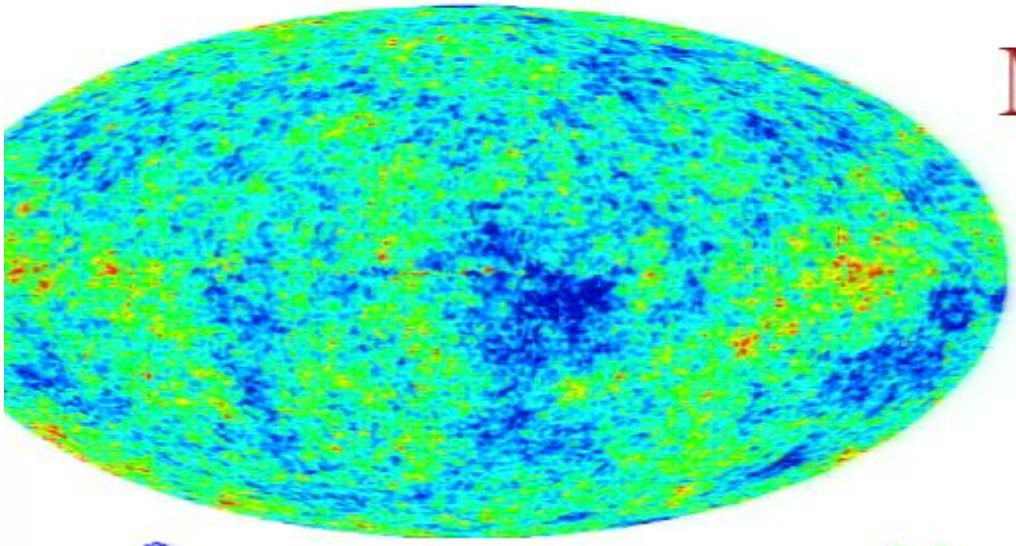
Title: Modeling the Galaxy Population

Date: Mar 29, 2011 02:00 PM

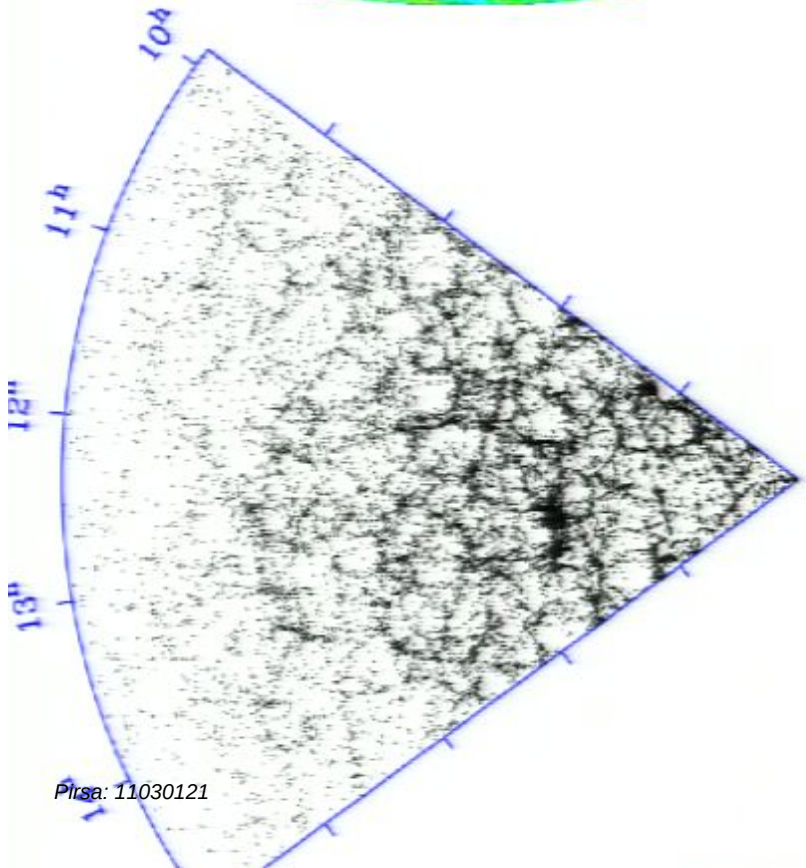
URL: http://pirsa.org/11030121

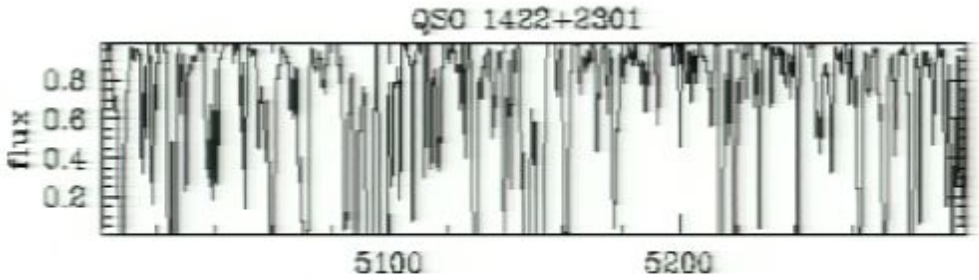
Abstract: TBA

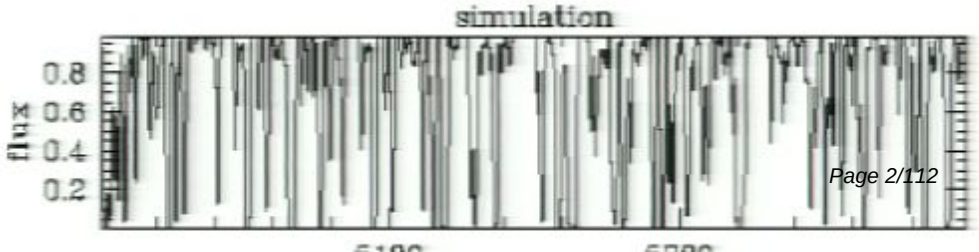


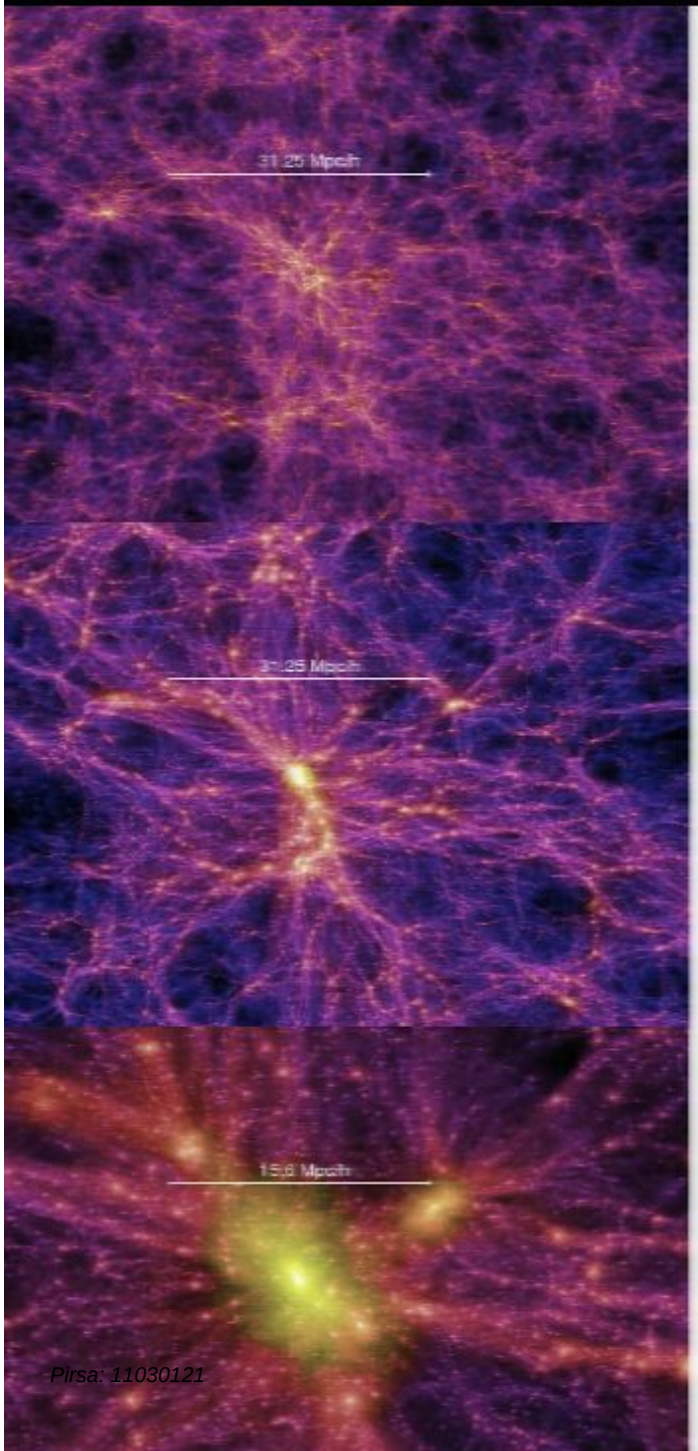
Modelling the galaxy population

Simon White
Max Planck Institut für Astrophysik







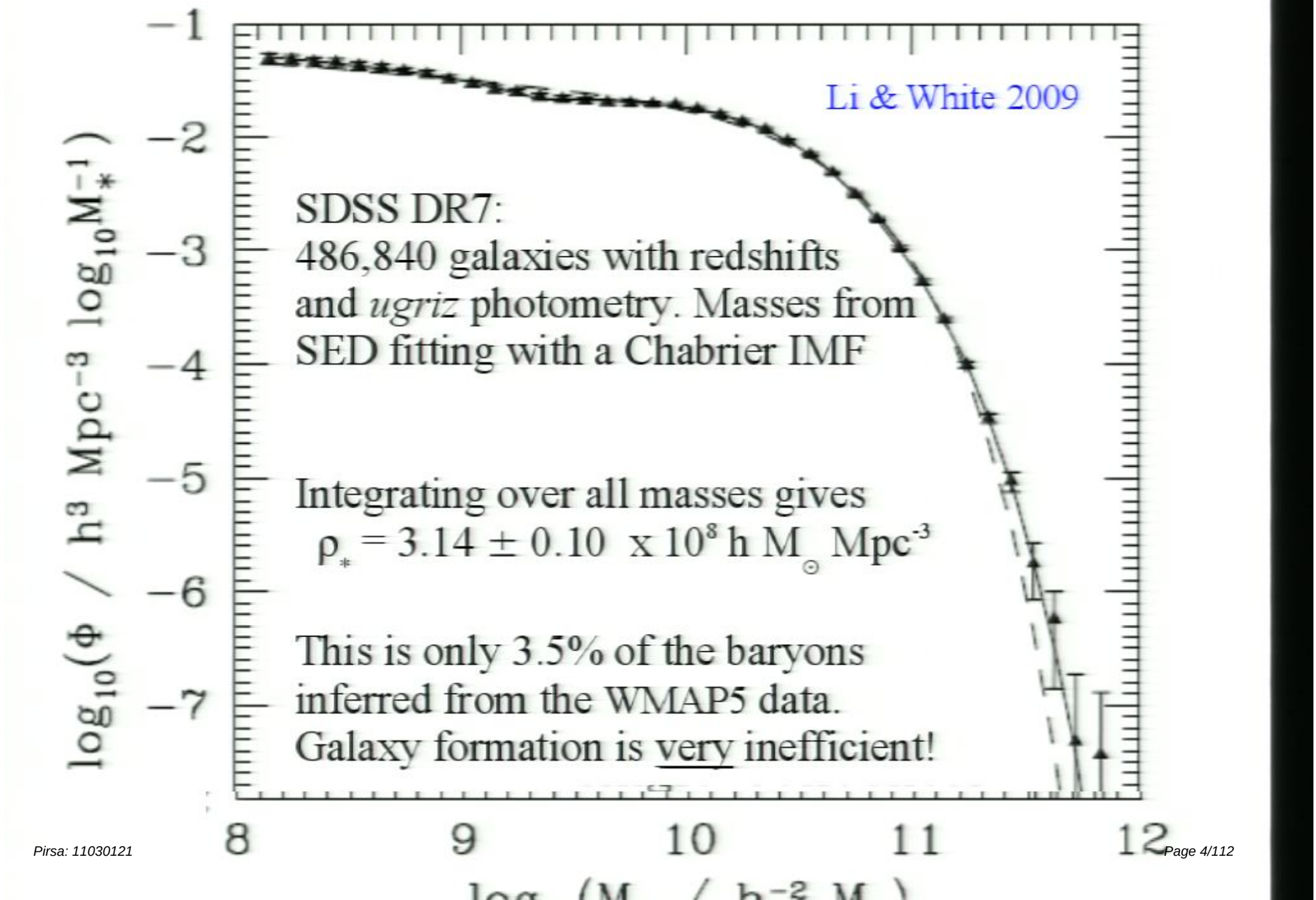


- The standard model reproduces
  - -- the linear initial conditions
  - -- IGM structure during galaxy formation
  - -- large-scale structure today
- Simulation of the standard model gives *precise* predictions for the
  - -- abundance
  - -- internal structure
  - -- assembly history
  - -- spatial/peculiar velocity distributions
  - -- merger rates

  of DM halos at all redshifts

How do galaxies form and evolve within this frame?

Can their formation and evolution be


Li & White 2009
SDSS DR7:
486,840 galaxies with redshifts
and *ugriz* photometry. Masses from
SED fitting with a Chabrier IMF
Integrating over all masses gives
$\rho_* = 3.14 \pm 0.10 \times 10^8$ h $M_\odot$ Mpc^{-3}
This is only 3.5% of the baryons
inferred from the WMAP5 data.
Galaxy formation is very inefficient!
$\log_{10}(\Phi / h^3\ \mathrm{Mpc}^{-3}\ \log_{10} M_*^{-1})$
−1
−2
−3
−4
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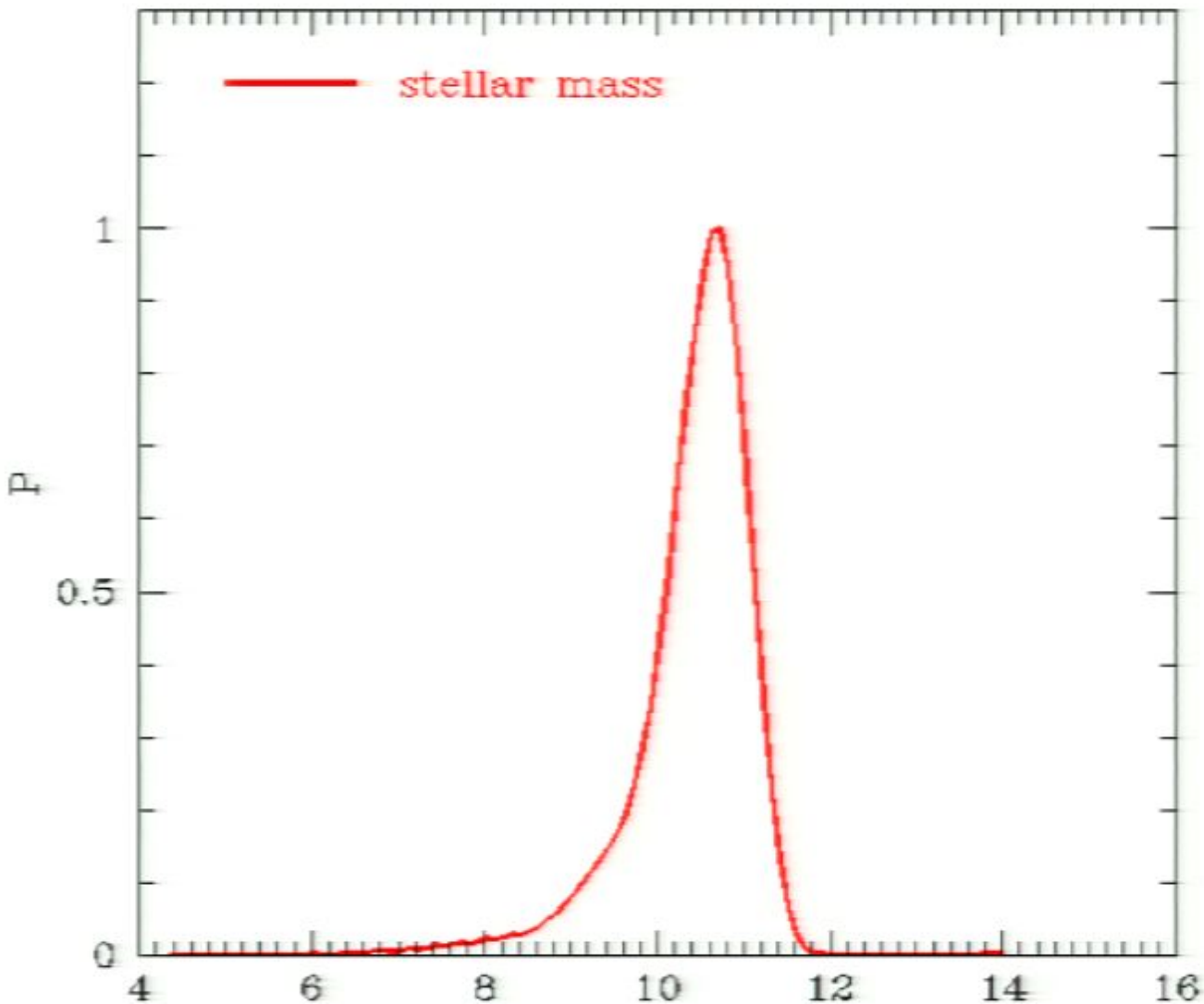
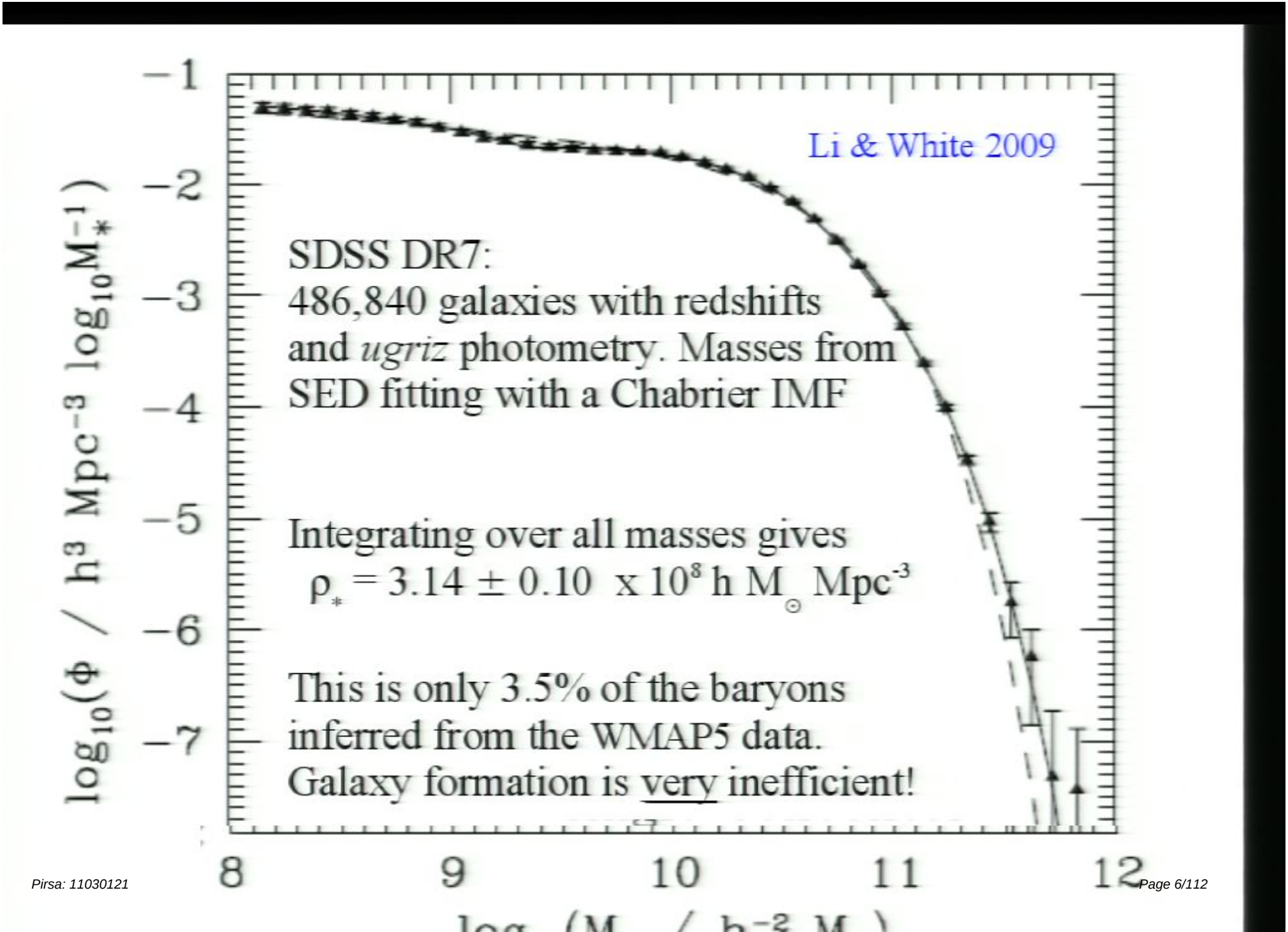
−7
8
9
10
11
12

Most stars are in galaxies with similar stellar mass to the Milky Way

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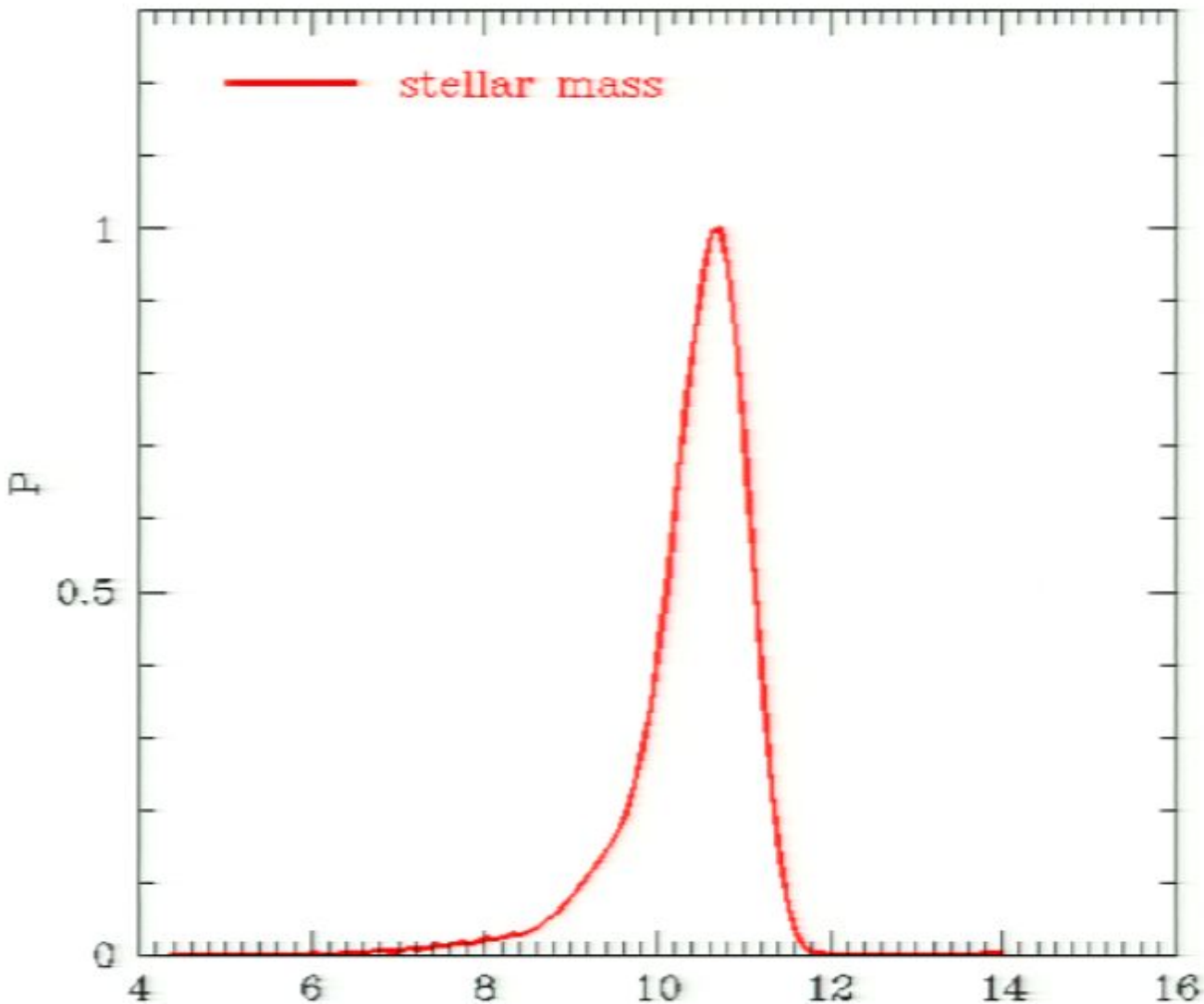

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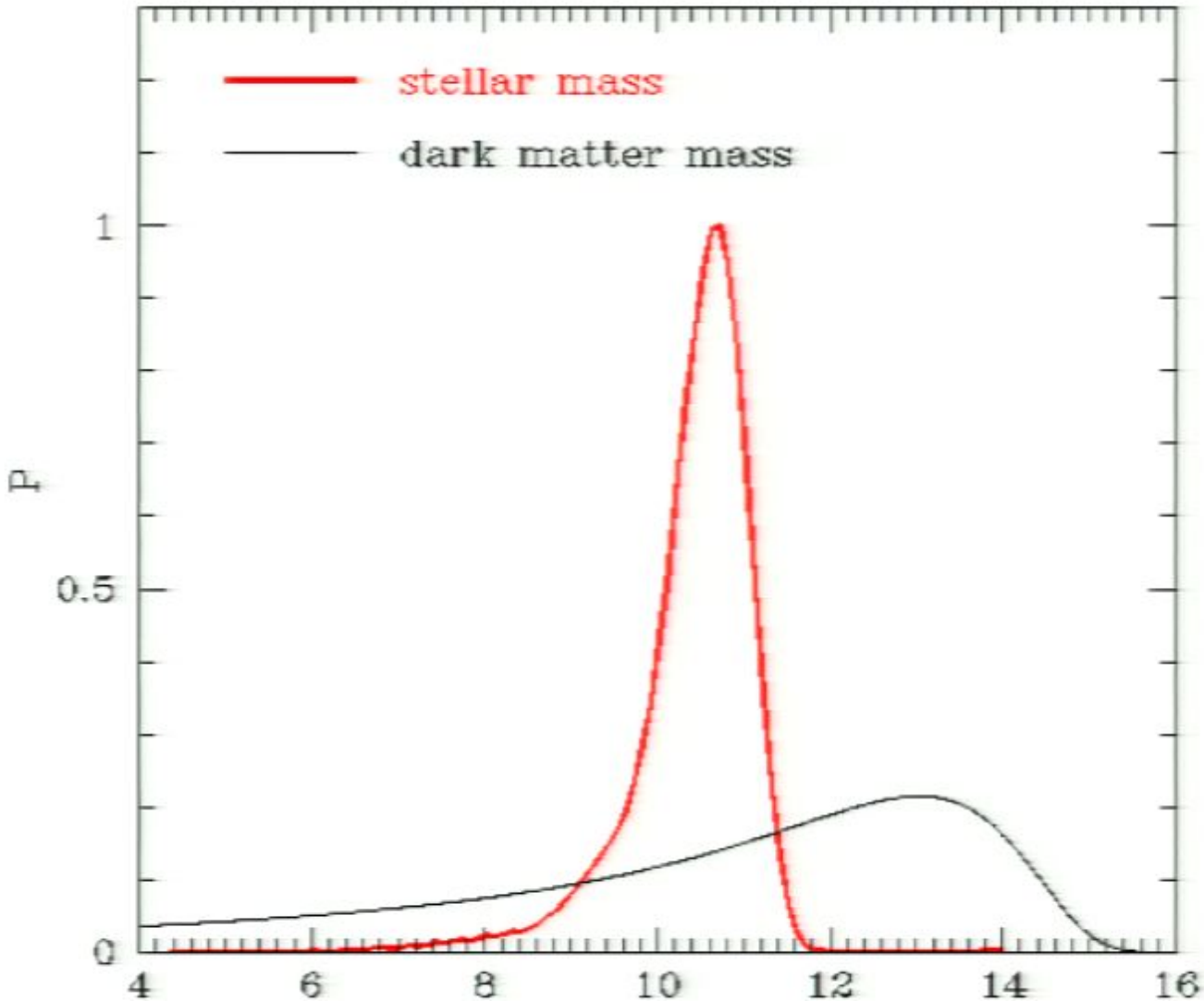

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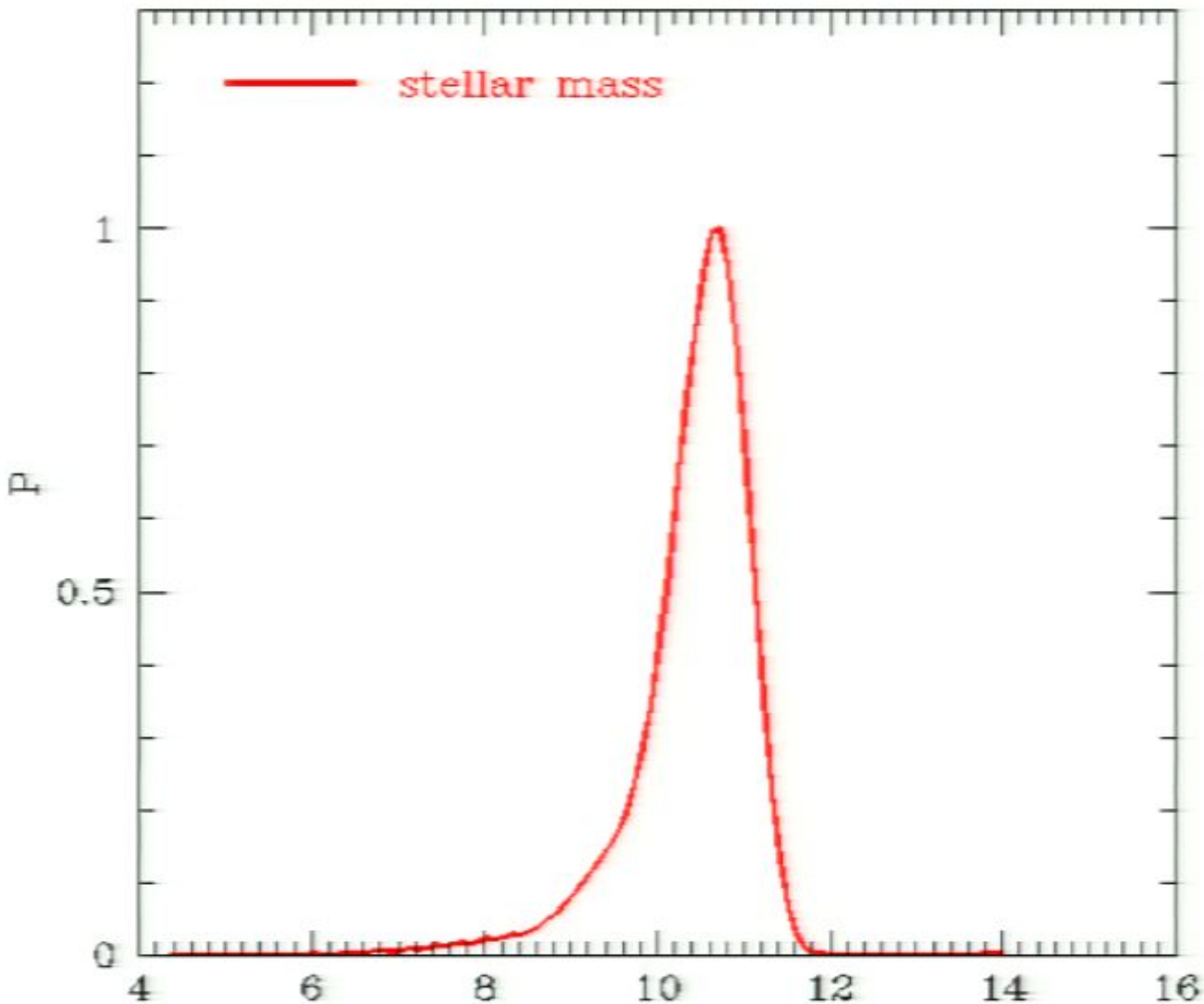

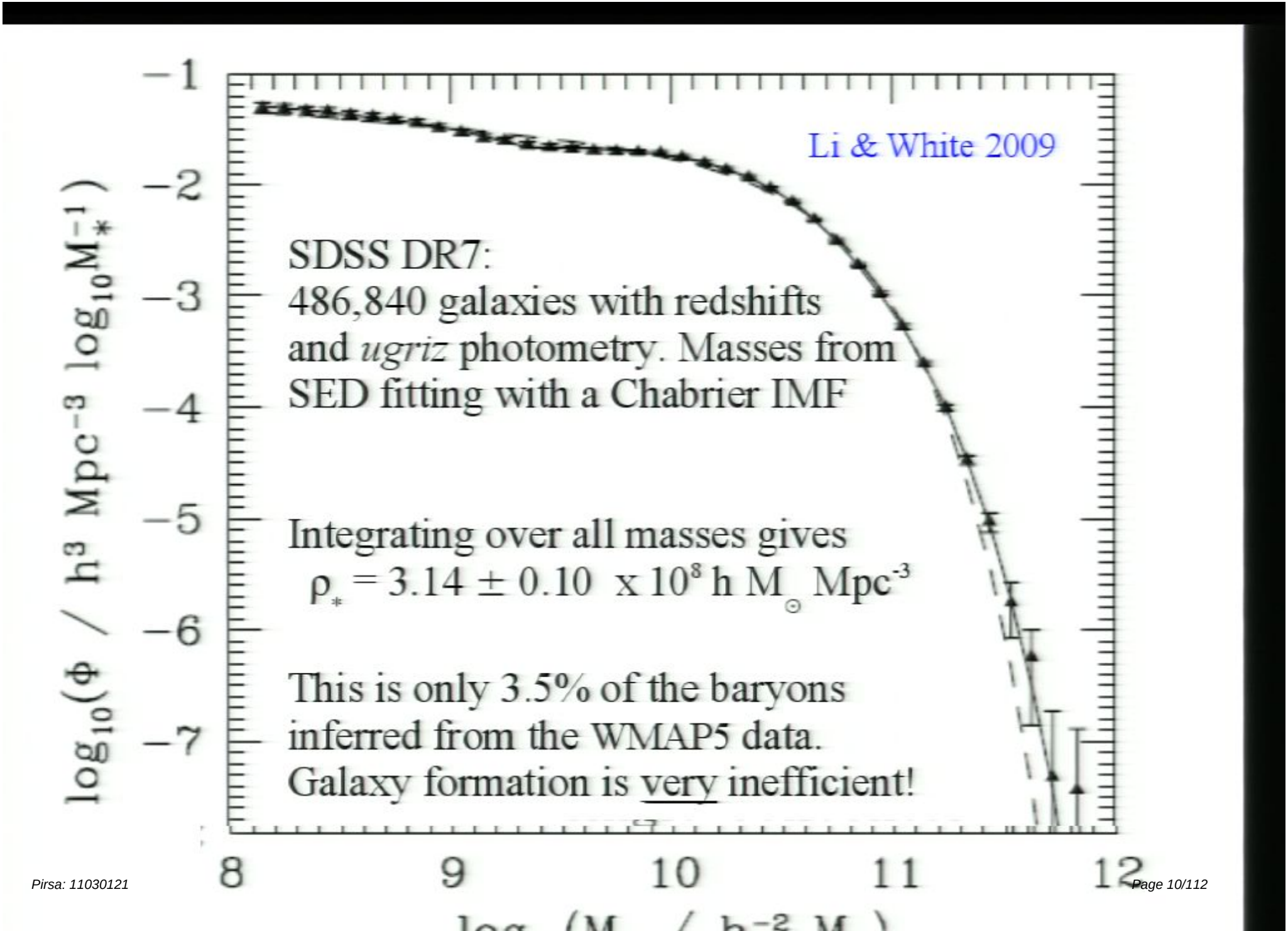
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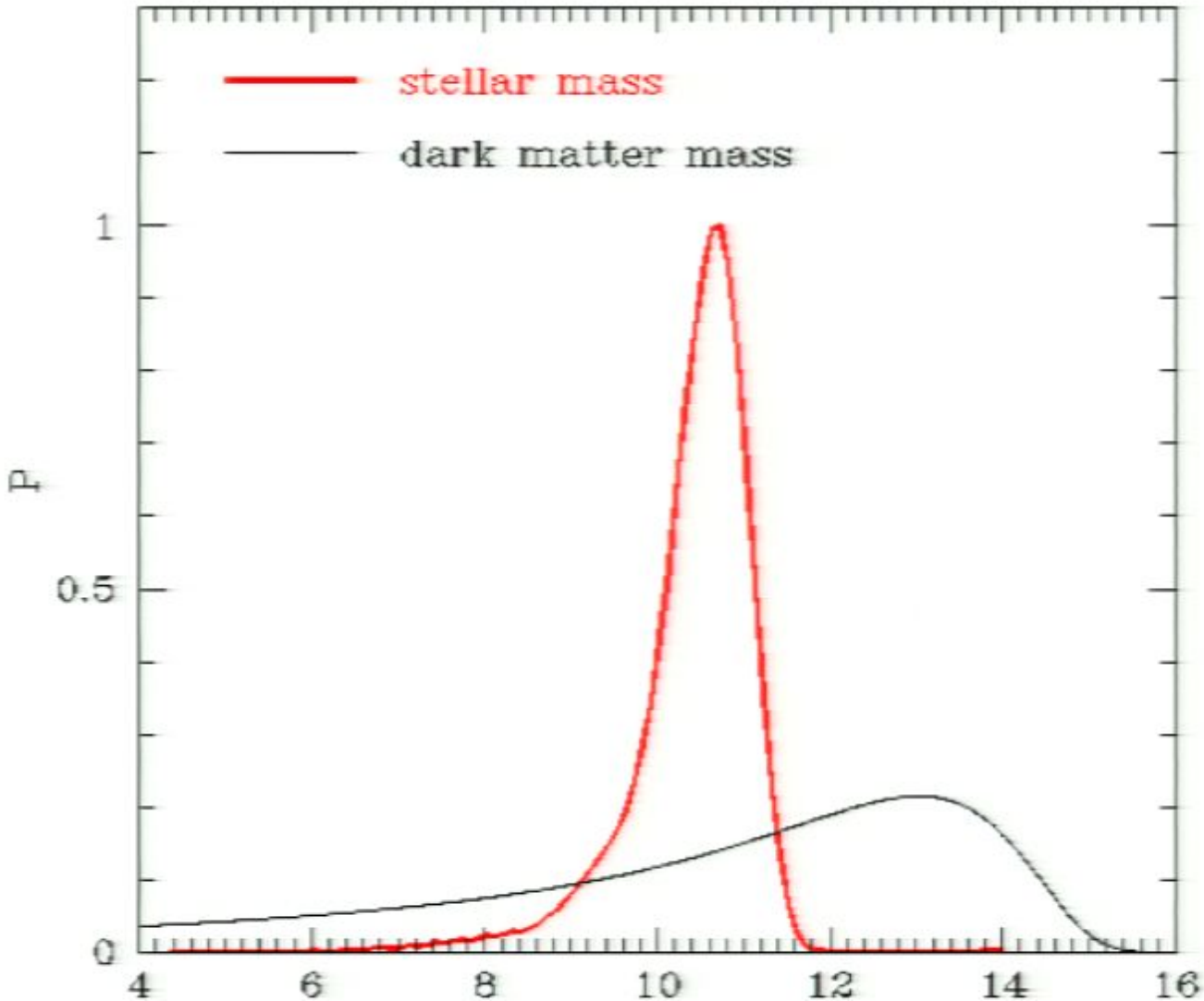
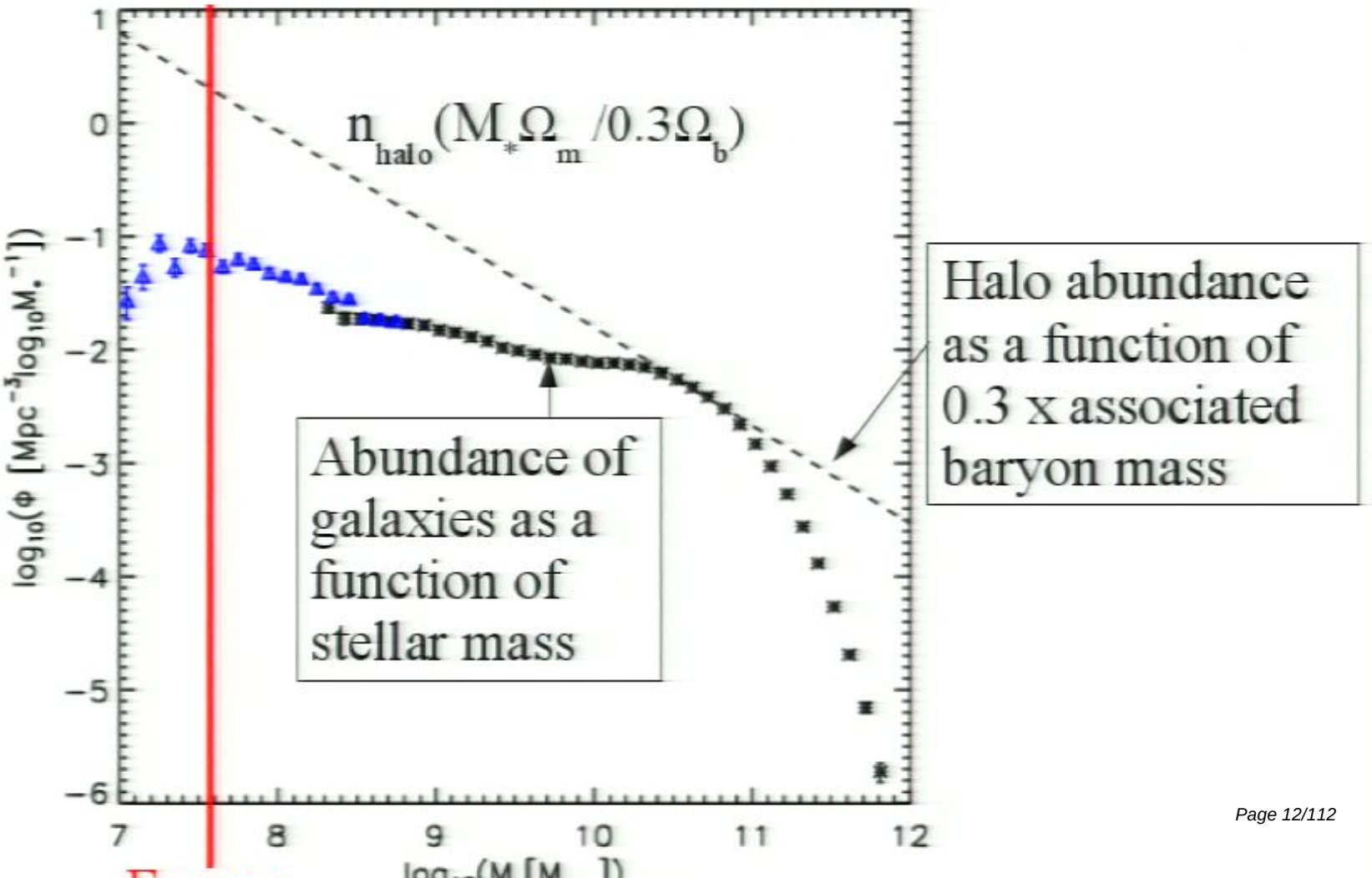


The problem with matching dwarfs in ΛCDM

A formation efficiency which matches abundance of "Milky Ways" overproduces the number of "Fornax's" by a factor of 30!



counting argument to relate halo and galaxy masses

The SDSS/DR7 data give a precise measurement of the abundance of galaxies as a function of stellar mass threshold, $n(>M_*)$

High-resolution simulations allow all halos/subhalos massive enough to host z=0 galaxies to be identified

Define $M_{h,max}$ as the maximum mass *ever* attained by a halo/subhalo

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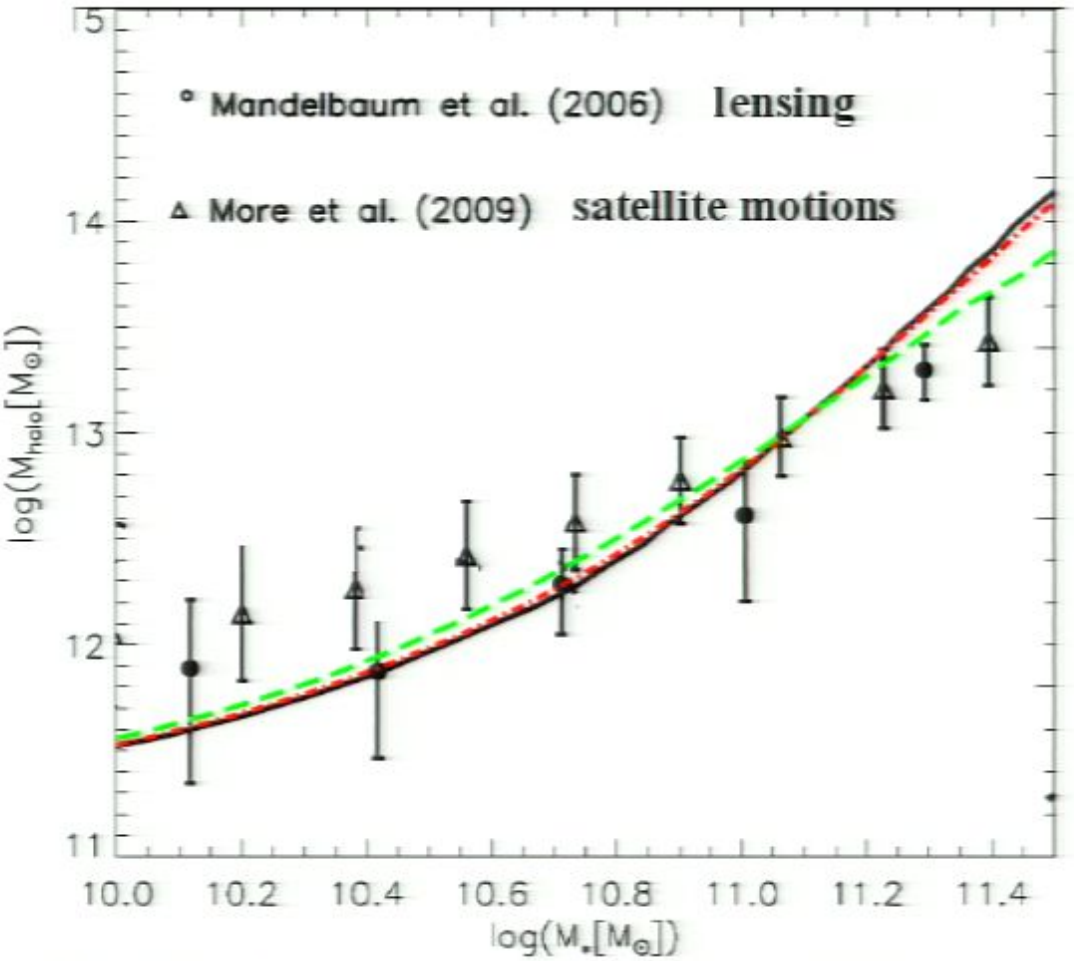
Ansatz: Assume the stellar mass of a galaxy to be a monotonically increasing function of the maximum mass ever attained by its halo

We can then derive $M_*(M_{h,max})$ by setting $n(>M_*) = n(>M_{h,max})$

Consistency of ΛCDM for galaxy halos

Guo et al 2010



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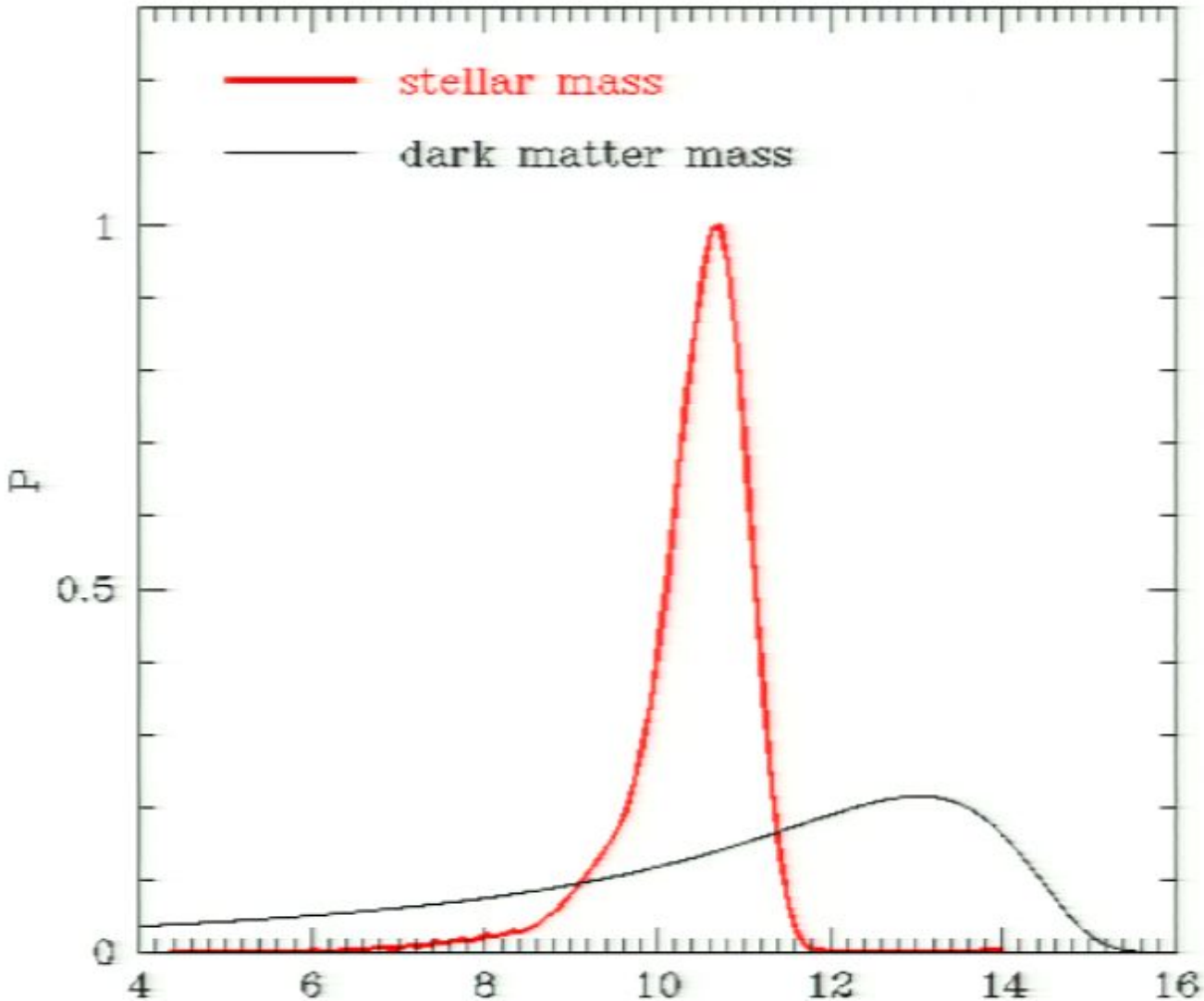

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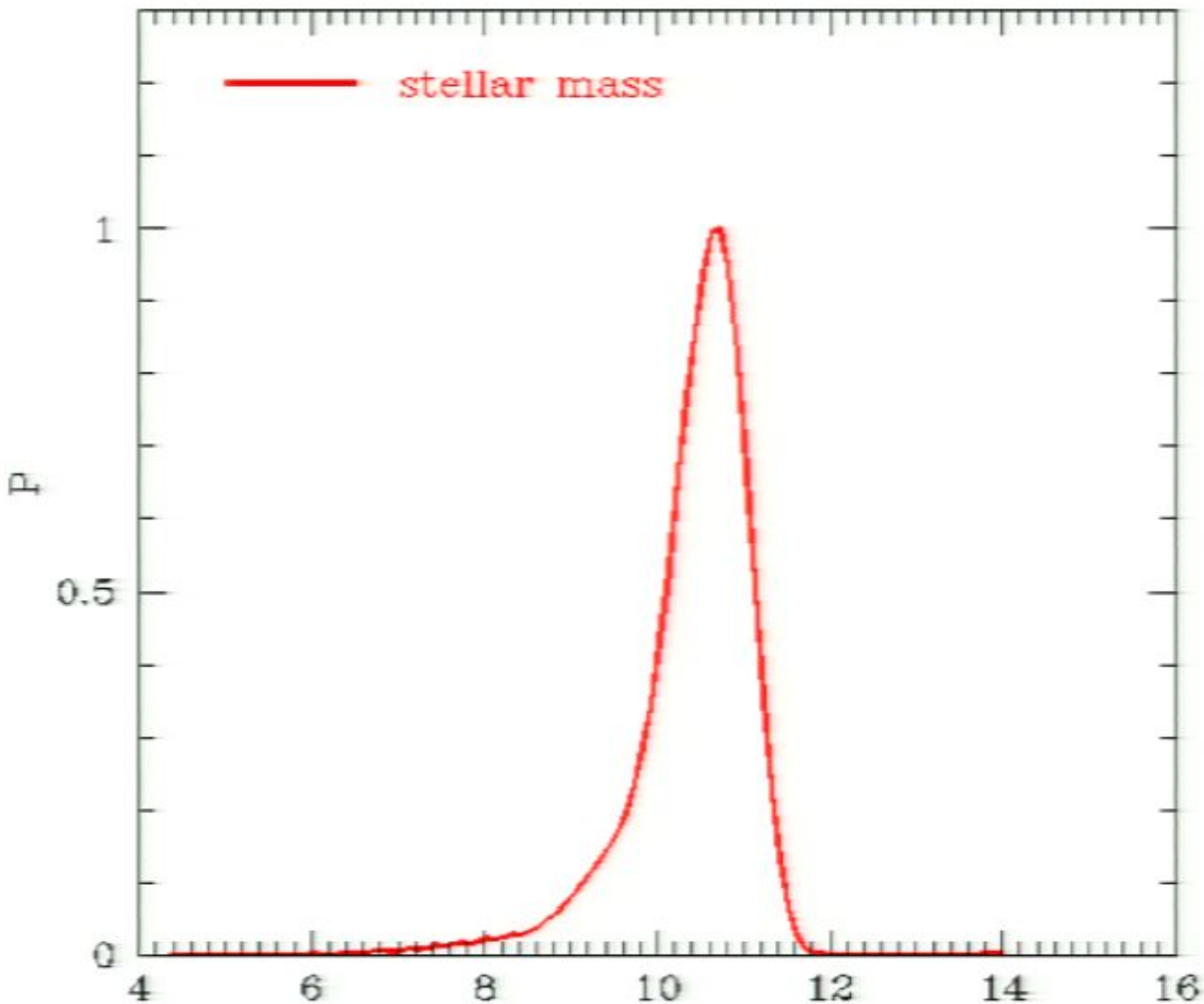

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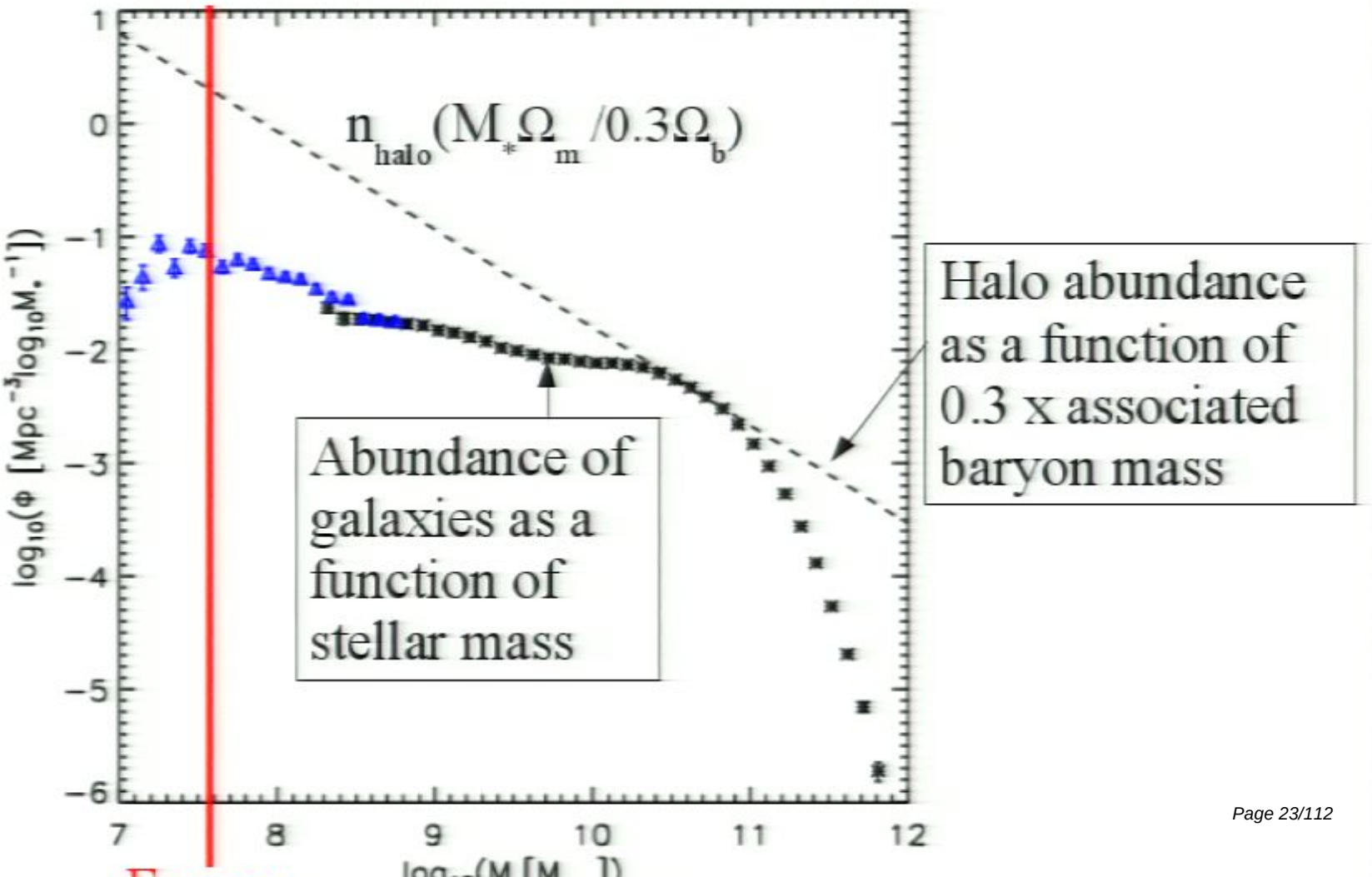

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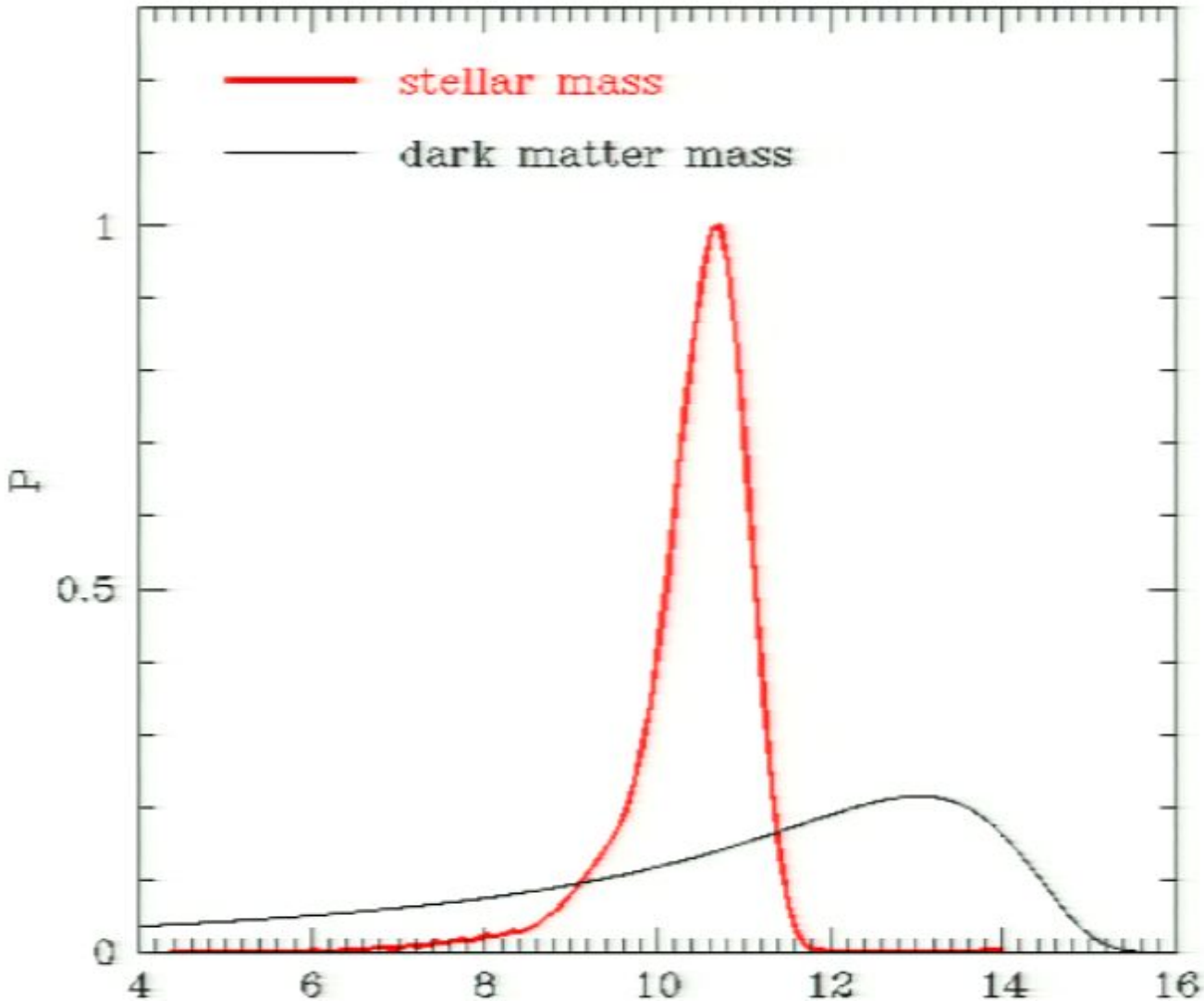

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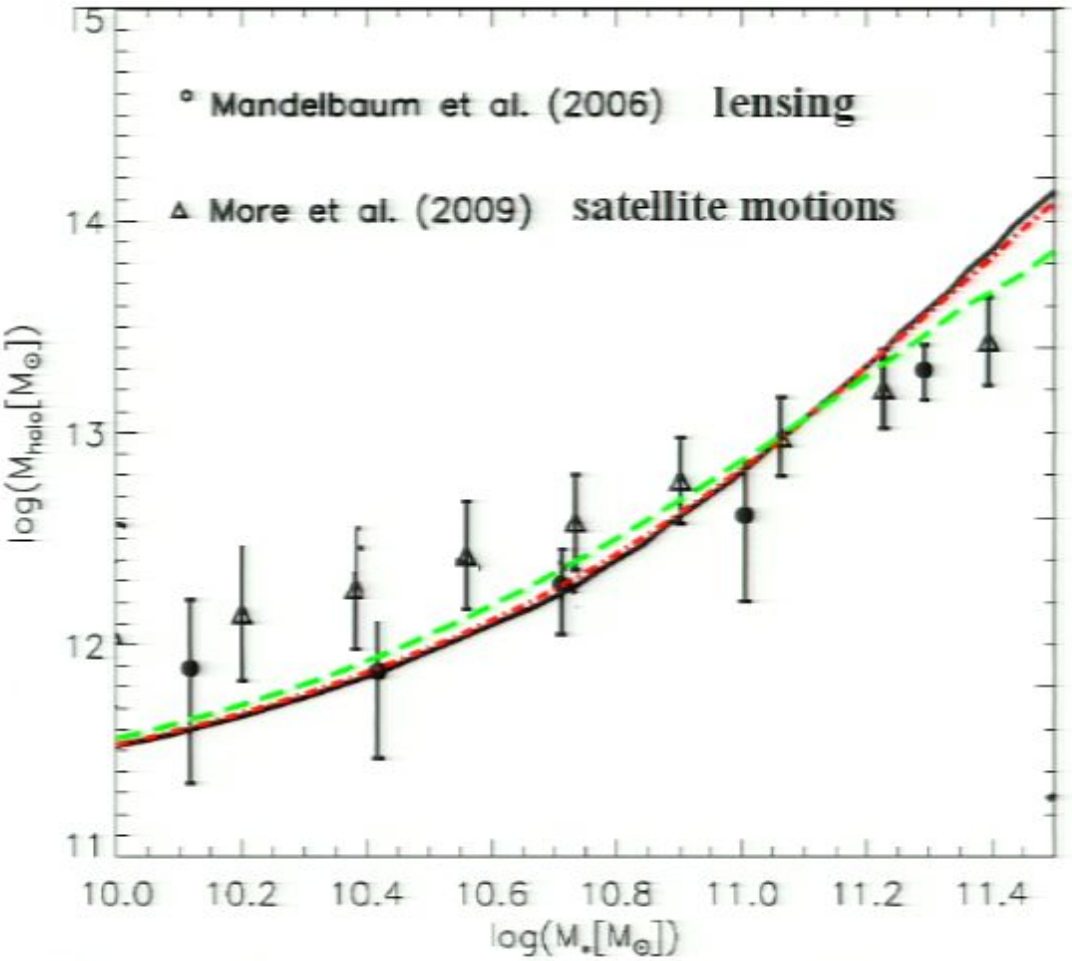

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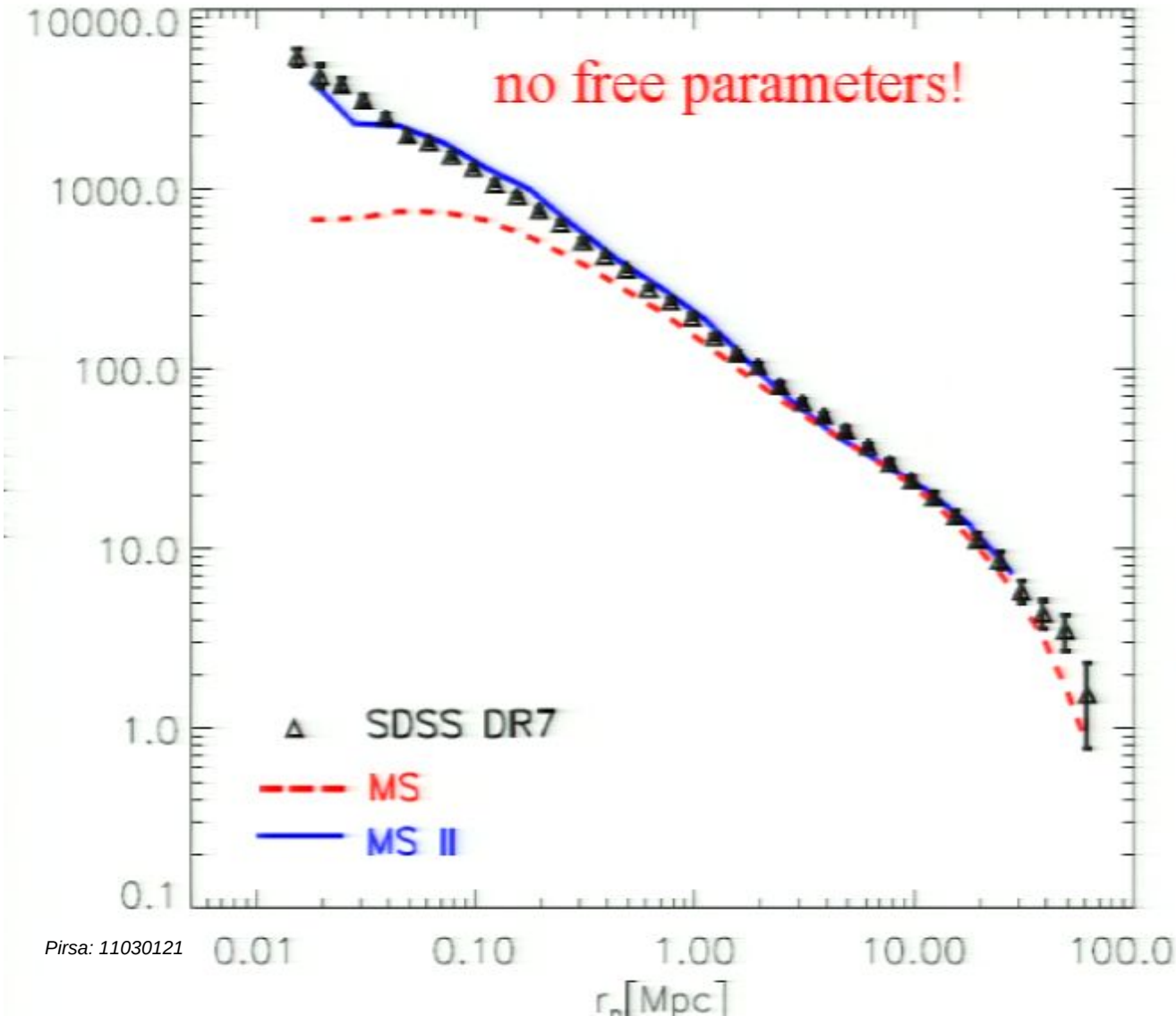
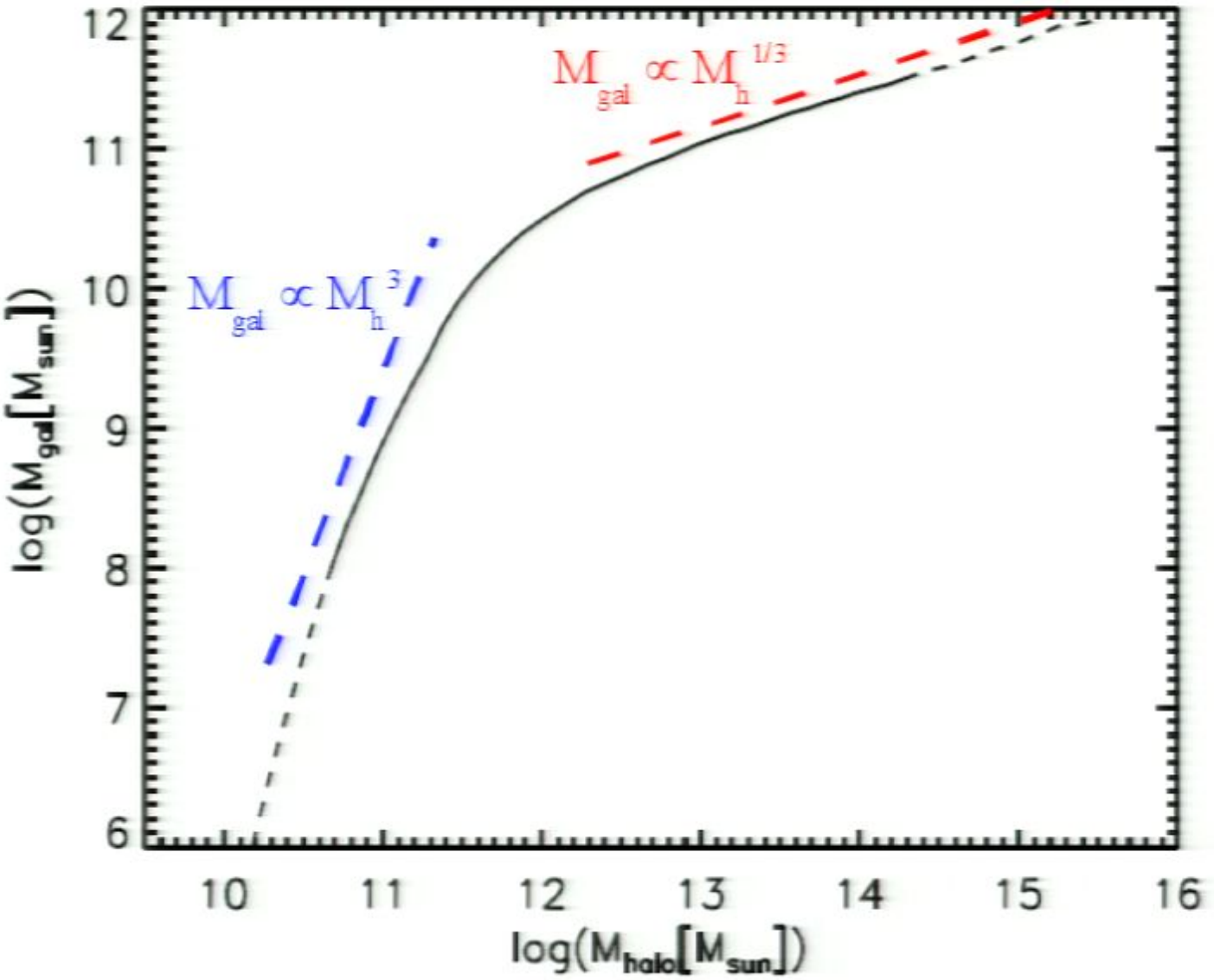
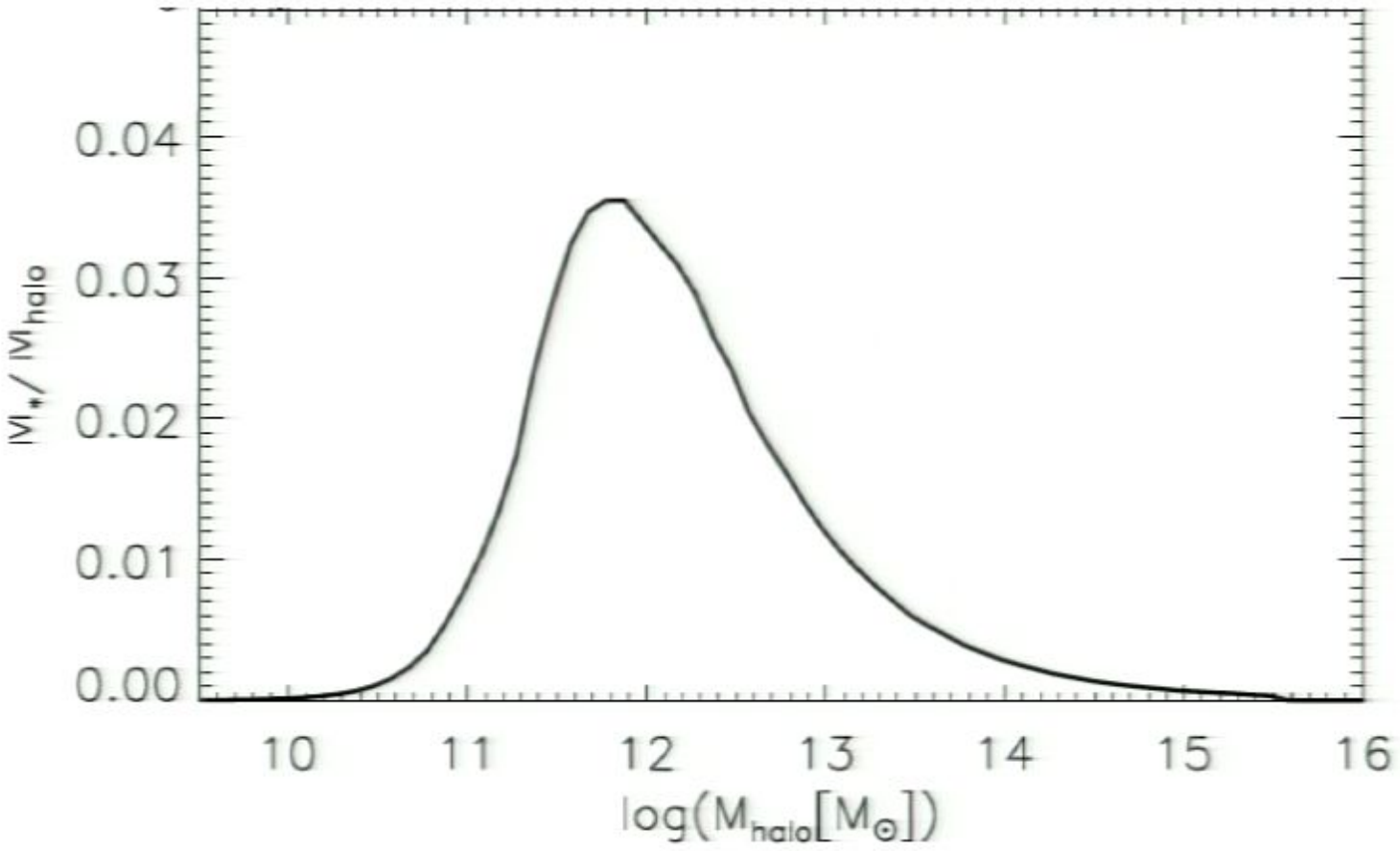


Populating halos/sub-halos by assigning galaxies as inferred by abundance matching to the stellar mass function gives an excellent fit to the observed clustering of stellar mass



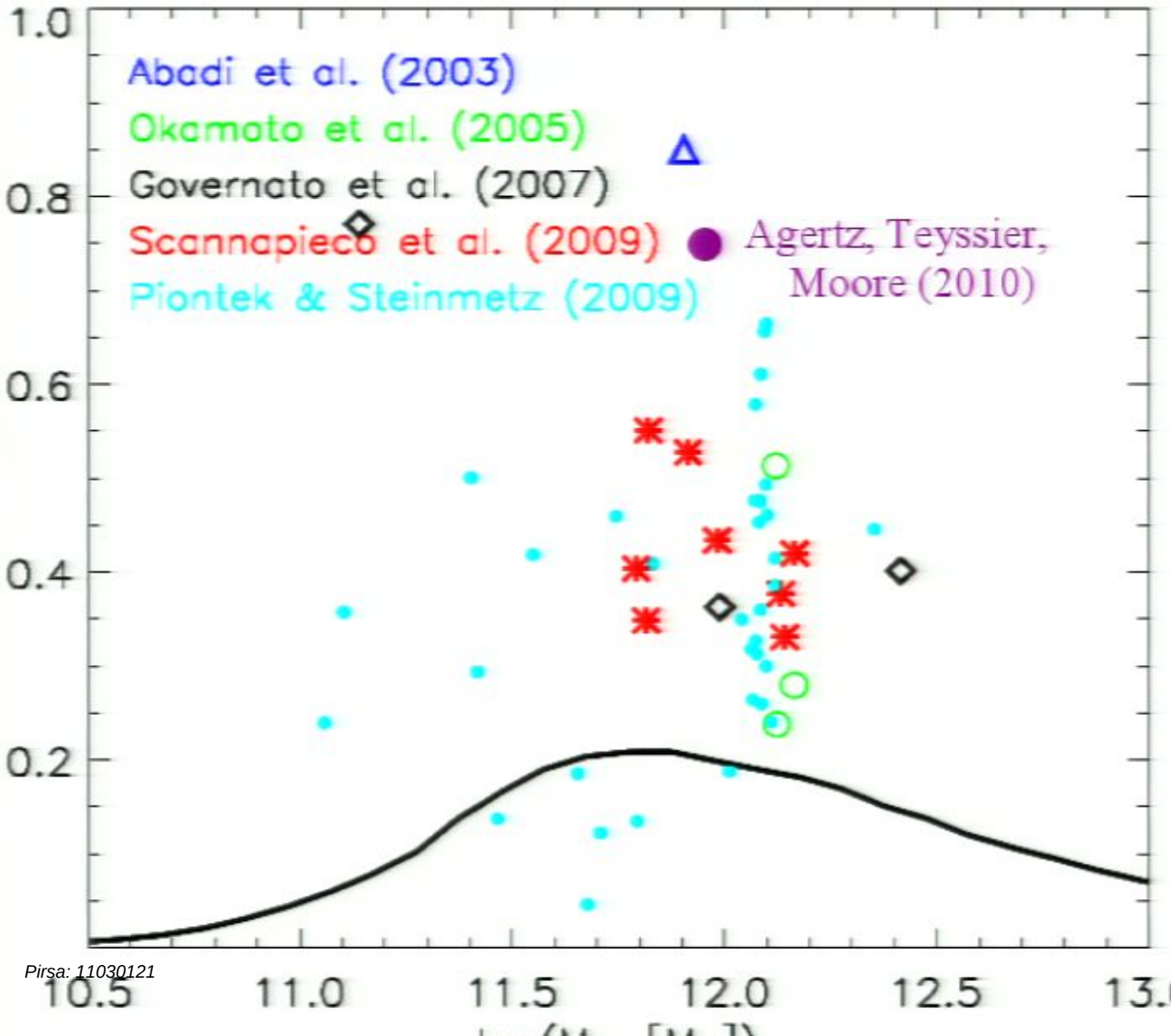
- The stellar mass of the central galaxy increases rapidly with halo mass at small halo mass, but slowly at large halo mass

The efficiency of galaxy formation is low!



The ratio of central galaxy stellar mass to maximum past halo mass *maximises* at just 3.5% at halo masses of $\sim 10^{12} M_\odot$

"Successful" simulations fail to match this...



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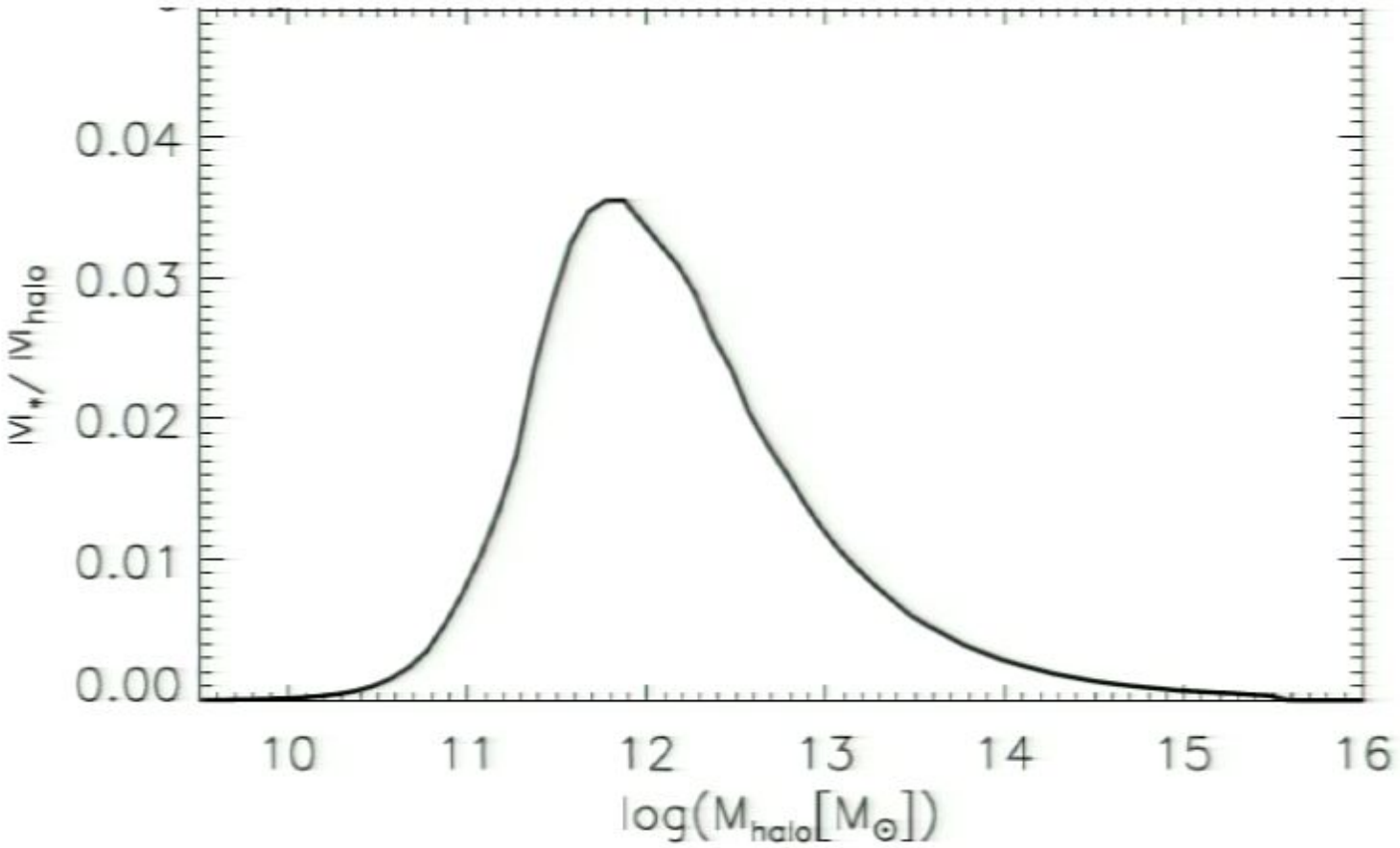

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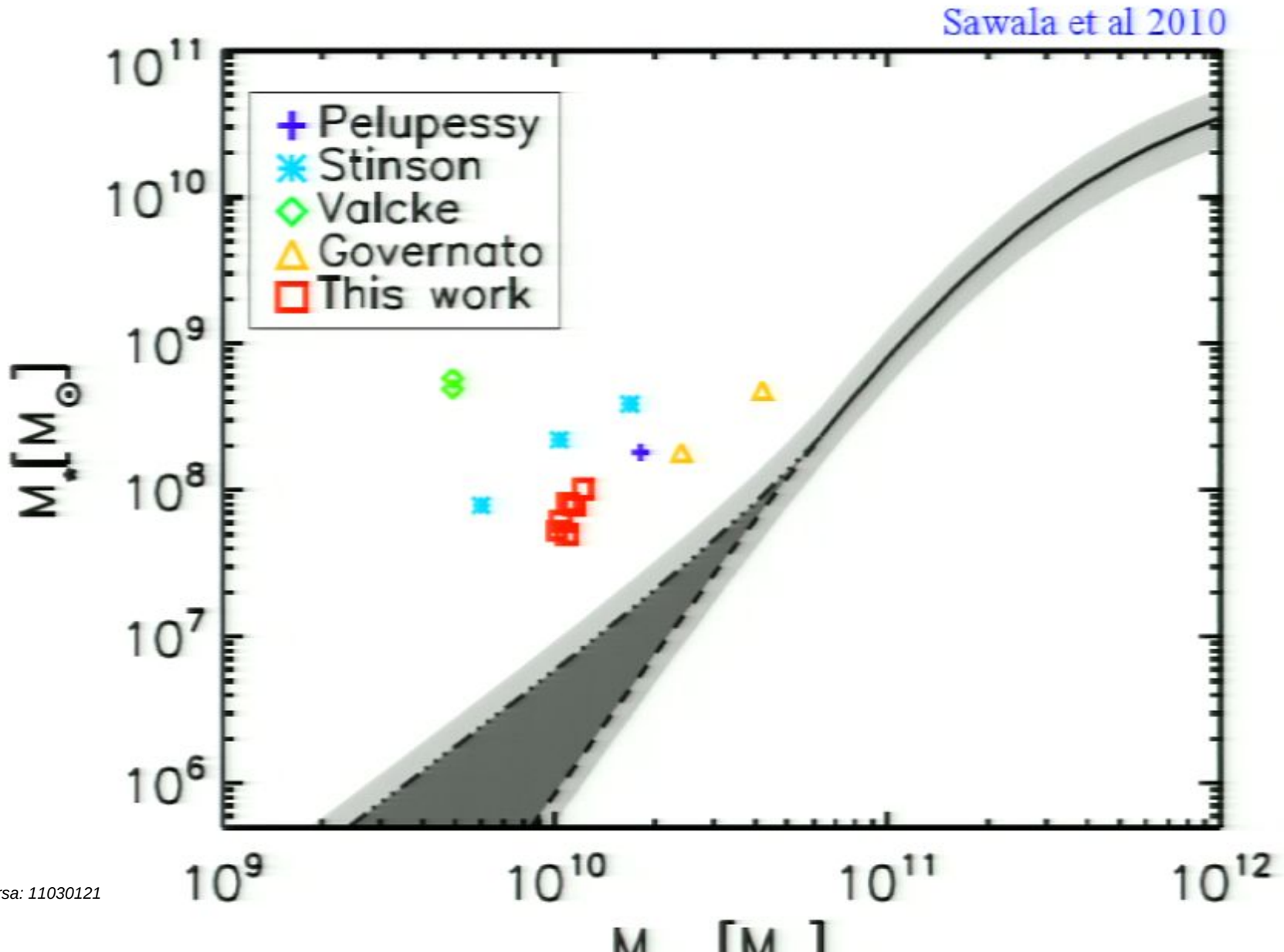

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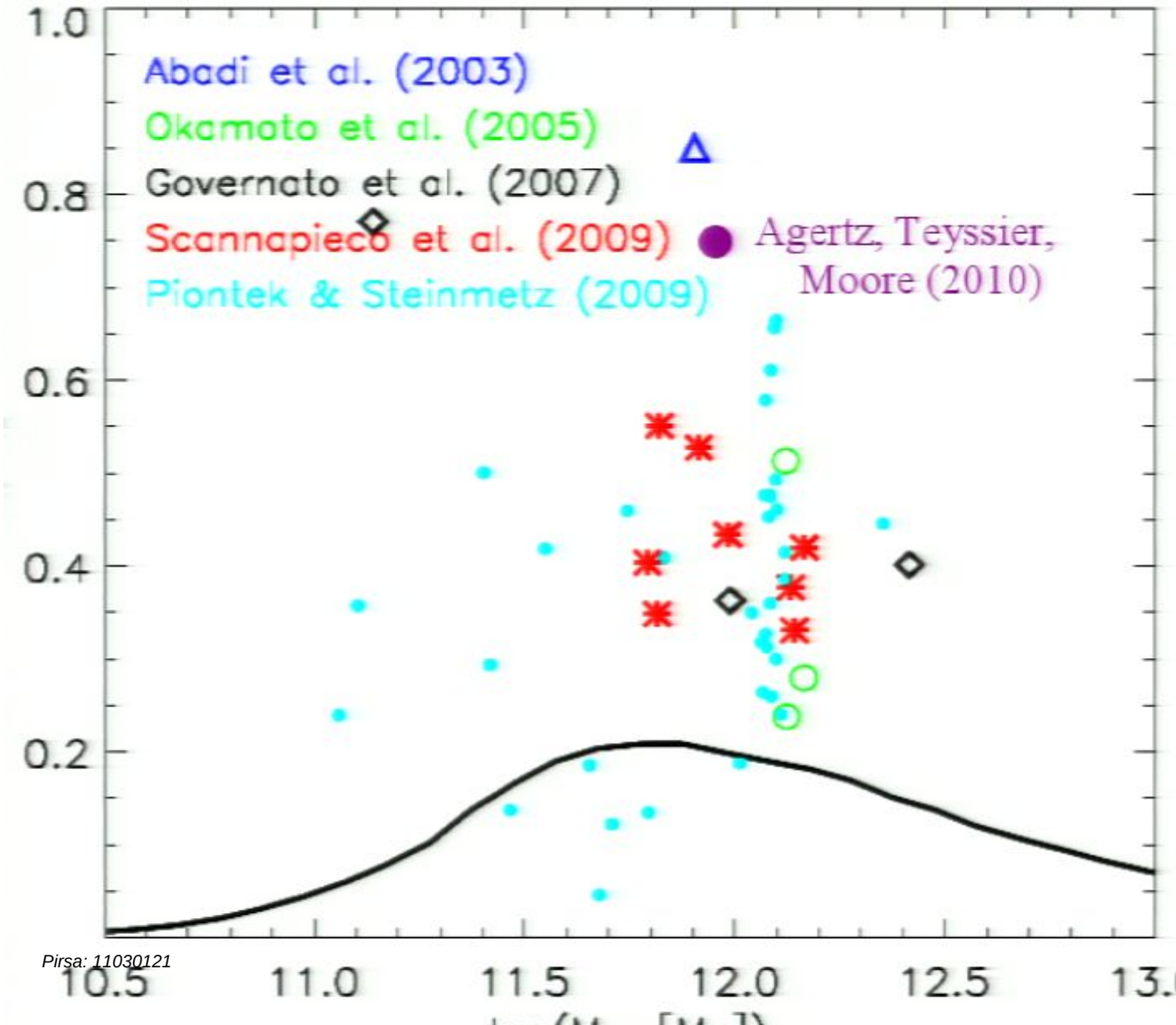

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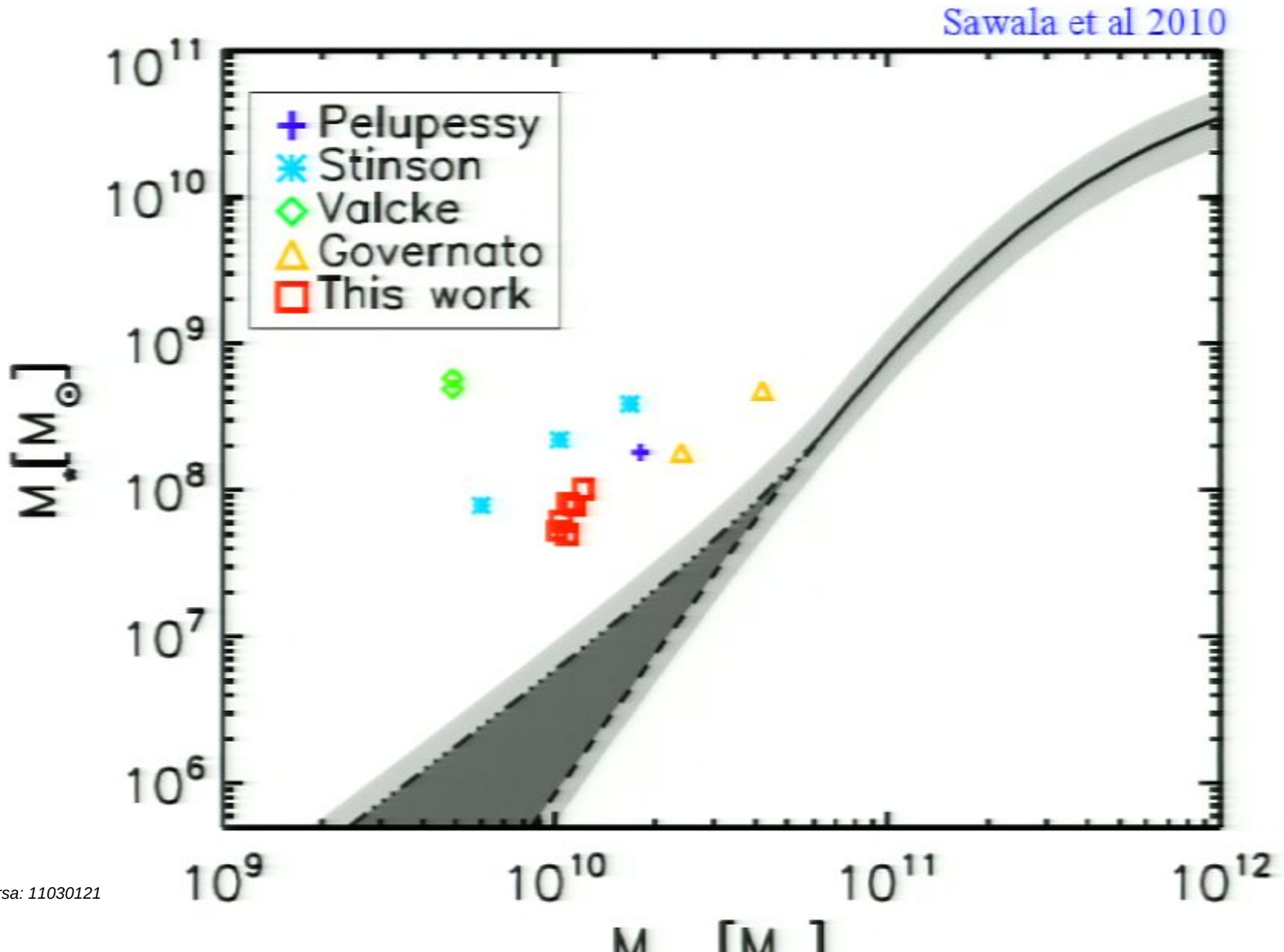
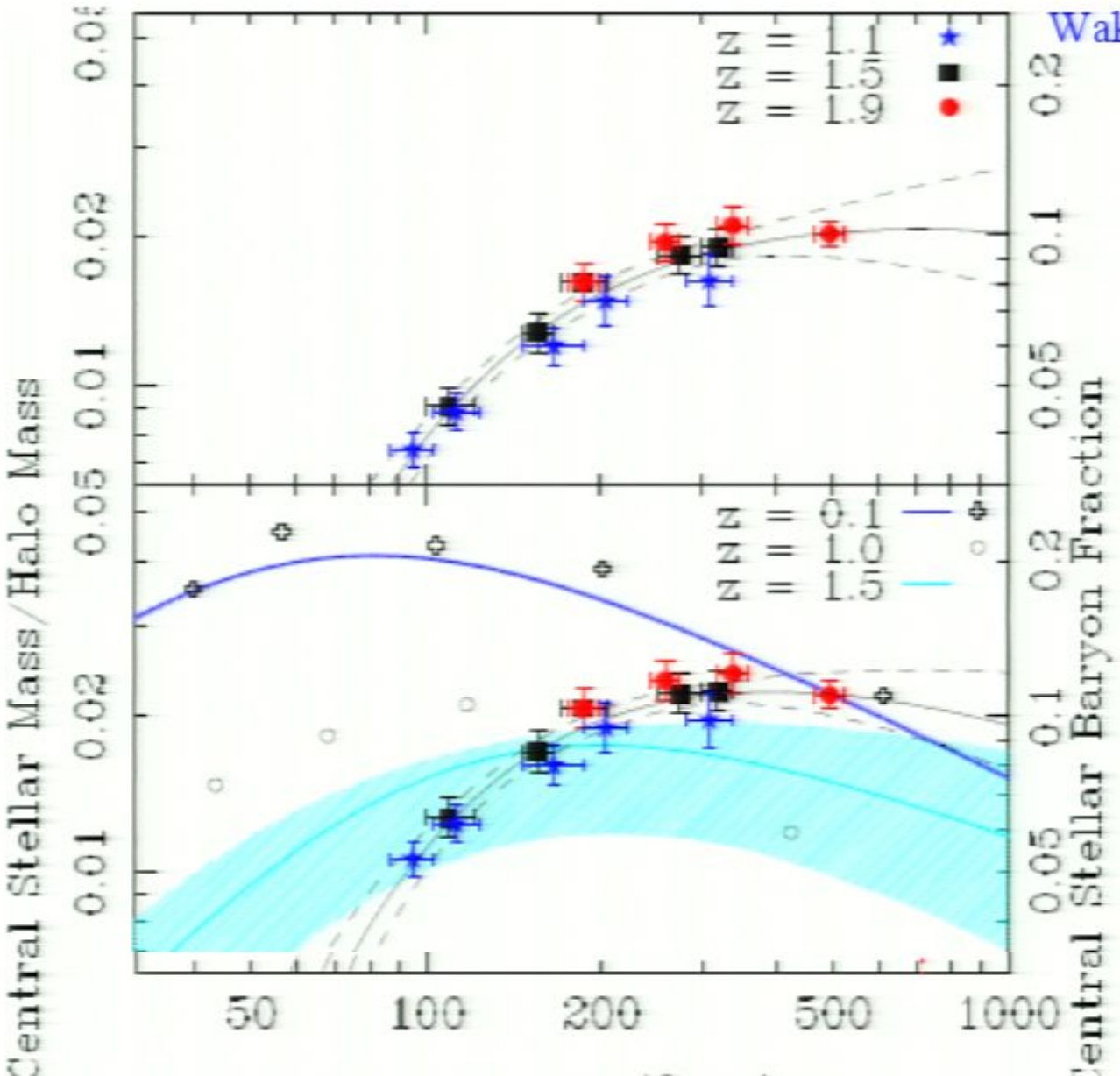


Formation efficiencies are lower at high z!



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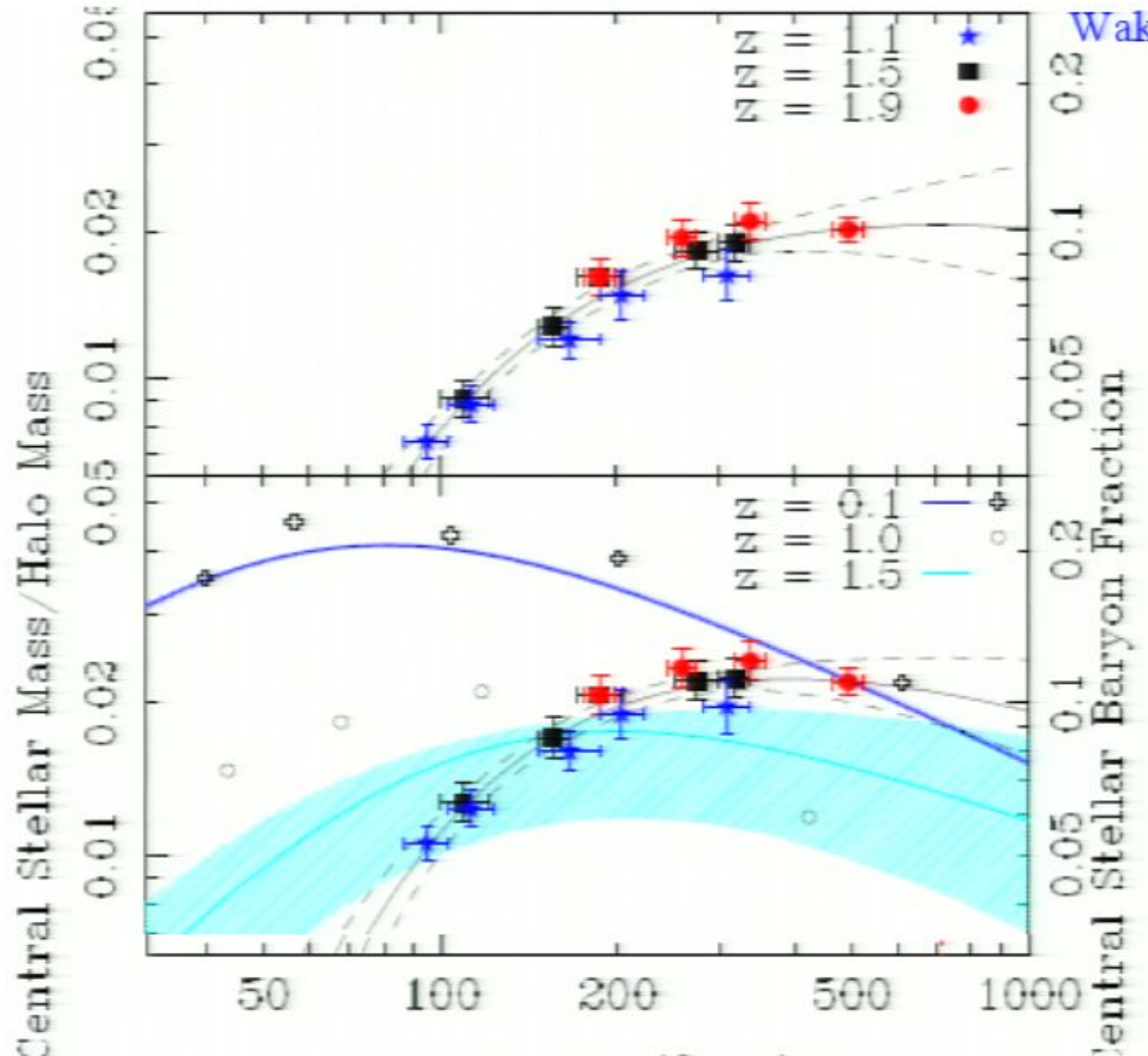
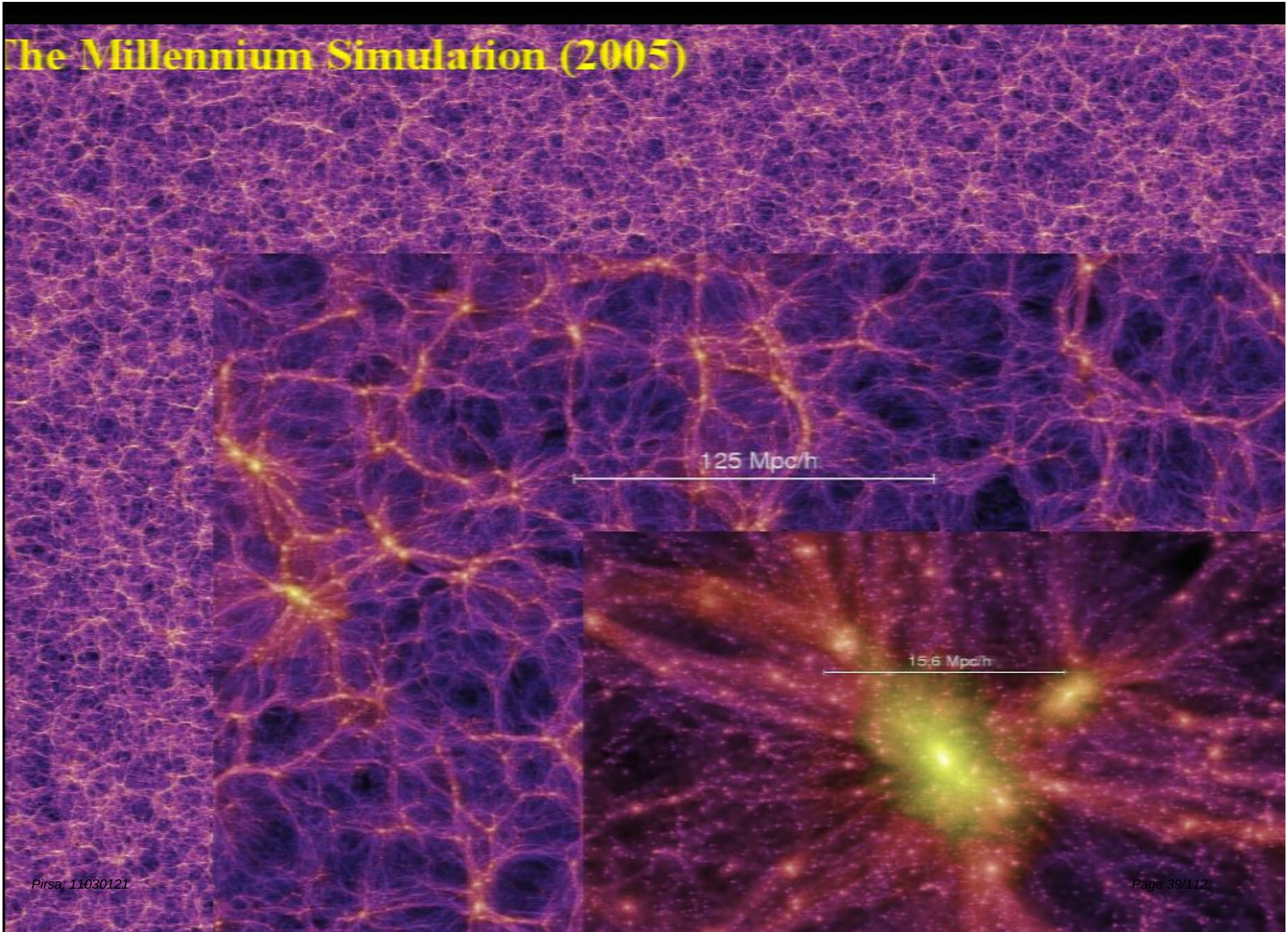
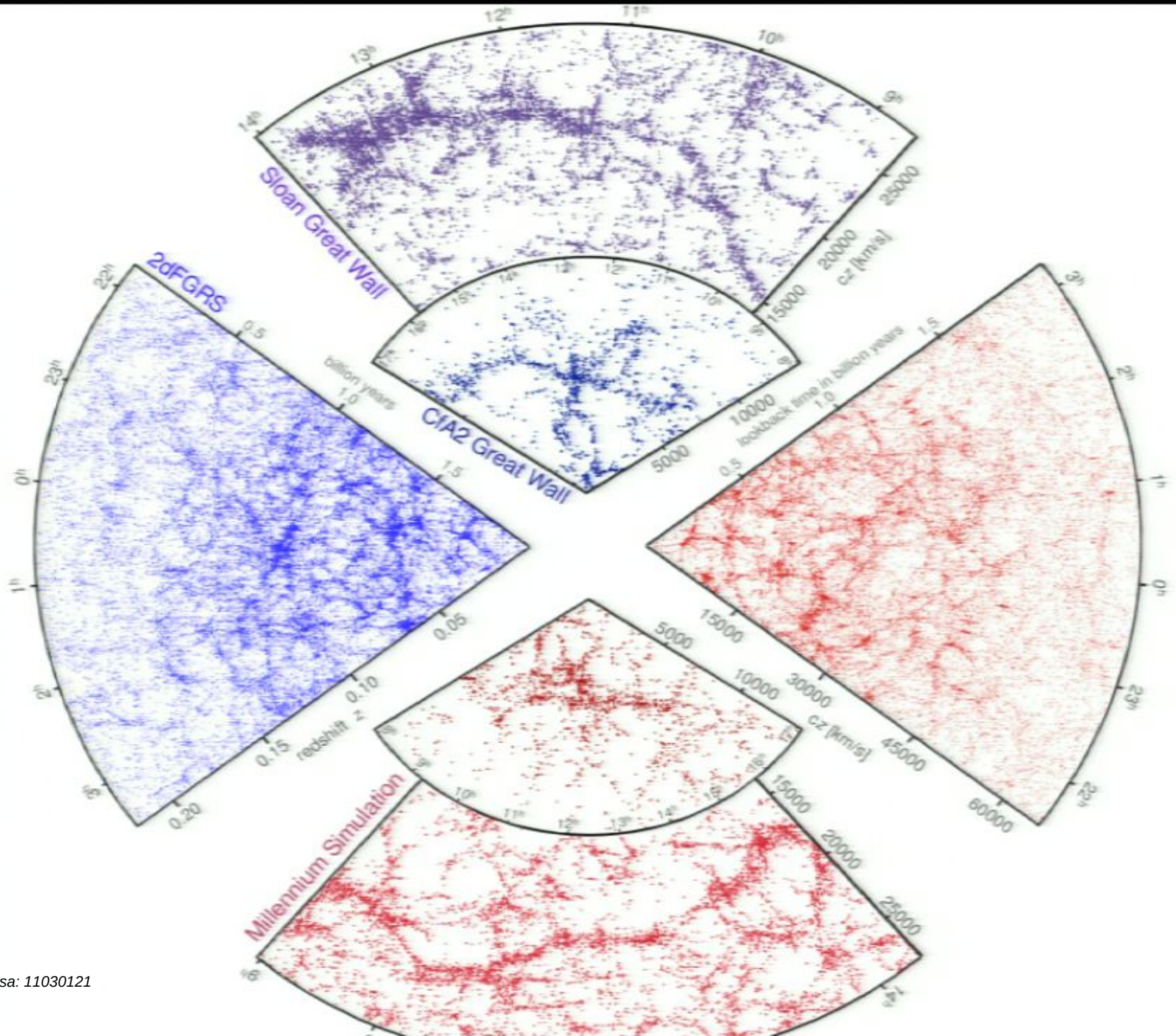


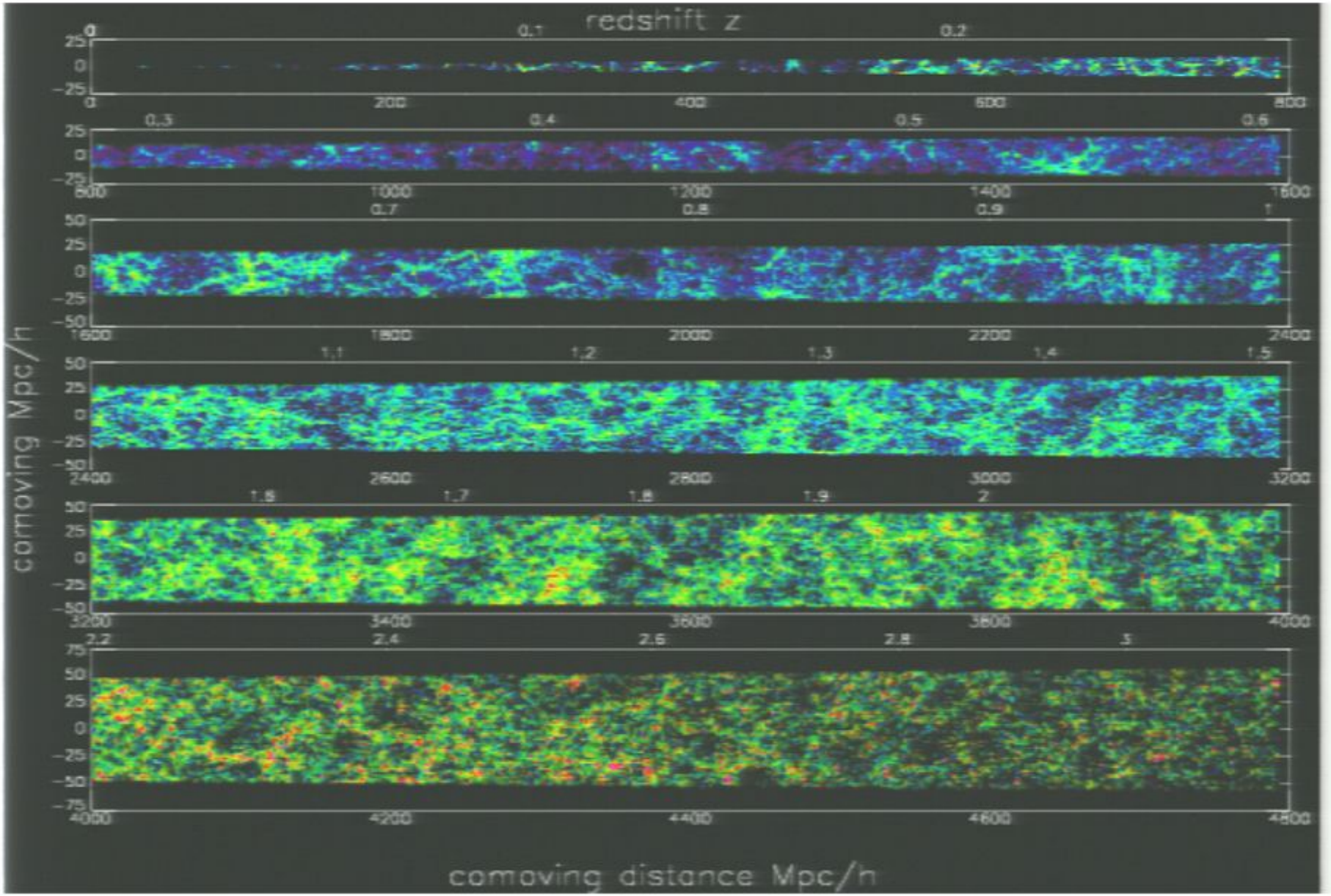
How to proceed with model-building --the semianalytic program--

- Begin with counts!
  - -- luminosity/mass functions, central/satellite abundances
- Use clustering measurements!
  - -- correlations as a function of stellar mass and colour
- Use assembly history information from simulations!
  - -- base on high-resolution DM simulations
  - -- use simulated assembly history/substructure data directly
- Use physically plausible recipes for relevant processes
  - -- tie recipes to detailed simulations when possible
  - -- otherwise use observational phenomenology

- Separate measurement from hypothesis when model-testing


The Millennium Simulation (2005)
125 Mpc/h
15.6 Mpc/h


Sloan Great Wall
2dFGRS
CfA2 Great Wall
Millennium Simulation
cz [km/s]
redshift z
lookback time in billion years
billion years



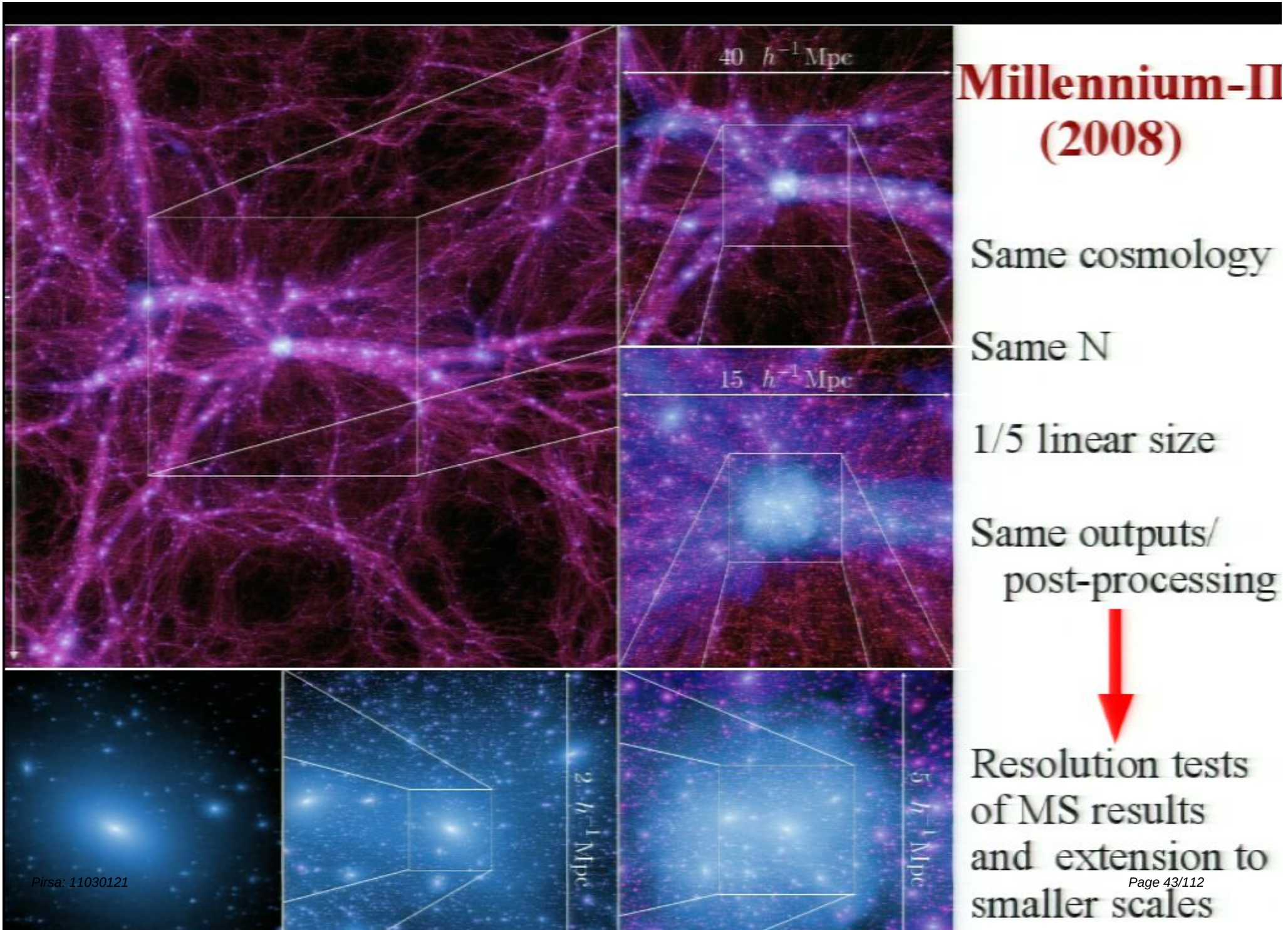
370 papers making direct use of data from the MS (31-3-2011)

Most by authors unassociated with the consortium

Most based on the galaxy catalogues, particularly mock surveys

Limitations of the Millennium Simulation

- Limited volume – too small for BAO work, precision cosmology
- Limited resolution – too poor to model formation of dwarfs
- No convergence tests – are galaxy results numerically converged?
- Only one ("wrong") cosmology
- Users unable to test dependences on parameters/assumptions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Millennium-II
(2008)
Same cosmology
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1/5 linear size
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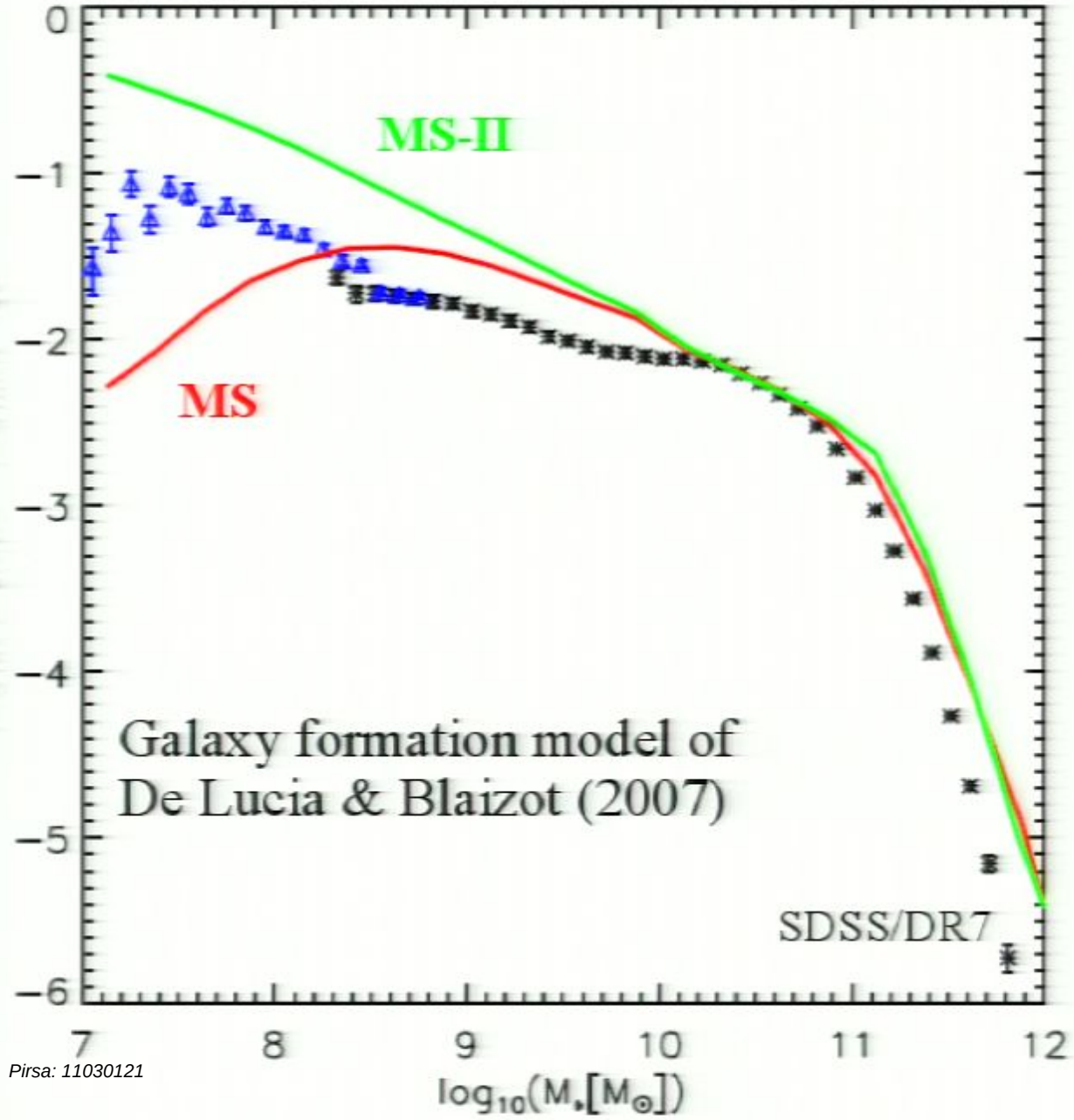


Galaxy formation modelling on the MS is affected by resolution for $\log M_* < 9.5$

The current standard models do not fit recent "precision" data

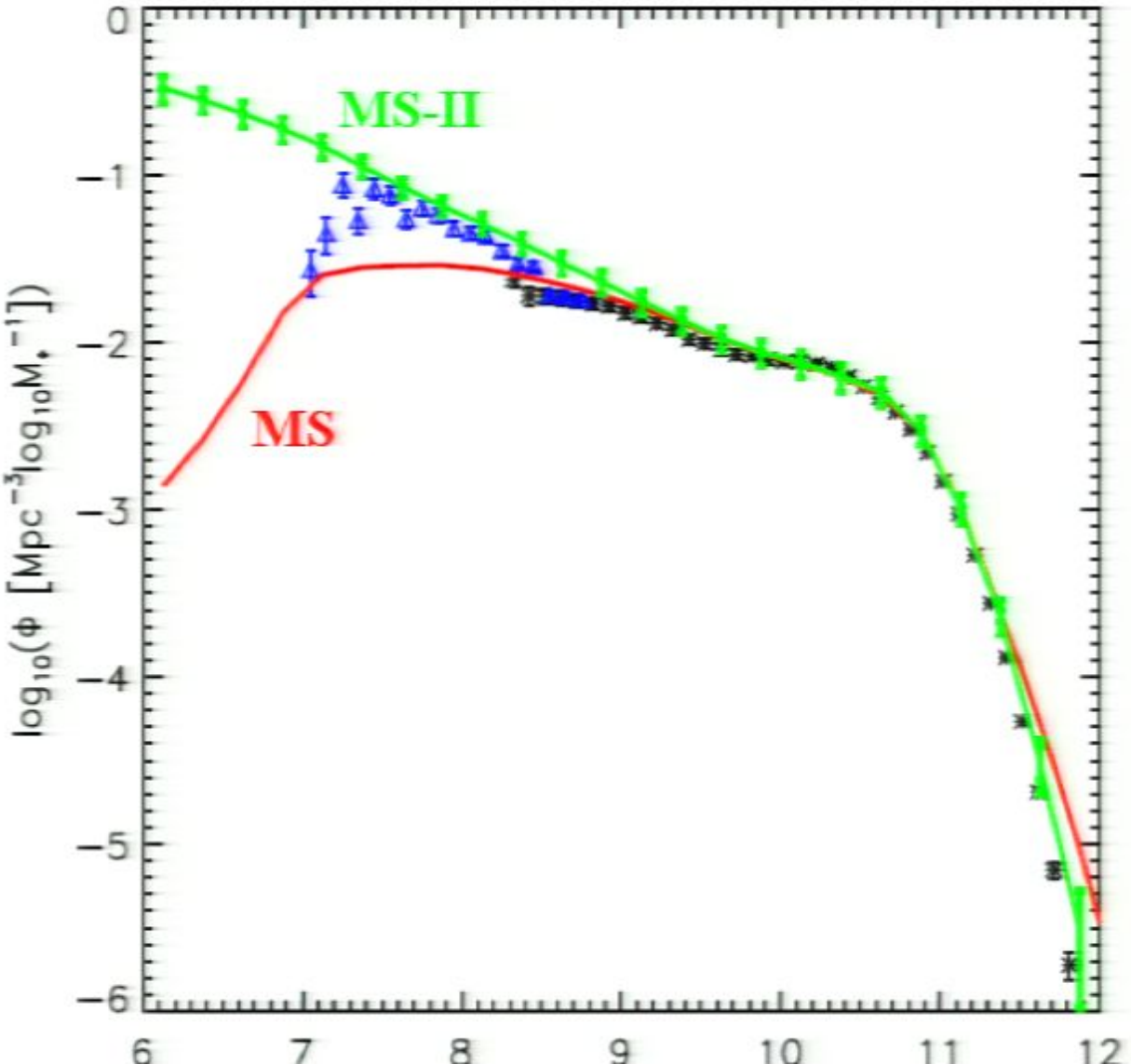
New galaxy formation models based on MS+MS-II

Qi Guo et al 2011

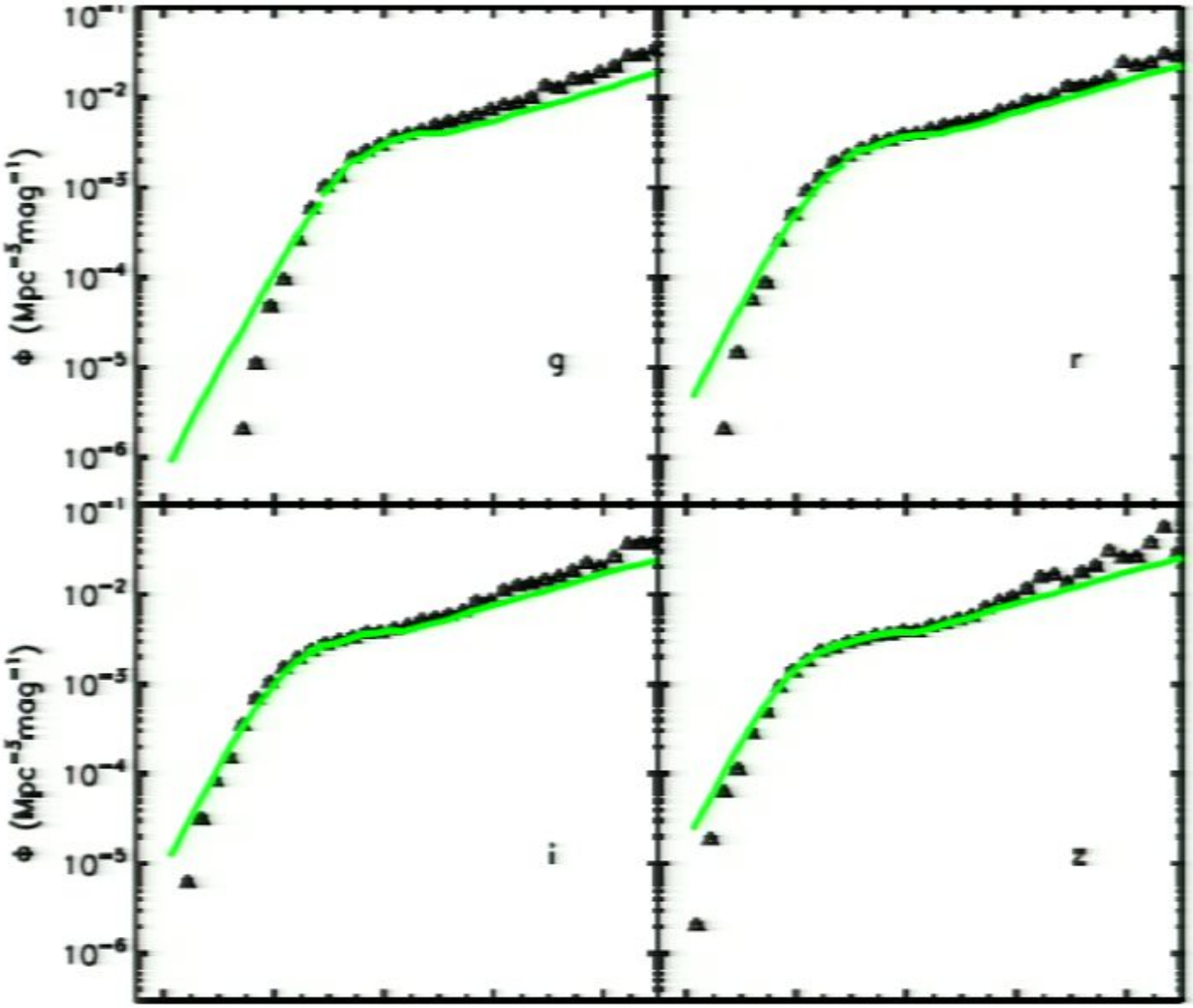
- Implement modelling simultaneously on MS and MS-II
- Test convergence of galaxy properties near resolution limit of MS
- Extend to properties of dwarf galaxies
- Improve/extend treatments of "troublesome" astrophysics
- Adjust parameters to fit new, more precise data
- Test against clustering and redshift evolution

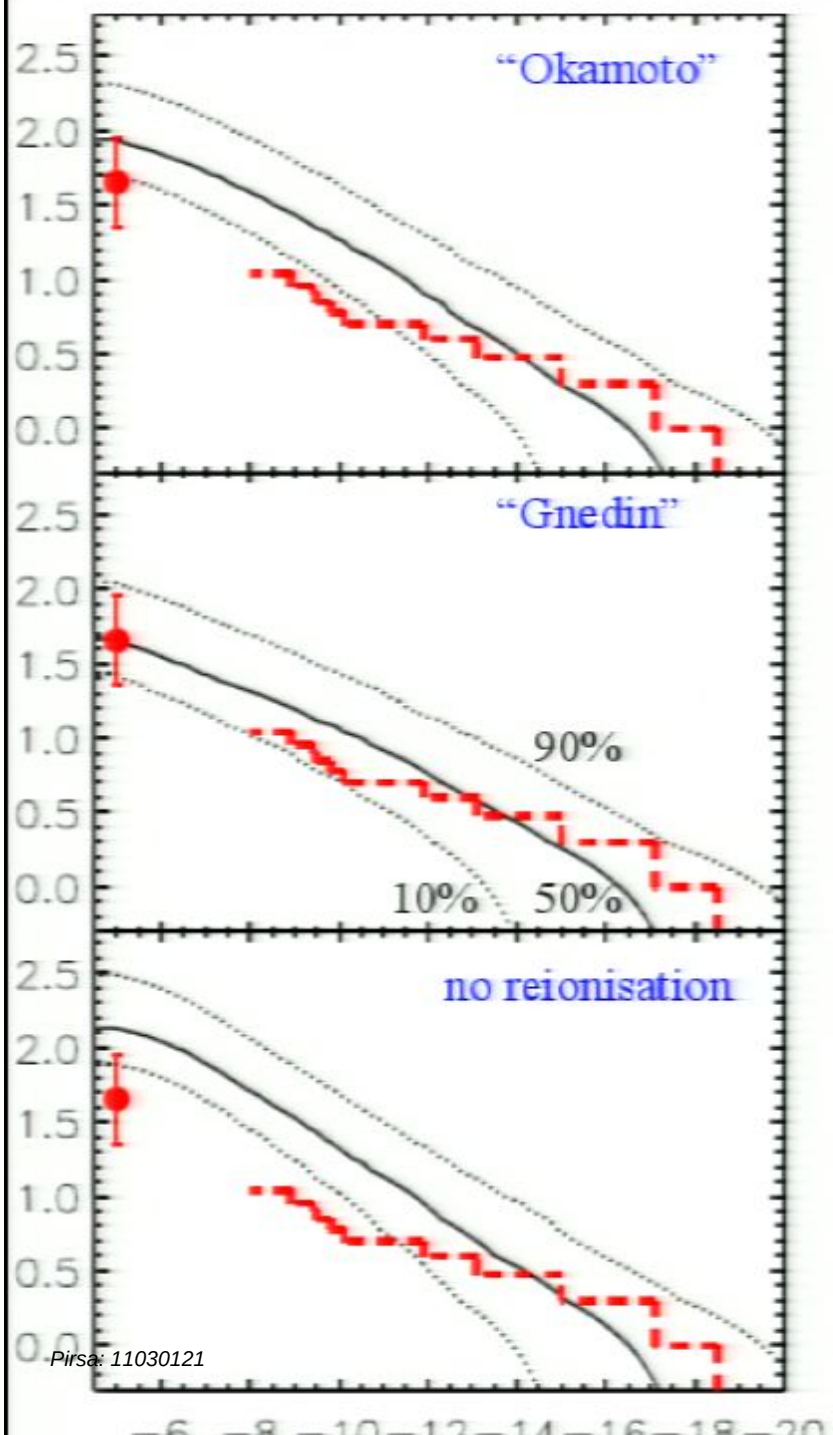
Things that work well

The stellar mass function of galaxies



Luminosity functions of galaxies

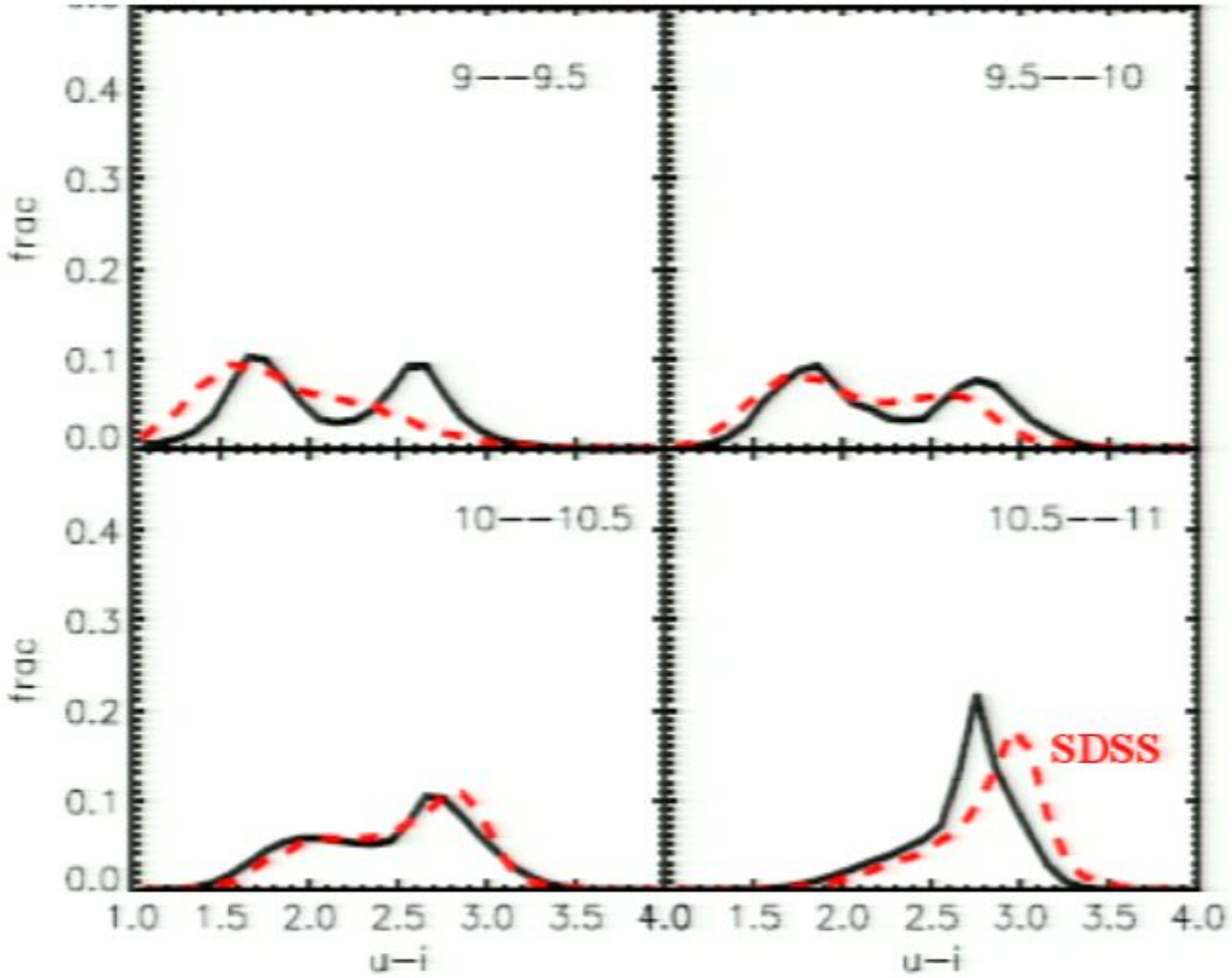




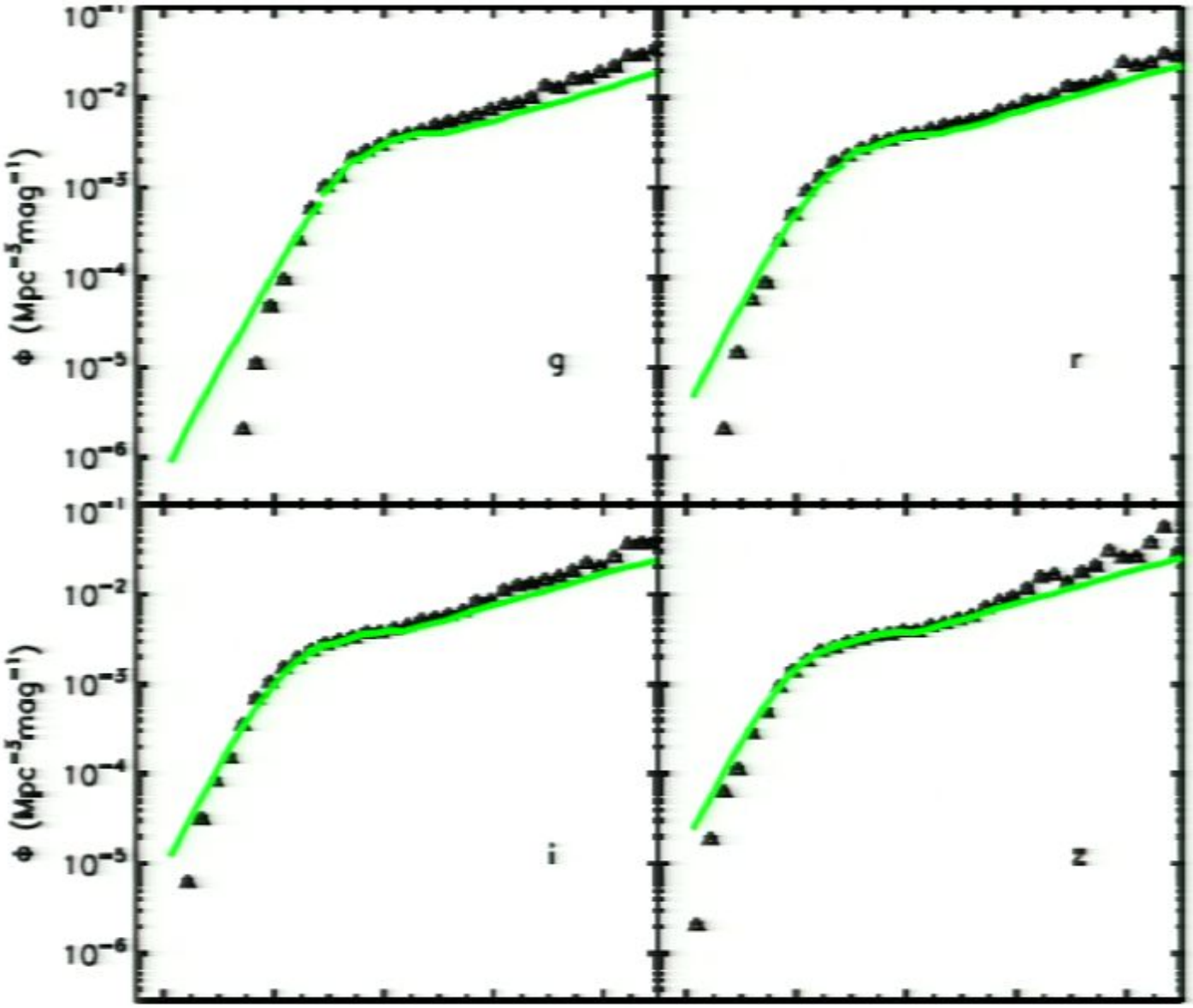
Luminosity function of Milky Way satellites

Luminosity functions of satellites around 1500 "Milky Ways" i.e. isolated disk galaxies with $\log M_* = 10.8$

Galaxy colour distributions



Luminosity functions of galaxies



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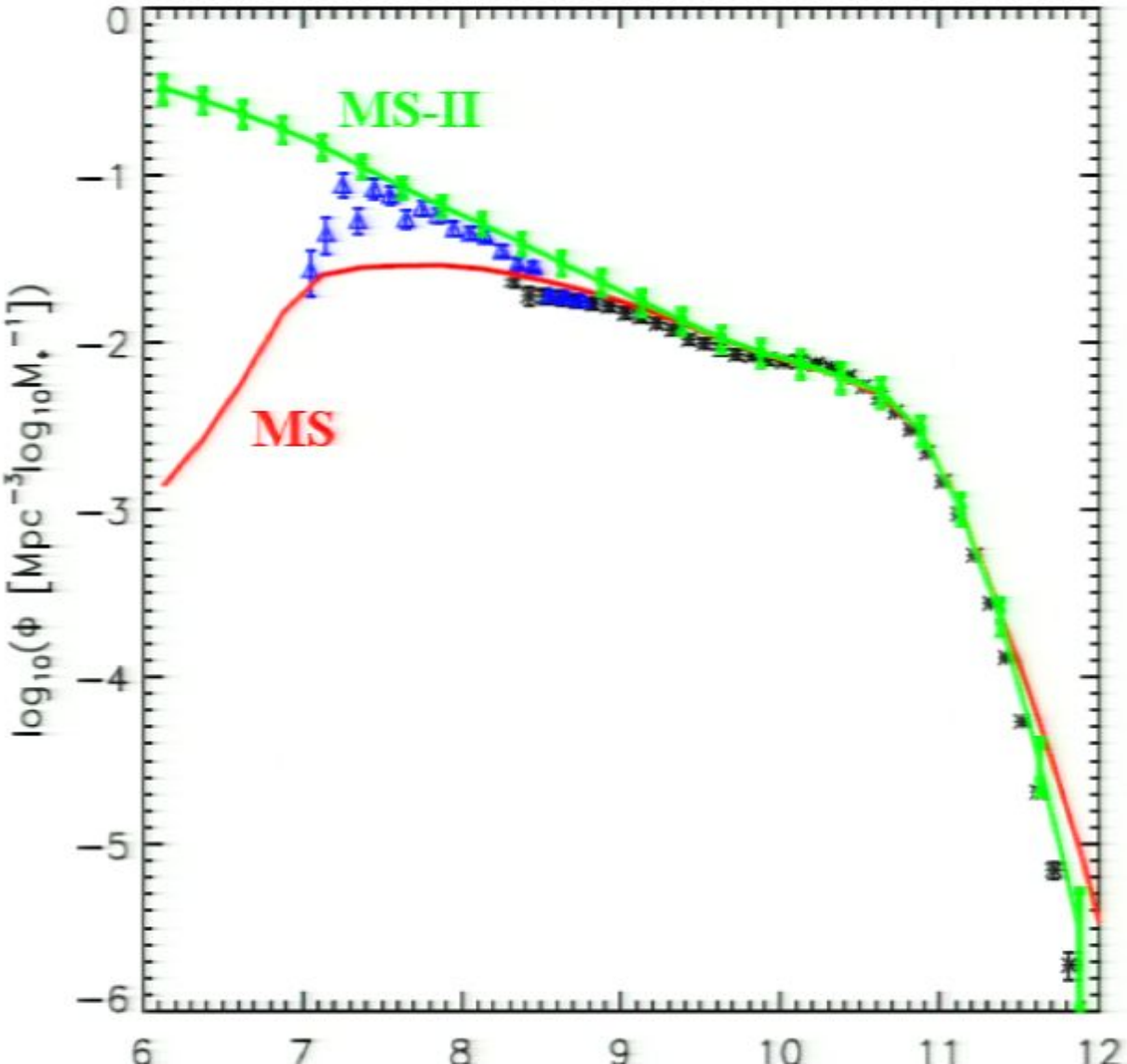

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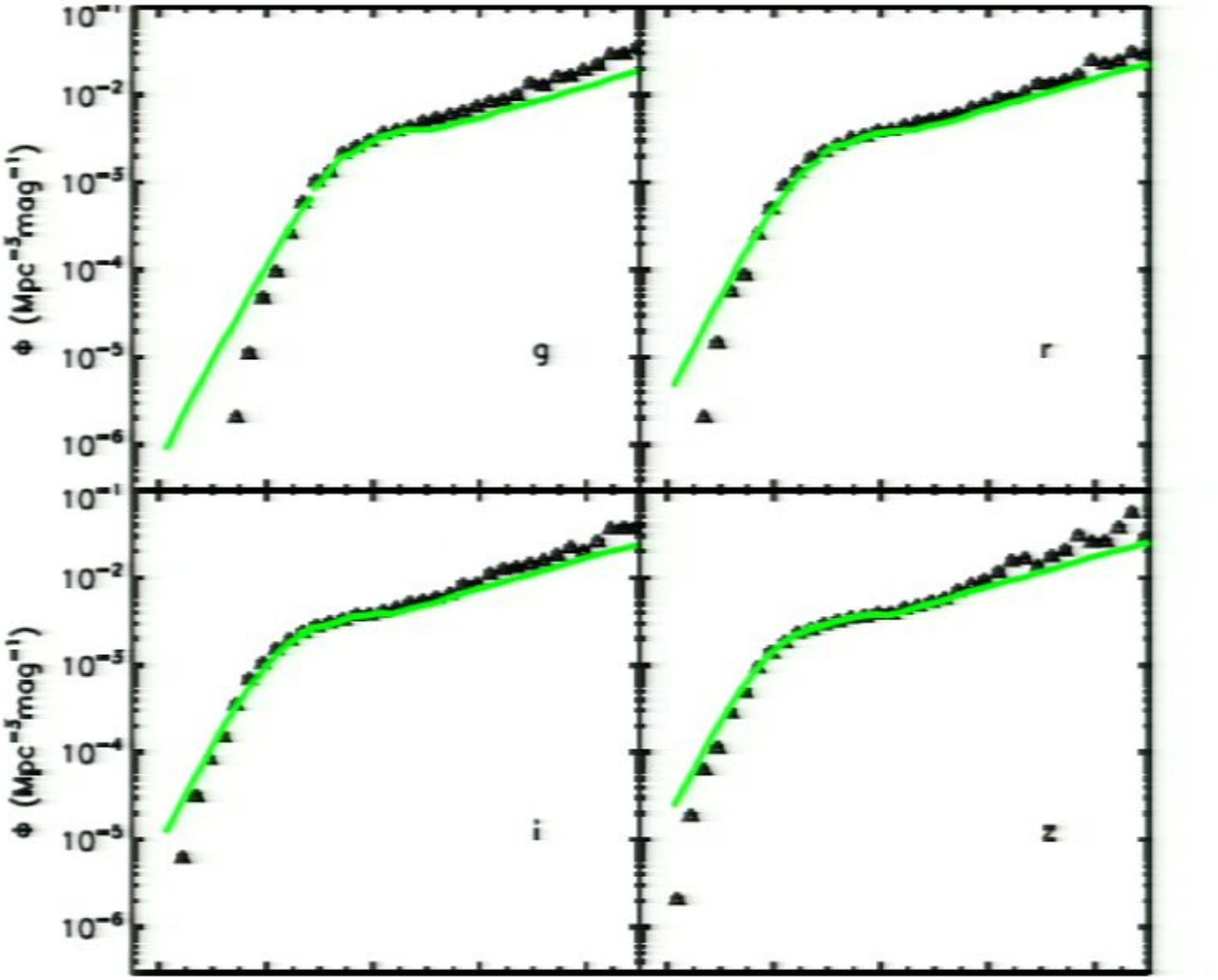

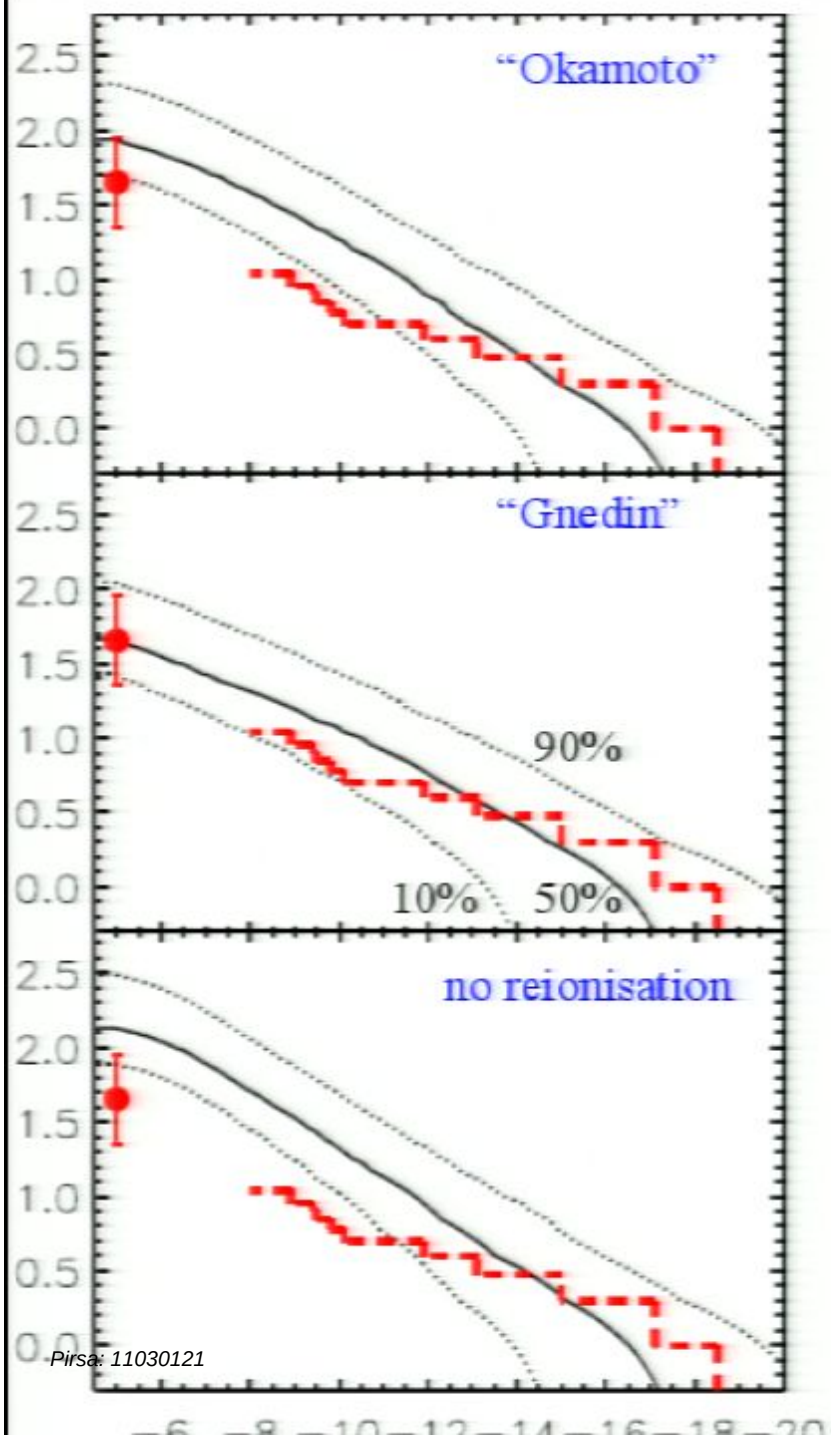

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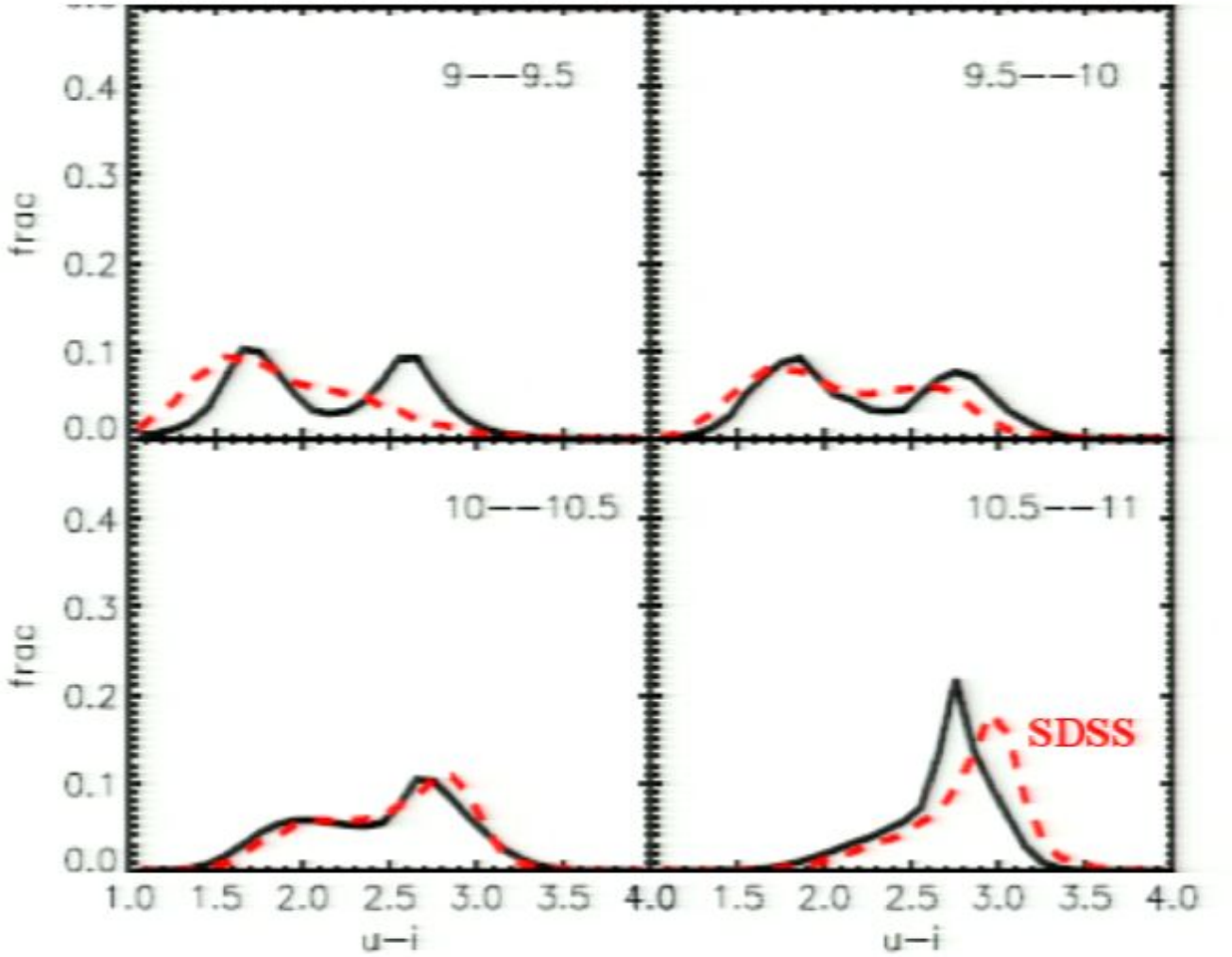
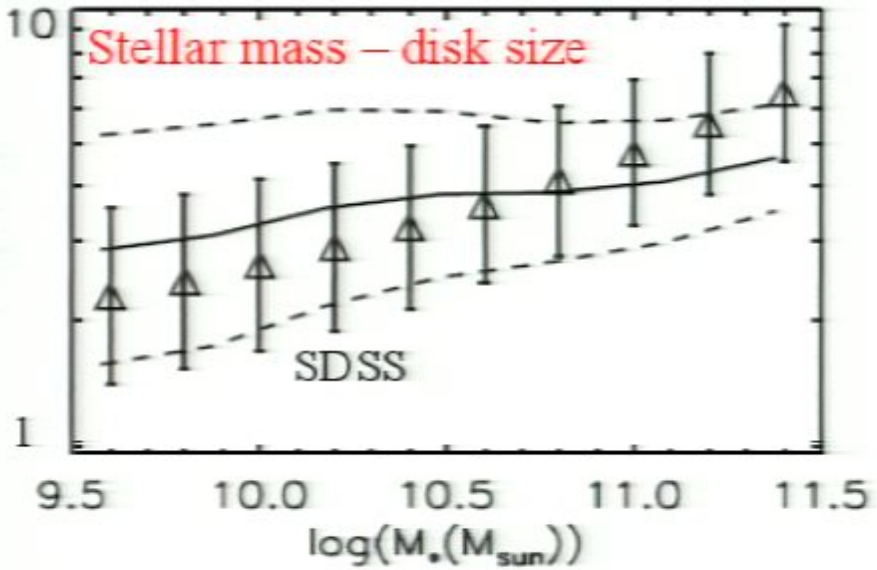
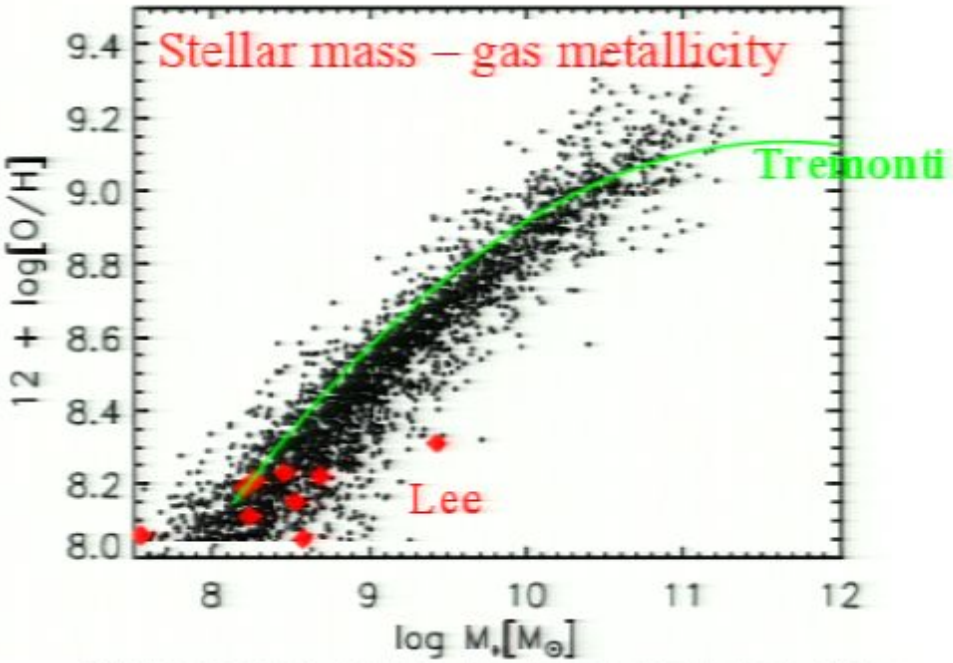
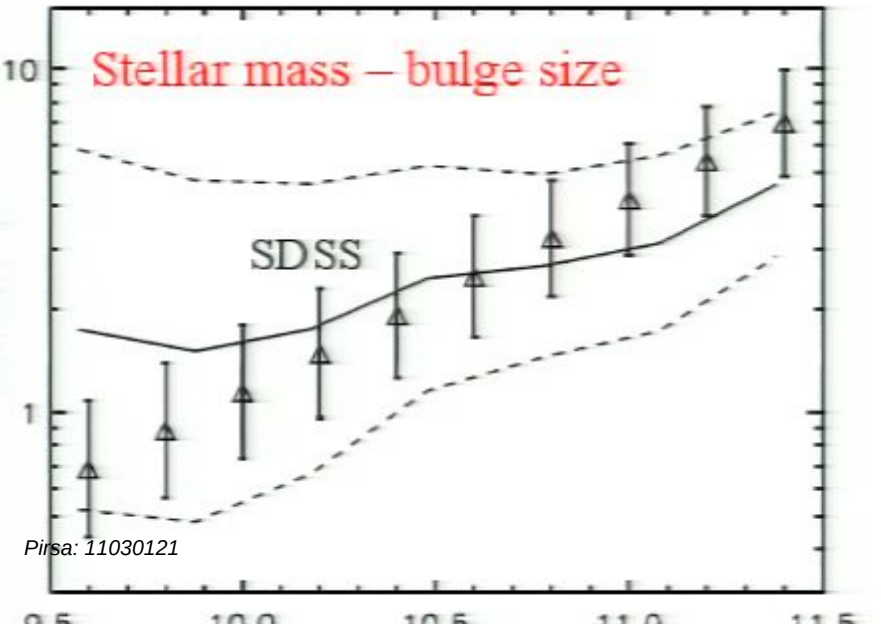
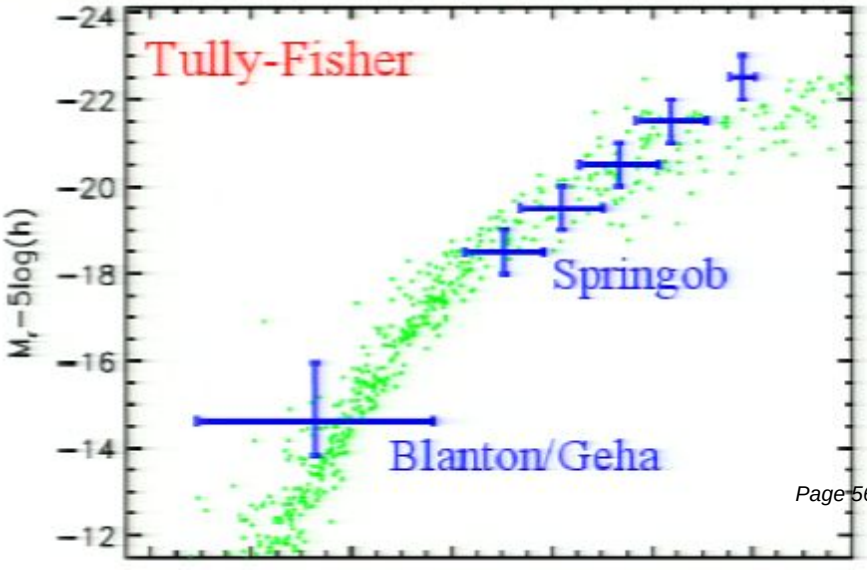


Scaling relations

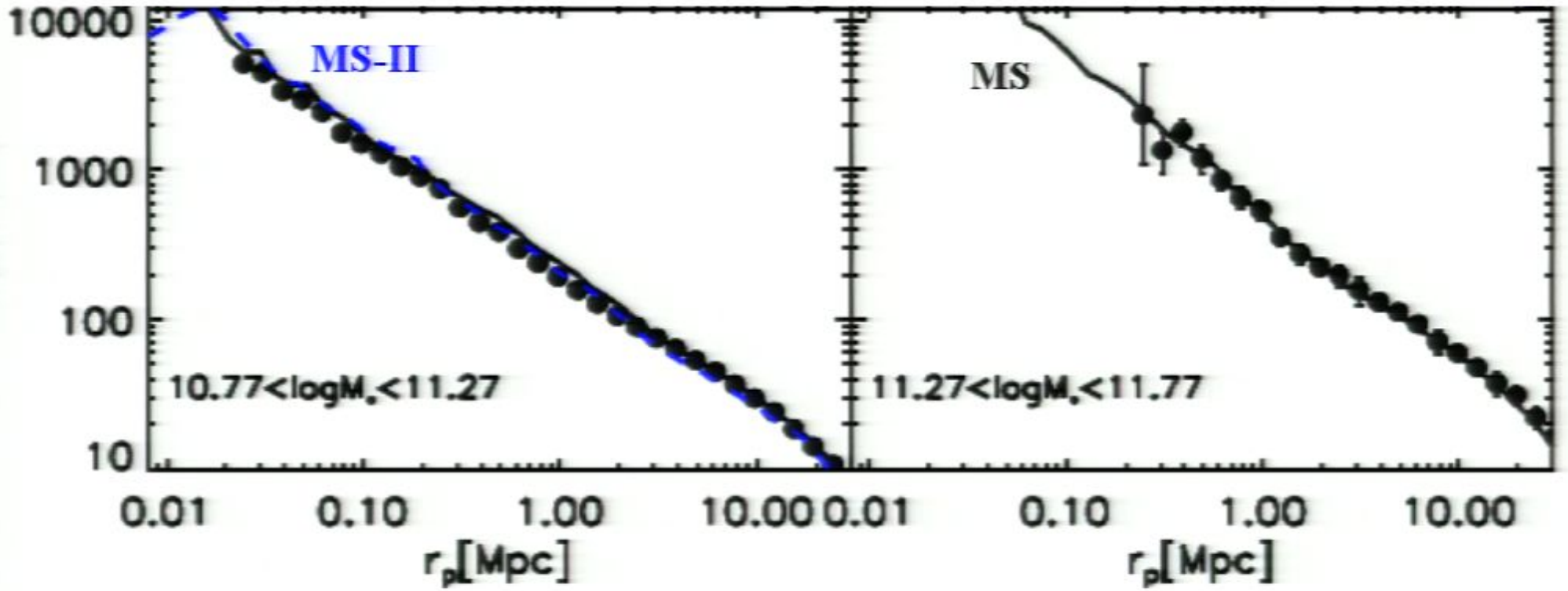




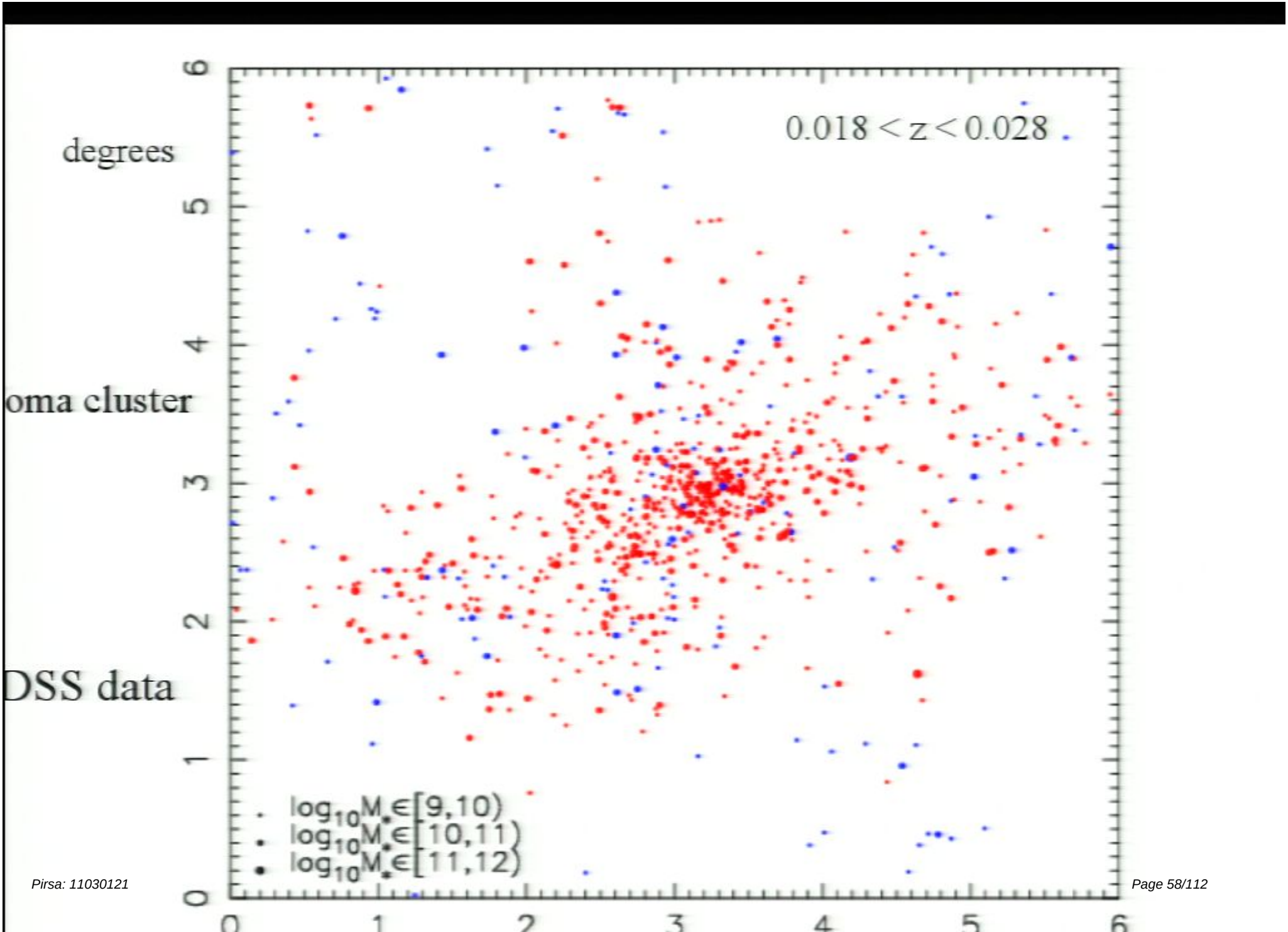




Clustering of massive galaxies

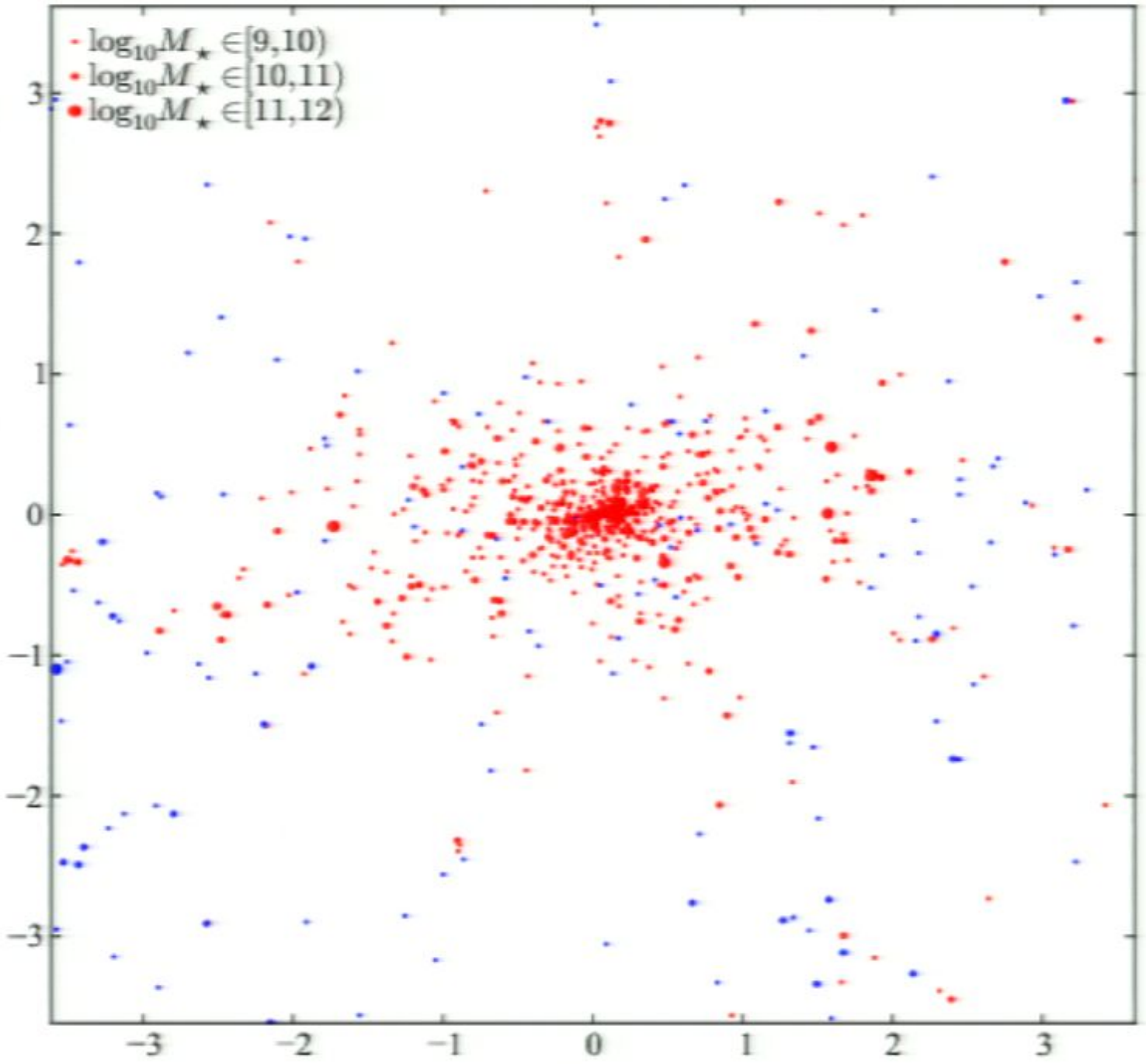


Data from SDSS/DR7

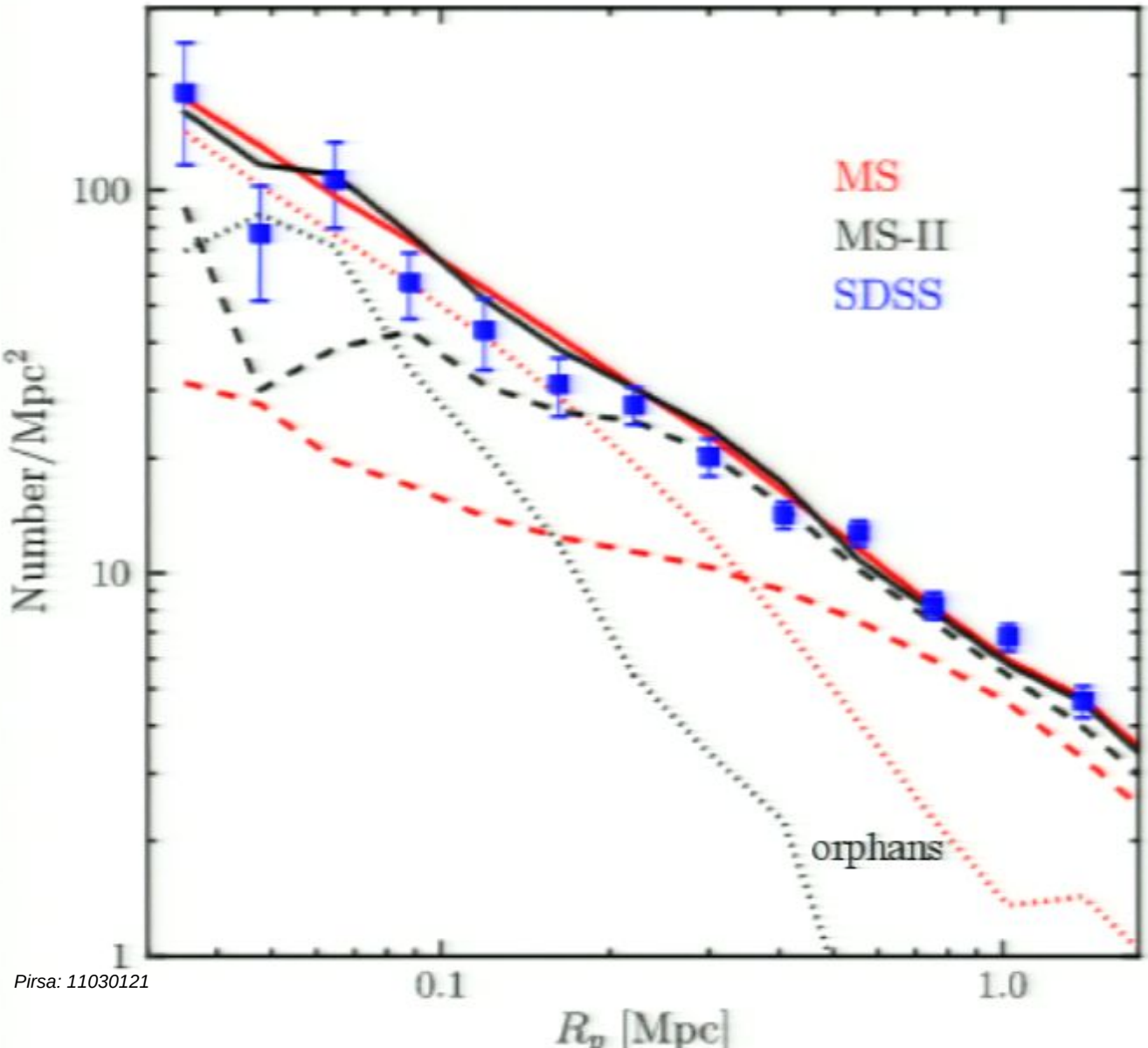

degrees
oma cluster
DSS data
0.018 < z < 0.028
log10M*∈[9,10)
log10M*∈[10,11)
log10M*∈[11,12)
0
1
2
3
4
5
6

h^{-1} Mpc

IS cluster



Projected galaxy number density profiles of clusters



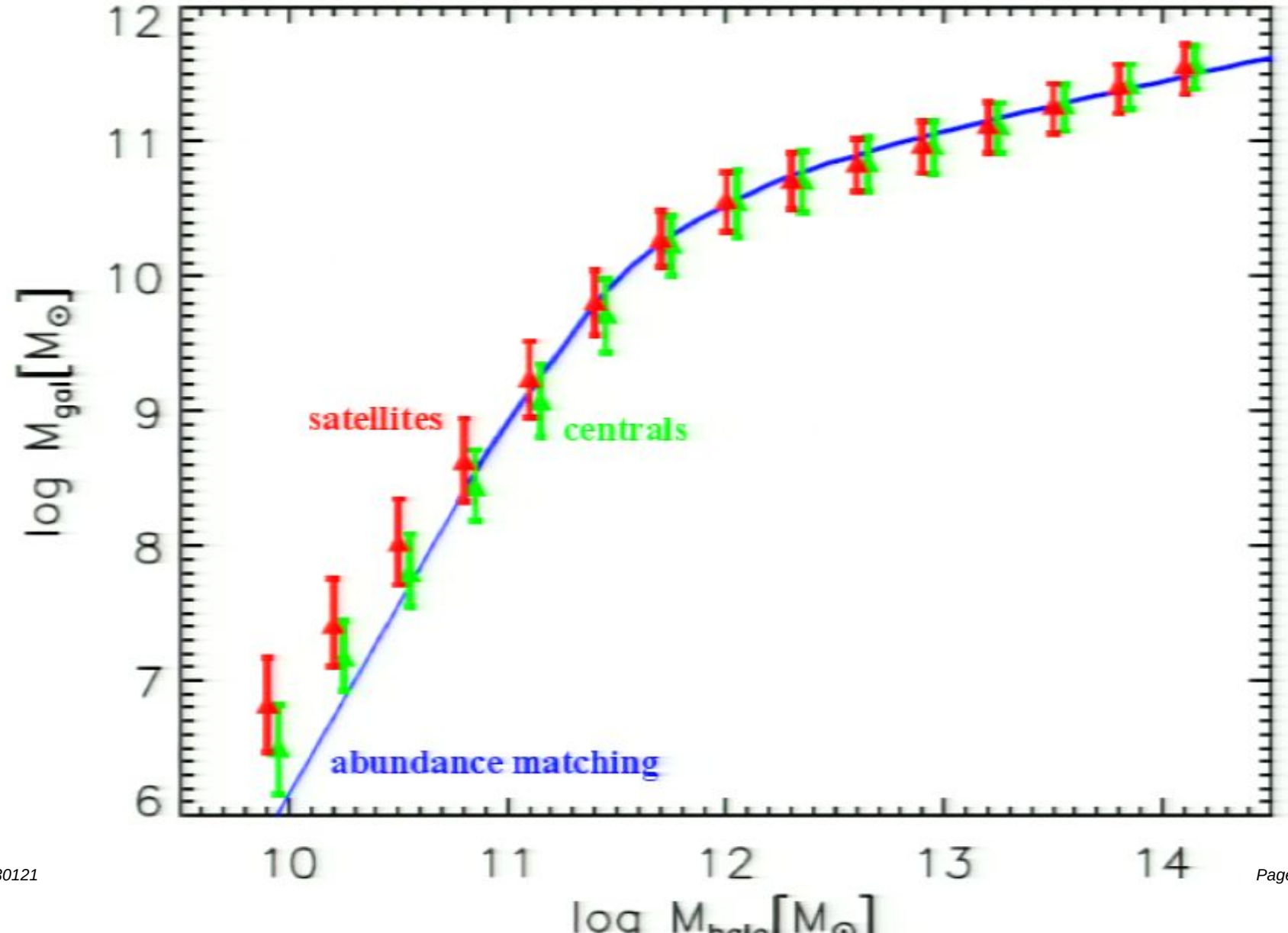
$\log M_{gal} > 10.0$

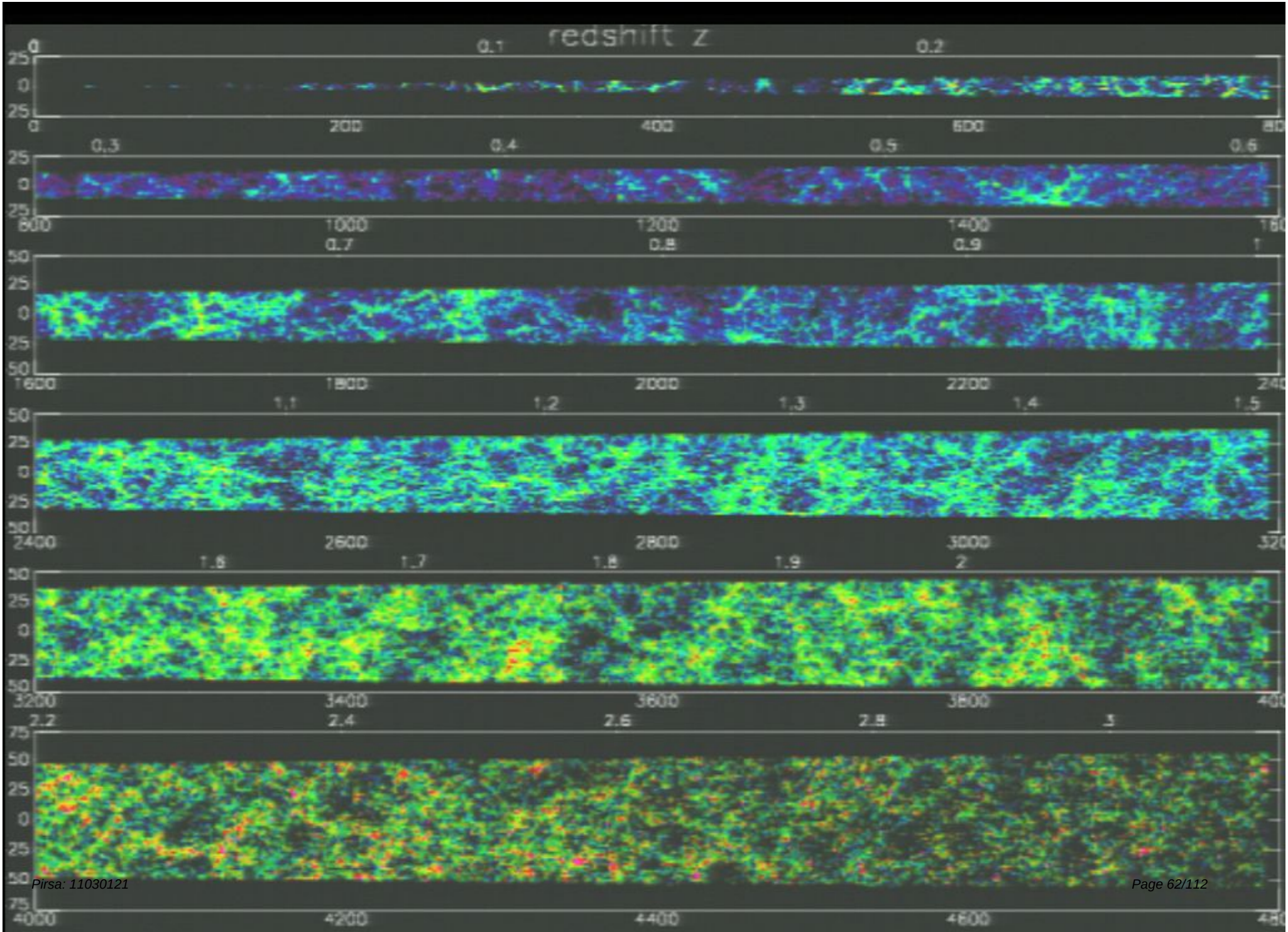
$14.0 < \log M_{clus} < 14.3$

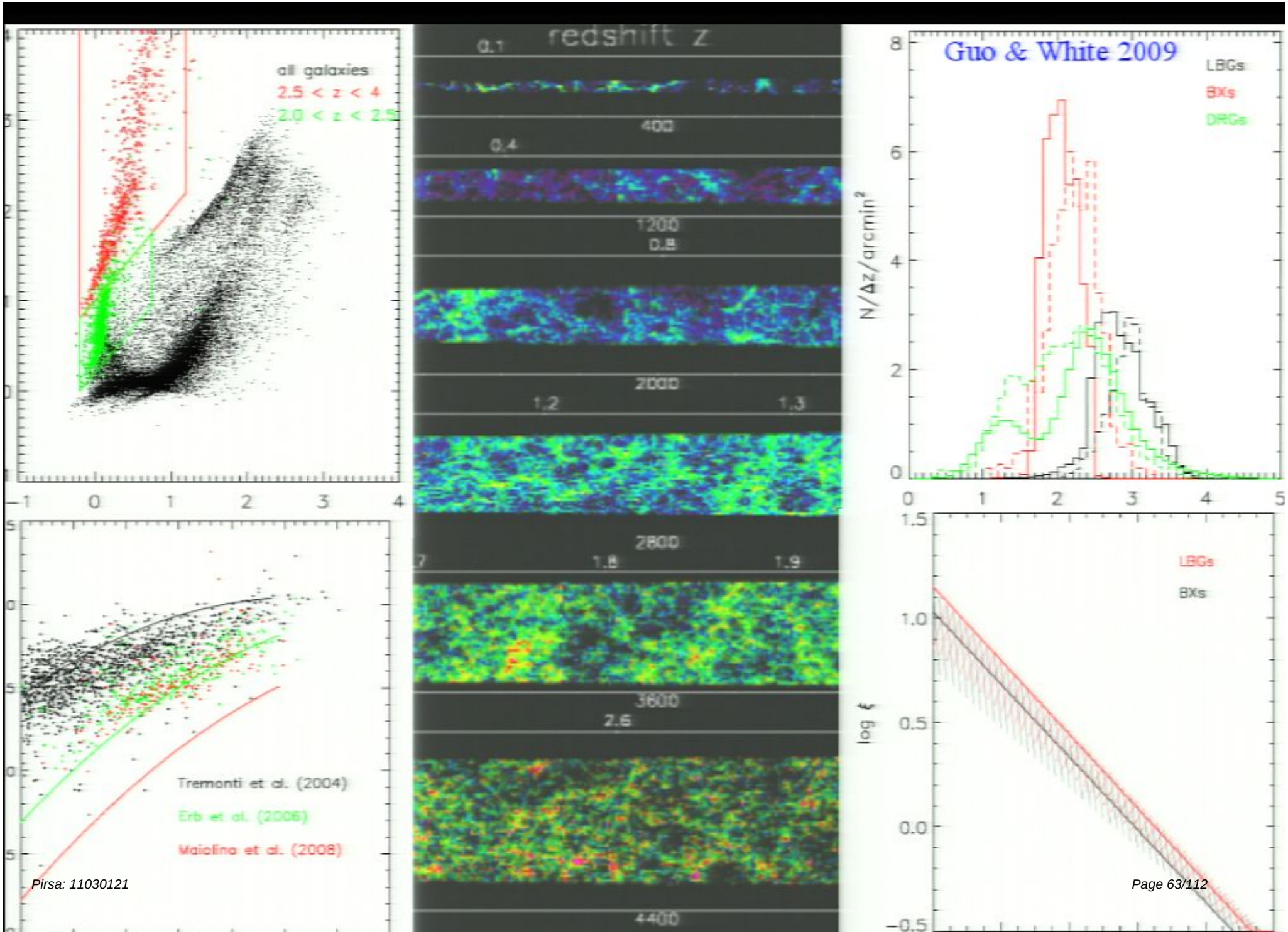
Note: good agreement of MS with MS-II is *only* when orphans are included

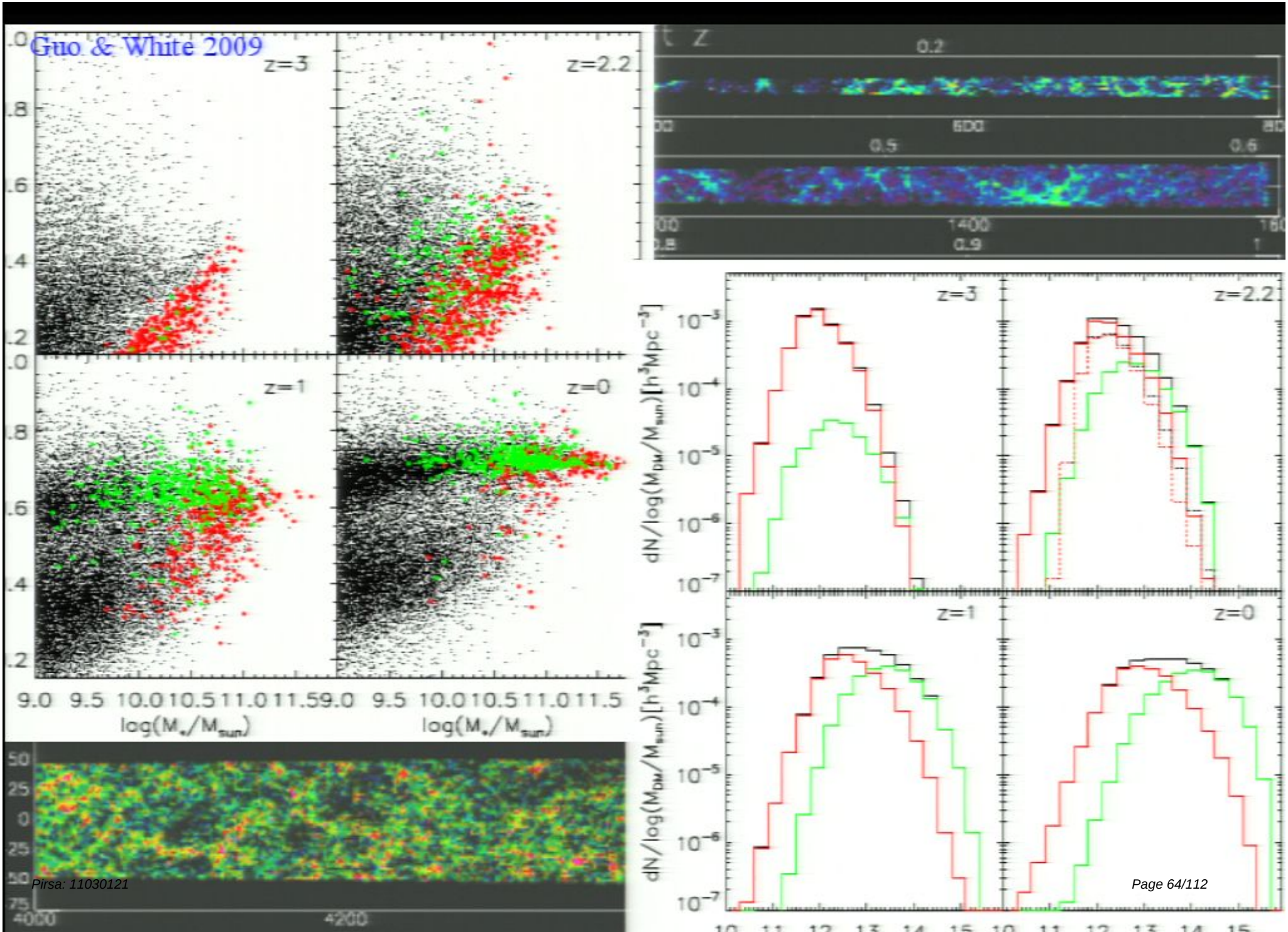
Orphan treatment is physically consistent and needed to fit SDSS

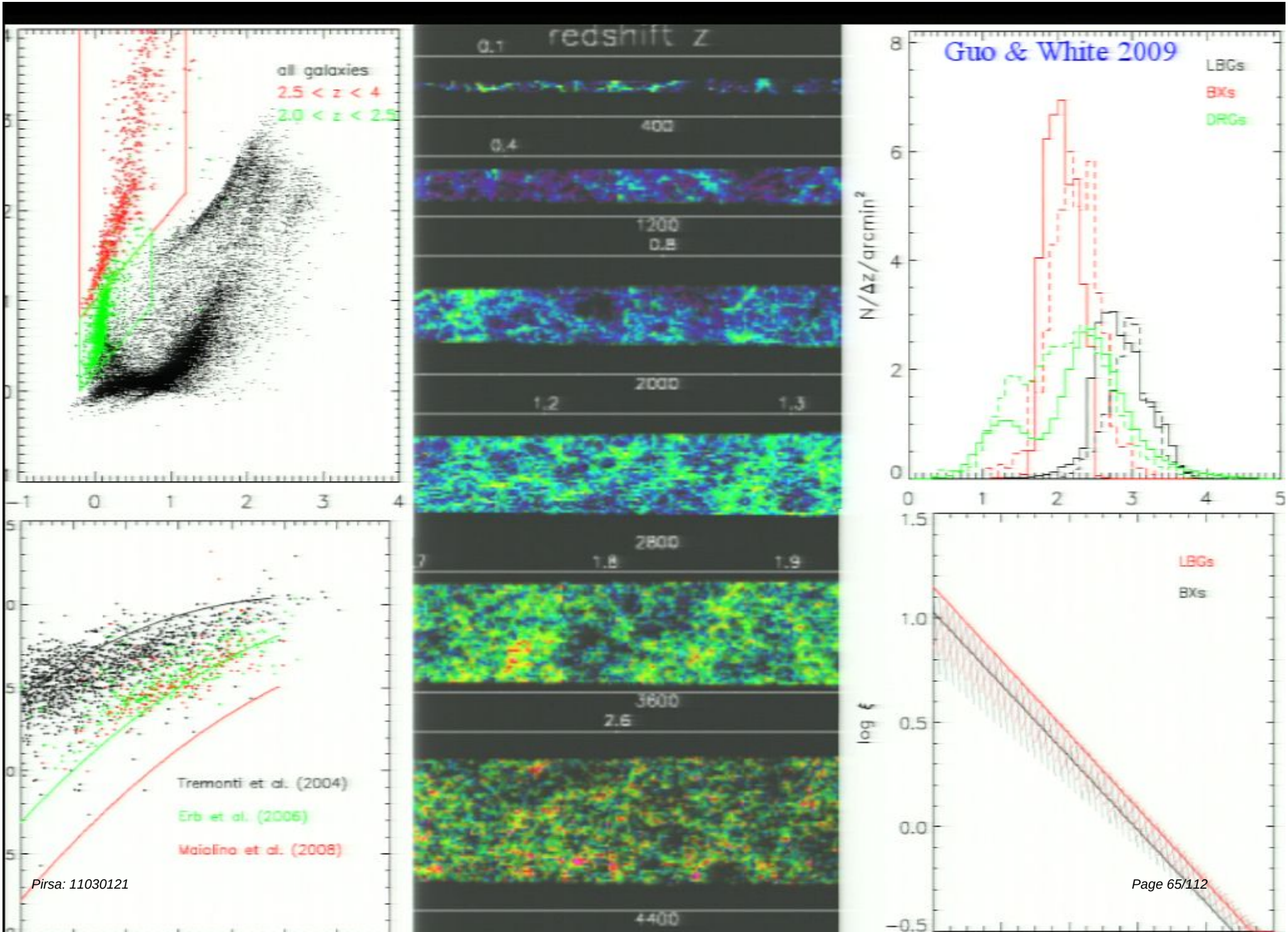
Galaxy stellar mass versus maximum past halo mass




redshift z
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.2
2.4
2.6
2.8
3
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600


all galaxies
2.5 < z < 4
2.0 < z < 2.5
redshift z
0.1
400
0.4
1200
0.8
2000
1.2
1.3
2800
1.8
1.9
3600
2.6
4400
Guo & White 2009
LBGs
BXs
DRGs
N/Δz/arcmin²
Tremonti et al. (2004)
Erb et al. (2006)
Maiolino et al. (2008)
LBGs
BXs
log ξ


Guo & White 2009
z=3
z=2.2
z=1
z=0
log(M*/Msun)
log(M*/Msun)
z
0.2
0.5
0.6
0.9
dN/log(MDM/Msun)[h3Mpc-3]
dN/log(MDM/Msun)[h3Mpc-3]


all galaxies
2.5 < z < 4
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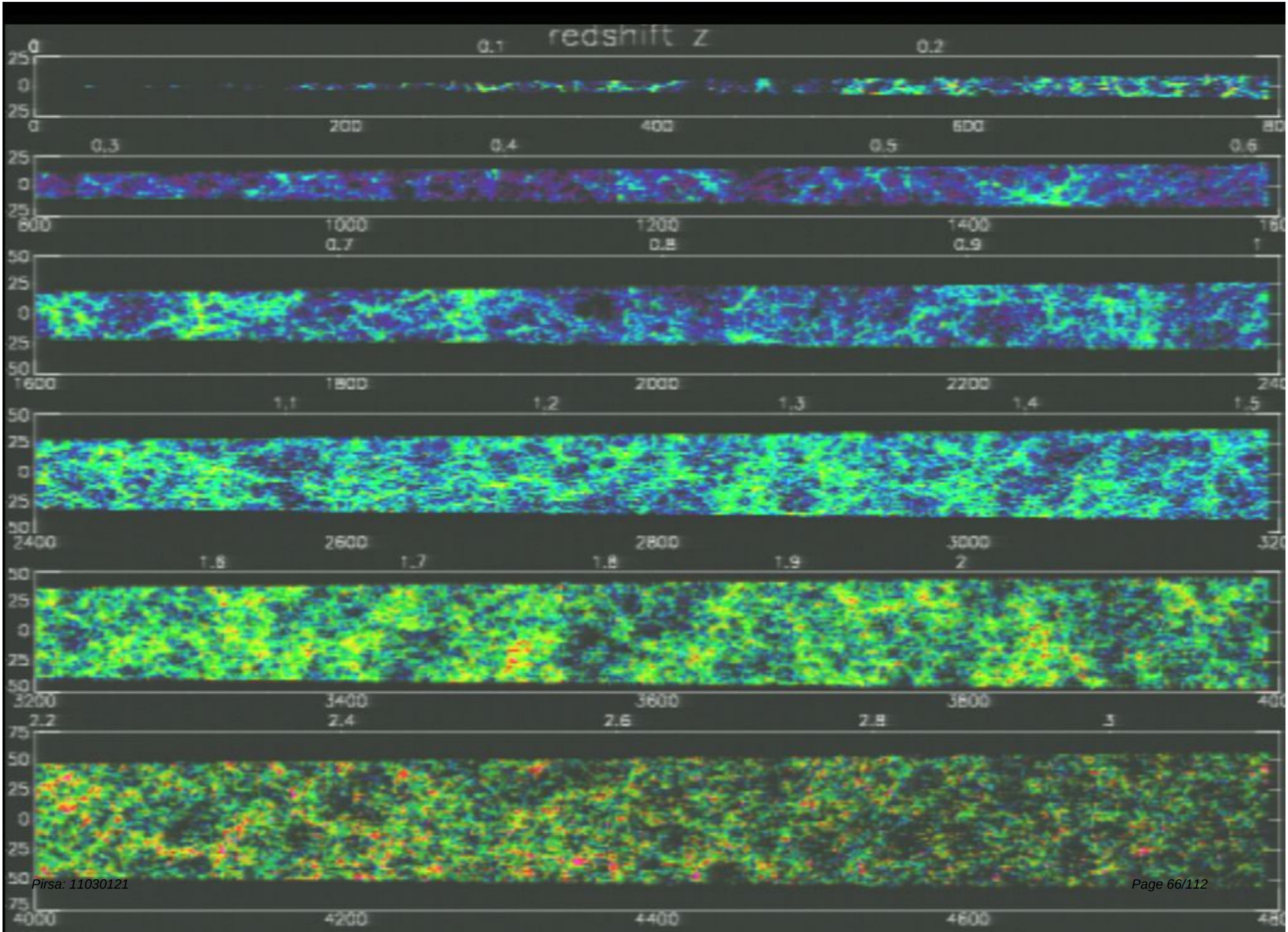
redshift z
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.2
2.4
2.6
2.8
3
200
400
600
800
1000
1200
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3400
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4200
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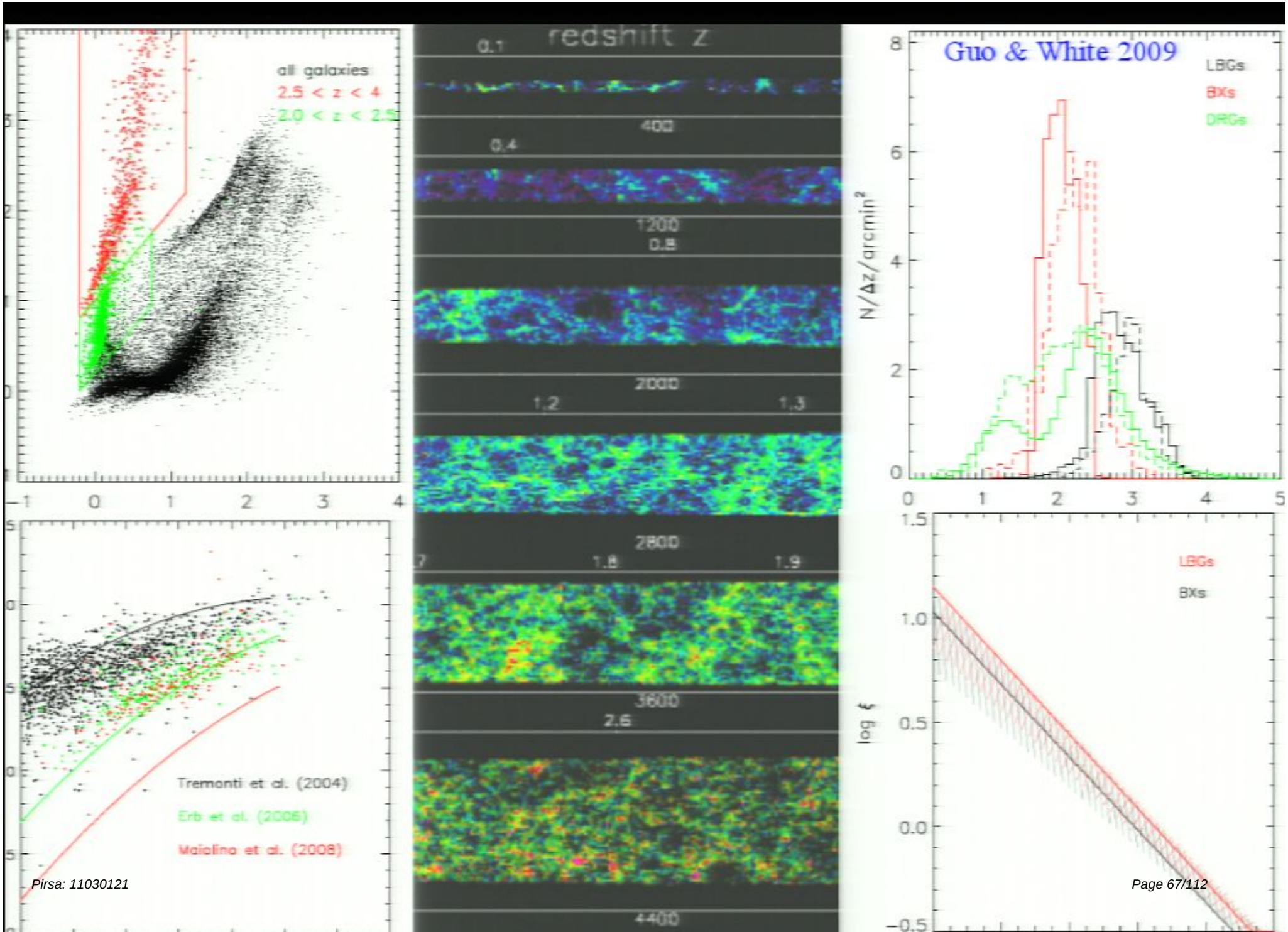
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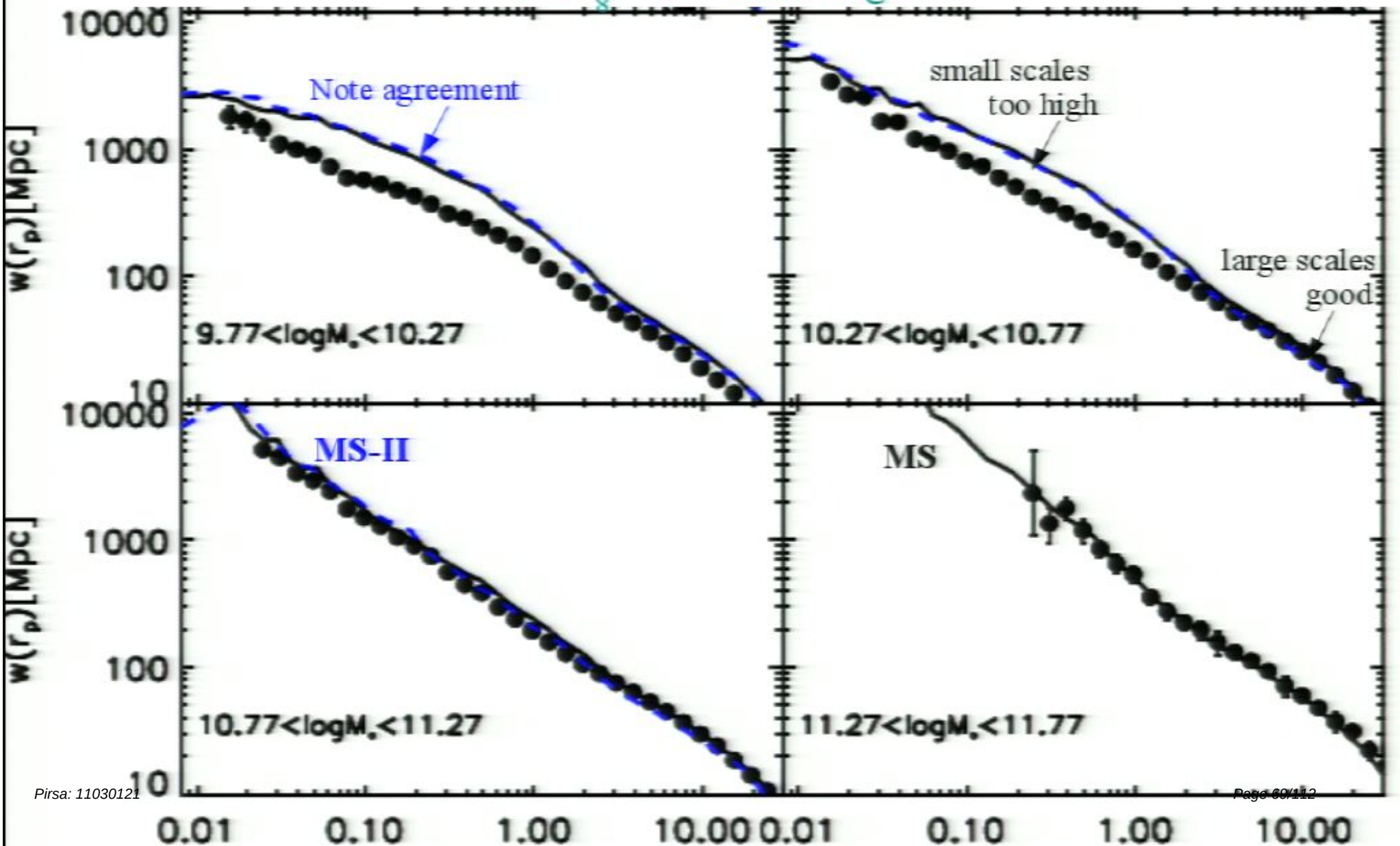
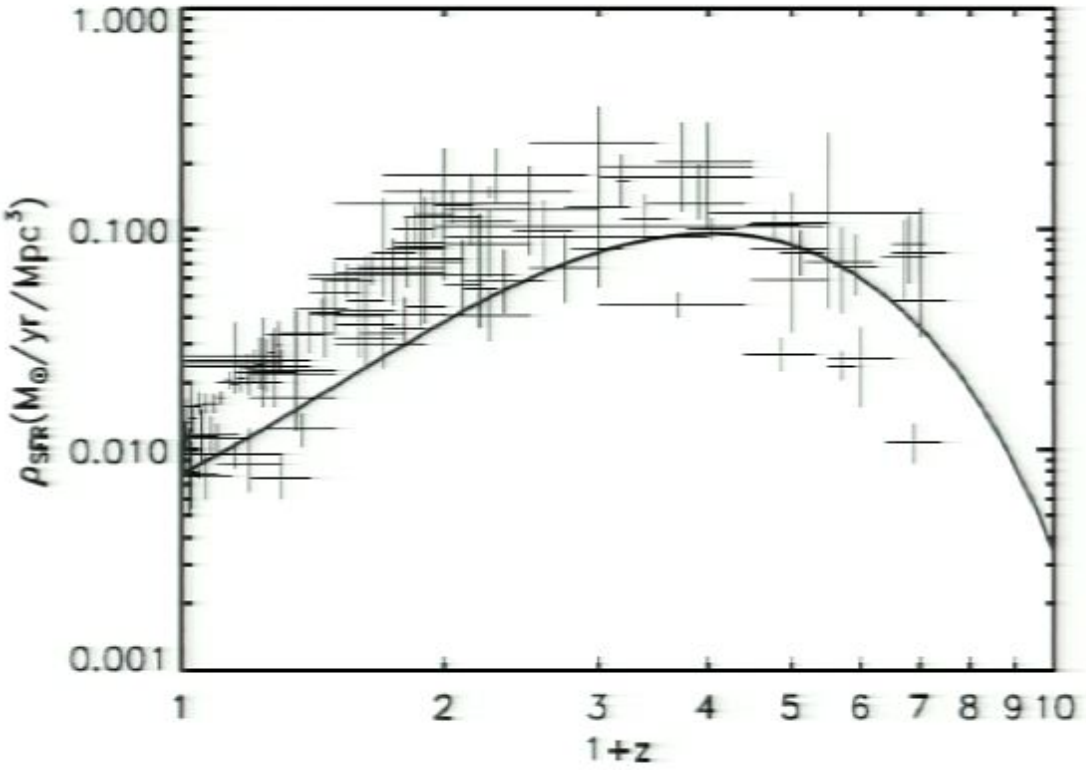
Things that work less well

Clustering of less massive galaxies

--- $\sigma_8 = 0.9$ is too high ---



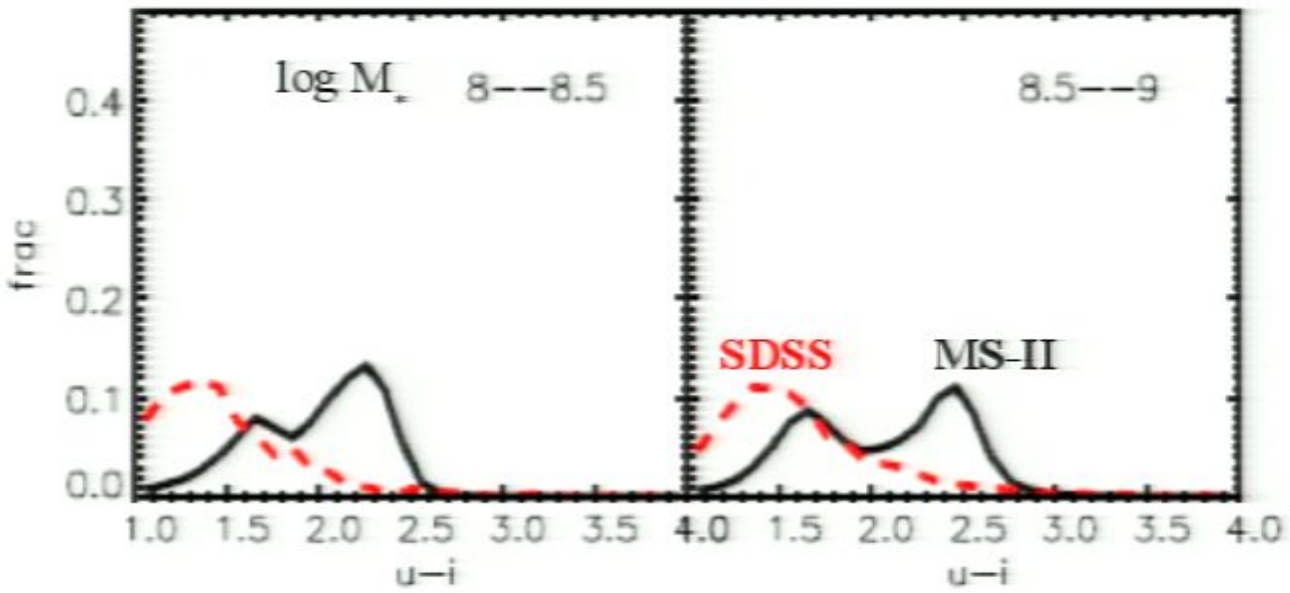
The cosmic star formation density history



--- observed SFR are inconsistent with observed stellar masses ---

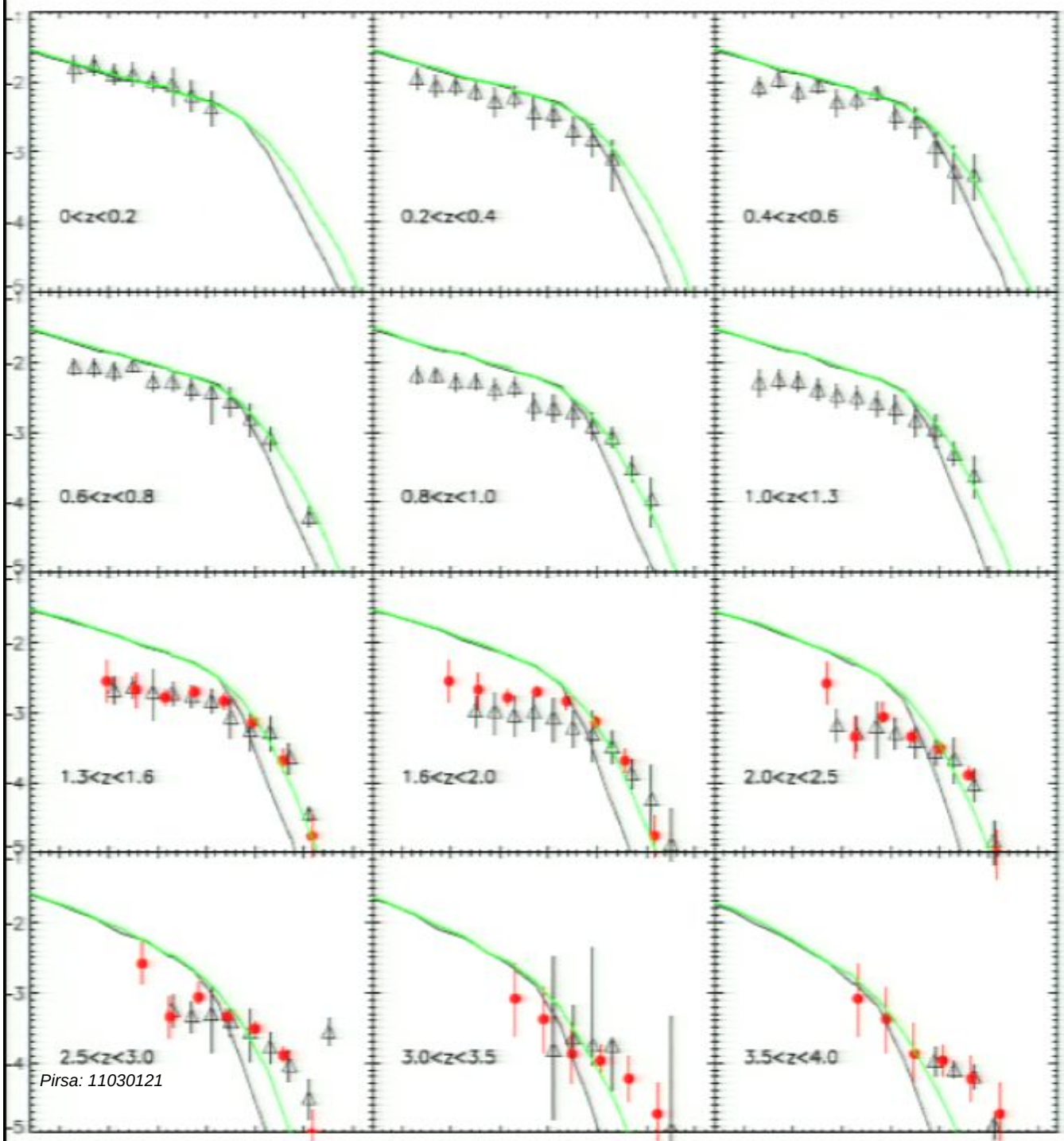
--- star formation peaks too early in the model ---

Colours of dwarf galaxies



Too many passive low mass galaxies in the MS-II

--- formation is too fast/too early ---



Evolution of stellar mass function

Lower mass galaxies
$\log M_* < 10.5$
form too early

Conclusions

"Precision" modelling of the formation and evolution of the galaxy population is now possible

Viable models should address abundances *and* scaling relations *and* clustering *and* evolution

Viable models require strong SN? feedback at low masses and strong AGN? feedback at high masses to match observed LF's

The Millennium Simulation amplitude $\sigma_8 = 0.9$ is too high

In current models star formation occurs *too early* in low-mass systems

→ Need a better understanding of star formation and a lower fluctuation amplitude

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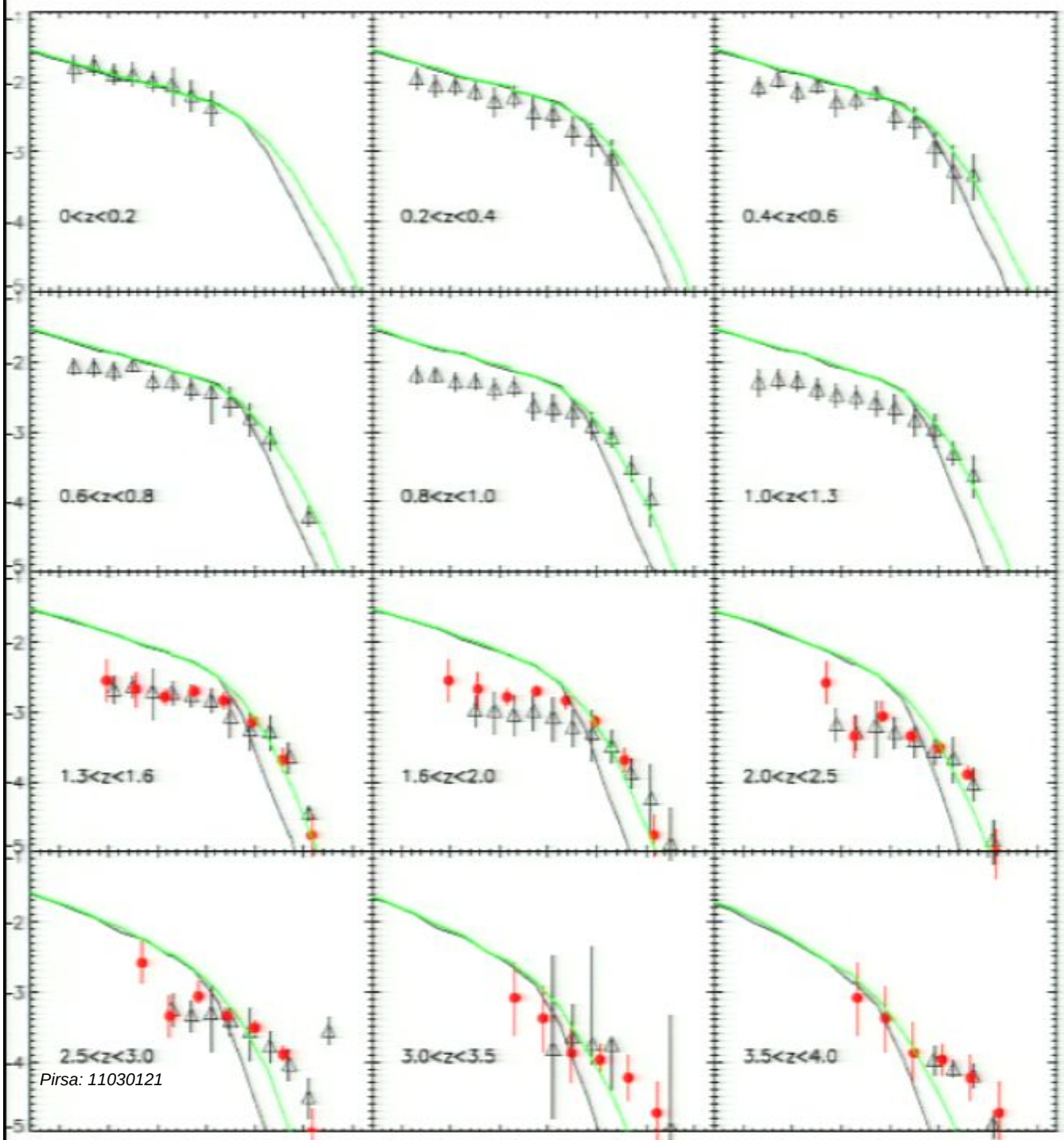

Evolution of stellar mass function

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Scaling Simulations to neighboring cosmologies

Angulo & White 2010

For example: `WMAP1' – $\Omega_m = 0.25,\ \Omega_b = 0.045,\ \sigma_8 = 0.9$

to `WMAP3' – $\Omega_m = 0.238,\ \Omega_b = 0.0418,\ \sigma_8 = 0.76$

1) Scale simulation size to match power spectrum slopes of original and target cosmologies on the scales of the original z=0 halos

-- 500 Mpc/h 433 Mpc/h

2) Reassign redshifts to match linear amplitudes on these scales

-- $z = 0.57,\ 1.68,\ 2.92$ $z = 0,\ 1,\ 2$

3) Scale particle masses and velocities to match Ω_m and new size

-- $9 \times 10^8\ M_\odot/h$ $5.6 \times 10^8\ M_\odot/h$

4) Adjust for the difference between amplitudes of original and

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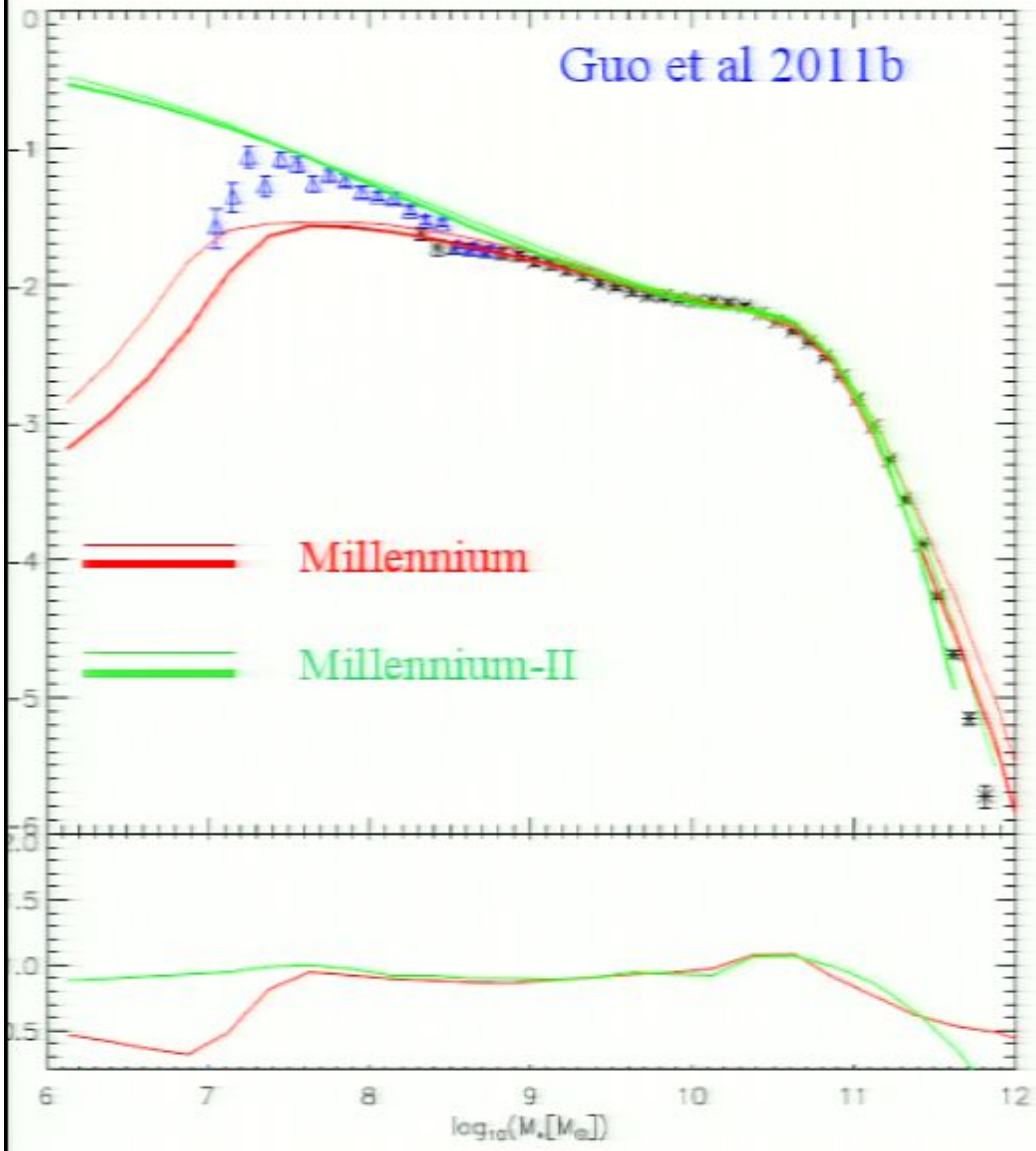


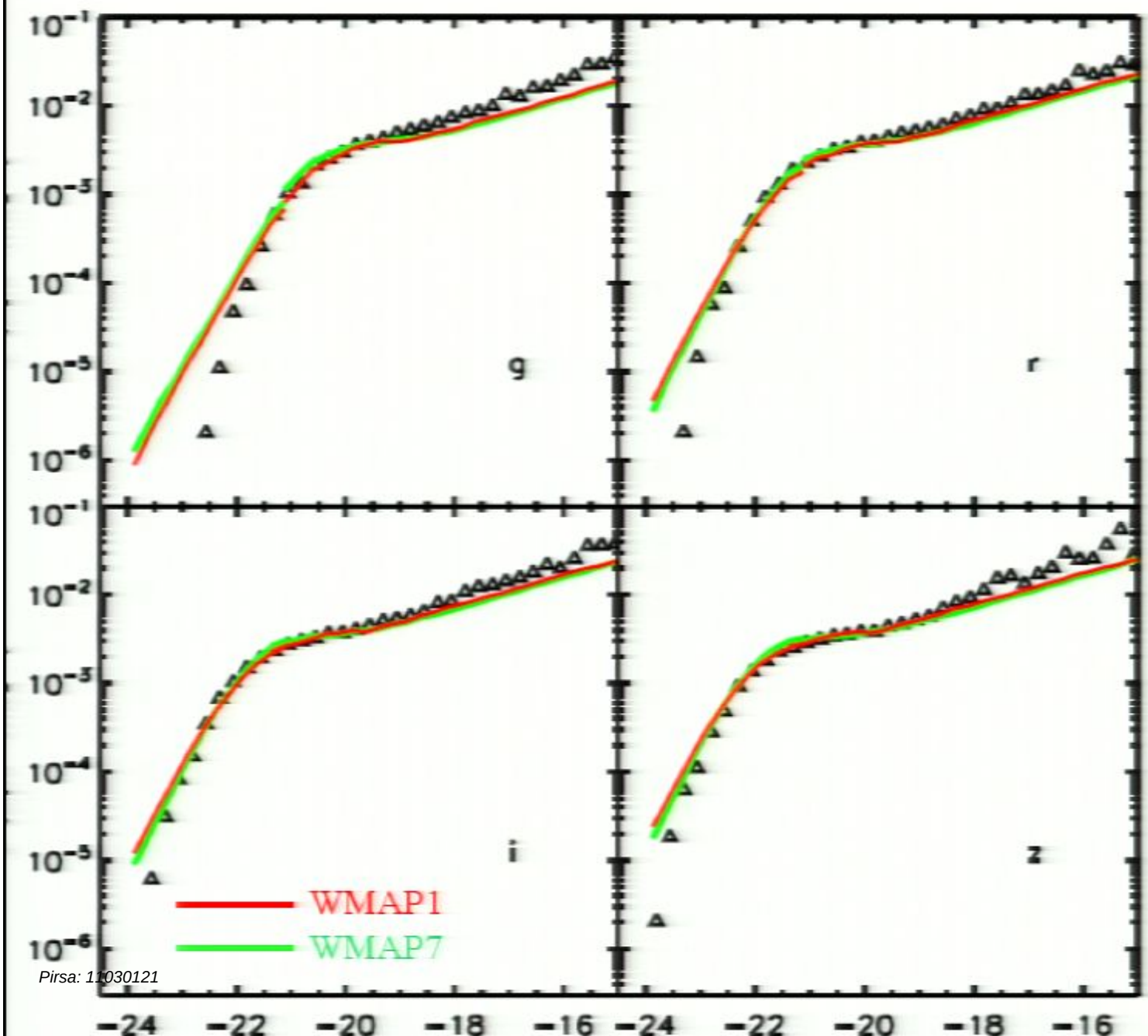
Switching from WMAP1 to WMAP7

Small shifts in the parameters of the galaxy formation model allow the galactic stellar mass function to be fit equally well in the two different cosmologies despite

$$\sigma_8 = 0.90 \longrightarrow \sigma_8 = 0.81$$

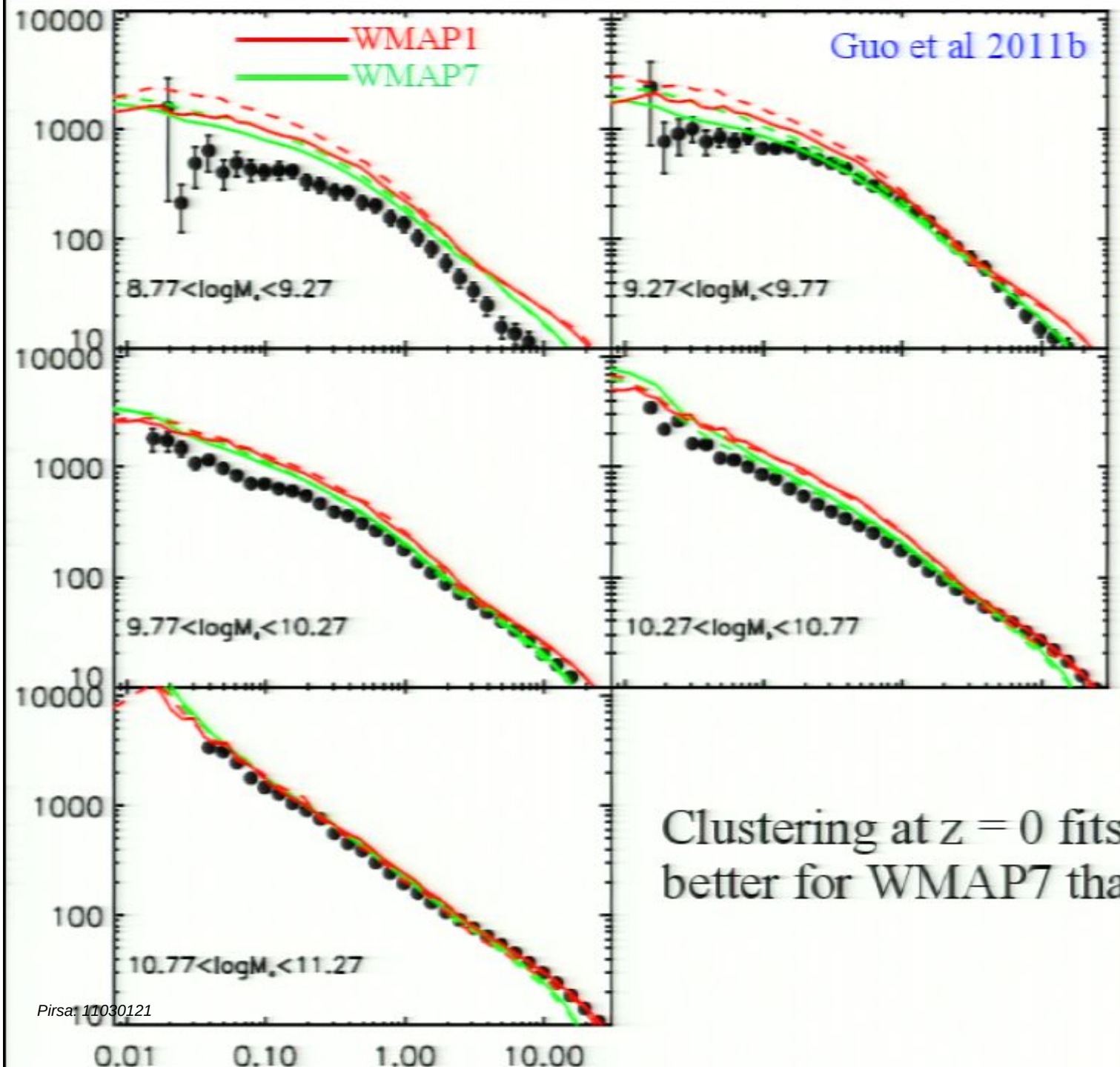
Parameter	Description	WMAP1	WMAP7
α	Star formation efficiency	0.02	0.016
ϵ	Amplitude of SN reheating efficiency	6.5	4.5
η	Amplitude of SN ejection efficiency	0.32	0.2

Guo et al 2011b



Switching from WMAP1 to WMAP7

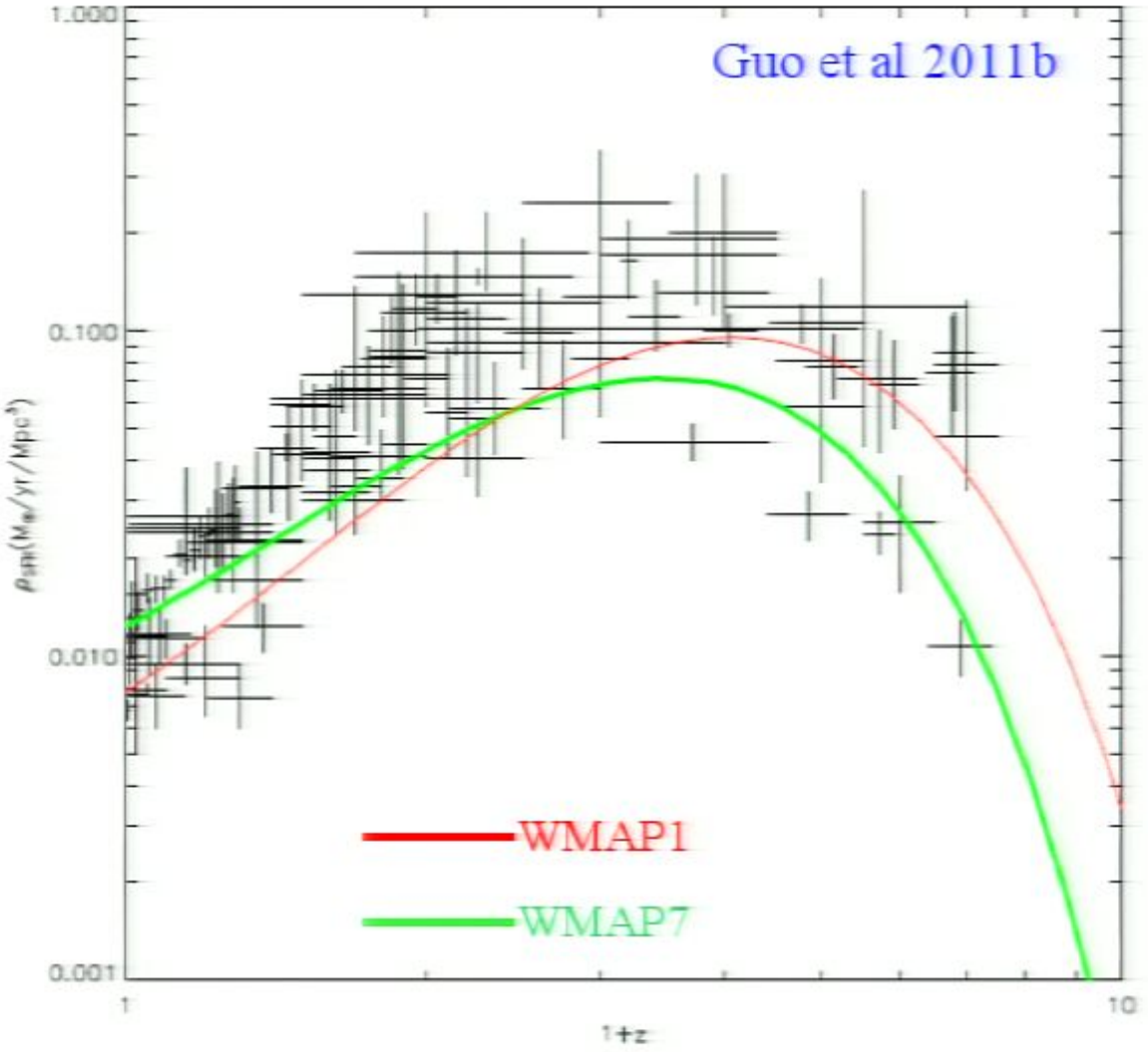
Luminosity functions fit equally well in the two cosmologies



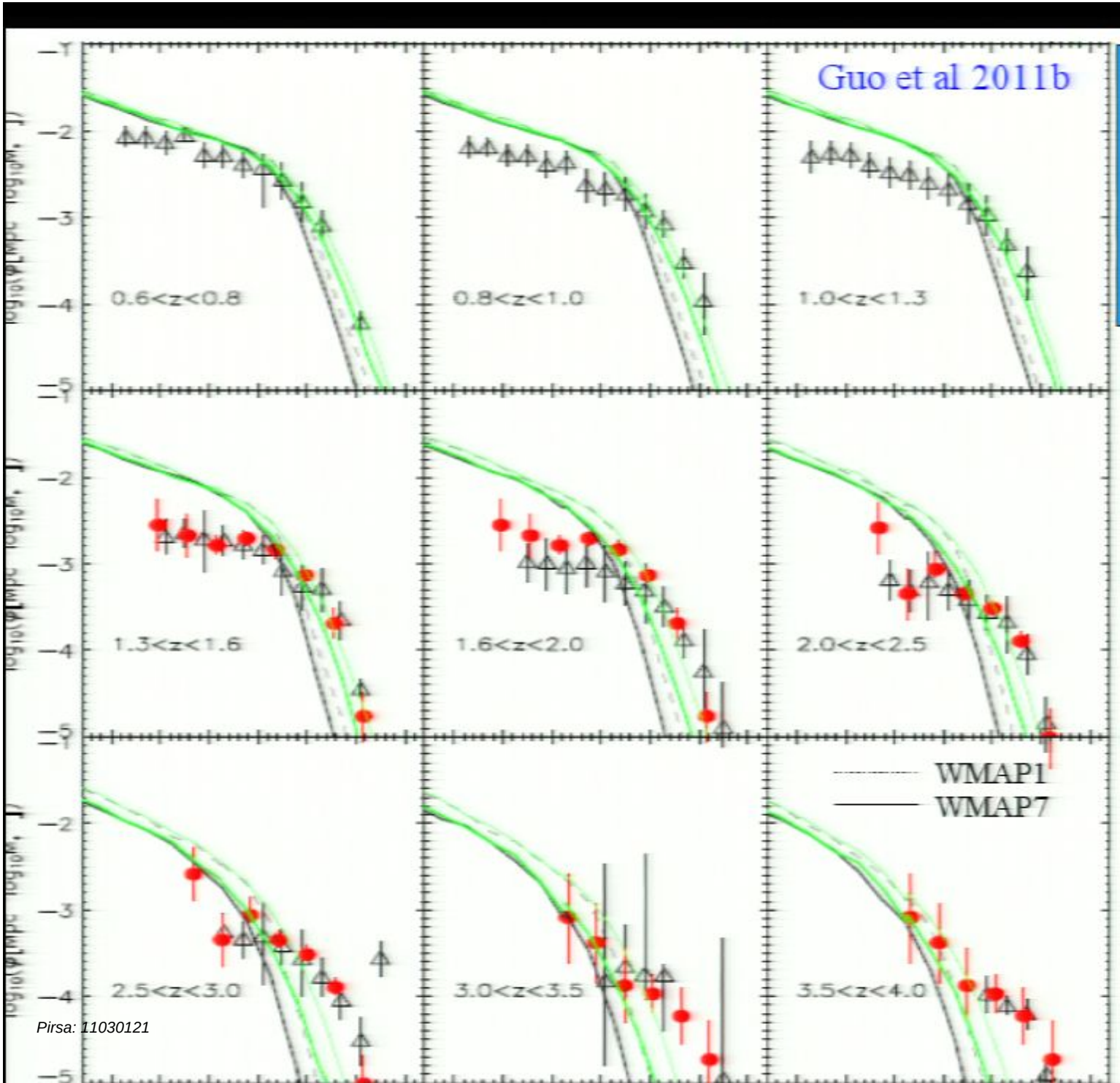
Switching from WMAP1 to WMAP7

Clustering at z = 0 fits observation better for WMAP7 than for WMAP1

Switching from WMAP1 to WMAP7



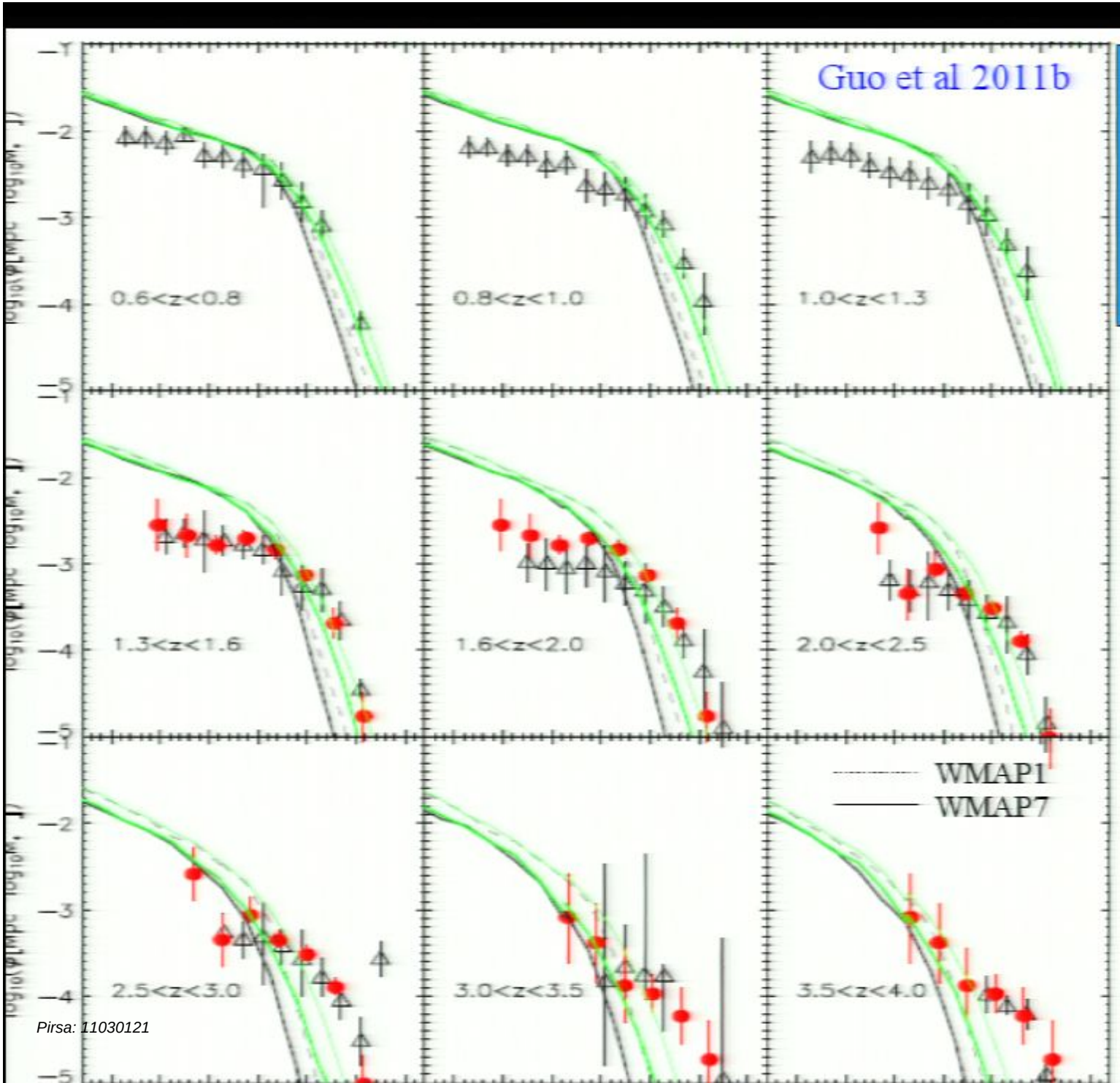
Galaxies form later in the WMAP7 cosmology than in WMAP 1



Switching from WMAP1 to WMAP7

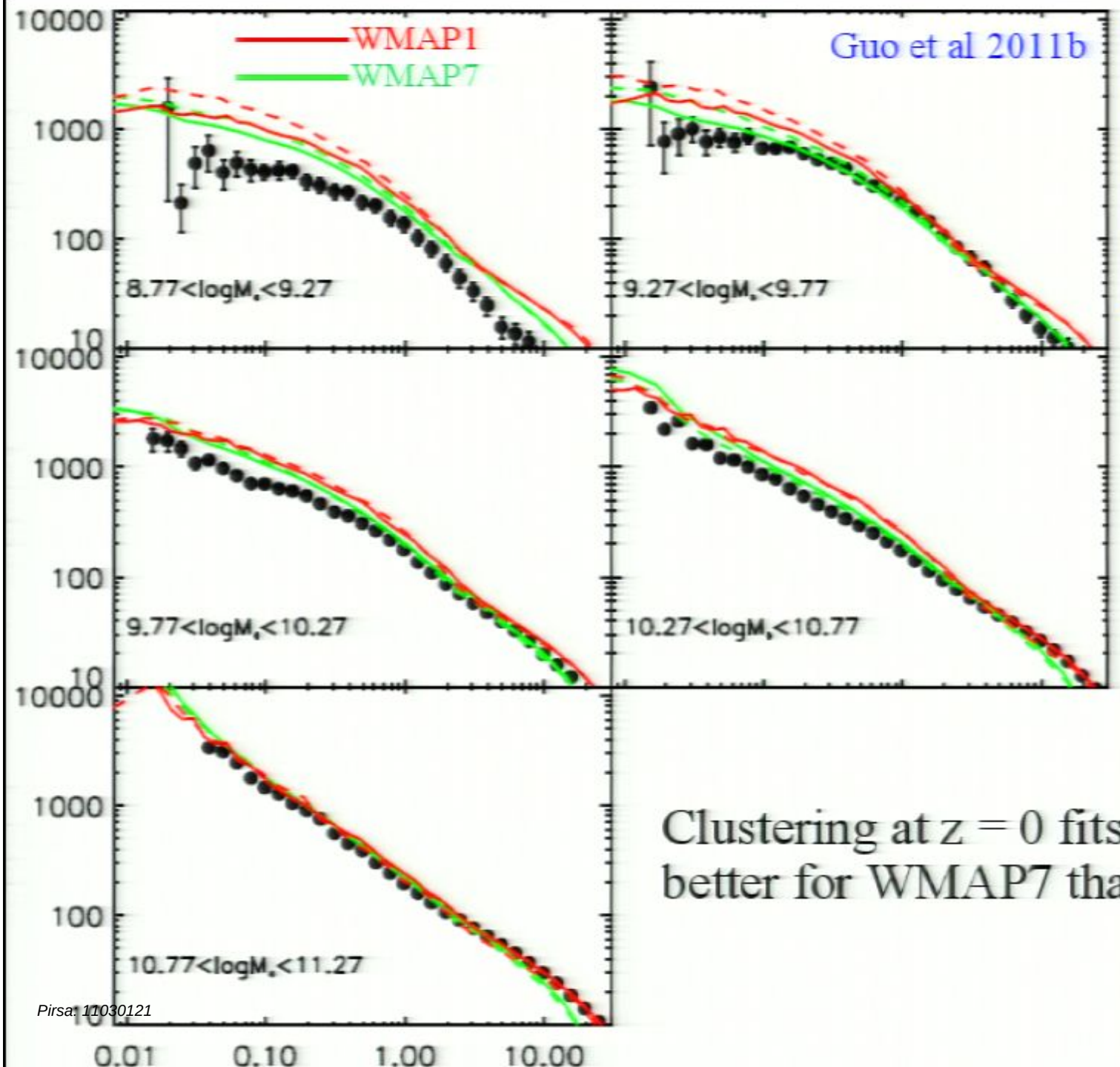
..but the galaxy formation sequence is still incorrect

lick to exit presentation...



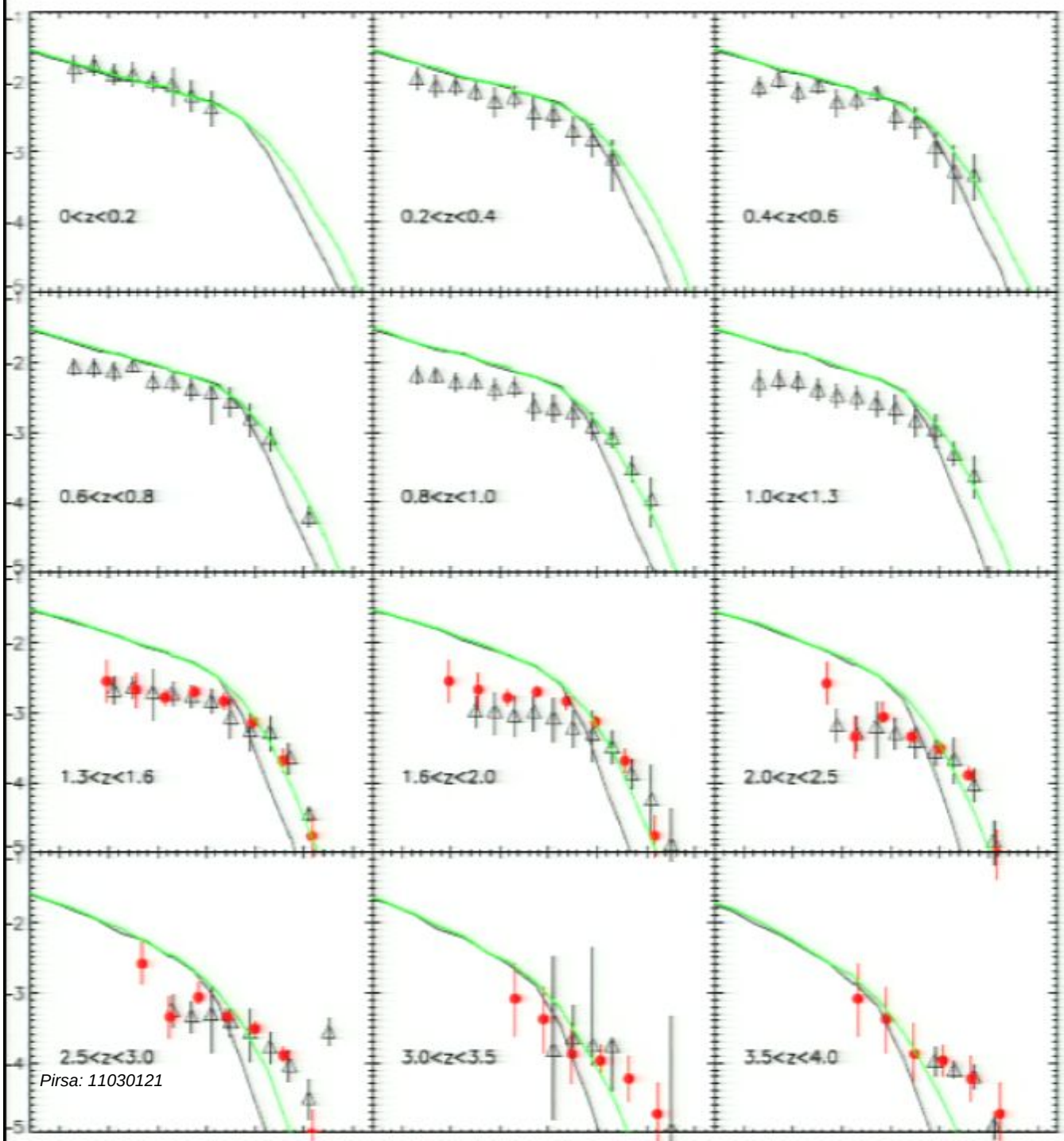
Switching from WMAP1 to WMAP7

..but the galaxy formation sequence is still incorrect



Switching from WMAP1 to WMAP7

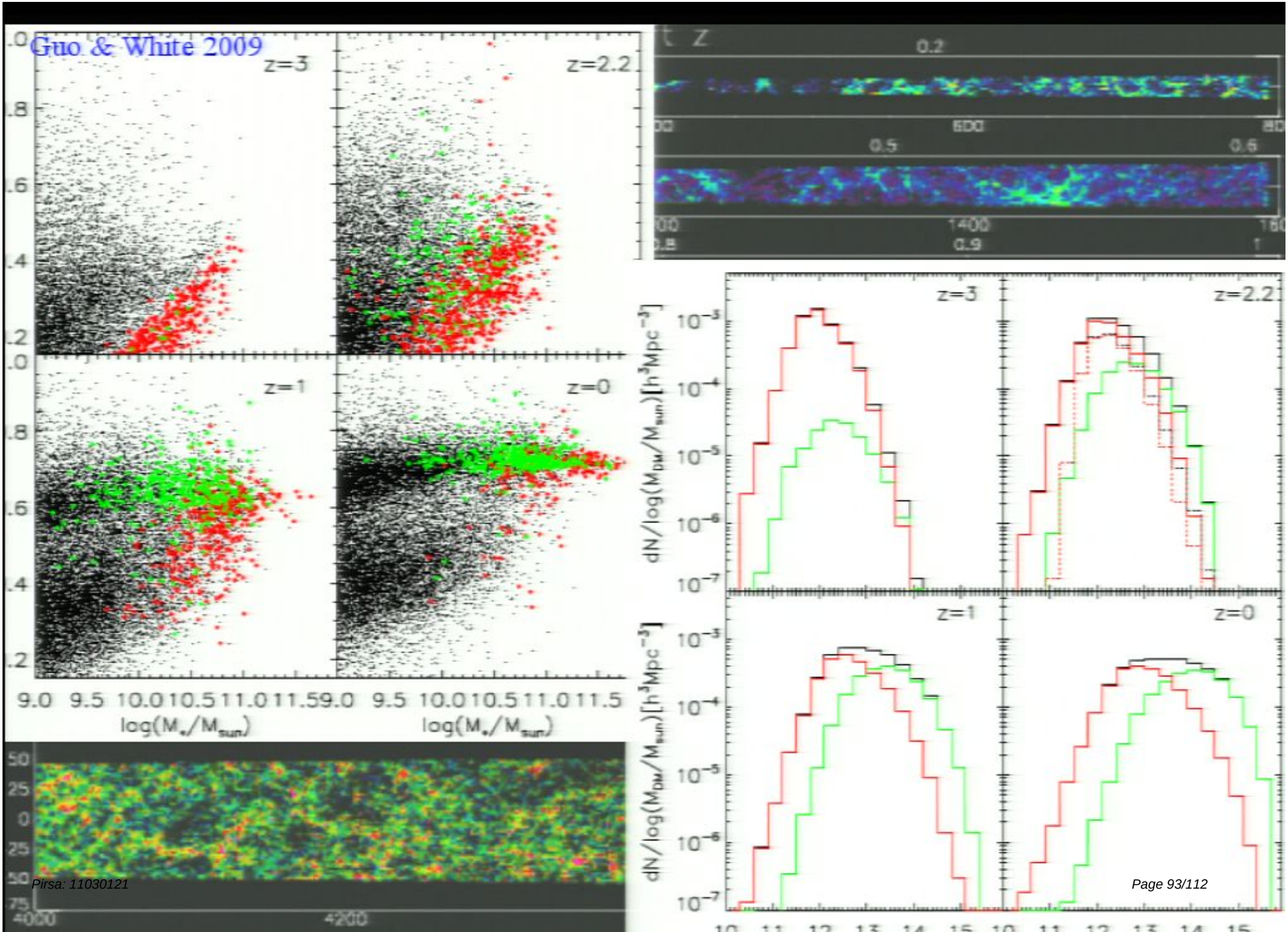
Clustering at z = 0 fits observation better for WMAP7 than for WMAP1

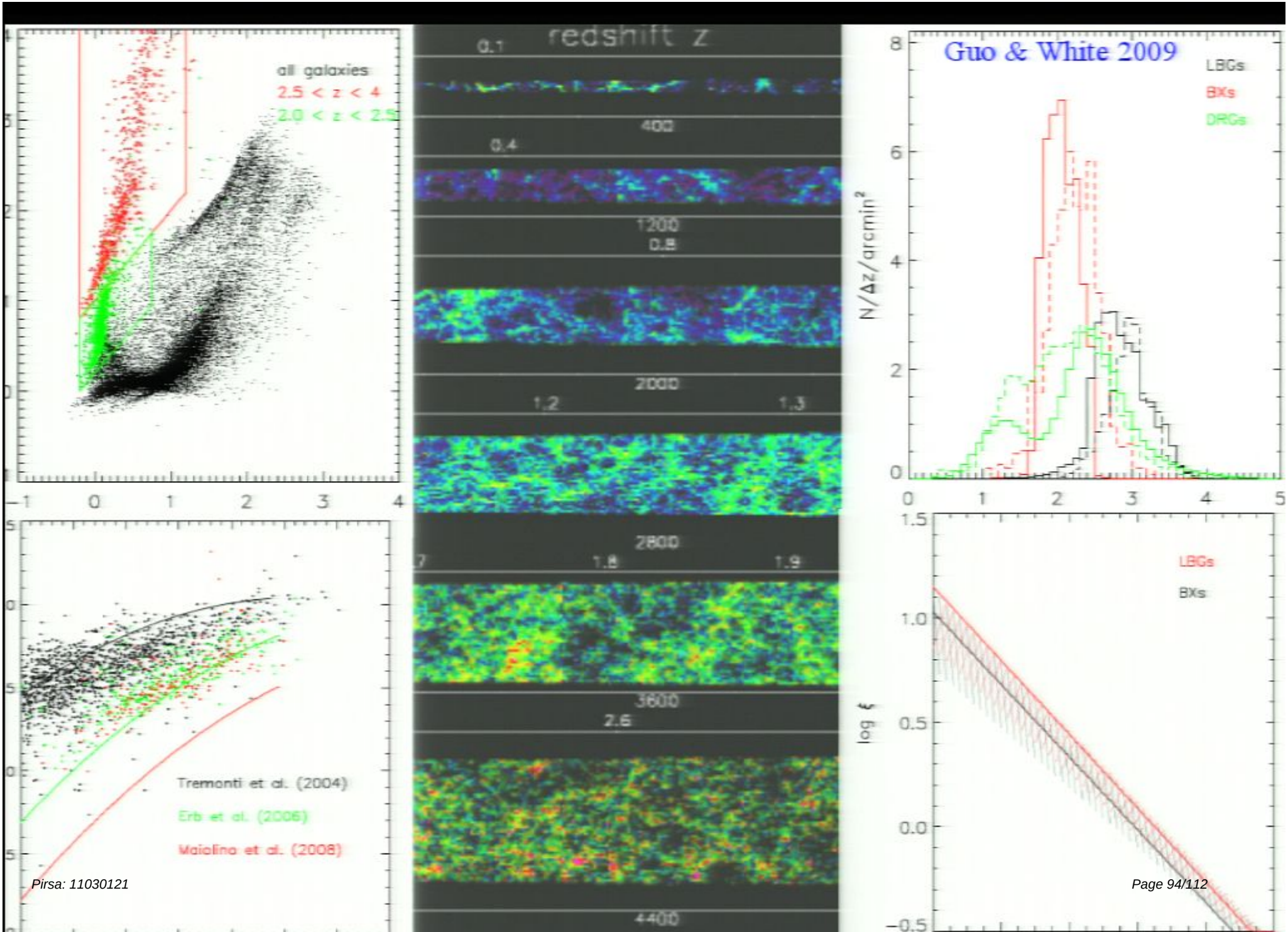


Evolution of stellar mass function

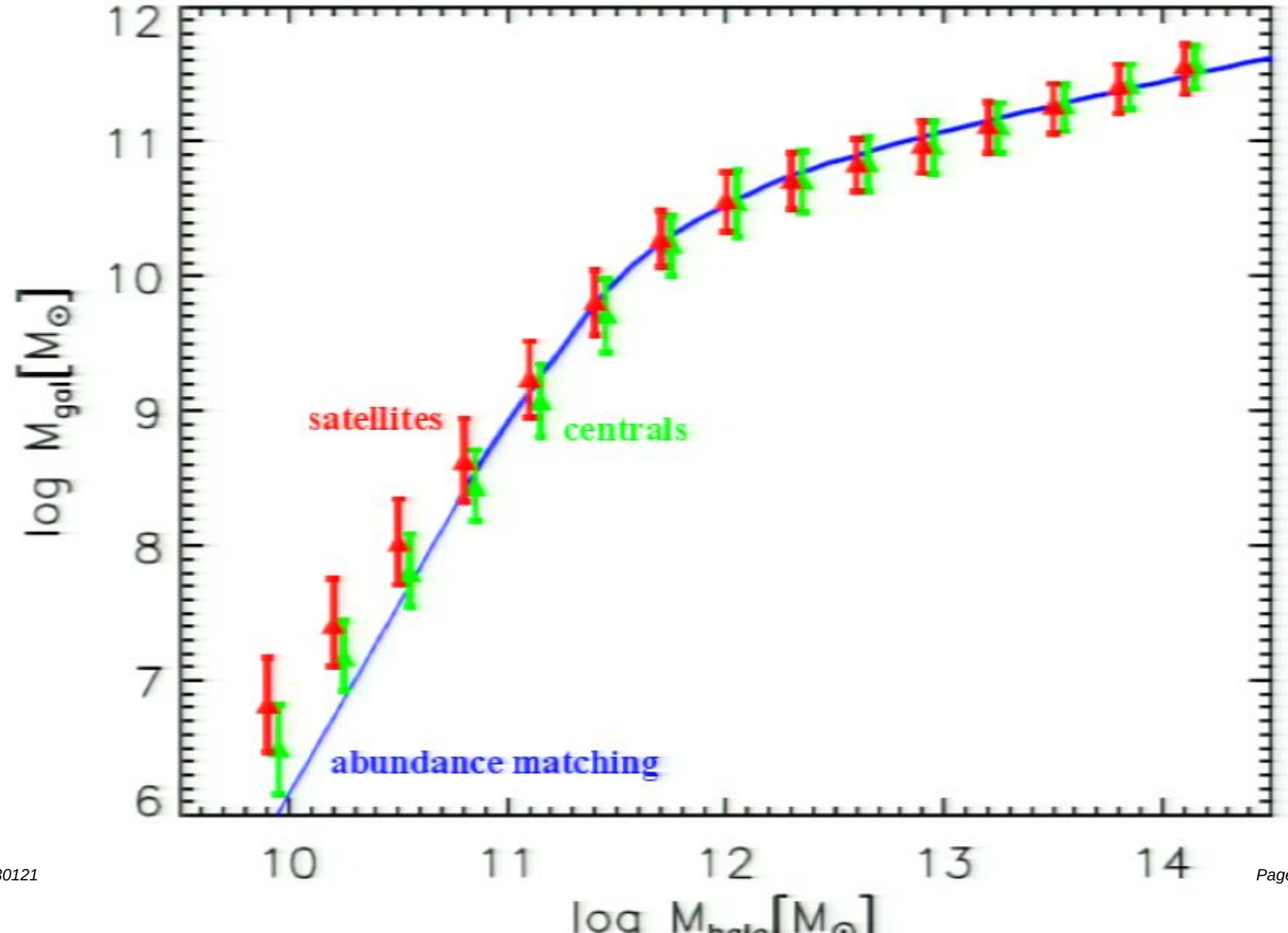
Lower mass galaxies
$\log M_* < 10.5$
form too early

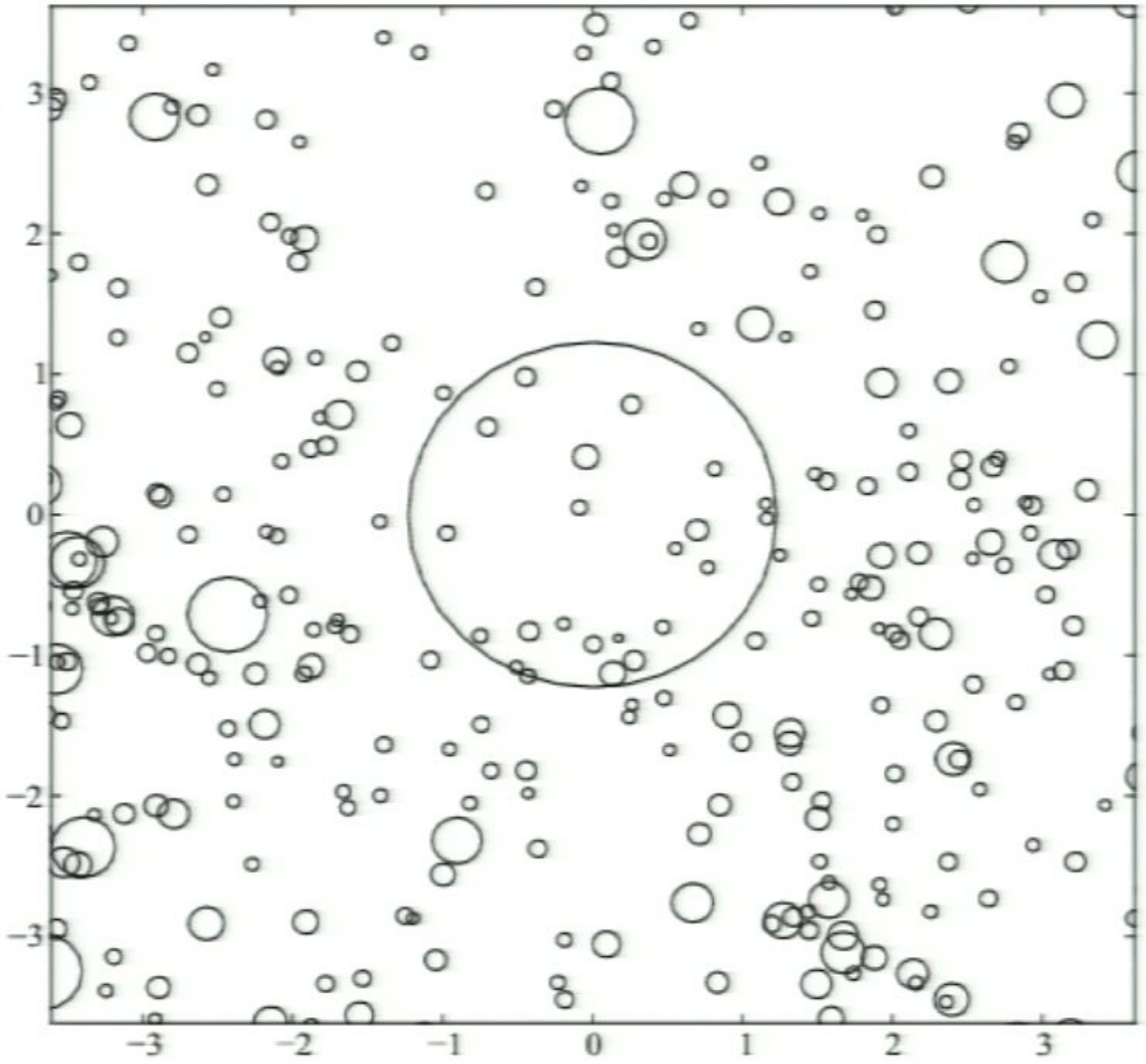
Things that work less well


Guo & White 2009
z=3
z=2.2
z=1
z=0
log(M*/Msun)
log(M*/Msun)
dN/log(MDM/Msun)[h3Mpc-3]
dN/log(MDM/Msun)[h3Mpc-3]


all galaxies
2.5 < z < 4
2.0 < z < 2.5
redshift z
0.1
400
0.4
1200
0.8
2000
1.2
1.3
2800
1.8
1.9
3600
2.6
4400
Guo & White 2009
LBGs
BXs
DRGs
N/Δz/arcmin²
Tremonti et al. (2004)
Erb et al. (2006)
Maiolino et al. (2008)
LBGs
BXs
log ξ

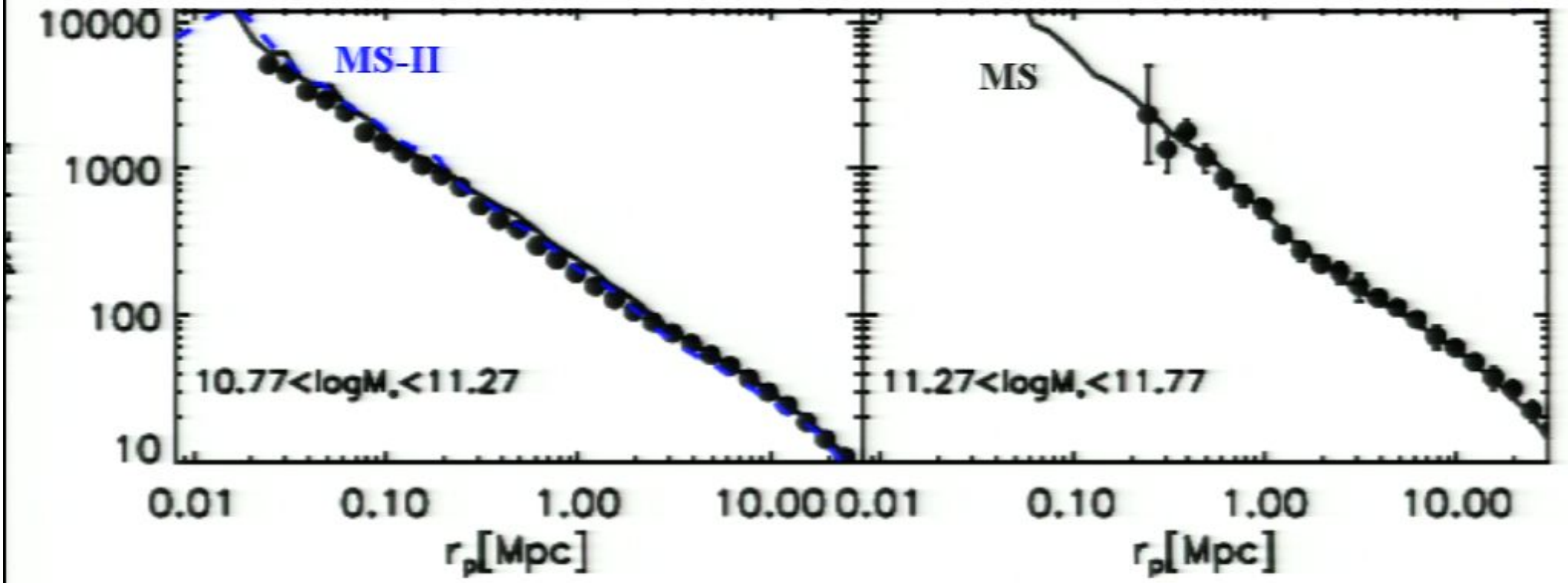
Galaxy stellar mass versus maximum past halo mass





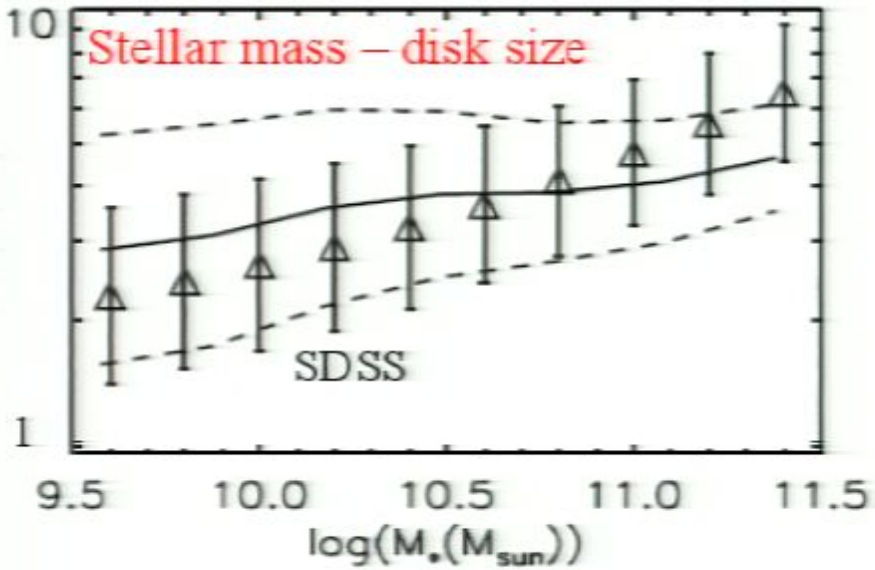
IS cluster
alos only

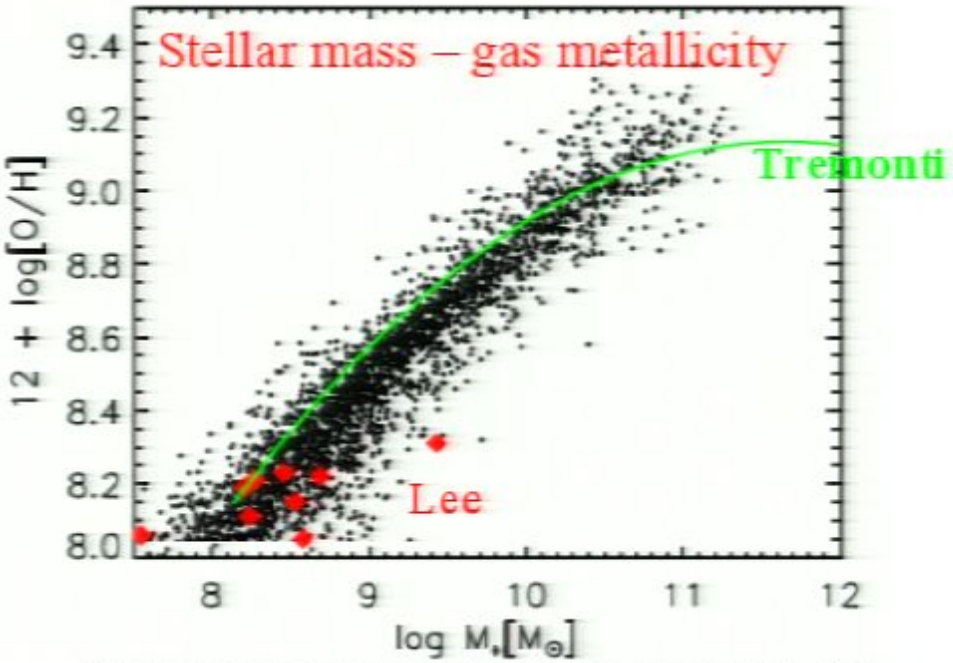
Clustering of massive galaxies

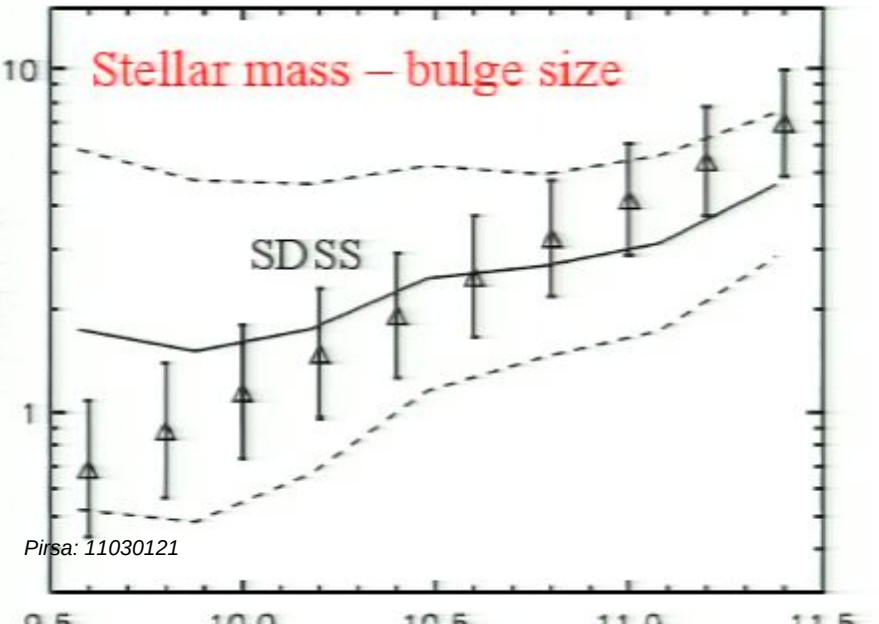


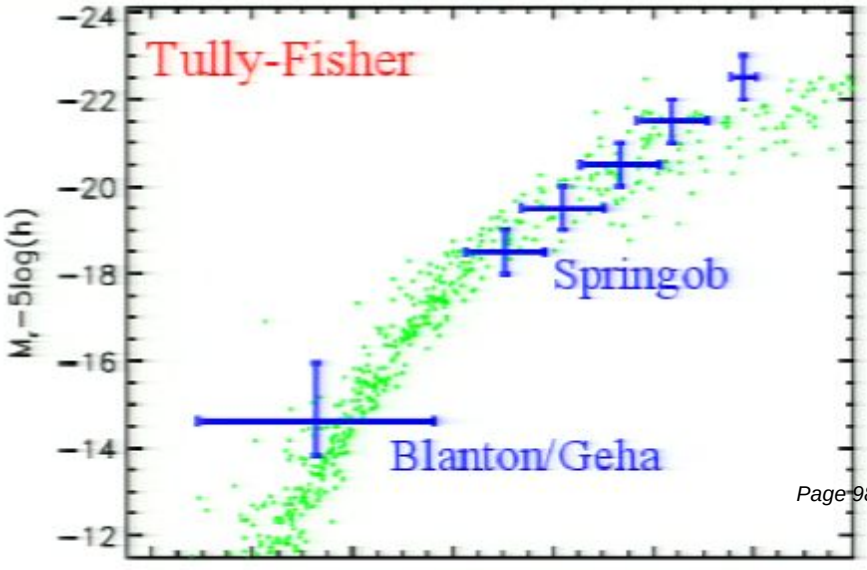
Data from SDSS/DR7

Scaling relations

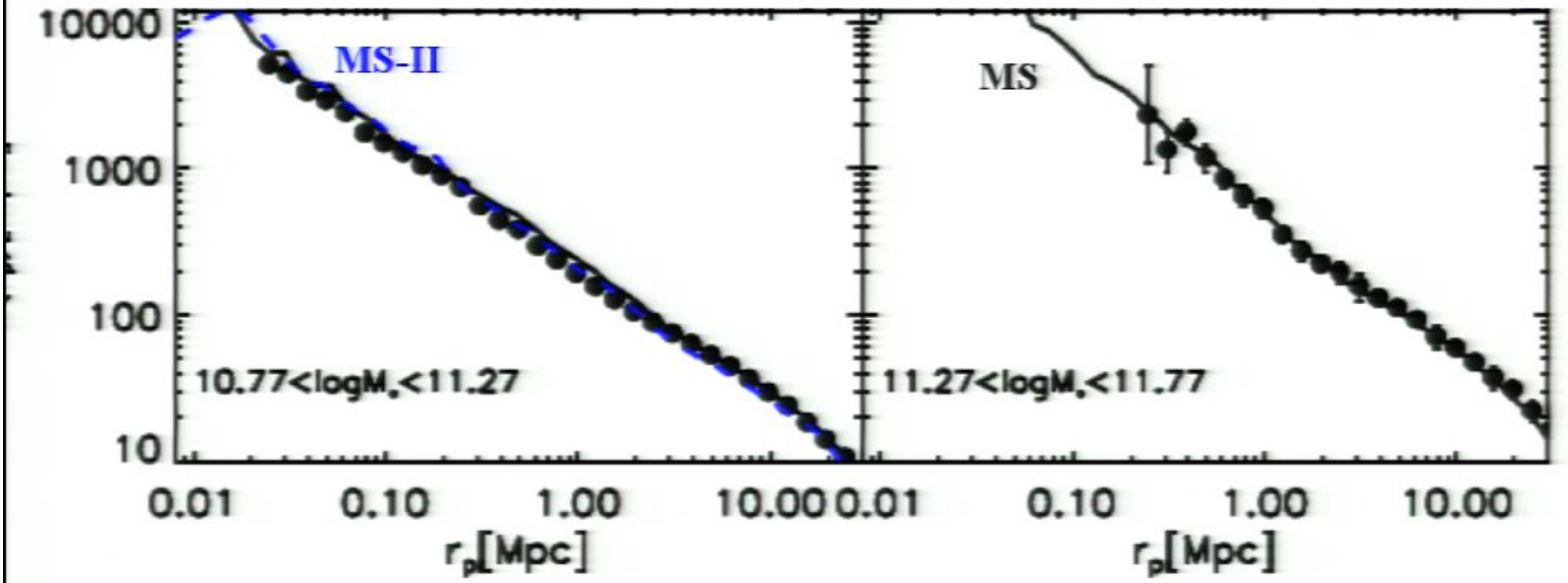




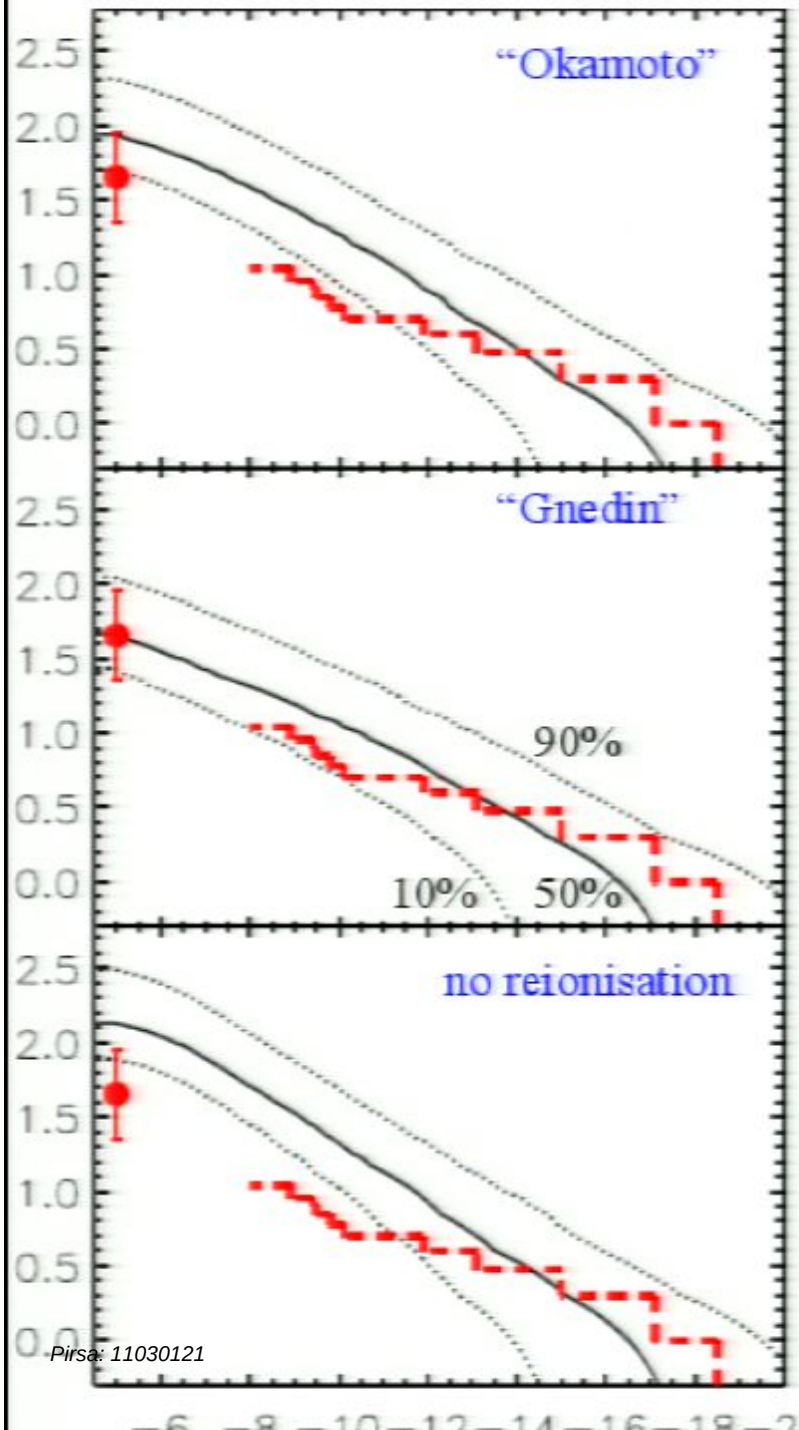




Clustering of massive galaxies



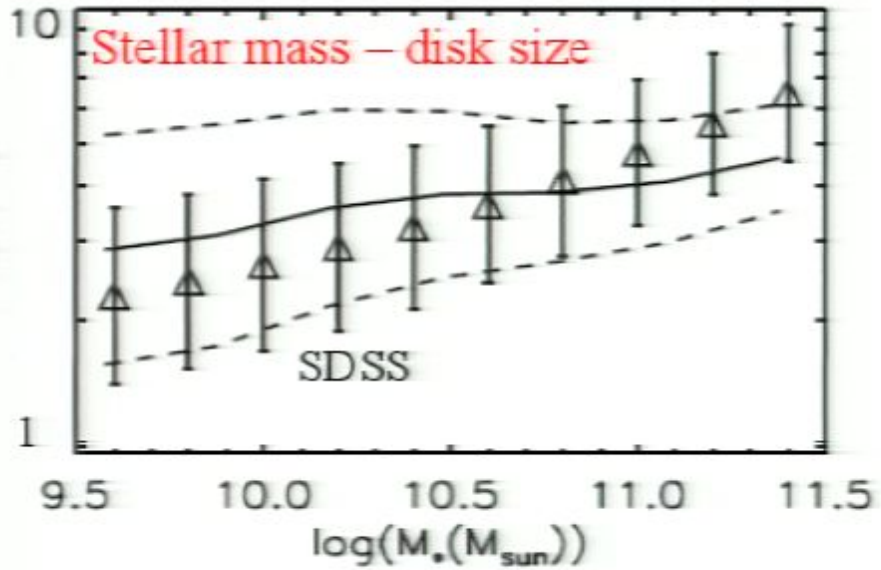
Data from SDSS/DR7

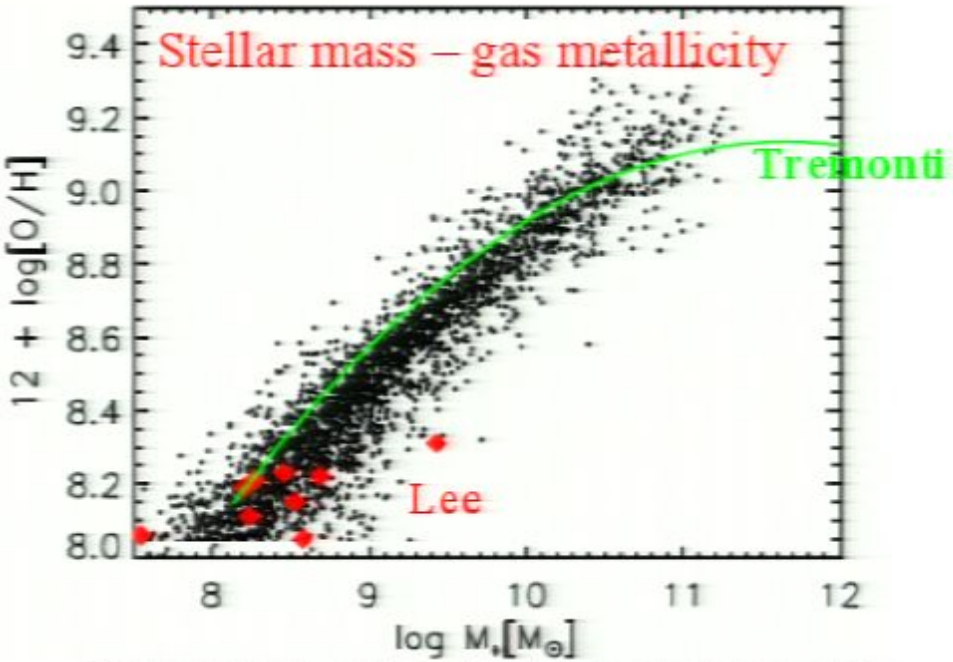


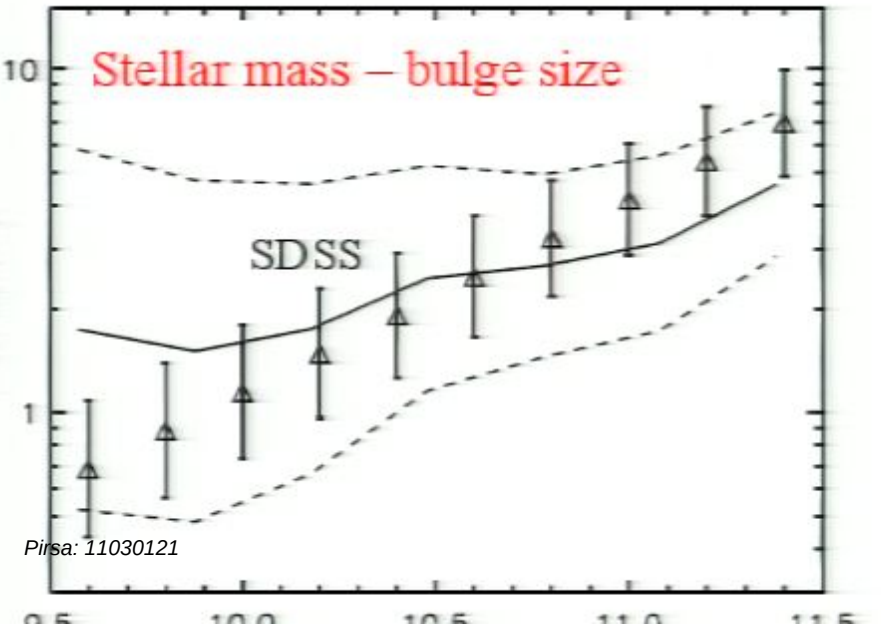
Luminosity function of Milky Way satellites

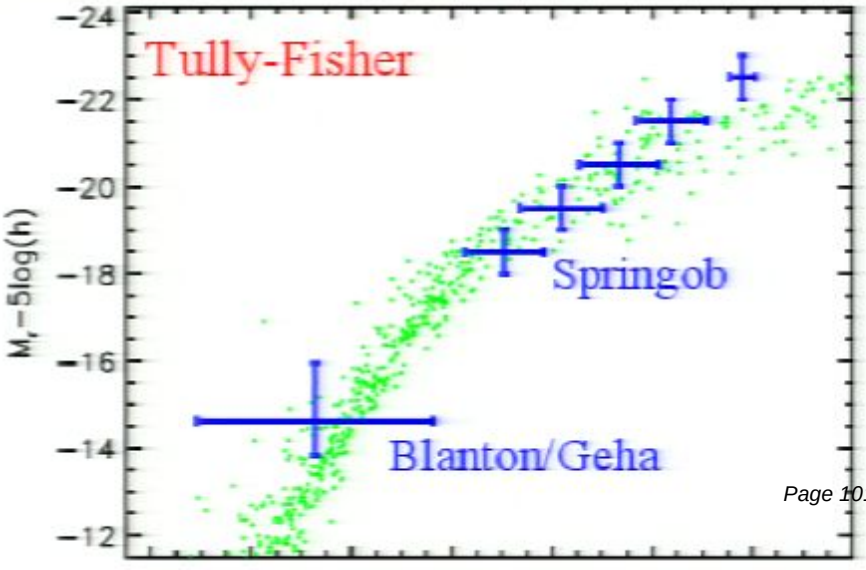
Luminosity functions of satellites around 1500 "Milky Ways" i.e. isolated disk galaxies with $\log M_* = 10.8$

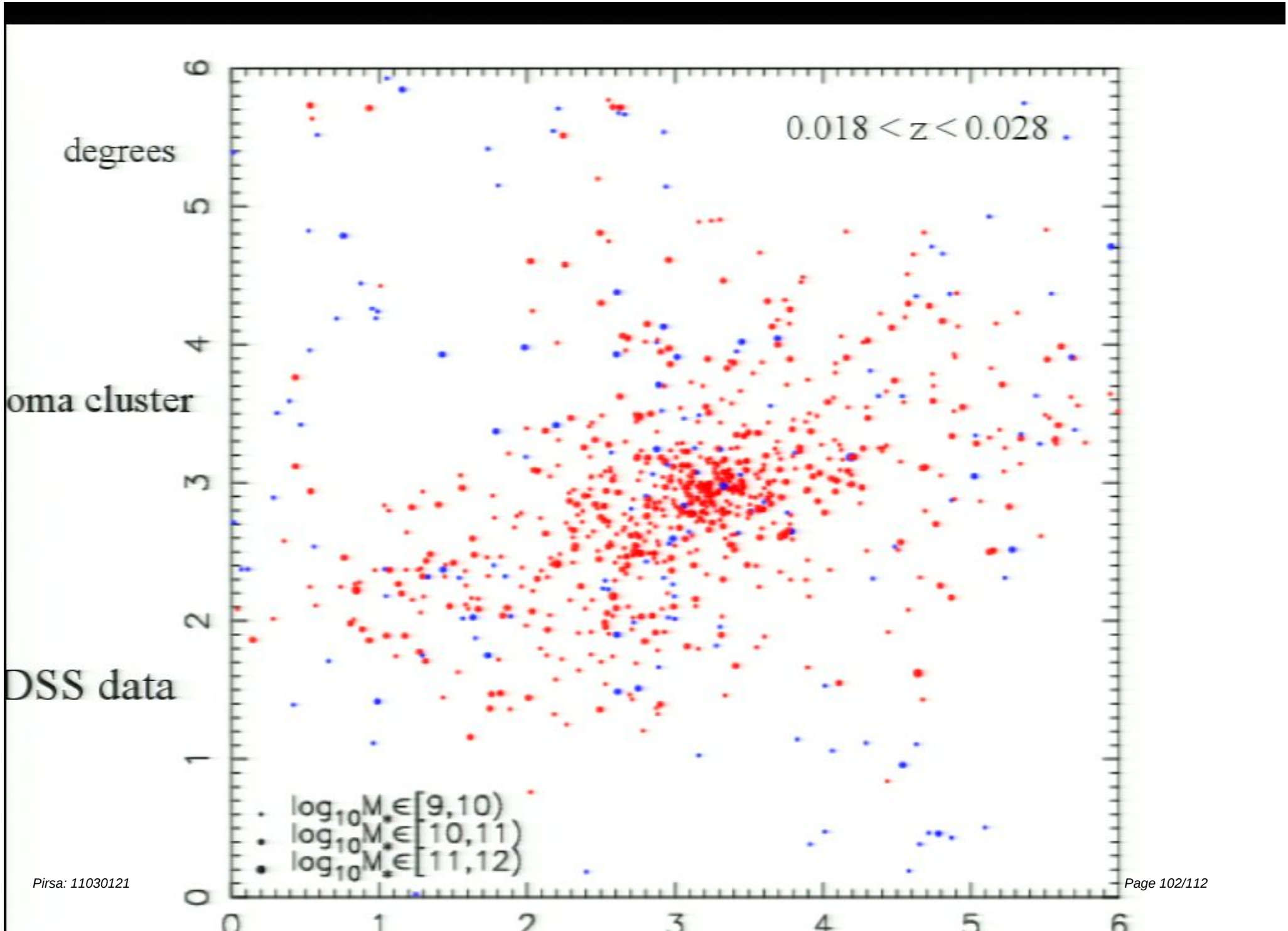
Scaling relations



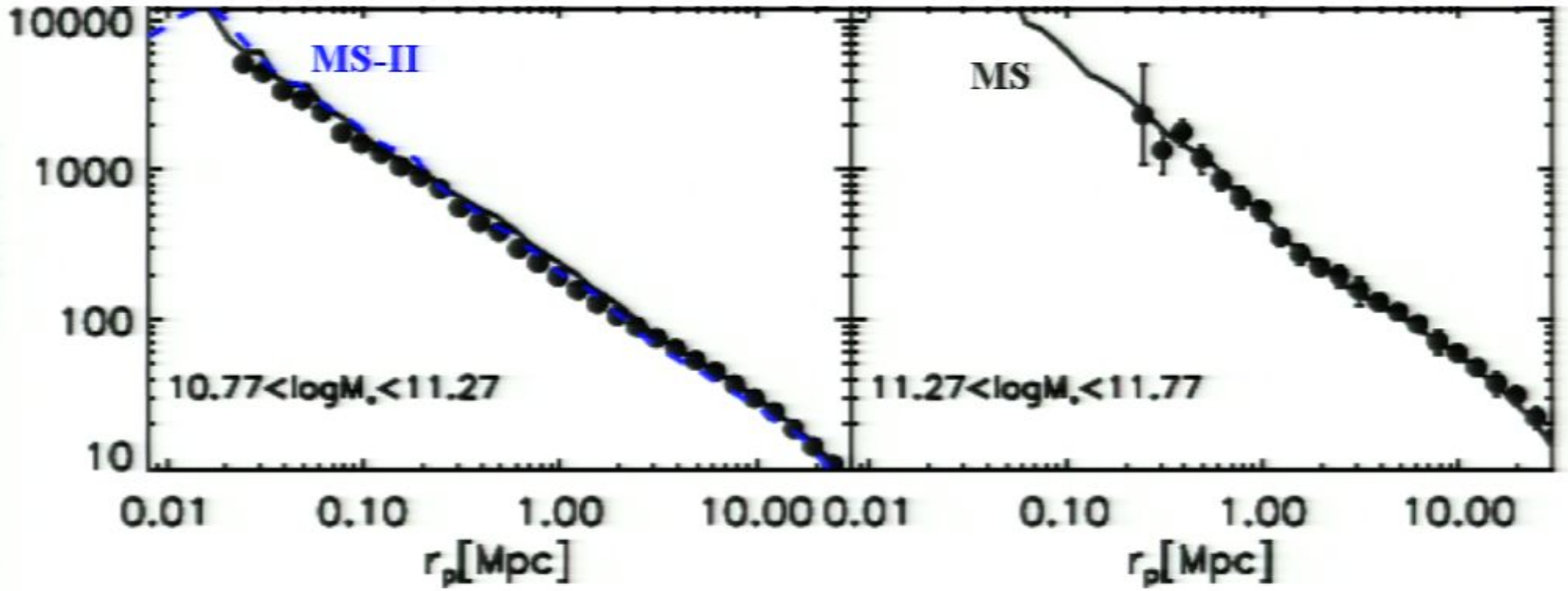






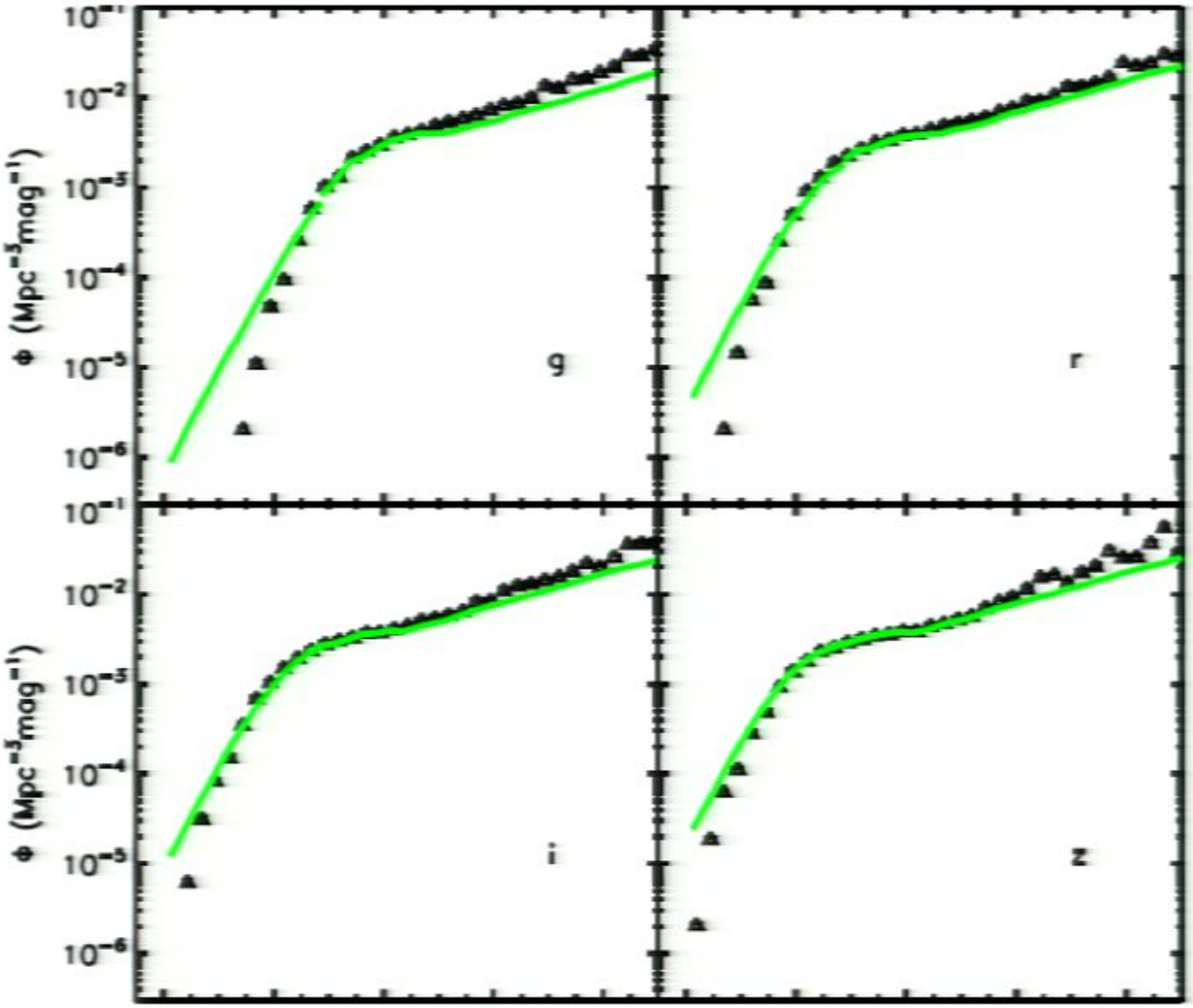

degrees
oma cluster
DSS data
0.018 < z < 0.028
log10M*∈[9,10)
log10M*∈[10,11)
log10M*∈[11,12)
0
1
2
3
4
5
6

Clustering of massive galaxies

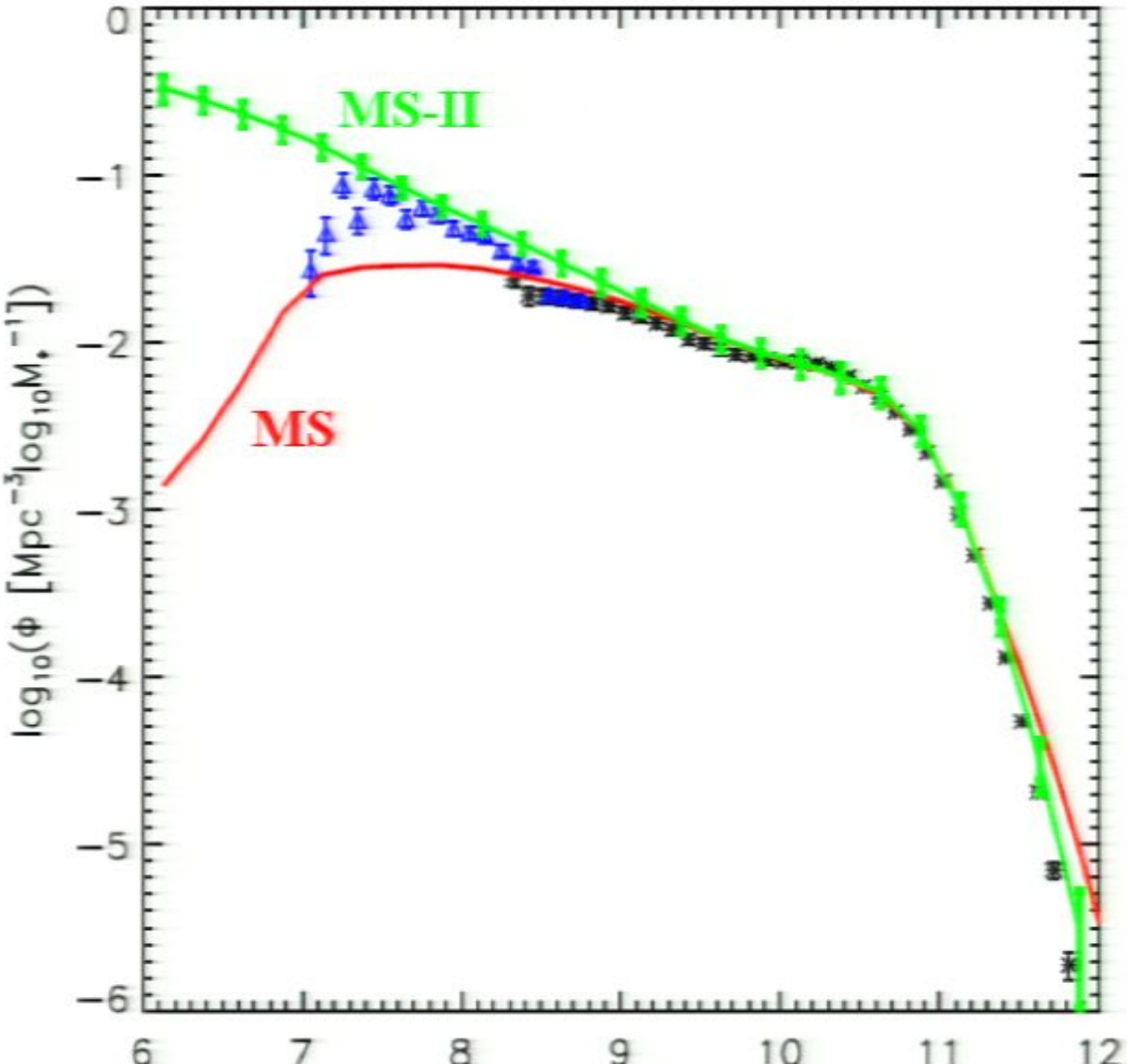


Data from SDSS/DR7

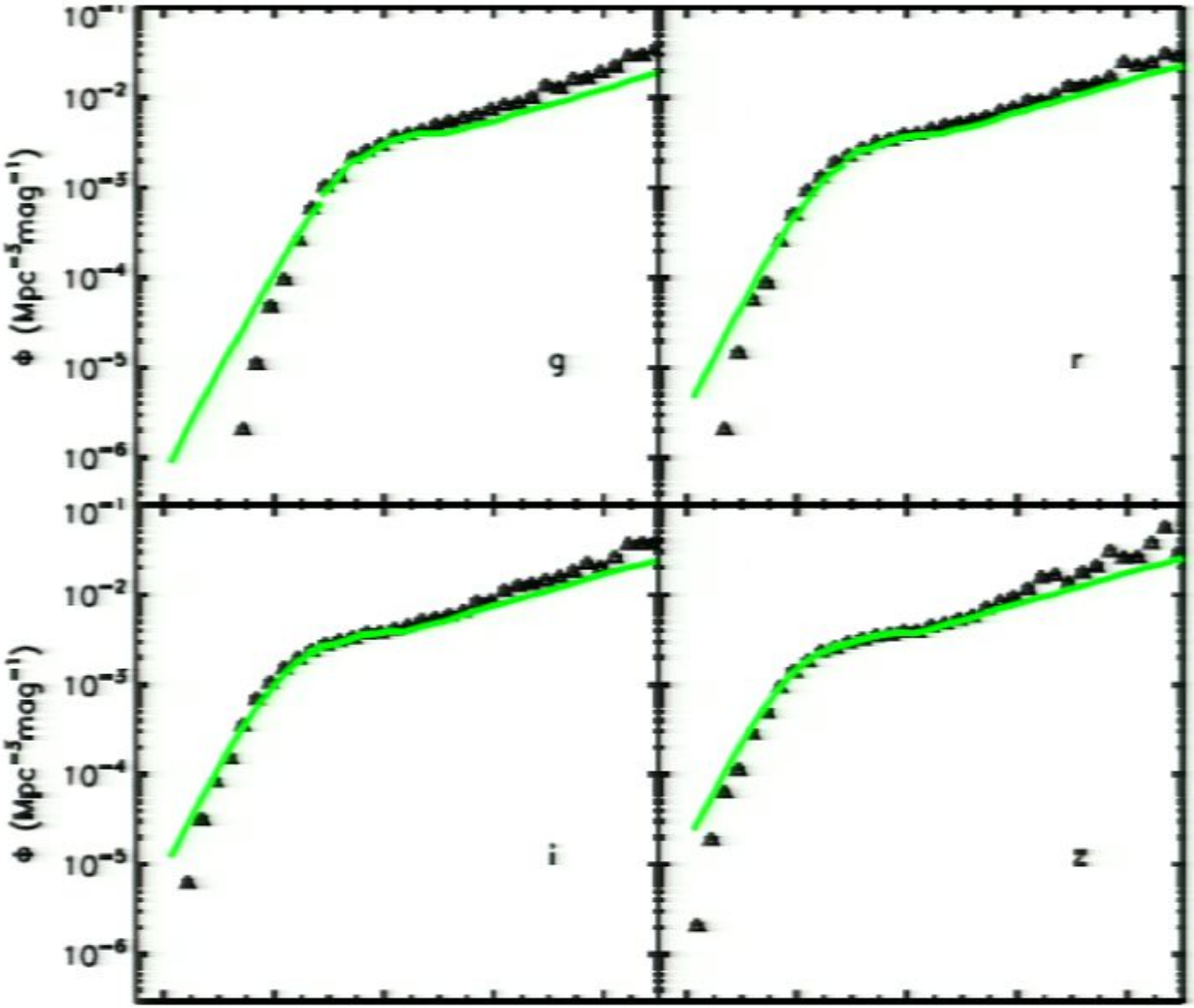
Luminosity functions of galaxies



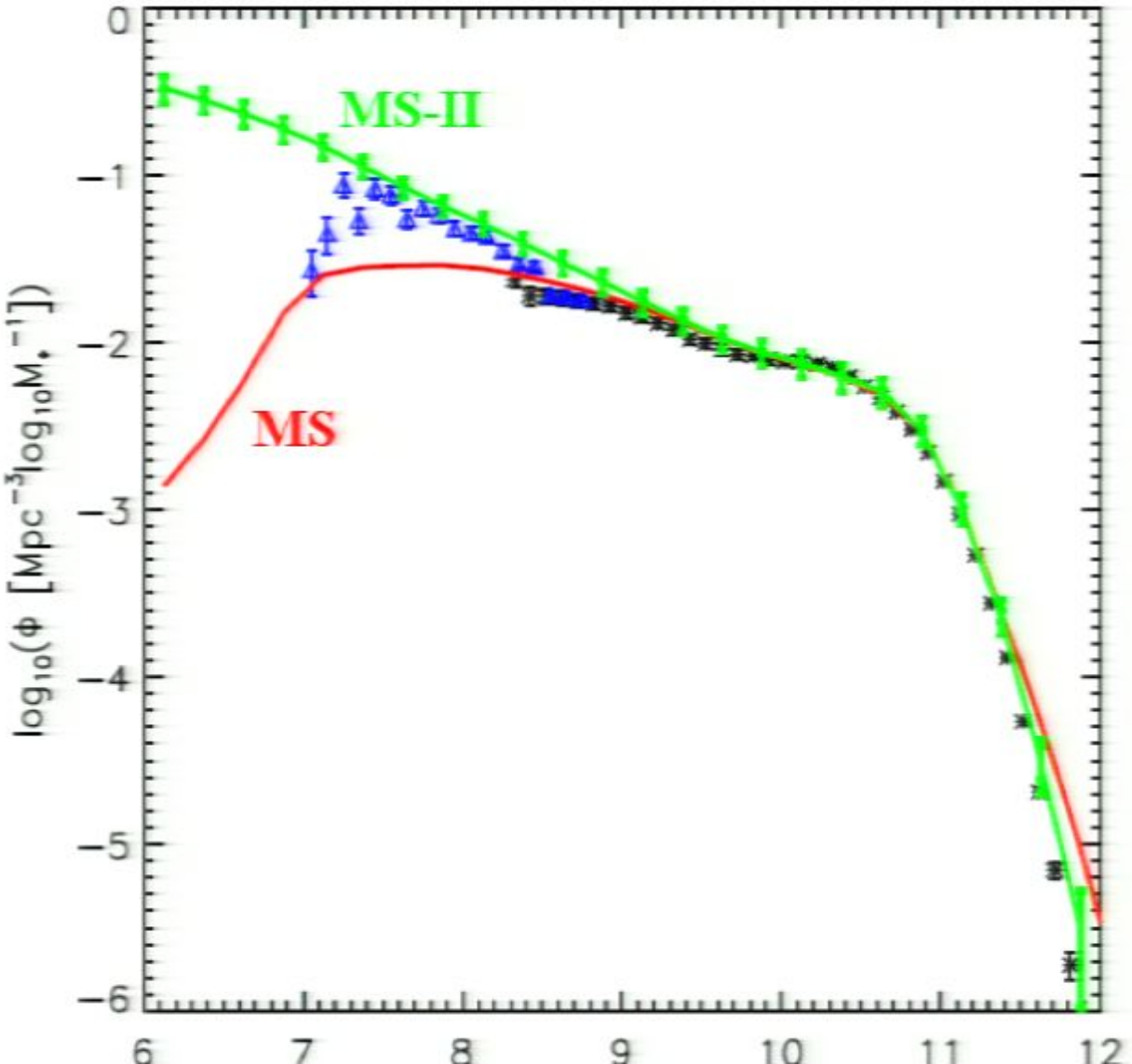
The stellar mass function of galaxies

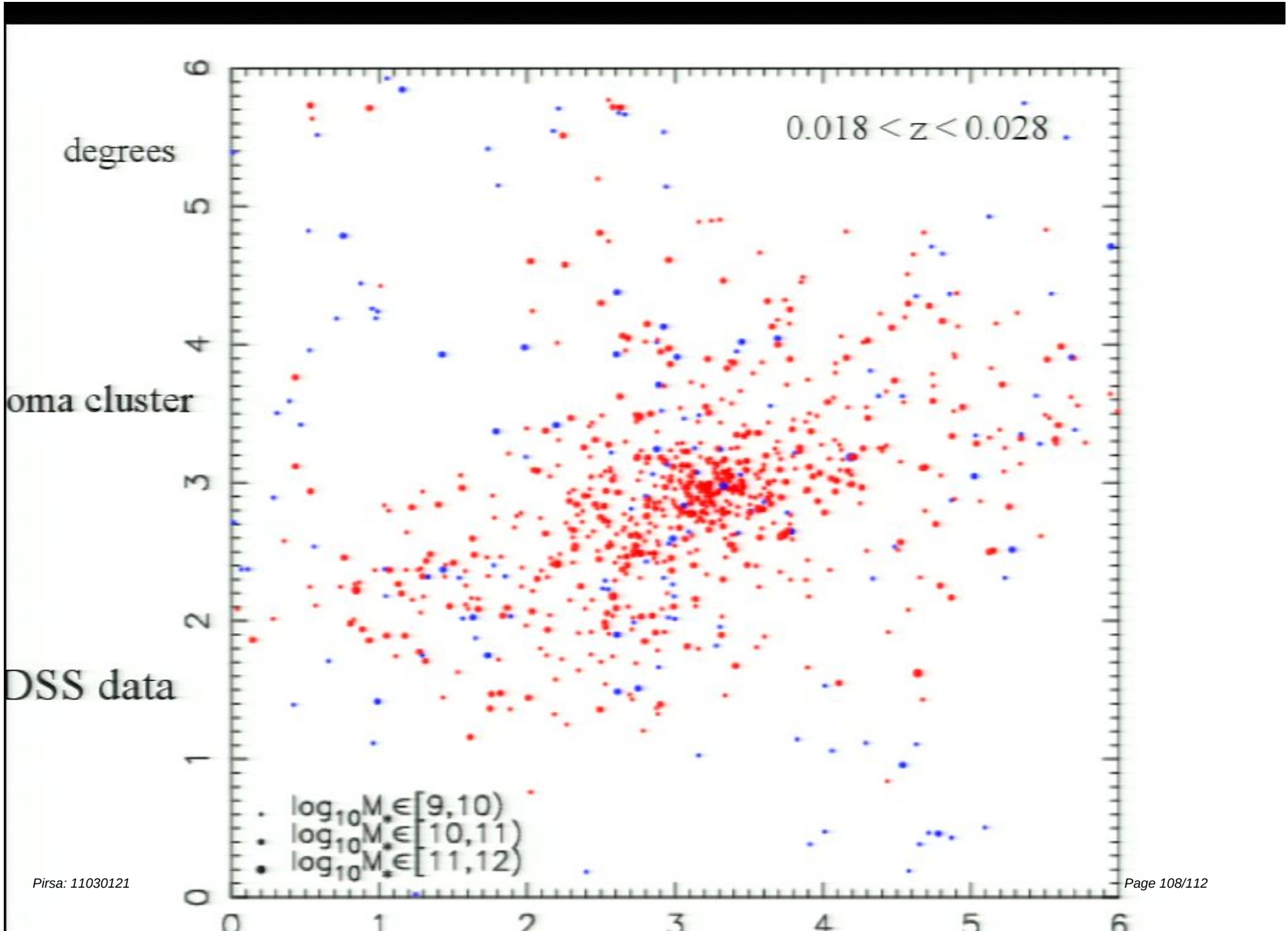


Luminosity functions of galaxies

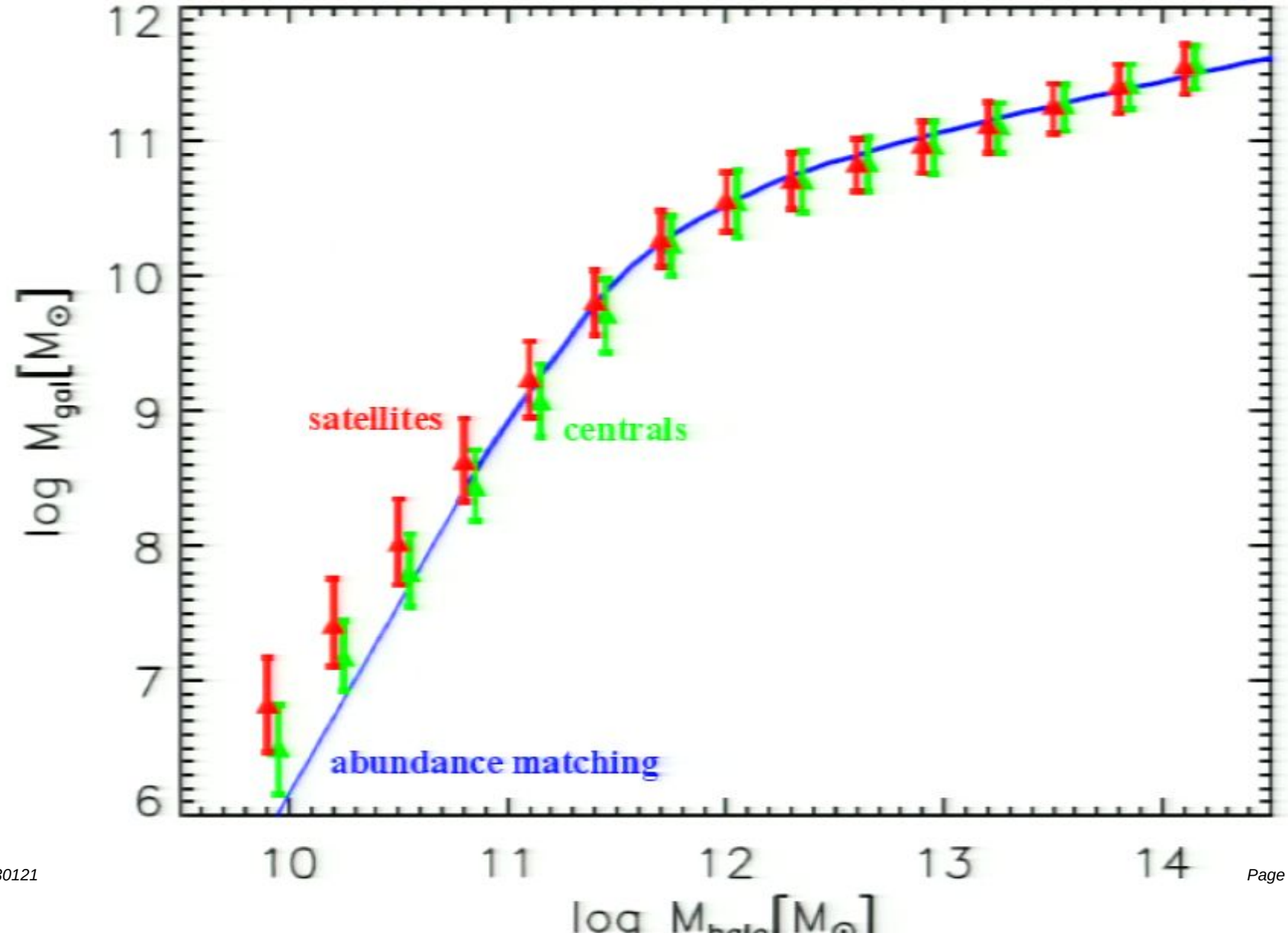


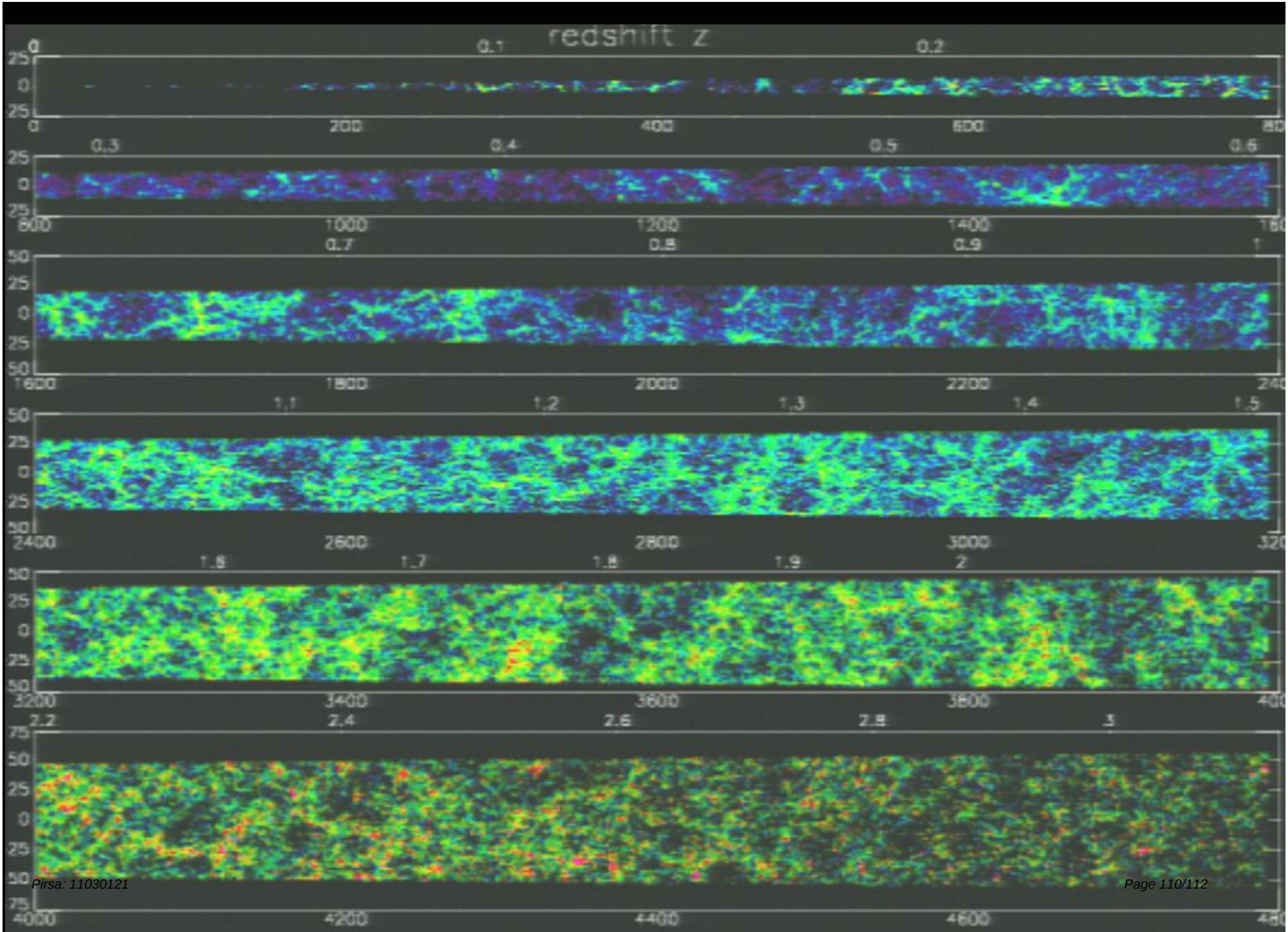
The stellar mass function of galaxies



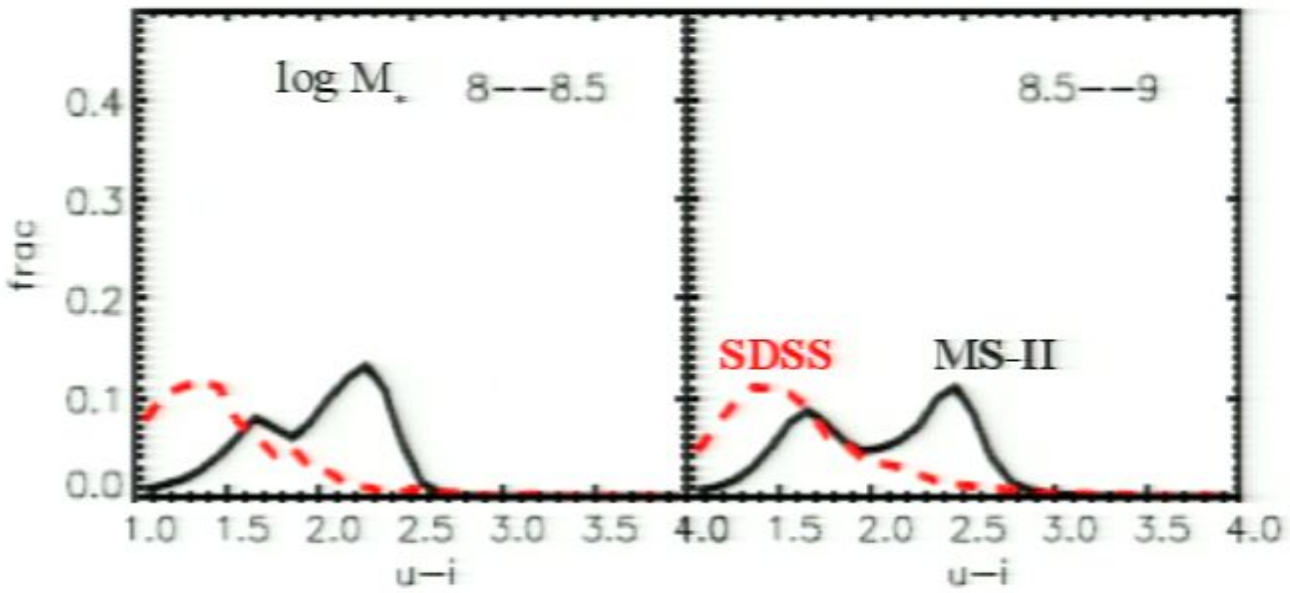

degrees
oma cluster
DSS data
0.018 < z < 0.028
log10M*∈[9,10)
log10M*∈[10,11)
log10M*∈[11,12)
0
1
2
3
4
5
6

Galaxy stellar mass versus maximum past halo mass




redshift z
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.2
2.4
2.6
2.8
3
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600

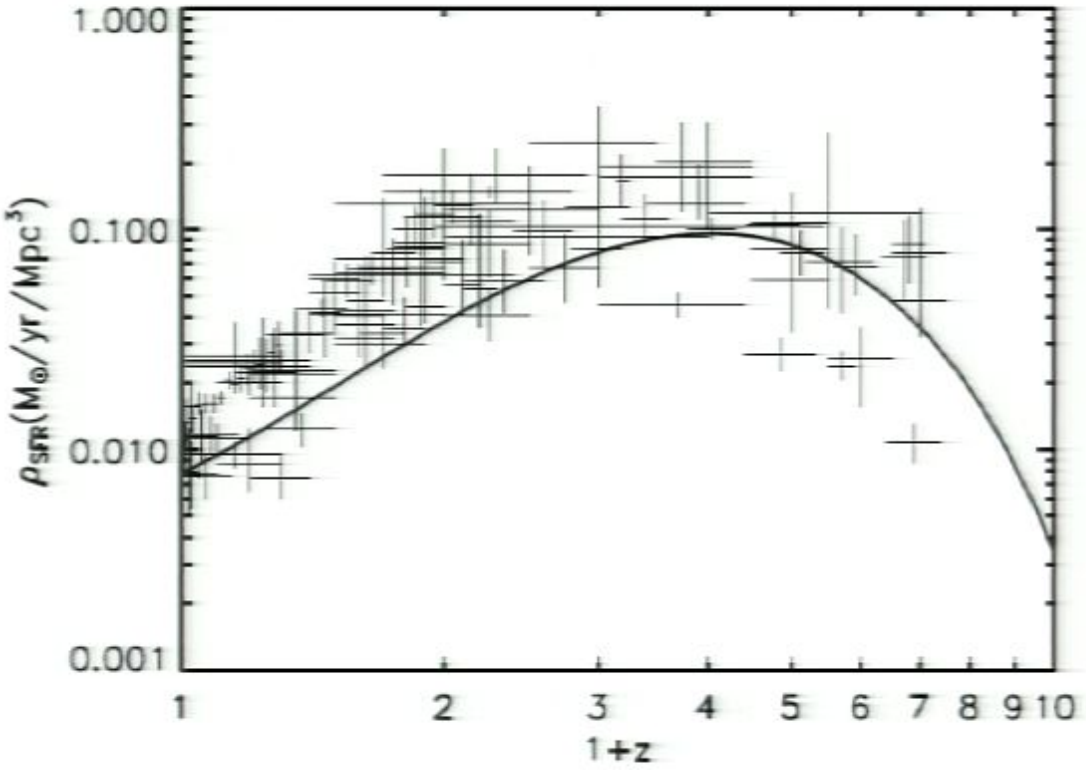
Colours of dwarf galaxies



Too many passive low mass galaxies in the MS-II

--- formation is too fast/too early ---

The cosmic star formation density history



--- observed SFR are inconsistent with observed stellar masses ---

--- star formation peaks too early in the model ---