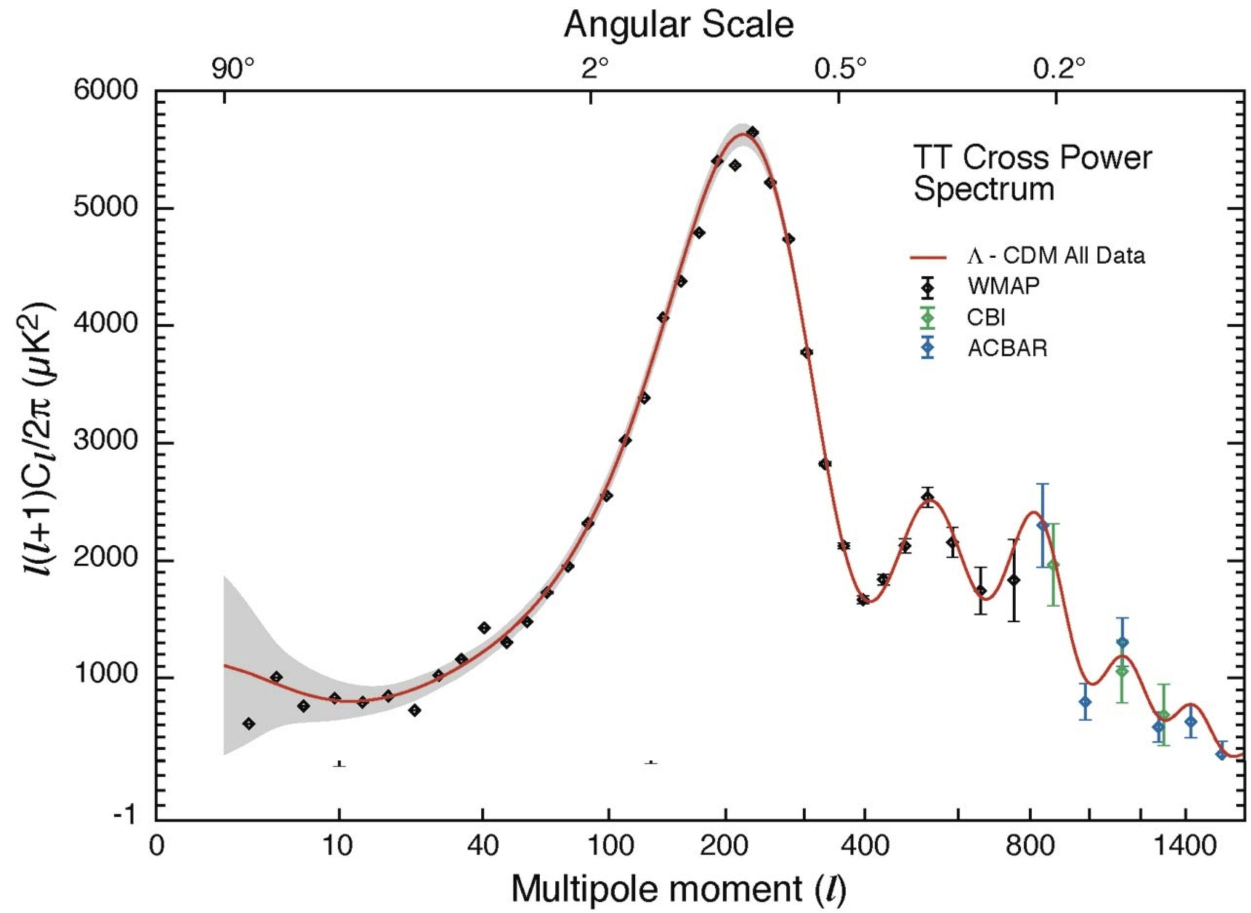
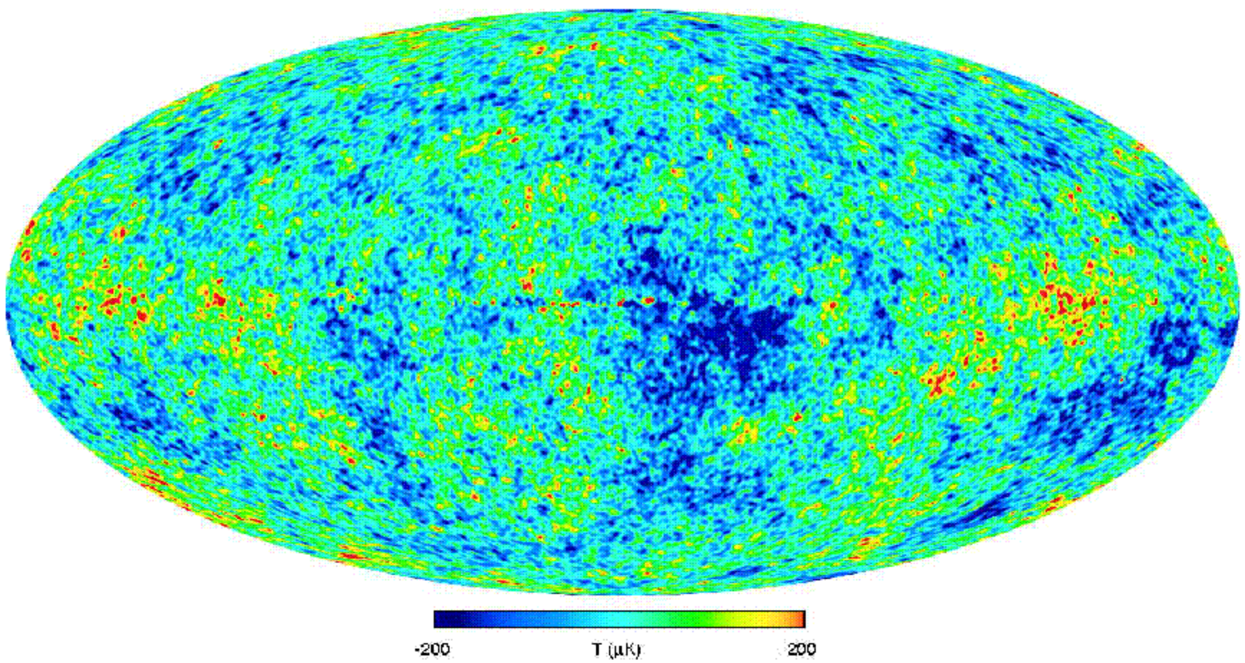
Physics and Evolution of Galaxies

Simon White, Max Planck Institut für Astrophysik

ELT2006
Marseille

The Emergence of the Cosmic Initial Conditions





- Temperature and polarisation power spectra for *WMAP* and interferometers
- Best ΛCDM model (1year)

$t_o = 13.7 \pm 0.2$ Gyr

$h = 0.71 \pm 0.03$ $\sigma_8 = 0.84 \pm 0.04$

$\Omega_t = 1.02 \pm 0.02$ $\Omega_m = 0.27 \pm 0.04$

$\Omega_b = 0.044 \pm 0.004$

$\tau_e = 0.17 \pm 0.07$

- Parameters in excellent agreement with other astronomical data

Goals for studies of galaxy formation/evolution

- A physical *understanding* of the development of current complexity from initial simplicity
- Clarification of the links between apparently diverse phenomena
- Identification of all significant components of the large-scale Universe

Tools

- Uniformity of the laws of physics
- Availability of many realisations of all phenomena
- Complementarity of archaeological and look-back approaches

Open questions for the next decades

- What were the first objects to form and when did they form?
- How was the Universe reionised? By what?
- What is the assembly sequence of the major components of galaxies? What morphological transformations occur in Nature?
- What is the role of internal versus external processes in building galaxies? Secular evolution vs environment vs bias.
- How do heavy elements cycle between galaxy components and with the IGM? Where are most of the heavy elements?
- How is the growth of galaxies and SMBH's related? How is this reflected in different varieties of AGN?
- What can galaxies/clusters tell us about the nature of dark matter?

Physical processes

- Dark matter dynamics
- Gas shocking and cooling, HI and molecular cloud formation
- Star formation, stellar evolution
- Stellar winds, SN energy feedback, galactic winds
- Heavy element production, ejection and mixing. Dust formation.
- Black hole formation. Radiative and hydrodynamic output
- Ejection of magnetic field, cosmic rays.
- Radiative transfer – reionisation, ISM properties
- Stellar/gas dynamics of galaxy structure

Is it all too messy?

Is it all too messy?

No!

- The cosmological standard model is well specified, and has simple IC's

Is it all too messy?

No!

- The cosmological standard model is well specified, and has simple IC's
- Evolution in the dark matter distribution is affected little by baryons and can be calculated accurately

Is it all too messy?

No!

- The cosmological standard model is well specified, and has simple IC's
- Evolution in the dark matter distribution is affected little by baryons and can be calculated accurately
- Galaxy phenomenology shows strong regularities suggesting convergent evolution (scaling relations, Kennicutt “laws”, structural “laws”)

Is it all too messy?

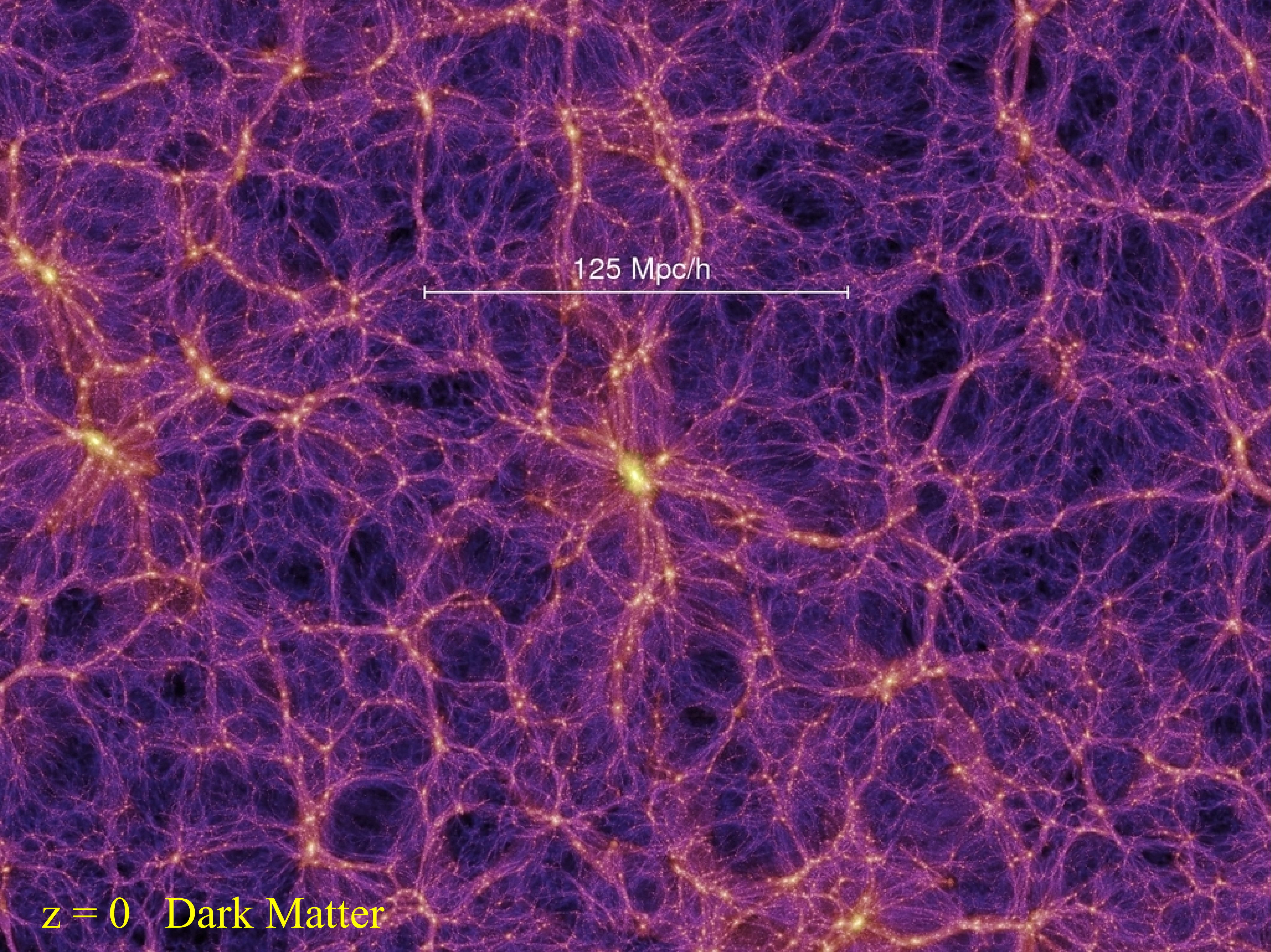
No!

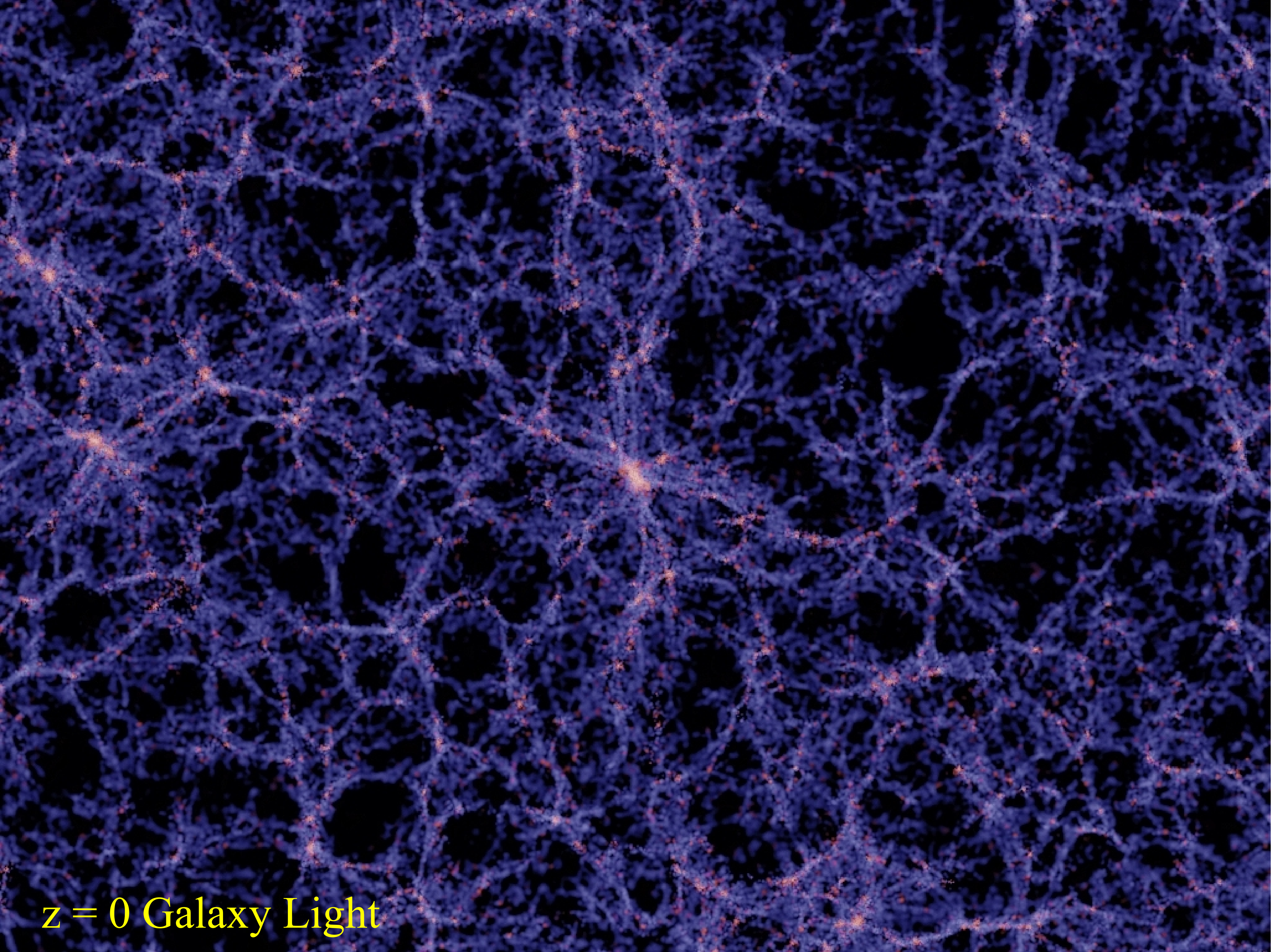
- The cosmological standard model is well specified, and has simple IC's

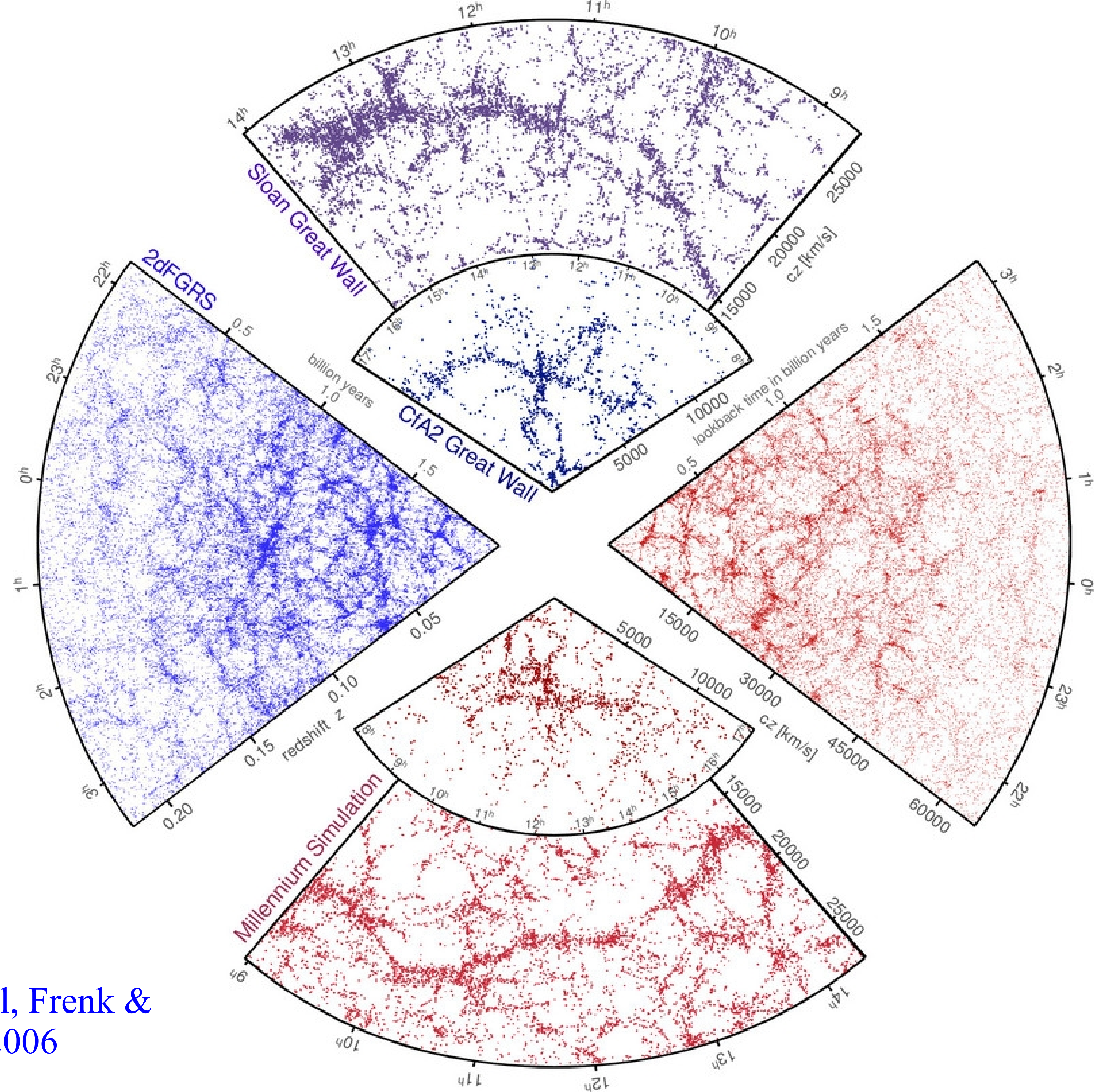
- Evolution in the dark matter distribution is affected little by baryons and can be calculated accurately

- Galaxy phenomenology shows strong regularities suggesting convergent evolution (scaling relations, Kennicutt "laws", structural "laws")

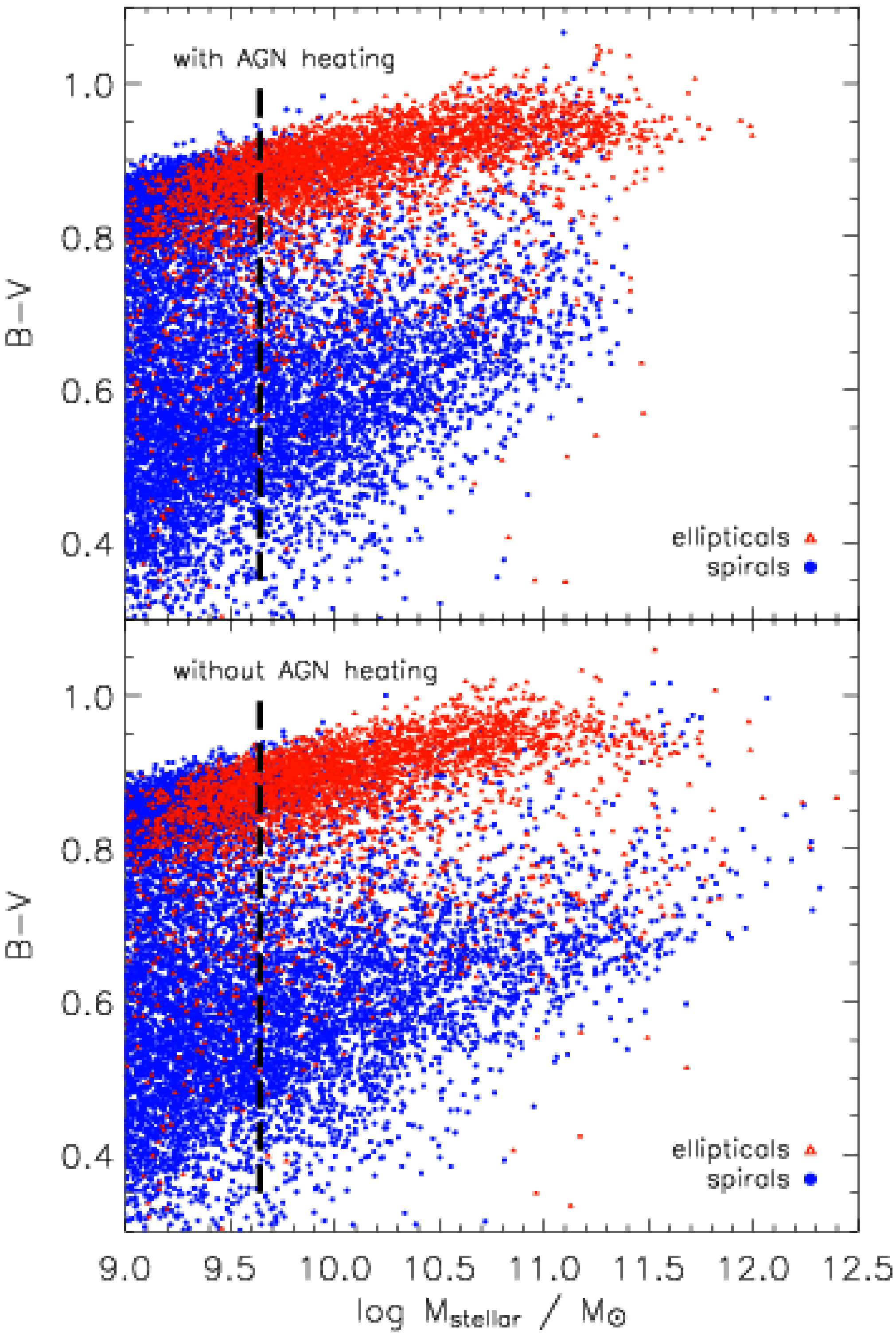
- Problems can be broken down by scale: clustering
  → global properties → internal structure
  → AGN feeding → star formation


125 Mpc/h
z = 0 Dark Matter


z = 0 Galaxy Light



Springel, Frenk &
White 2006

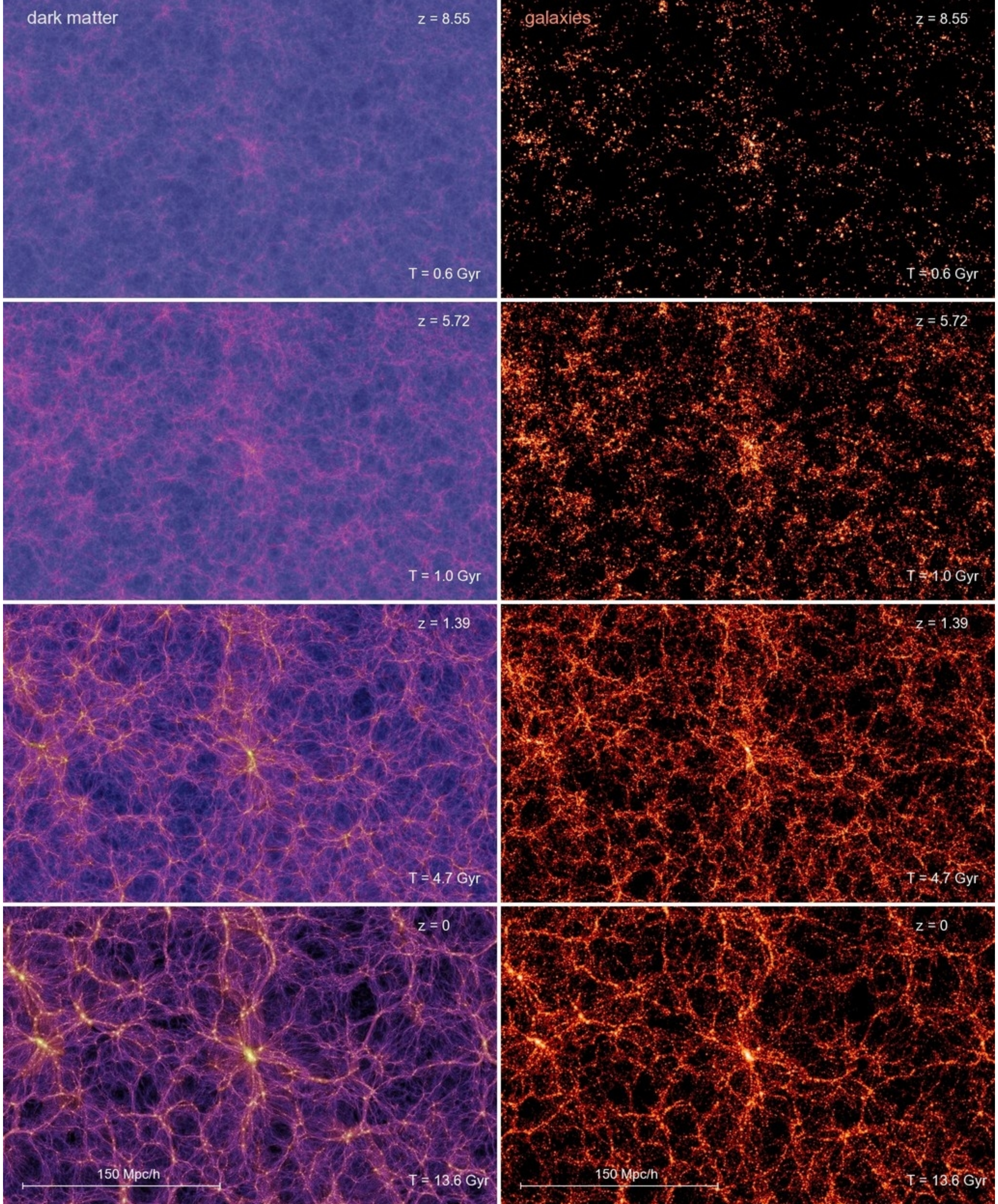


The effects of "radio mode" feedback on z=0 galaxies

Croton et al 2006

- In the absence of a "cure" for the cooling flow problem, the most massive galaxies are:
  - too bright
  - too blue
  - disk-dominated
- With cooling flows suppressed by "radio AGN" these galaxies are
  - less massive
  - red
  - elliptical

Large-scale structure at high redshift



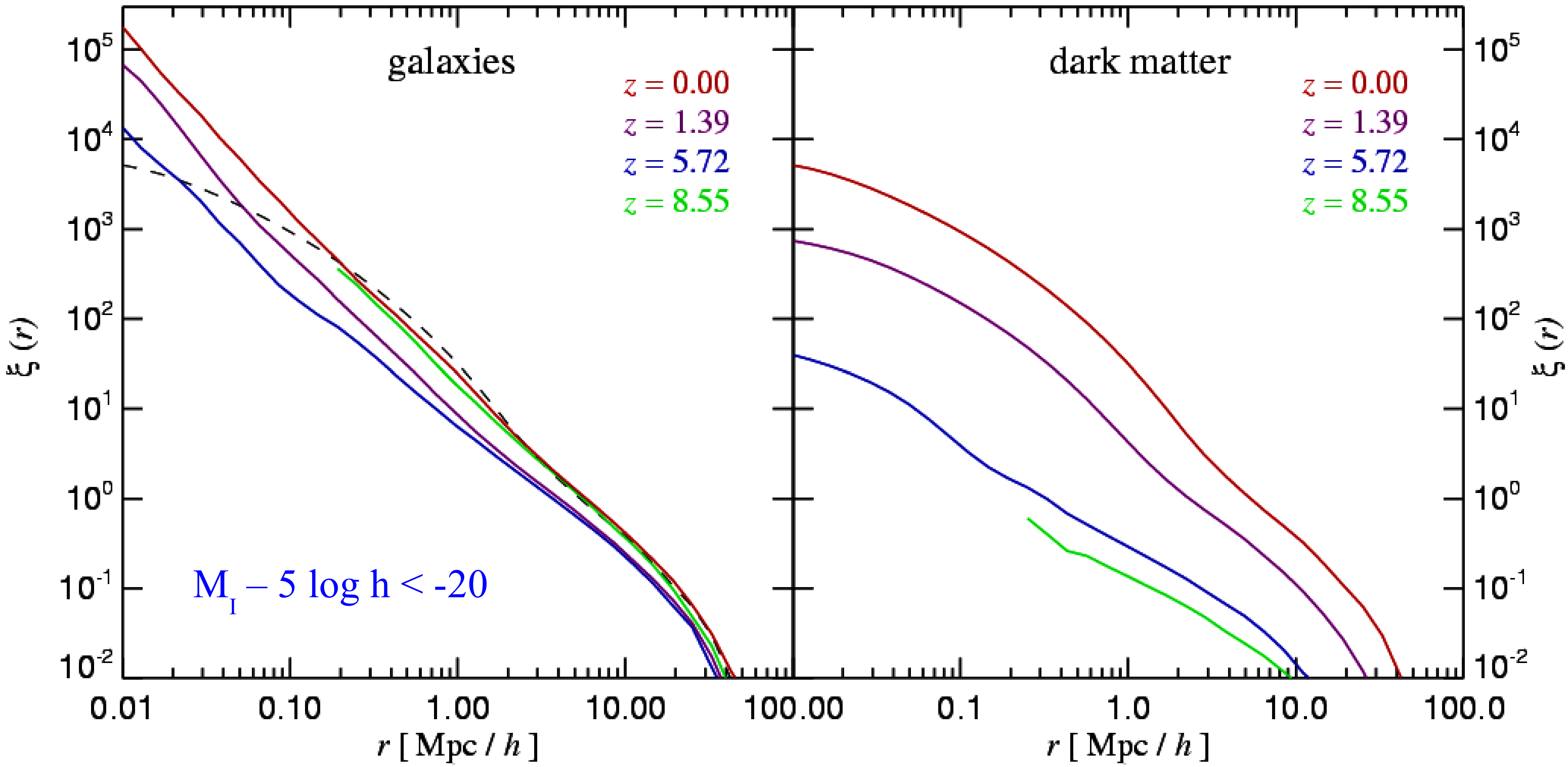
Springel, Frenk & White 2006

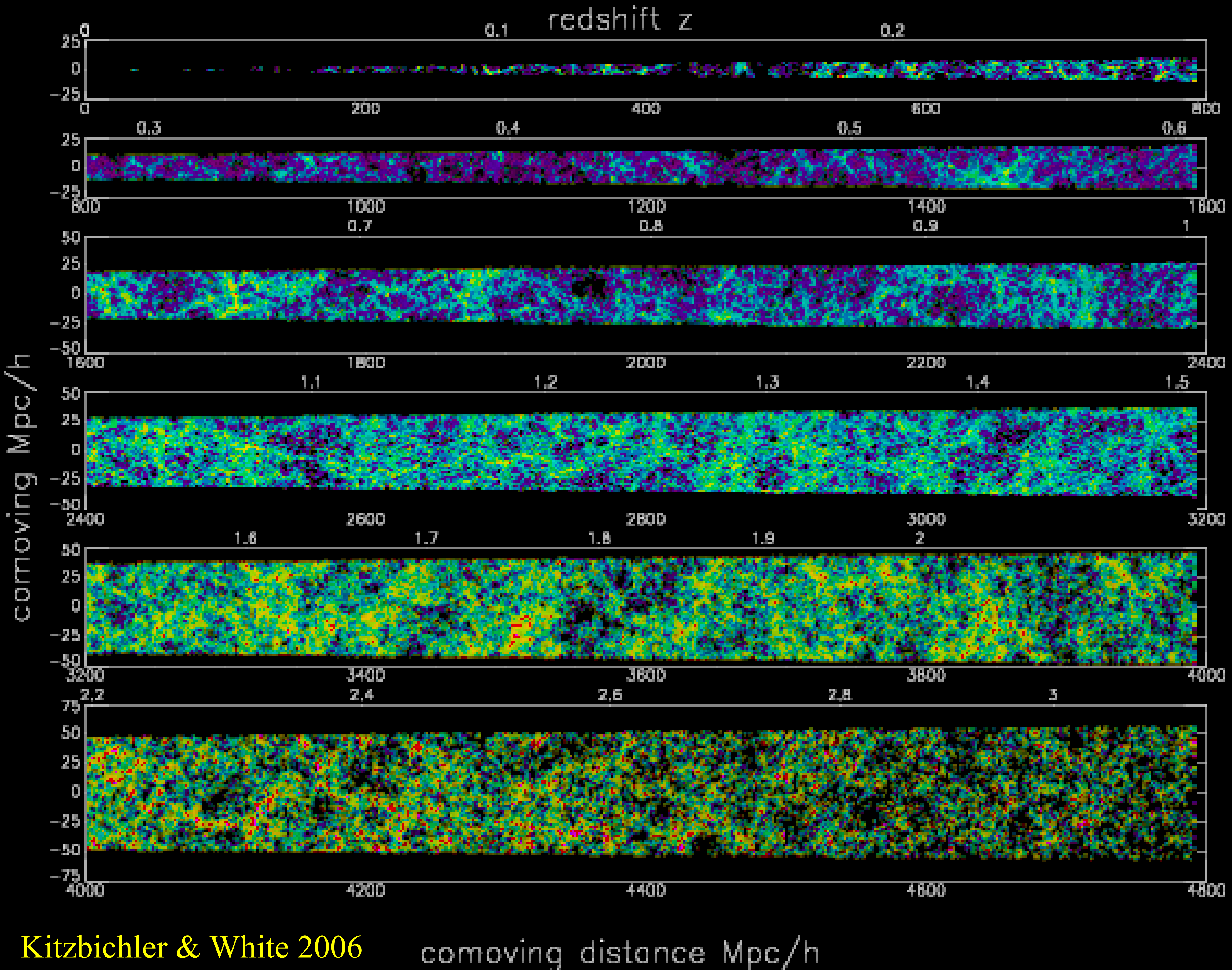
Large-scale structure in the galaxy distribution evolves very little with redshift

It is as strong at z=8.5 as at z=0

Evolution of mass and galaxy correlations

Springel, Frenk & White 2006

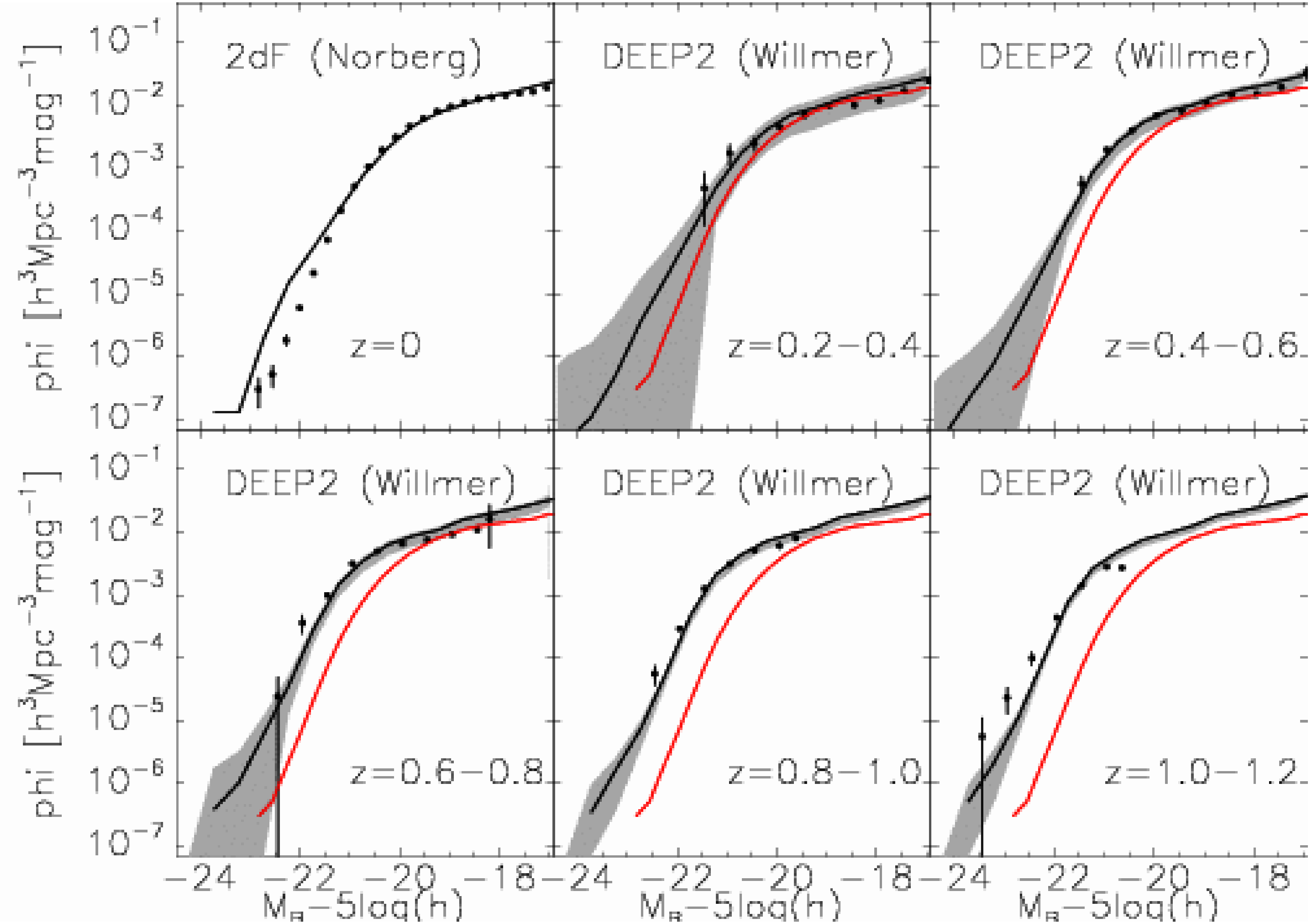




Kitzbichler & White 2006

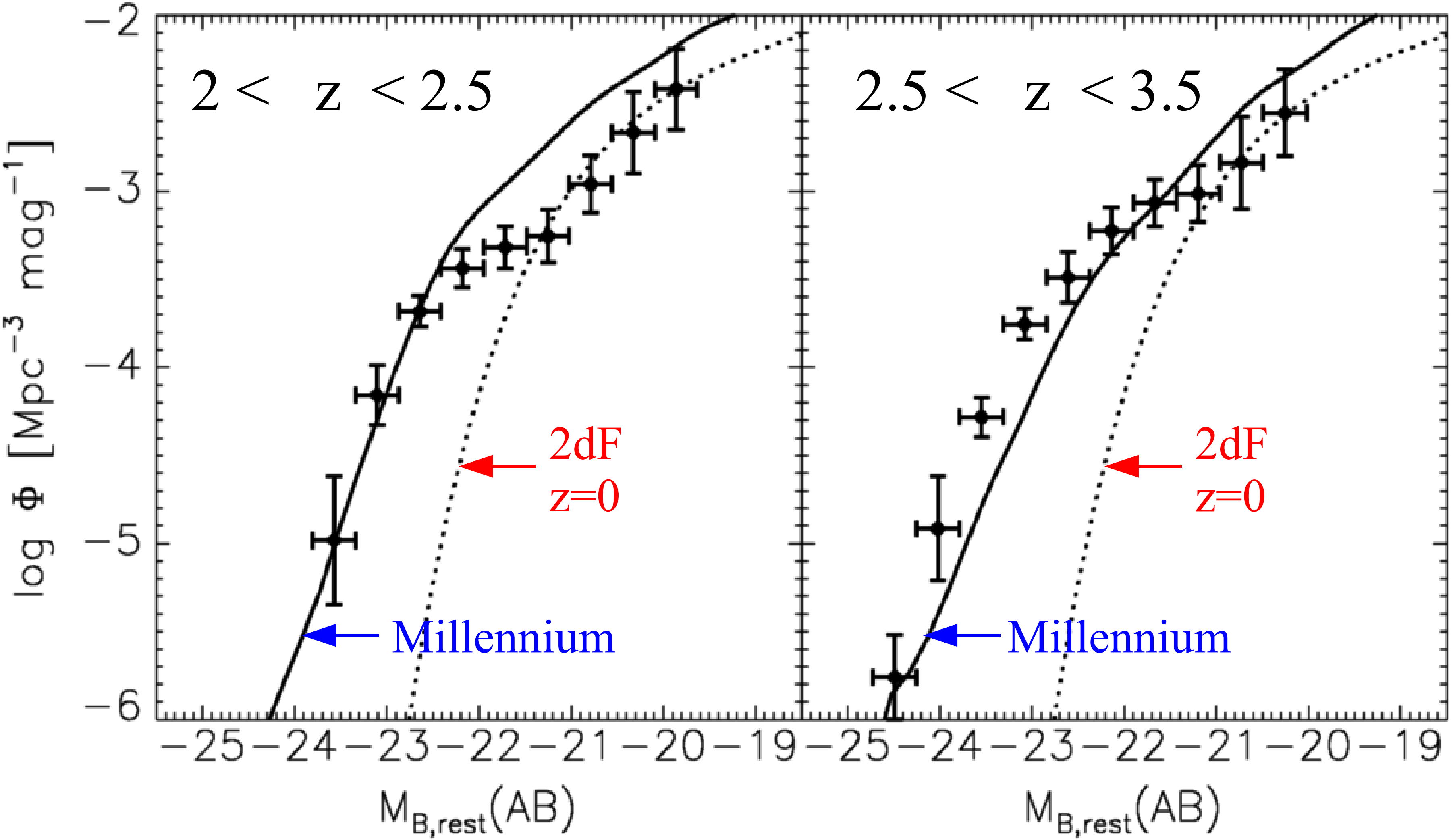
Deep galaxy luminosity functions

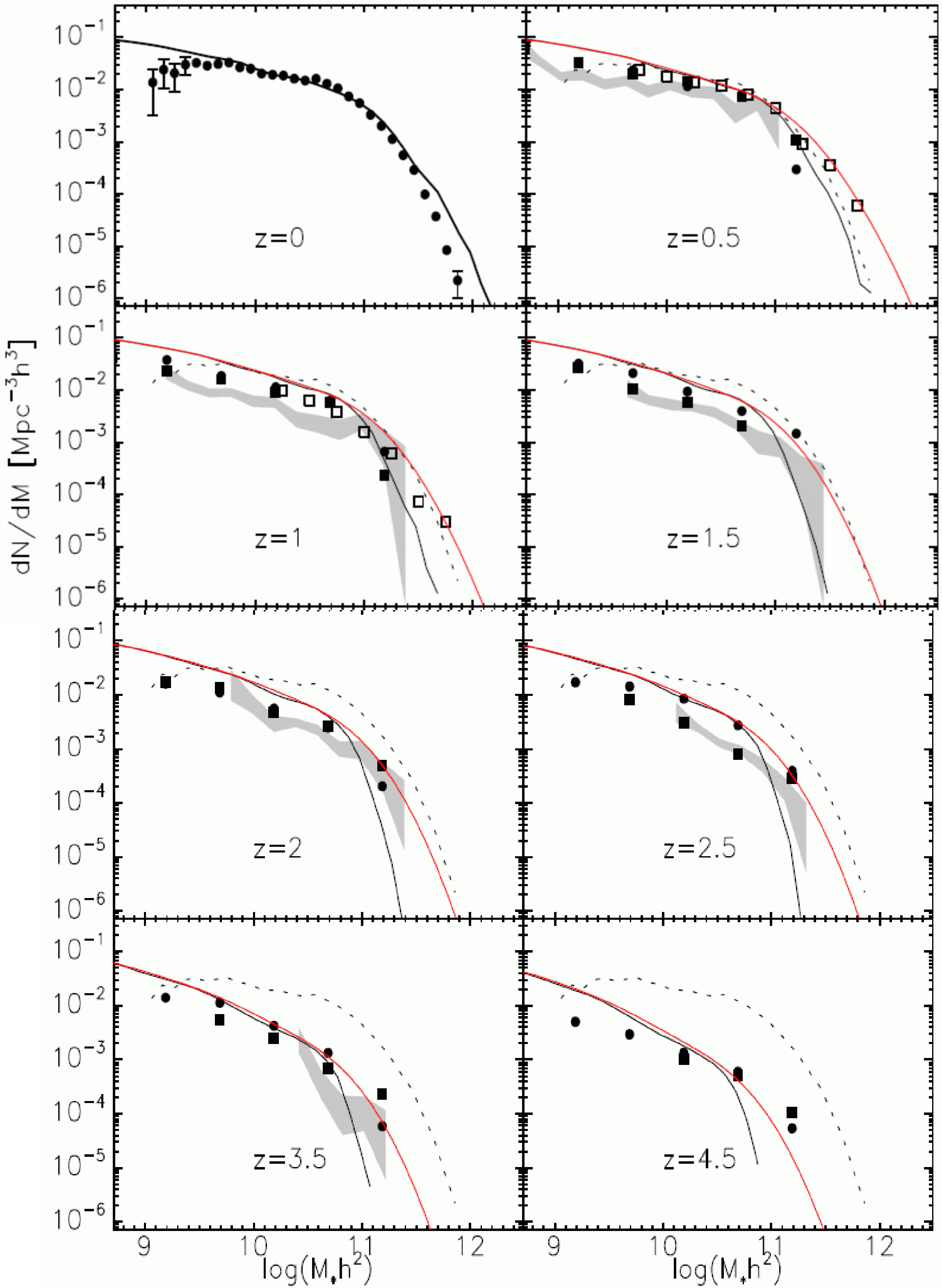
Kitzbichler & White 2006



Deep galaxy luminosity functions

Marchesini et al 2006





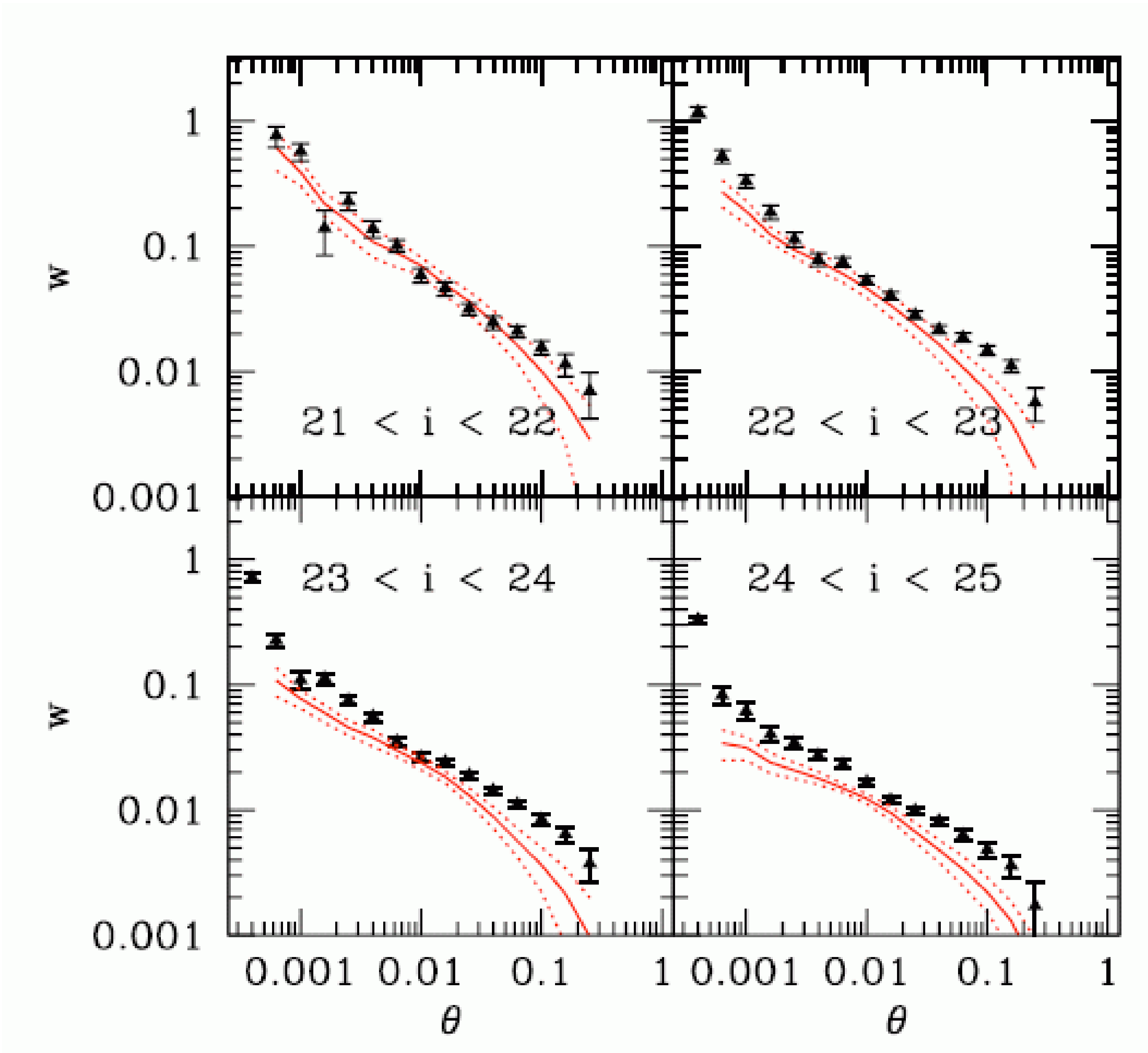
Deep galaxy mass functions

Kitzbichler & White 2006

Observational estimates:

Cole et al (2001) $z = 0$
Drory et al (2005) $z = 0.5$ to 4.5
Fontana et al (2006) $z = 0.5$ to 3.5

Angular correlations in the COSMOS data and in the Millennium Simulation

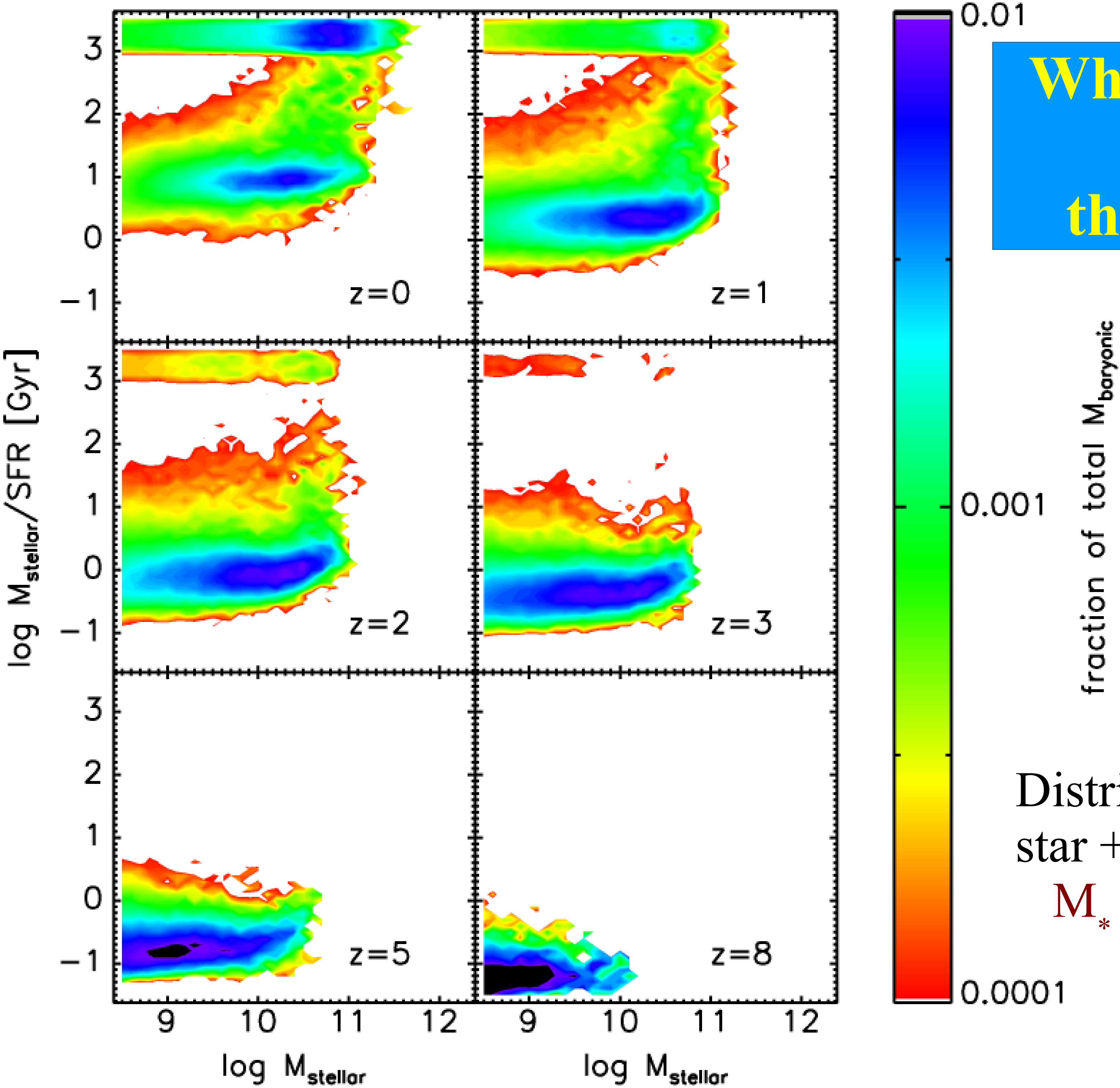


The COSMOS team

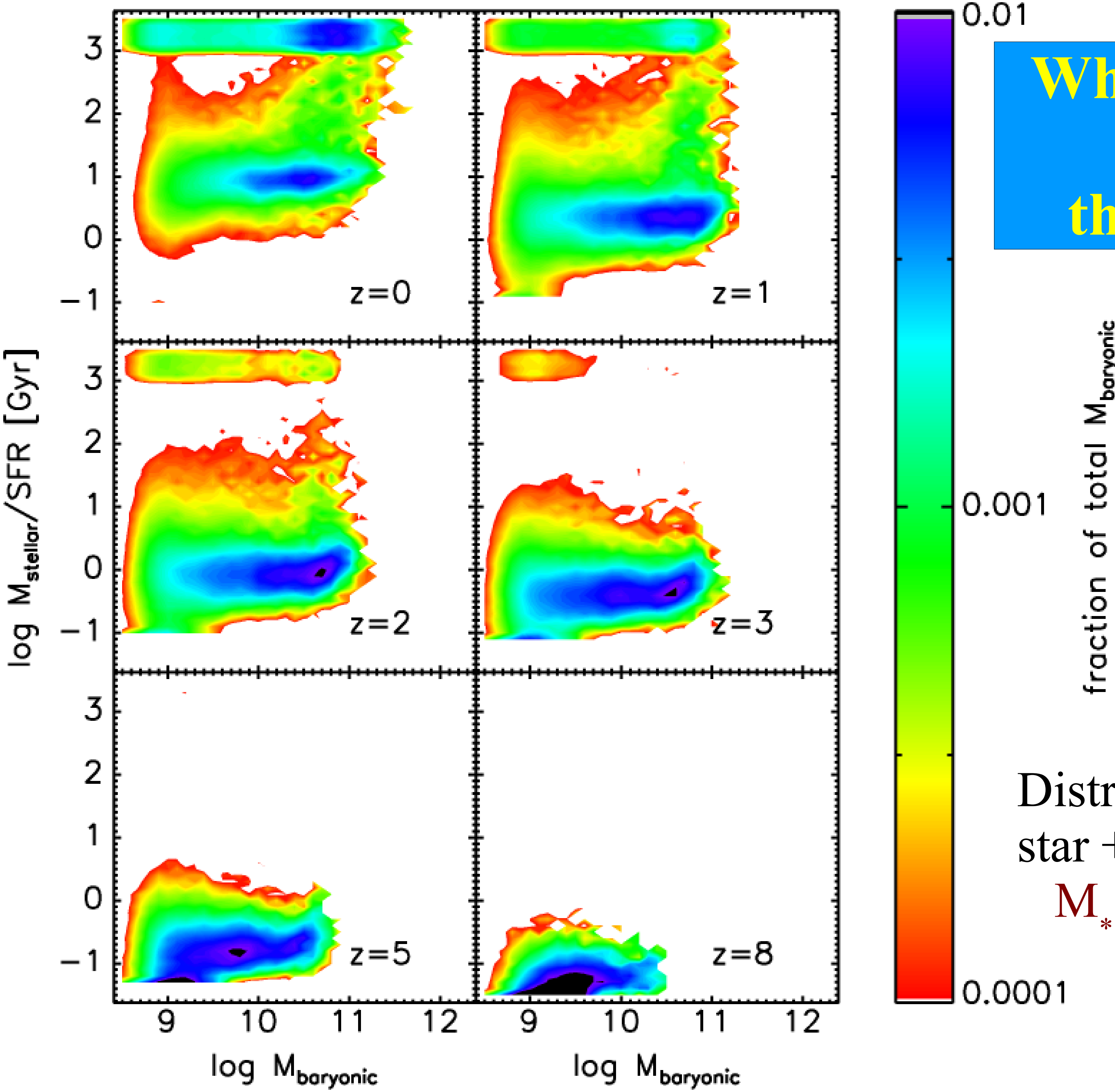
McCracken et al 2006

Which galaxies host the baryons?

Kitzbichler & White 2007



Distribution of total star + ISM mass over $M_* / \dot{M}_*$ and M_*



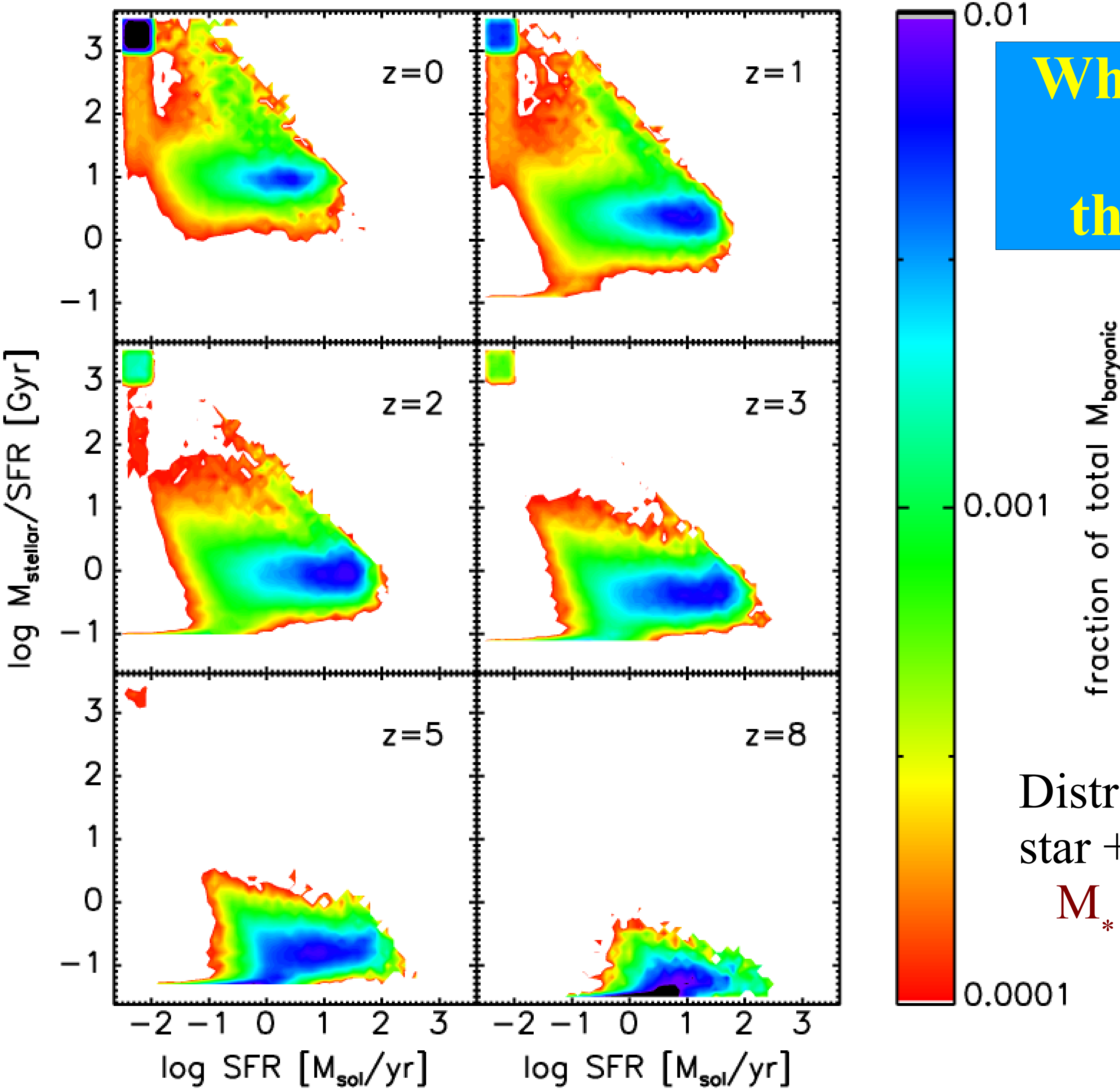
Which galaxies host the baryons?

Kitzbichler & White 2007

Distribution of total star + ISM mass over $M_* / \dot{M}_*$ and M_{bar}

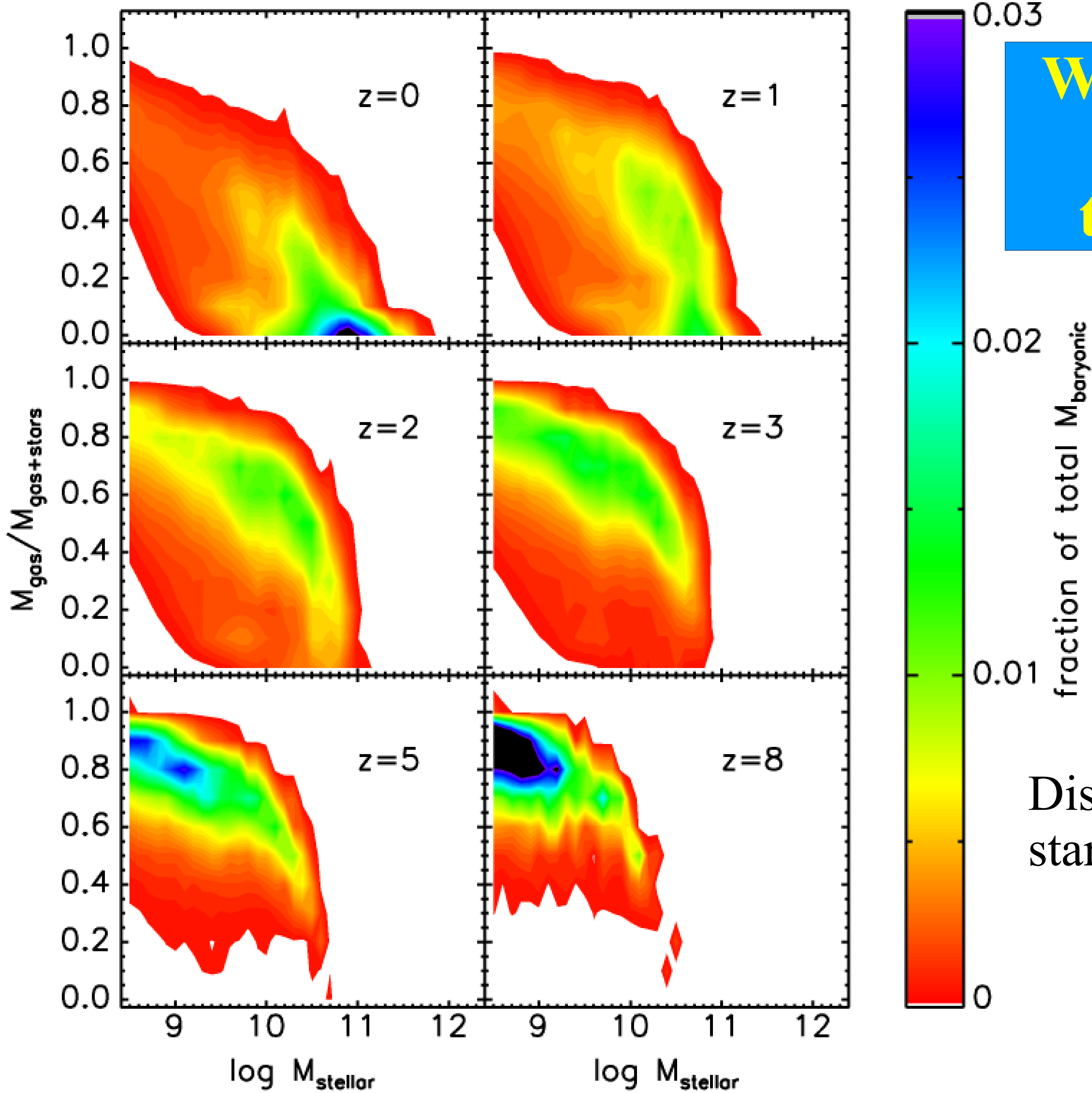
Which galaxies host the baryons?

Kitzbichler & White 2007



Distribution of total star + ISM mass over $M_* / \dot{M}_*$ and $\dot{M}_*$

Which galaxies host the baryons?

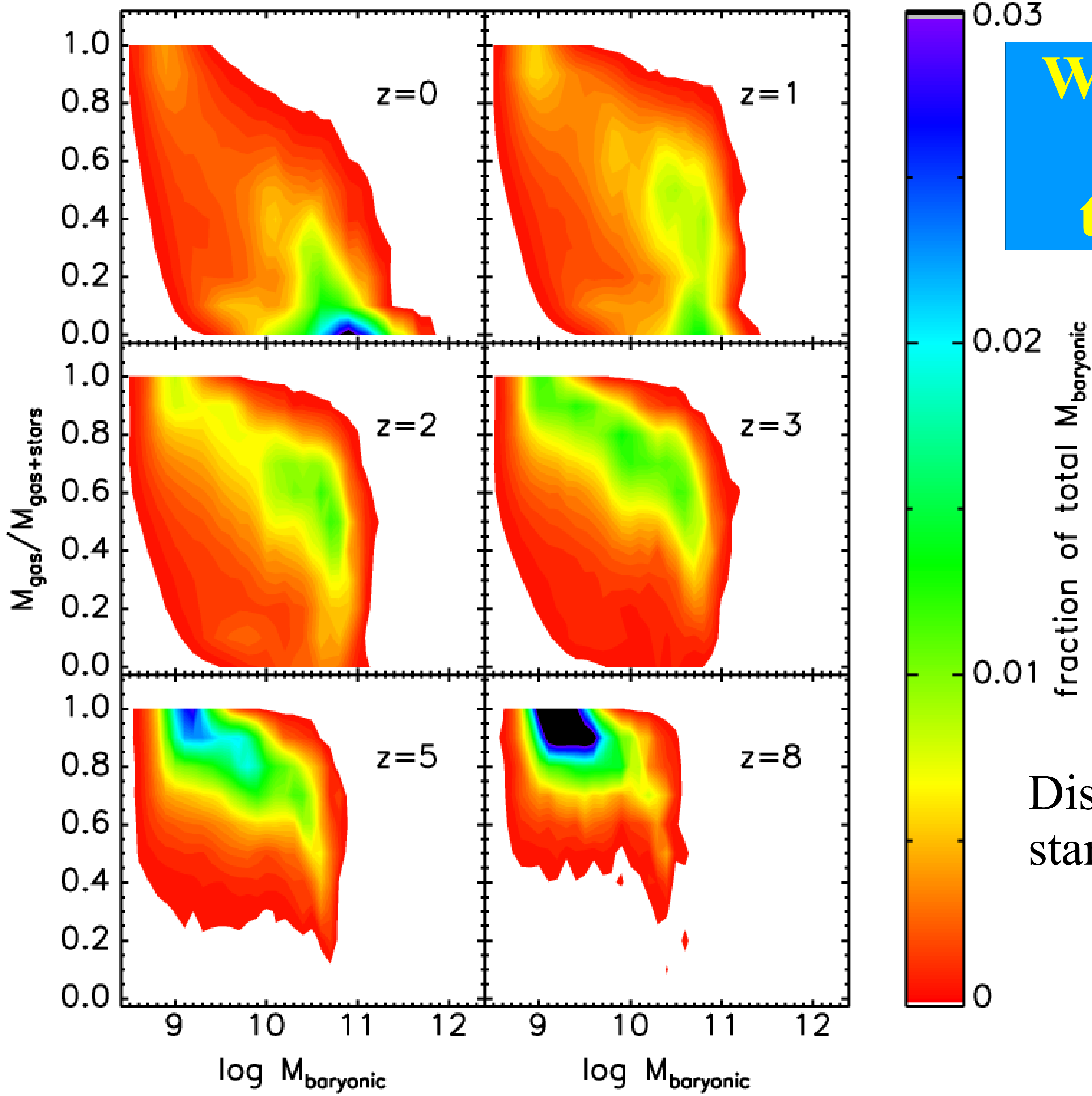


Kitzbichler & White 2007

Distribution of total star + ISM mass over F_{gas} and M_*

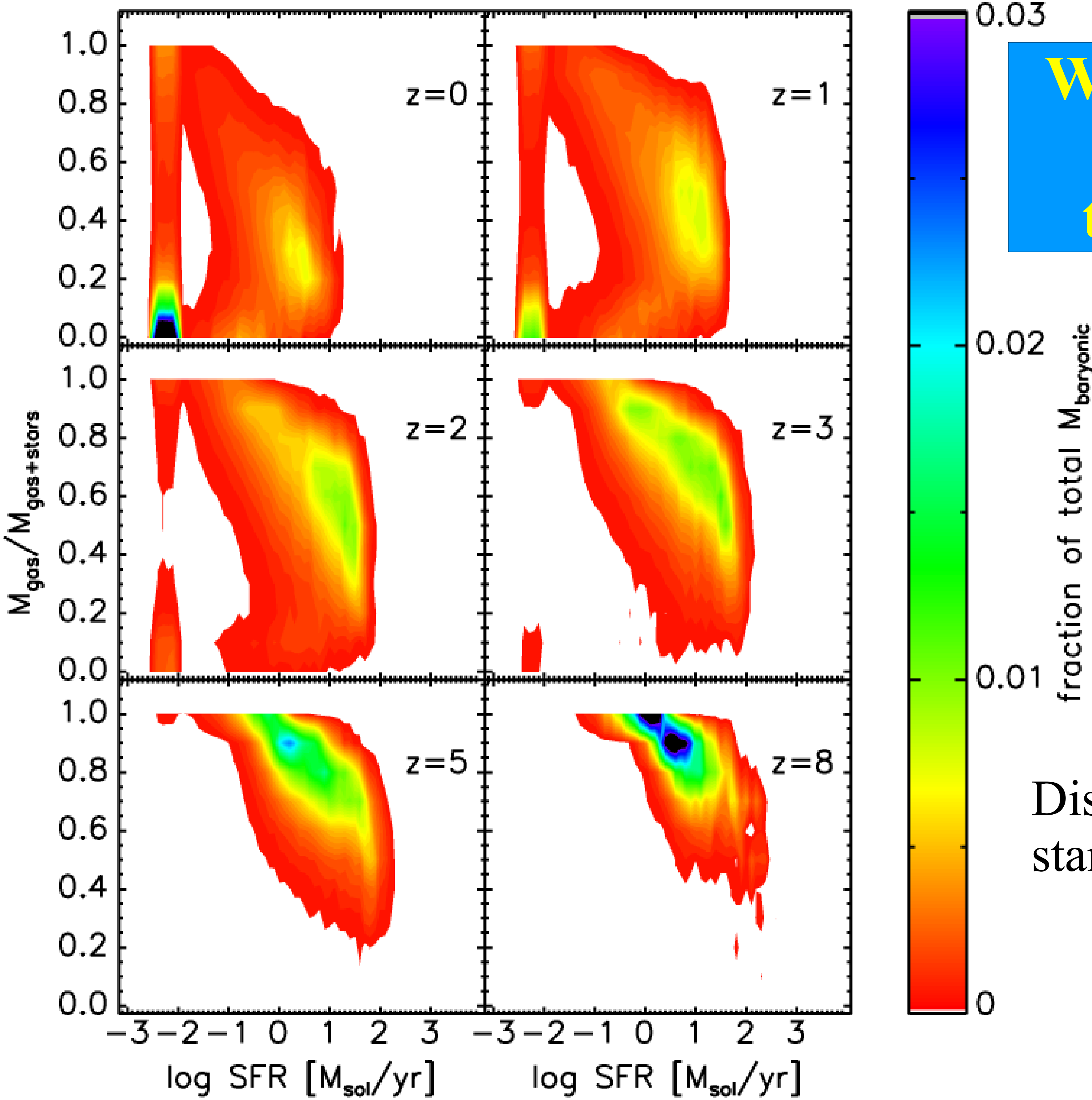
Which galaxies host the baryons?

Kitzbichler & White 2007



Distribution of total star + ISM mass over F_{gas} and M_*

Which galaxies host the baryons?

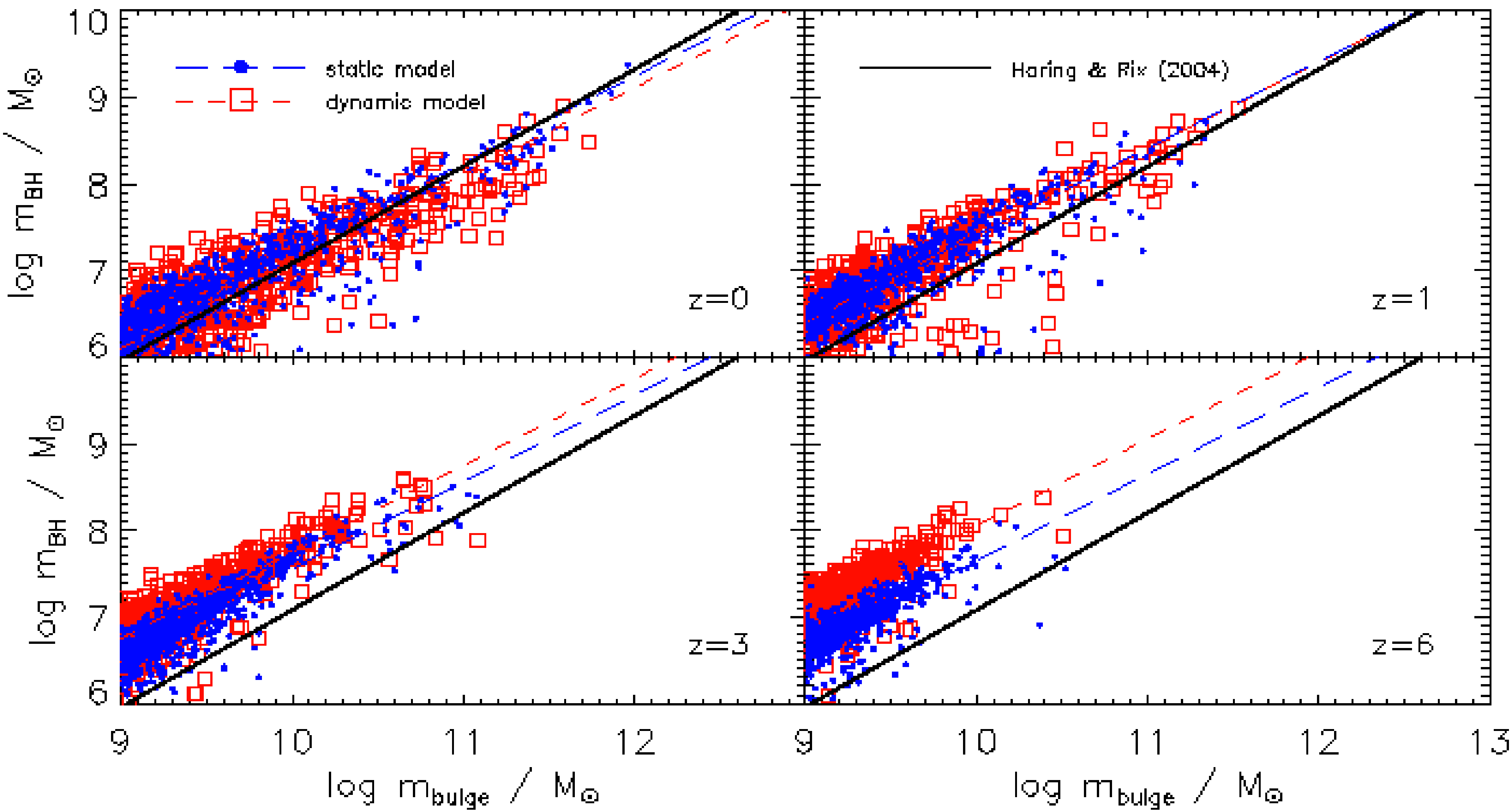


Kitzbichler & White 2007

Distribution of total star + ISM mass over F_{gas} and $\dot{M}_*$

Models for evolution of the BH-bulge relation

Croton 2006



GERMAN ASTROPHYSICAL GAVO VIRTUAL OBSERVATORY

Exploring the milli-Millennium simulation with a relational database

Documentation


```
select D.I_HALO,
       D.SNAPNUM,
       D.N_P as D_NP,
       P1.N_P as P1_NP,
       P2.N_P as P2_NP
  from HALO P1,
       HALO P2,
       HALO D
 where P1.SNAPNUM=P2.SNAPNUM
   and P1.I_HALO < P2.I_HALO
   and P1.I_DESCENDANT = D.I_HALO
   and P2.I_DESCENDANT = D.I_HALO
   and P1.N_P >= .2*D.N_P
   and P2.N_P >= .2*D.N_P
   and D.N_P > 1000
```

Execute Query | Clear all | Help

Maximum number of rows to return to the query form: 10

Previous queries :

Halo 1 | Galaxy 1 — Find halos/galaxies at a given redshift (SNAPNUM) within a certain part of the simulation volume (X,Y,Z).

Halo 2 — Find the whole progenitor tree, in depth-first order, of a halo identified by its id (I_HALO)

Halo 3 — Find the progenitors at a given redshift (SNAPNUM) of all halos of mass (N_P) greater than 4000 at a later redshift (SNAPNUM). The progenitors are limited to have mass >= 100.

Halo 4 — Find all the halos of mass (N_P) >= 1000 that have just had a major merger, defined by having at least two progenitors of mass >= 0.2*descendant mass.

Halo 5 | Galaxy 5 — Find the mass/luminosity function of halos/galaxies at z=0 using logarithmic intervals.

Galaxy 6 — Find the Tully-Fisher relation, Mag_b/v/i/k vs V_vir for galaxies with bulge/total mass ratio < 0.1. Subsample by about 1% (RANDOM between 20000 and 30000).

Reformat | CSV

Plot (VOPlot) — This button wil attempt to start up VOPlot within an applet, so that the current result can be explored graphically. This clearly requires that the browser has been configured for viewing applets.
DISCLAIMER This functionality has been partially tested only. Any problems are our responsibility, not VOPlot's.
It seems that the applet does not work properly with Konqueror.

Query time (in millisec) = 15623
Number of rows retrieved from database = 12 (Maximum # = 10000)

http://www.mpa-garching.mpg.de/Millennium

i_halo	snapnum	d_np	p1_np	p2_np
2576	60	1079	924	222

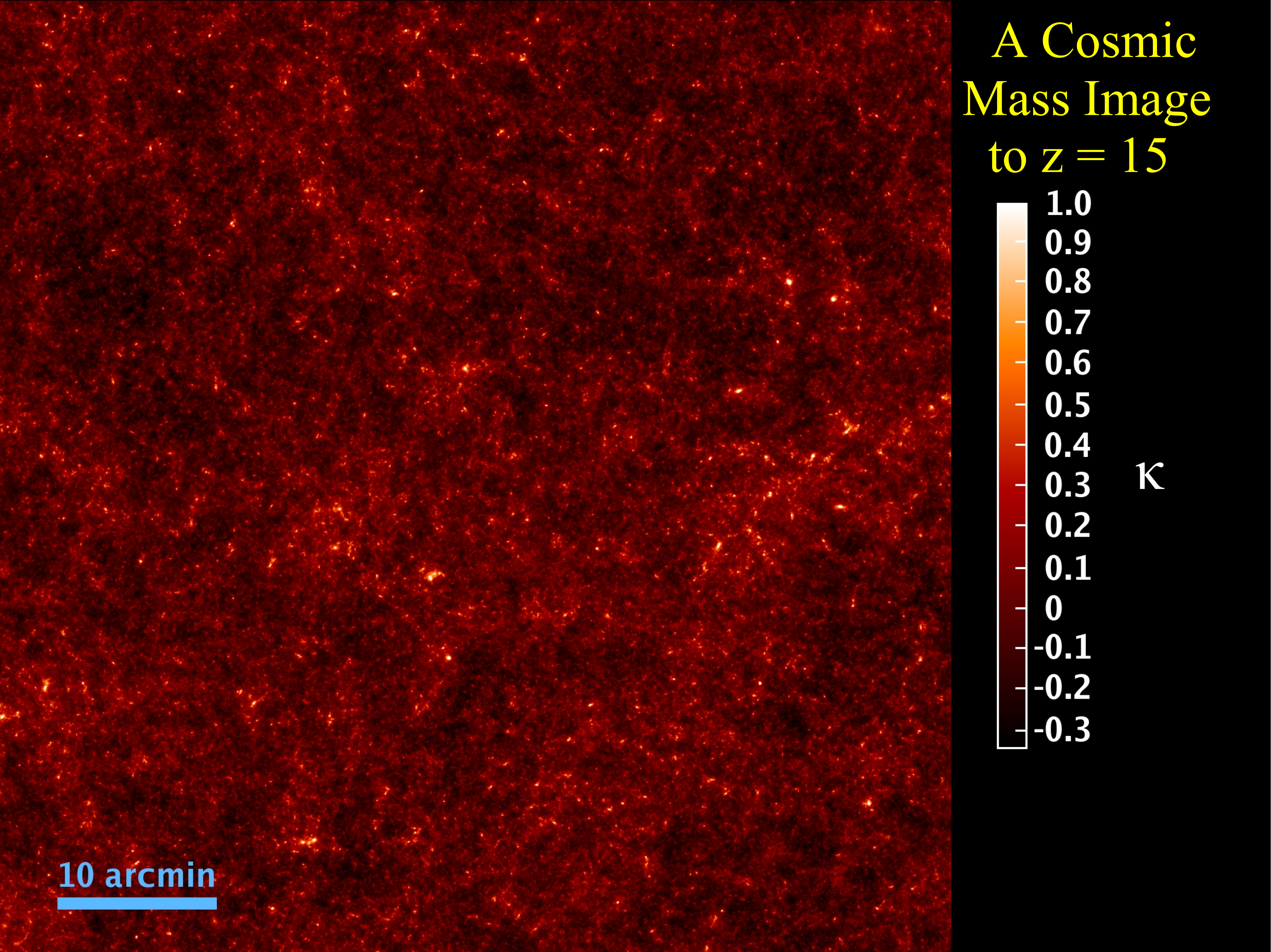
ELT opportunities for galaxy formation/evolution

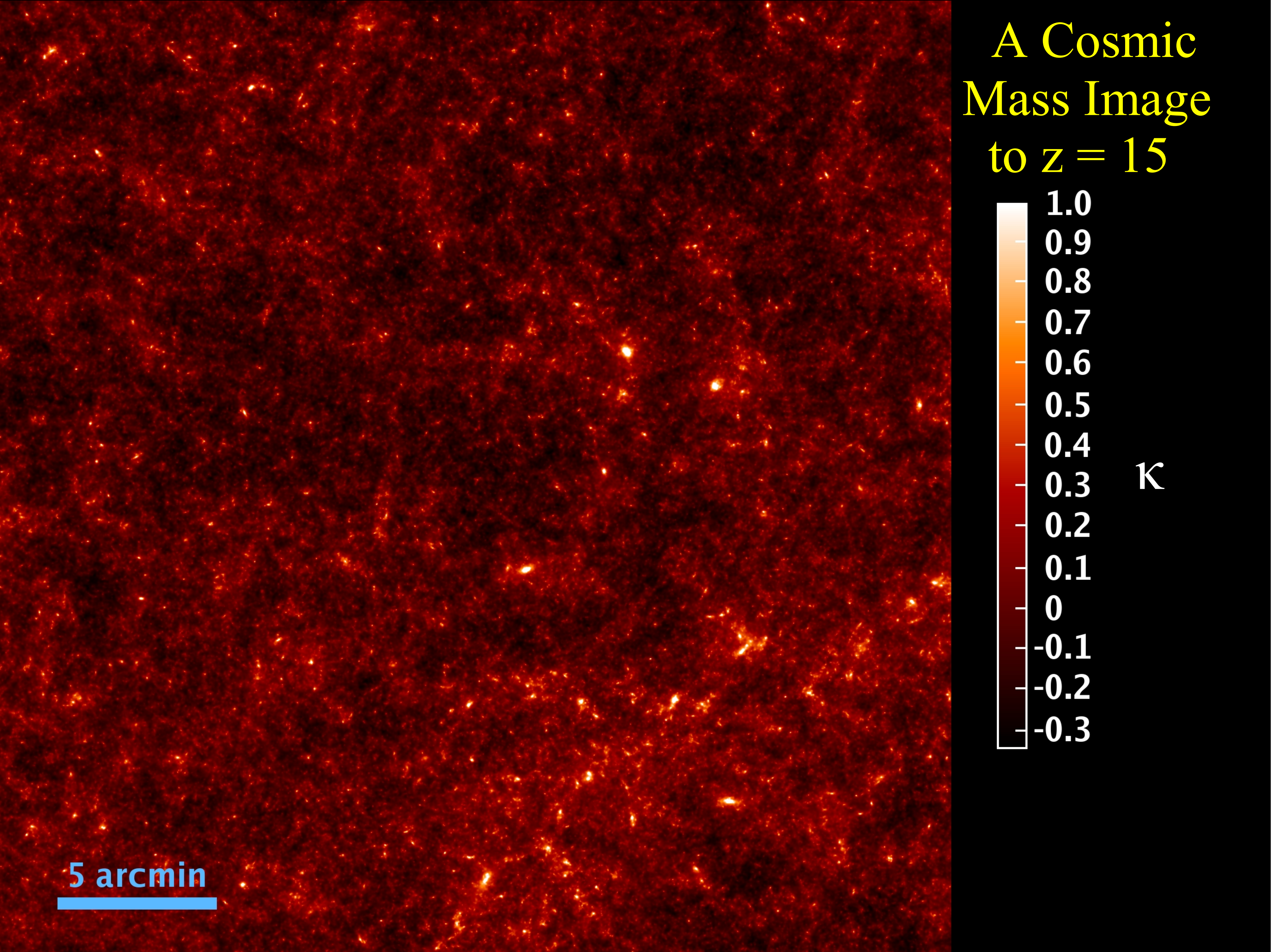
(Increased resolution, light-gathering power, smaller field)

- Reaching more distant and different types of galaxies for archaeological (resolved star) studies
- Exploring BH feeding in nearby systems
- Structure and kinematics in distant (lensed?) galaxies
- Spectroscopic stellar population studies at high redshift
- Studying in/outflows through absorption line studies of hi-z galaxies
- BH mass determinations and QSO host studies at high redshift

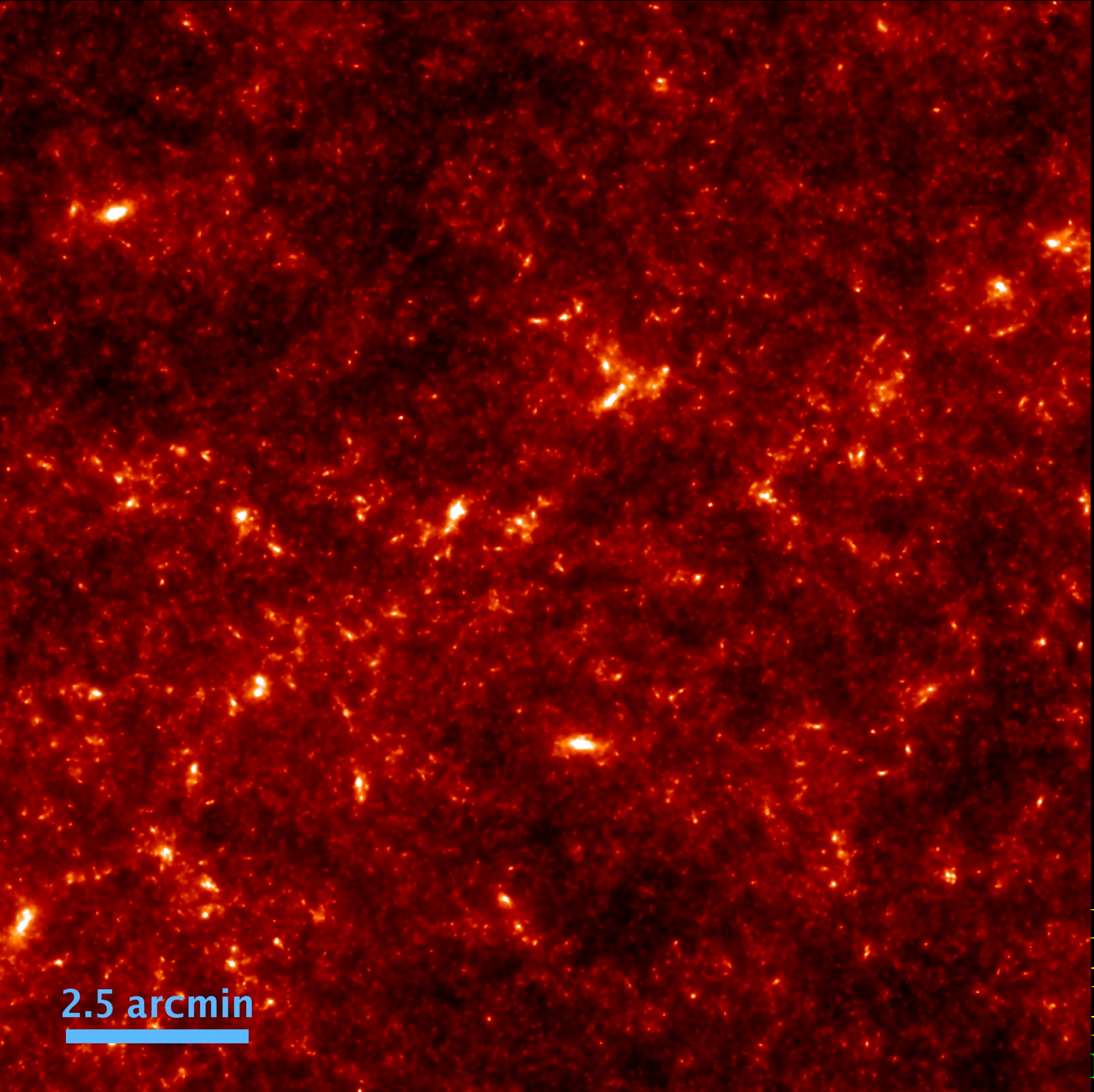
Challenges

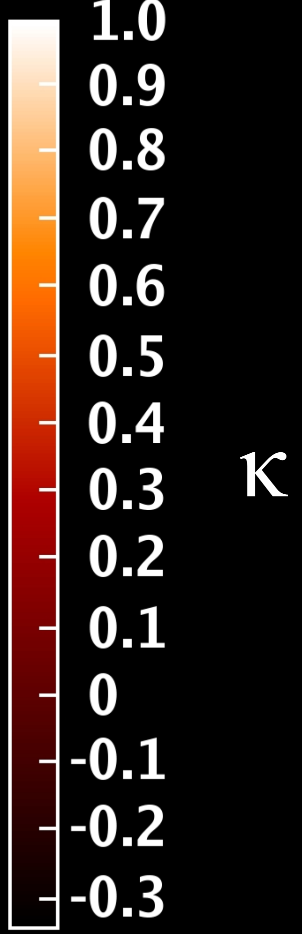
- Assembling big enough spectroscopic samples for population studies
- Characterising the dominant gas component at high redshift


A Cosmic Mass Image to z = 15
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
κ
10 arcmin


A Cosmic Mass Image to z = 15
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
κ
5 arcmin

A Cosmic Mass Image to z = 15





Resolution and S/N feasible with a low-frequency radio ELT

Metcalf & White 2006