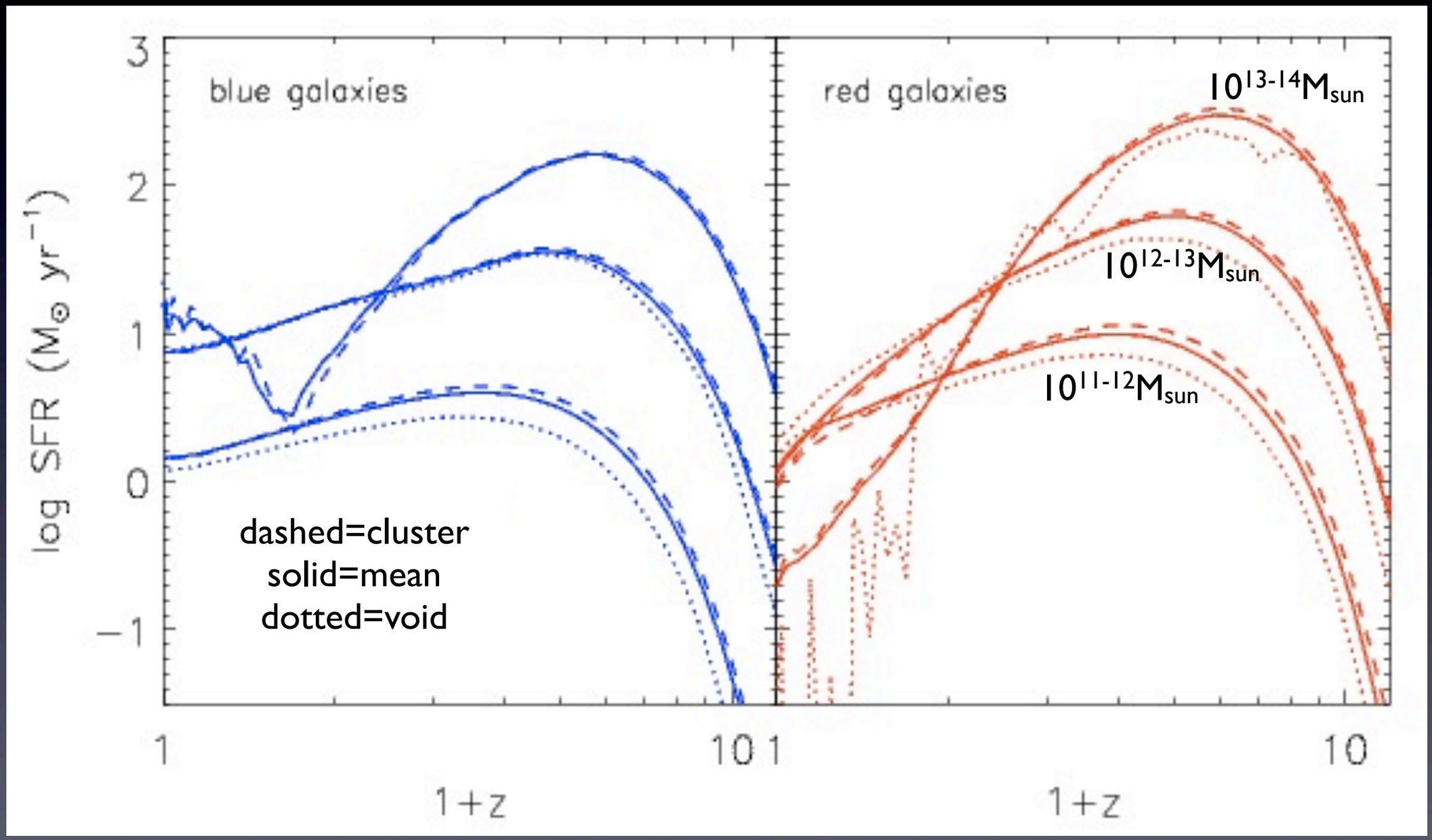
So what's special about early-type void galaxies?

Croton & Farrar (2008)



Halo mass function in different environments

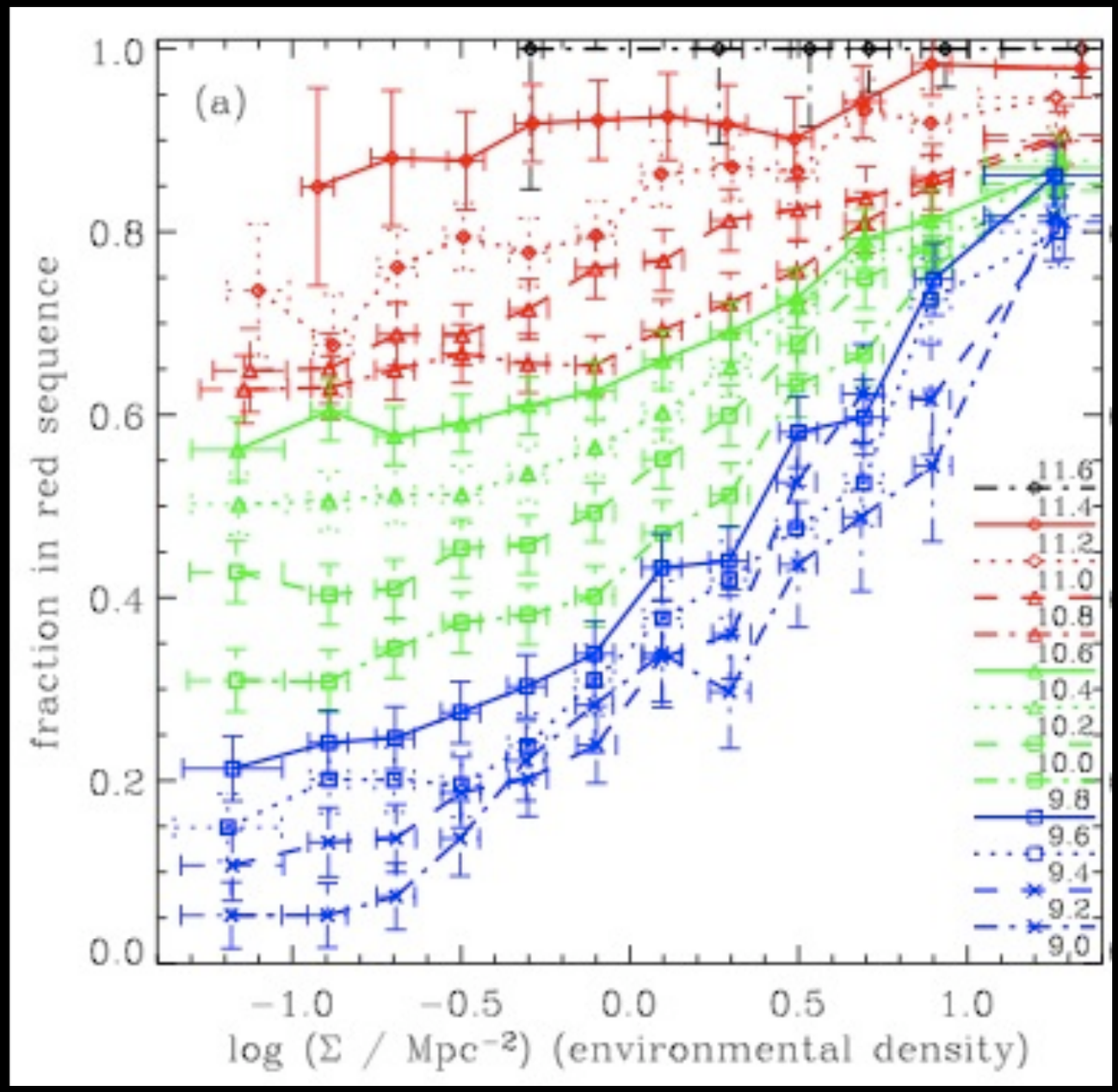
Is environment important for star formation quenching?



Croton & Farrar (2008)

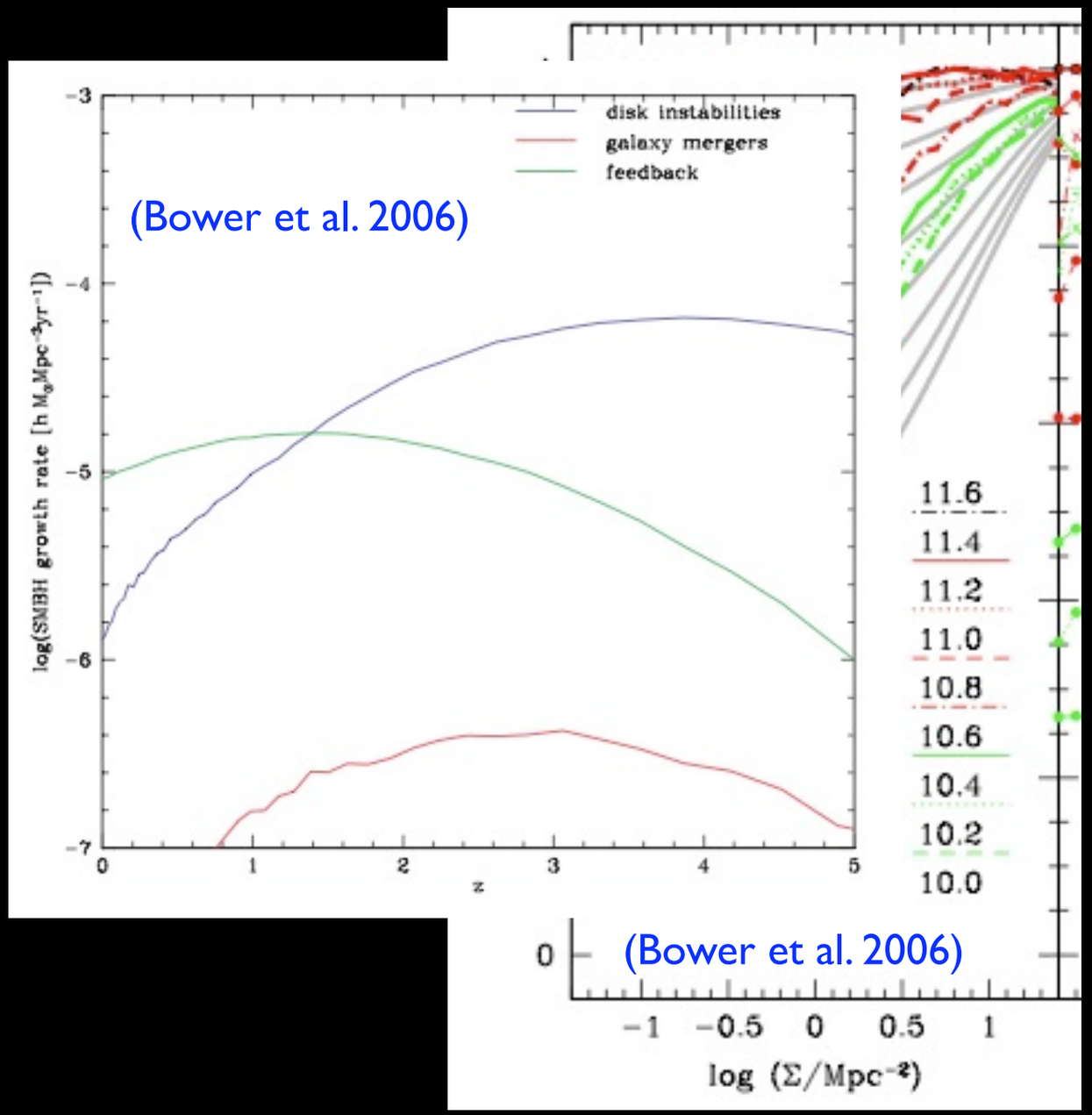
SFR vs. redshift in DM halos of fixed final mass

Problems in detail?



(Baldry et al. 2006)

Problems in detail?



(Bower et al. 2006)

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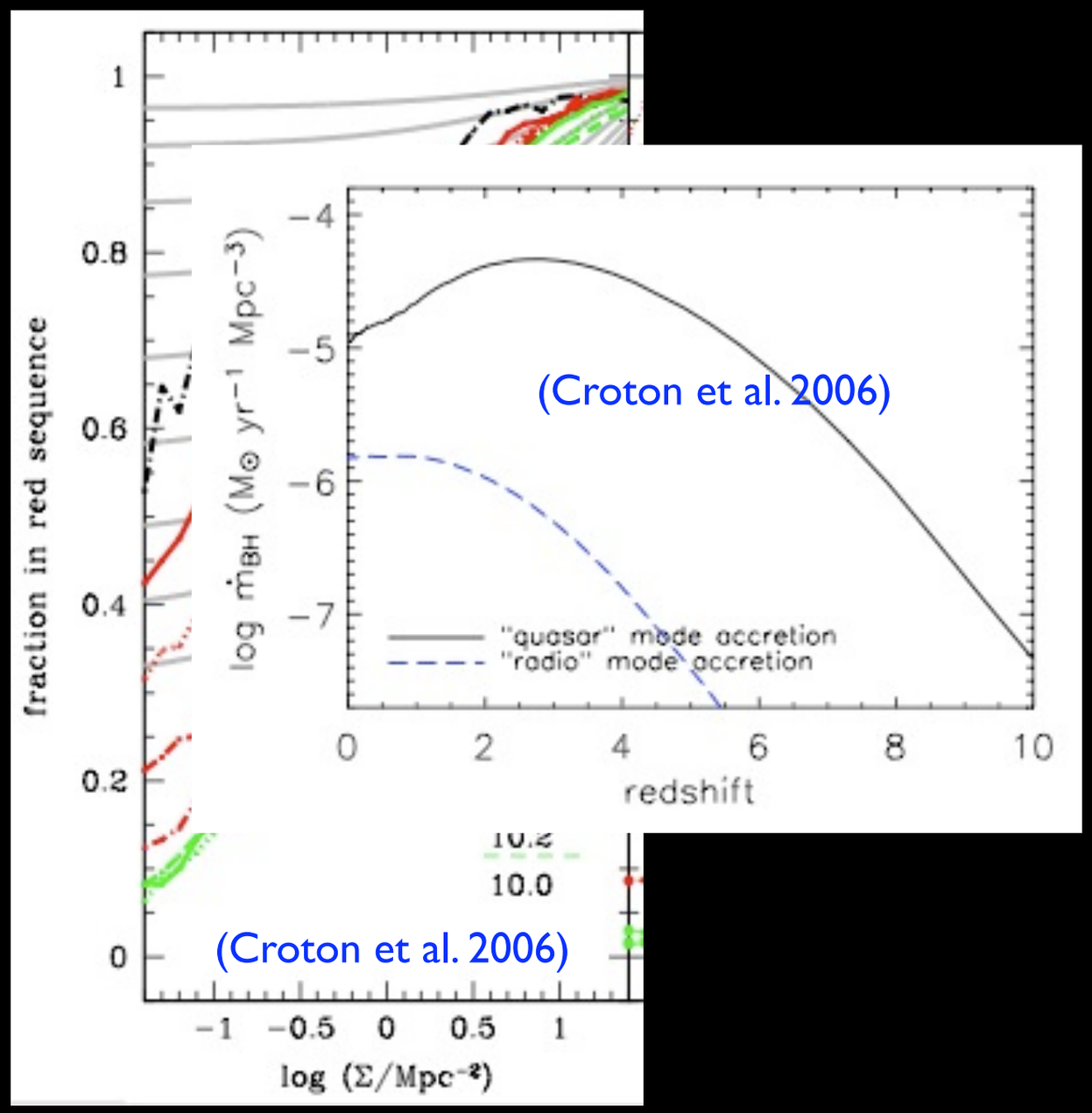


(Croton et al. 2006)

(Croton et al. 2006)

(Baldry et al. 2006)

How do we grow black holes?

Merger driven scenario:

During a merger some fraction of the cold gas is driven onto the central BH.

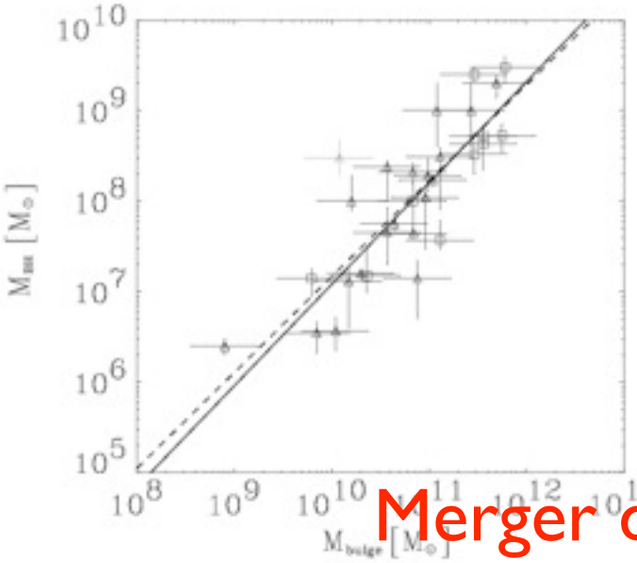
$$\Delta m_{\rm BH} \sim 0.03\, m_{\rm R}\, m_{\rm cold}$$

Disk instability scenario:

As the stellar disk becomes unstable, some fraction of the cold gas is dragged inward to accrete onto the BH.

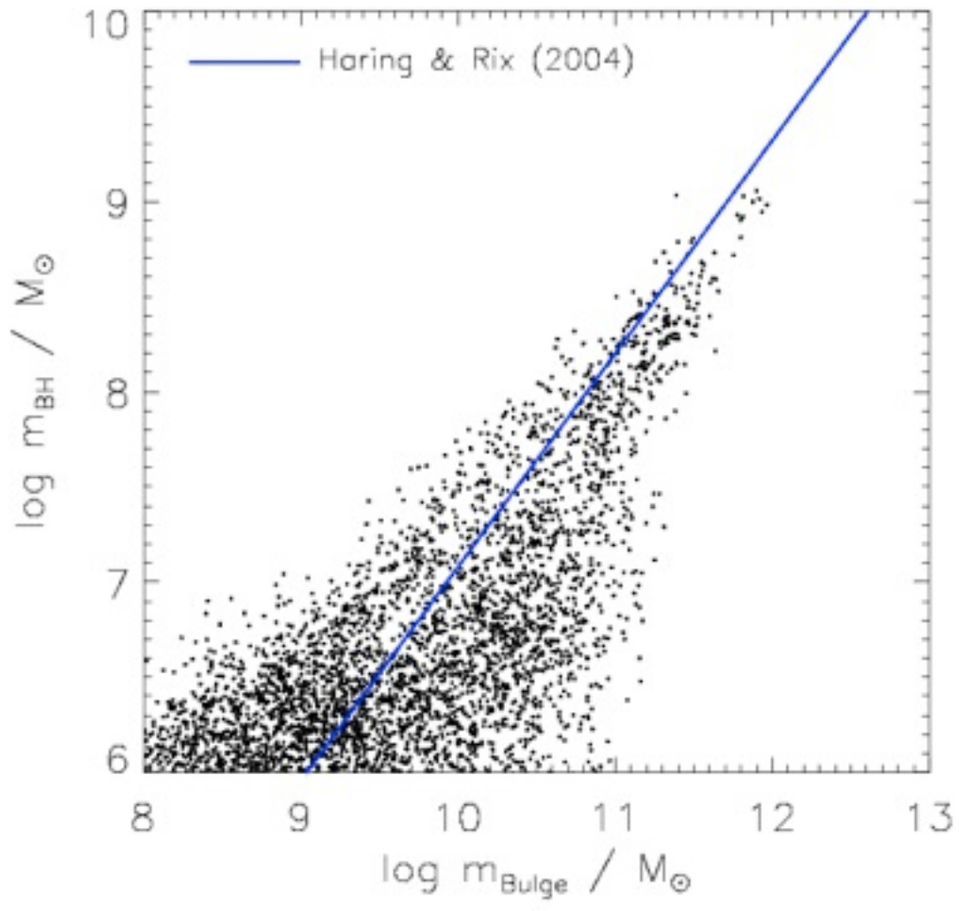
$$\Delta m_{\rm BH} \sim 0.01\, m_{\rm cold}$$

Both involve the gas losing angular momentum in some way
Both have a different environmental dependence

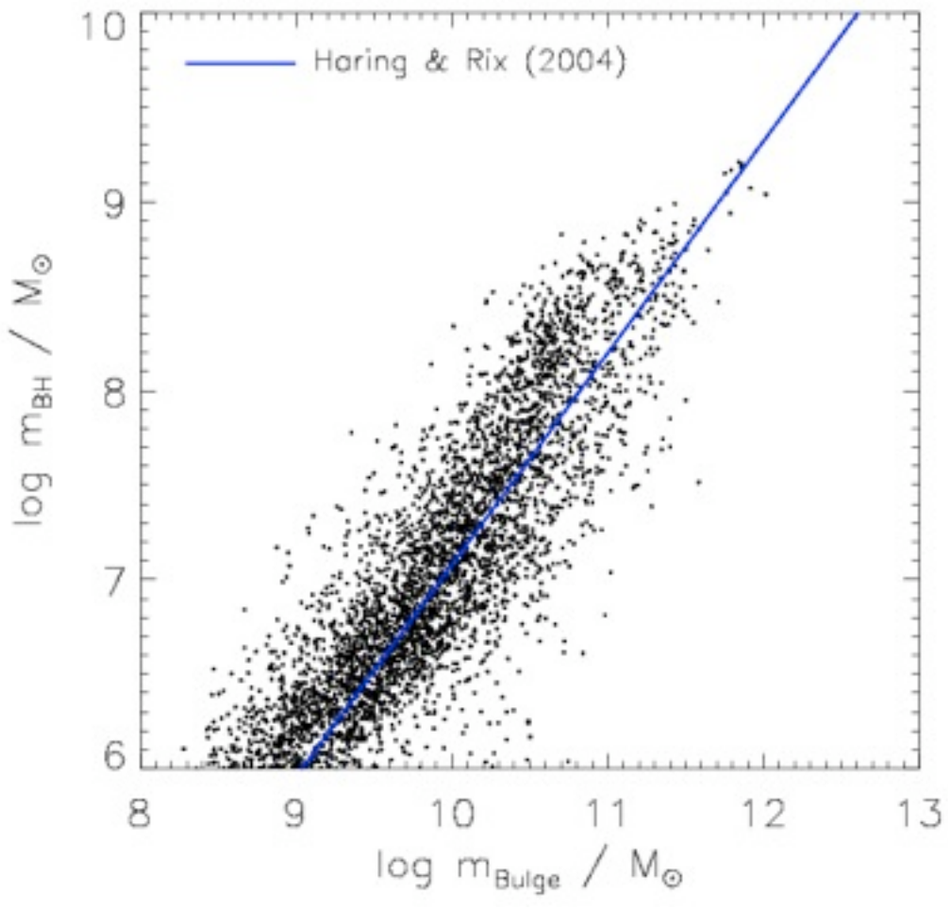


BH-bulge relation

Merger driven growth



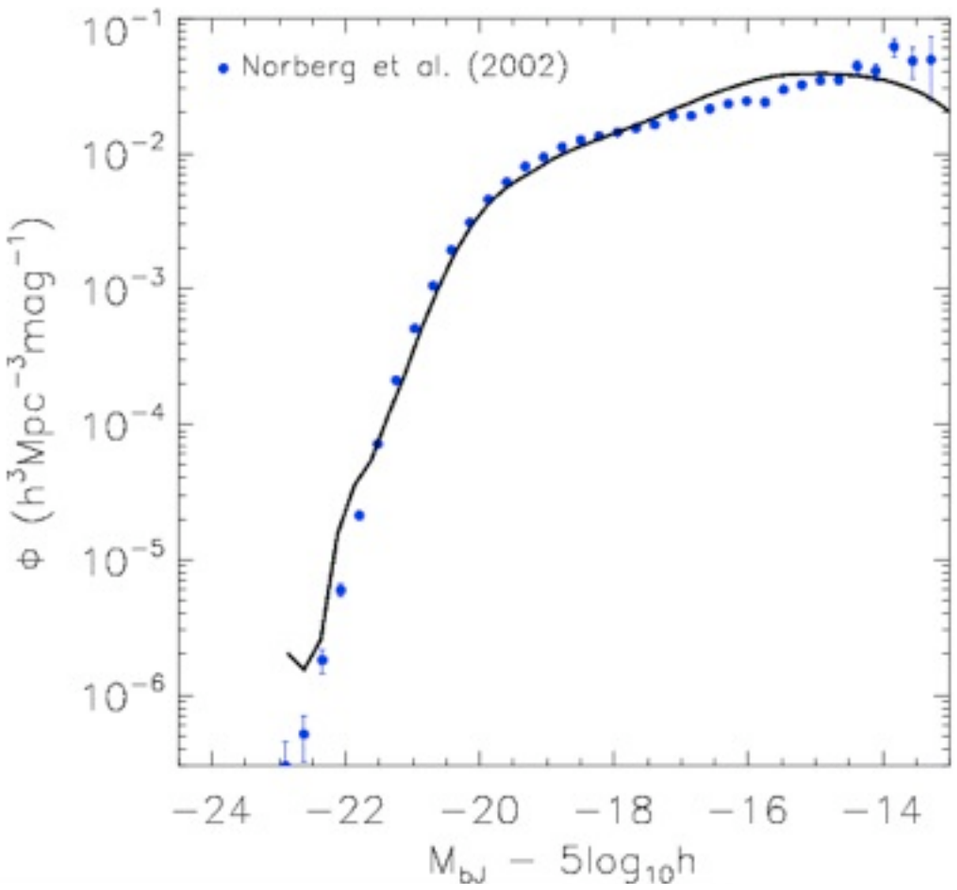
Disk instability driven growth



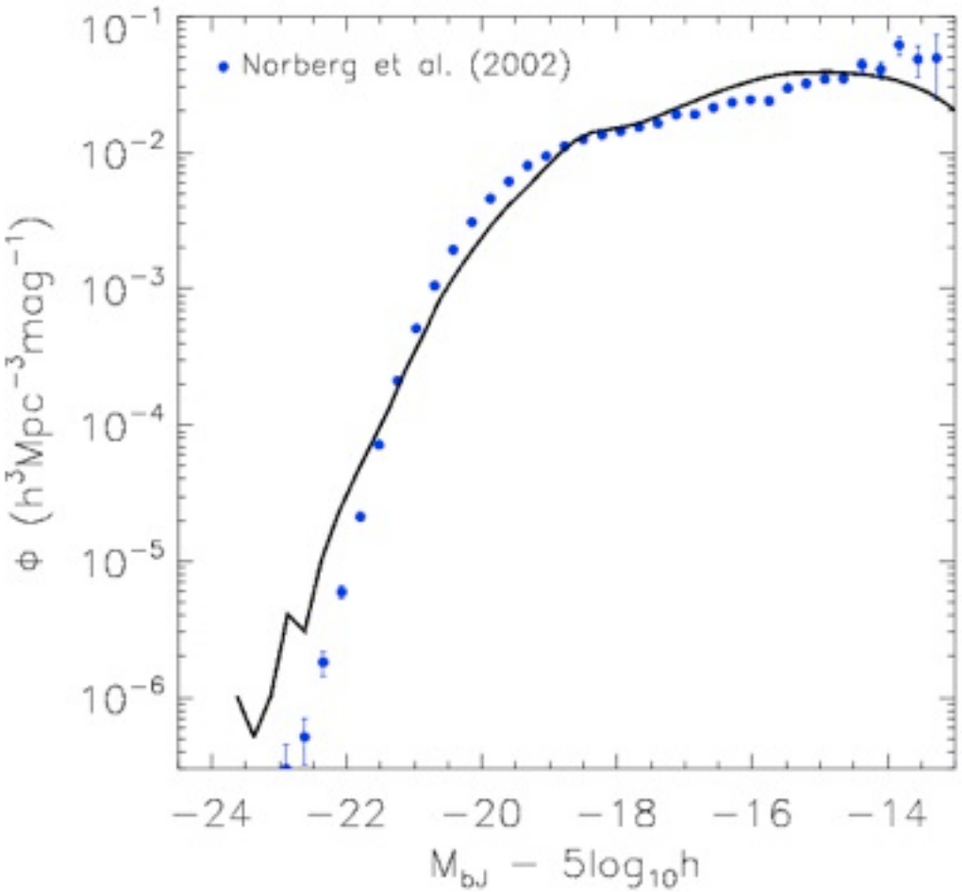
Different behaviour at the low mass end but both still in agreement with the observations

Global luminosity functions

Merger driven growth



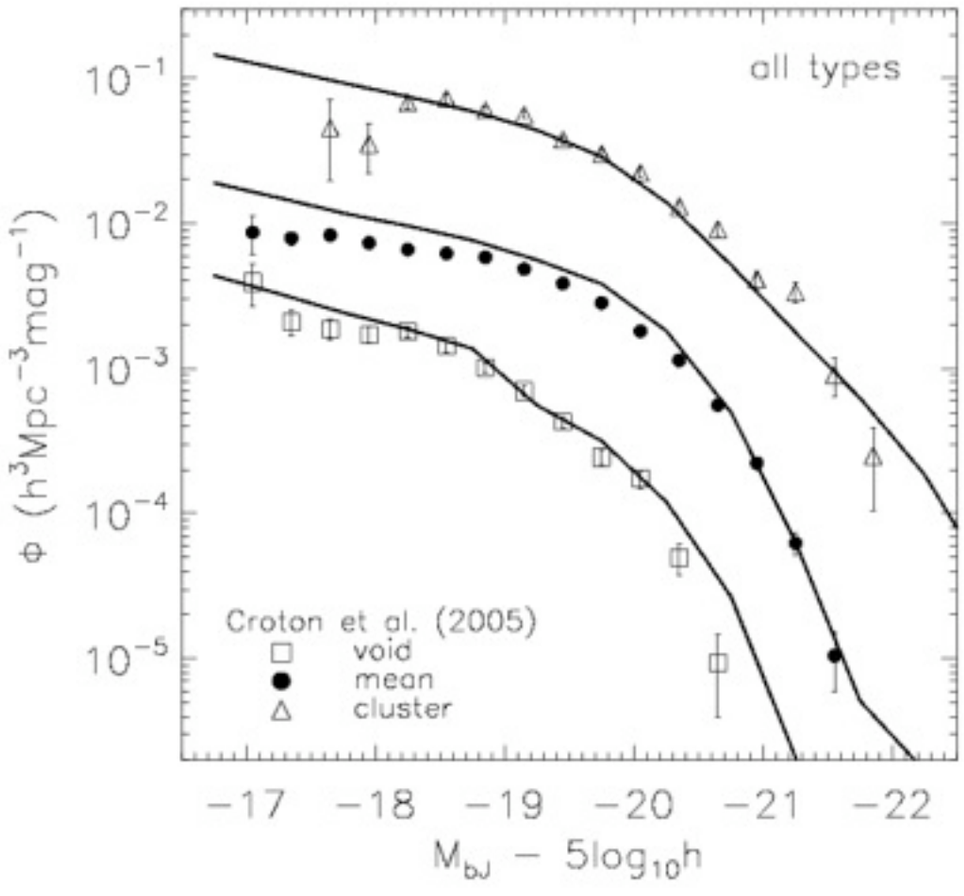
Disk instability driven growth



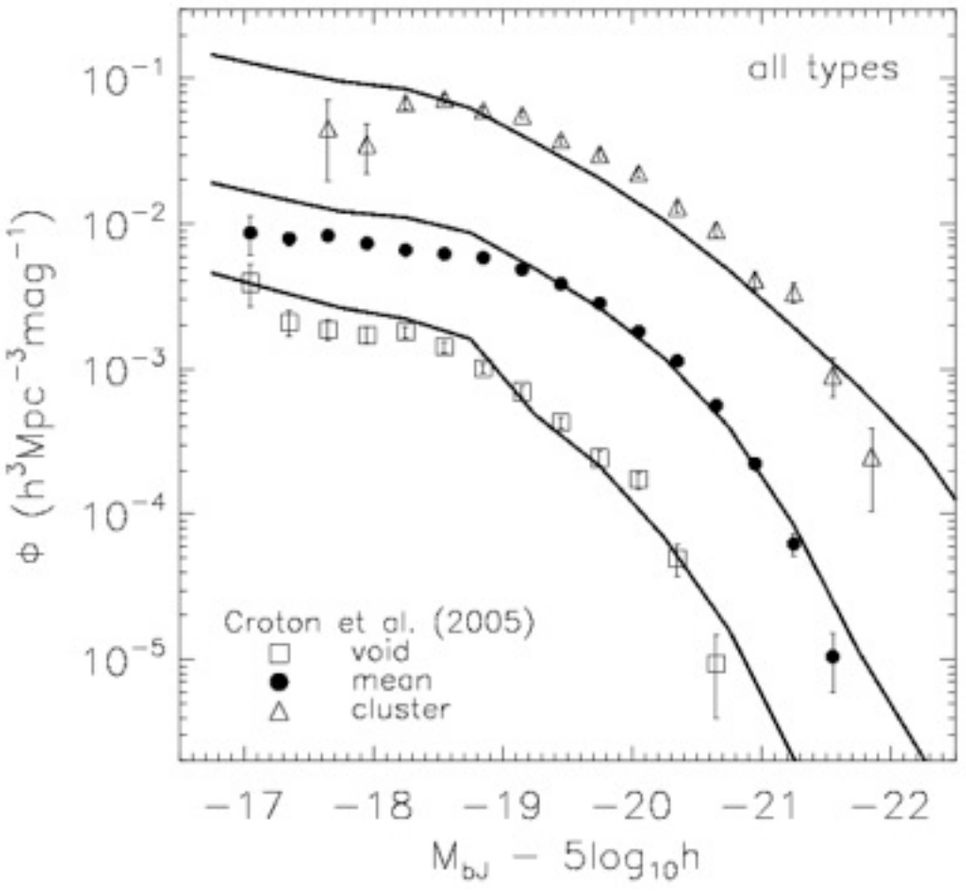
Reasonable agreement for identical parameter choices

Environment luminosity functions

Merger driven growth



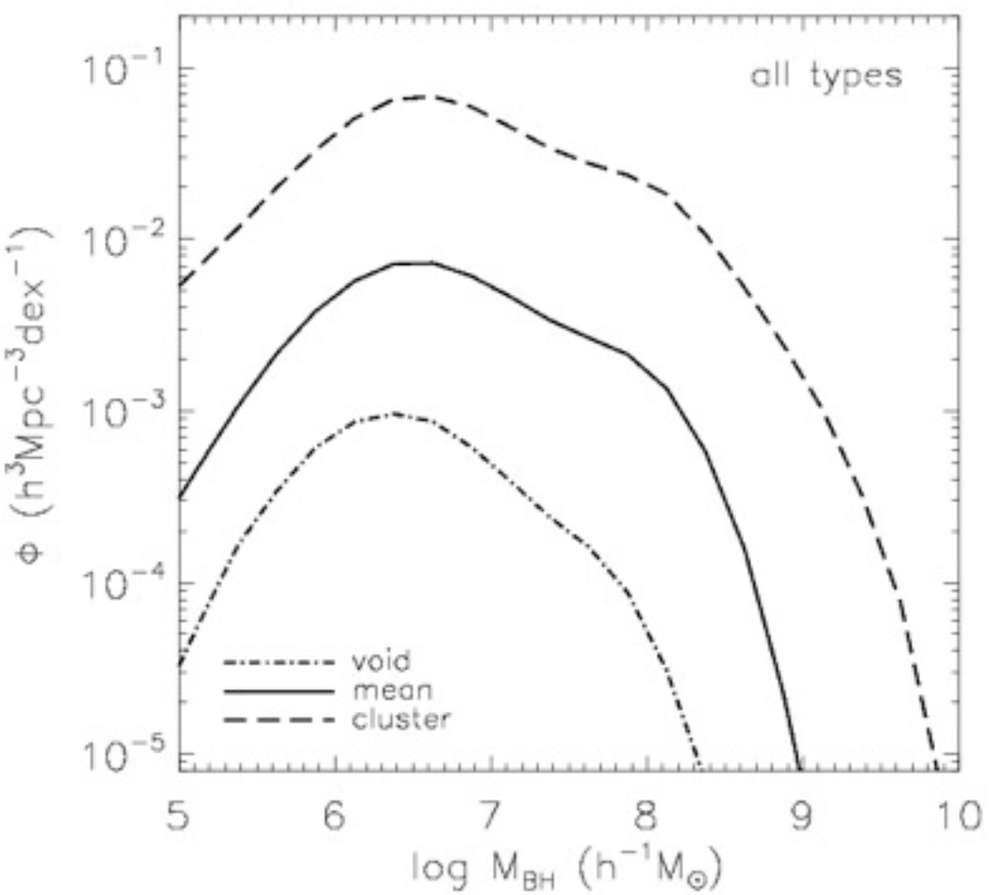
Disk instability driven growth



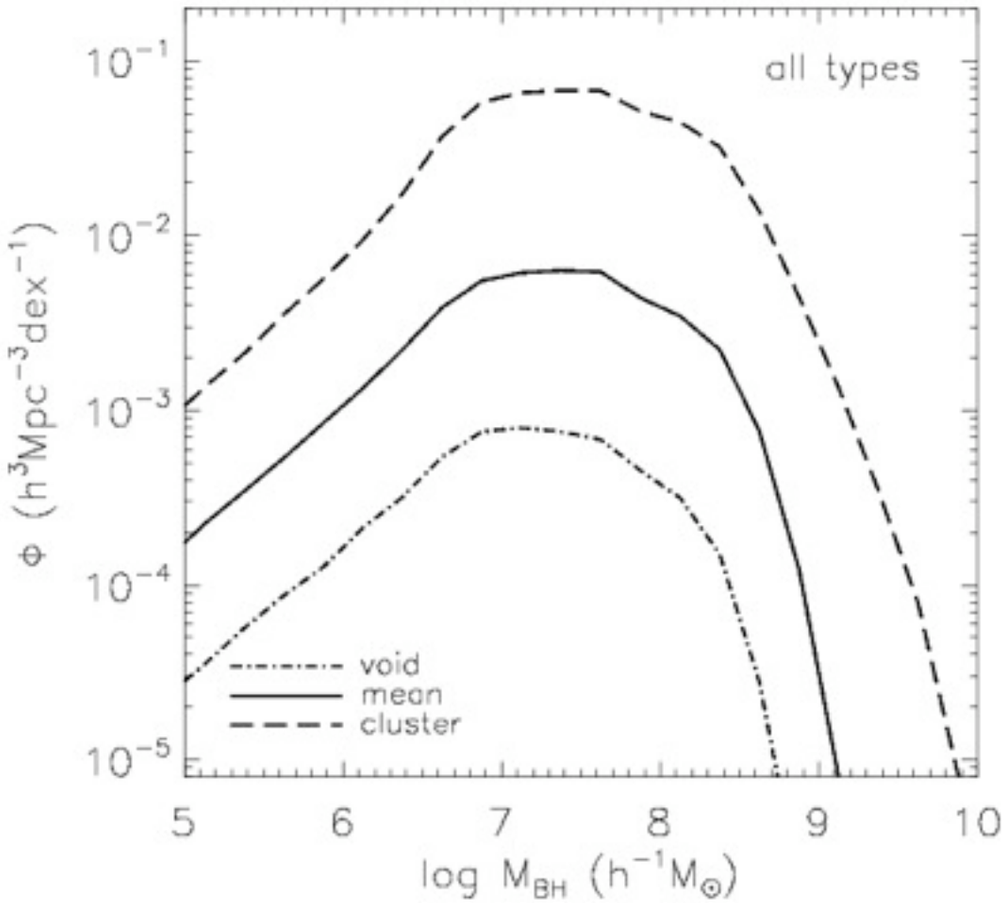
void: $\delta_8 < -0.75$; mean $-0.42 < \delta_8 < 0.32$; cluster: $\delta_8 > 6.0$

Black hole mass function vs. environment

Merger driven growth



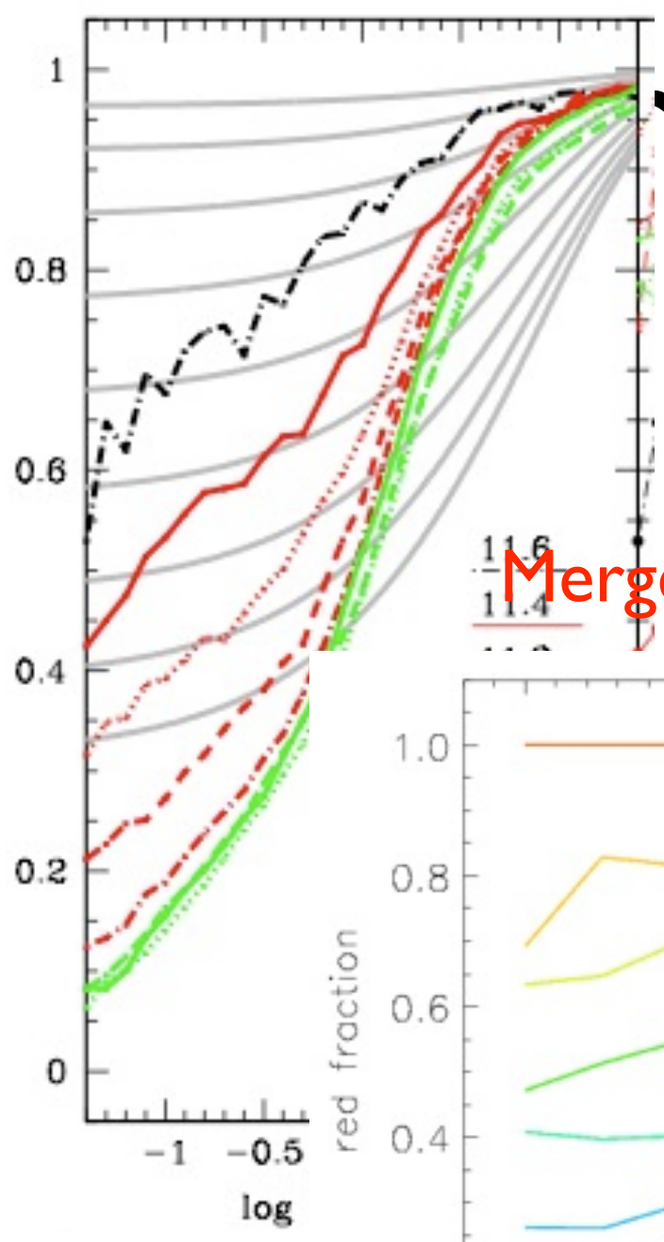
Disk instability driven growth



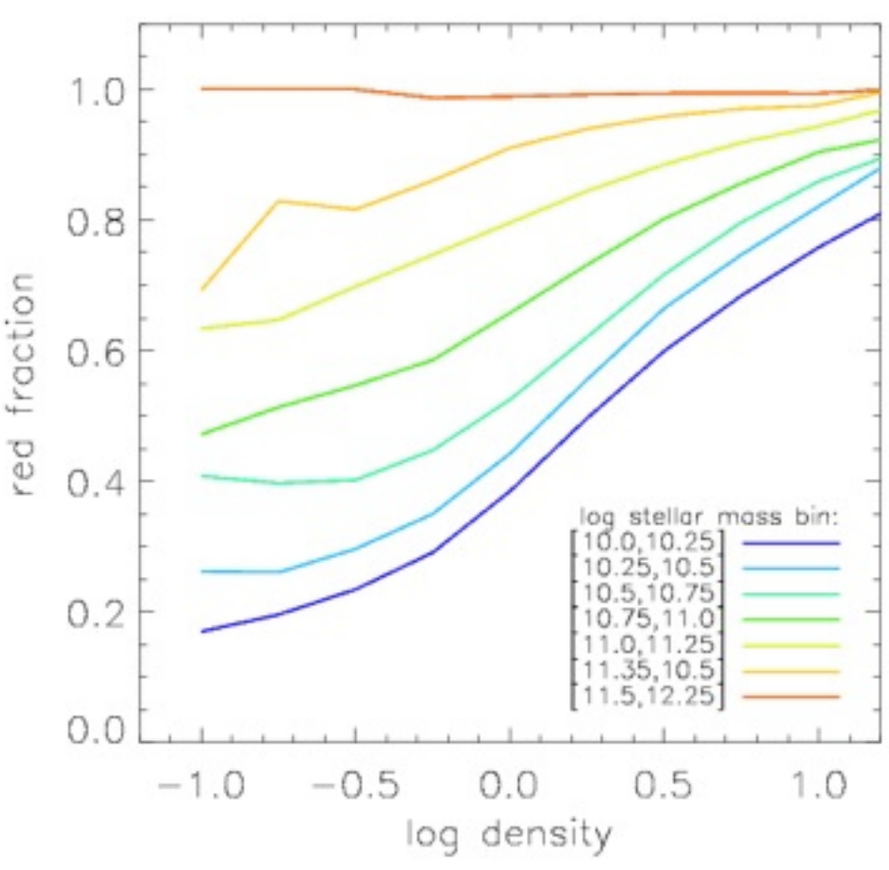
in galaxies with $M_* > 10^{10}$Msun

Substantial differences in the BH mass functions in different environments

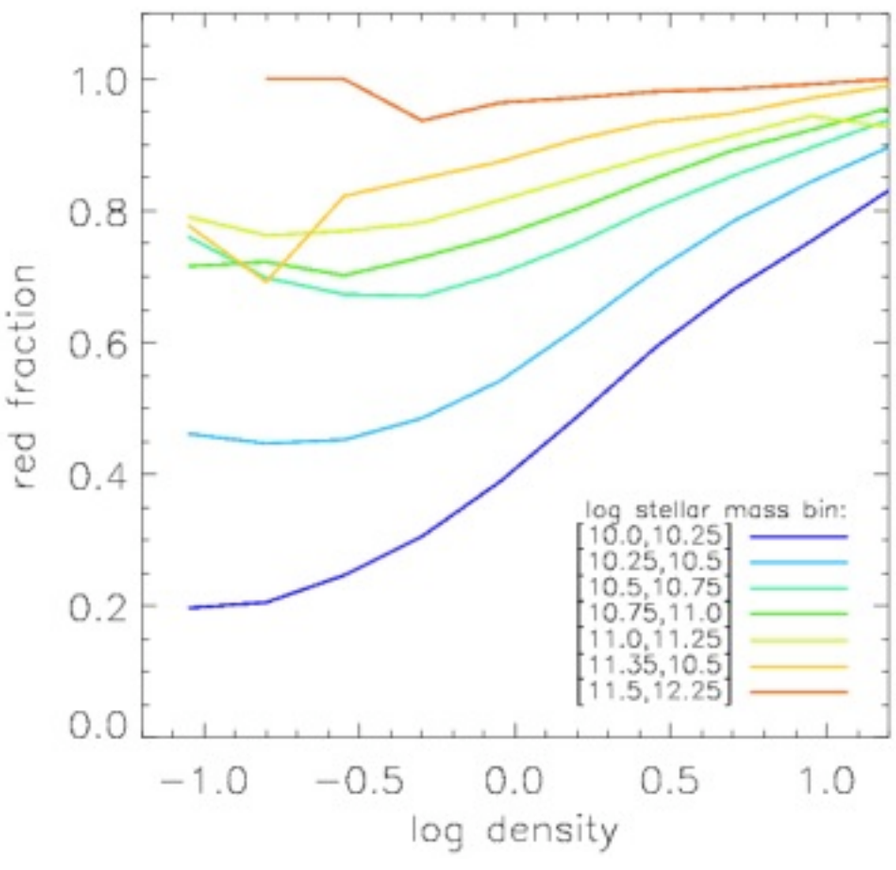
ractions vs. environment and stellar mass



Merger driven growth



Disk instability driven growth



In the most under-dense regions the low mass red fraction remains unchanged, for other mass ranges its significantly higher.

Observational measures of the
BHMF vs. environment
will help constrain the
BH growth mechanism
as well as subsequent
star formation quenching.

Take home message

(1) Simple models help interpret the data, and more complex observations require more complex modeling.

(2) AGN are have the ability to bring the theory into line with observation.

(3) *Environment independent* radio-mode AGN heating is sufficient to reproduce (at least some of?) the observed environmental trends of passive galaxies.

Punchline: halo mass is king