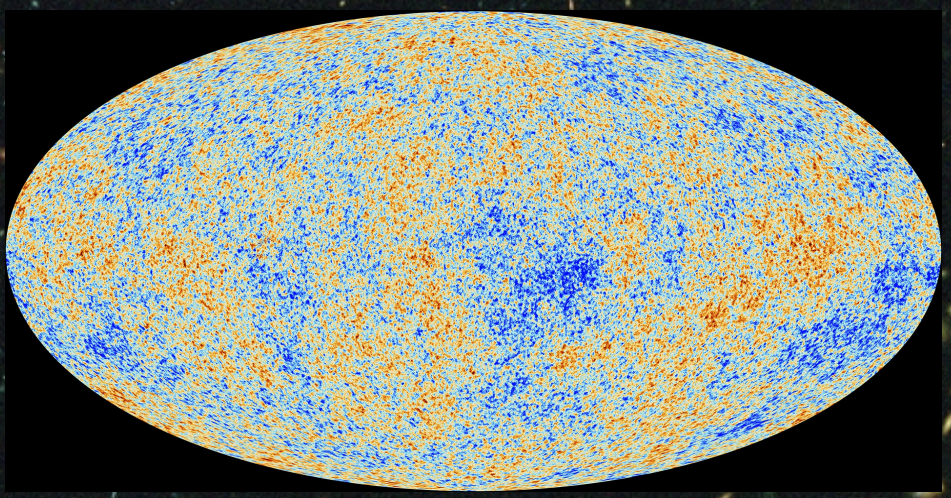
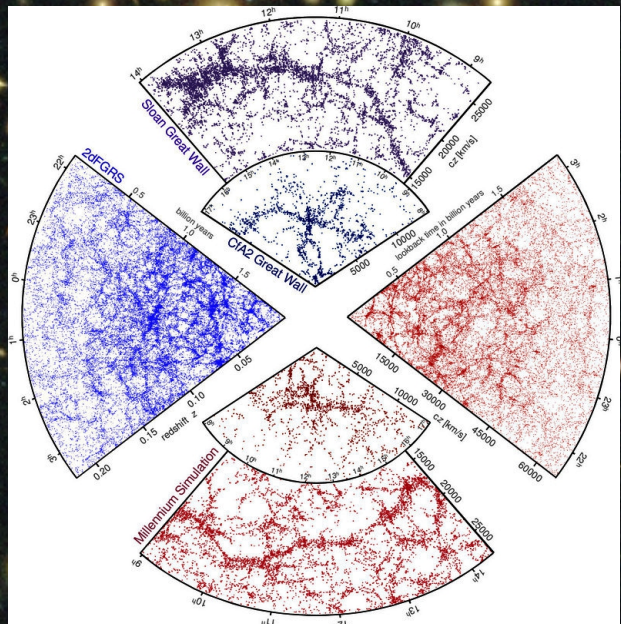


Aspen, February 2014

Galaxy population simulations



Simon White
Max Planck Institute for Astrophysics

"semi-analytic" simulations provide a tool...

To explore the statistics and interactions of the many processes affecting stars and gas within growing ΛCDM structures

To understand how the effects of these processes are reflected in the various observed population properties of galaxies

-- abundances, scaling relations, clustering, evolution --

To allow interpretation of large observational surveys in terms of the rates, efficiencies and significance of these processes

"semi-analytic" simulations provide a tool...

To explore the statistics and interactions of the many processes affecting stars and gas within growing ΛCDM structures

To understand how the effects of these processes are reflected in the various observed population properties of galaxies

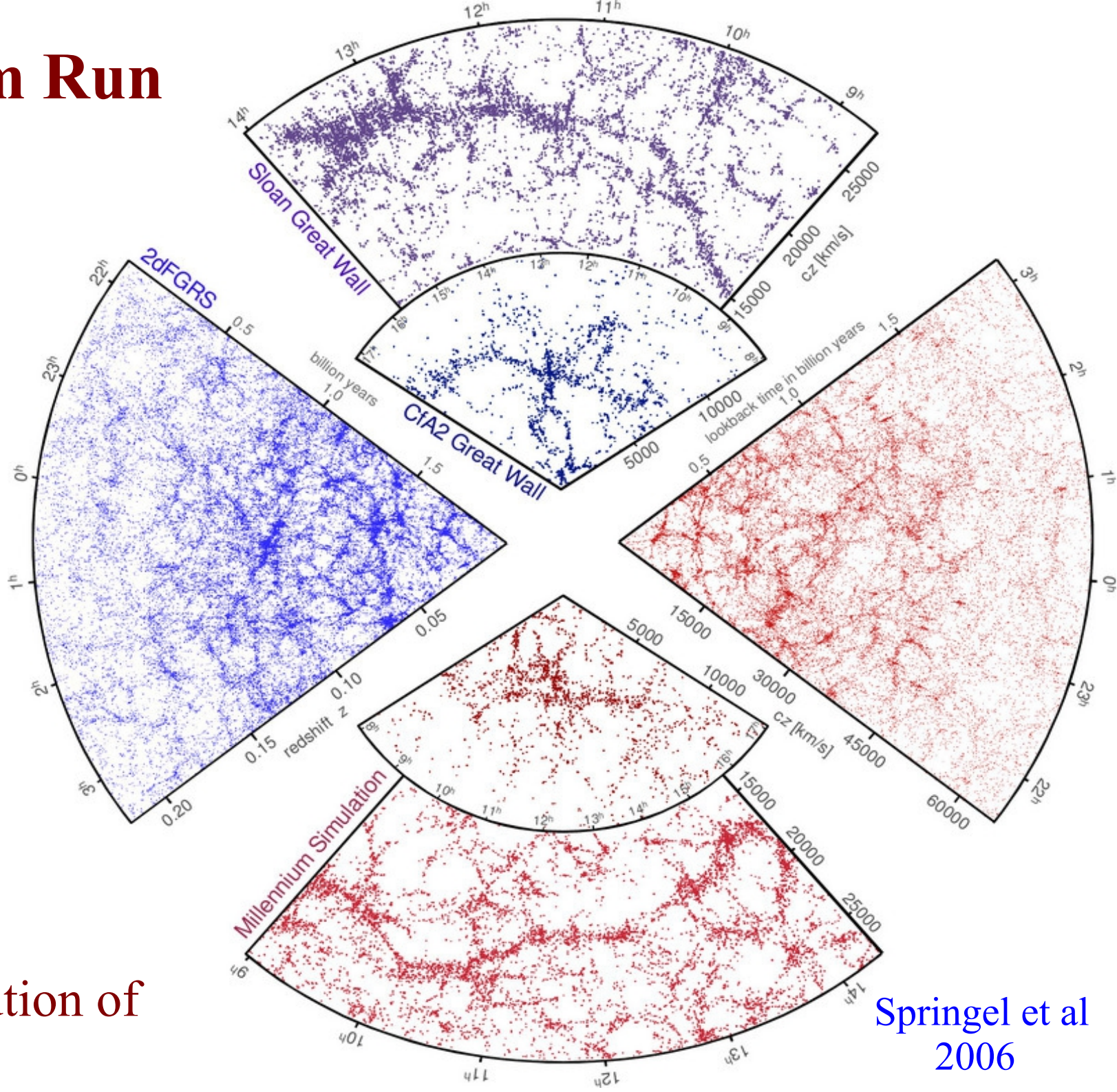
-- abundances, scaling relations, clustering, evolution --

To allow interpretation of large observational surveys in terms of the rates, efficiencies and significance of these processes

NOT to make a definitive *a priori* physical model for the formation of everything from linear ΛCDM initial conditions

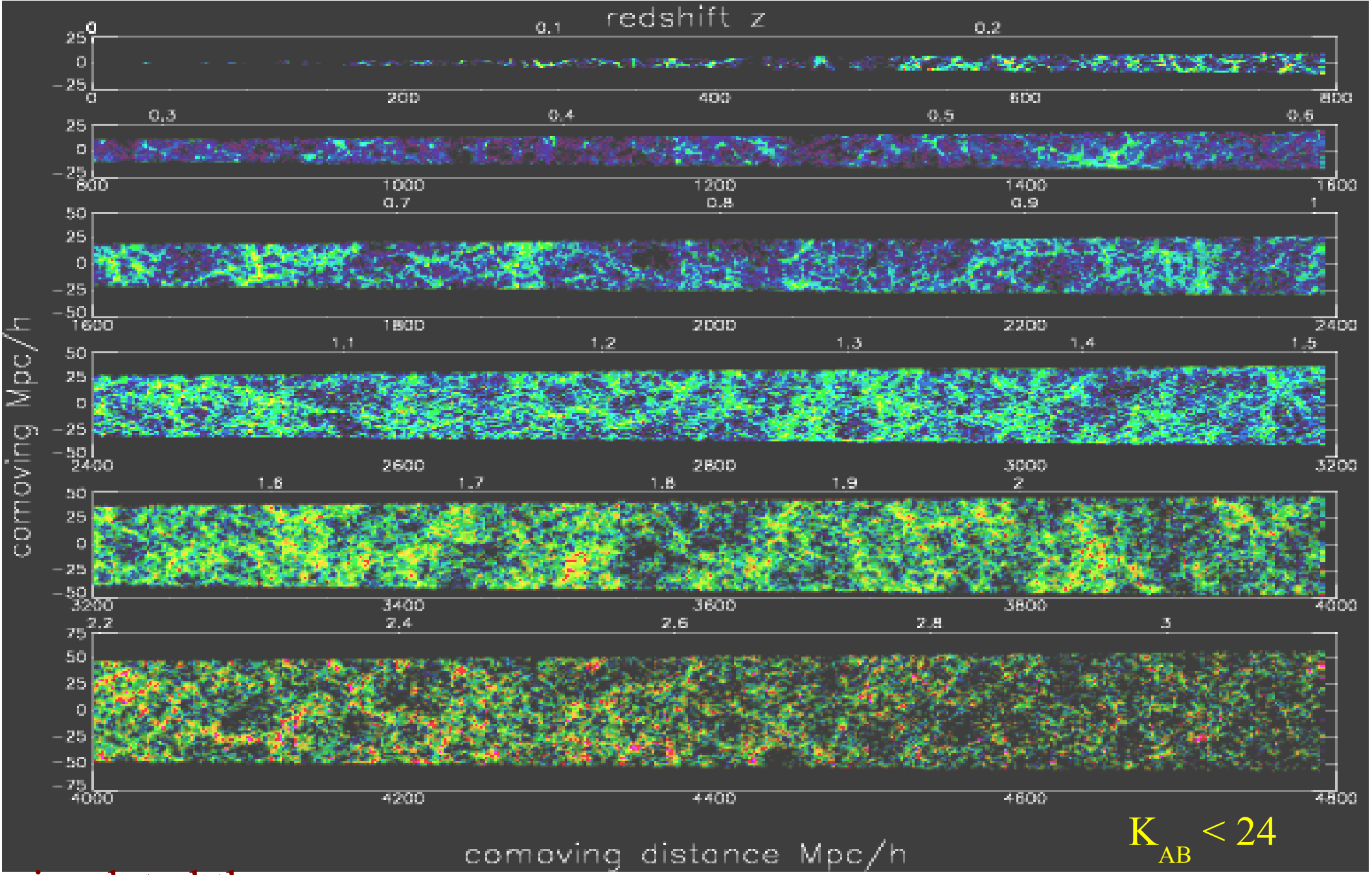
NOR to represent the internal structure of individual galaxies at anything but the most schematic level

Millennium Run 2004



simulated the formation/evolution of 2×10^7 galaxies

Springel et al 2006



simulated the formation/evolution of 2×10^7 galaxies from z = 10 to z = 0

Kitzbichler & White 2007

Virgo - Millennium Database

Documentation

CREDITS/Acknowledgments

Registration

News

FAQ

Public Databases
- DGalaxies
- DHaloTrees
- Guo2010a
- Guo2013a
- Henriques2012a
- MField
- MillenniumII
- millimil
- miniMilII
- MMSnapshots
- MPAGalaxies
- MPAHaloTrees
- MPAMocks
- Snapshots

Private (MyDB) Databases
- sampling_db (r)
- swhite_db (rw) (context)

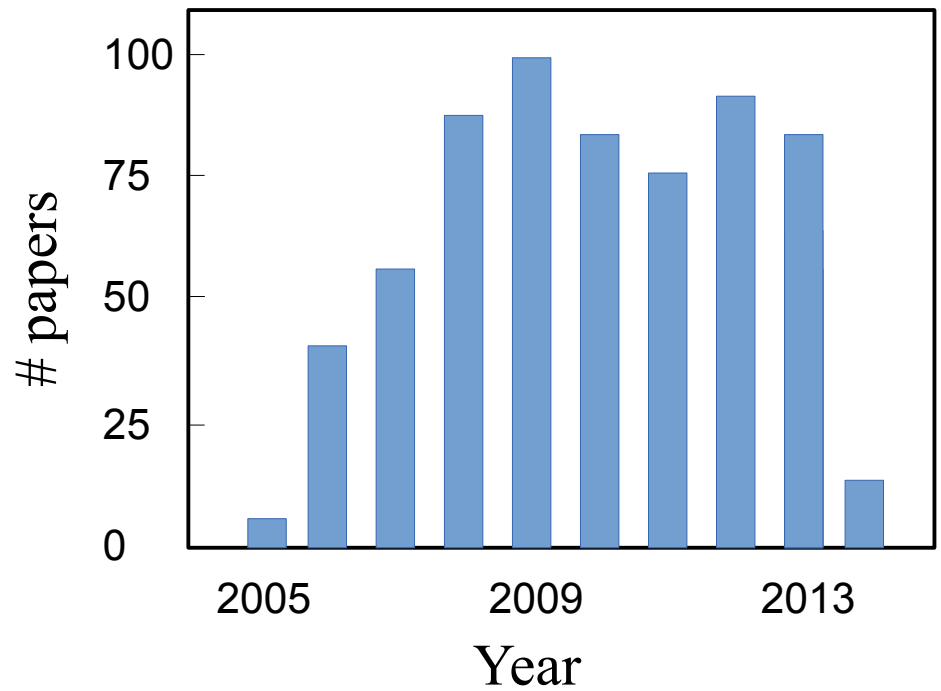
Welcome Simon White.
Streaming queries return unlimited number of rows in CSV format and are cancelled after 420 seconds.
Browser queries return maximum of 1000 rows in HTML format and are cancelled after 30 seconds.

- The MS halo and galaxy databases have been public since 2006
- >600 papers have directly used MS data
- Most use the galaxies and are by authors unassociated with the Virgo Consortium

Query (stream)

Query (browser)

Help



scribed in some more detail on this page.

e state of a private database.

yDB Table Size

Recent extensions of the Millennium programme

Millennium-II increased the resolution by a factor of 125

→ modelling of the dwarf population
convergence tests for mass resolution effects

Millennium-XXL increased the volume by a factor of 216

→ evaluation of cross-talk between precision LSS cosmology and galaxy formation

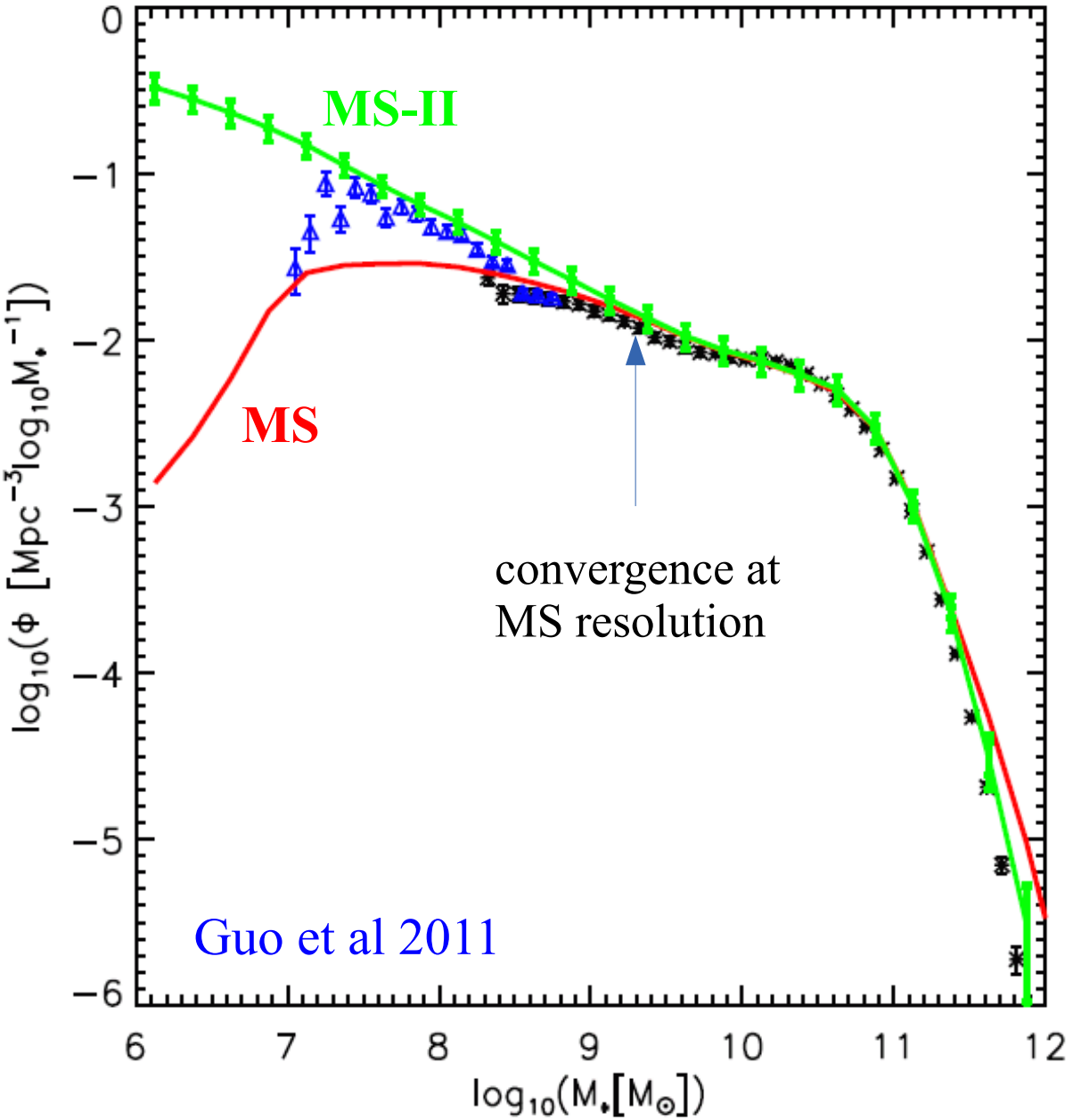
Procedures for accurate scaling to “neighboring” cosmologies

→ eliminates need to rerun simulations for updated cosmologies

MCMC procedures for systematic parameter space exploration

Refinement of astrophysical modelling to remove discrepancies with observed evolutionary and environment variations

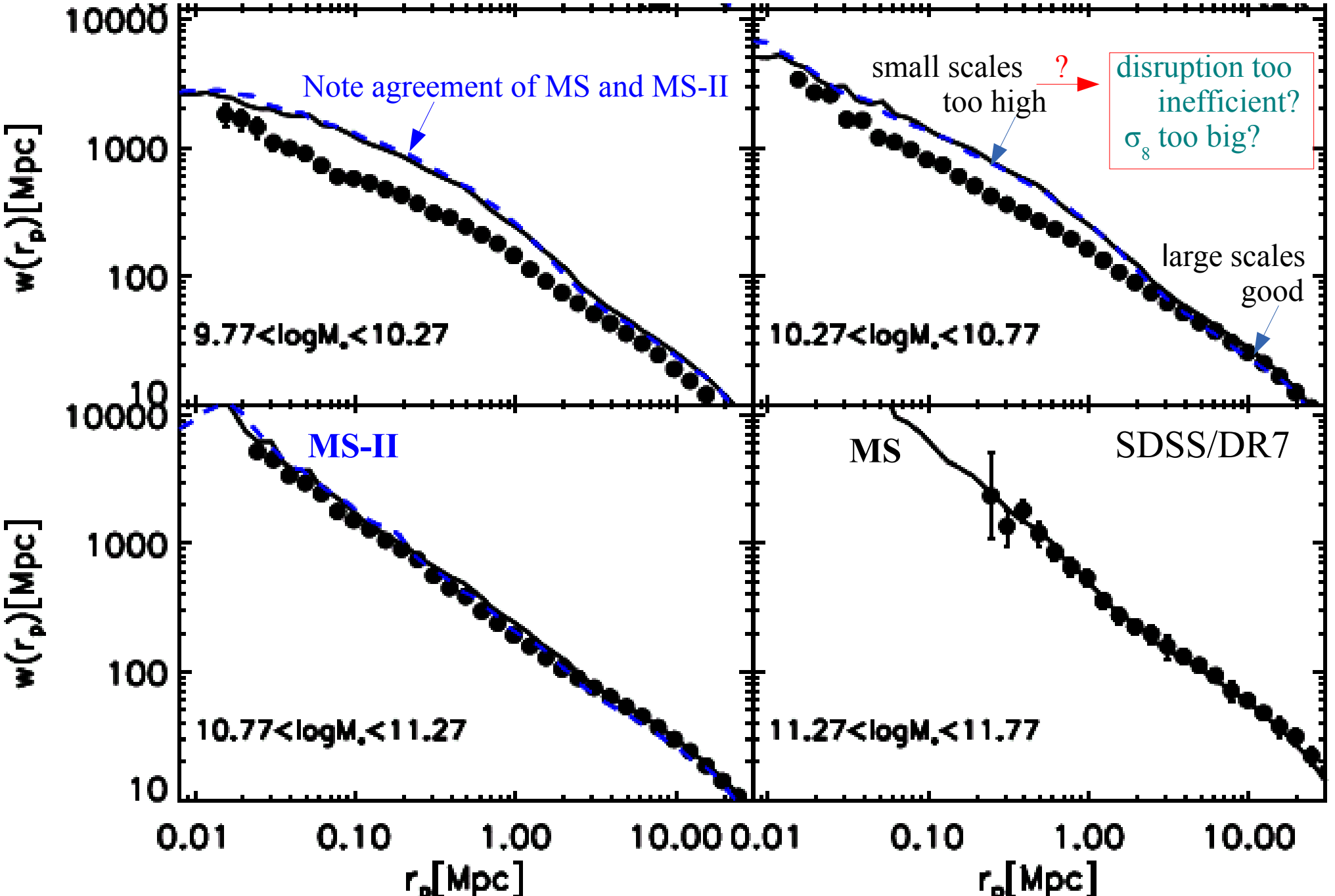
The stellar mass function of galaxies



Note that the simulated mass function fits the data over 5 dex in stellar mass!

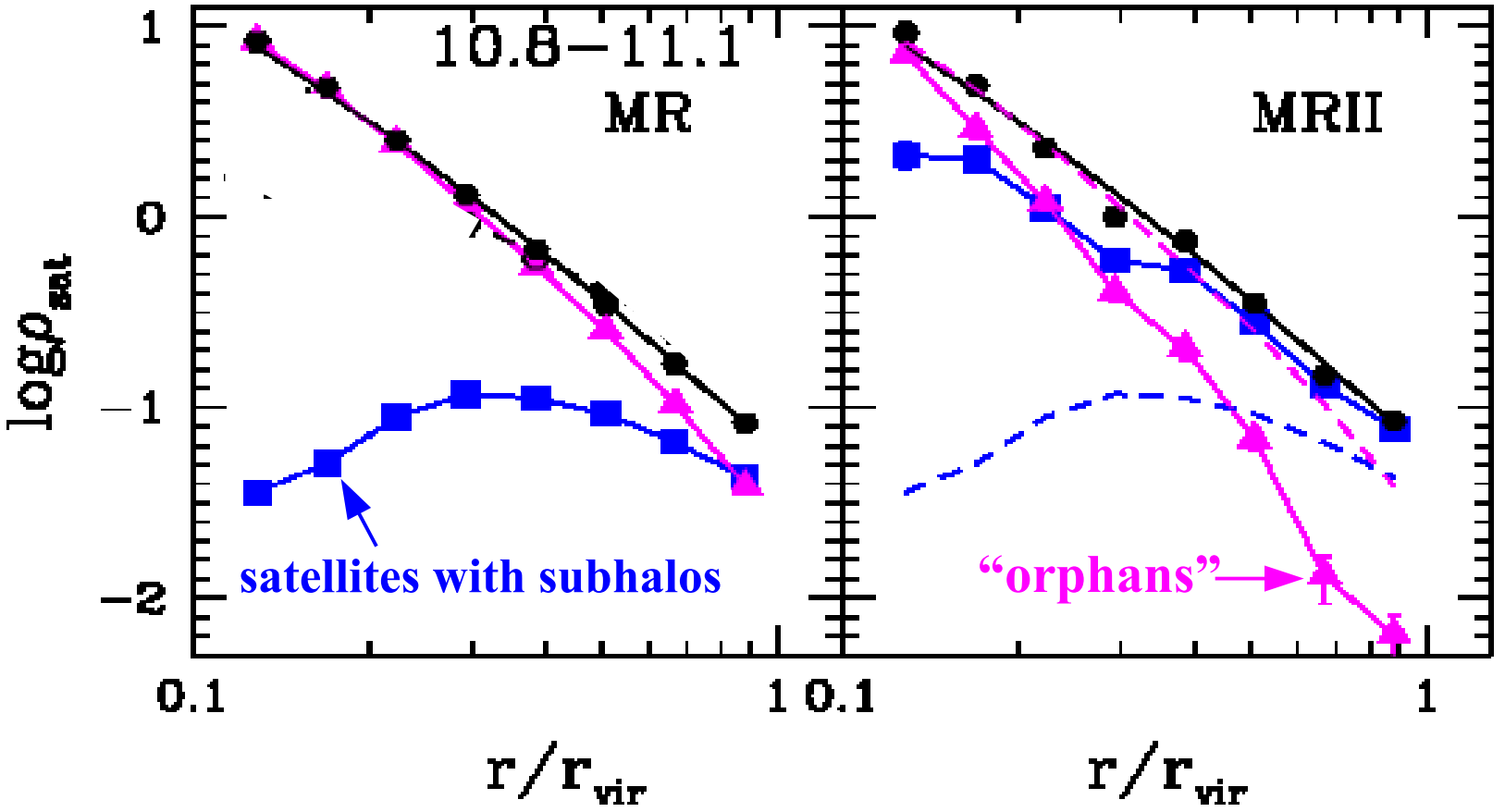
Mass-dependent galaxy clustering

Guo et al 2011



Satellite galaxy distributions

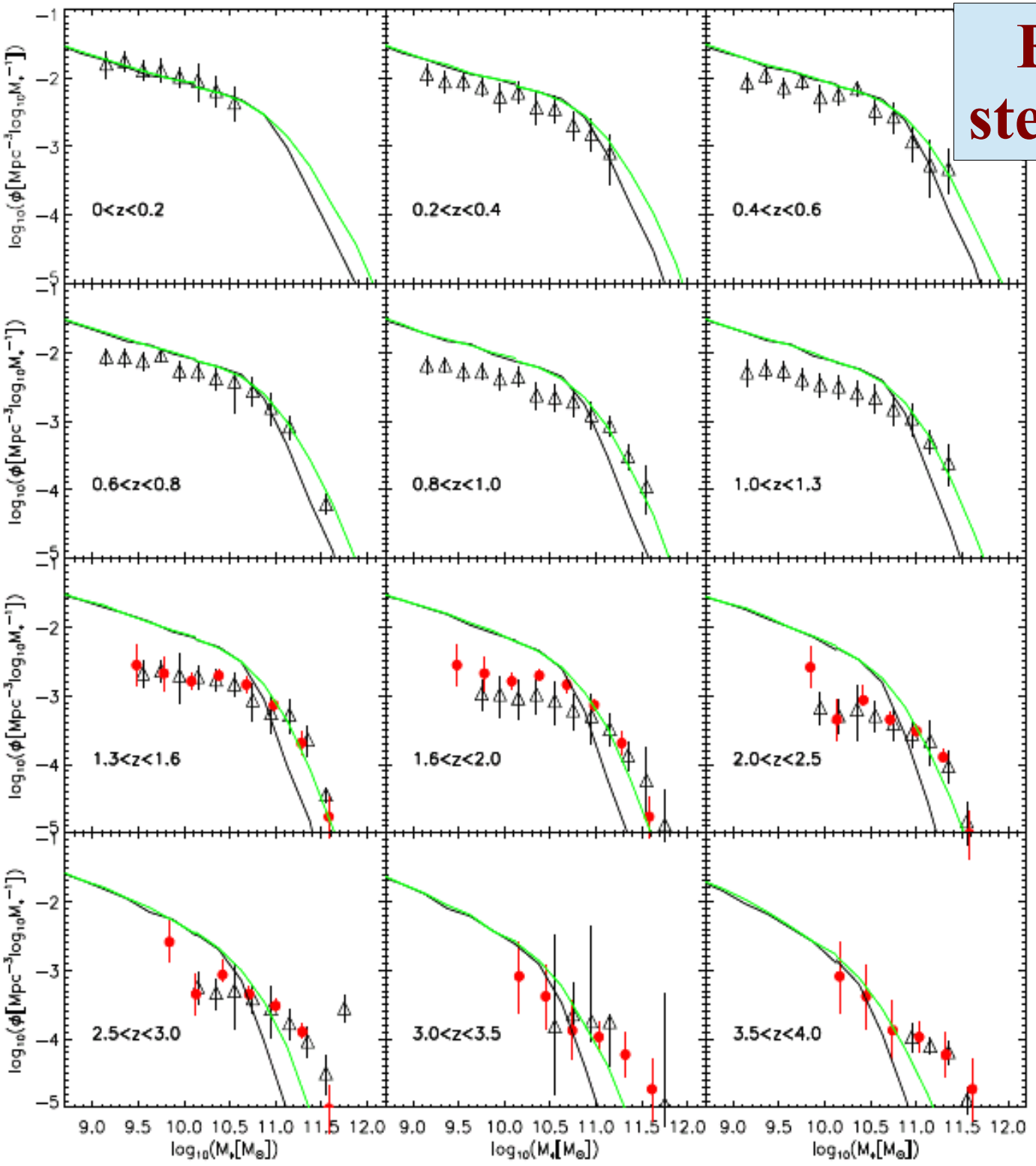
Wang et al 2014



Radial distribution of satellites with $\log M_* / M_\odot > 9.0$ around isolated primaries with $\log \langle M_* \rangle / M_\odot \sim 10.95$

Black line is an NFW profile with concentration equal to that of the mean DM profile and is identical in the two panels

Evolution of the stellar mass function



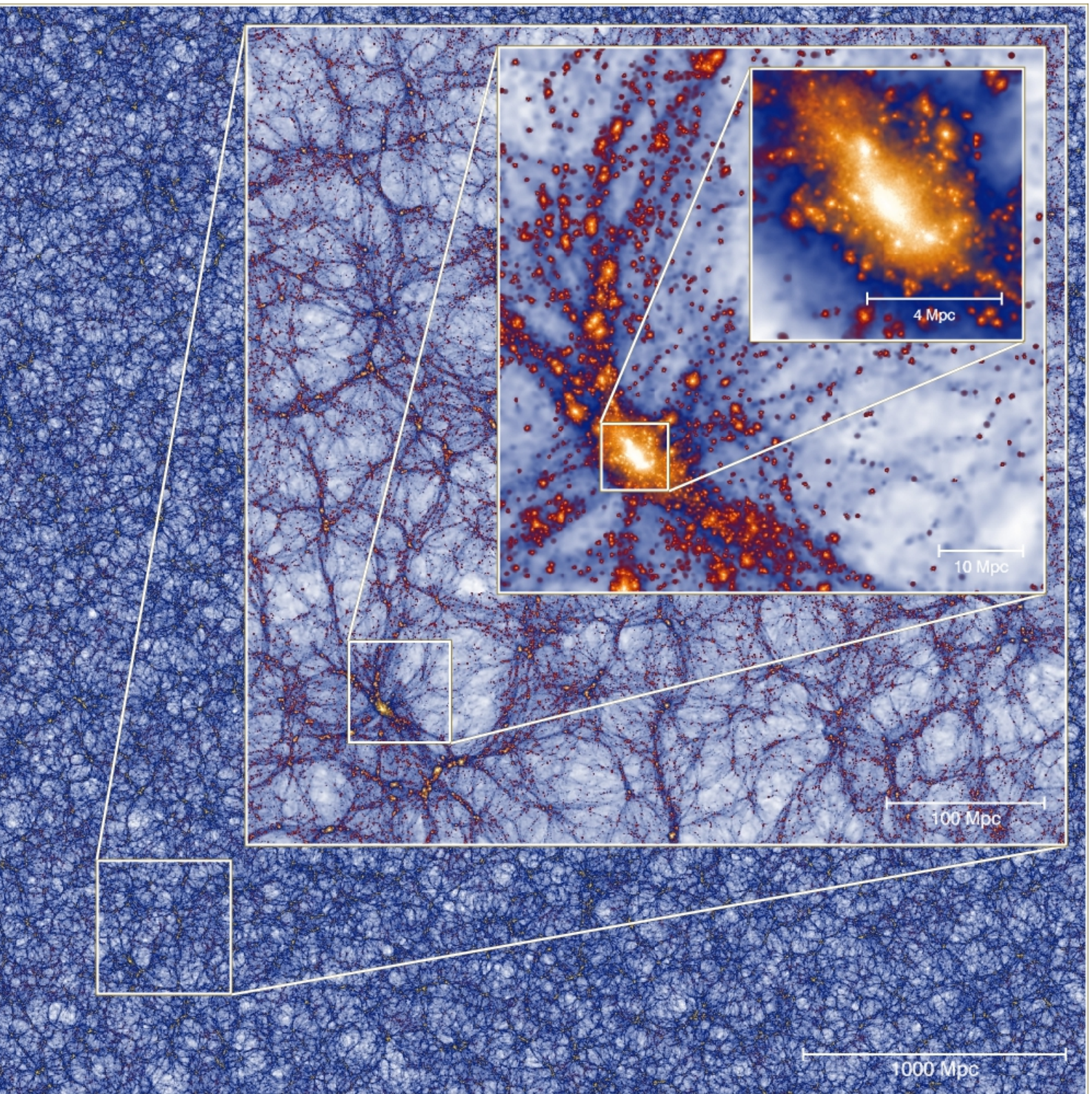
△ Perez-Gonzalez et al 2008

● Marchesini et al 2009

Lower mass galaxies
log M_* < 10.5
form too early

Efficiency of star-formation is too high in lower mass objects at high z?

Guo et al 2011



The MXXL

(2010)

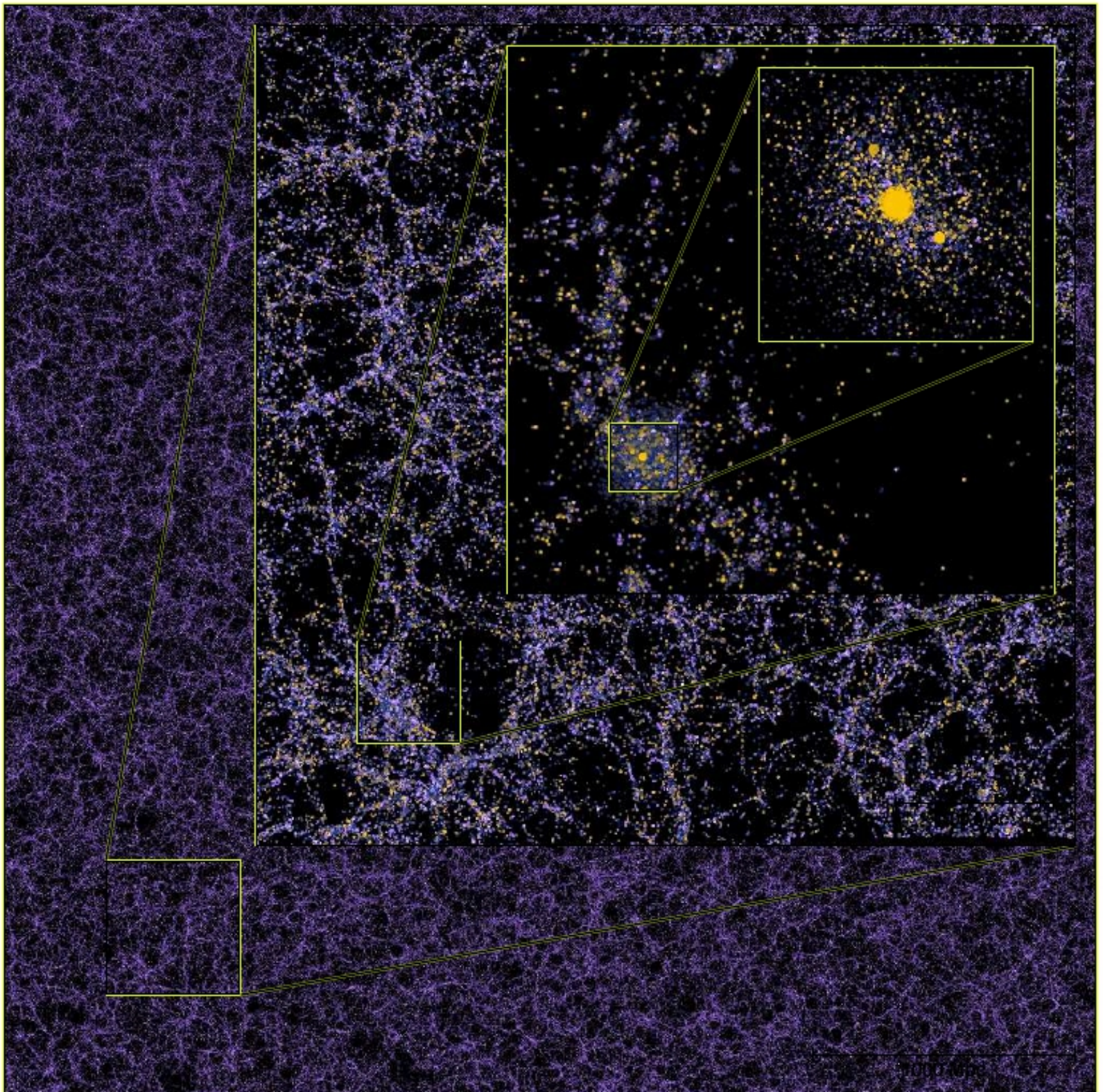
Angulo et al 2011

Bigger than the Millennium Run by factors of

30 in $N_{particle}$

216 in Volume

6 in $m_{particle}$



The MXXL

(2010)

Angulo et al 2011

Bigger than the Millennium Run by factors of

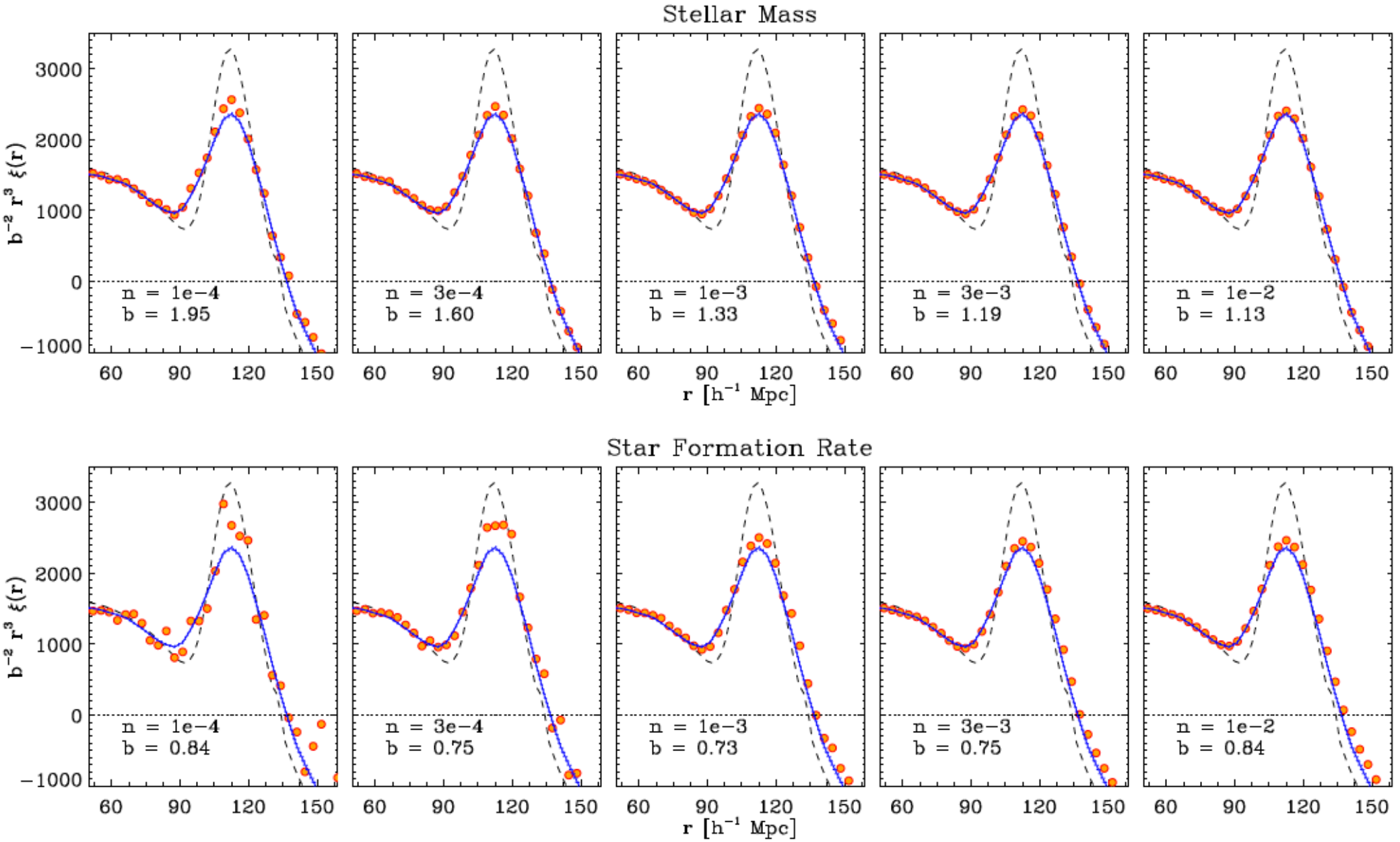
30 in $N_{particle}$

216 in Volume

6 in $m_{particle}$

3.3×10^8 galaxies at $z = 0$ with $\log M_*/M_\odot > 10$

Distortions of BAO feature in the galaxy population



Small but measurable shifts for different selection methods

Angulo et al 2013

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 target z=0 halos

-- 685 Mpc 620 Mpc

2) Reassign redshifts to match linear amplitudes on these scales

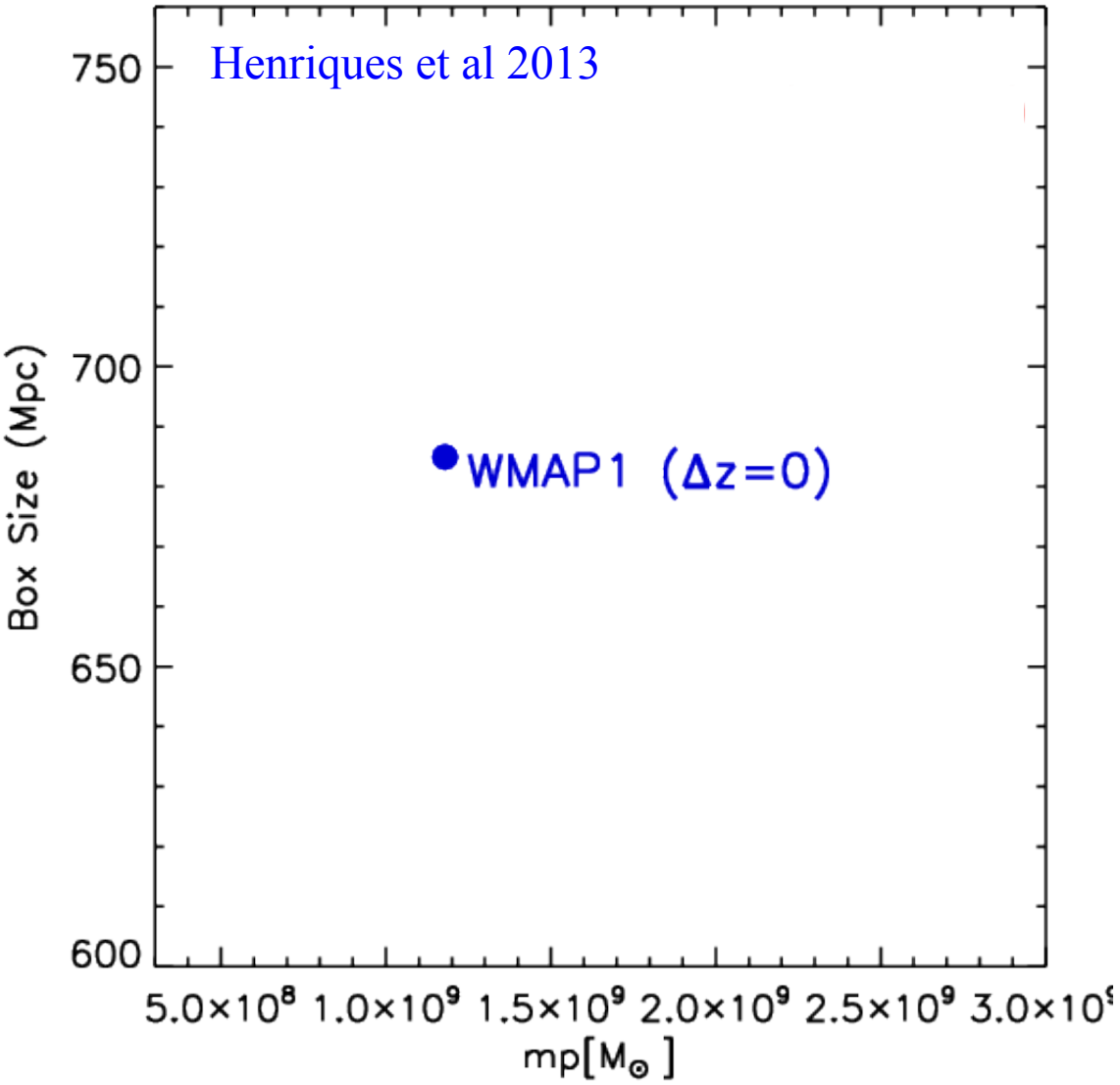
-- z = 0.69, 1.75, 3.02 z = 0, 1, 2

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

-- $1.1 \times 10^9\ M_\odot$ $7.1 \times 10^8\ M_\odot$

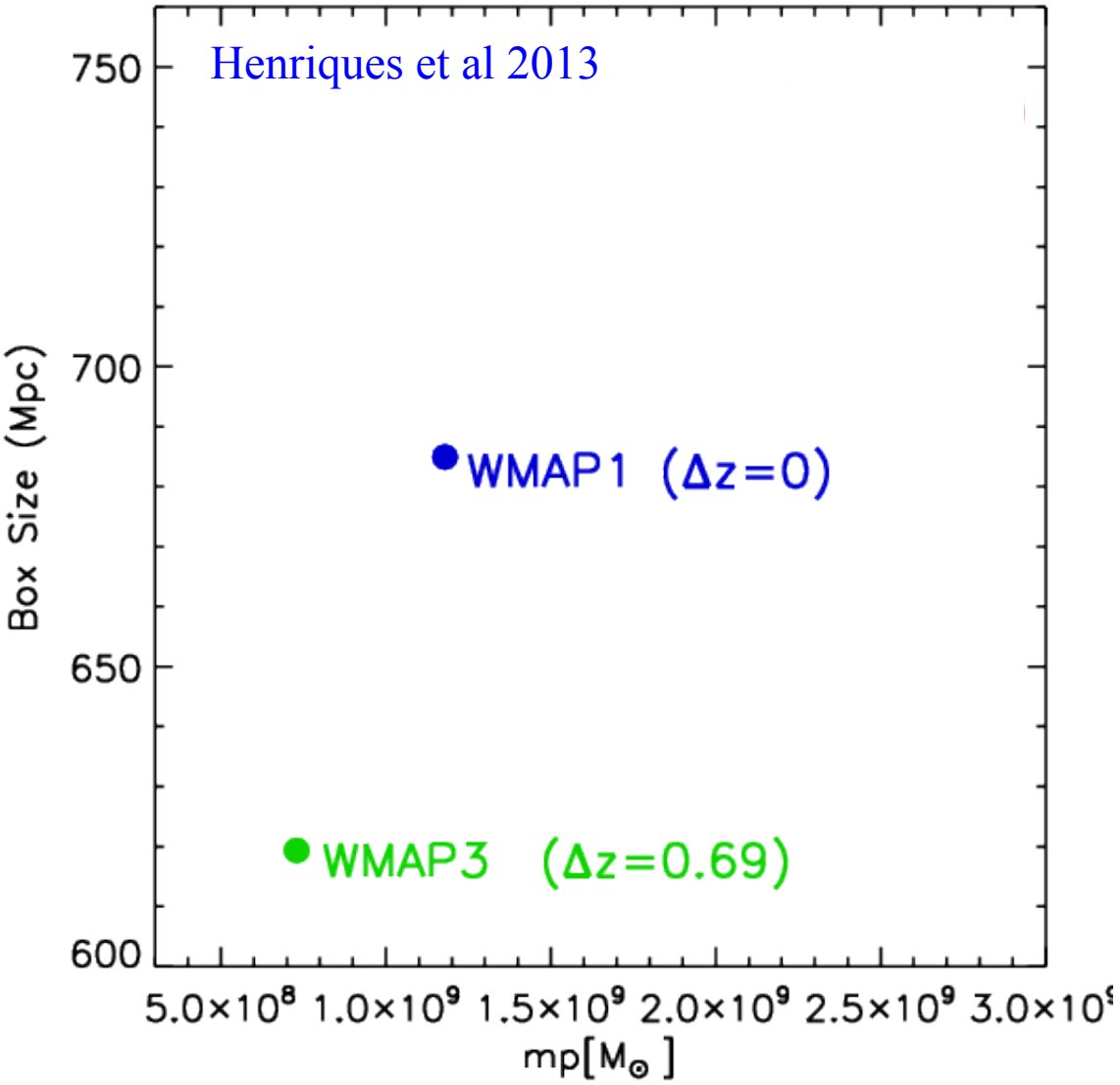
4) Adjust for the difference between amplitudes of original and target power spectra on large scales using linear theory.

Effect of changing cosmology on structure growth



Scalings needed to adapt the MS to changing CMB cosmologies

Effect of changing cosmology on structure growth



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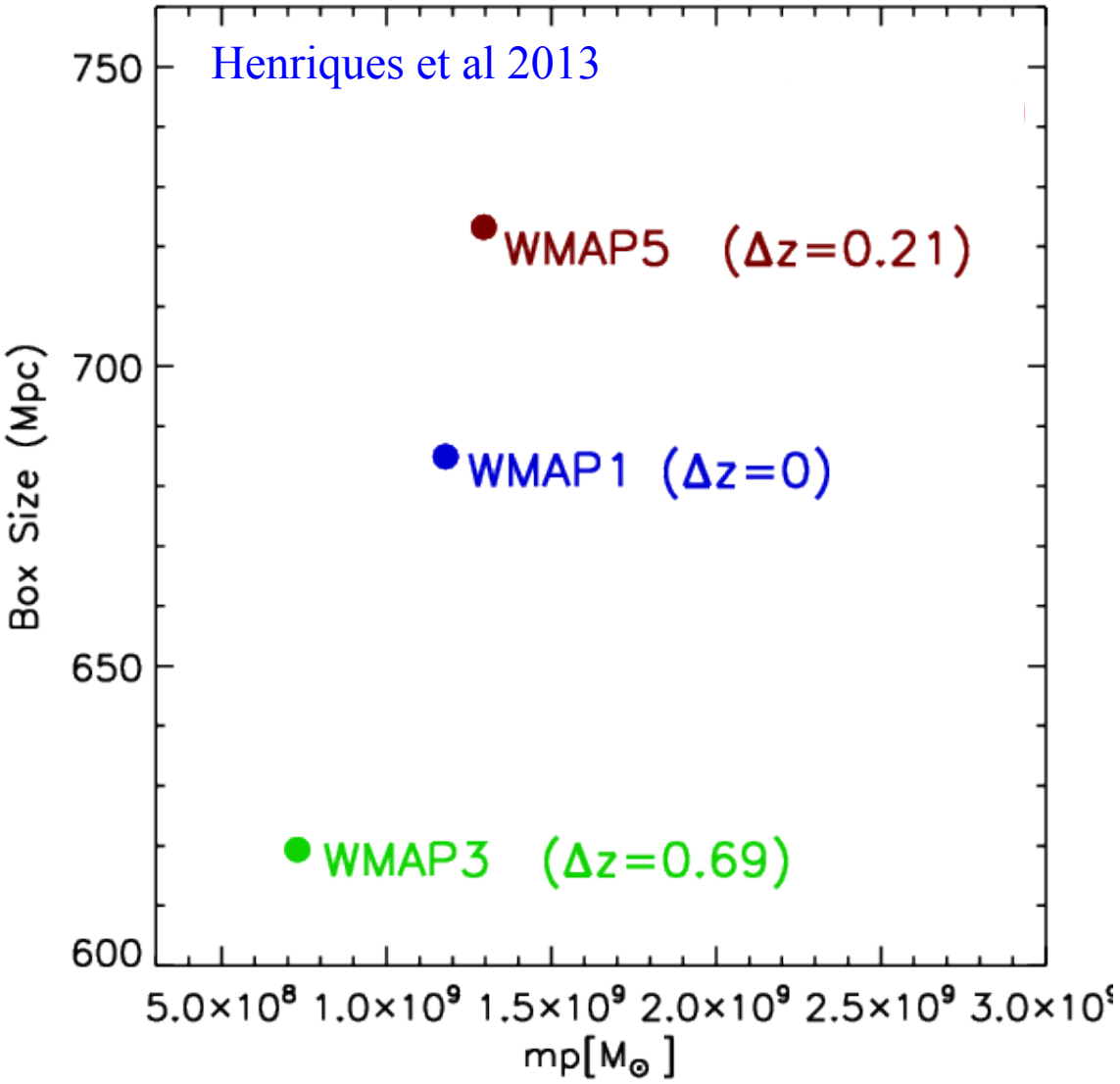

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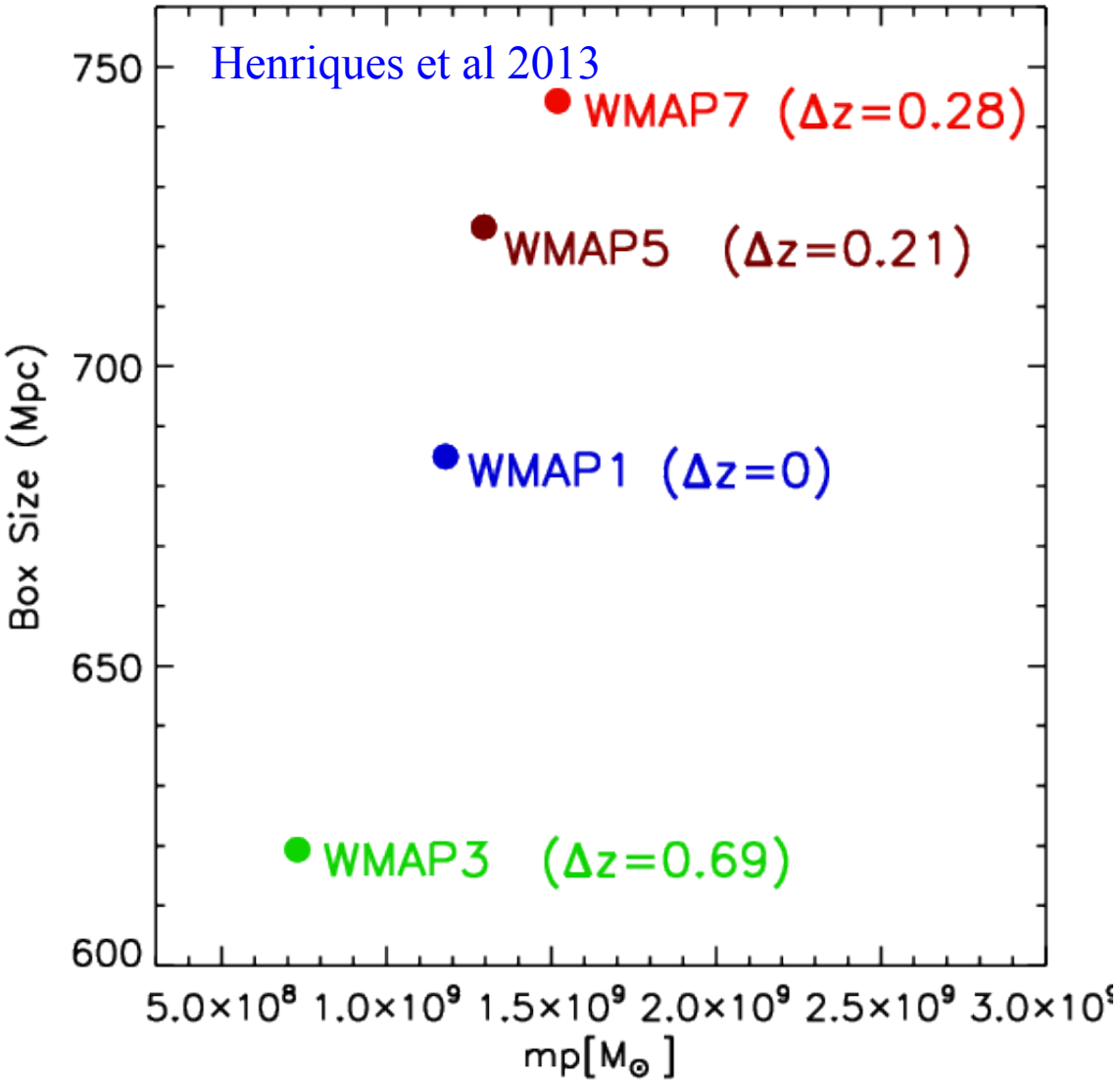

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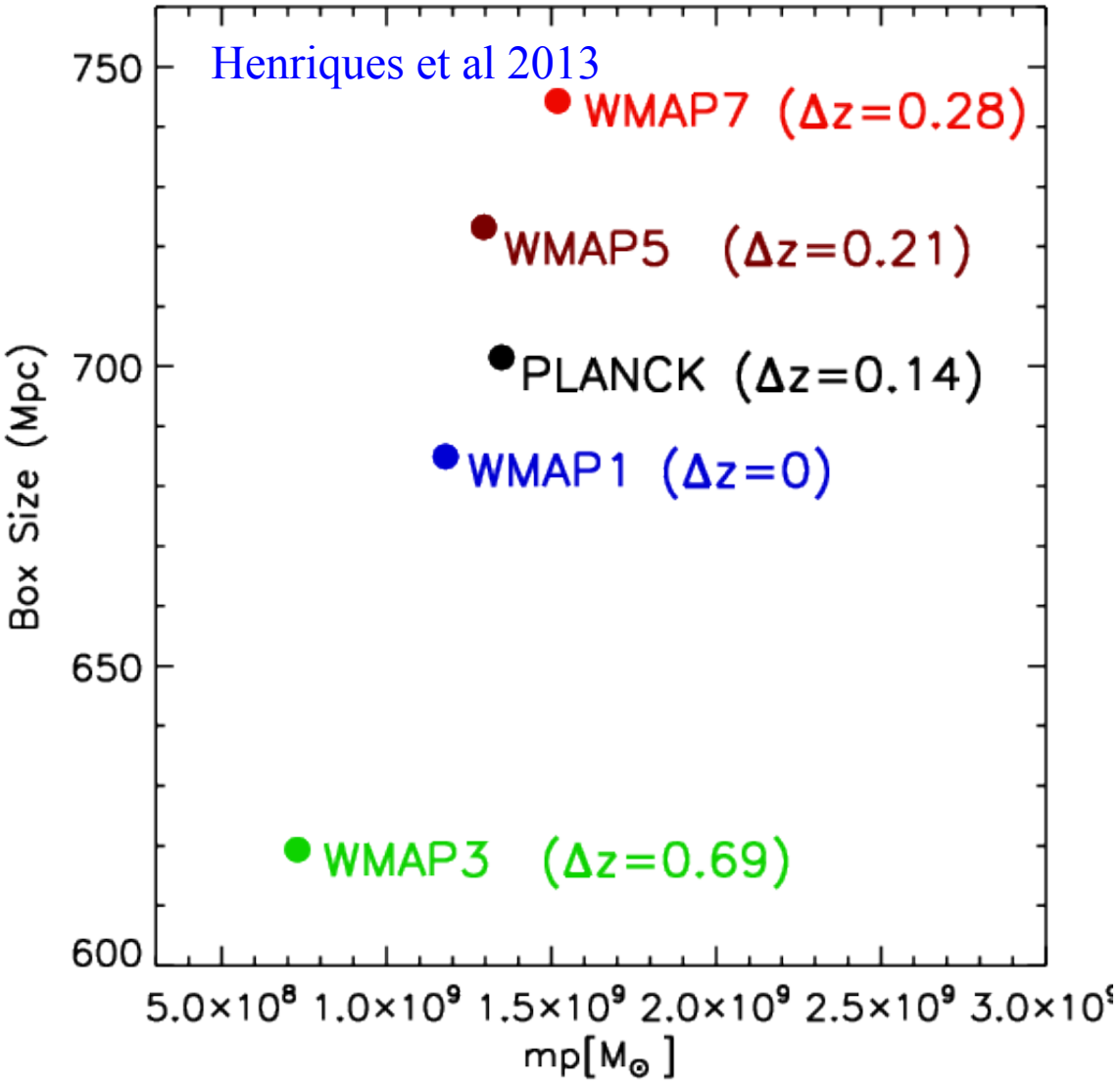
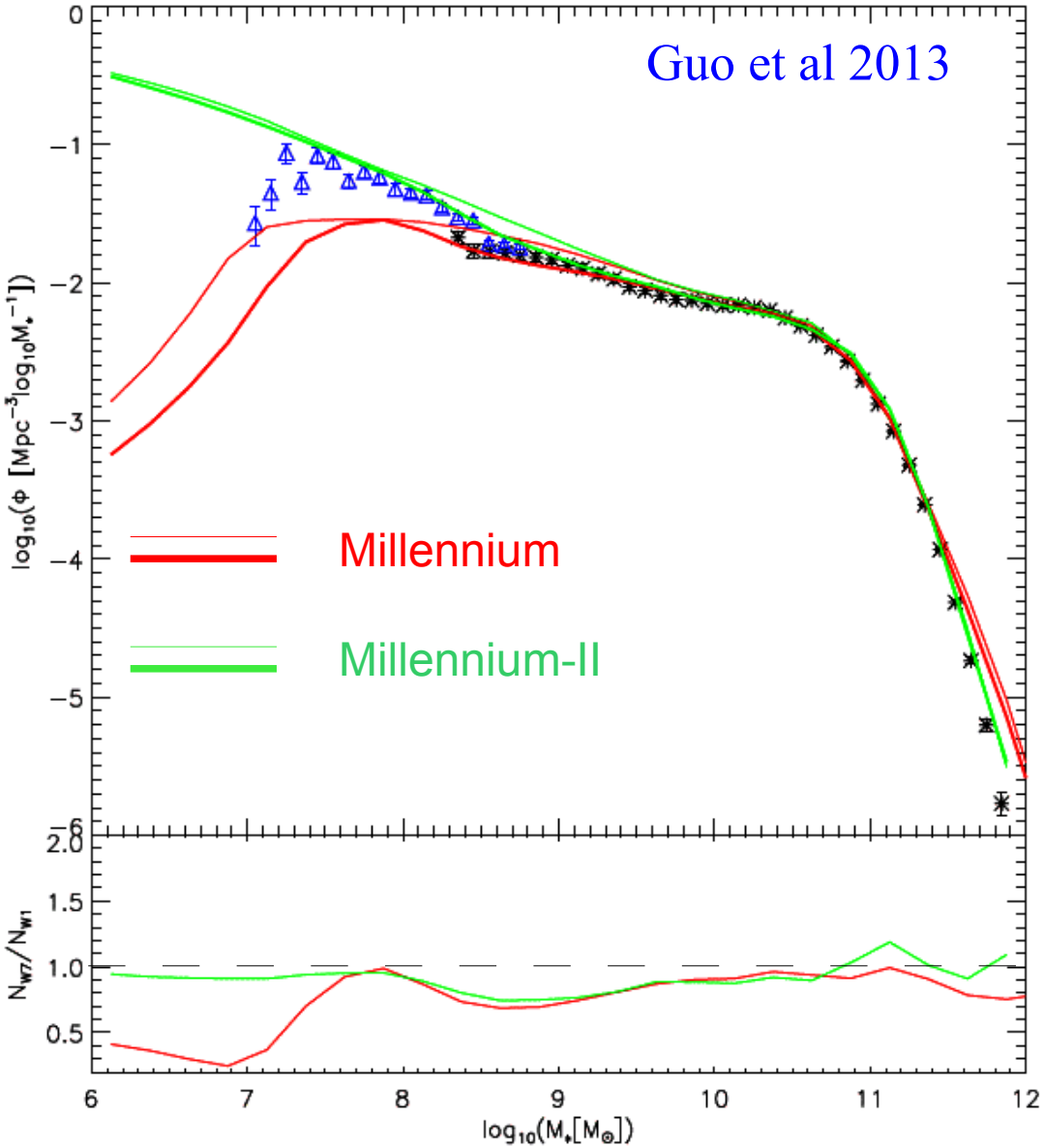


Scalings needed to adapt the MS to changing CMB cosmologies



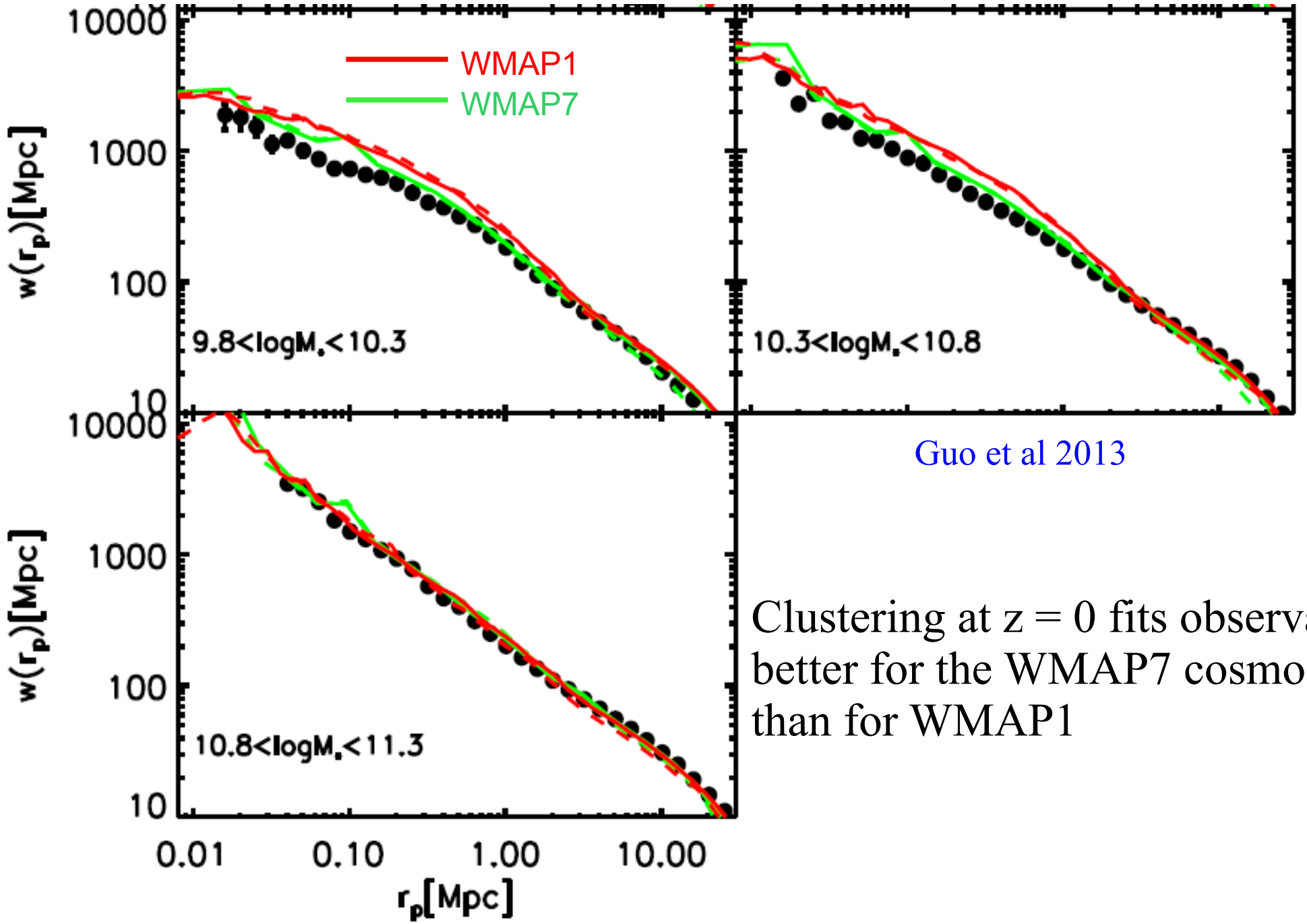
Switching from WMAP1 to WMAP7

Small shifts in the parameters of the galaxy formation model allow the z = 0 stellar mass function to be fit equally well in the two cosmologies despite

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

Parameter	Description	WMAP1	WMAP7
α	Star formation efficiency	0.02	0.015
ϵ	Amplitude of SN reheating efficiency	6.5	4.5
β_1	Slope of SN reheating efficiency	3.5	4
V_{reheat}	normarlization of SN reheating efficiency dependence on Vmax	70	80
η	Amplitude of SN ejection efficiency	0.32	0.33
β_2	Slope of SN ejection efficiency	3.5	6.5
V_{eject}	normarlization of SN ejection efficiency dependence on Vmax	70	80
κ	Hot gas accretion efficiency onto black holes	1.5×10^{-5}	6.0×10^{-6}

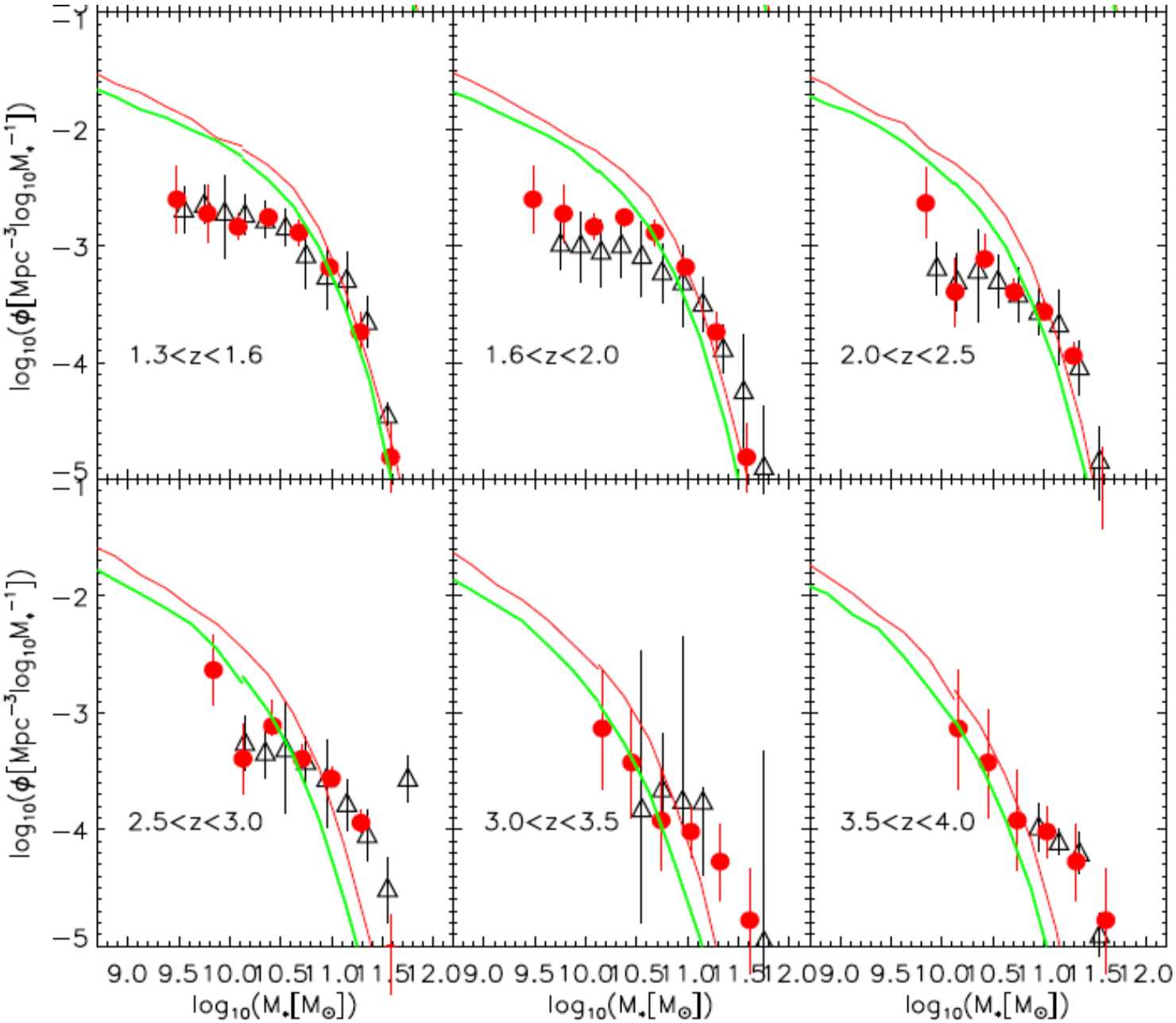
Switching from WMAP1 to WMAP7



Guo et al 2013

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

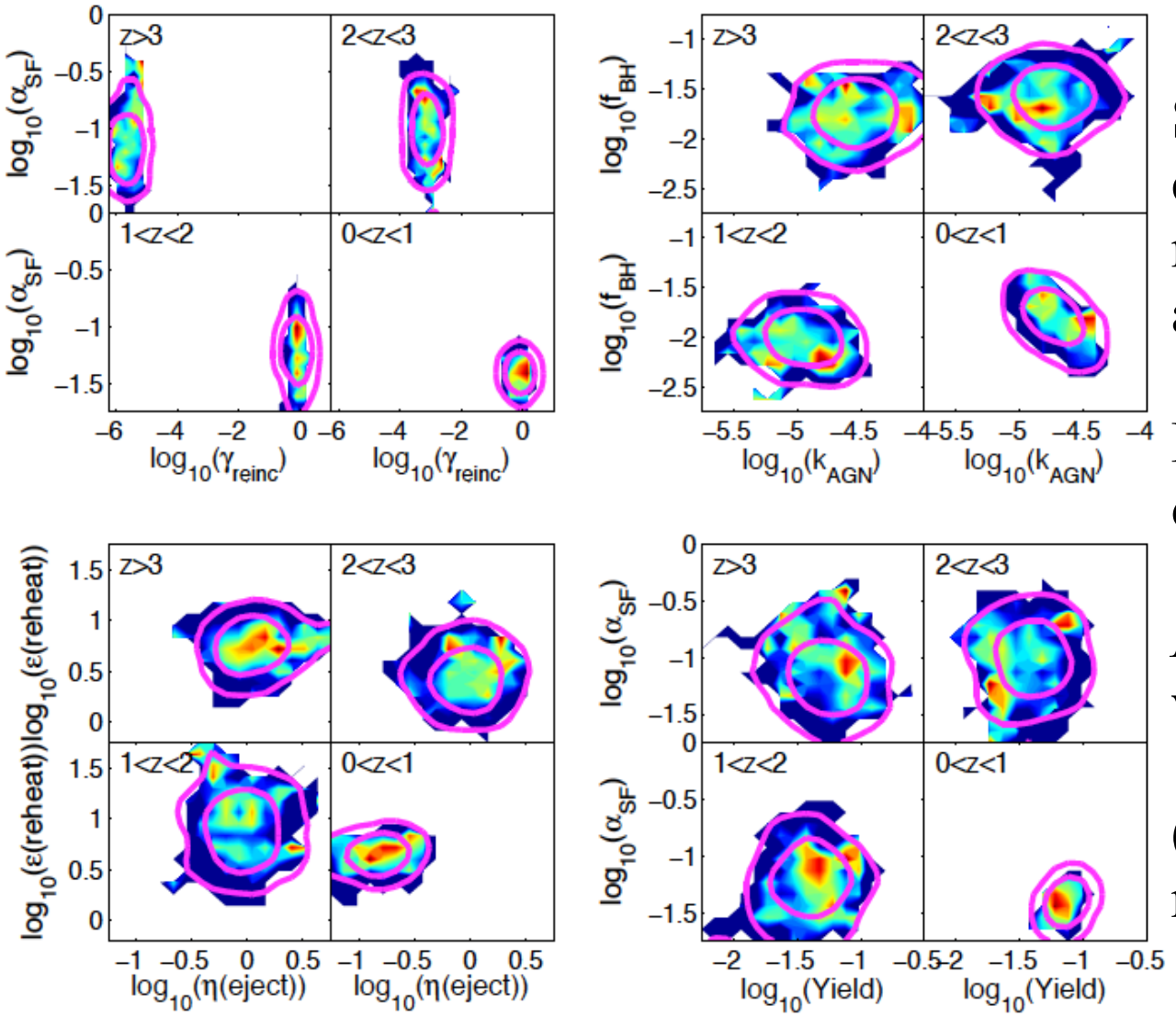
Switching from WMAP1 to WMAP7



Guo et al 2013

..but the galaxy formation sequence is still incorrect

MCMC allows exploration of parameter space



SA model of Guo et al (2011) constrained by observed stellar mass and luminosity functions at $z = 0, 1, 2$ and 3

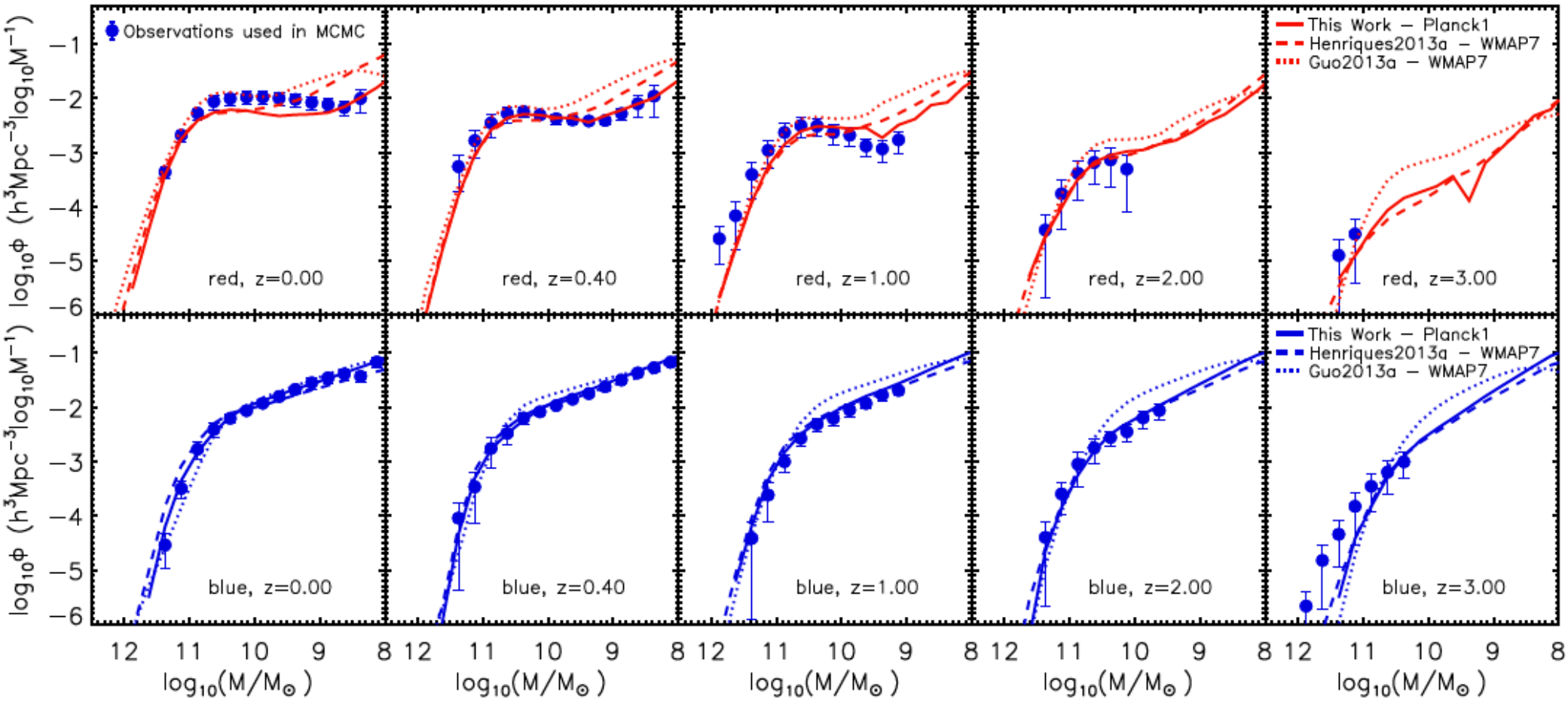
Parameters are determined by data at each individual redshift

No parameter set is consistent with data at all redshifts

(At least) one parameter is required to vary with redshift

Henriques et al 2013

Henriques et al 2014, Planck cosmology



Changing the assumed timescale for reincorporation of wind ejecta

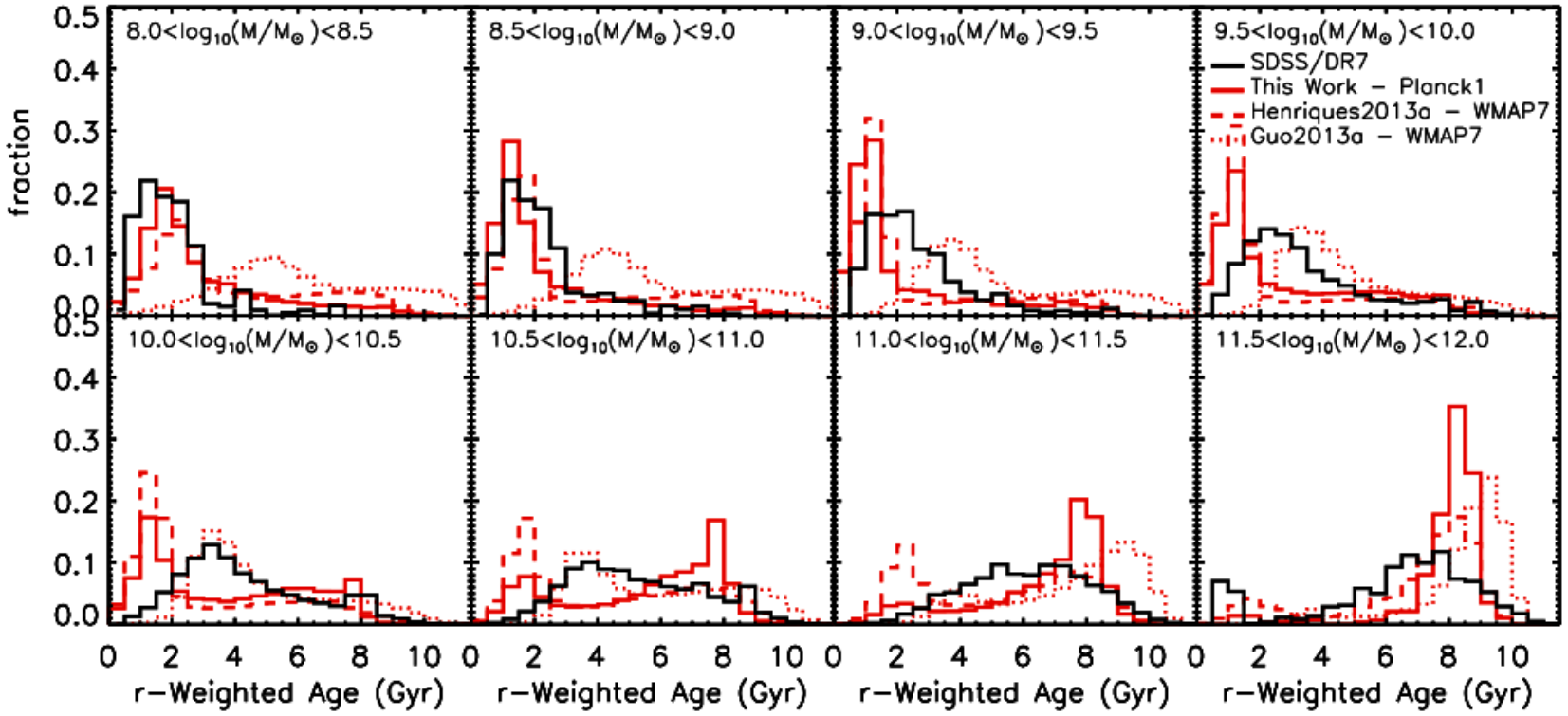
$$t_{return} = \text{const.} / H(z)\, V_{halo} \longrightarrow t_{return} = \text{const.} / M_{halo}$$

allows a good fit to data at all redshifts for the same # of parameters

Further recent updates to astrophysical modelling

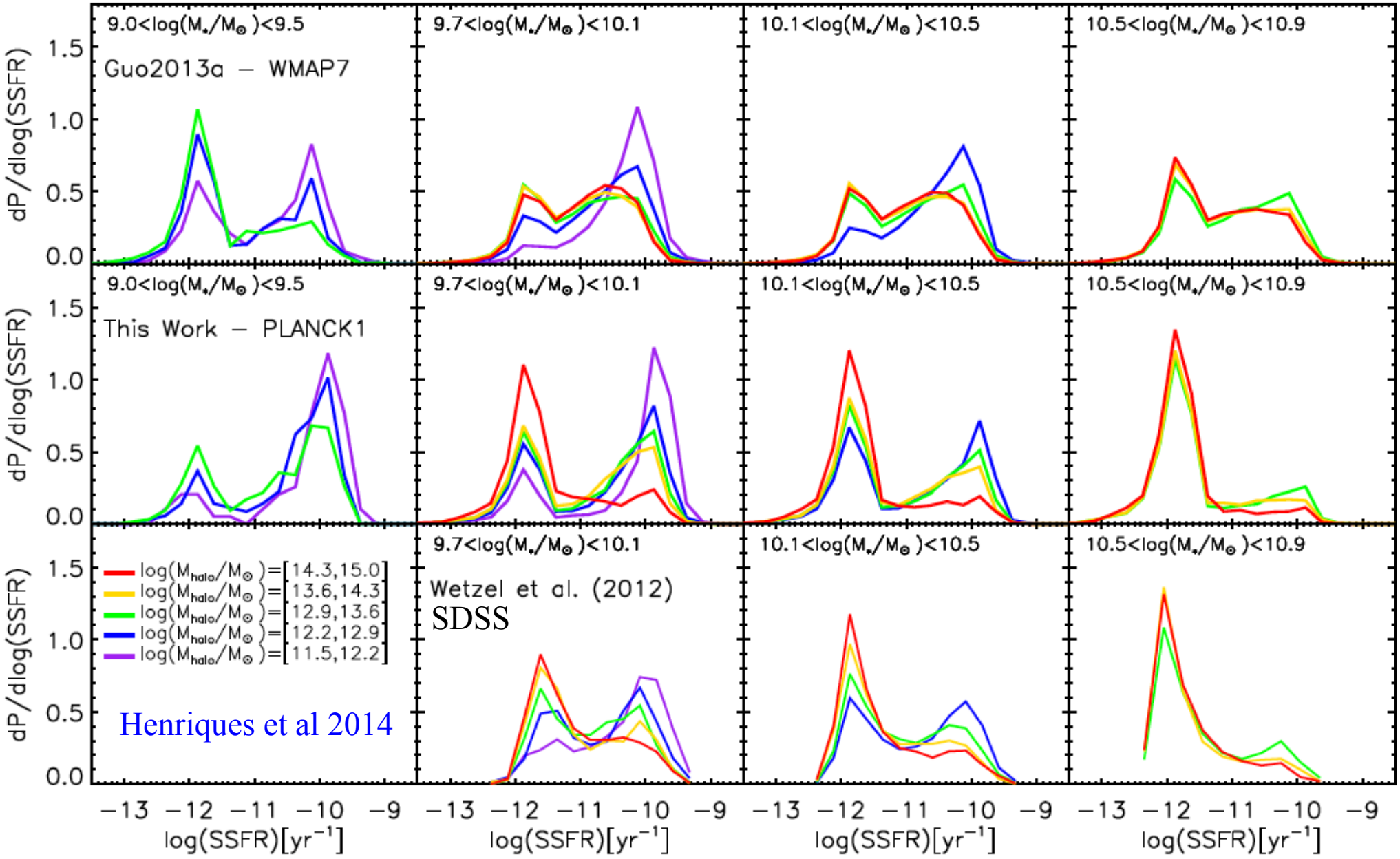
- Adjust efficiency and z-dependence of AGN feedback/mass quenching
- Eliminate ram-pressure stripping in low-mass halos (log M < 14)
- Reduce gas surface density threshold for star formation
- Switch to Planck (2013) cosmology

Henriques et al 2014

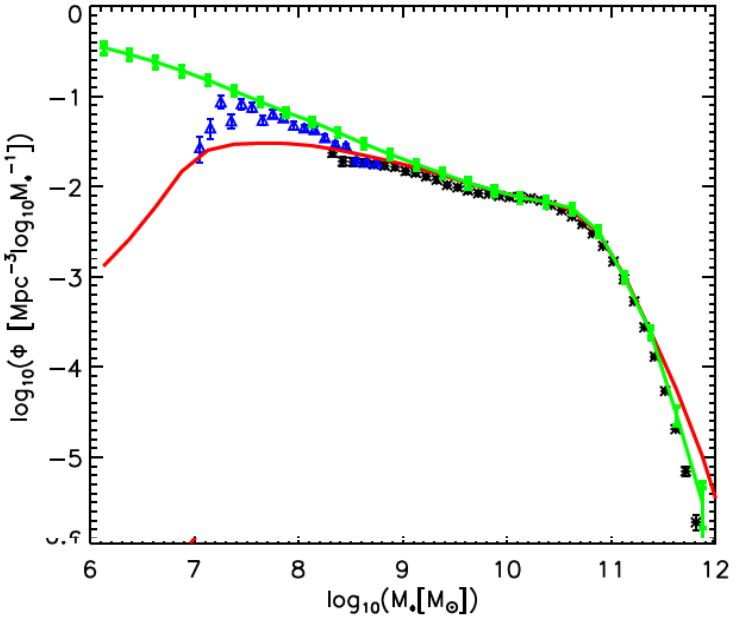


Further recent updates to astrophysical modelling

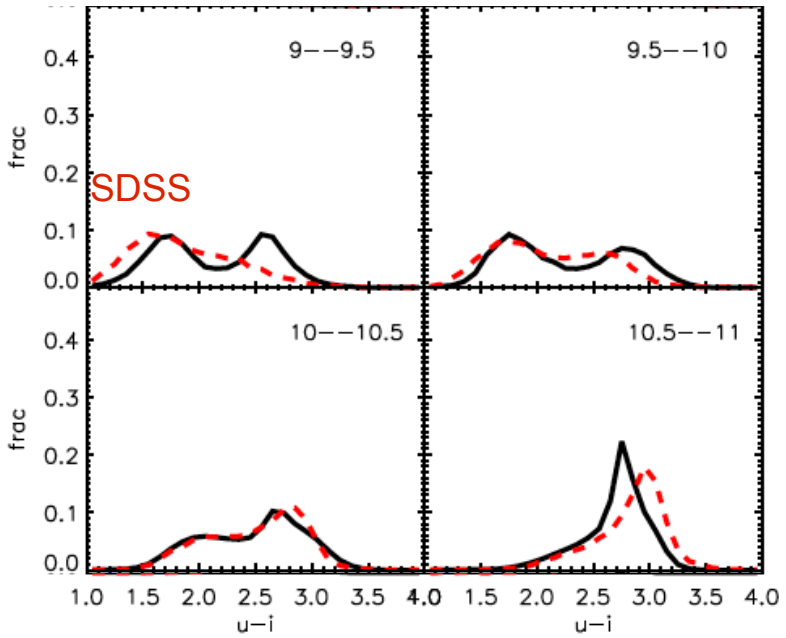
Specific star formation rates of satellites as a function of halo mass



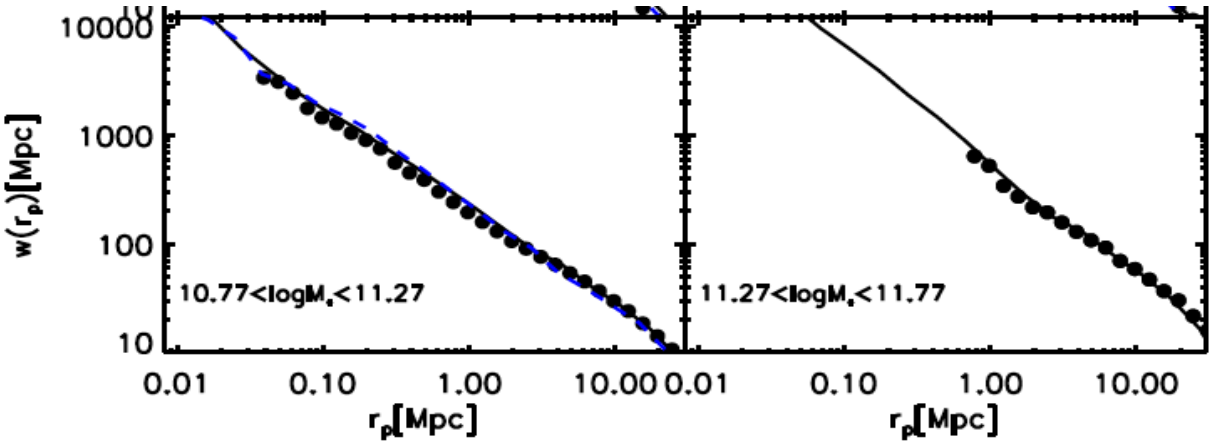
How do we learn from population simulations?



When simulating the astrophysics of galaxy formation, agreement with data is a measure of success...



Guo et al 2011



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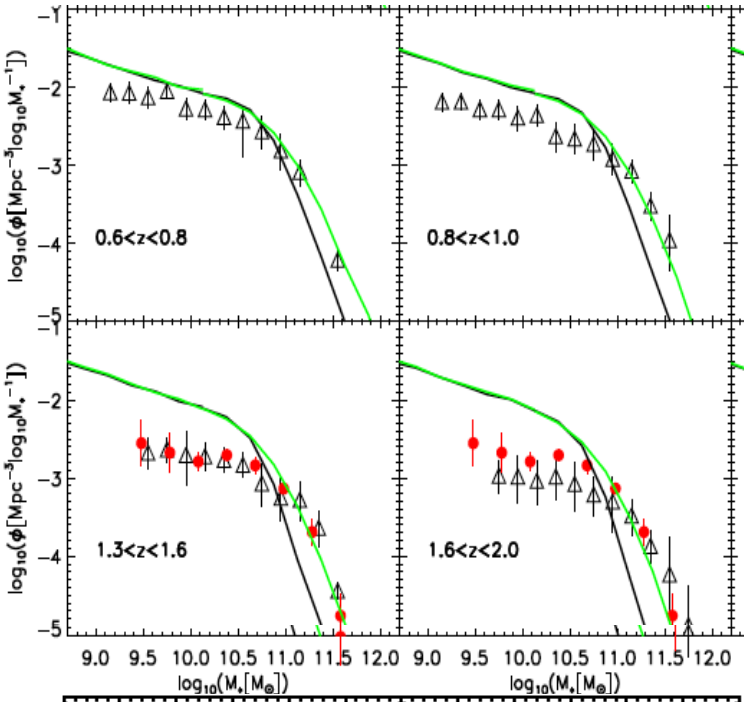
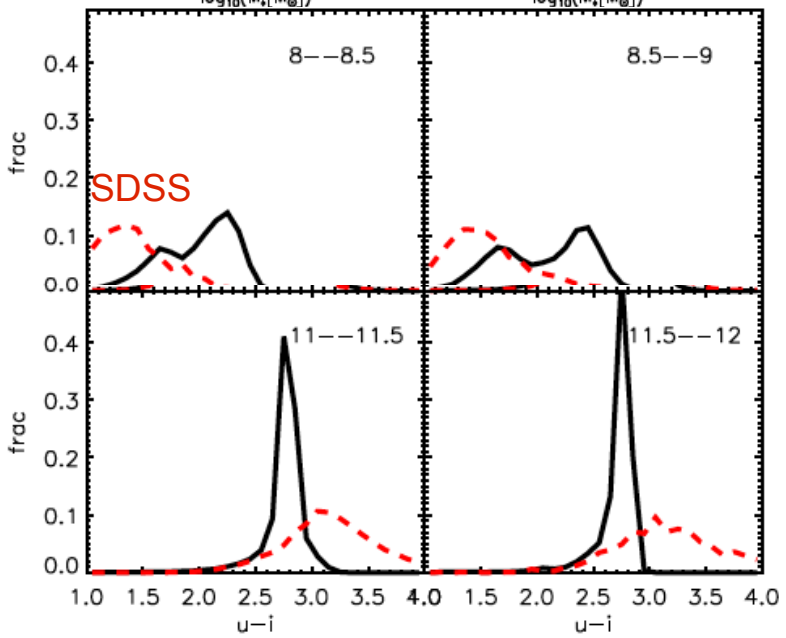


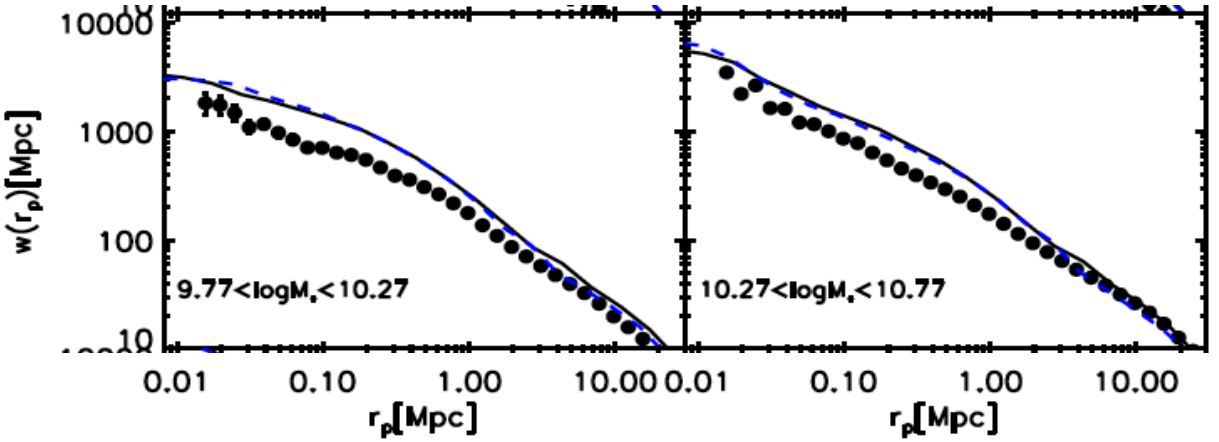


When simulating the astrophysics of galaxy formation, agreement with data is a measure of success...

...but it is the failures which show where there is missing or inadequate physics

cosmology? star formation? enrichment and feedback? environmental effects?

Guo et al 2011



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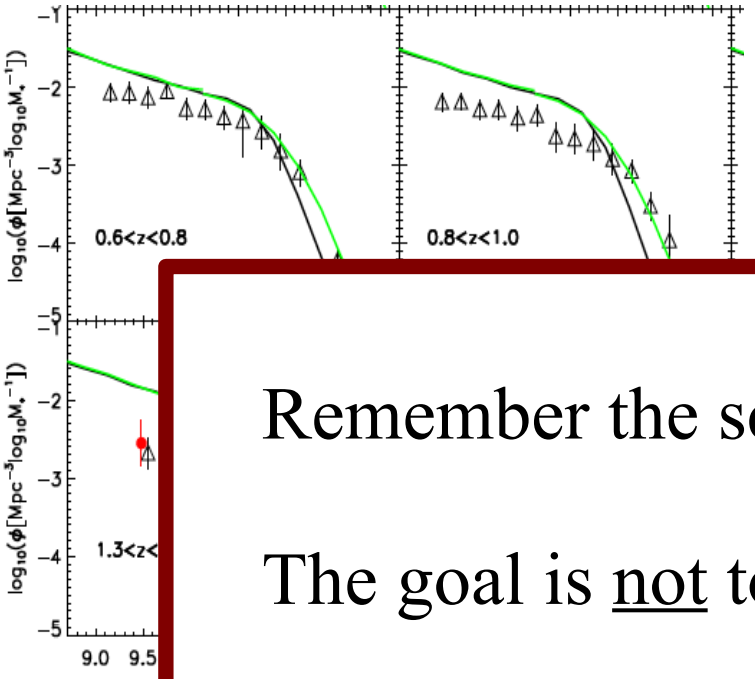

When simulating the astrophysics of galaxy formation, agreement with data is a measure of success...

re

nt

Remember the scientific method!

The goal is <u>not</u> to fit the observations

It is to improve understanding of the real world by framing hypotheses based on available data, and then <u>testing</u> them through acquisition of new data