

From the Role of Galaxy Environment to Outstanding Problems in Theory

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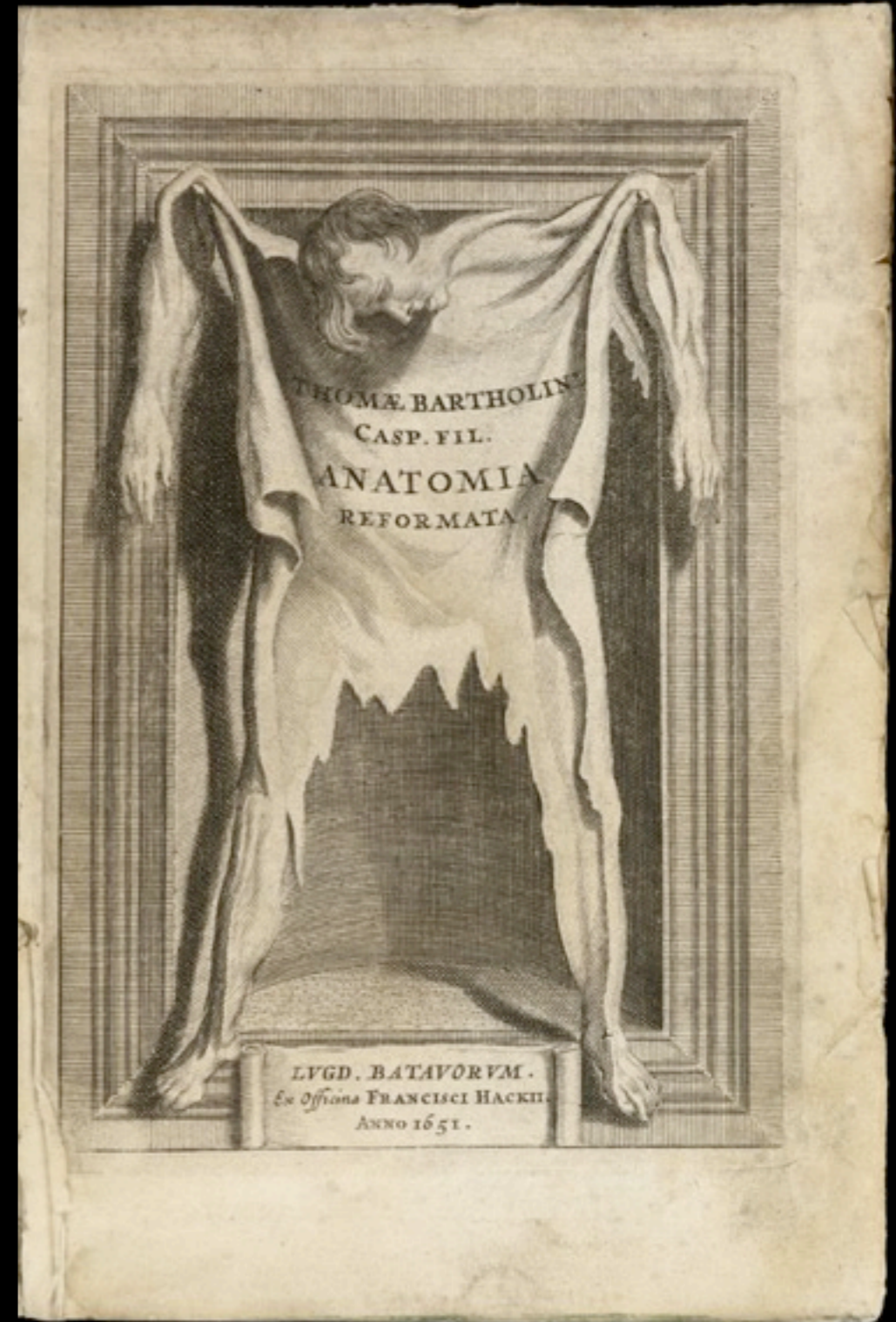
dcroton@astro.swin.edu.au



Let's recap...



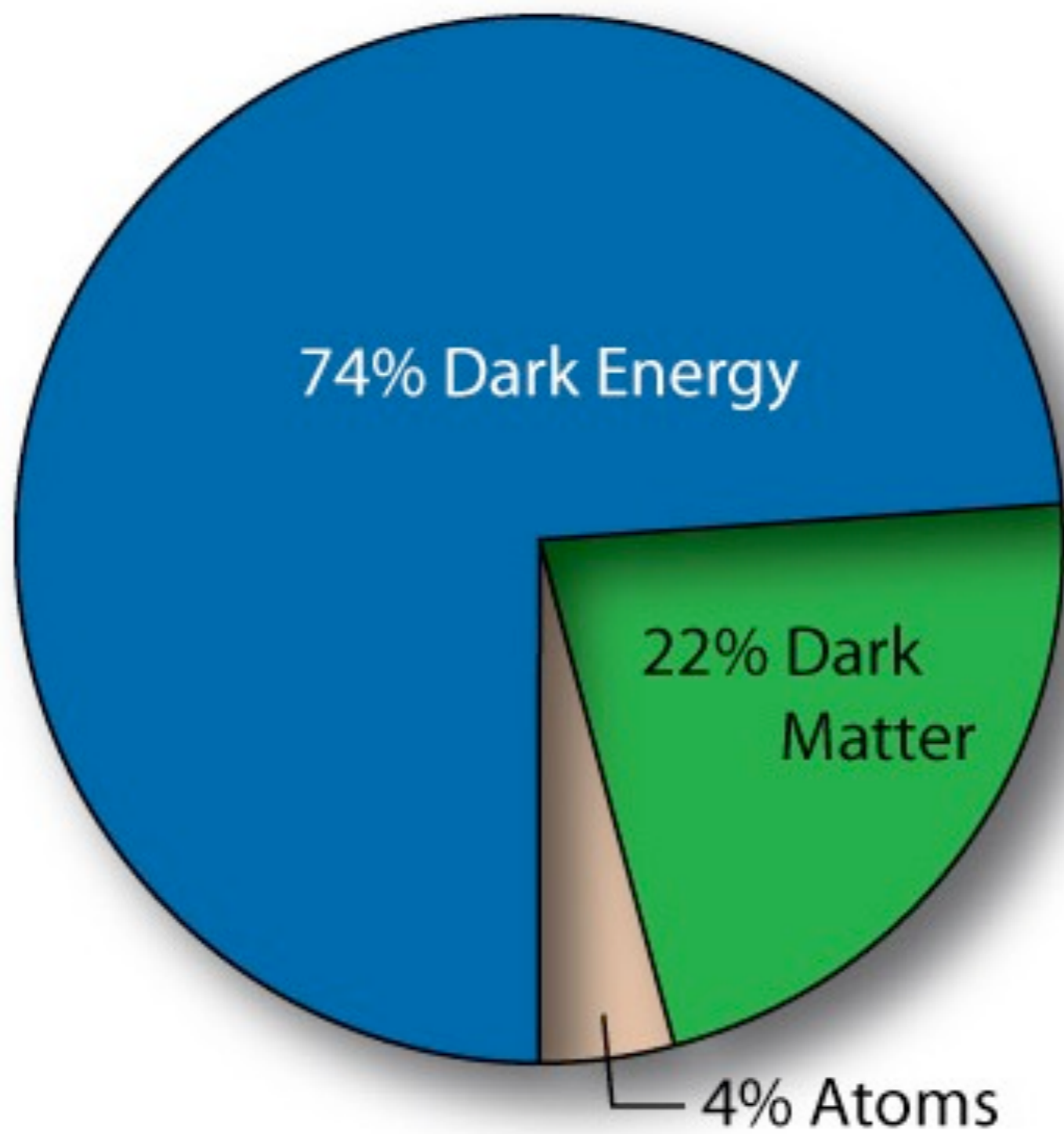
The skeleton

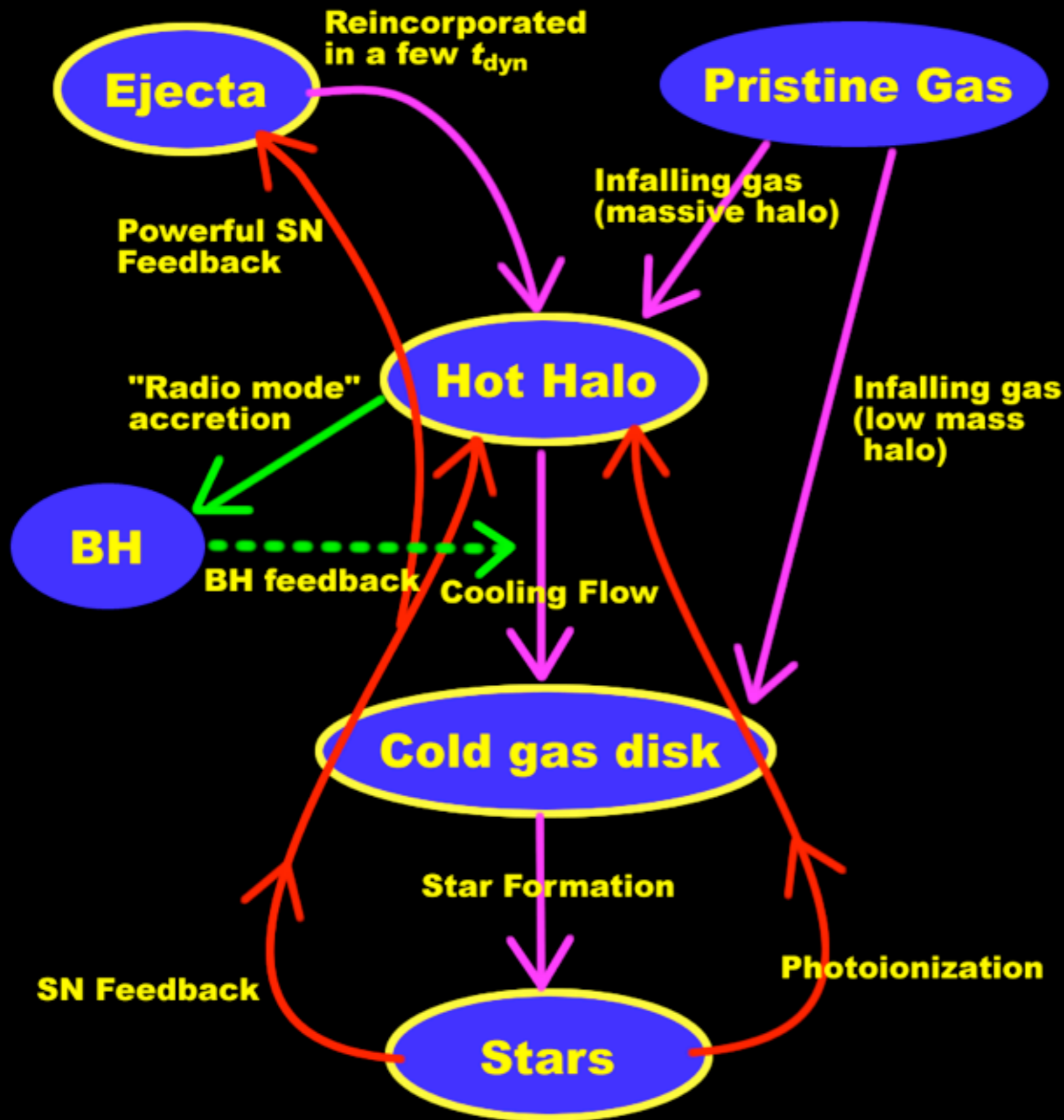


The flesh





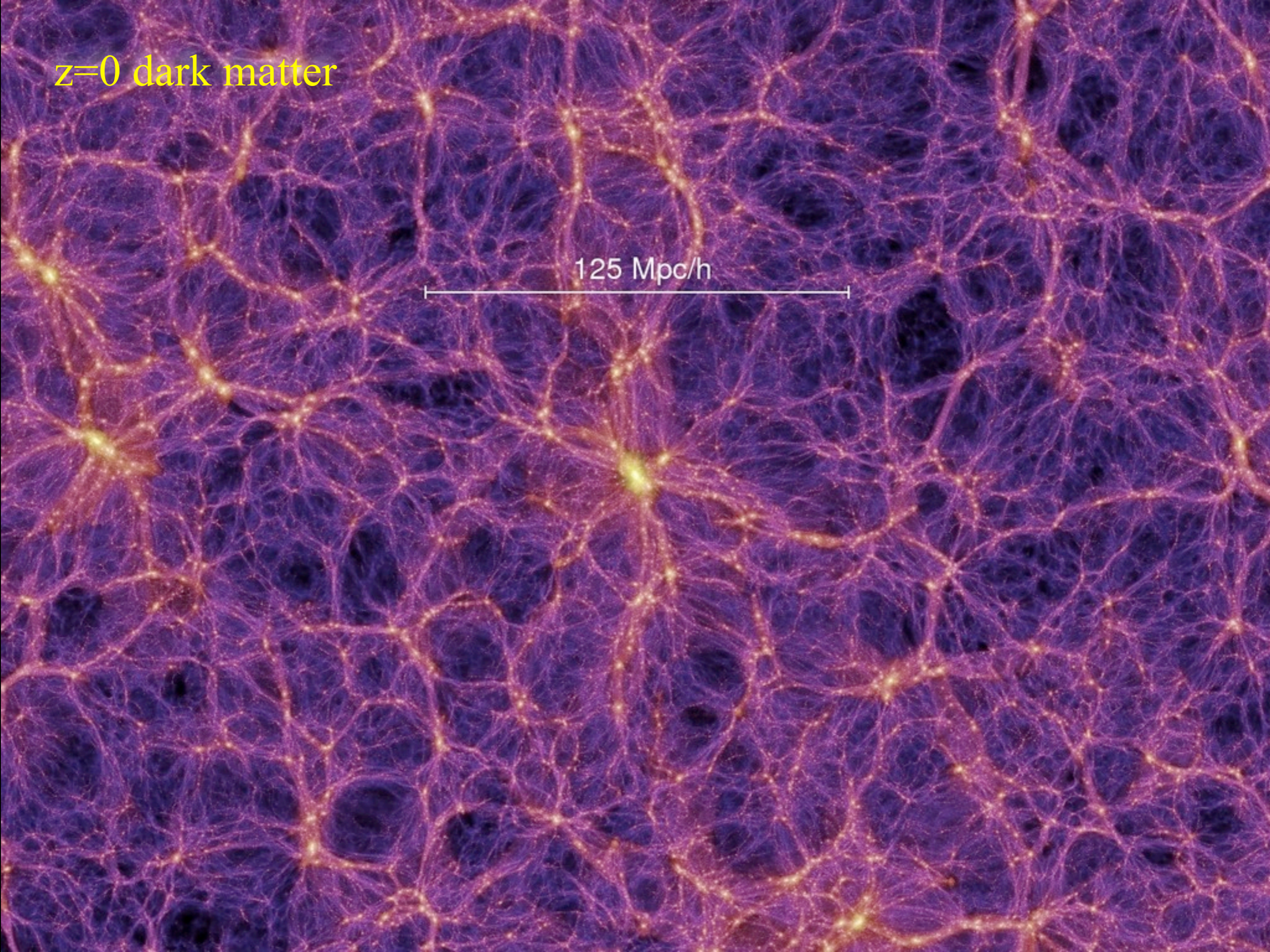




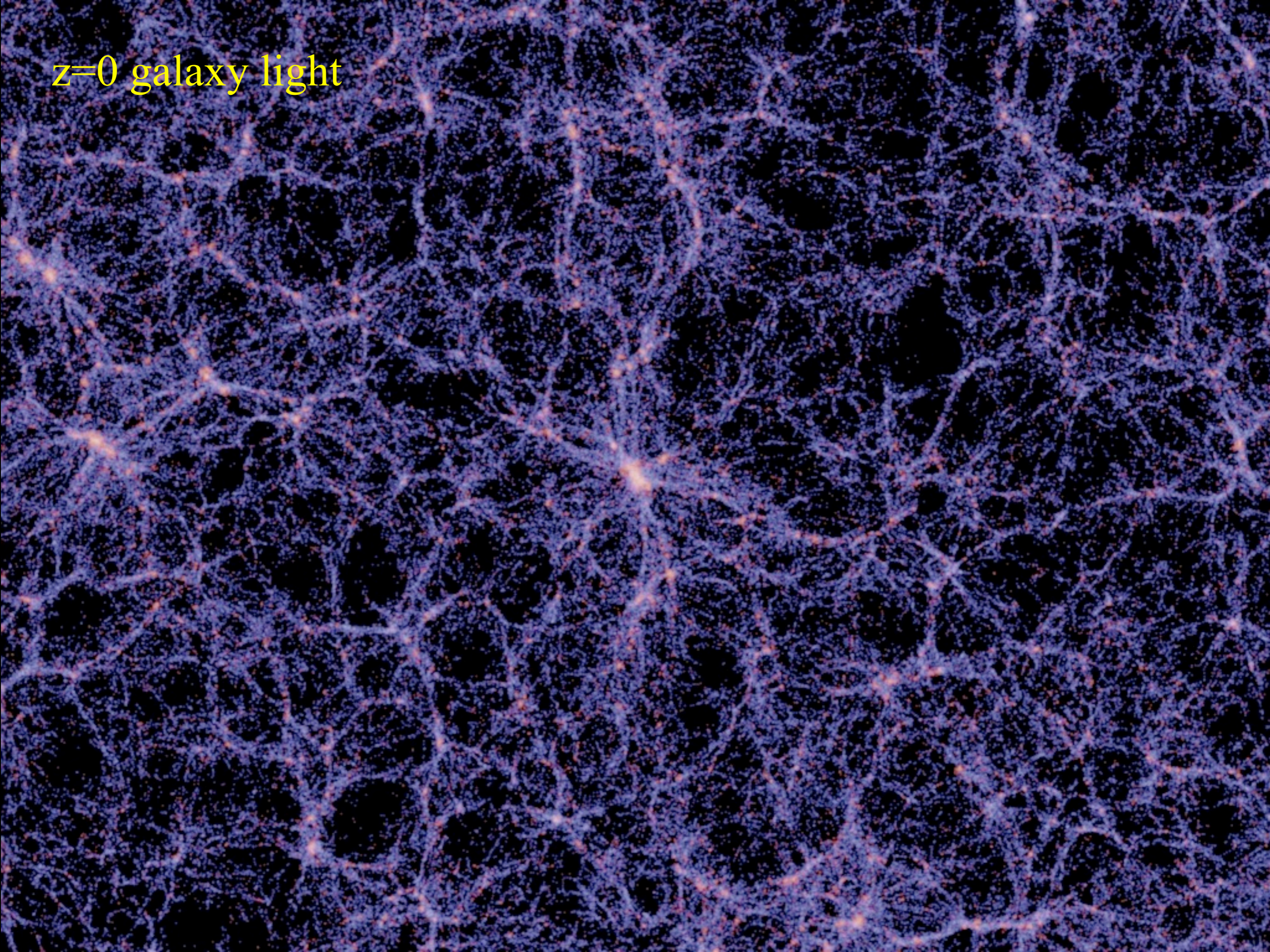
- ▶ Schmidt law star formation
- ▶ SFR dependent SN winds
- ▶ satellite gas stripping
- ▶ morphological transformation
- ▶ assembly through mergers
- ▶ starbursts through mergers
- ▶ Magorrian relation BH growth
- ▶ jet & bubble AGN feedback

$z=0$ dark matter

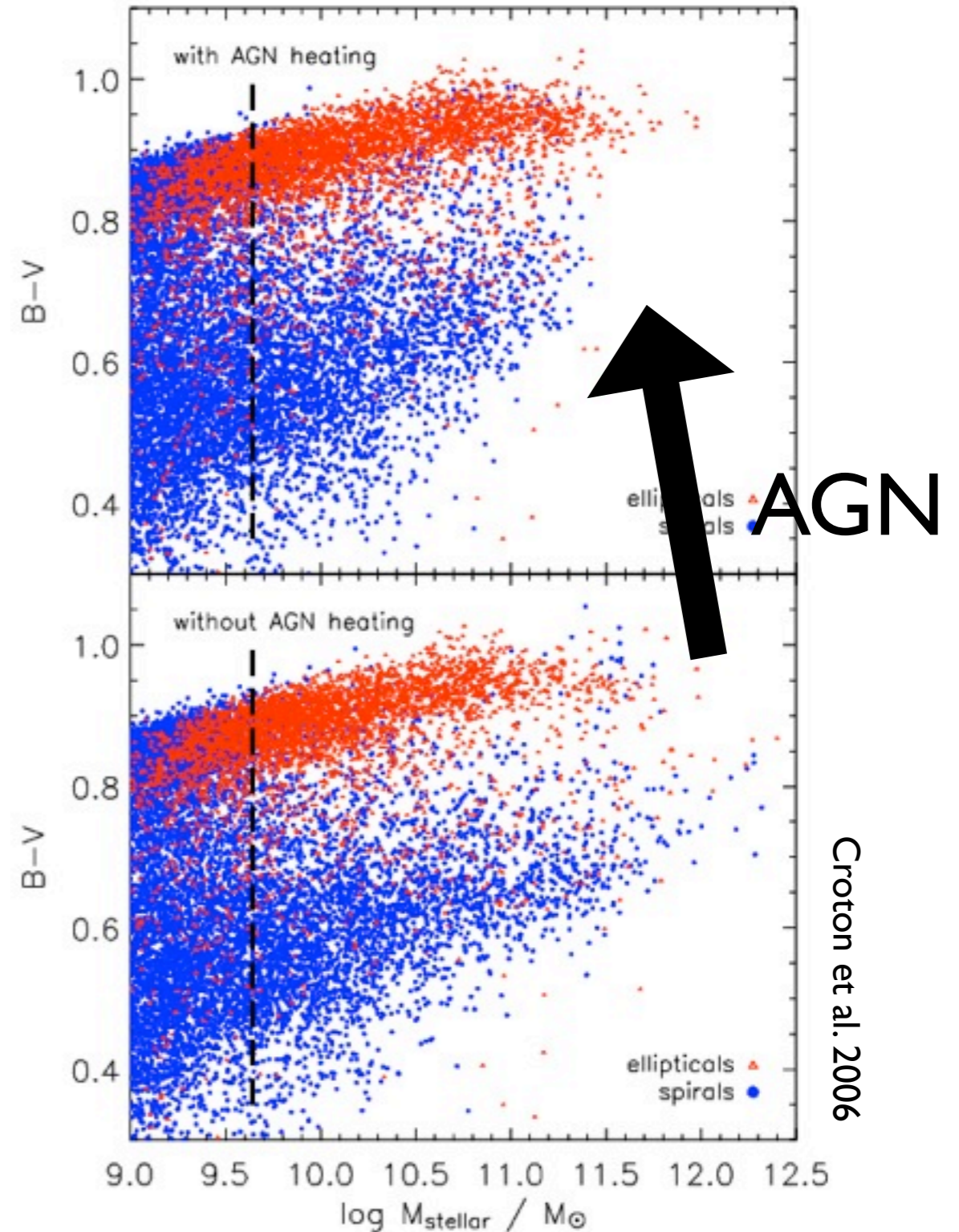
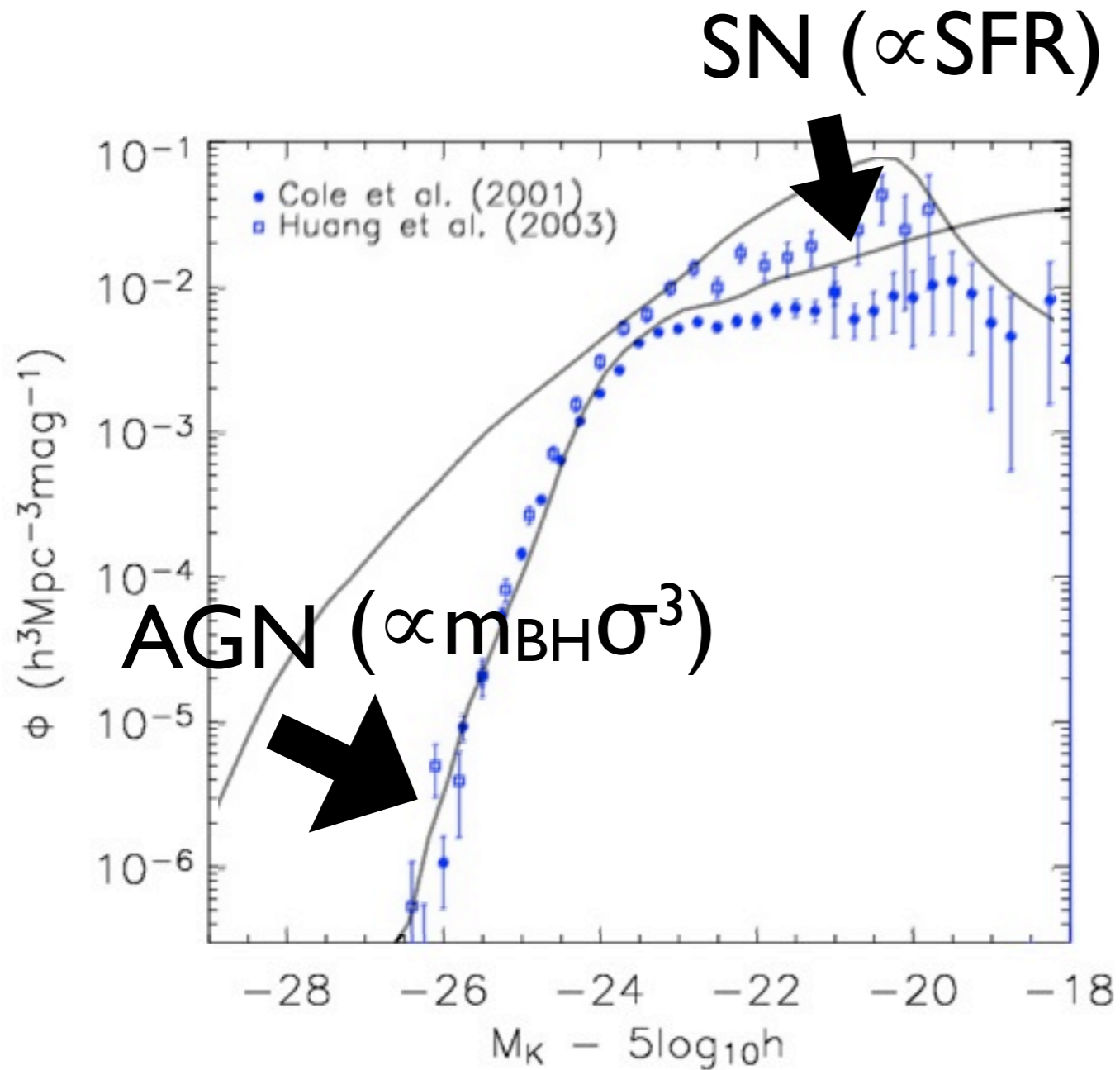
125 Mpc/h



$z=0$ galaxy light

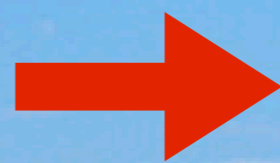


Physical consequences



Alien invasion

height & shape,
density, pressure,
gravity, ...



flexibility, running,
jumping, ...

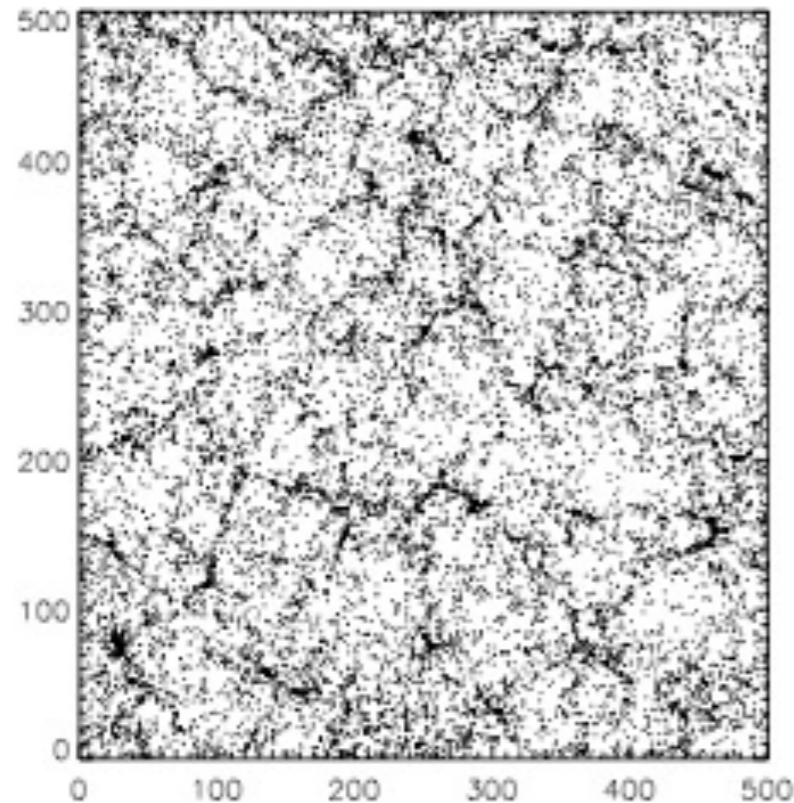


(human)

Do we understand dark matter halos?

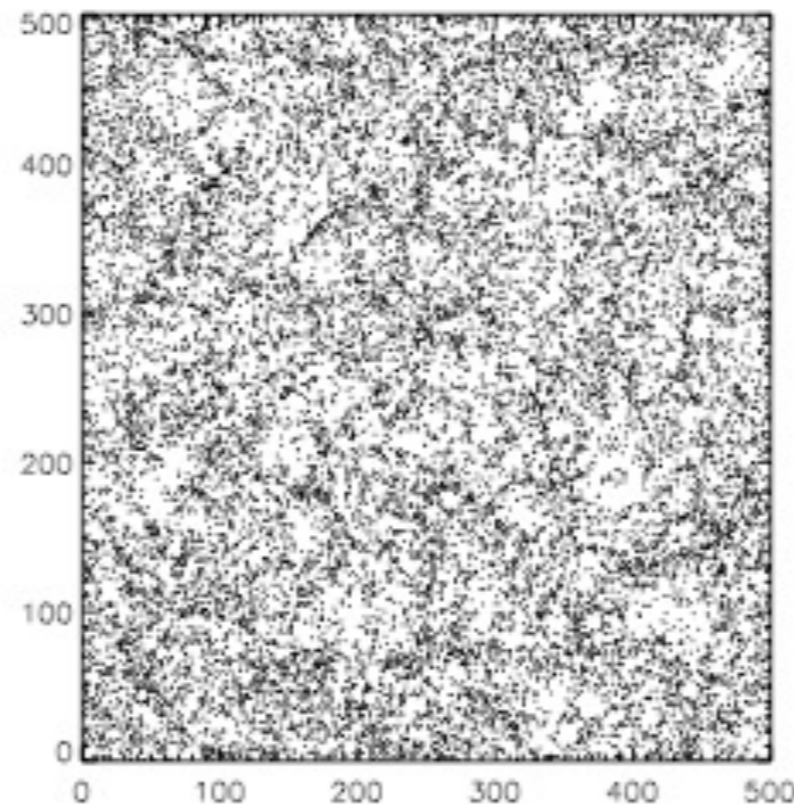
Gao et al. 2005
(Croton et al. 2007)

Assembly bias...

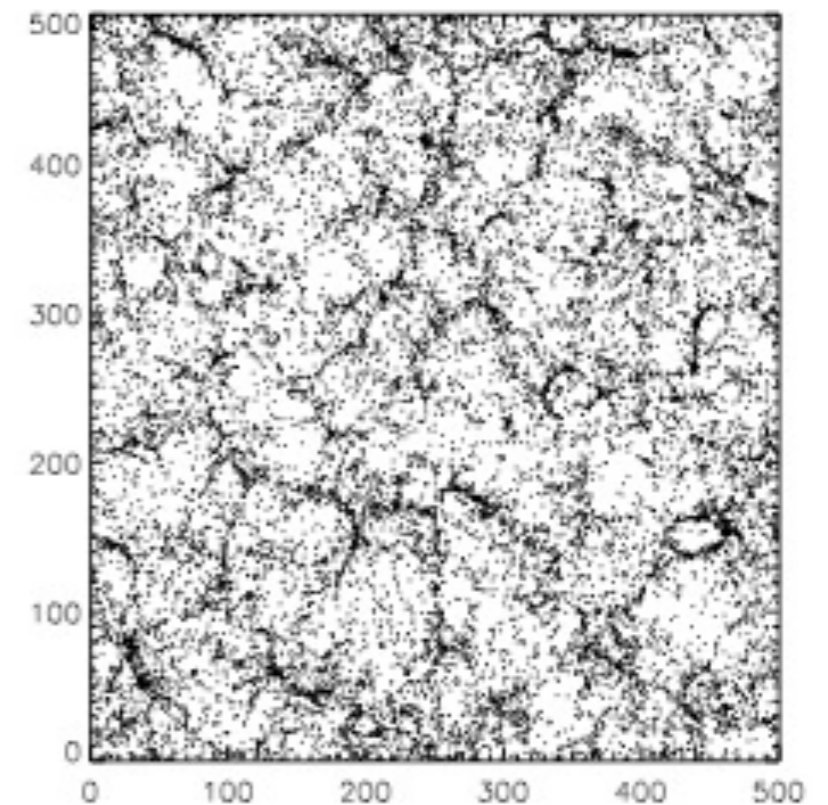


all $10^{11} M_{\text{sun}}$ halos

latest forming 20%



earliest forming 20%



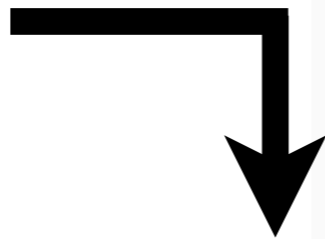
A hammer with a metal head and a wooden handle is positioned at the top of the frame, pointing downwards. Below it, a pink piggy bank is shown with a sad facial expression, characterized by slanted eyes and a downturned mouth. The text "Why study environment?" is written in a black, handwritten-style font across the middle of the image, overlapping the hammer and the piggy bank.

Why study environment?

Environment shapes the physics of galaxy formation

1. Gas accretion

2. Gas removal



1. Galaxy mass and luminosity

2. Galaxy colour

3. Baryon (inc. metal) abundance

4. ...



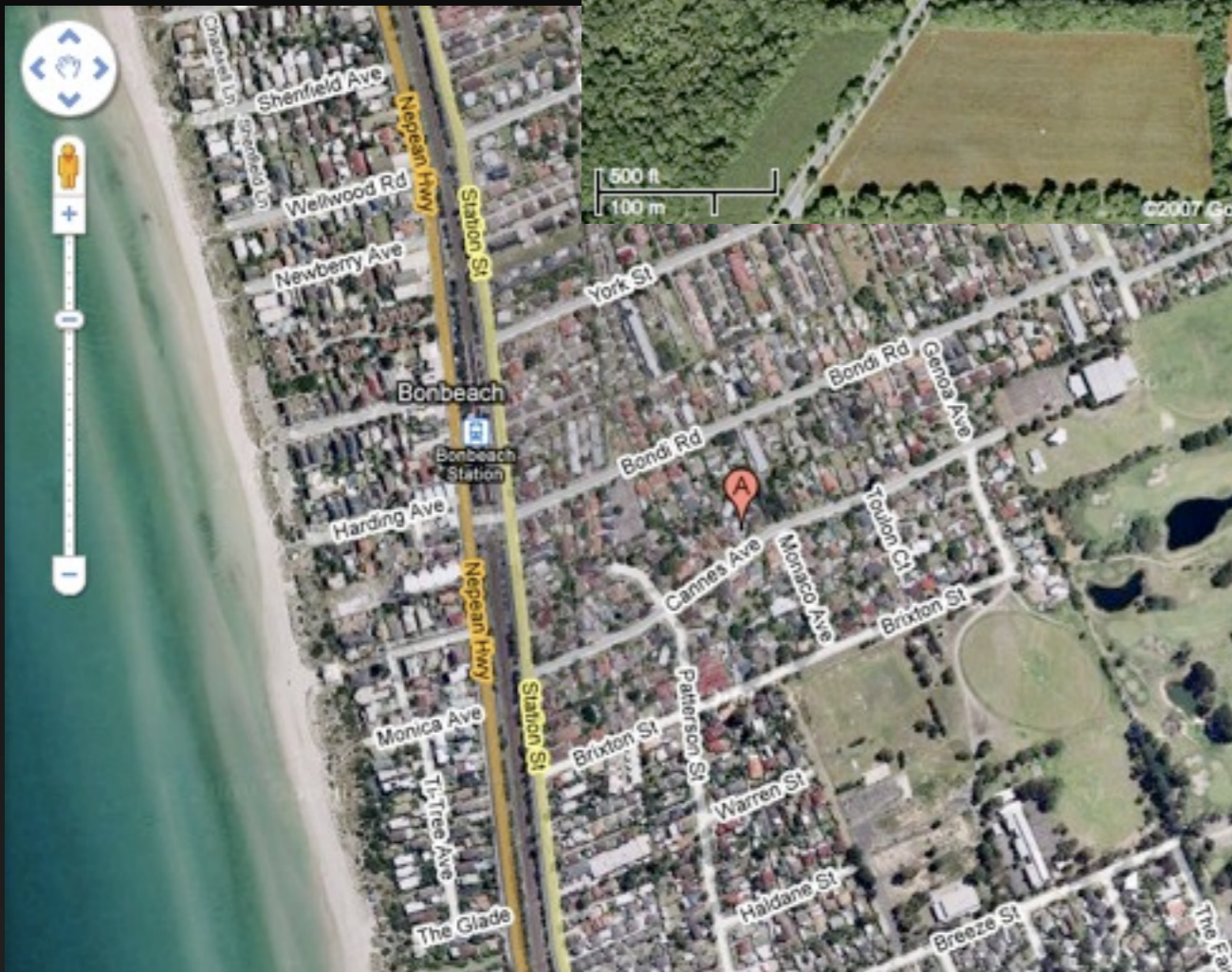
Munich

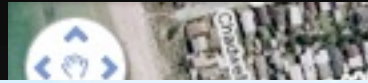
De

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Mell

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Group finders

Close pairs

N'th nearest
neighbour

Fixed aperture

Background
density field

Galaxy
clustering

Halo mass

Void finders

Shape statistics

Intra-halo
processes

Can we find agreement between different environment methods?

apply multiple environment measures to a
common mock catalogue:

1. How do different measures of environment compare?
2. How are our end results coloured by the environment measures we use?

Participants

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The Millennium Simulation

[edit]

The mock catalogue is constructed from the Millennium Simulation halo merger trees ([Springel et al. 2005](#)). The Millennium Simulation is a 10 billion particle dark matter simulation of structure formation in a $(500\text{Mpc}/h)^3$ box with halo mass resolution $\sim 5 \times 10^{10} M_{\text{sun}}/h$. The simulation assumes a WMAP1+2dFGRS cosmology with $\Omega_M=0.25$, $\Omega_L=0.75$, $h=0.73$ and $\sigma_8=0.9$. The halo merger trees are publicly available at the [German Astrophysical Virtual Observatory](#) (GAVO).

Mock galaxy catalogue

[edit]

From the merger tree at $z=0$ we construct a local Universe mock galaxy catalogue using the halo occupation distribution (HOD) method described in [Skibba & Sheth \(2009\)](#). The mock is constrained to match the local SDSS luminosity function, colour-magnitude distribution, and 2-point clustering. Due to limitations in the methodology this match can only be made down to $M_r(\text{cut})-5\log(h)=-19$, which is where we cut the mock (it actually turns out to be slightly brighter than that).

The mock can be downloaded in two forms, in the original simulation cube or as a light cone. The cone has an opening angle of 90×90 degrees and a depth of $500\text{Mpc}/h$.

[Download mock cube \(71Mb\)](#)

[Download mock light cone \(29Mb\)](#)

(note these are gzipped ascii files)

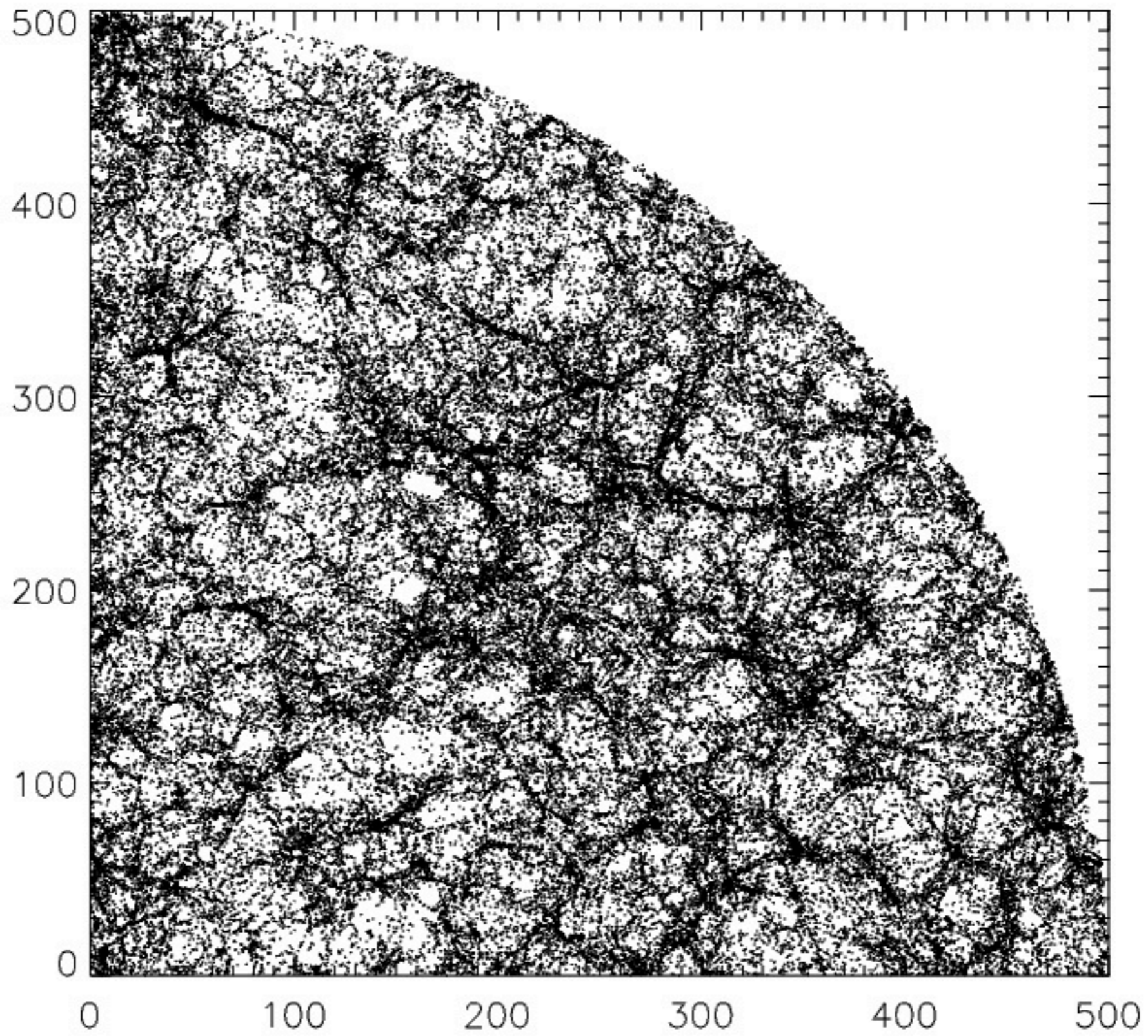
The following properties are available for each galaxy:

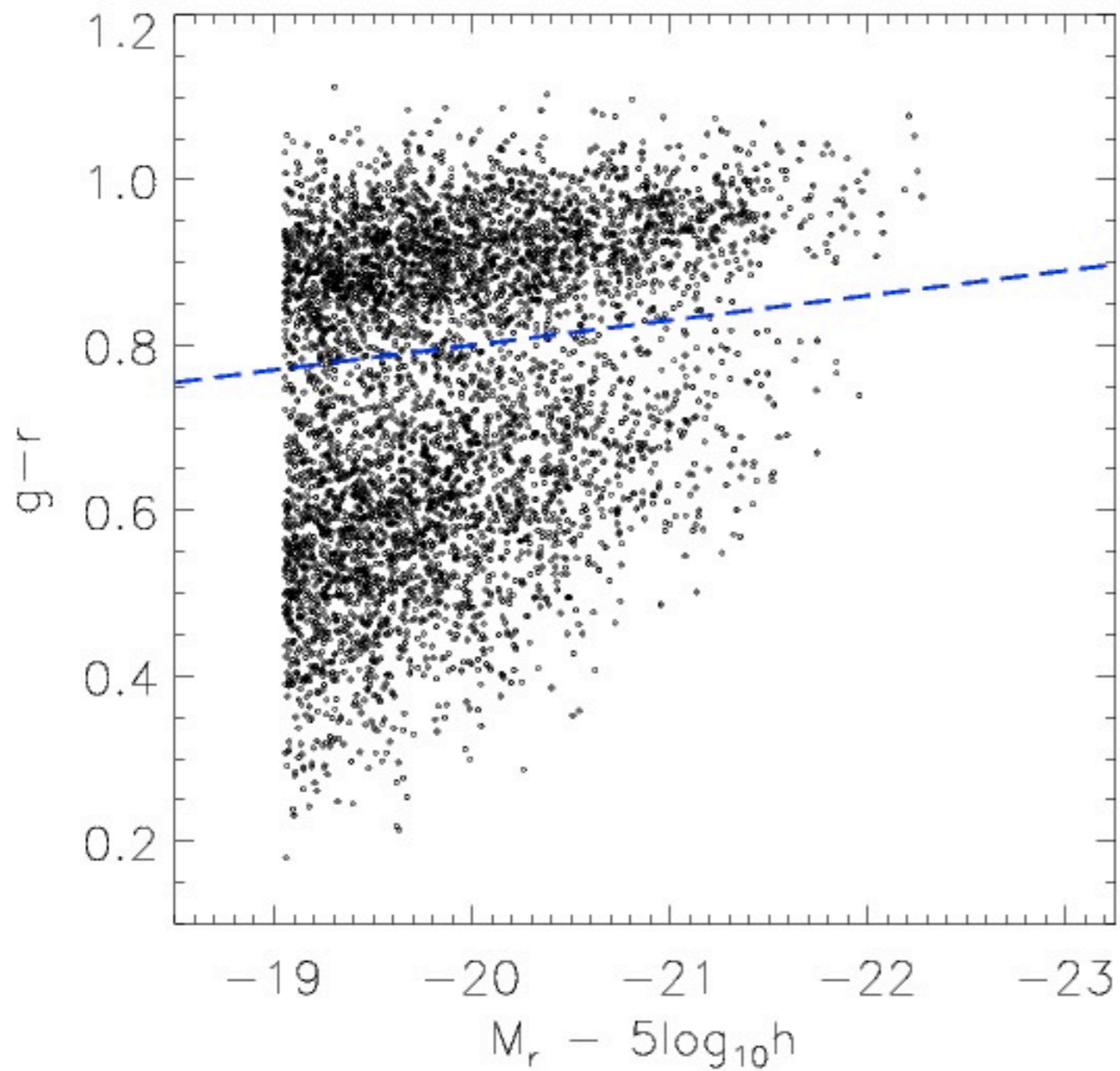
- *ID*: unique ID for each galaxy
- *x, y, z*: box co-ordinates in Mpc/h
- *z_{red}*: the redshift space distorted *z* box co-ordinate (use this instead of *z* to work in redshift space) in Mpc/h
- *ra, dec, distance*: cone co-ordinates in redshift space using radians and Mpc/h
- *M_r*: SDSS r-band absolute magnitude in units of $-5\log(h)$ (k-corrected to $z=0.1$)
- *g-r*: SDSS colour (k-corrected to $z=0.1$)
- *rank*: defined as 1 for centrals, 0 for satellites
- *M_{vir}*: the virial mass of the main halo of each galaxy in log units of M_{sun}/h

Box columns: ID, x, y, z, z_{red}, M_r, g-r, rank, M_{vir}

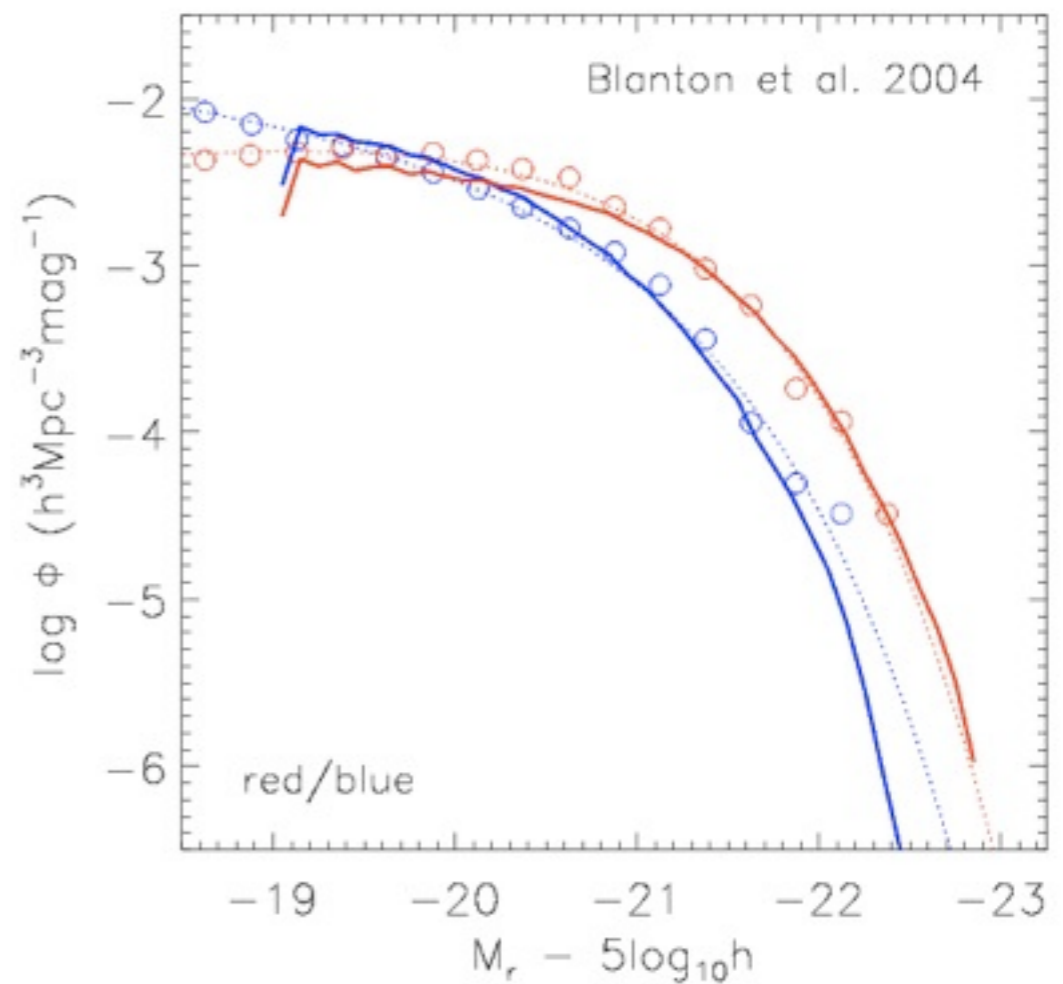
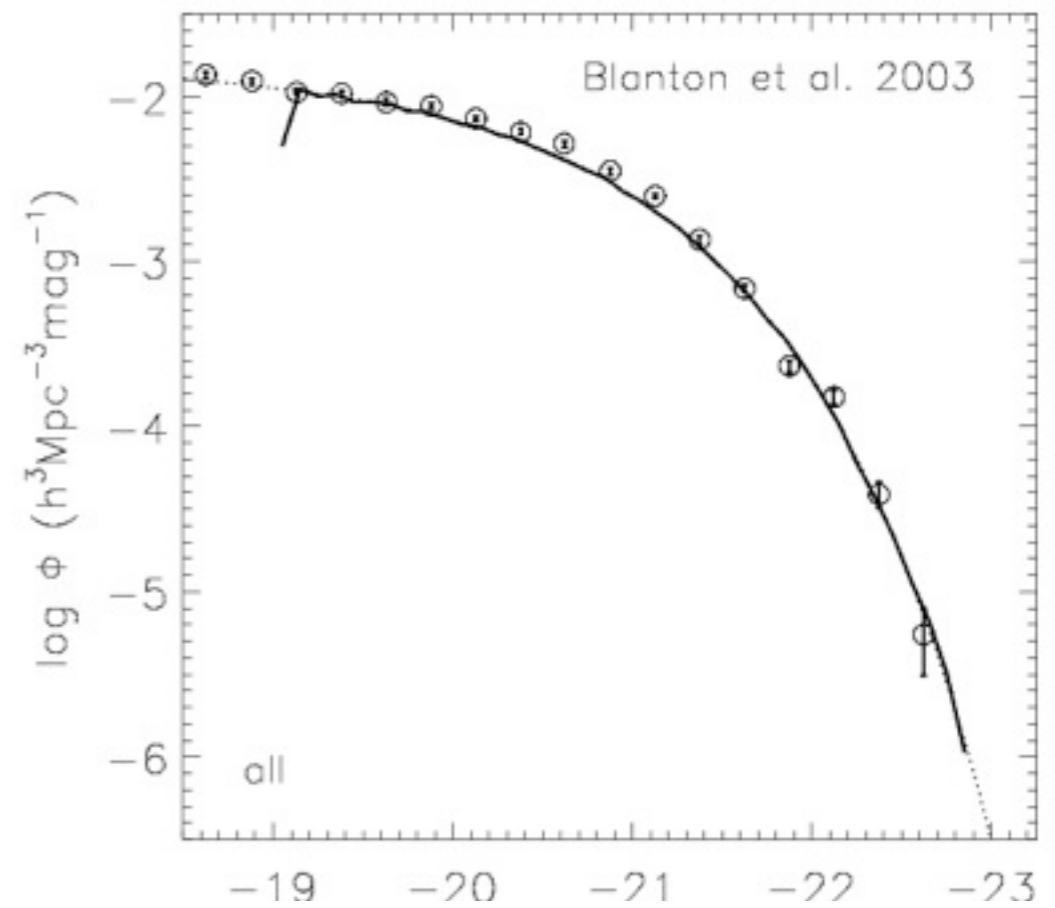
Cone columns: ID, ra, dec, distance, M_r, g-r, rank, M_{vir}

Luminosity functions and colour-magnitude diagrams for the mock can be found [here](#). 2-point correlation functions can be found [here](#).

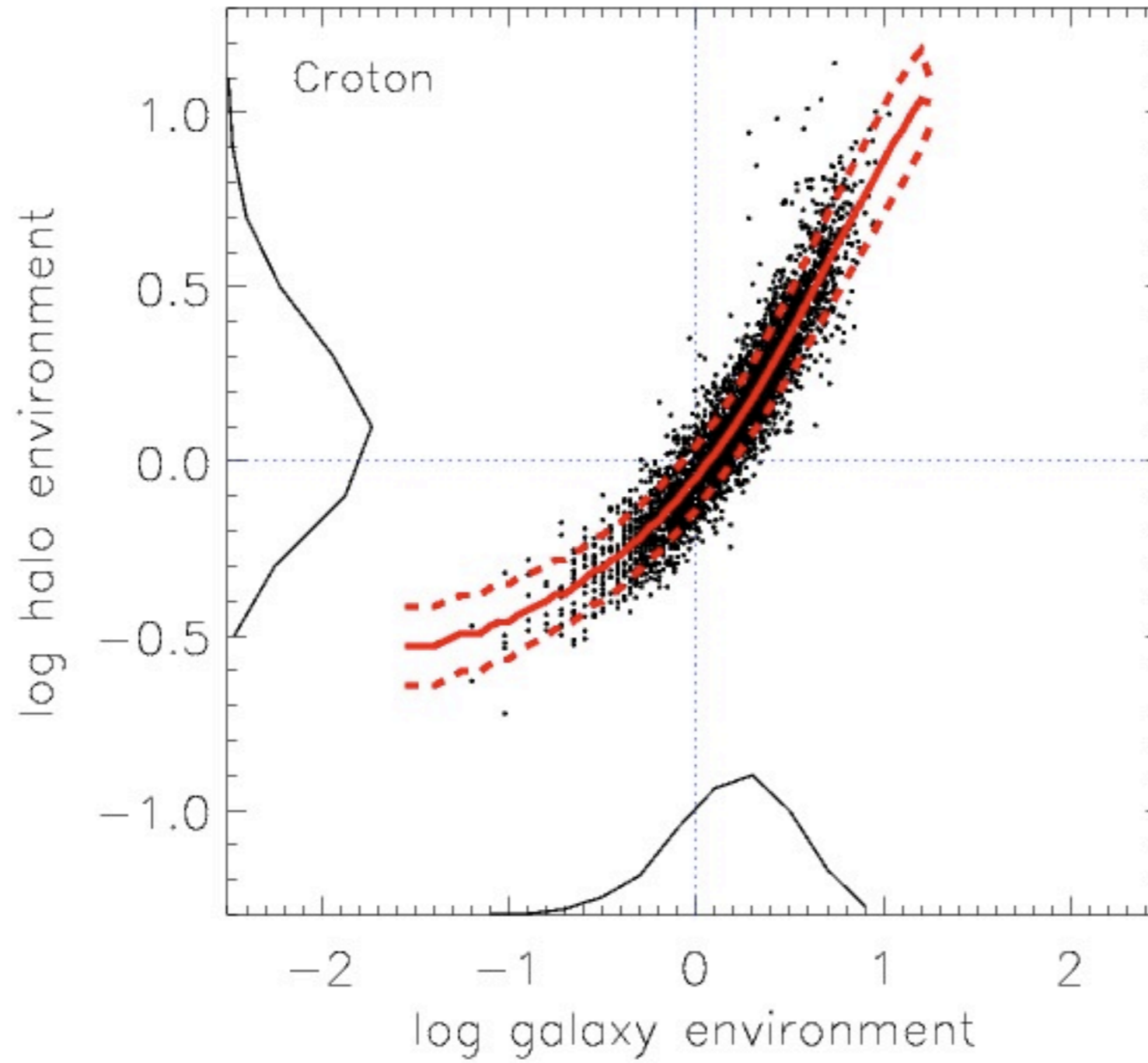




Skibba & Sheth 2009

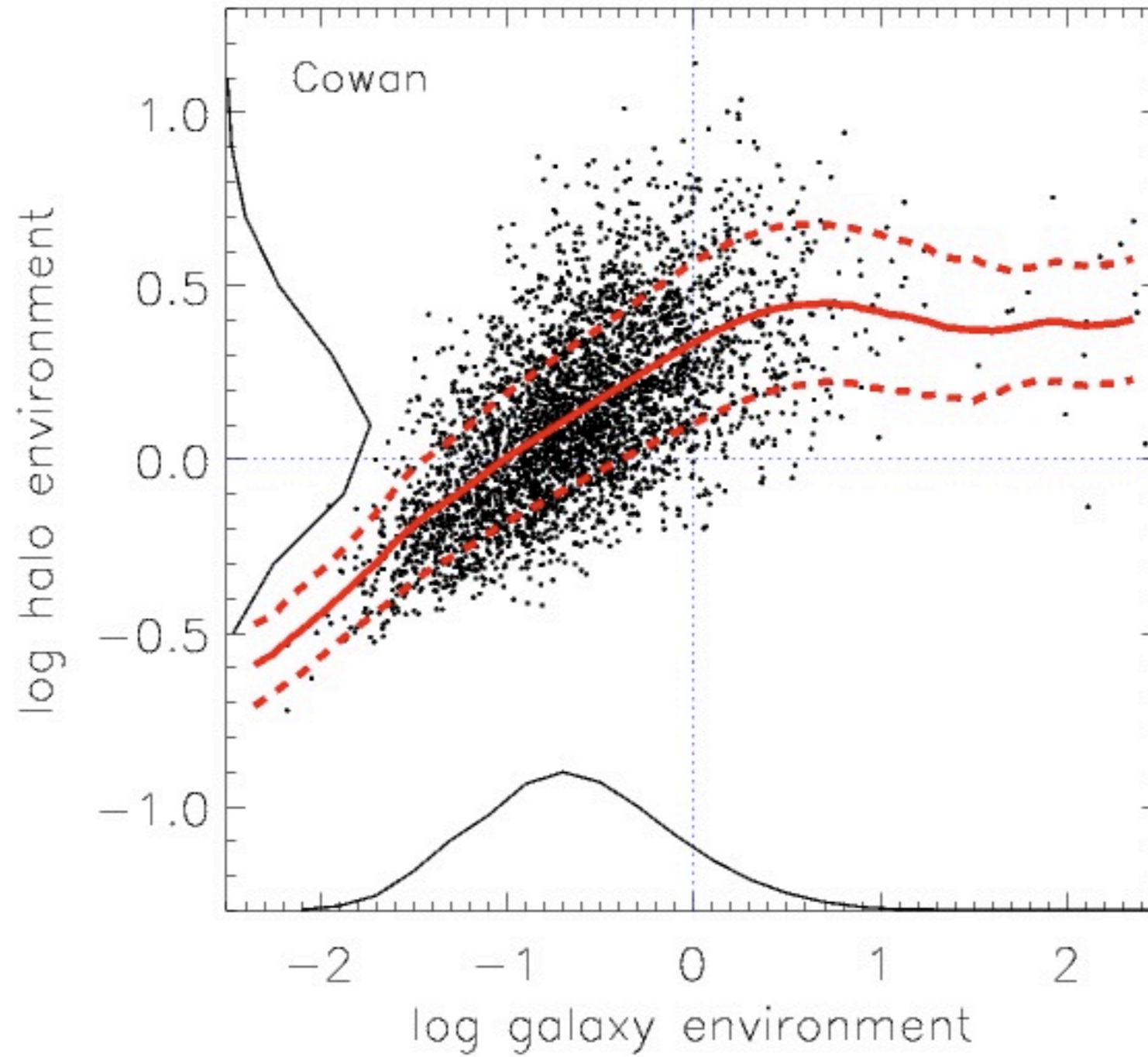


DM Gaussian smoothed $5h^{-1}\text{Mpc}$



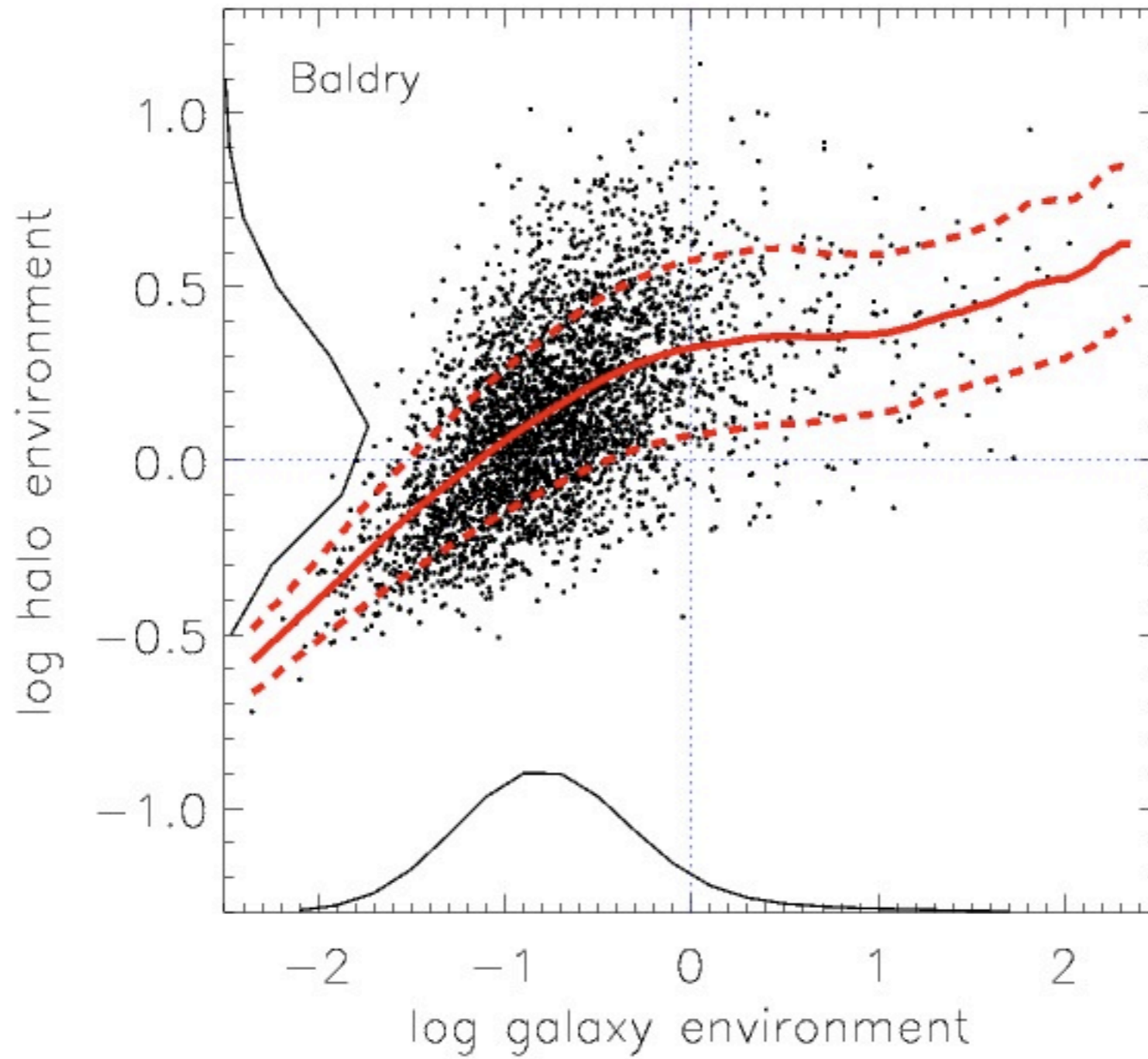
top hat sphere $8h^{-1}\text{Mpc}$

DM Gaussian smoothed $5h^{-1}\text{Mpc}$



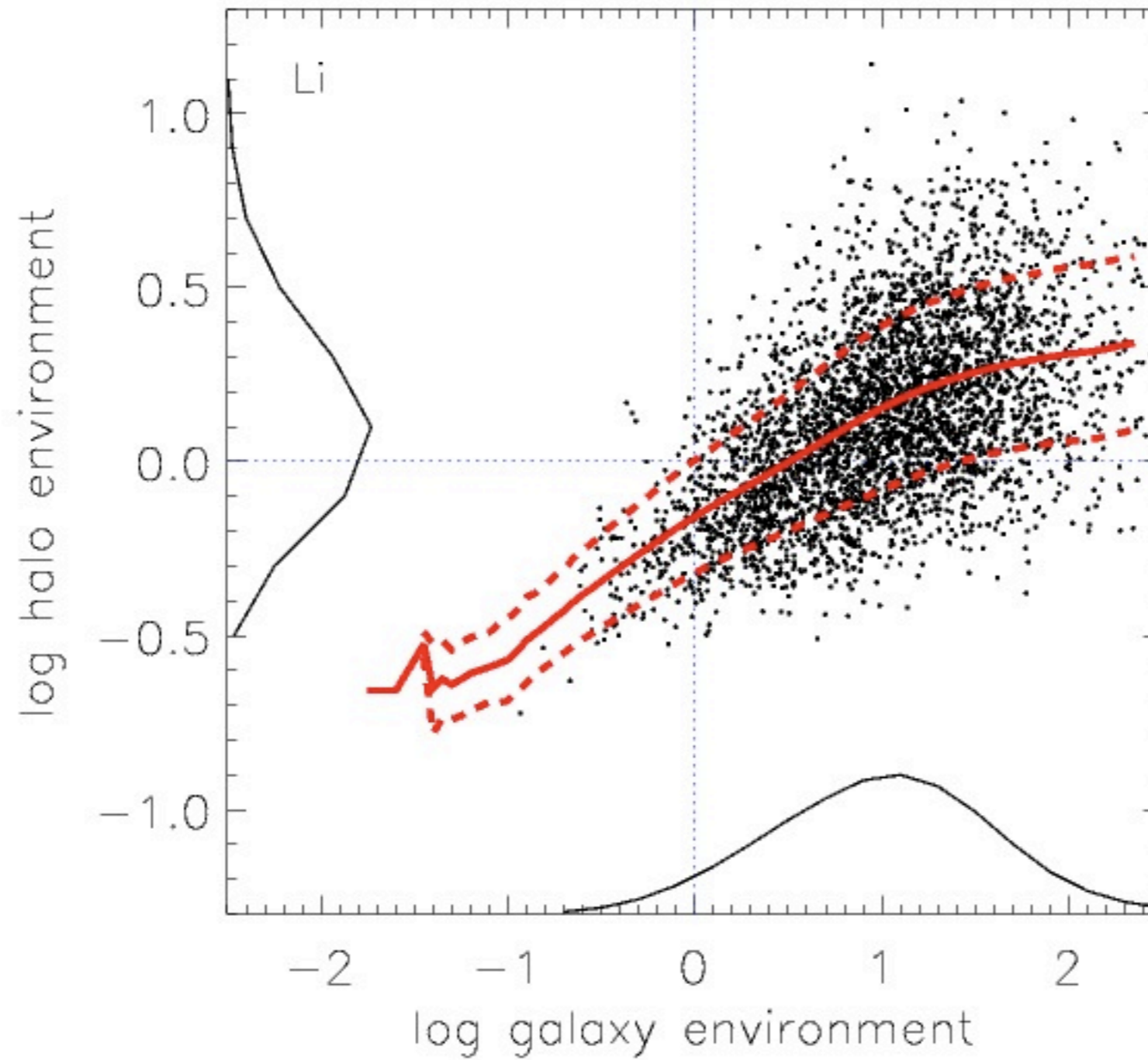
n'th nearest neighbour, $n=9$

DM Gaussian smoothed $5h^{-1}\text{Mpc}$



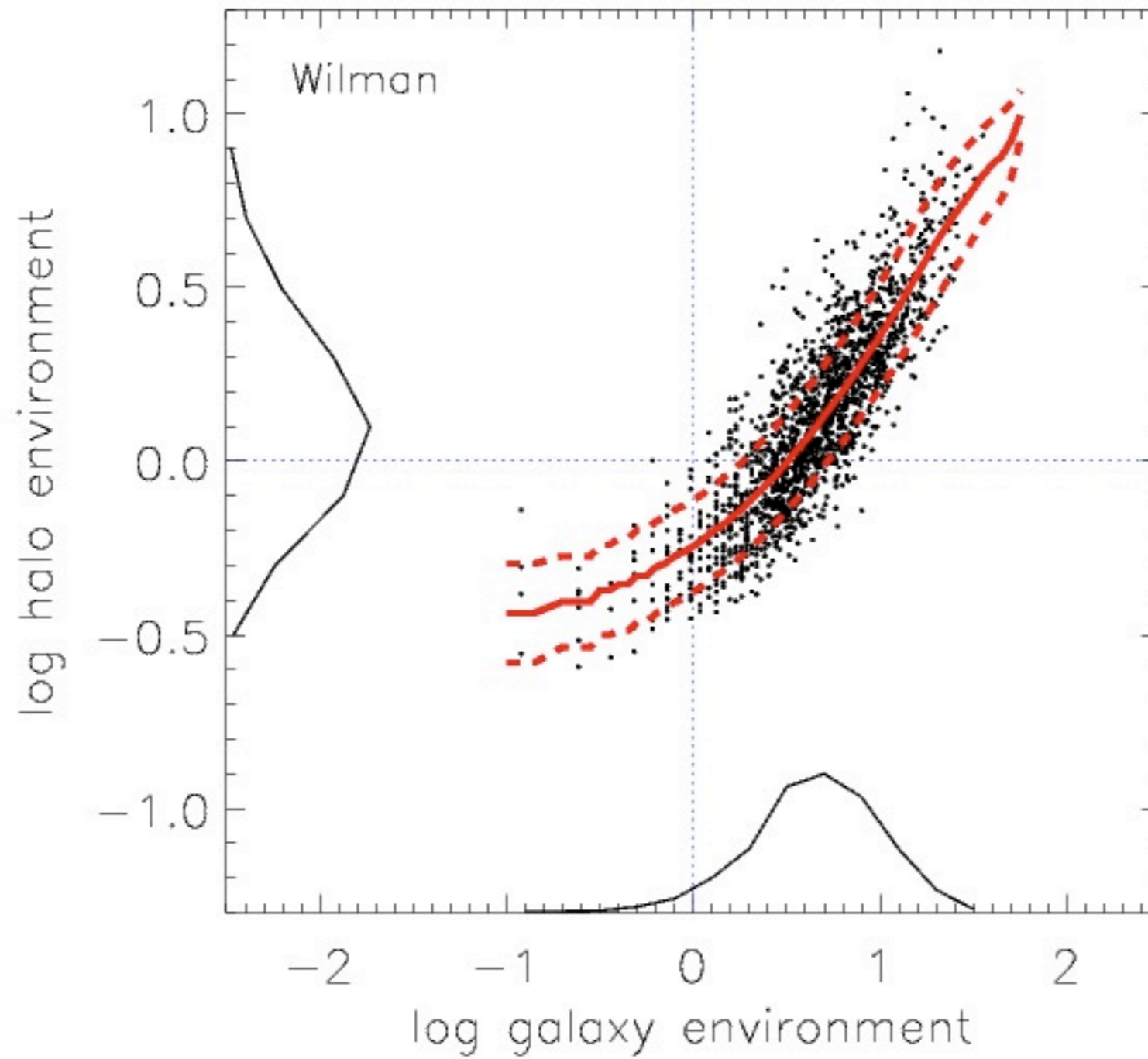
projected n'th nearest neighbour, n=5

DM Gaussian smoothed $5h^{-1}\text{Mpc}$



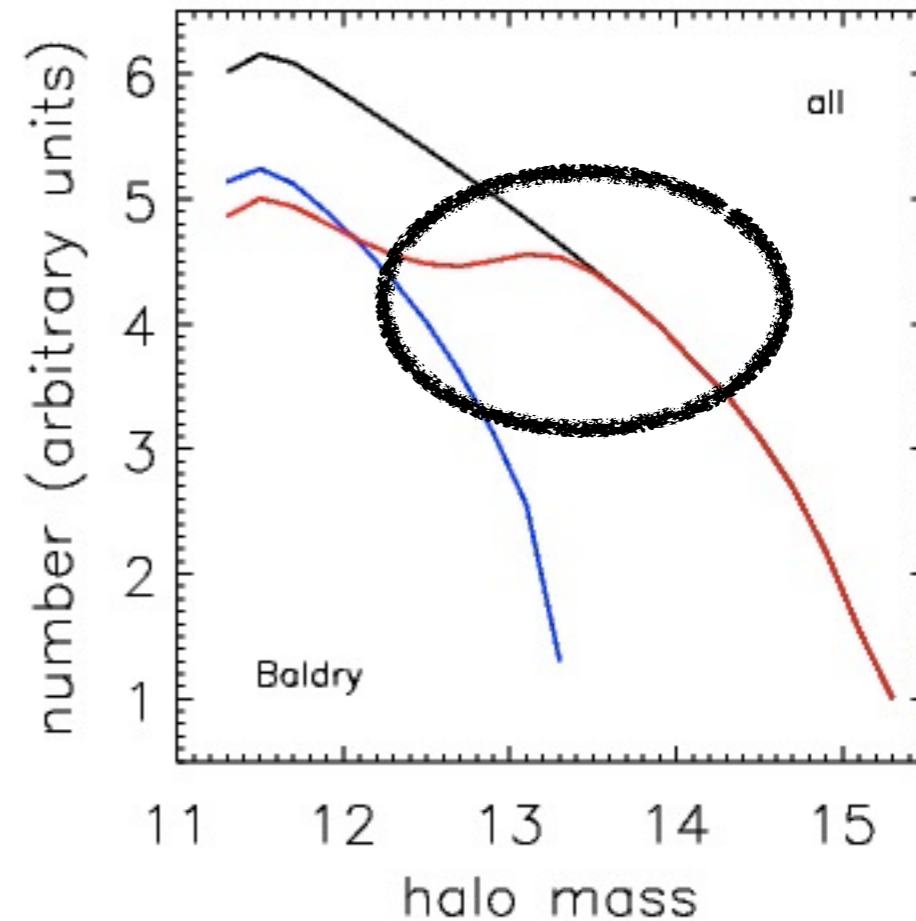
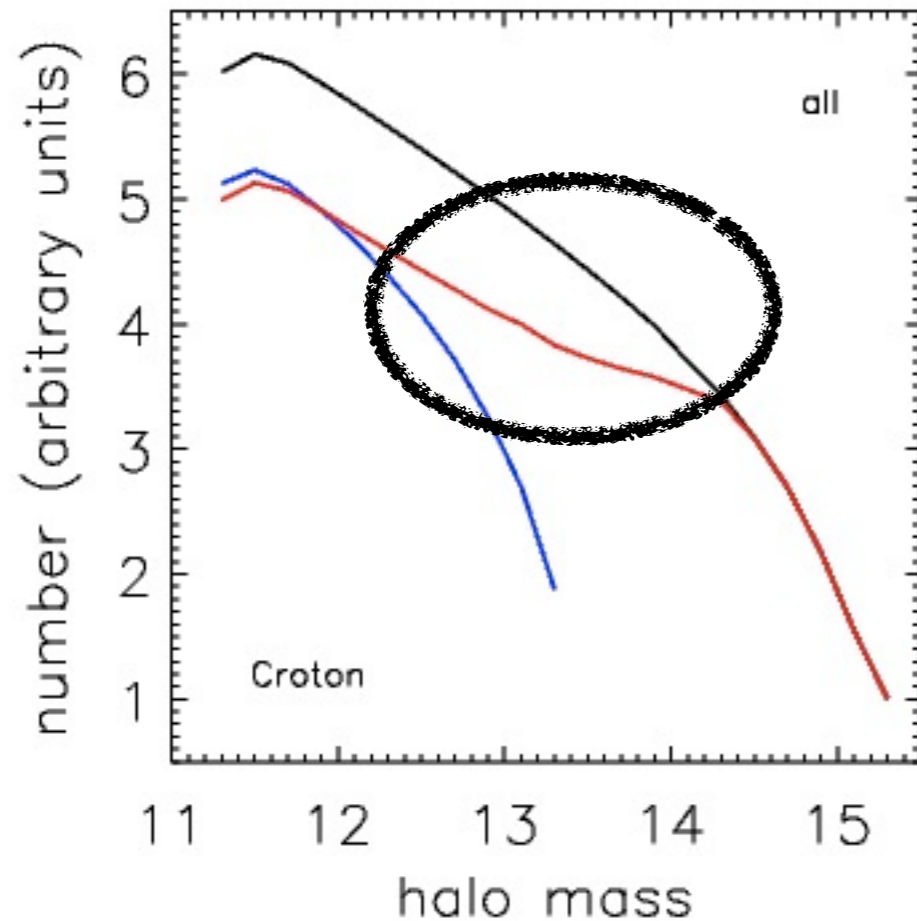
cylinder, R determined by n 'th nearest neighbour, $n=5$

DM Gaussian smoothed $5h^{-1}\text{Mpc}$



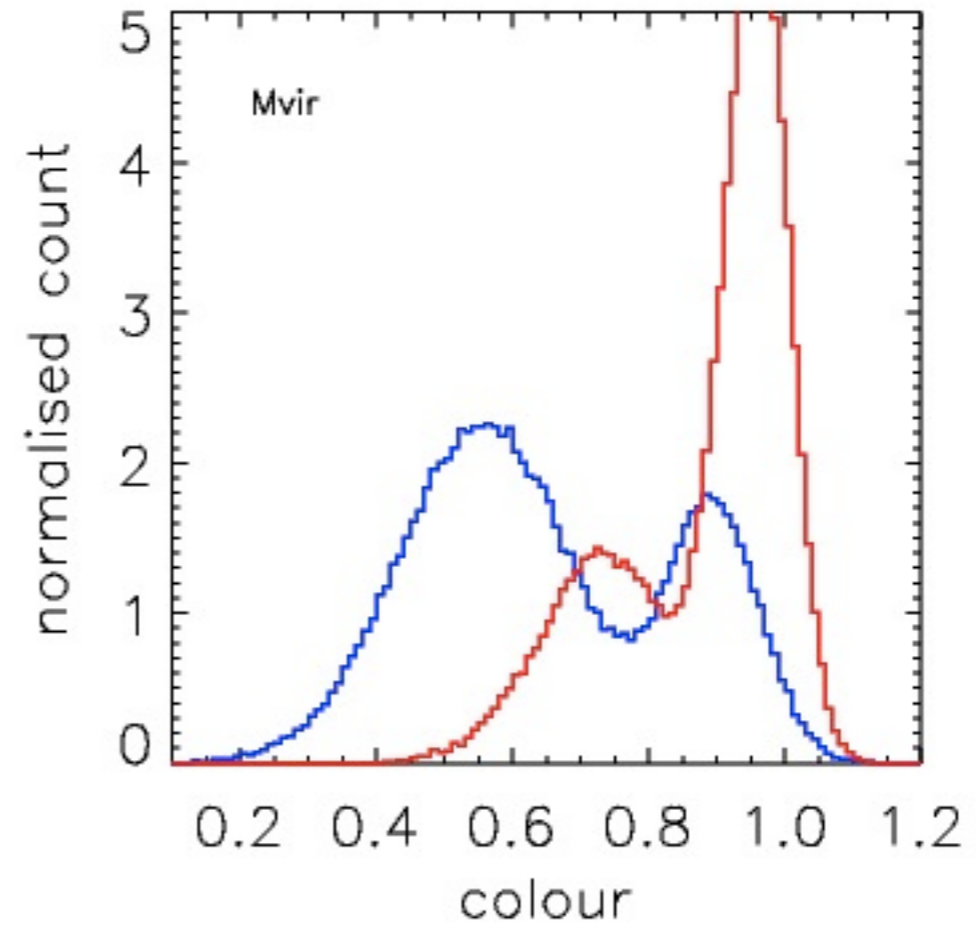
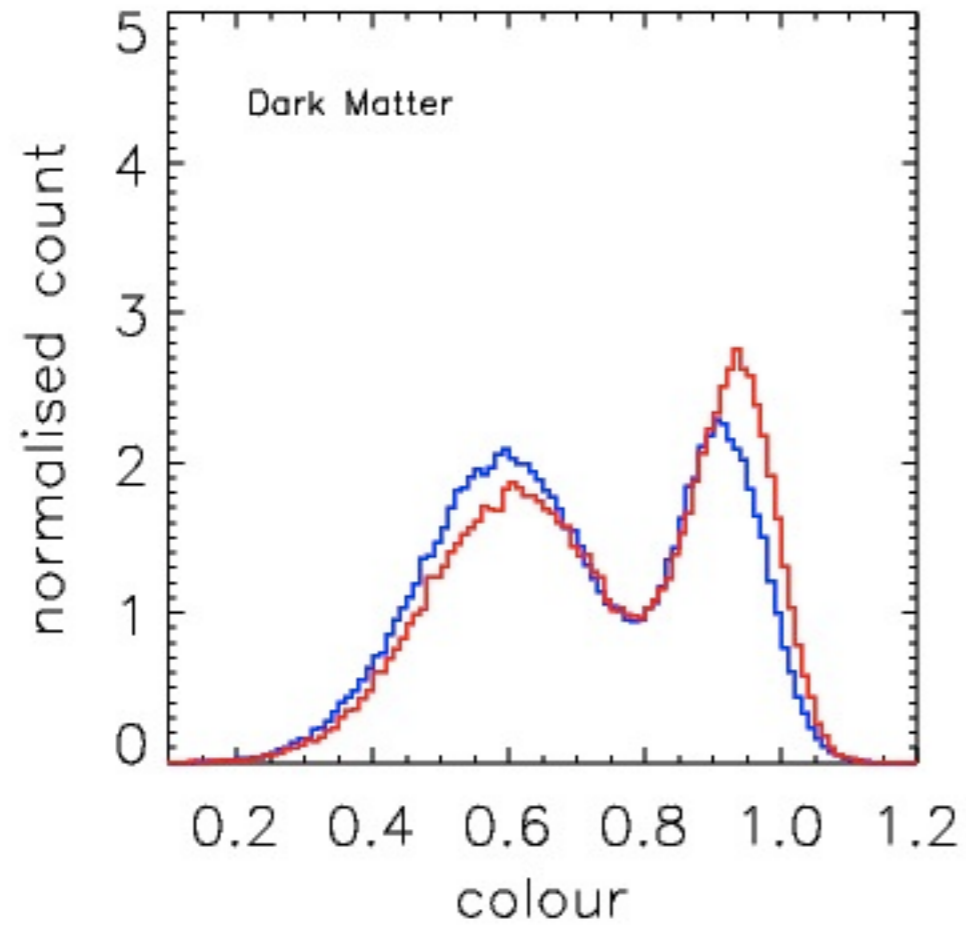
top hat cylinder, $3h^{-1}\text{Mpc}$

red=20% most dense, blue=20% least dense



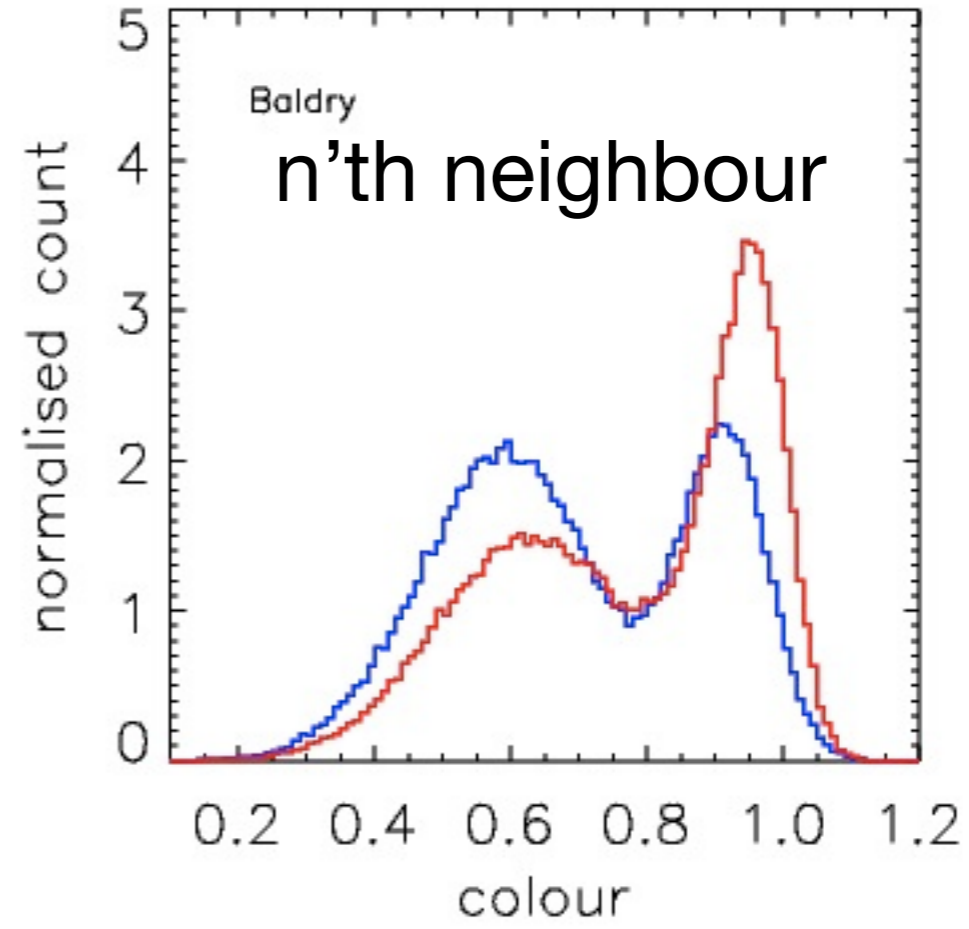
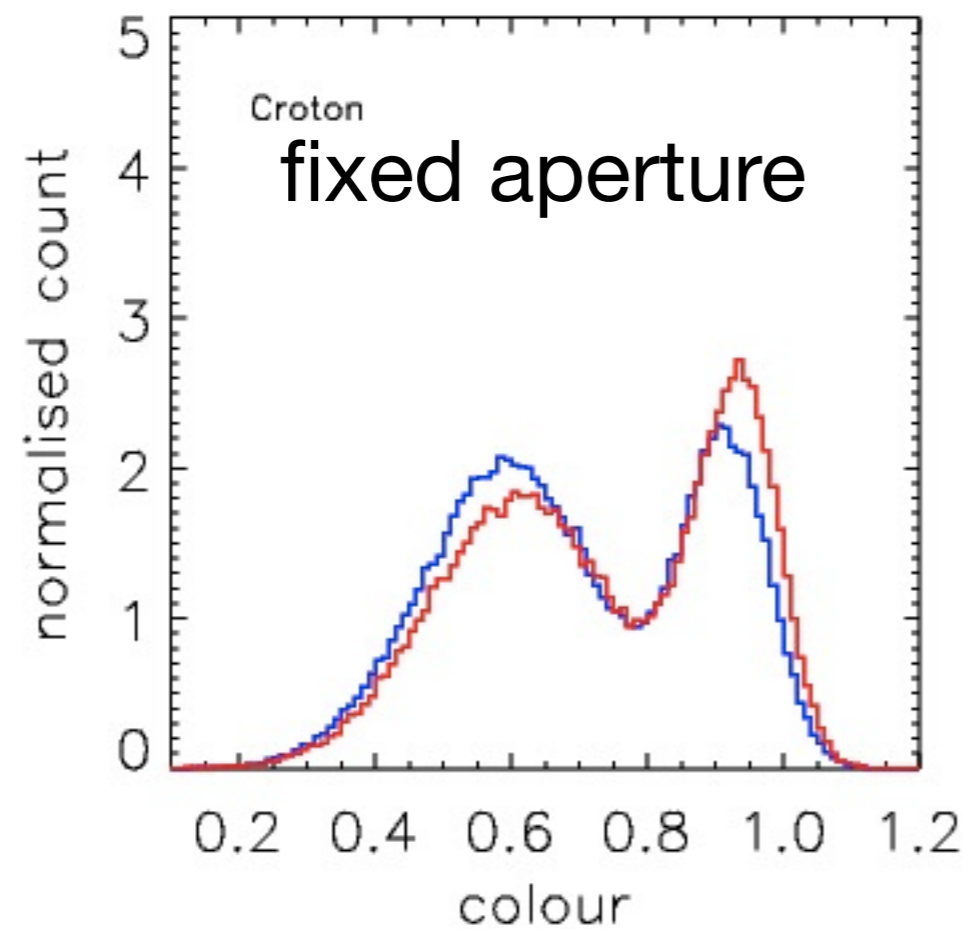
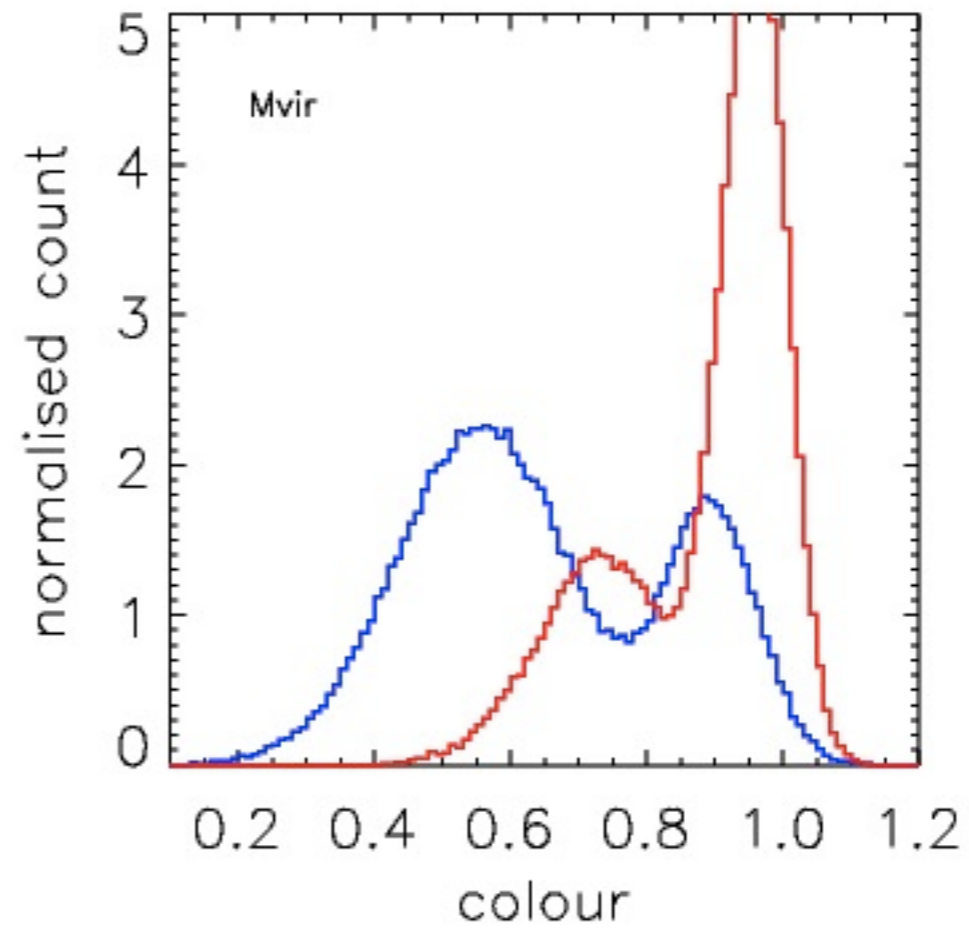
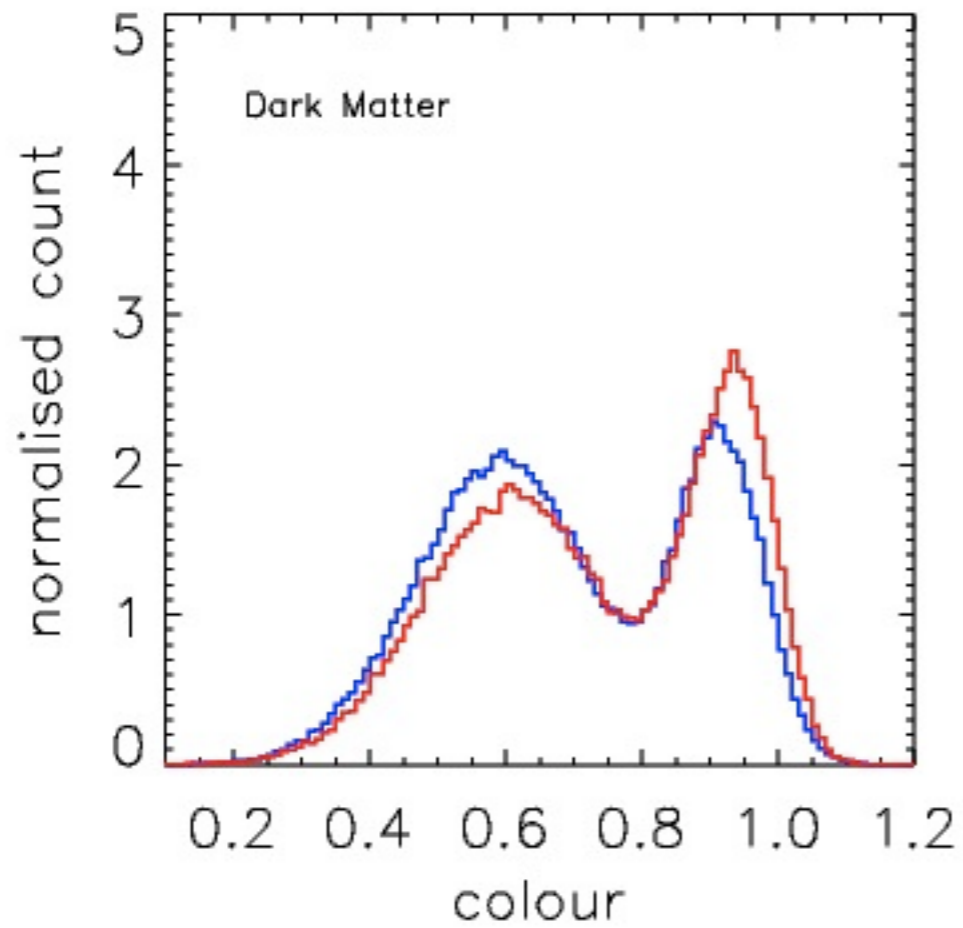
Different environment measures predict different abundances for group sized halos

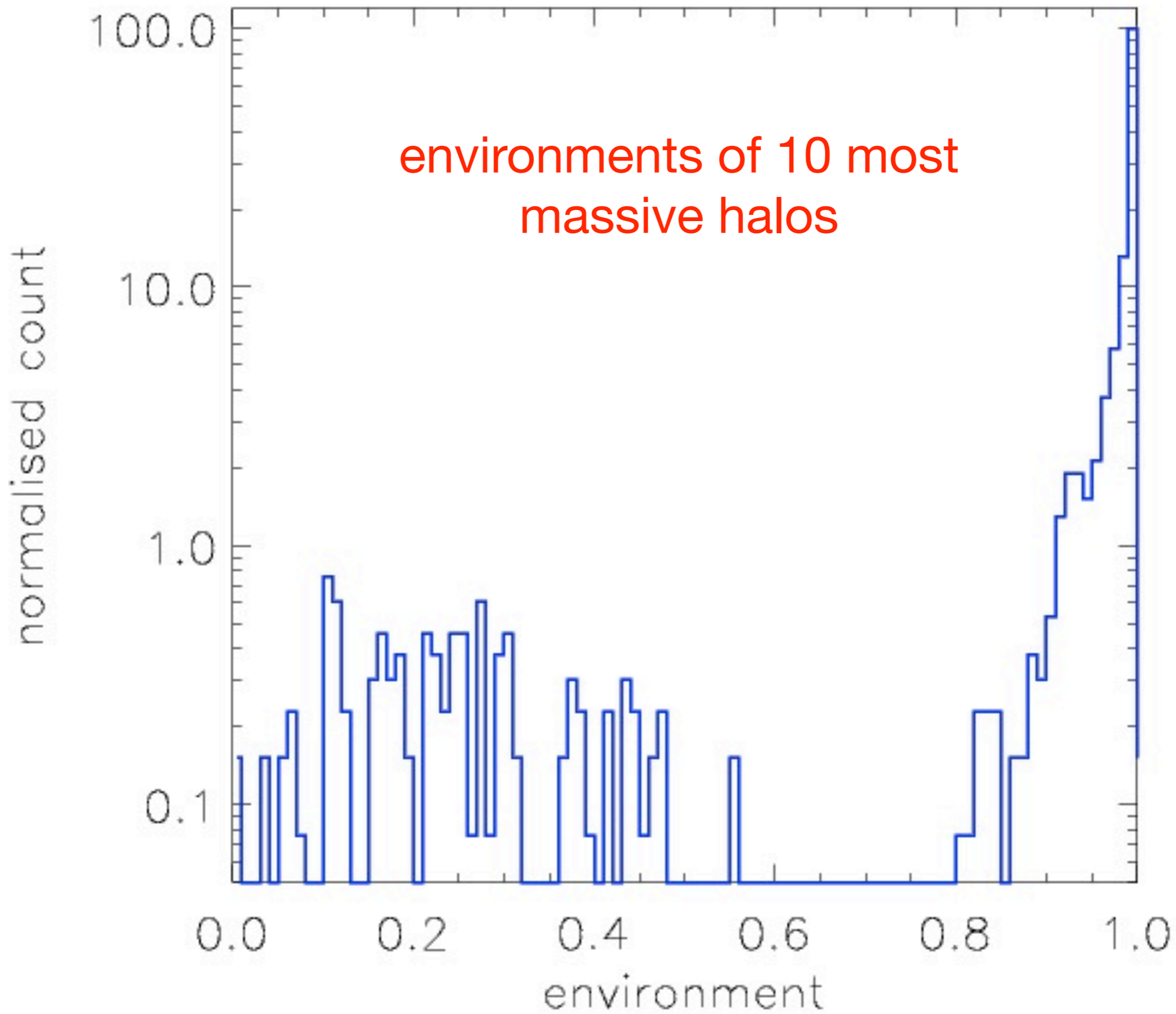
red=20% most dense, blue=20% least dense



halo mass correlates with colour,
smoothed DM density doesn't

red=20% most dense, blue=20% least dense





Is there agreement?

NO!

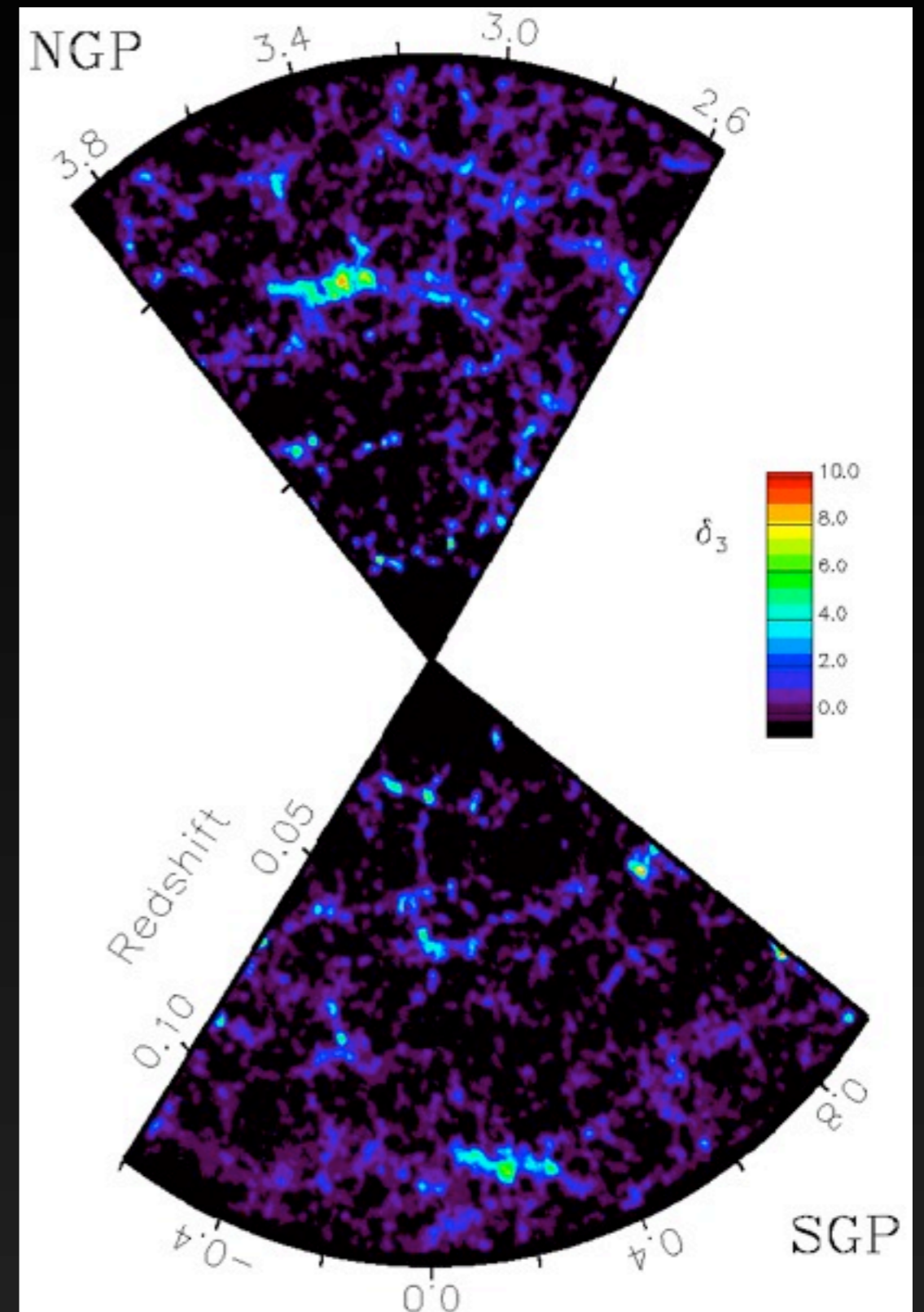
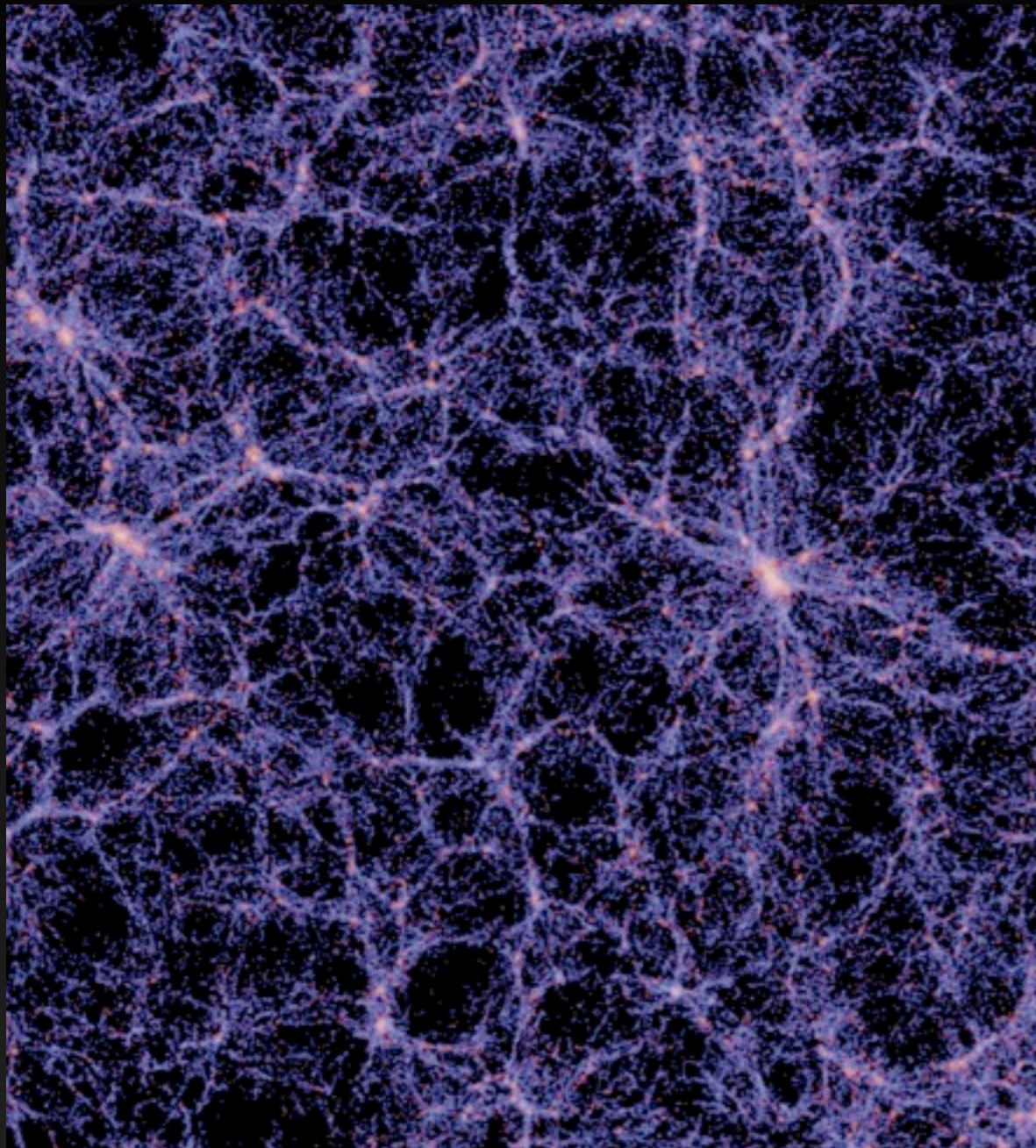
See: Measures of galaxy environment - I. What is “environment”?
Muldrew, Croton, Skibba, Pierce et al. 2011



Environment dependent quenching?

When I say “environment”, this is what I mean ...

Millennium Simulation
semi-analytic model



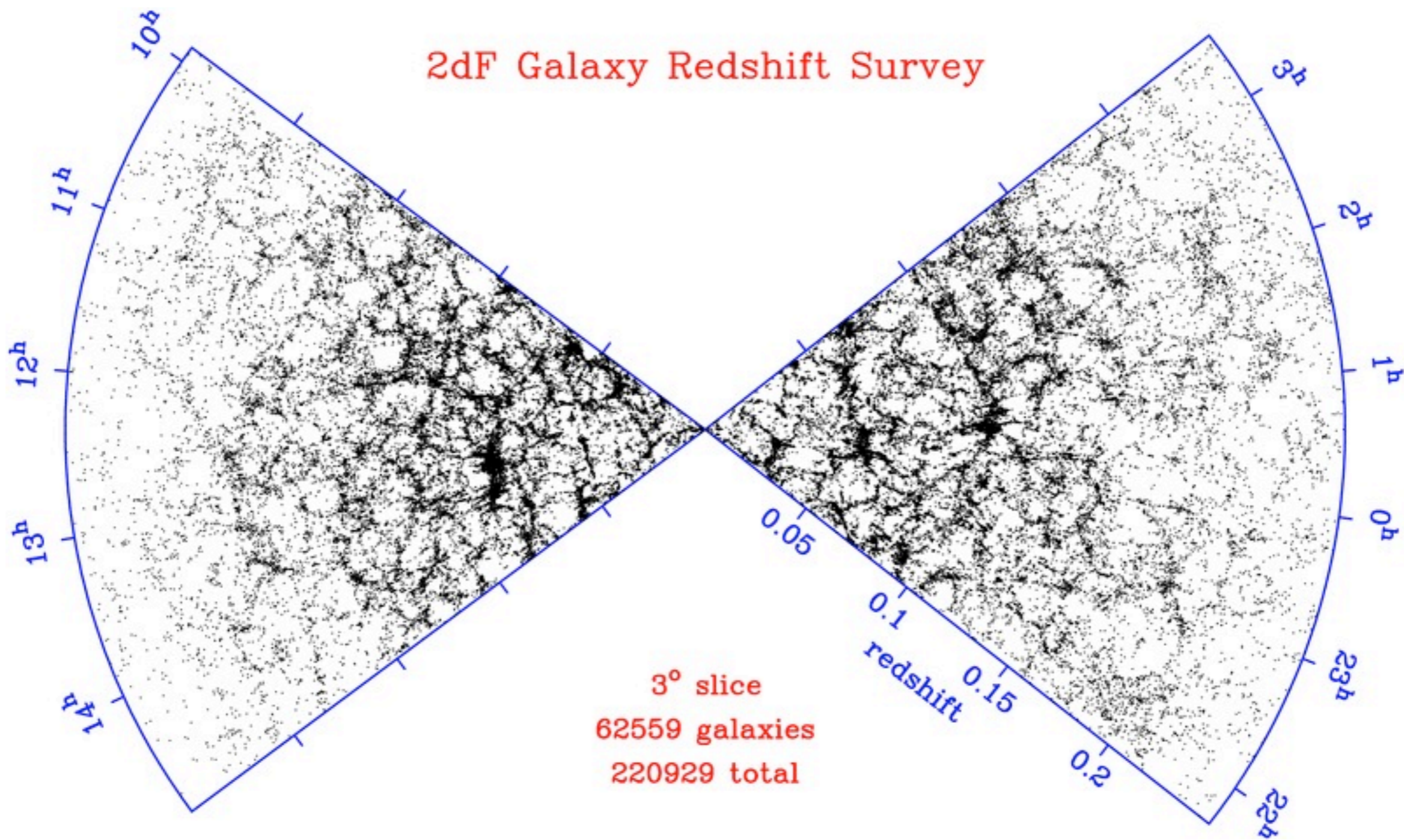
2DFGRS

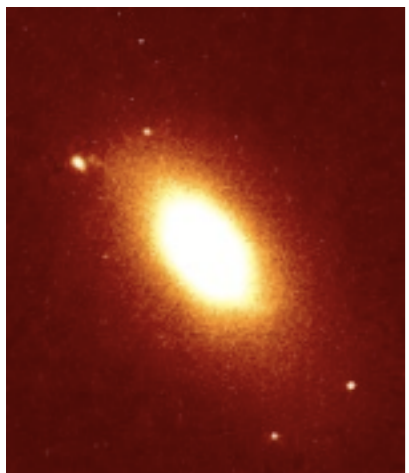
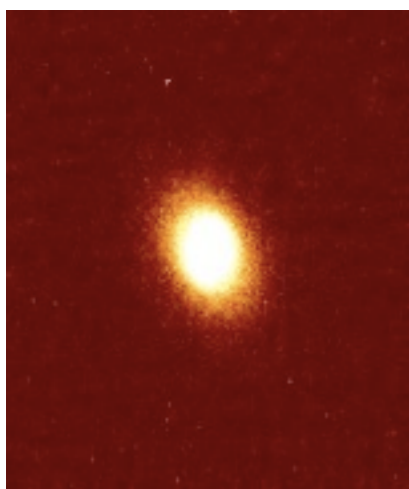
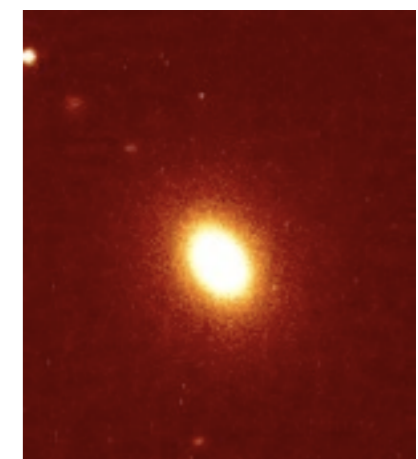
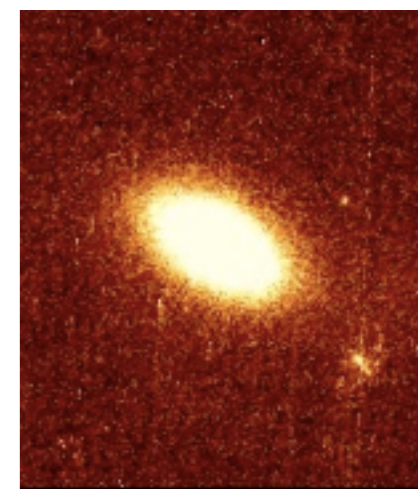
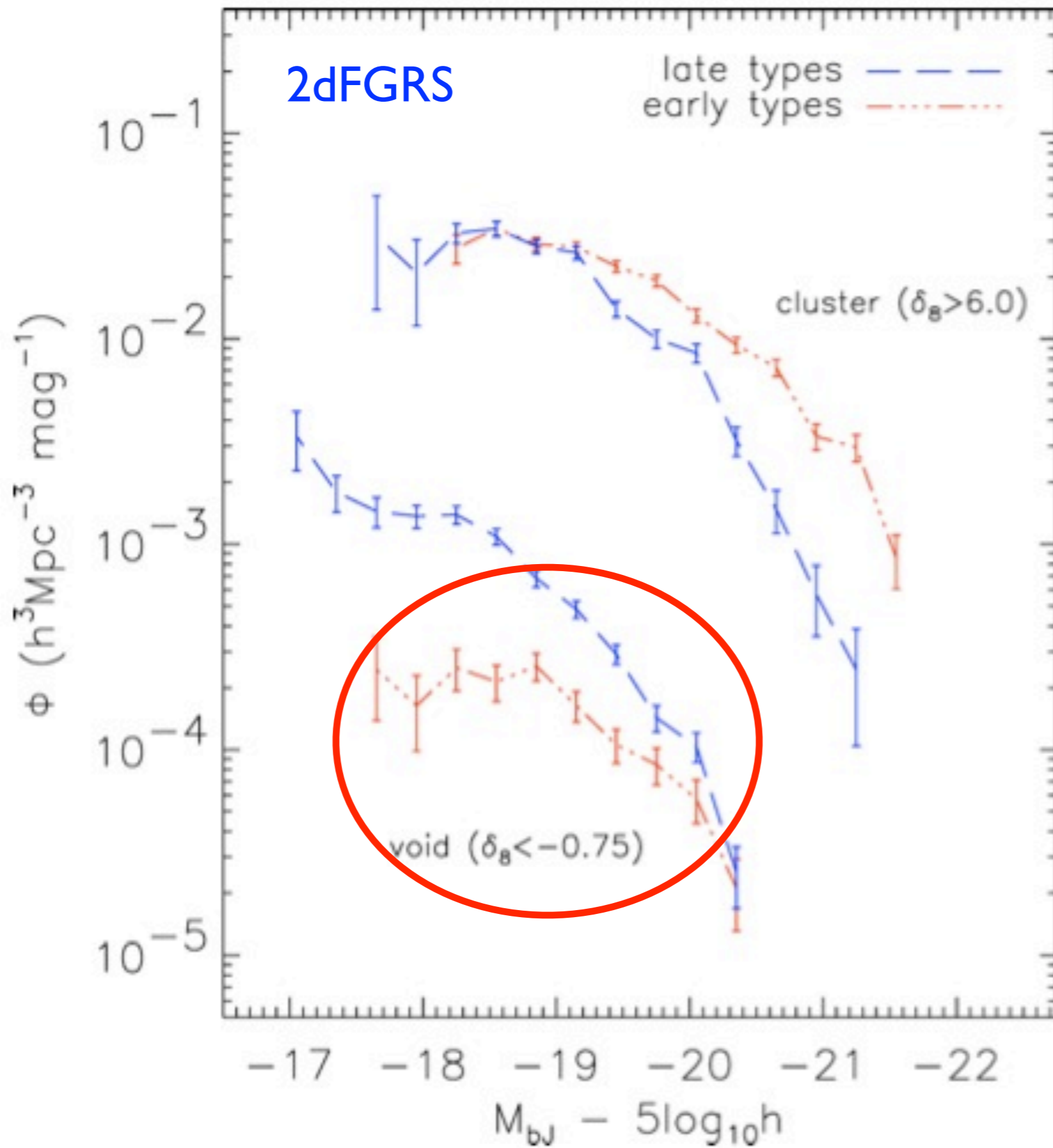
When I say “environment”, this is what I mean ...

Local (number) density is determined in top-hat spheres of radius $8h^{-1}\text{Mpc}$:

$$\delta_8 = \rho_g / \langle \rho_g \rangle - 1$$

2dF Galaxy Redshift Survey



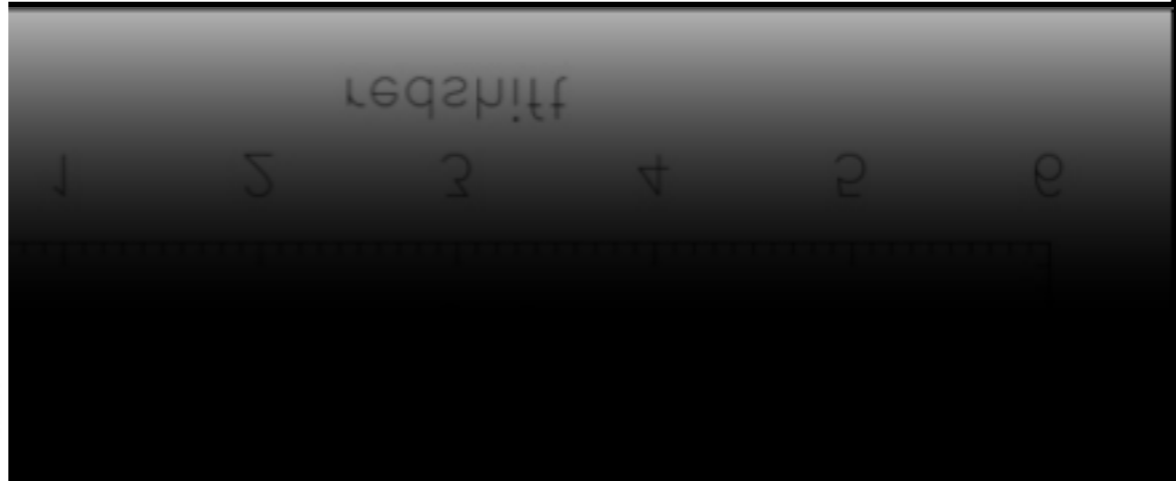
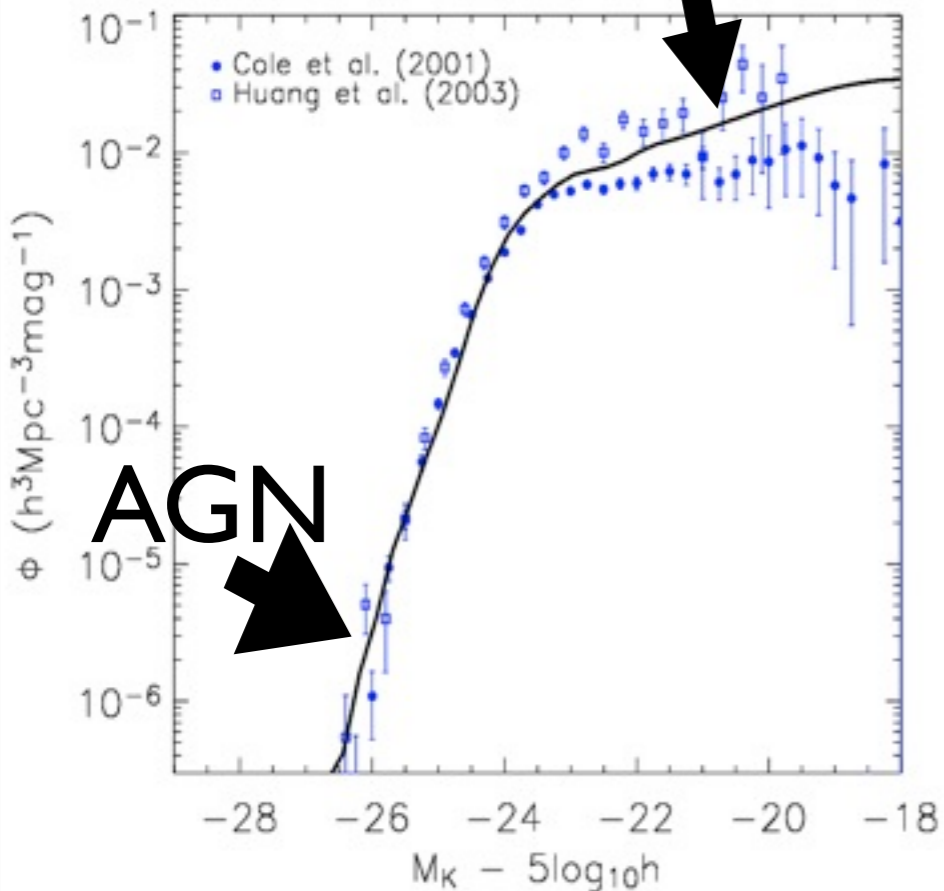
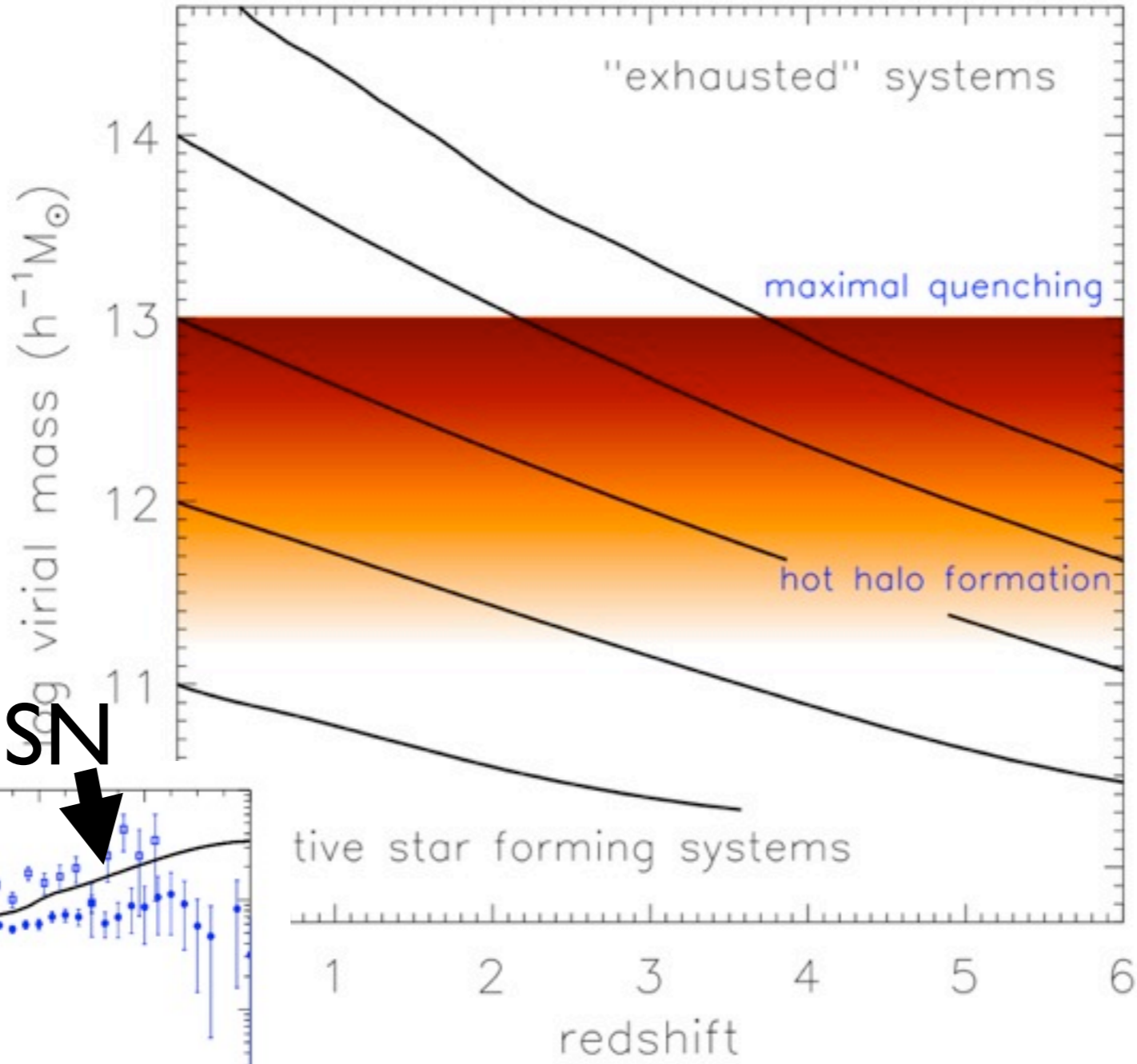


In voids, there exists a population of early-type (red) galaxies

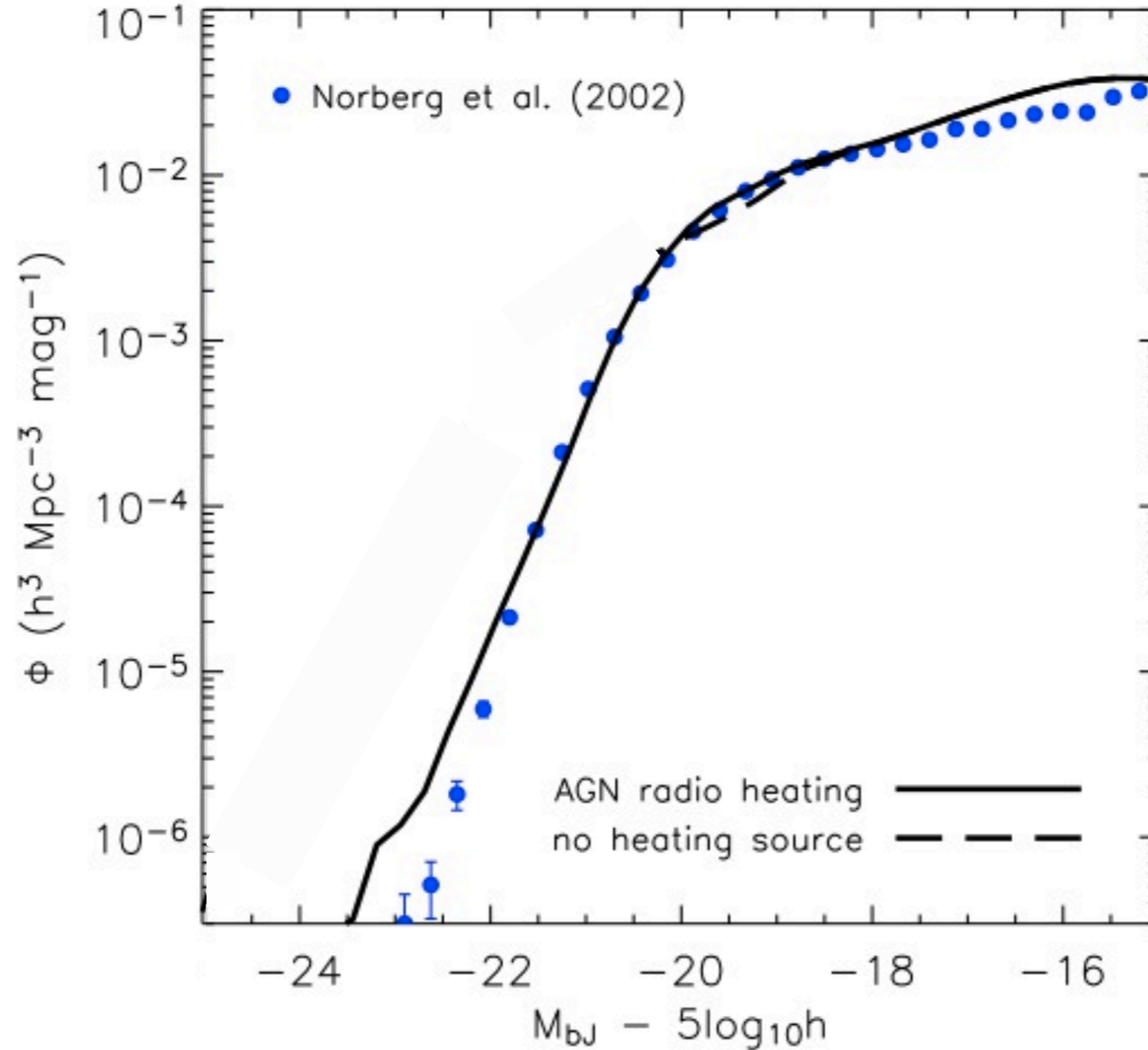
Furthermore, the brightest galaxies in voids are an equal mix of early and late-type galaxies

This is somewhat surprising given what we think we know about the nature of the void environment

Let's use a galaxy formation model to help understand this...

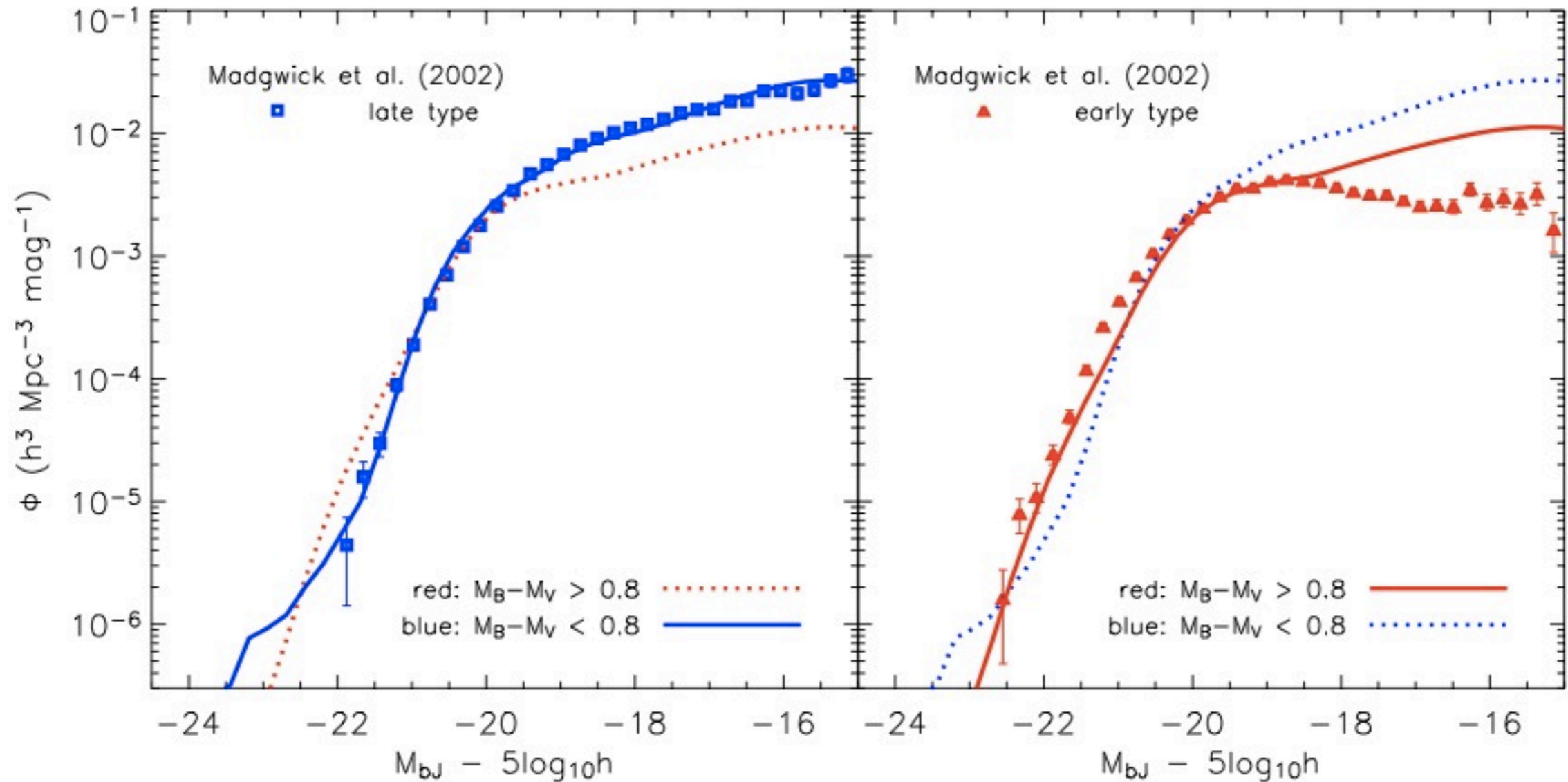


Model galaxy luminosity function - global



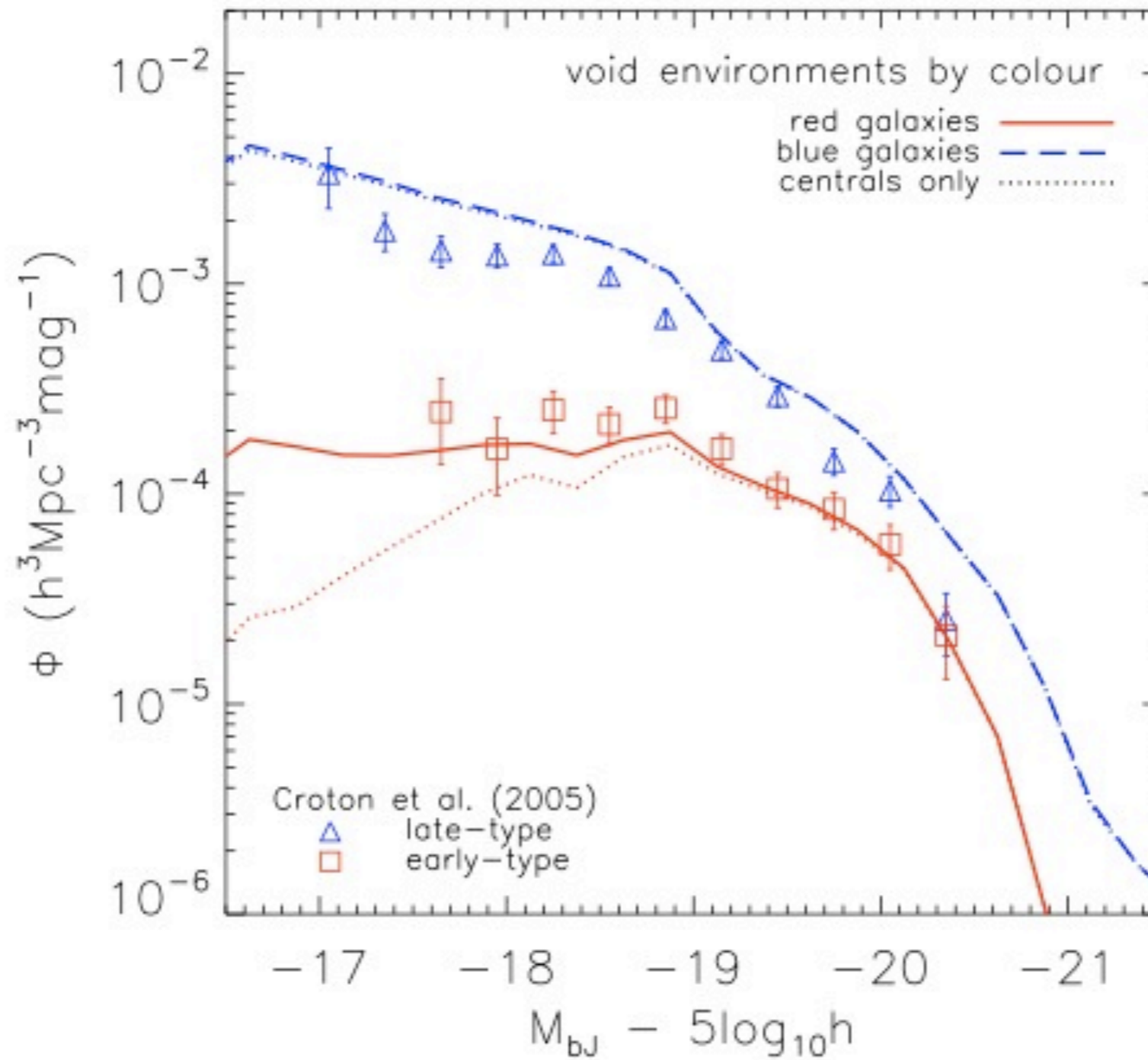
Croton et al. 2006

Model galaxy luminosity function - global



Croton et al. 2006

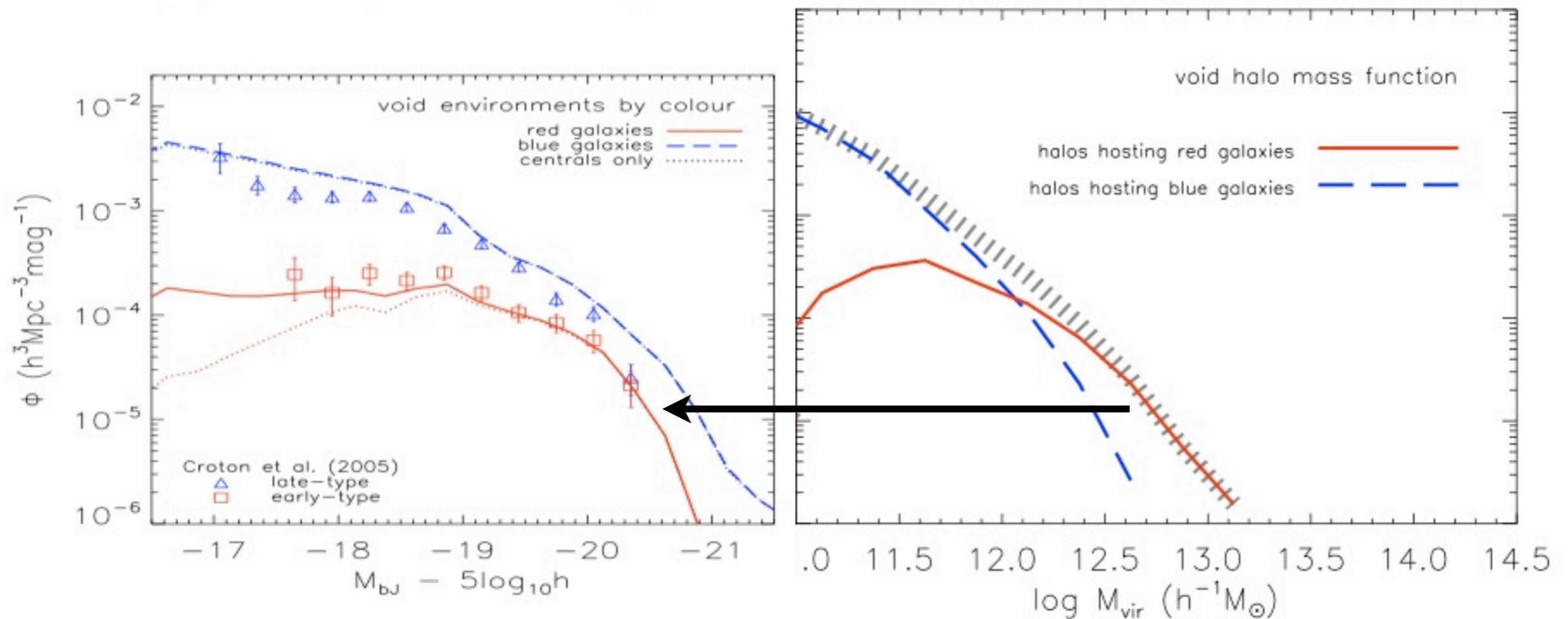
Croton & Farrar (2008)



Galaxy formation model in voids only..

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

Croton & Farrar (2008)



Halo mass function in different environments

The red/blue void galaxy abundance can be accounted for by the shift of the halo mass function with environment and an *environment independent* critical threshold for star formation quenching



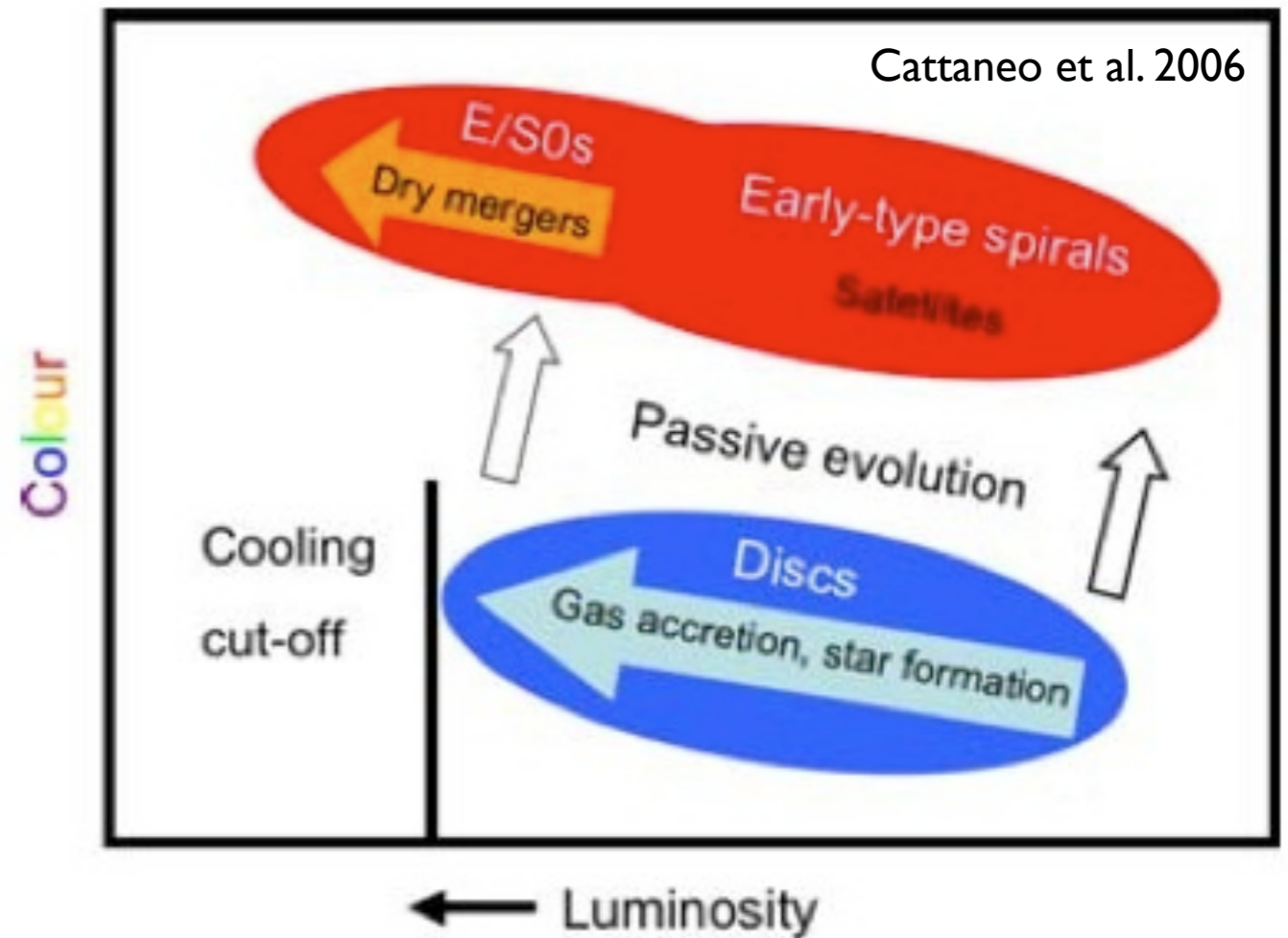
Outstanding Problems

What really shuts down star formation?

(or: how do galaxies evolve across the CMD?)

(or: to what degree is AGN even needed?)

- ▶ Important, why?
- ▶ Current understanding?
- ▶ Solutions?

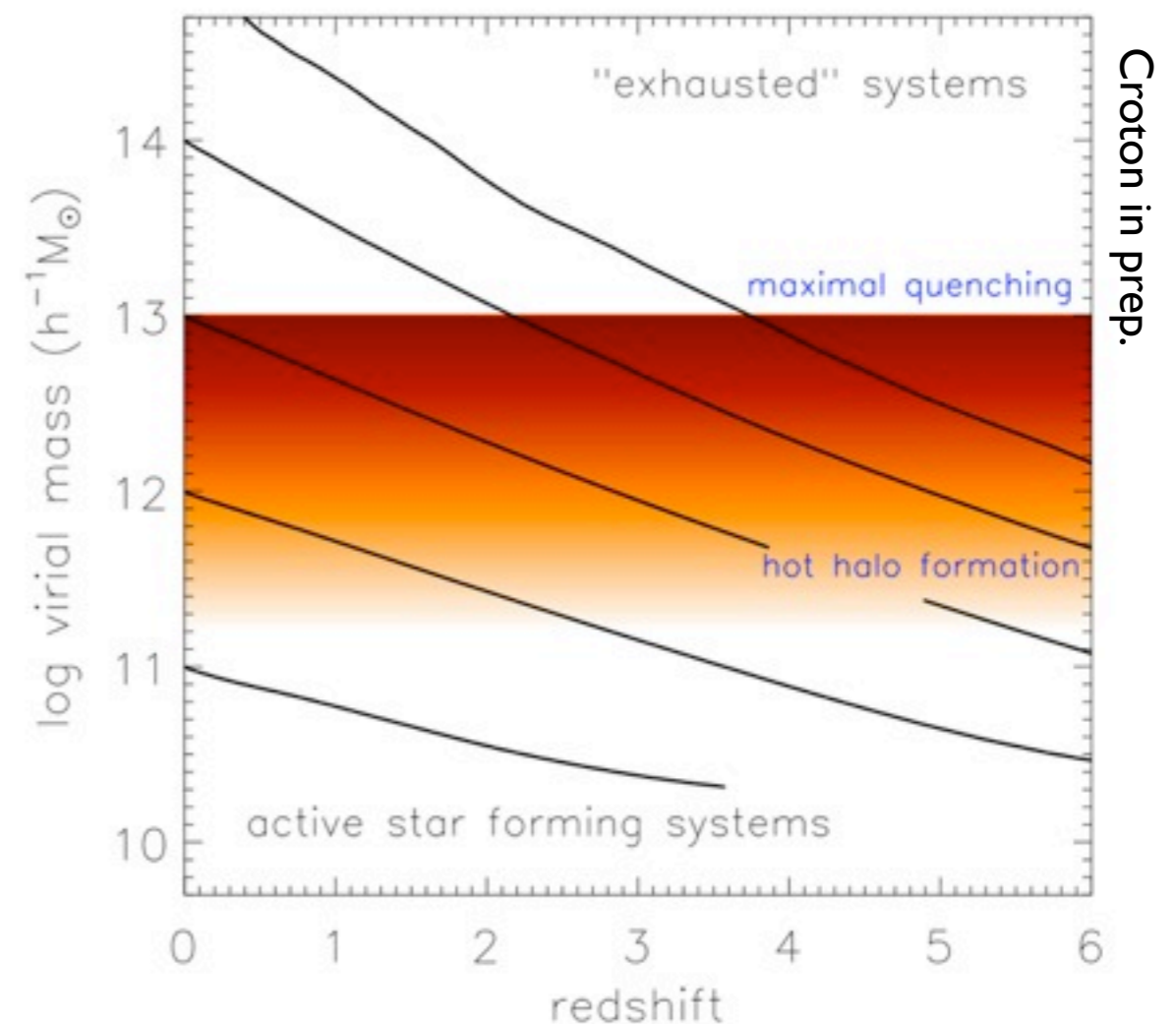


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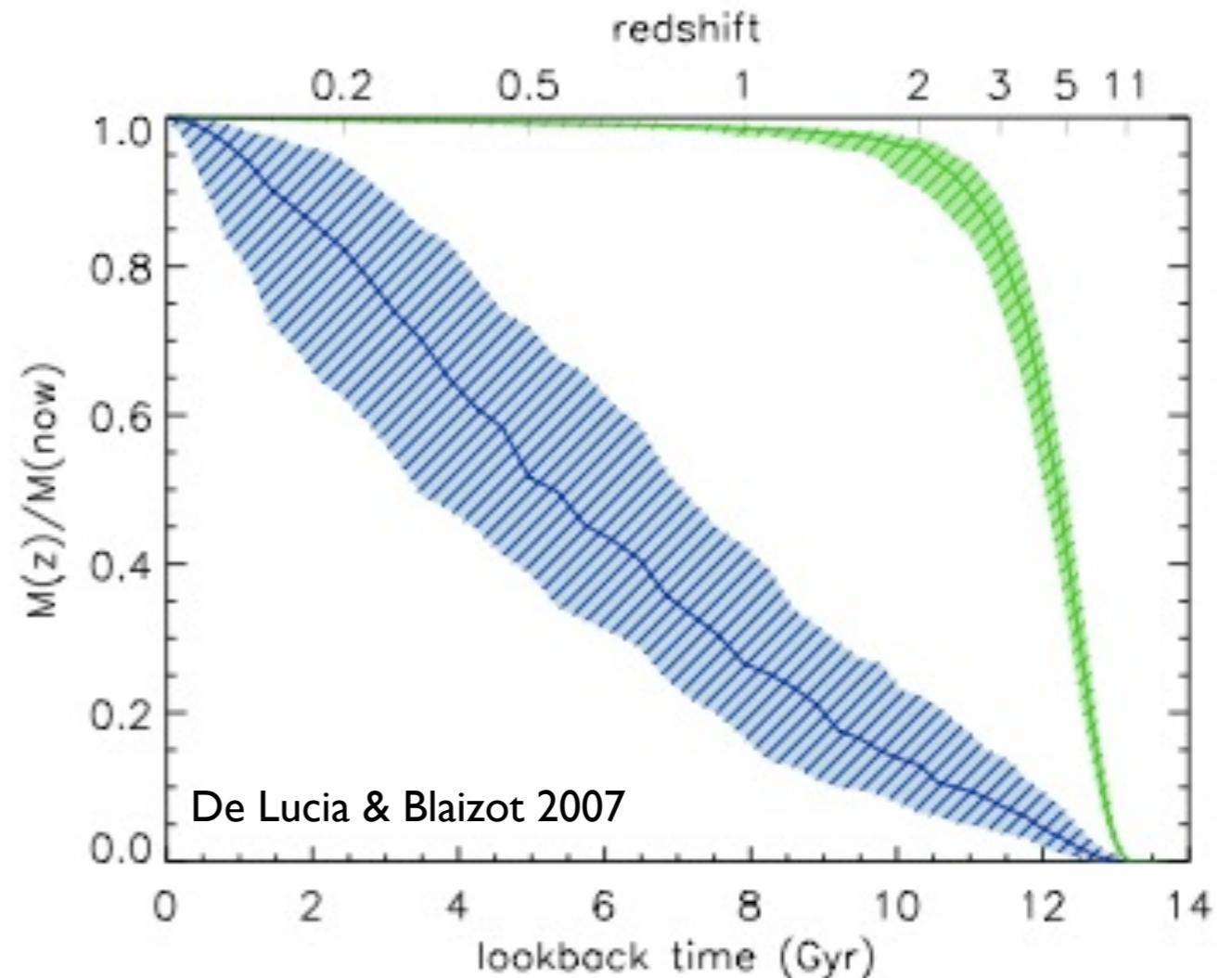
- ▶ Important, why?
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The assembly of massive galaxies?

(or: at what point does DM & baryon growth de-couple?)
(or: monolithic or hierarchical? a problem for CDM?)

- ▶ Important, why?
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- ▶ Solutions?

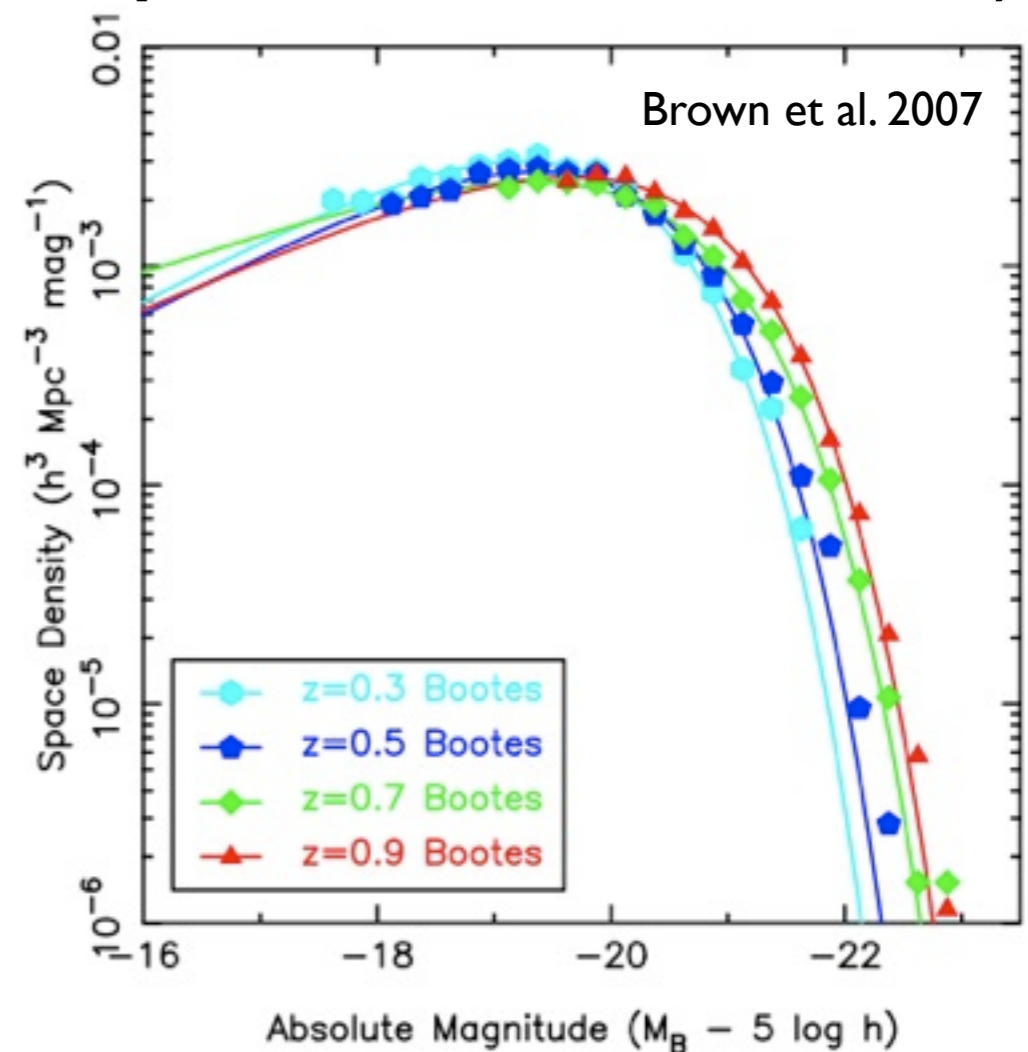


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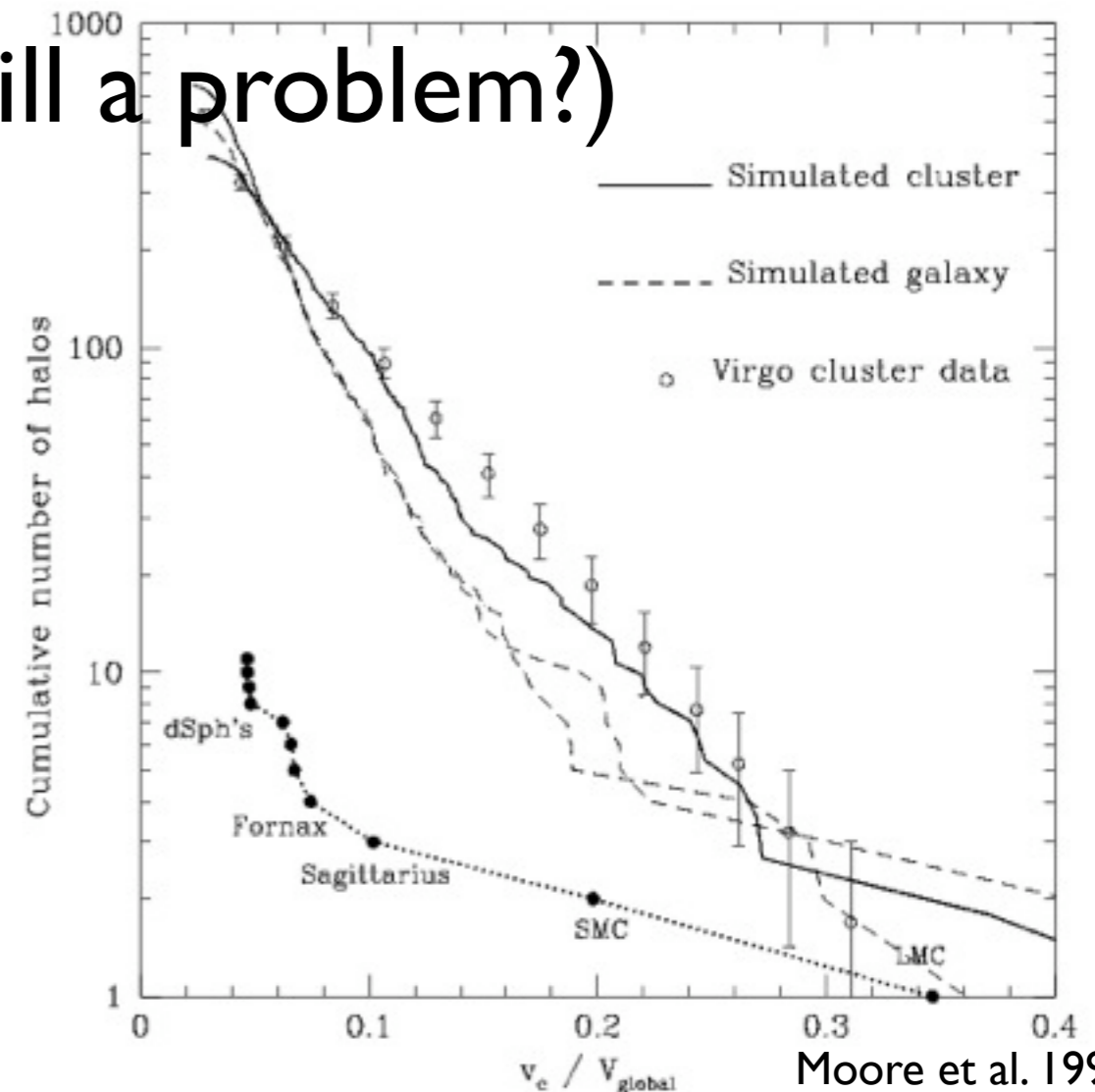
Satellite galaxy evolution?

(or: do central and satellite galaxies evolve differently?)

(or: merging vs. ICL?)

(or: is sub-structure still a problem?)

- ▶ Important, why?
- ▶ Current understanding?
- ▶ Solutions?



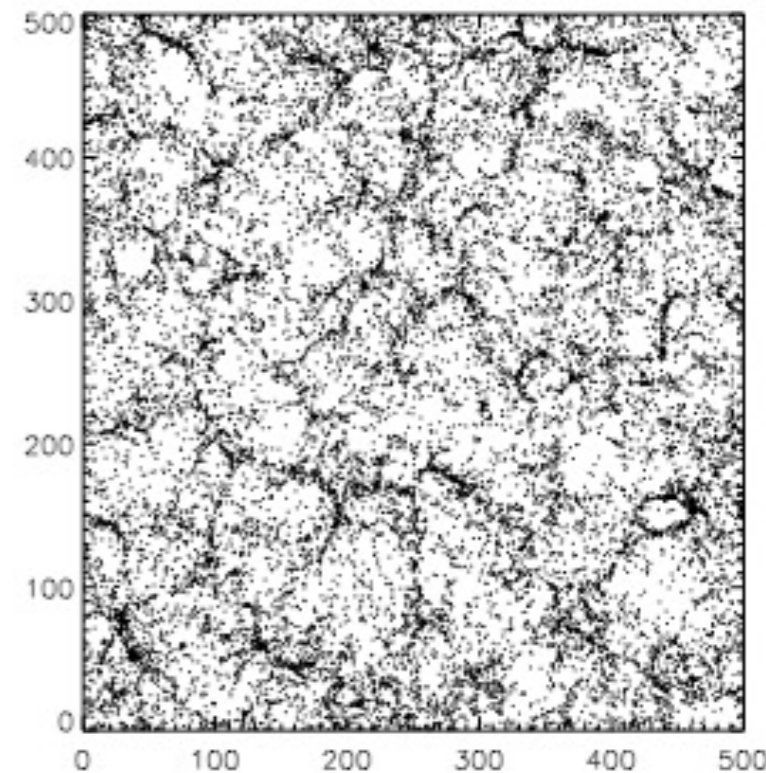
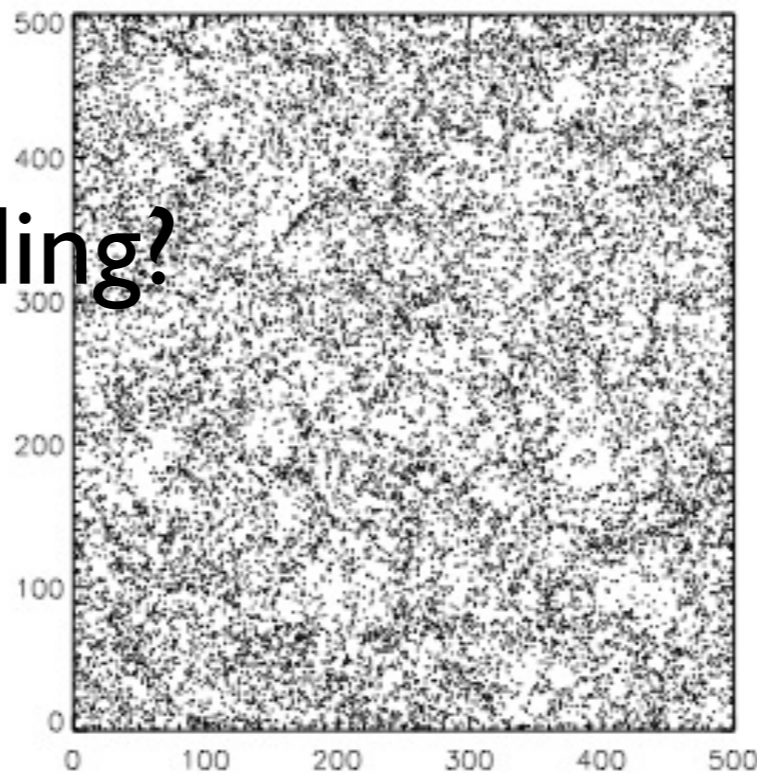
The role of environment?

(or: how important for cosmological measures?)

(or: is halo mass the fundamental property?)

- ▶ Important, why?
- ▶ Current understanding?
- ▶ Solutions?

Gao et al. 2005

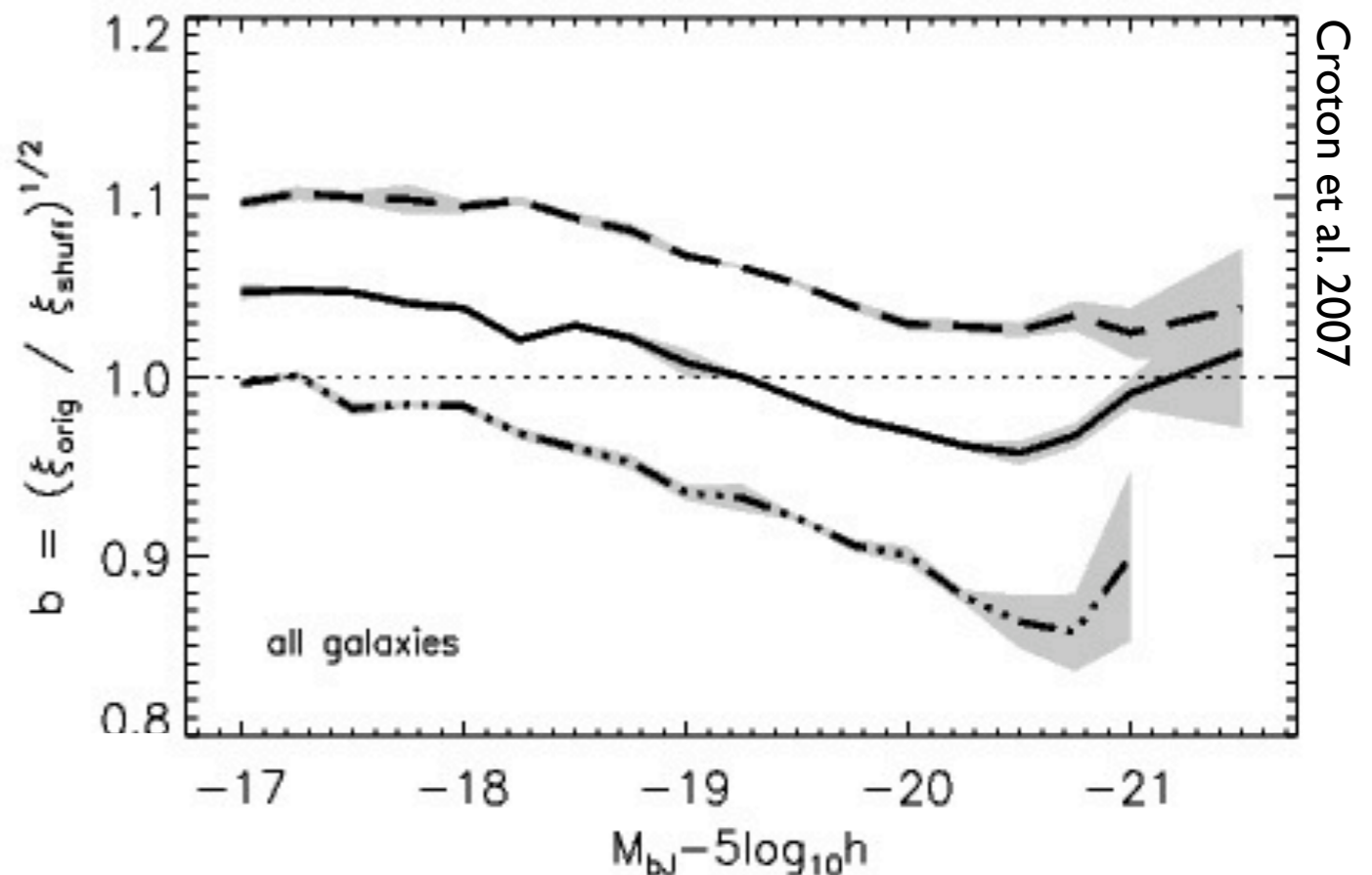


The role of environment?

(or: how important for cosmological measures?)

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And finally ...

w

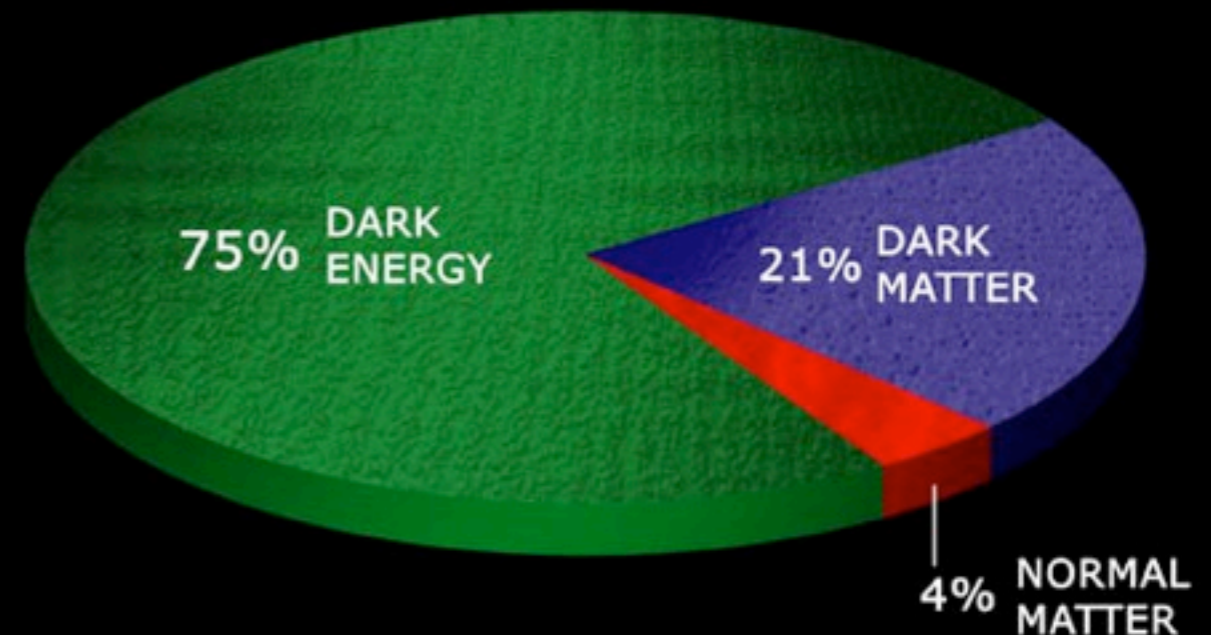
Probing dark energy

Weak & strong lensing

BOA's

Cluster counts

Supernova



- ◎ DES: ~**300 million galaxies** across 5,000 sq-degrees out to $z \sim 1.3$ in 4 bands ($r < 24.1$).
- ◎ LSST: **billions of galaxies** across 20,000 sq-degrees out to $z \sim 4$ in 6 bands ($AB < 29.0$).
- ◎ Other surveys/instruments: PanSTARRS, SKA, JWST, GLAST, SNAP, ... will provide equivalent multi-wavelength data sets.

What can you do with millions/billions of galaxies?

Statistics:

SDSS volume limited catalogue of ~50k galaxies can at most be sub-divided 1-2 more times

Next generation catalogues can be sub-divided multiple times on any property of interest

What can you do with millions/billions of galaxies?

Objects:

Multi-wavelength catalogues can be cross-correlated and studied together

Rare objects will become commonplace and will be analyzed with statistical confidence

Extra-galactic astronomy
covers a vast range of
disciplines.

These data sets will
produce vast amounts of
science.



Summary

- (1) Galaxy nature vs. nurture - what shapes the evolution of galaxies?
- (2) Are all environment measures equal? We should know before we compare results!
- (3) Is halo mass more fundamental than environment?
- (4) Next generation surveys will open up new science and provide great opportunities