AGN in Voids to Clusters:

the environmental dependence of black hole growth and its influence on galaxy evolution

Darren Croton
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VIRGO

Overview

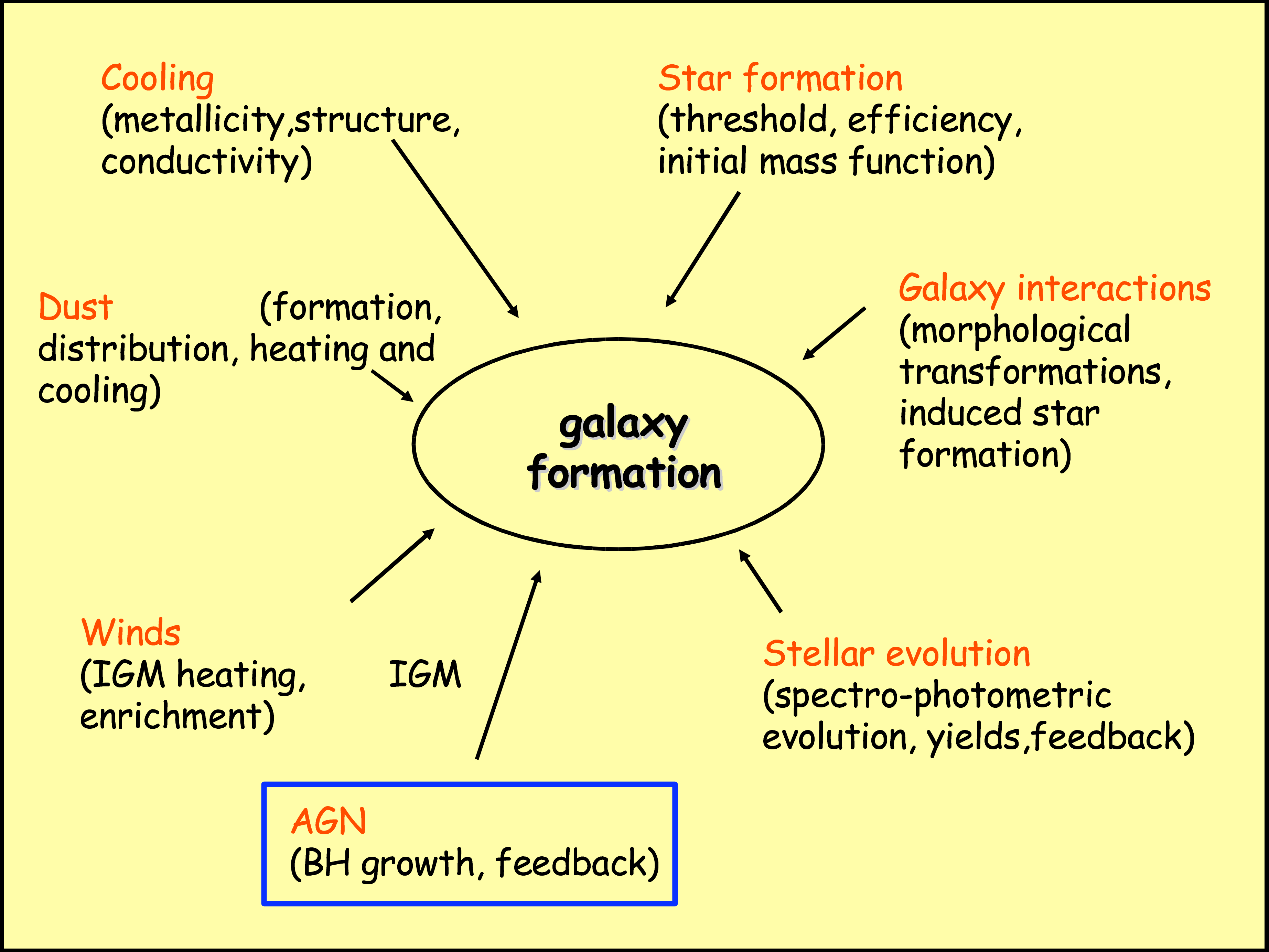
1. Galaxy formation: the zero'th order approximation

2. Some interesting problems

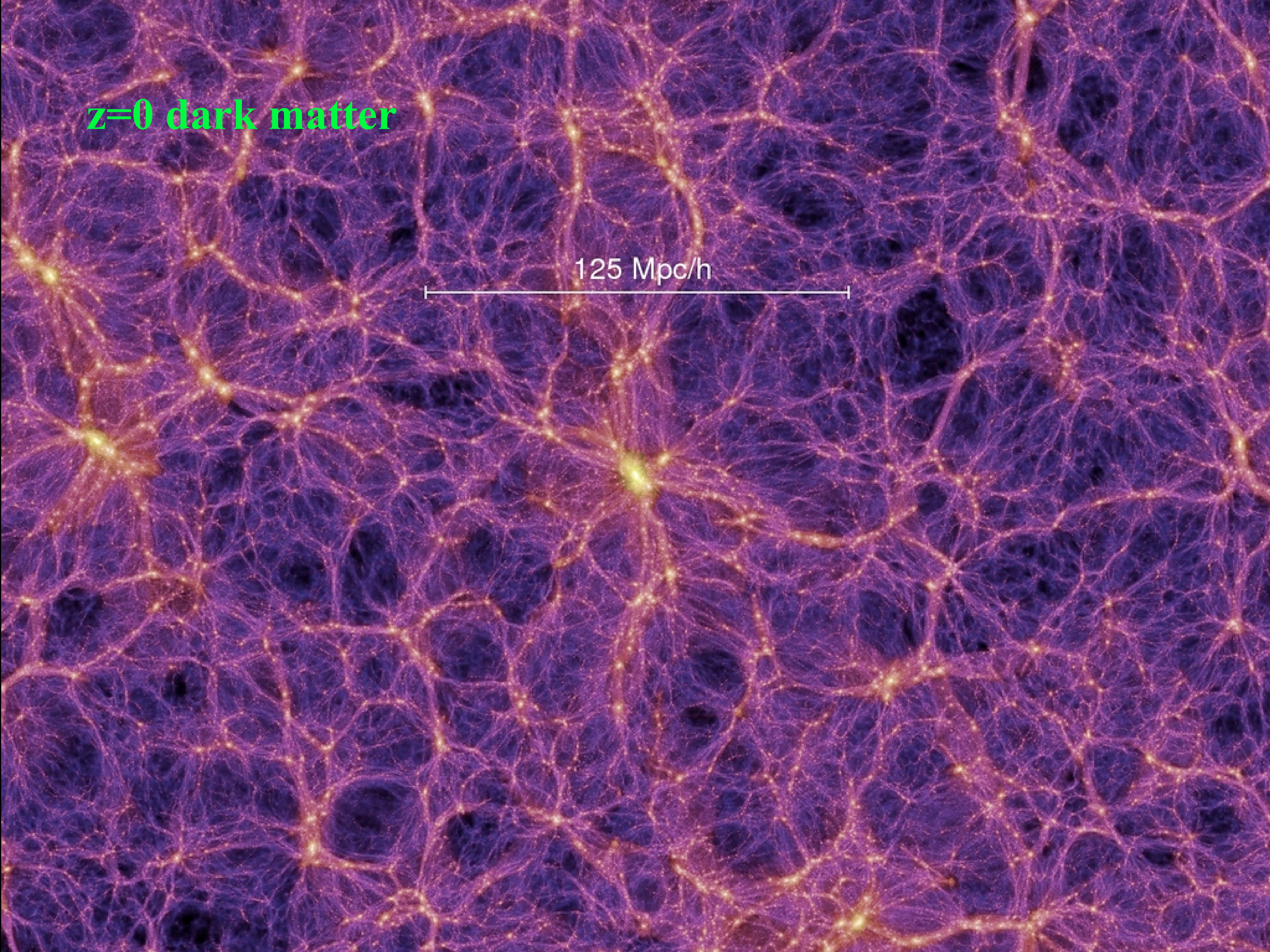
3. Some interesting answers?

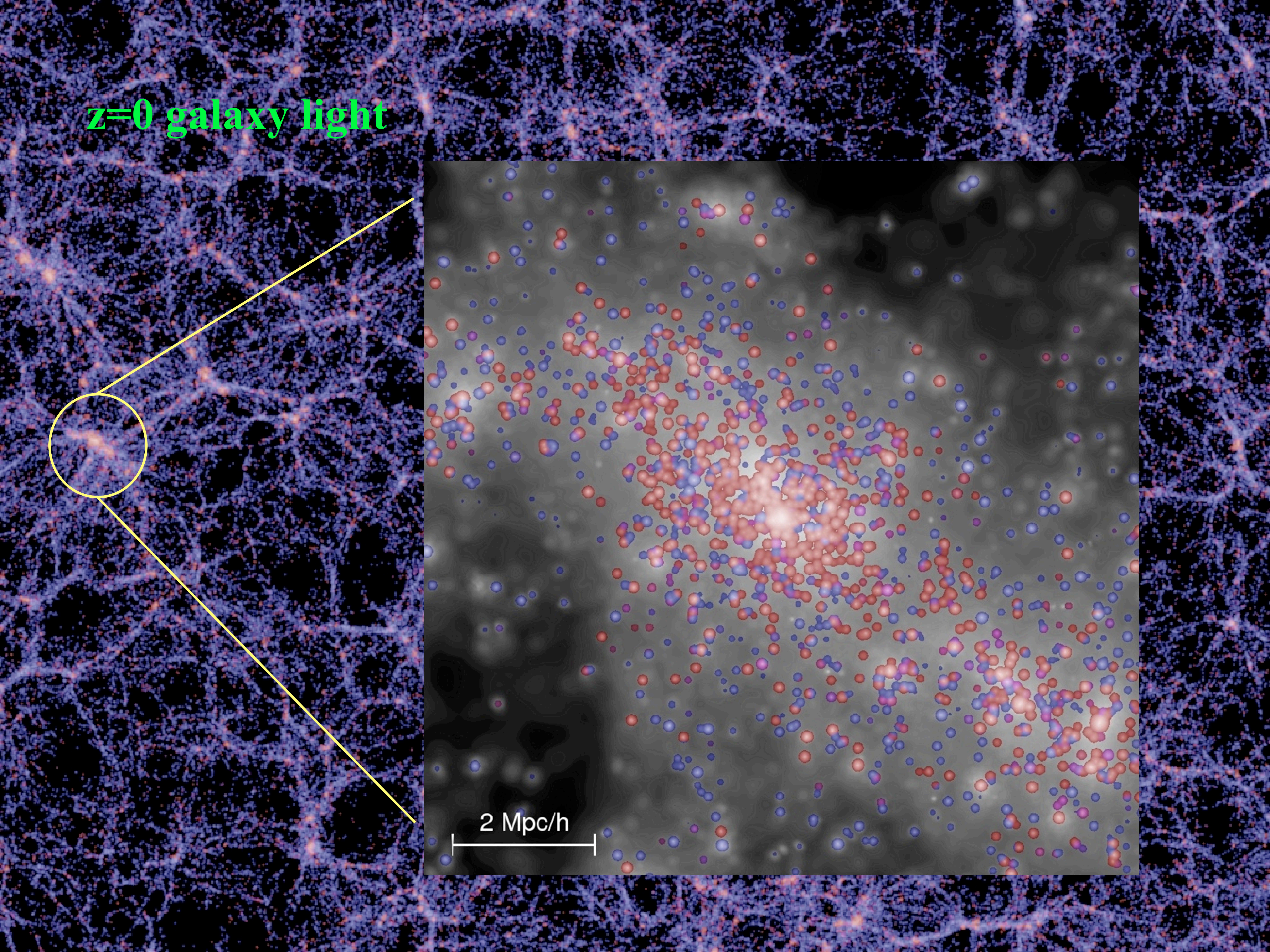
Galaxy formation: the zero'th order approximation

Semi-analytic models of galaxy formation

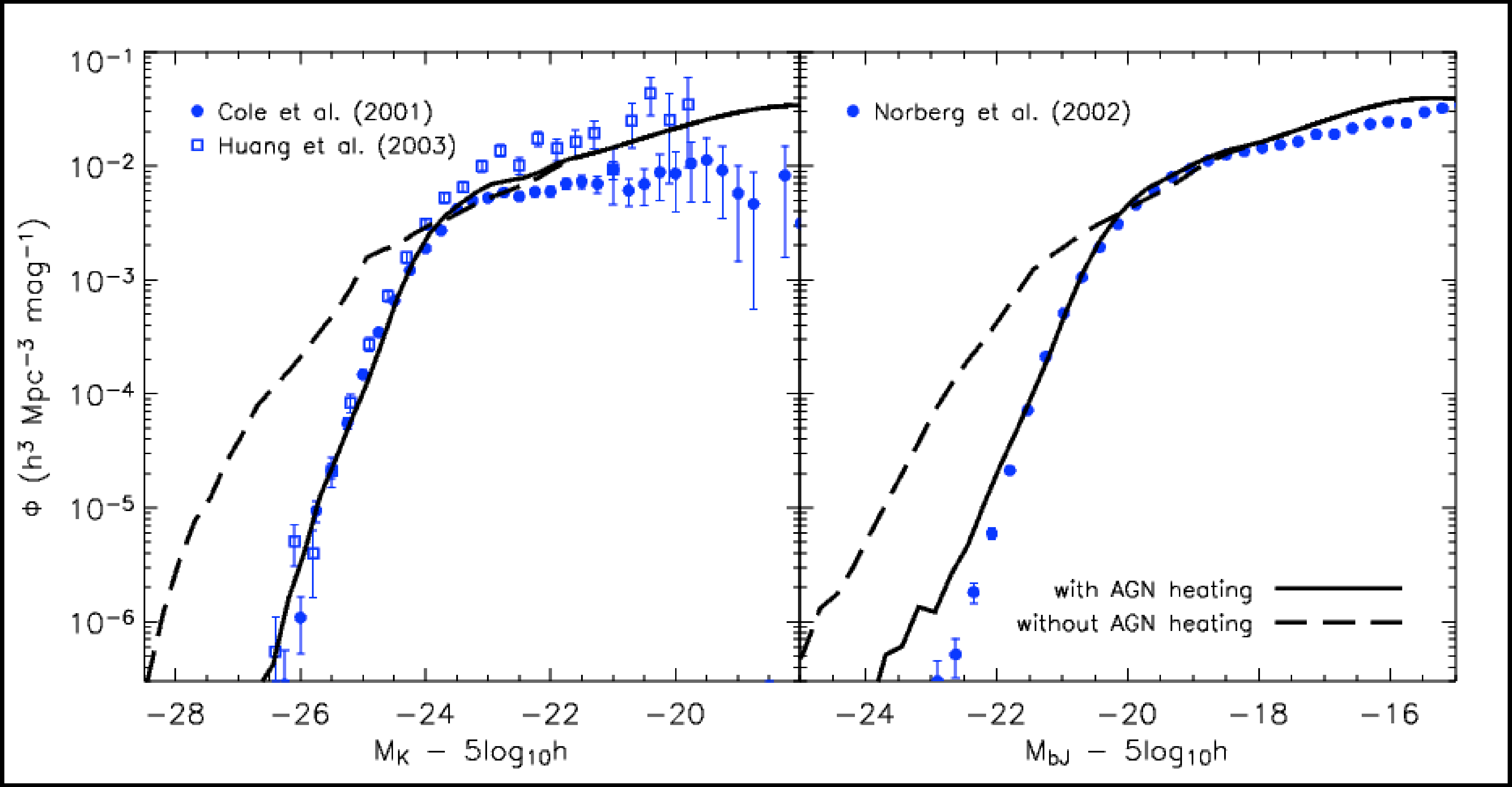


Croton et al. 2005


z=0 dark matter
125 Mpc/h


z=0 galaxy light
2 Mpc/h

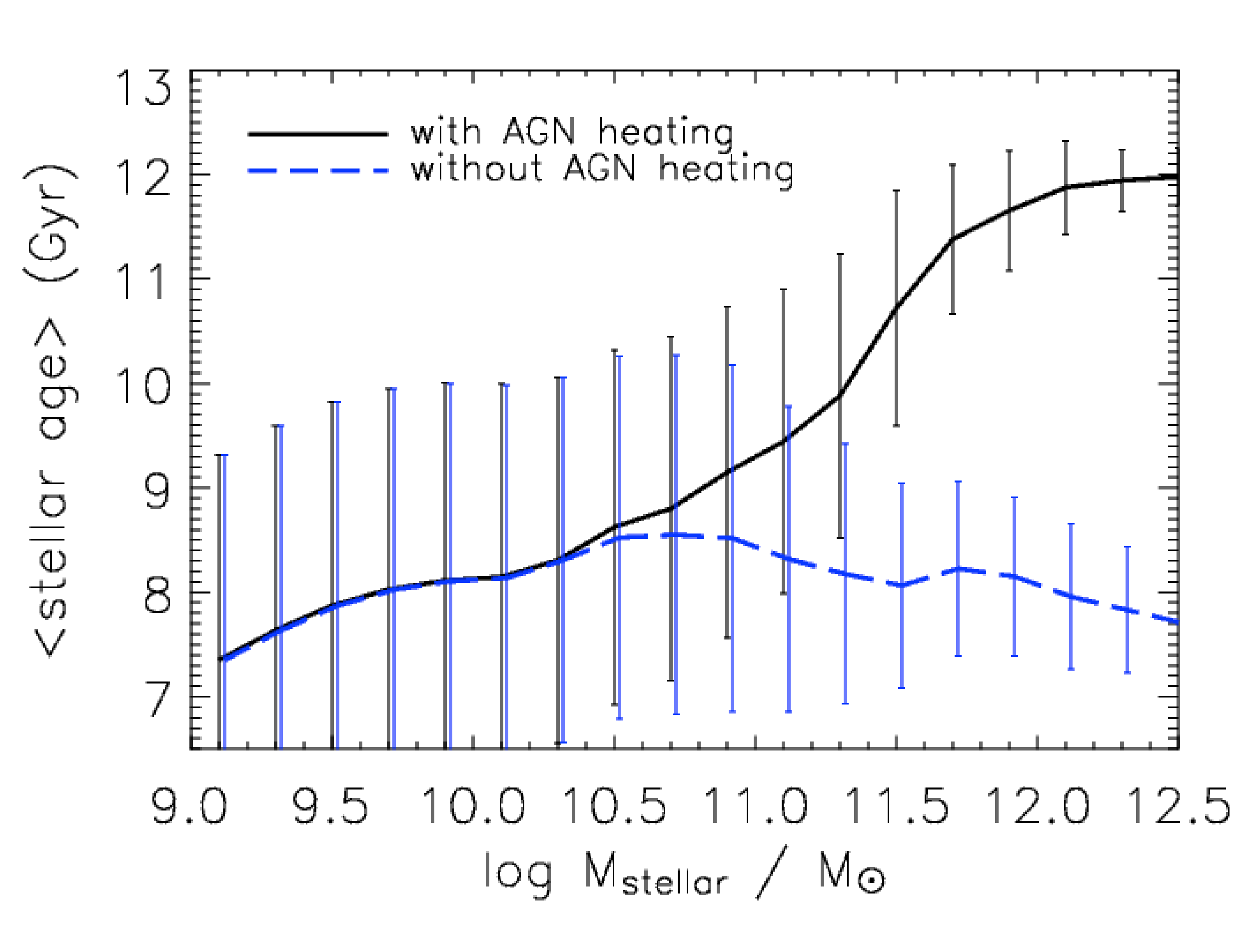
Luminosity functions

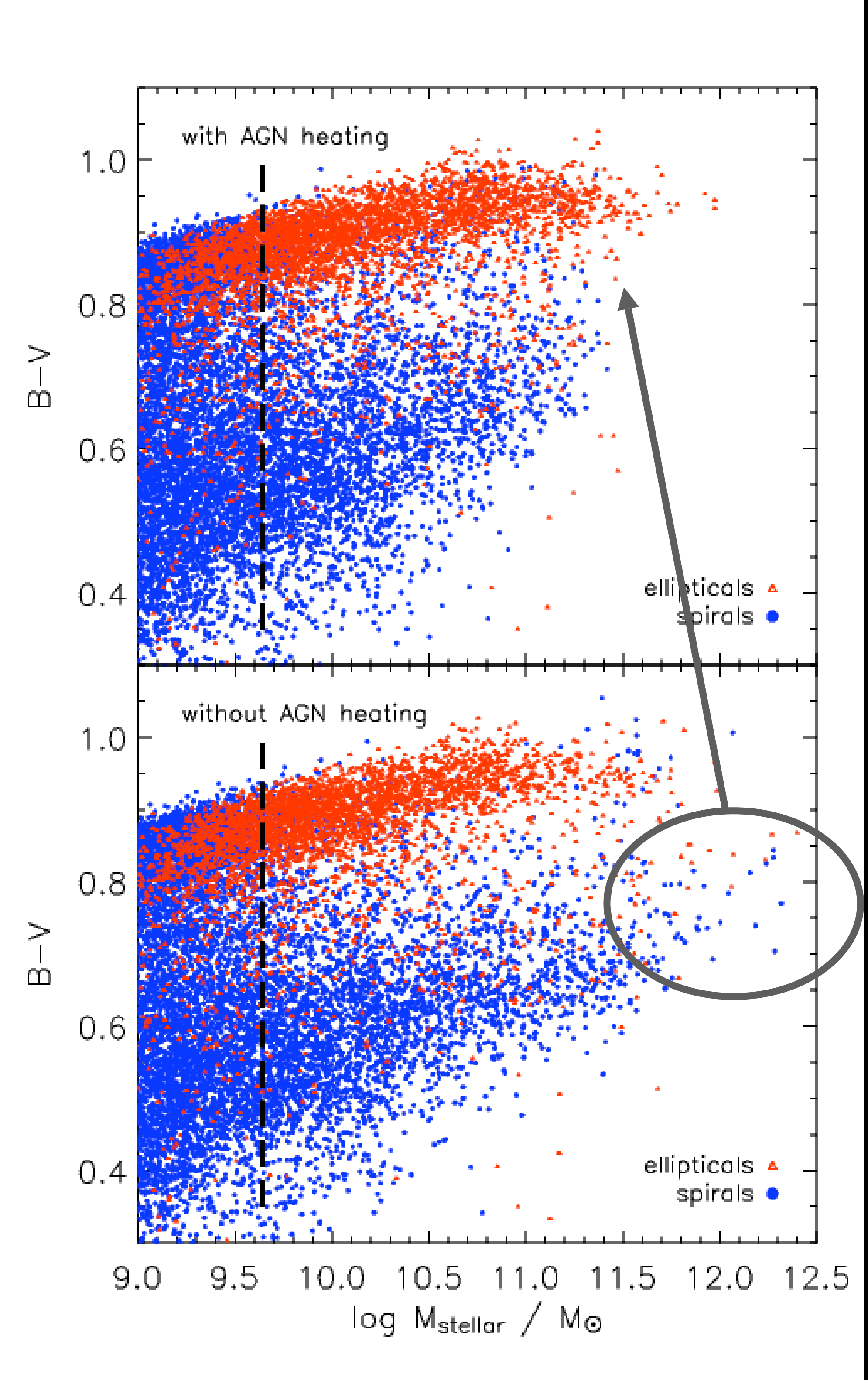


The K and bJ-band luminosity functions with and without AGN

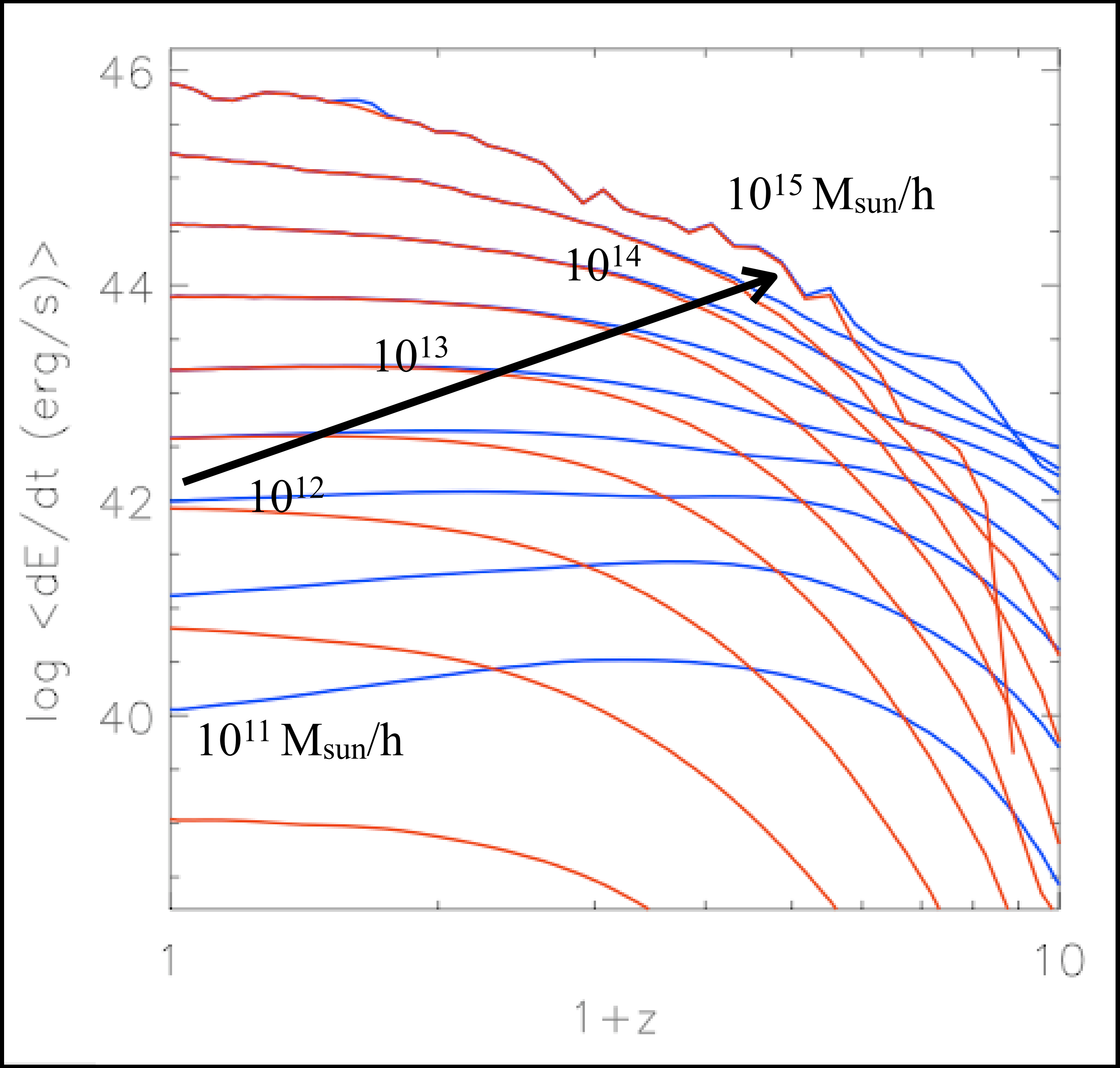
Galaxy colours and ages

B-V colour bi-modality
and mean stellar age





Quenching vs. halo mass

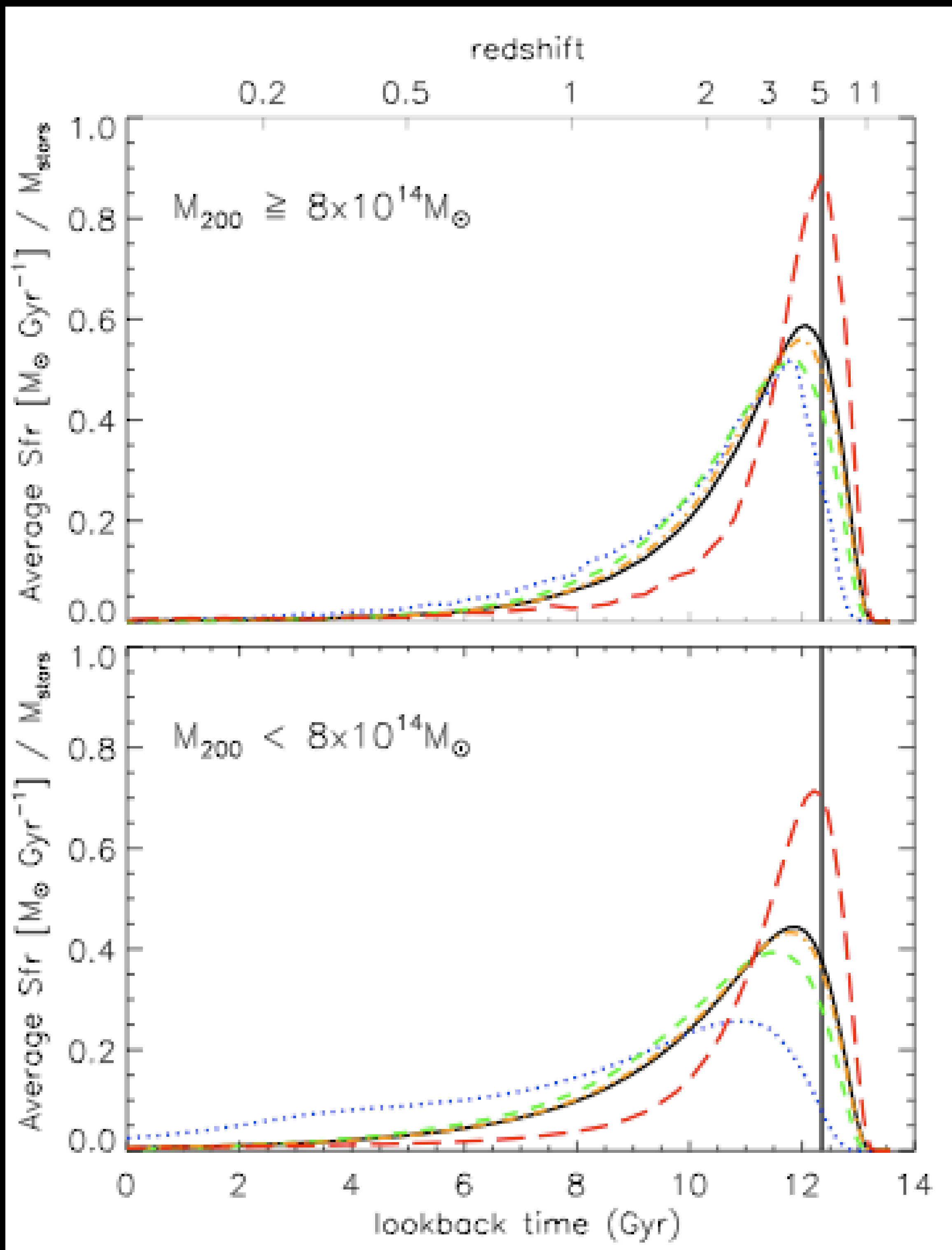


Cooling Rates
vs.
Heating Rates

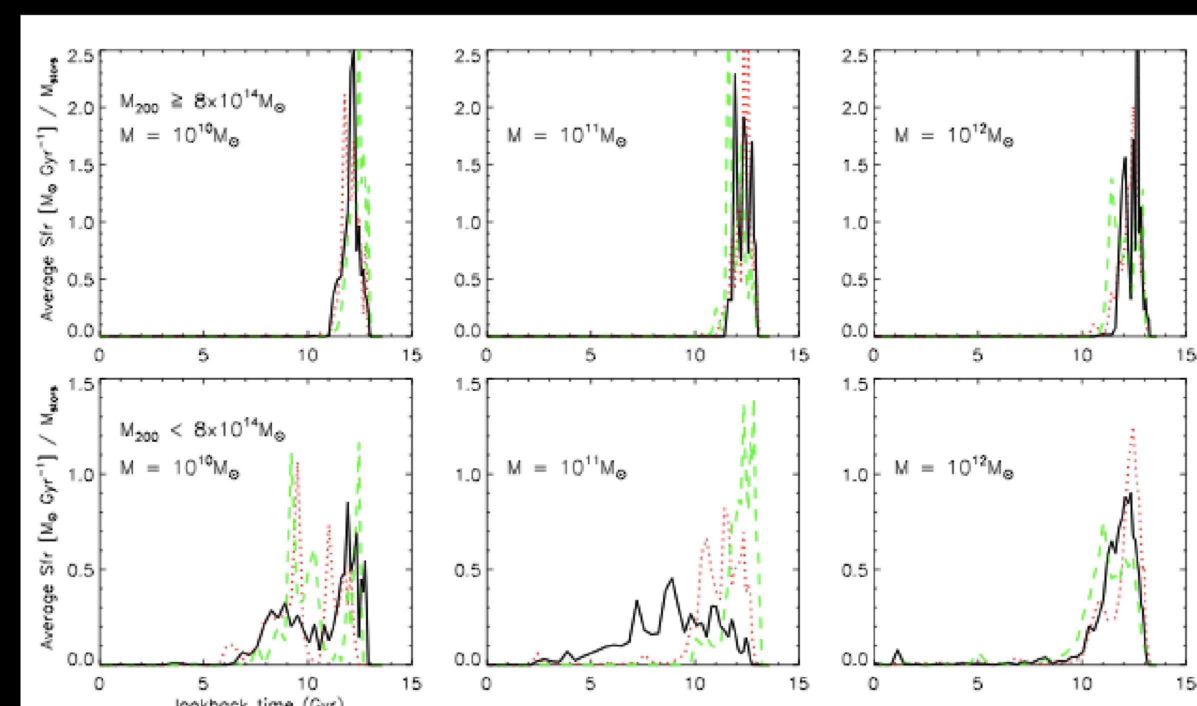
currently
$M_{vir} \sim 10^{12} M_{sun}/h$ halos are initiating quenching

(Croton et al in prep.)

Star formation histories

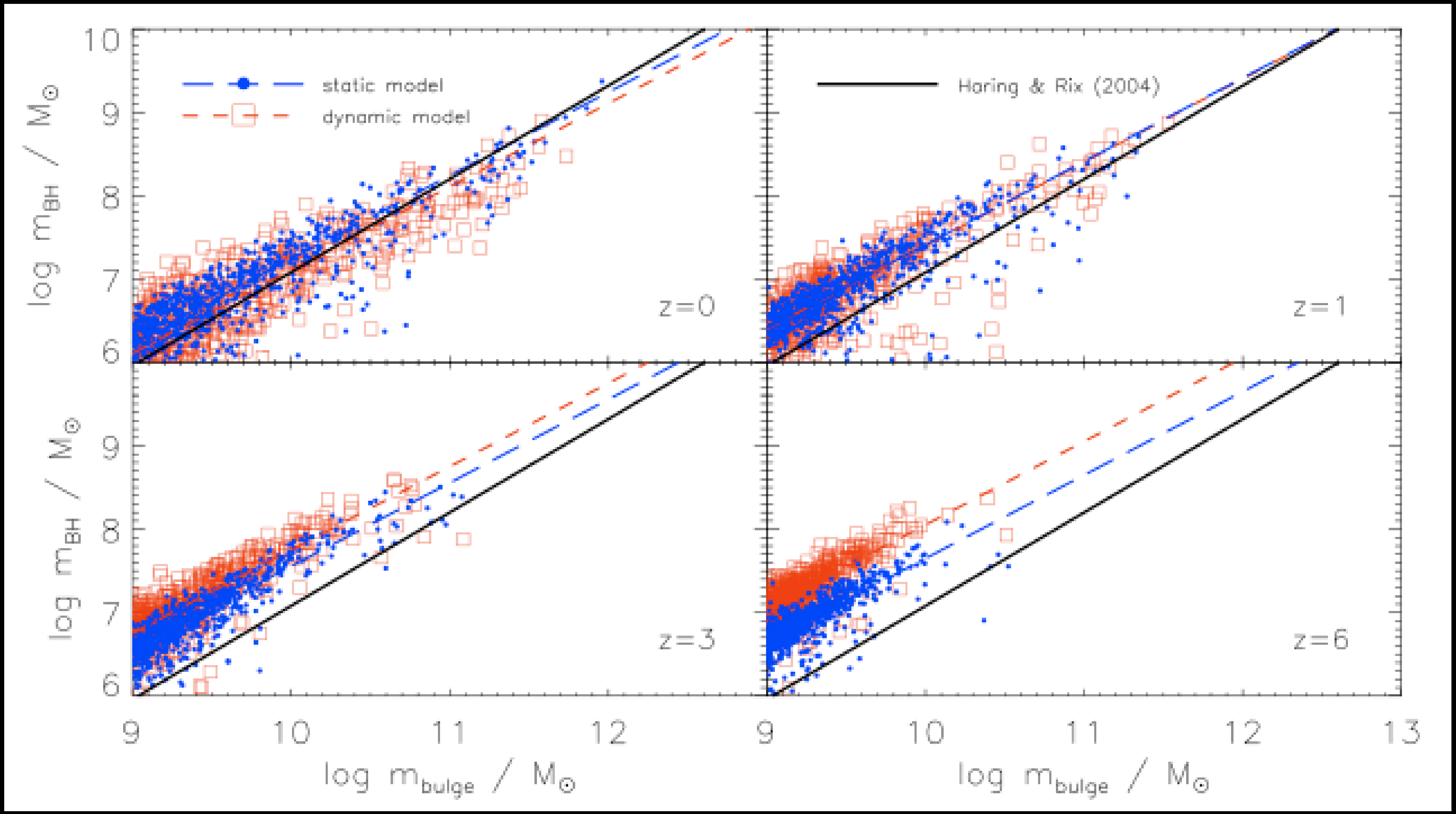


Elliptical galaxies in higher/lower mass environments



De Lucia et al. 2006

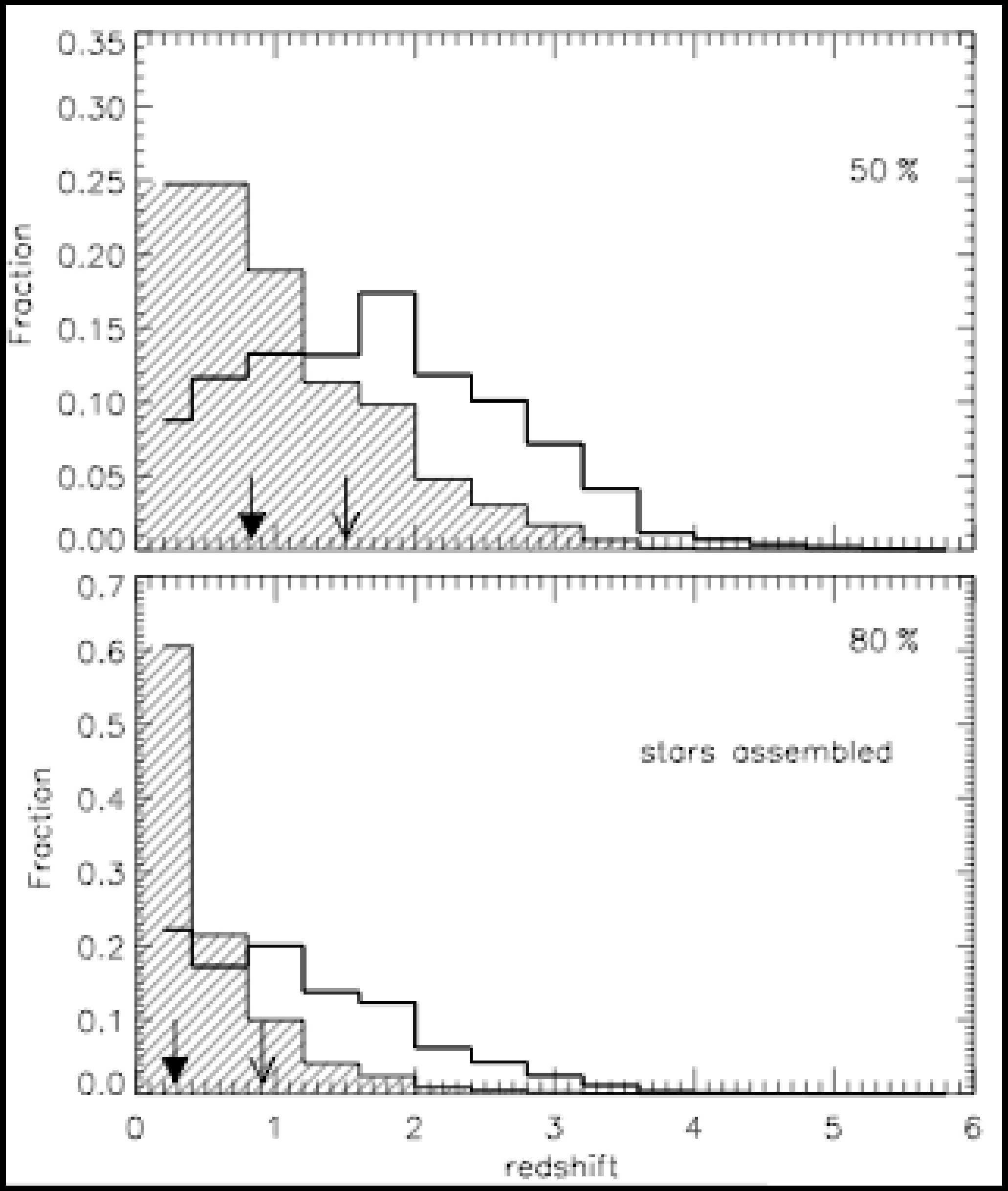
BH-bulge mass evolution

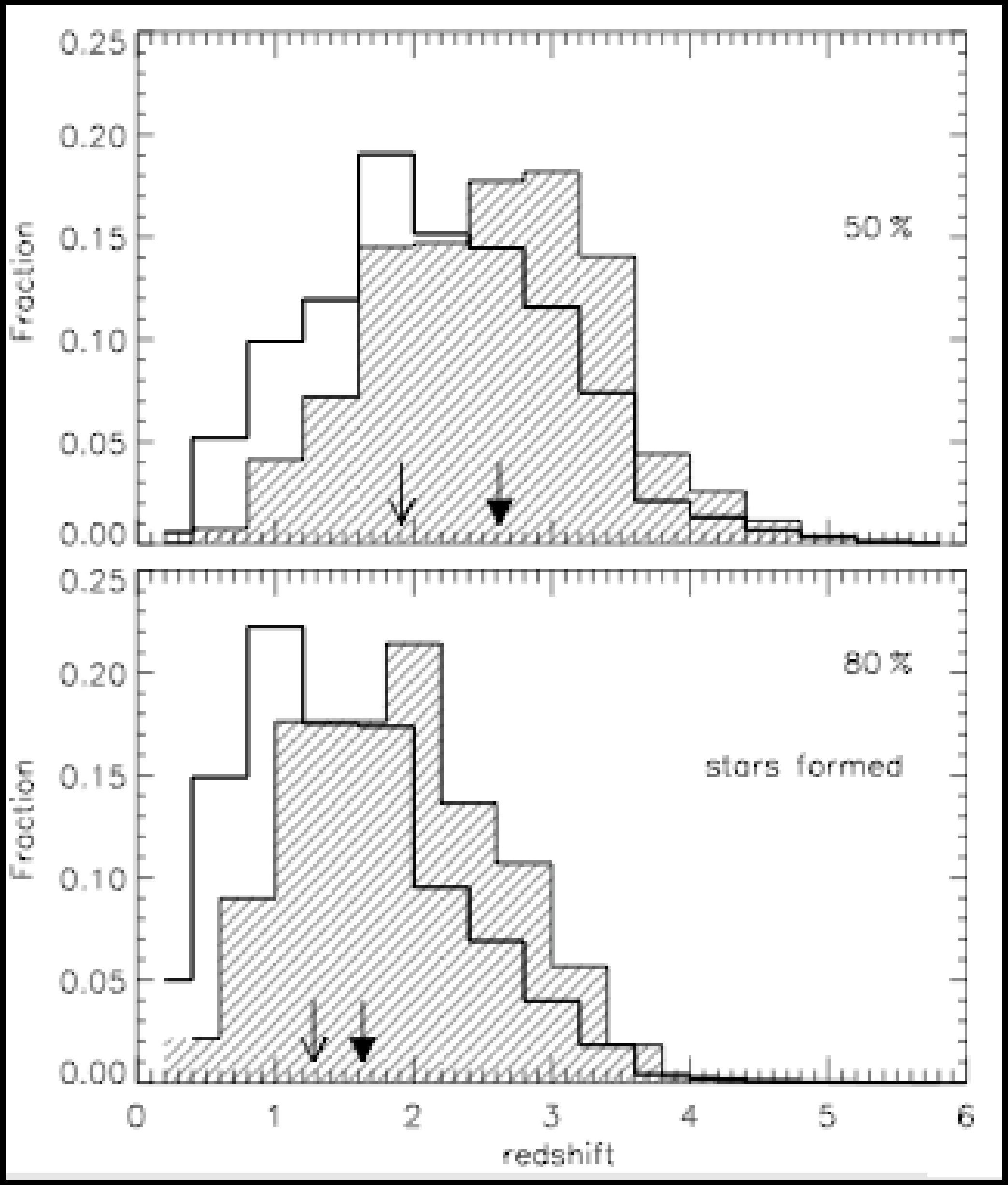


In a model that assumes no evolution the BH-bulge relation evolves with time

Croton 2006

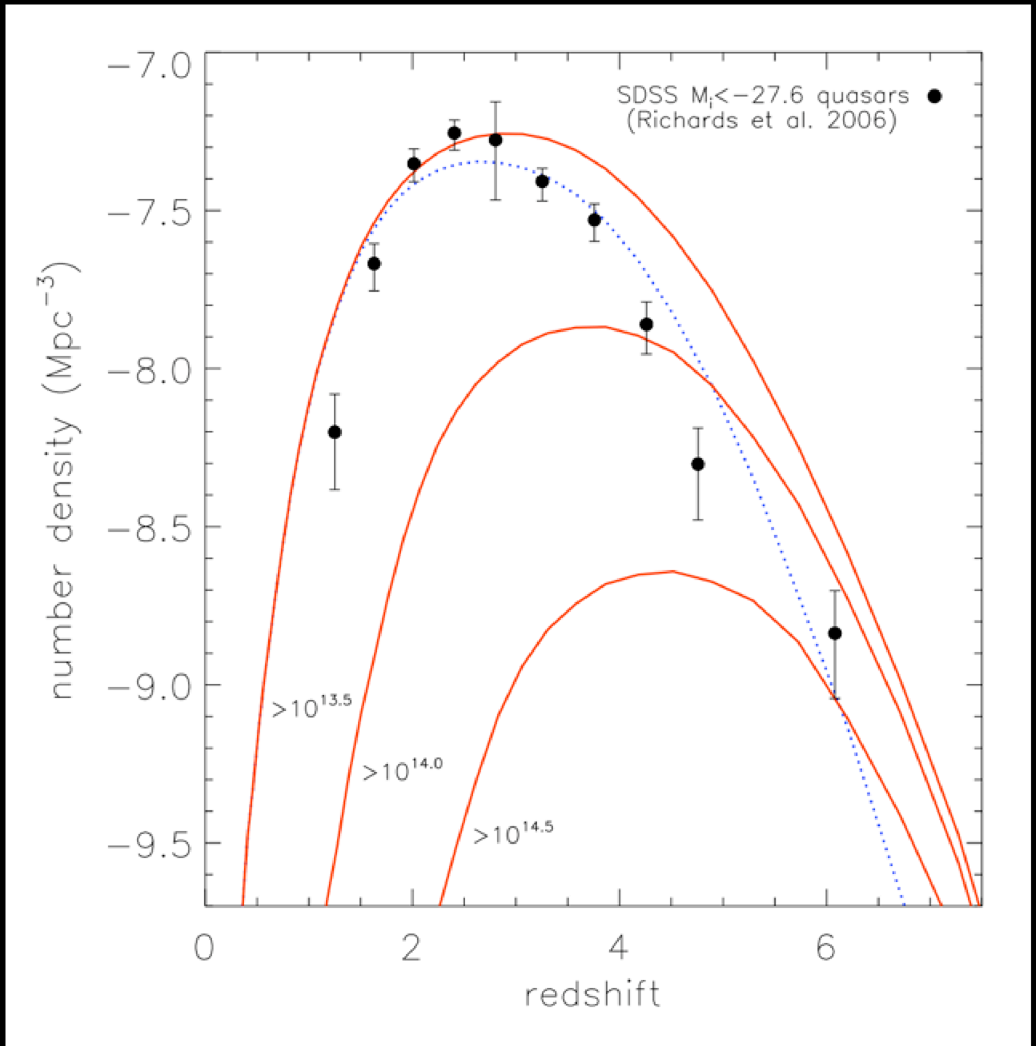
Star formation vs. galaxy assembly

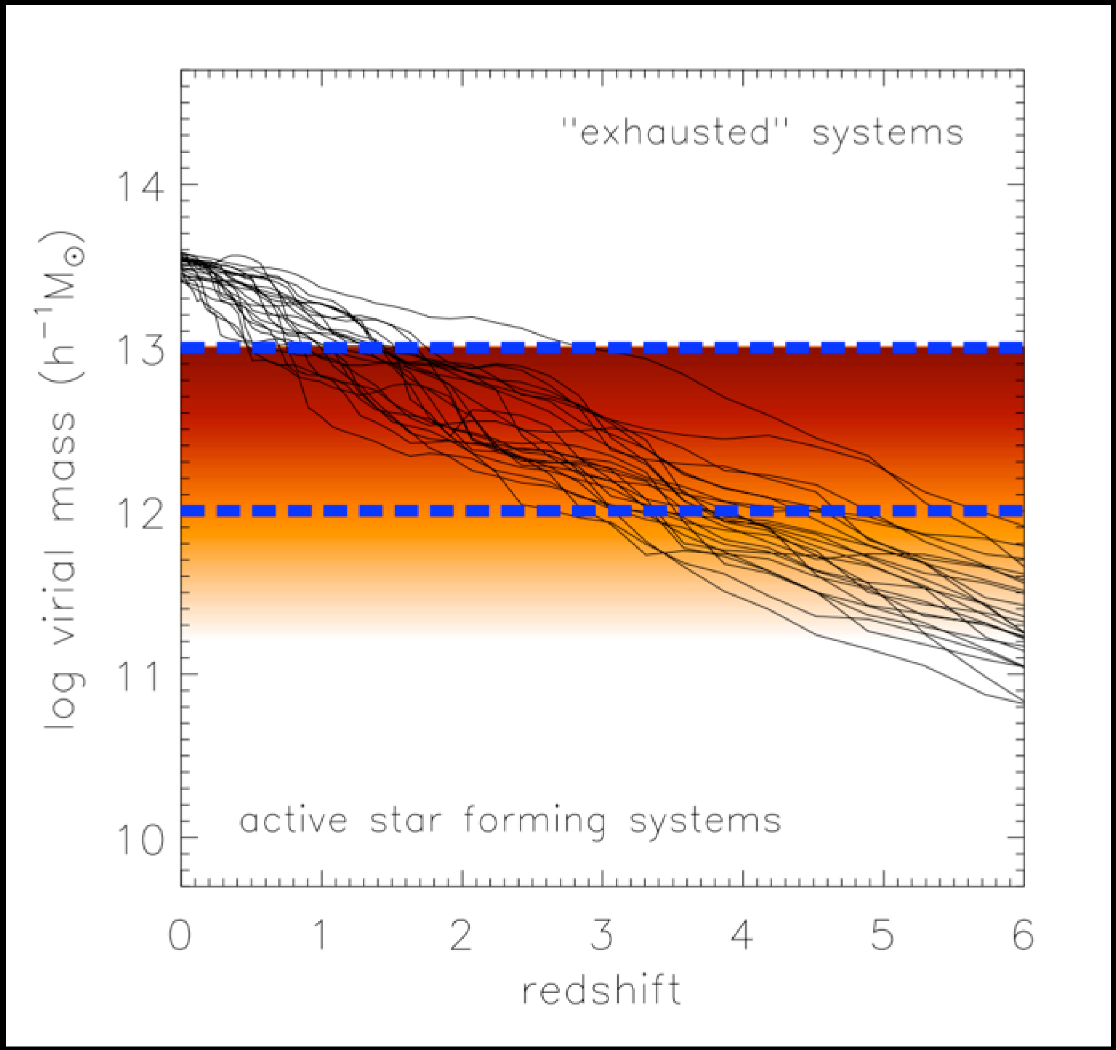




De Lucia et al. 2006

The evolution of the number density of quasars





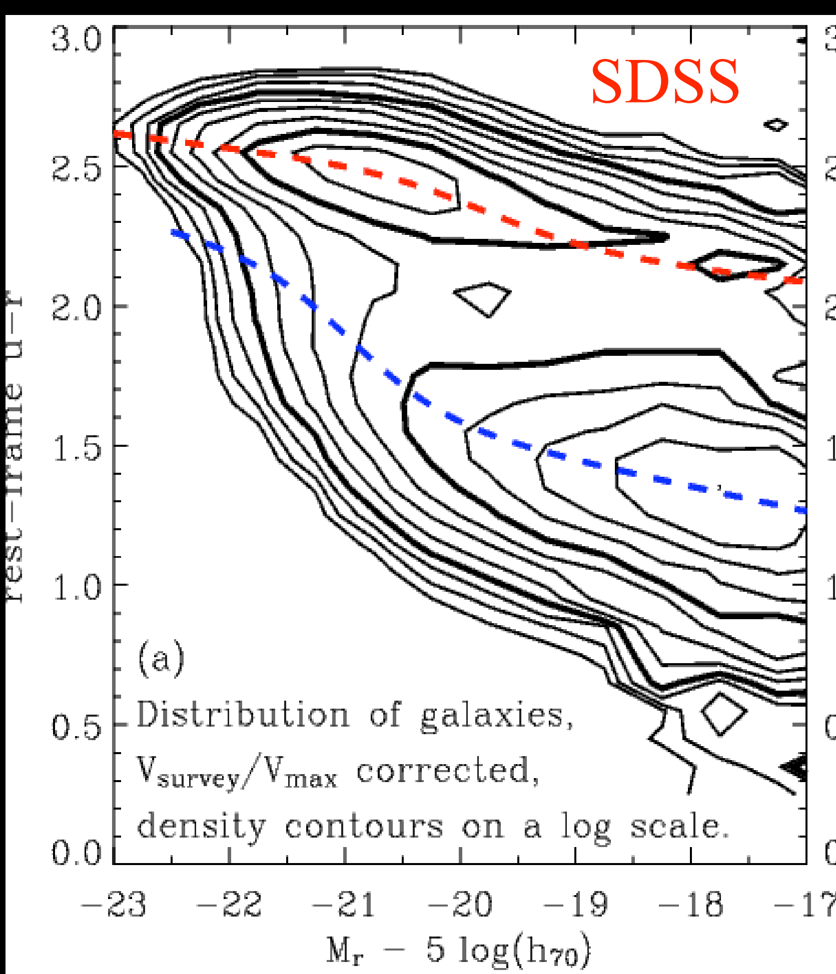
Croton in prep.

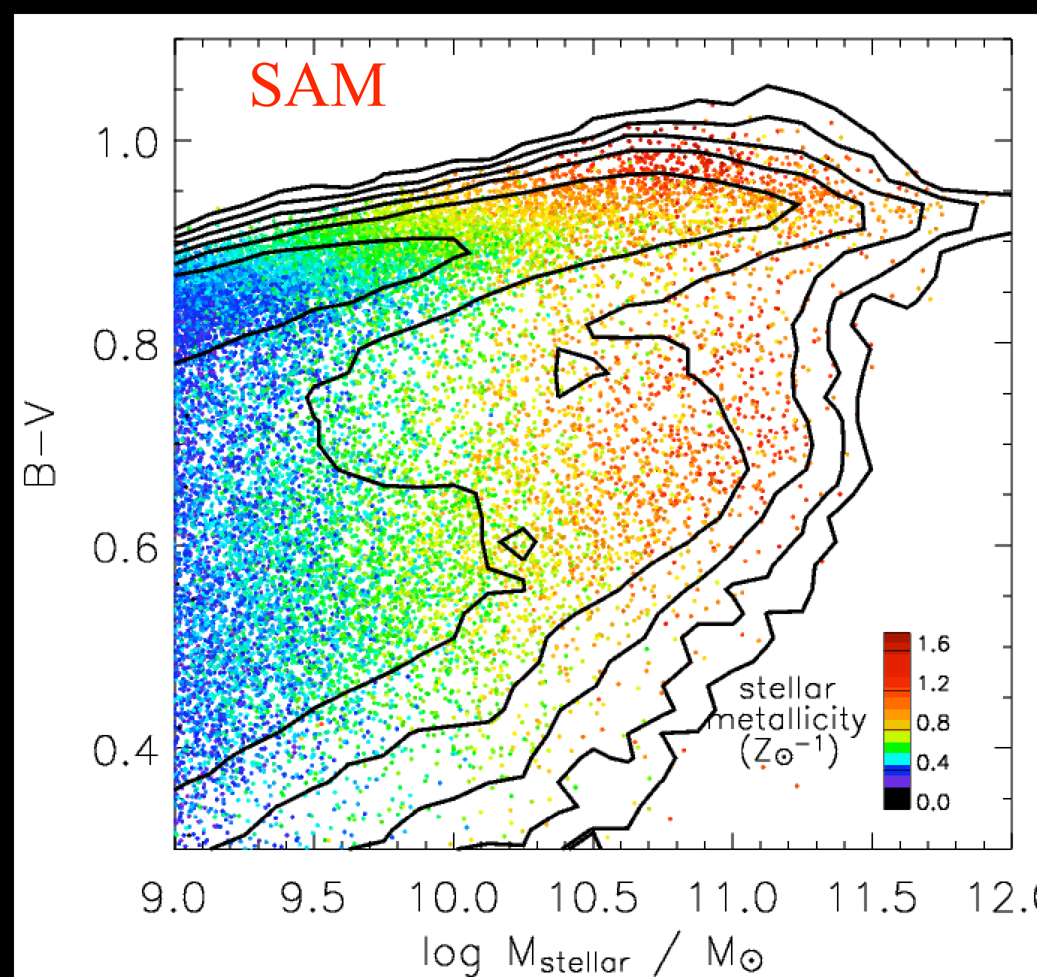
Some interesting problems

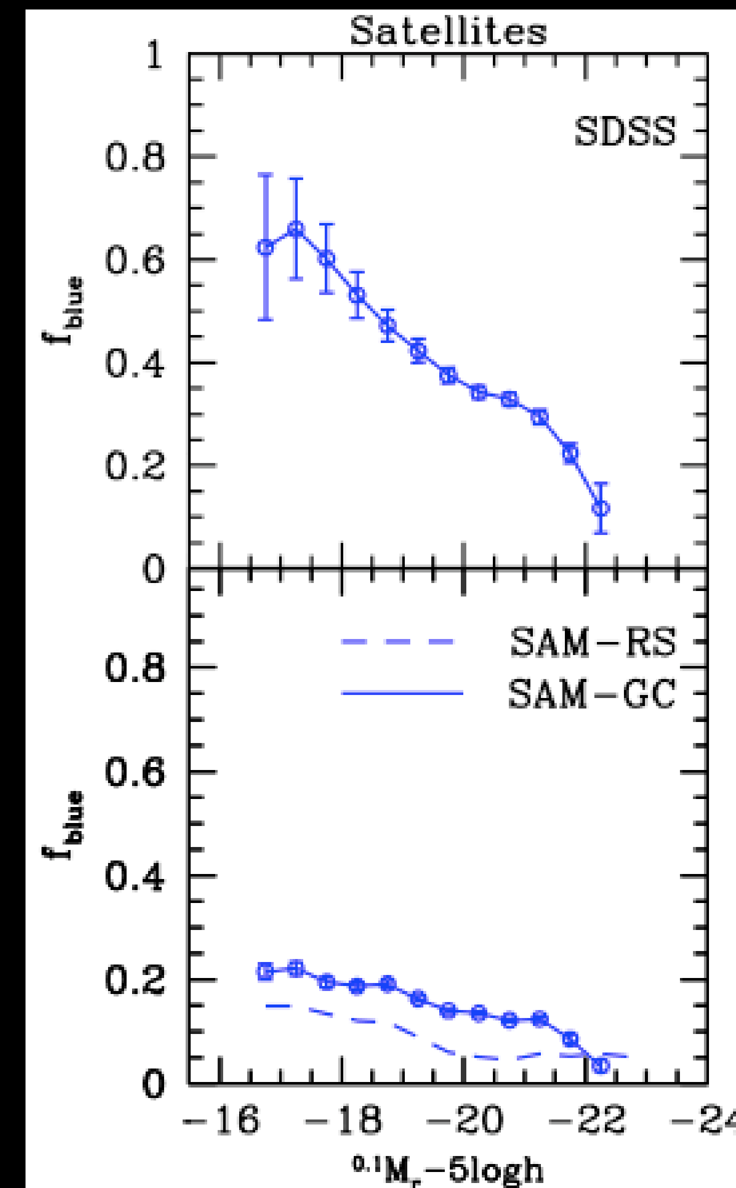
Satellites galaxies

The model produces an excess of red satellite galaxies

This is related to the treatment of hot gas stripping off newly accreted sub-halos

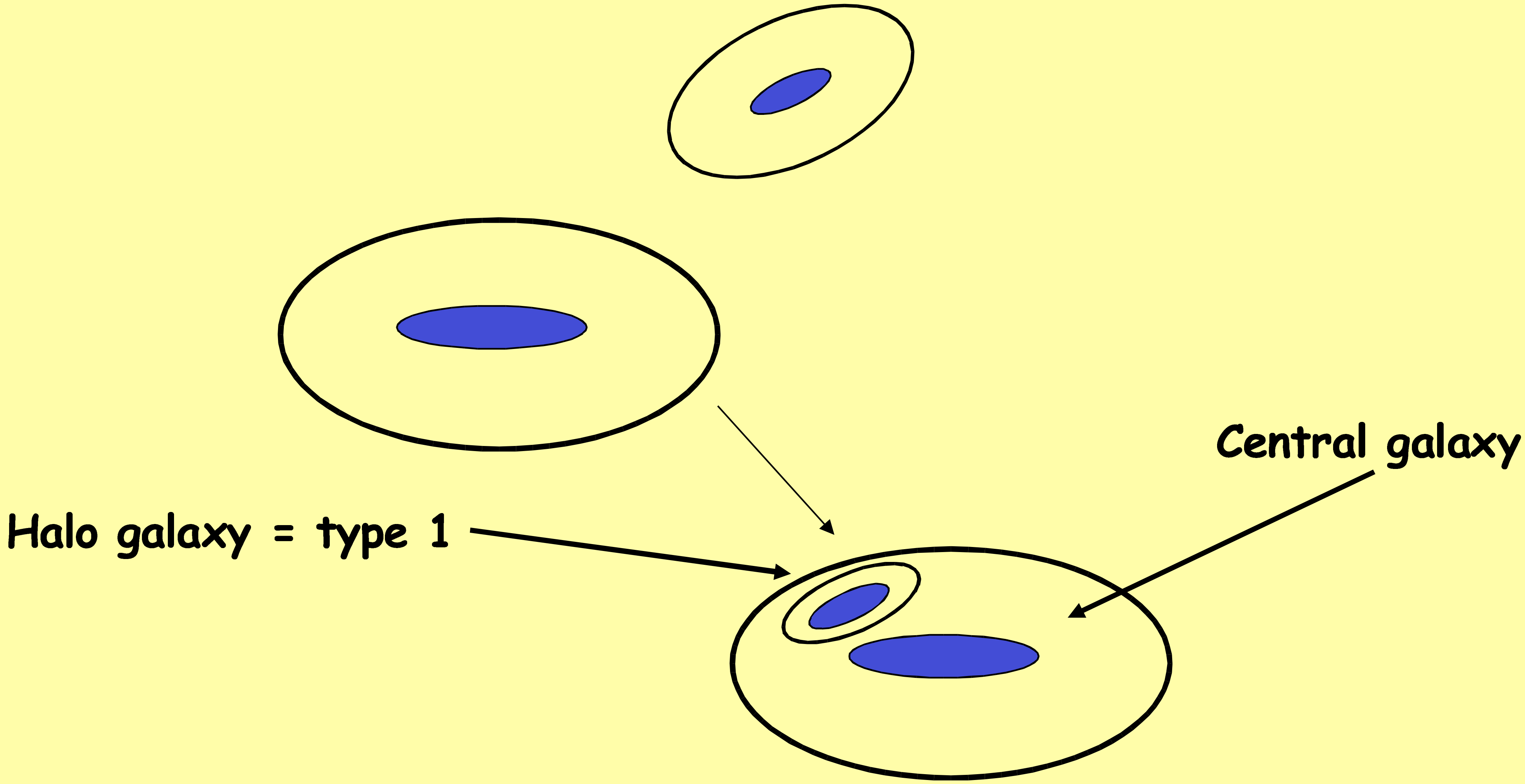






Weinmann et al. 2006

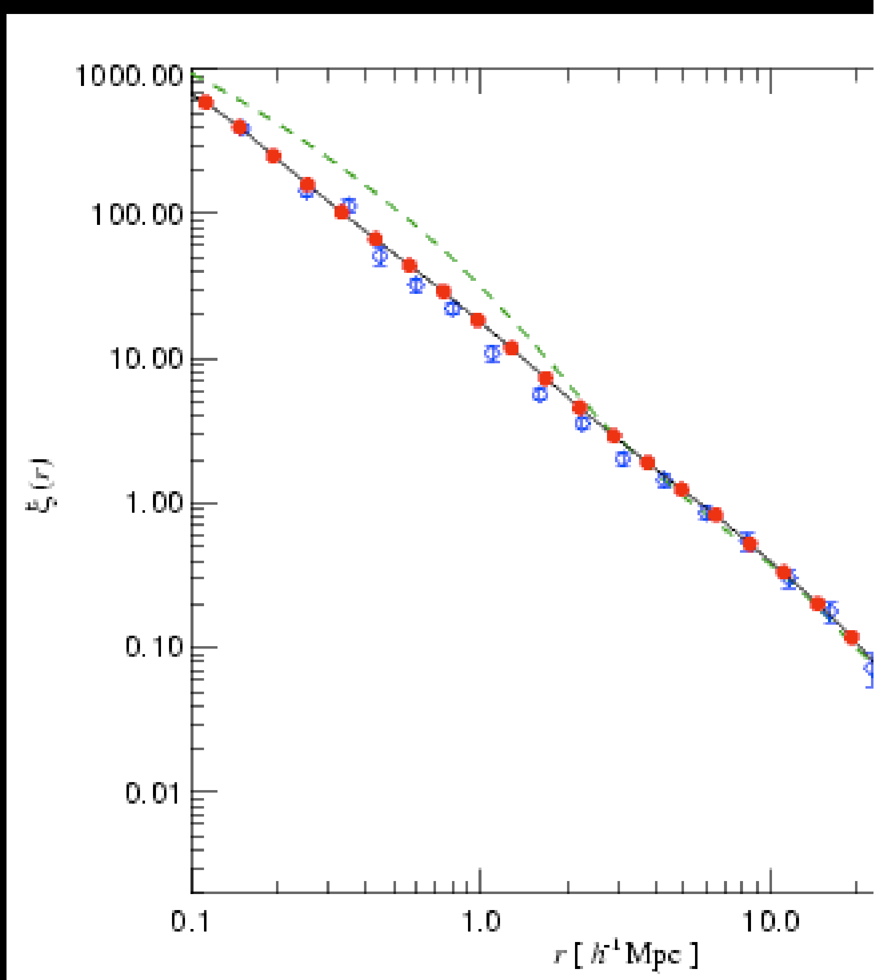
The galaxy "types":

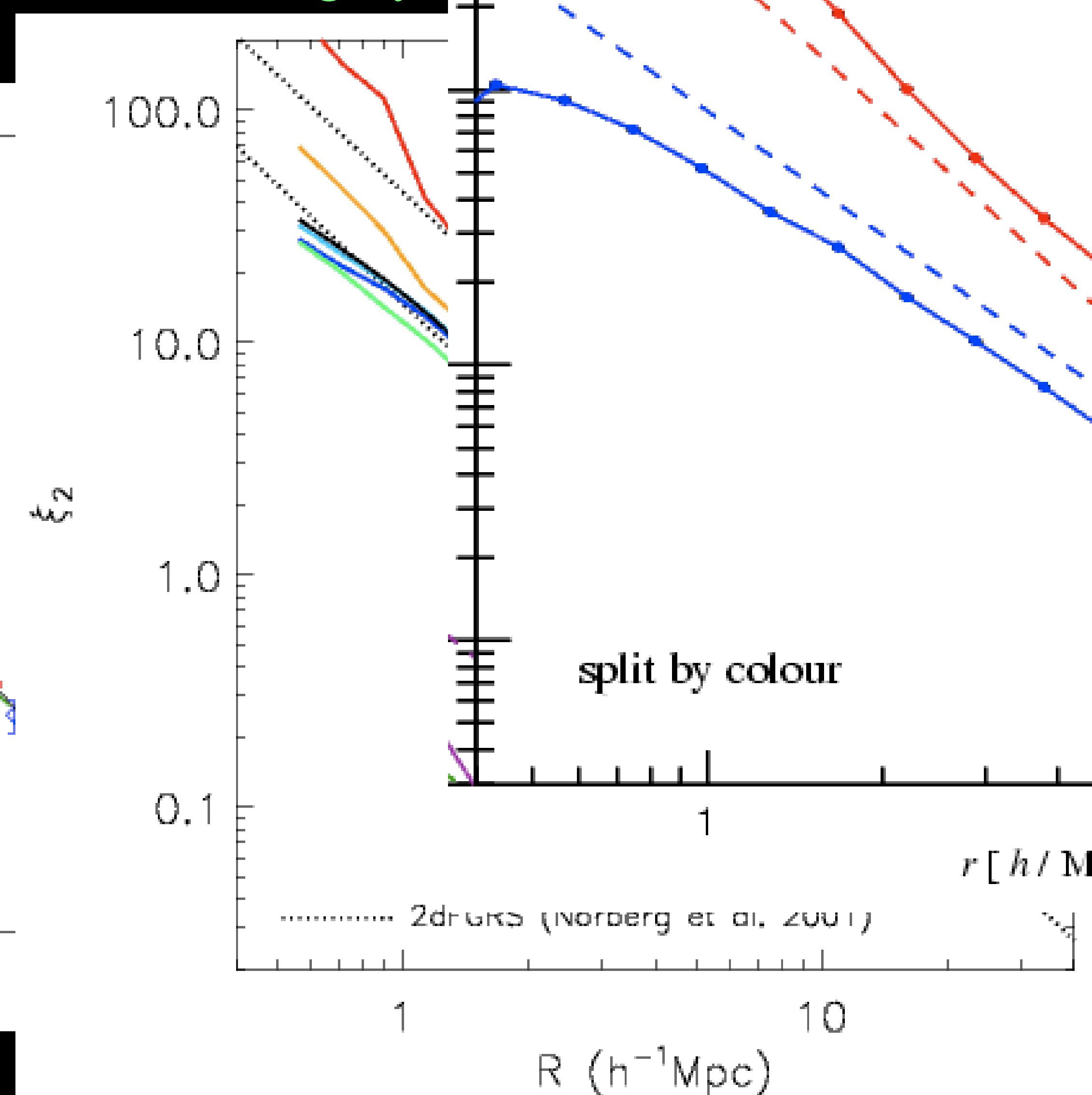


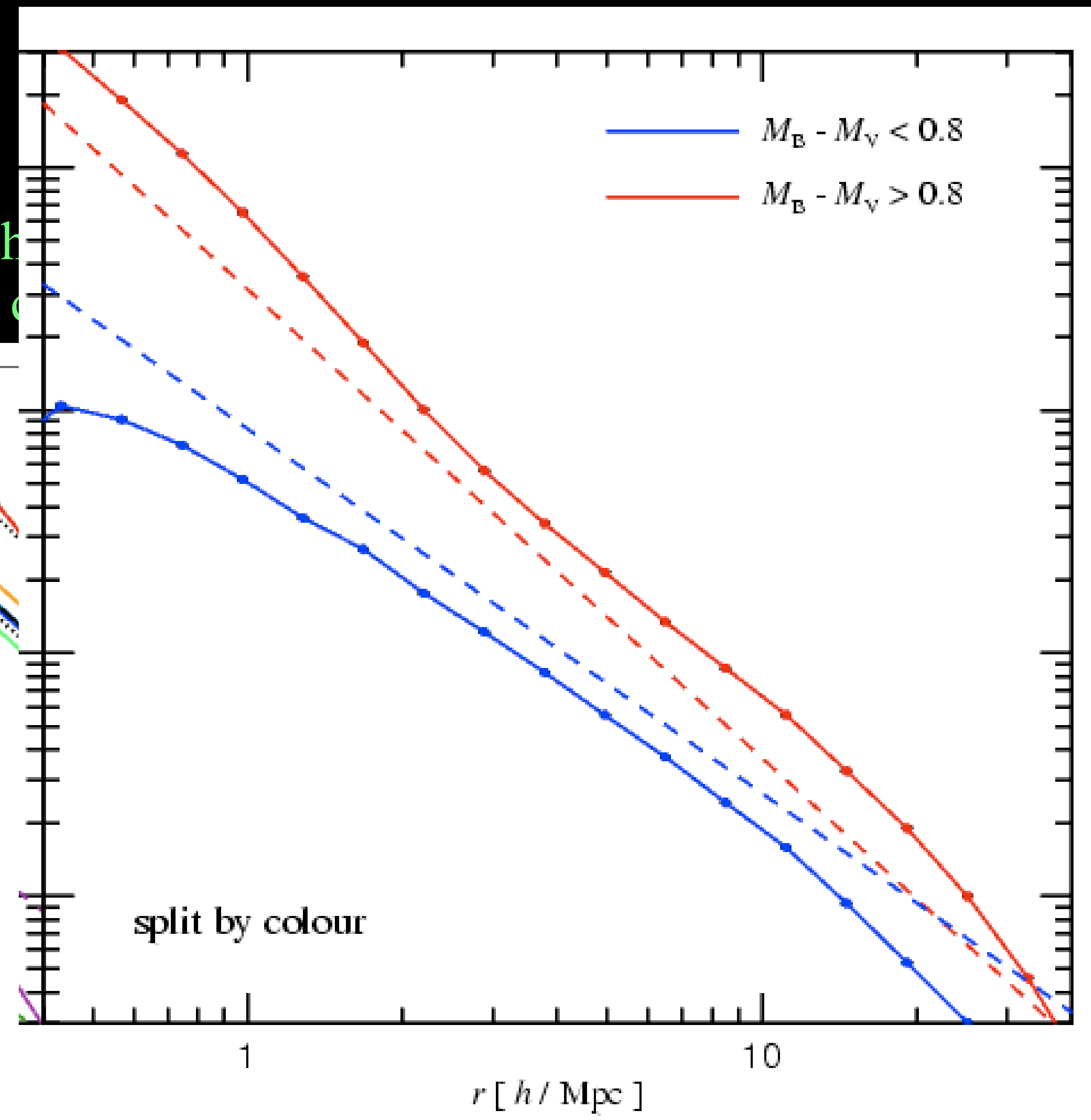
Springel et al. 2001, MNRAS, 328, 726

Red sequence galaxy clustering

Despite successfully reproducing th
distribution, clustering by c







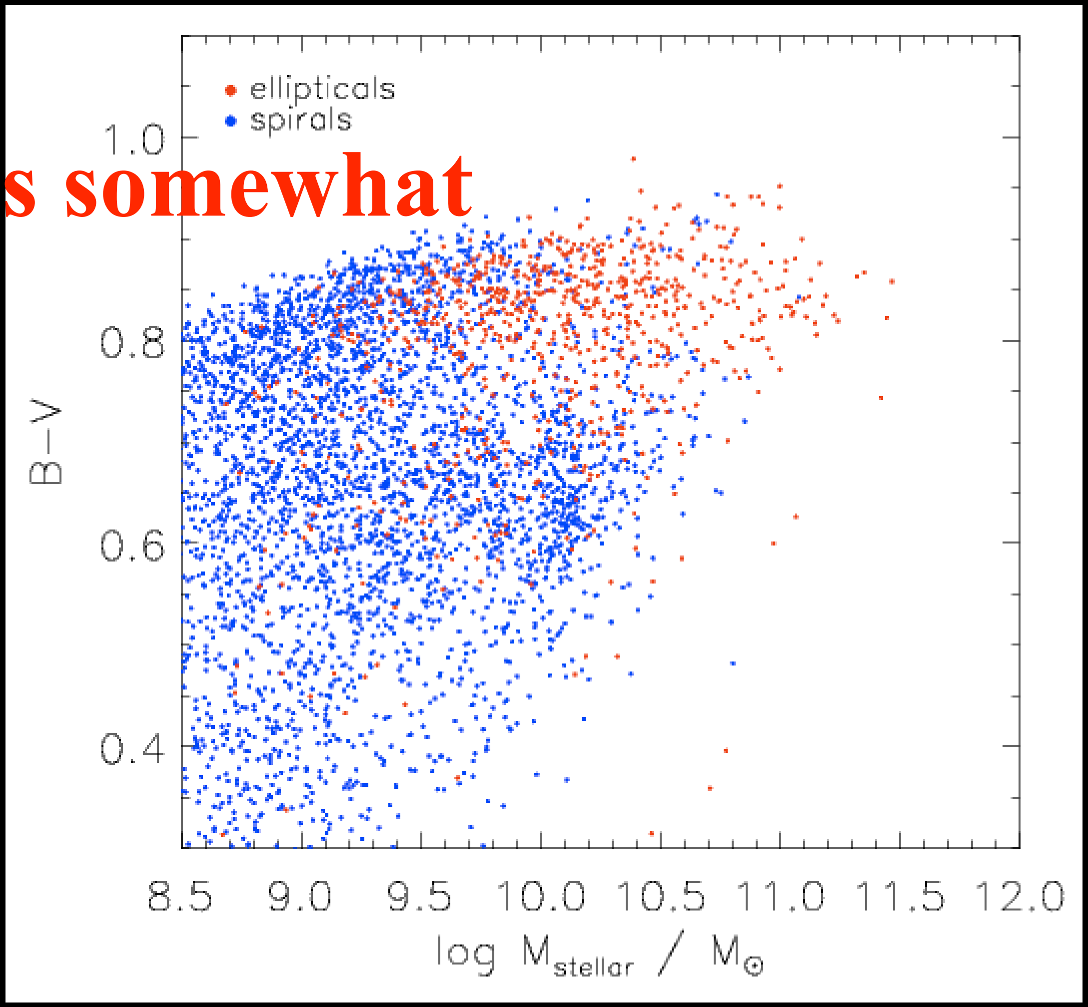
Springel et al. 2005

Are these problems related?

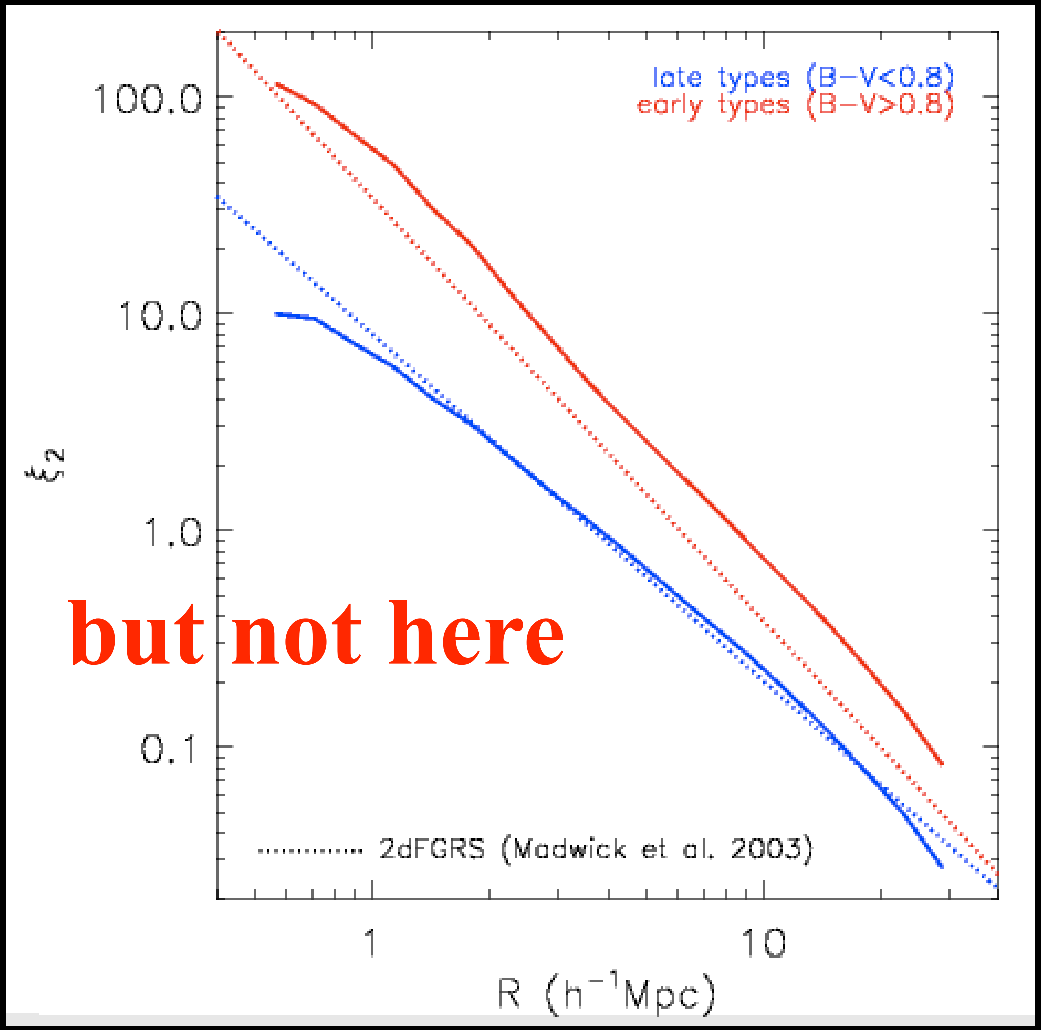
One might expect that making the satellites bluer would solve both problems.

I.e. less faint red galaxies in the CMD
implies
fewer very clustered satellites contributing to the red 2pt CF

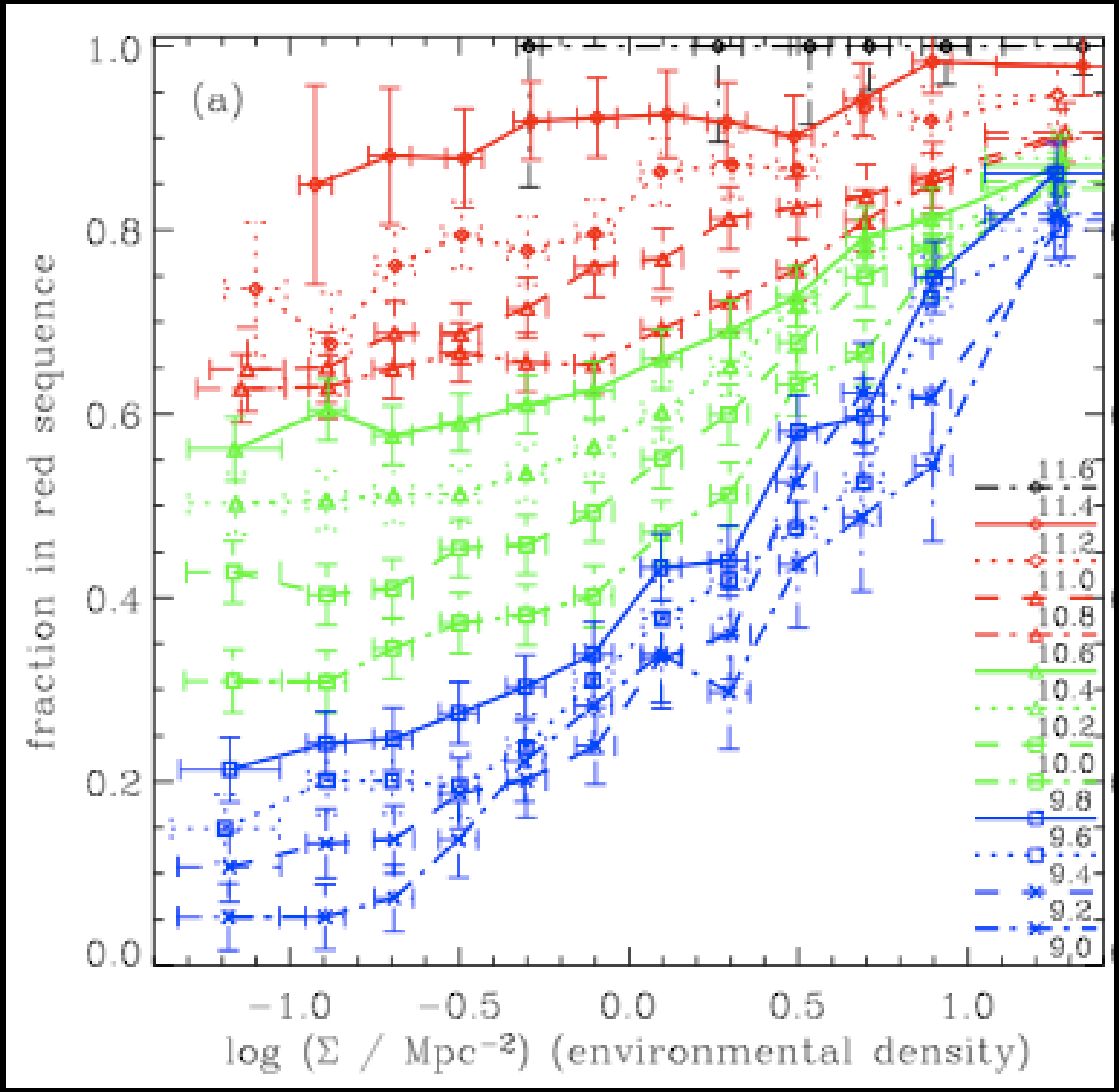
It helps somewhat



but not here



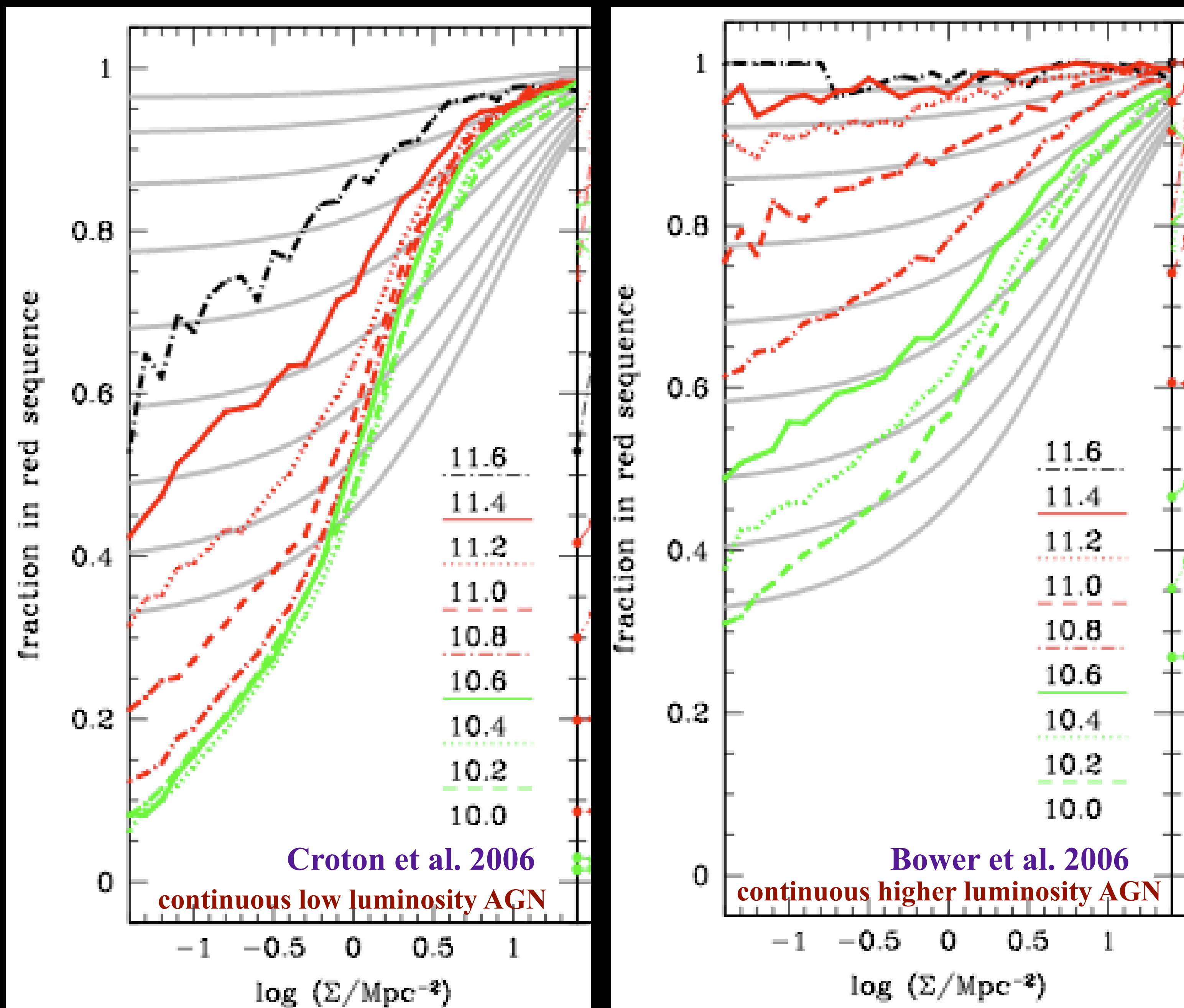
Further clues ...



(Baldry et al astro-ph/0607648)

SDSS red fraction
vs.
environment
in bins of stellar mass

Further clues ...



(Baldry et al astro-ph/0607648)

SDSS red fraction
vs.
environment
in bins of stellar mass

- does this suggest that stronger AGN (i.e. quenching) is required in low density environments?

- Does this suggest a different environmental distribution of BHs?

We can explore this possibility

Gas heating

Bondi-Hoyle black hole accretion (Bondi 1952)

Assumption: the hot gas around the central black hole is static and has uniform density:

$$\dot{m}_{\rm Bondi} = 2.5\pi G^2 \frac{m_{\rm BH}^2 \rho_0}{c_{\rm s}^3}$$

Assumption: maximal cooling flow. Thus, at the Bondi radius, the gas density is determined by equating the cooling time to the free fall time:

$$\frac{2r_{\rm Bondi}}{c_{\rm s}} \approx \frac{4Gm_{\rm BH}}{V_{\rm vir}^3} = \frac{3}{2}\frac{\bar{\mu}m_{\rm p}kT}{\rho_{\rm g}(r_{\rm Bondi})\Lambda(T,Z)}$$

=>

$$\rho_0 = \rho_{\rm g}(r_{\rm Bondi}) = \frac{3\mu m_{\rm p}}{8G}\frac{kT}{\Lambda}\frac{V_{\rm vir}^3}{m_{\rm BH}}$$

Using this local BH gas density gives a Bondi accretion rate of:

$$\dot{m}_{\rm Bondi} \approx G\mu m_{\rm p}\frac{kT}{\Lambda}m_{\rm BH}$$

Gas heating

(Croton et al 2006)

The quiescent AGN "radio" mode:

Such accretion leads to a low energy outflow from the black hole

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

By energy conservation this outflow can suppress the inflow of cooling gas

$$\dot{m}'_{\rm cool} = \dot{m}_{\rm cool} - \frac{L_{\rm BH}}{\frac{1}{2}V_{\rm vir}^2}$$

We assume that this model captures the mean behaviour of the black hole over timescales much longer then the duty cycle

How do we grow black holes?

Merger driven scenario:

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

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

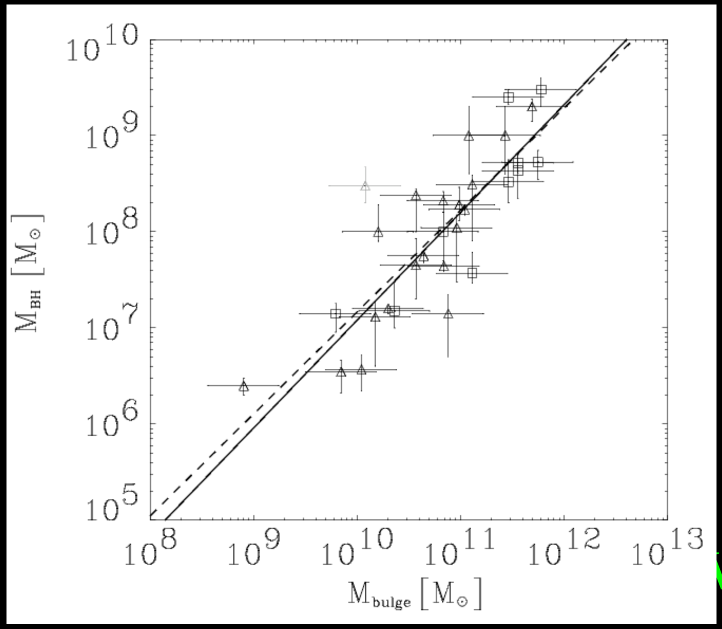
Bar instability scenario:

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

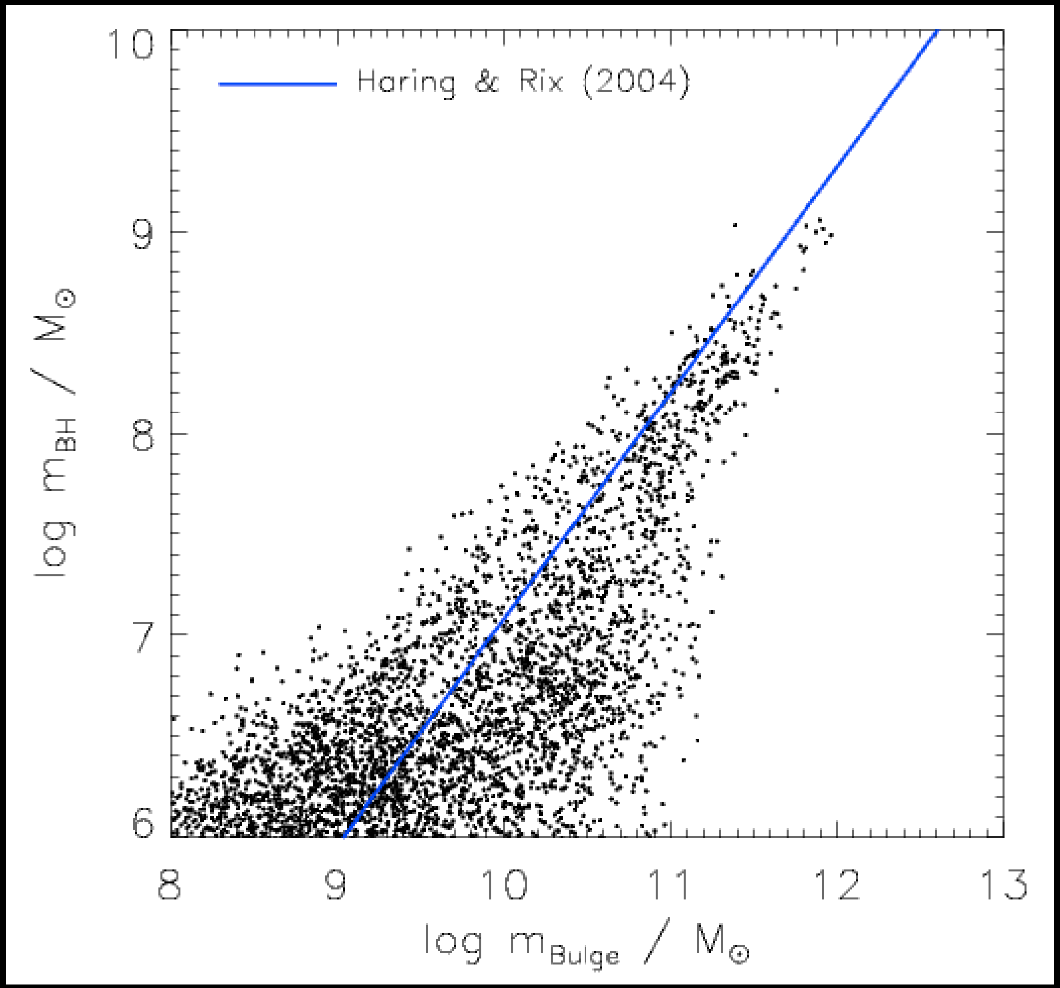
Both have a different environmental dependence

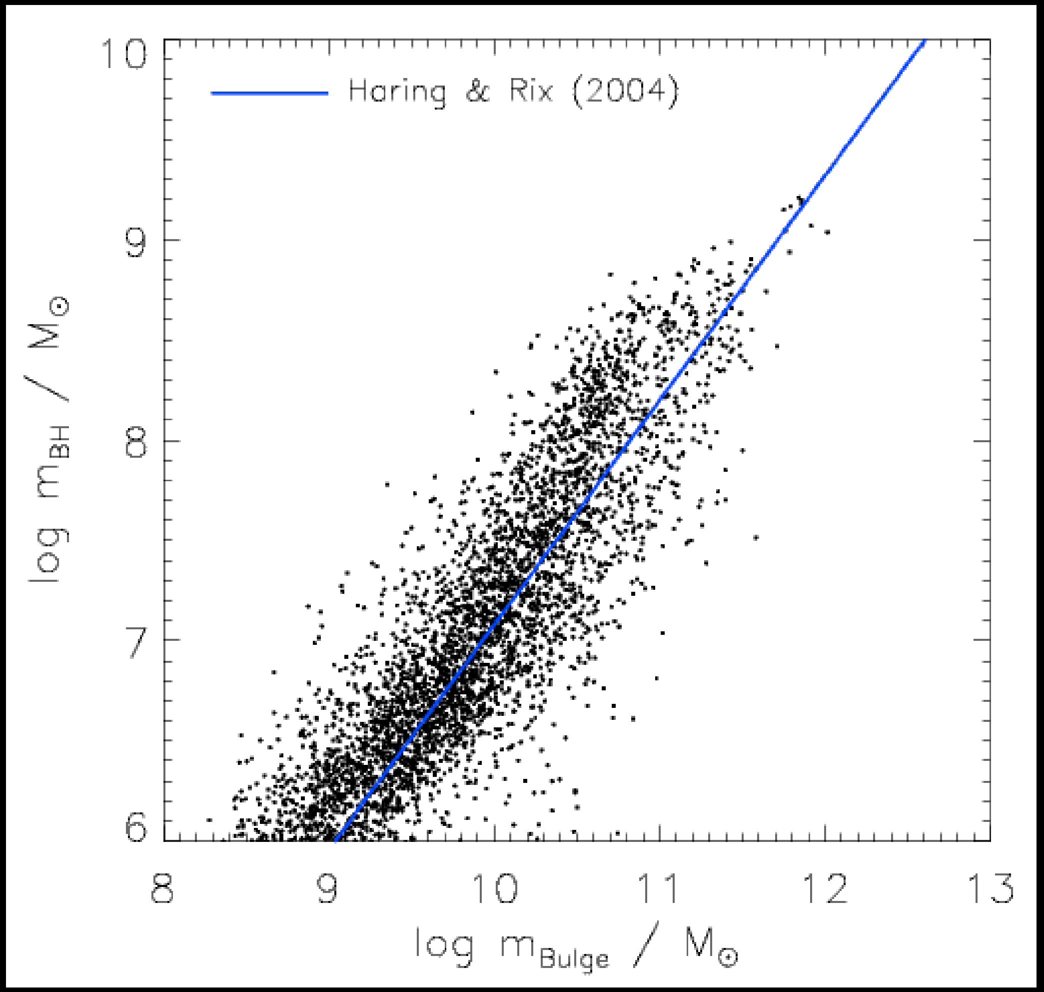


BH-bulge relation

driven
wth

Disk instability driven
growth

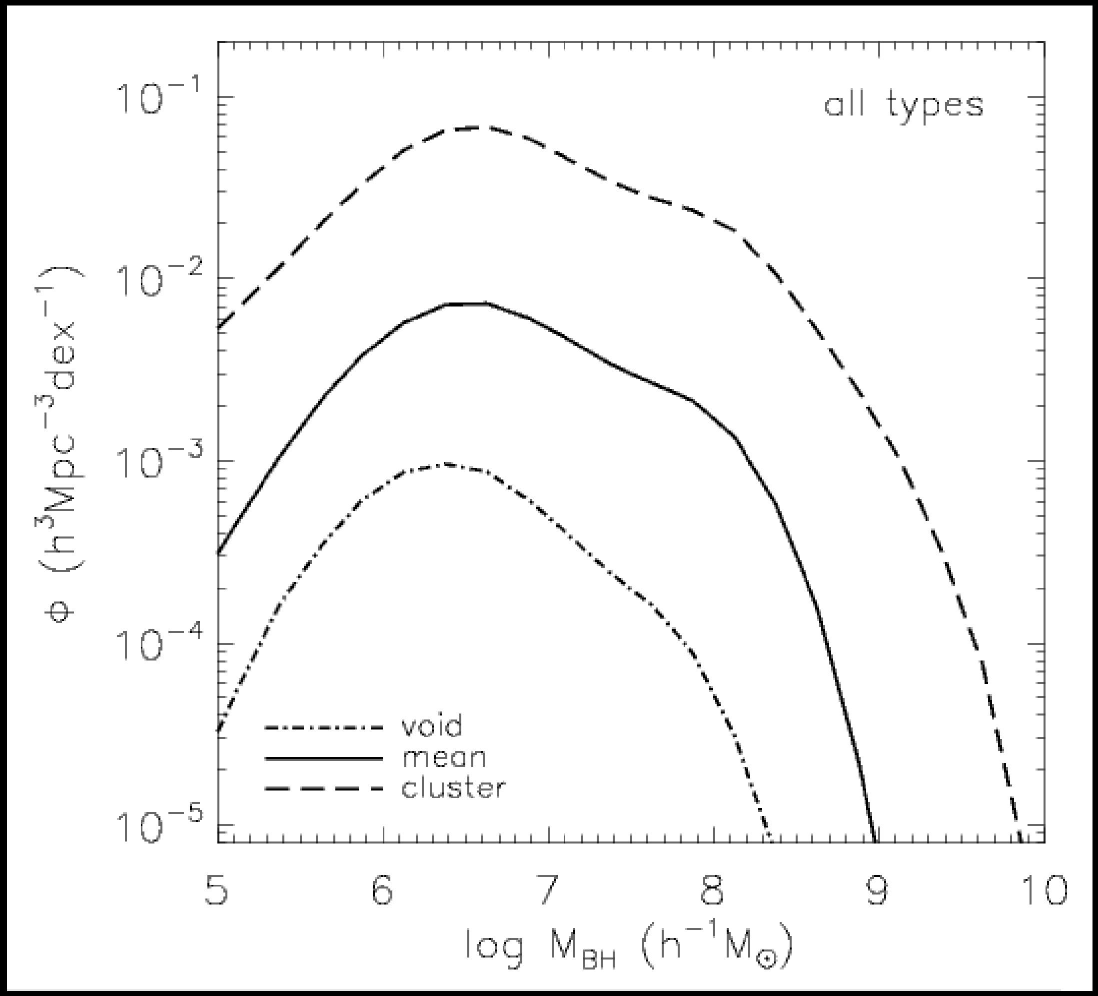




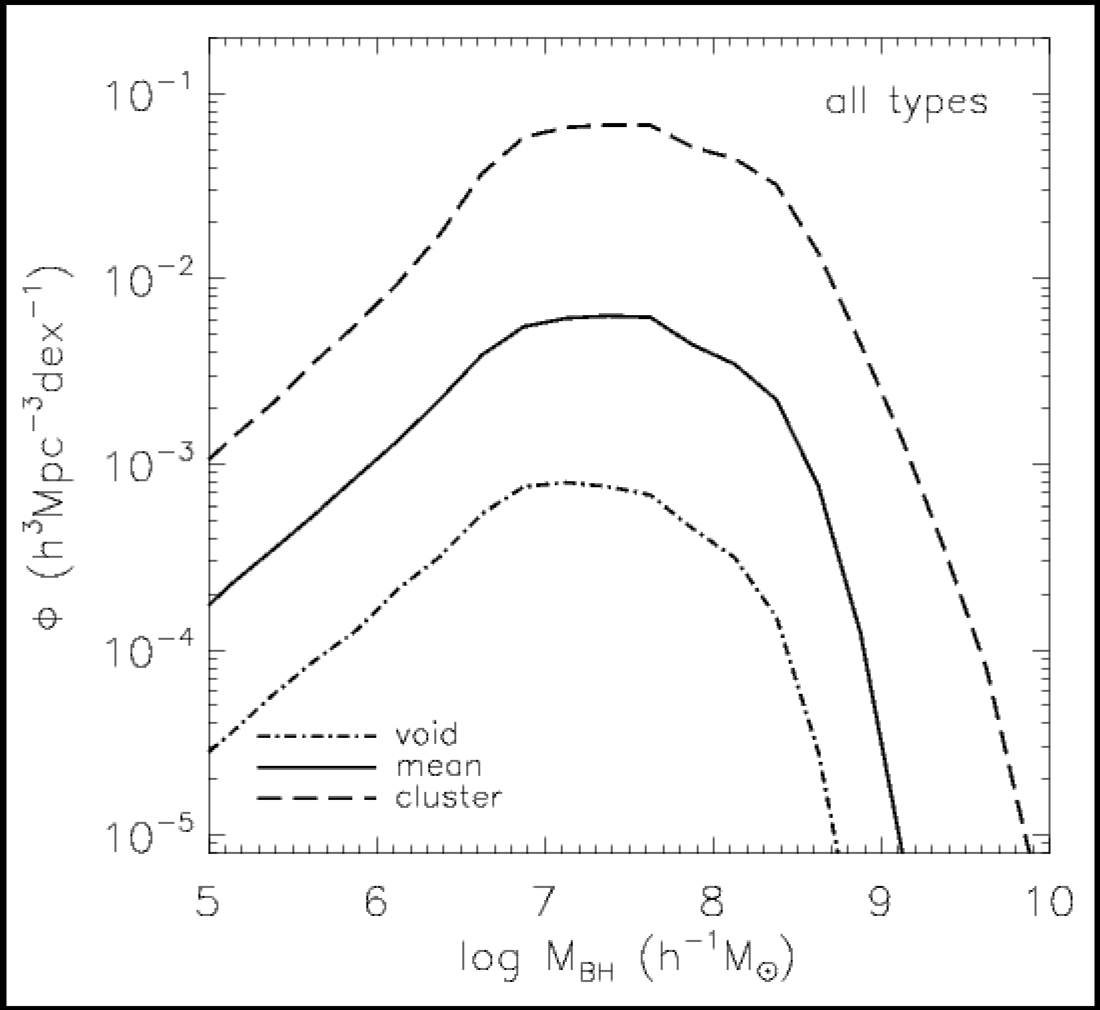
Different behaviour at the low mass end but both still in agreement with the observations

Black hole mass function vs. environment

Merger driven growth



Disk instability driven growth

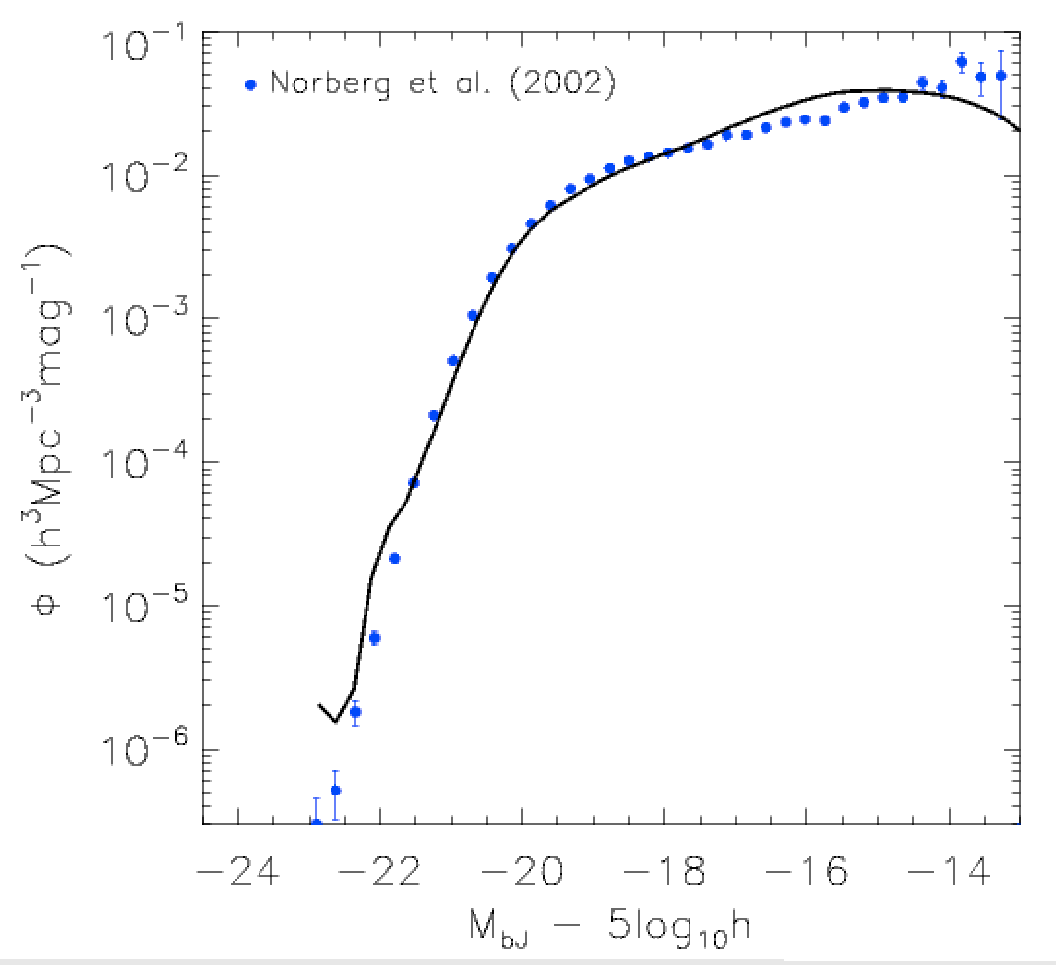


in galaxies with $M_* > 10^{10}$Msun

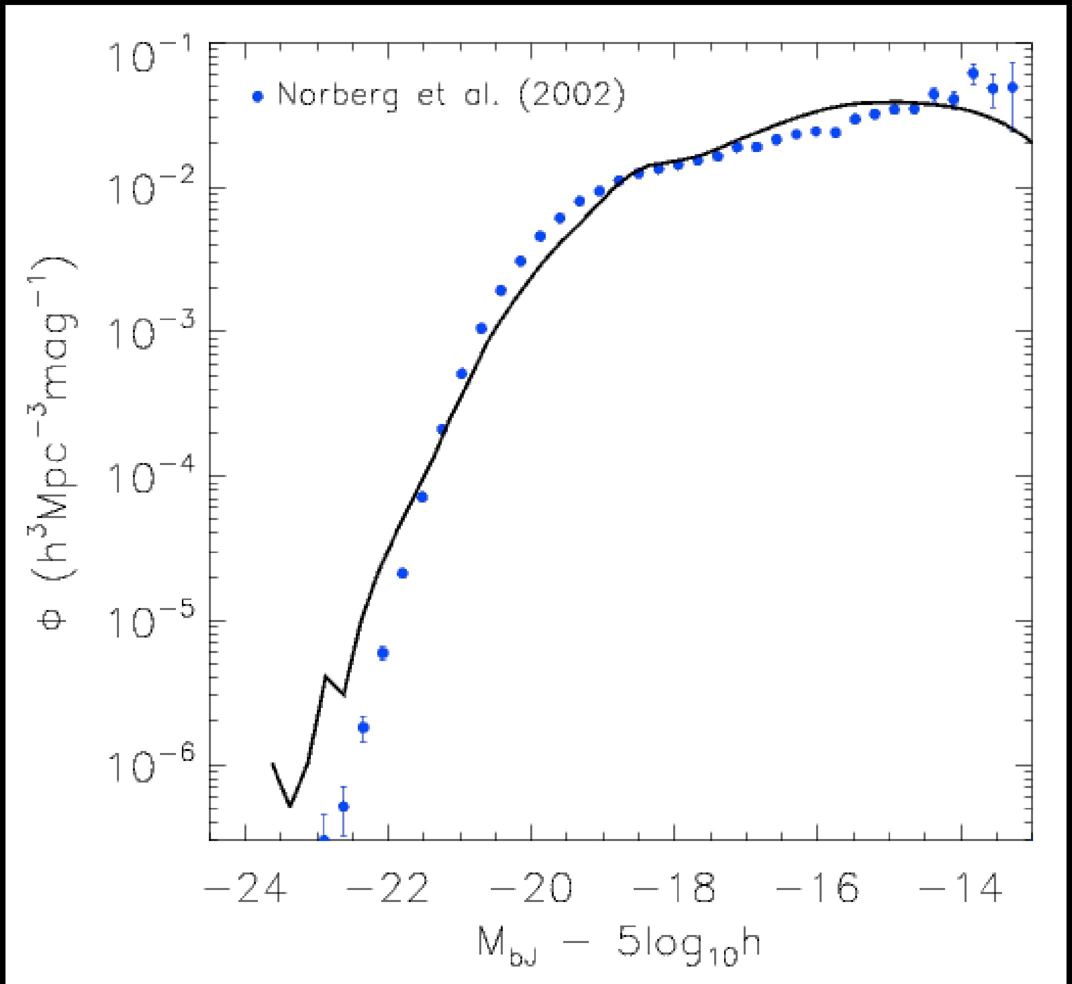
Substantial differences in the BH mass functions in different environments

Global luminosity functions

Merger driven growth



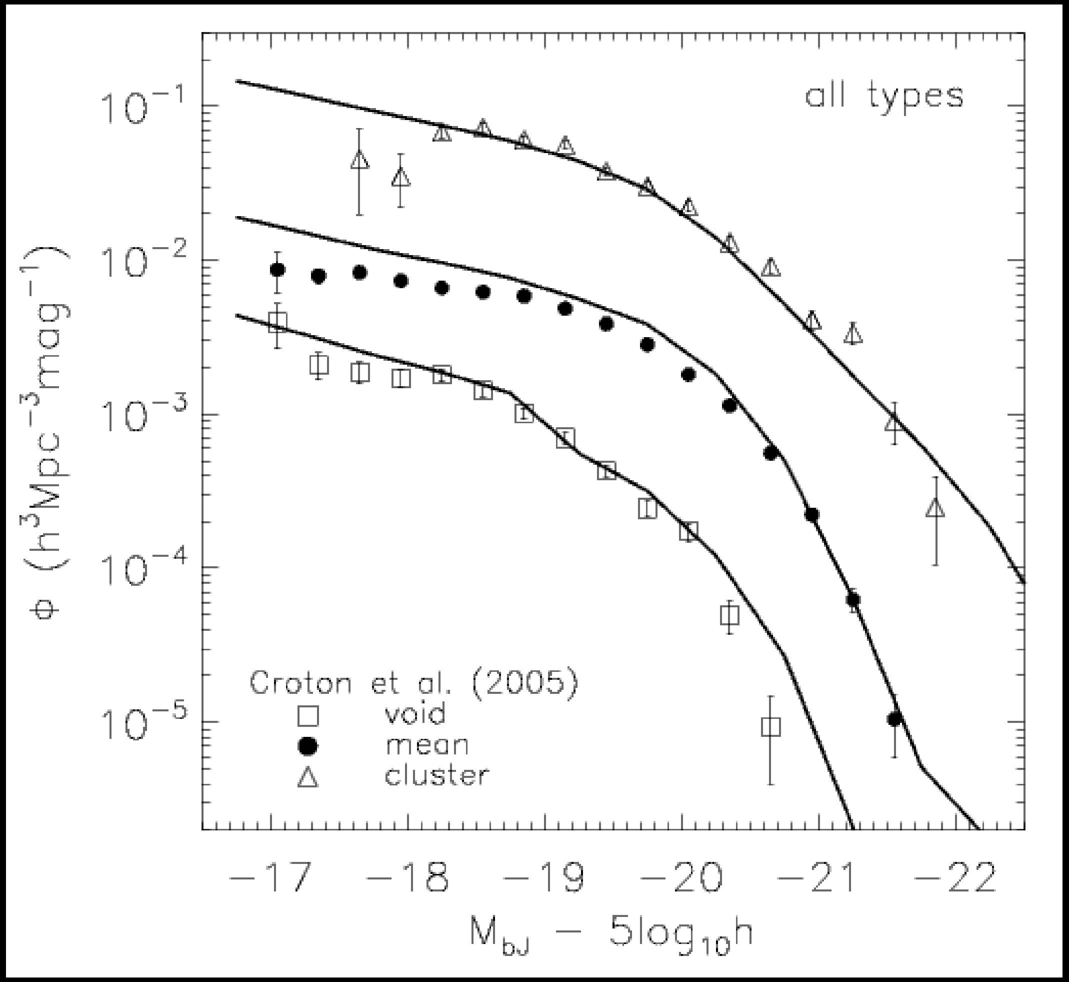
Disk instability driven growth



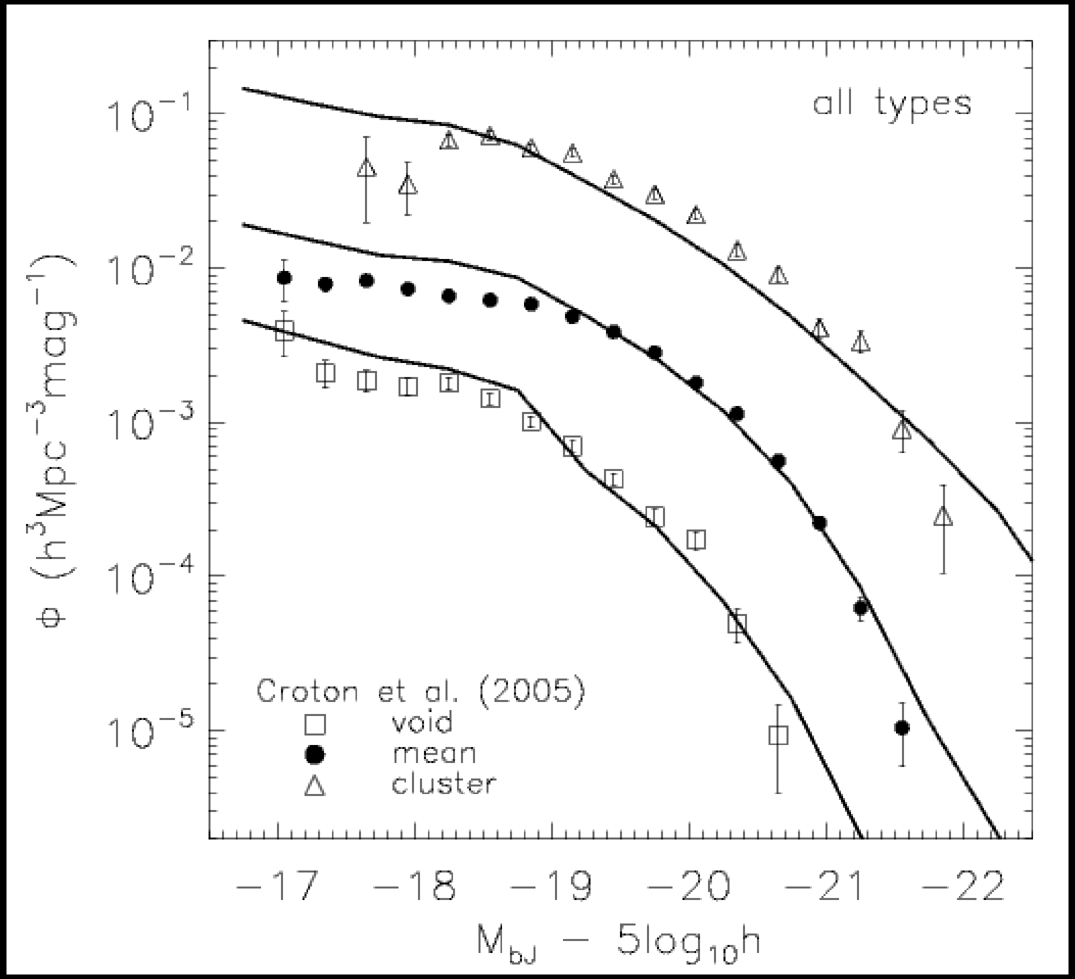
Reasonable agreement for identical parameter choices

Environment luminosity functions

Merger driven growth



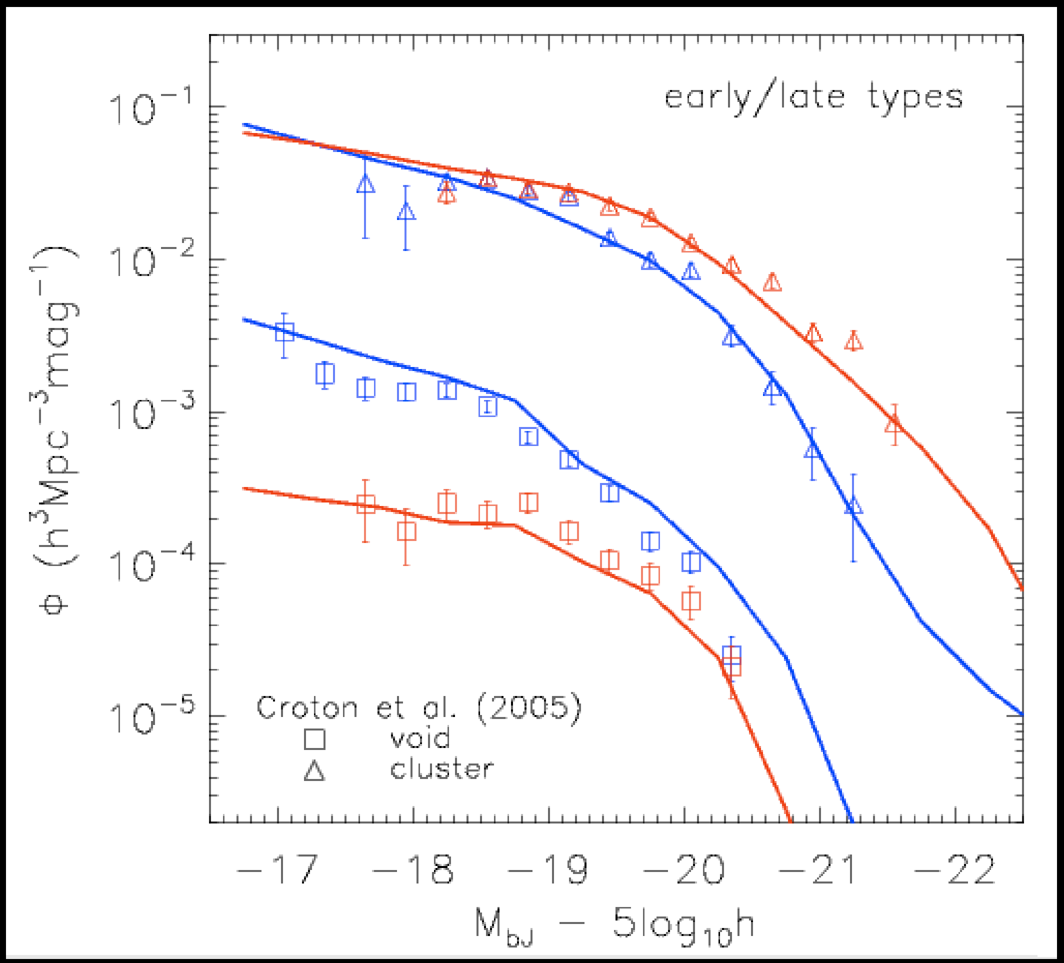
Disk instability driven growth



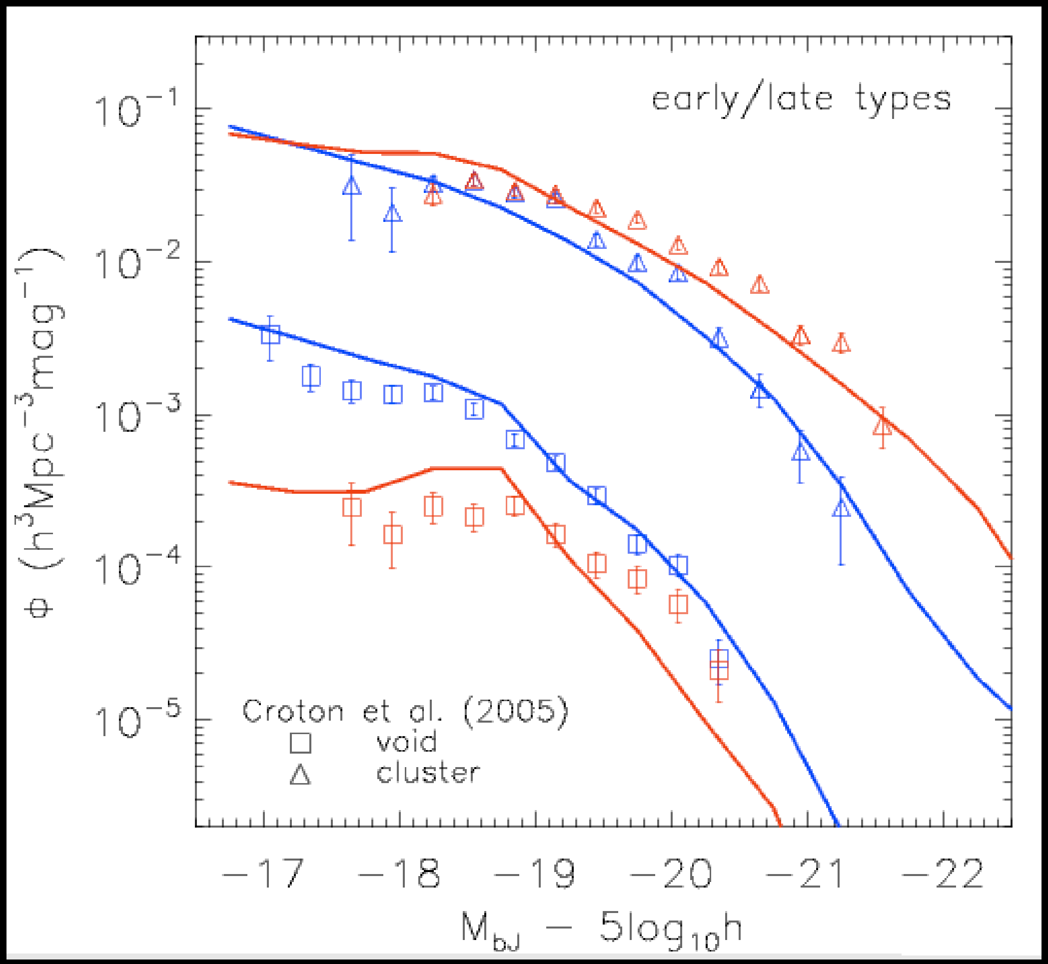
void: delta<-0.75, mean -0.42<delta8<0.32, cluster: delta8>6.0

Environment luminosity functions by colour

Merger driven growth

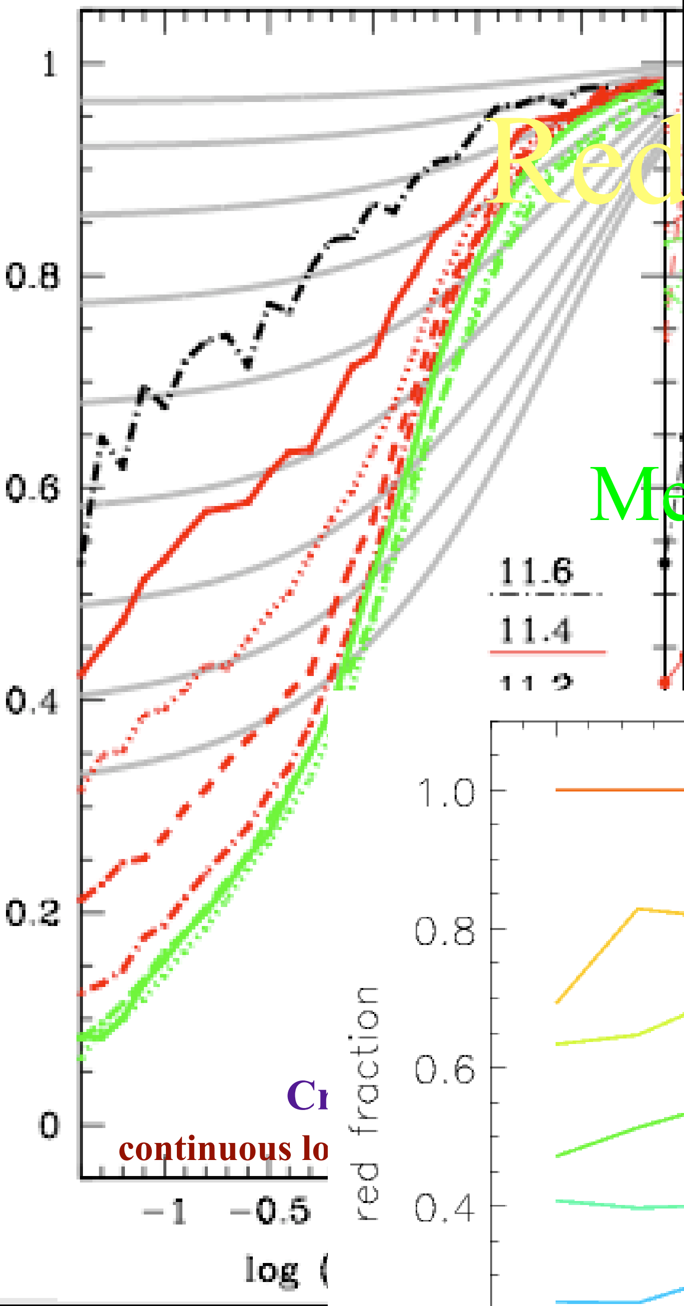


Disk instability driven growth

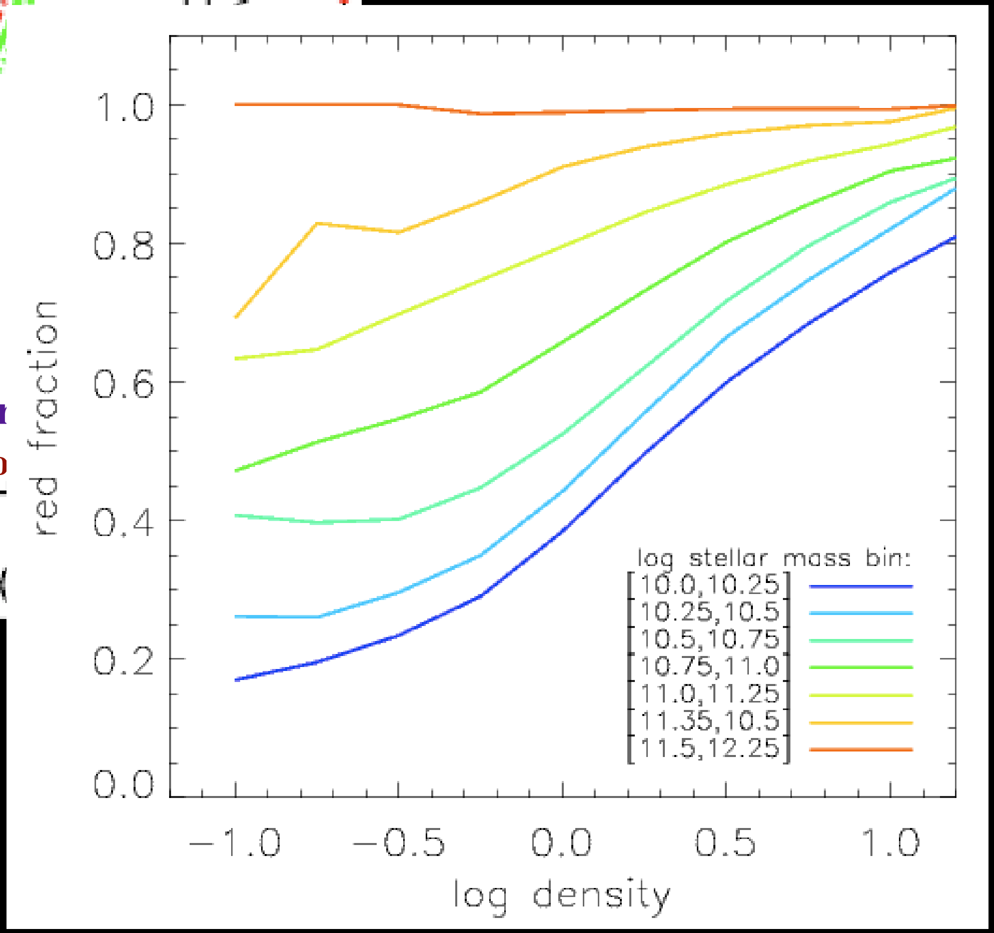


Some differences for early-type void galaxies

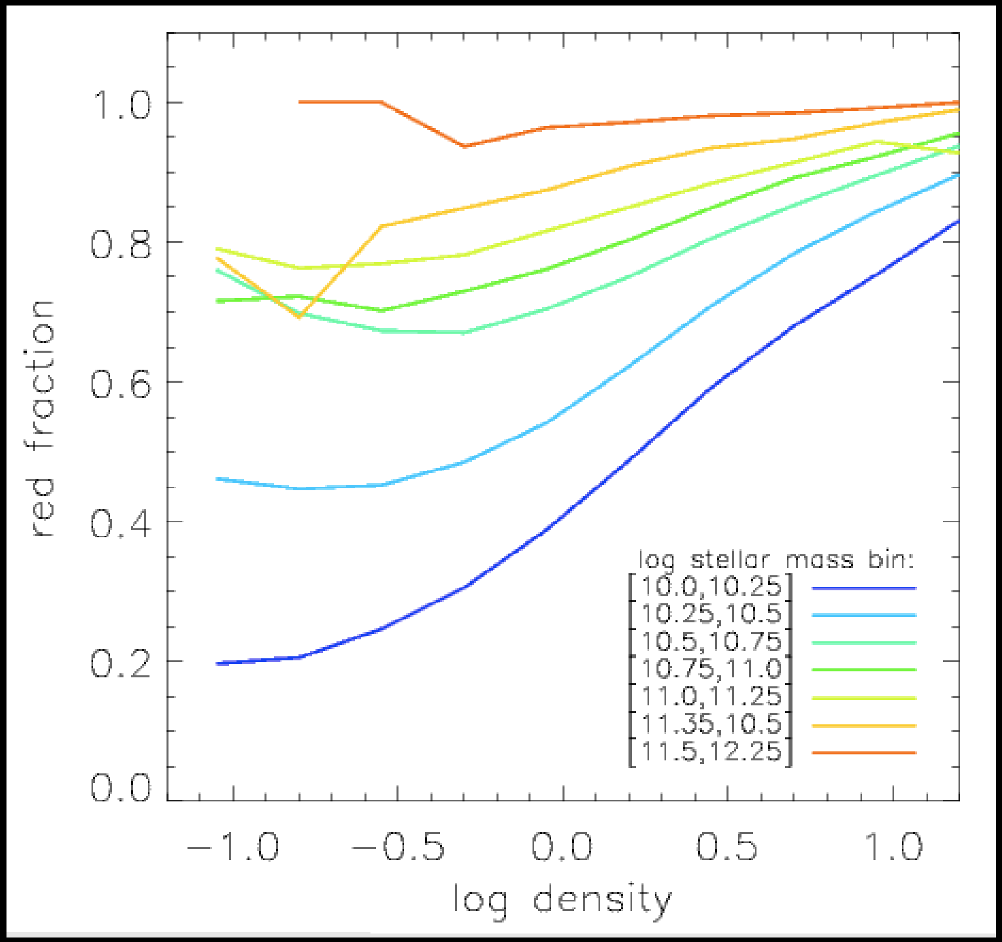
Red fractions vs. environment and stellar mass



Merger driven growth



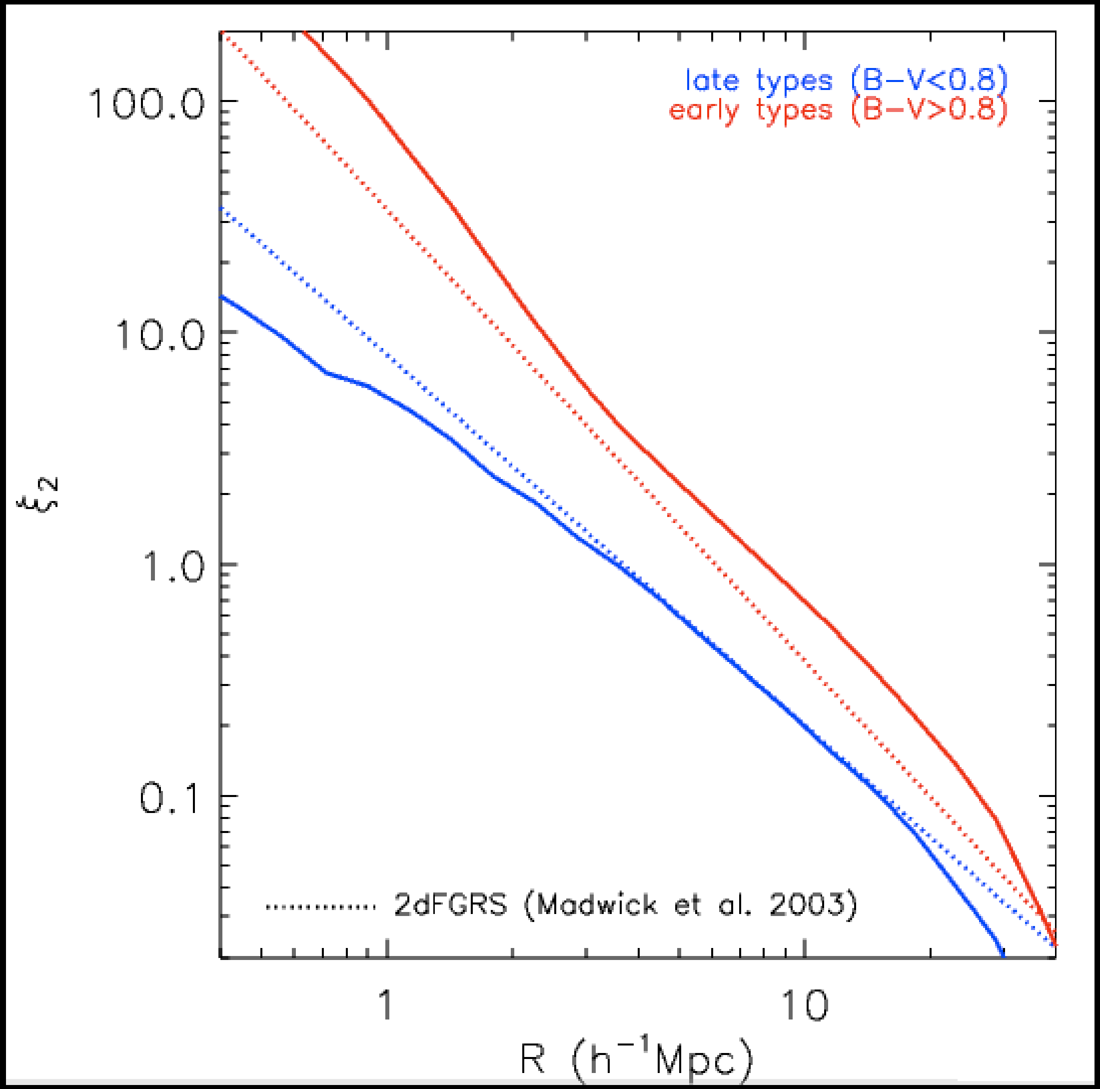
Disk instability driven growth



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

Galaxy clustering

Disk instability driven growth



Clustering is still too strong for red galaxies.
Something is missing/incorrect: physics, detail, ...

Conclusions

1. Low luminosity AGN can keep red galaxies on the red sequence in spite of the hierarchical growth of cosmic structure. The global properties, even by environment, can be reproduced

2. Many properties by colour are reproduced, however the clustering of red galaxies remains a elusive. Different heating mechanisms for different mass scales?

3. Red galaxies encapsulate much of the physics of galaxy evolution. The challenge is to understand the evolution of satellites and the physics governing the spatial distribution of galaxies as a function of colour.

The full Millennium Run galaxy + halo catalogues
(~25 million galaxies/halos, $0<z<127$)
are now available through the GAVO SQL interface for use by the community
http://www.mpa-garching.mpg.de/Millennium/ see astro-ph/0608019