# Do close pairs always merge? How long does it take? Calibrating observational estimates of the galaxy merger rate.

Simon White and Manfred Kitzbichler

## The Issue

- We believe that galaxy mergers occur, inducing AGN and star-formation activity while transforming galaxy morphology

- How can we estimate the *rate* of such mergers observationally?

## The Idea

- All mergers must appear as close pairs of galaxies shortly before they merge

$$\dot{n}_{merge} = n_{close\_pair} \times F_{merge} / T_{merge}$$

## The Problem

- How do we estimate $F_{merge}(z)$ and $T_{merge}(z)$ ?

# The Trouble with Morphology

- Morphology can give a clear indication that a dynamical interaction is occurring, and so would seem to offer the chance to construct uncontaminated catalogues of merging pairs

# The Trouble with Morphology

- Morphology can give a clear indication that a dynamical interaction is occurring, and so would seem to offer the chance to construct uncontaminated catalogues of merging pairs

**...BUT...**

- The detectability of interaction signatures in an image depends
  (i) on the morphology of the interacting systems (E, S, Irr...);
  (ii) on the viewing angle;
  (iii) on the time when the interaction is seen;
  (iv) on the redshift of the system; and
  (v) on the sensitivity, resolution and waveband of the observation.

# The Trouble with Morphology

- Morphology can give a clear indication that a dynamical interaction is occurring, and so would seem to offer the chance to construct uncontaminated catalogues of merging pairs

**...BUT...**

- The detectability of interaction signatures in an image depends
  (i) on the morphology of the interacting systems (E, S, Irr...);
  (ii) on the viewing angle;
  (iii) on the time when the interaction is seen;
  (iv) on the redshift of the system; and
  (v) on the sensitivity, resolution and waveband of the observation.

**...AND SO...**

- Since the abundance of morphologically detected interacting systems depends on all these highly uncertain factors, so also must the effective values of $F_{merge}(z)$ and $T_{merge}(z)$.

# Our Solution

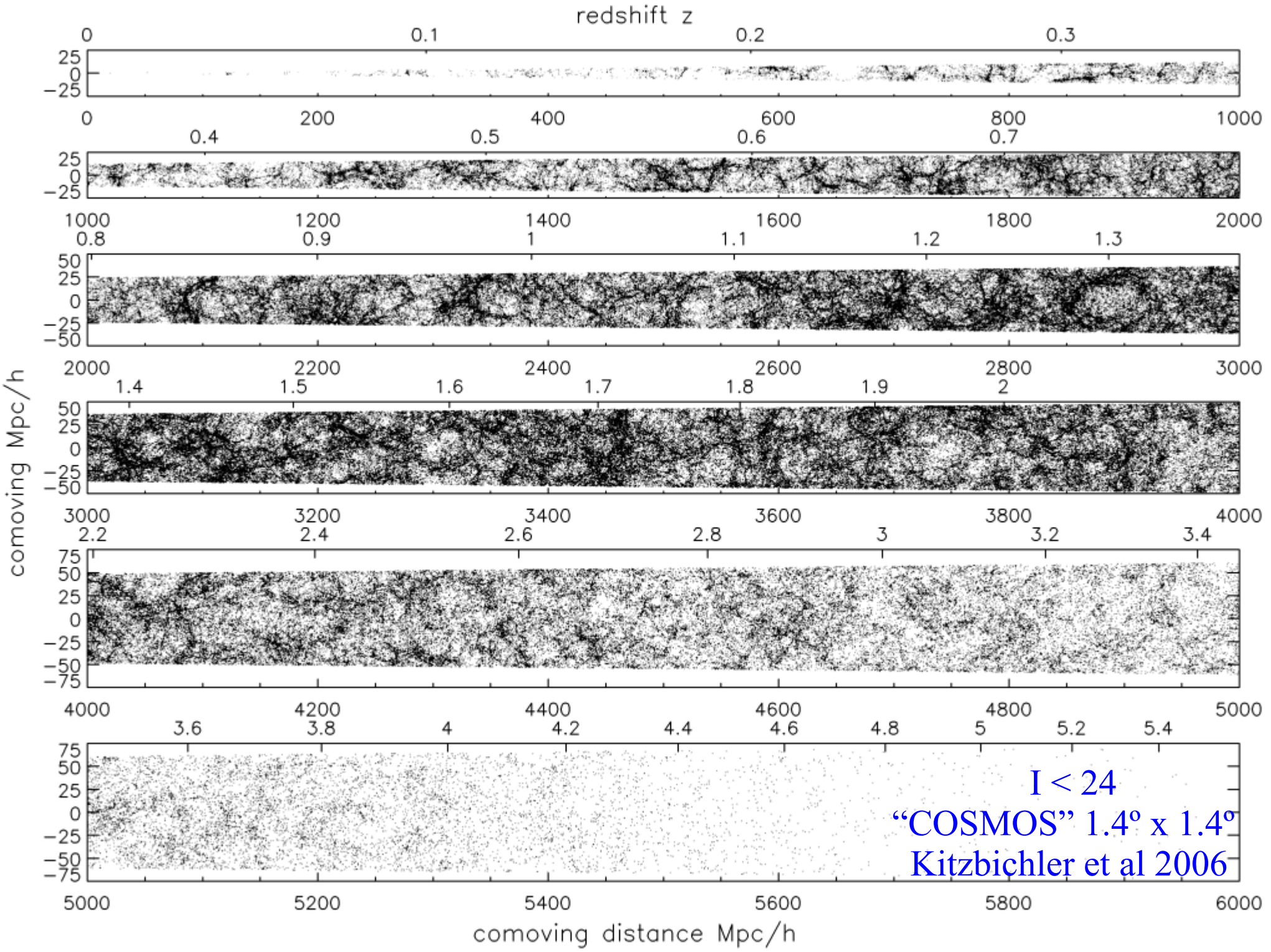
- Use the Millennium Simulation to create virtual samples of close pairs directly analogous to real observed surveys
- Measure $\dot{n}_{merge}(z)$ and $n_{close\_pair}(z)$ in the mock survey
- Use these to estimate $F_{merge}(z)$ and $T_{merge}(z)$
- Do not require any morphological signatures of interaction in either the simulated or the observed catalogues

# Our Solution

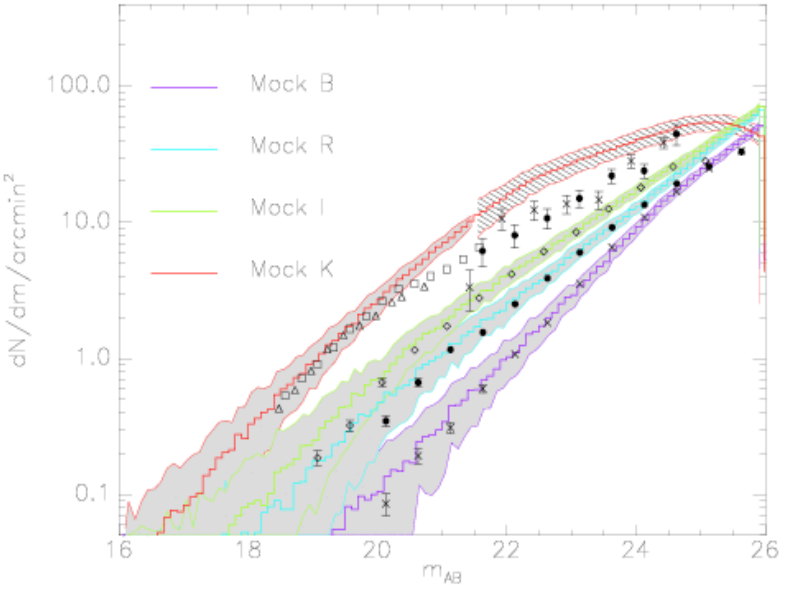
- Use the Millennium Simulation to create virtual samples of close pairs directly analogous to real observed surveys
- Measure $\dot{n}_{merge}(z)$ and $n_{close\_pair}(z)$ in the mock survey
- Use these to estimate $F_{merge}(z)$ and $T_{merge}(z)$
- Do not require any morphological signatures of interaction in either the simulated or the observed catalogues

# Caveat

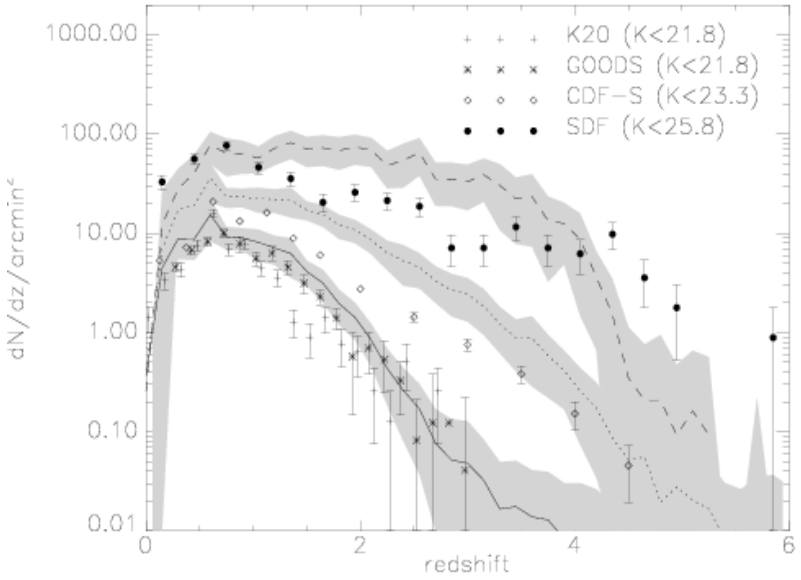
- Dynamical evolution in the Millennium Simulation must be realistic on the relevant scales (30 to 50 kpc).


redshift z
0
0.1
0.2
0.3
25
0
−25
0
200
400
600
800
1000
0.4
0.5
0.6
0.7
1000
1200
1400
1600
1800
2000
0.8
0.9
1
1.1
1.2
1.3
50
25
0
−25
−50
2000
2200
2400
2600
2800
3000
1.4
1.5
1.6
1.7
1.8
1.9
2
3000
3200
3400
3600
3800
4000
2.2
2.4
2.6
2.8
3
3.2
3.4
75
50
25
0
−25
−50
−75
4000
4200
4400
4600
4800
5000
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5000
5200
5400
5600
5800
6000
comoving Mpc/h
comoving distance Mpc/h
I < 24
“COSMOS” 1.4º x 1.4º
Kitzbichler et al 2006

# Does the MS produce the right number of faint galaxies?

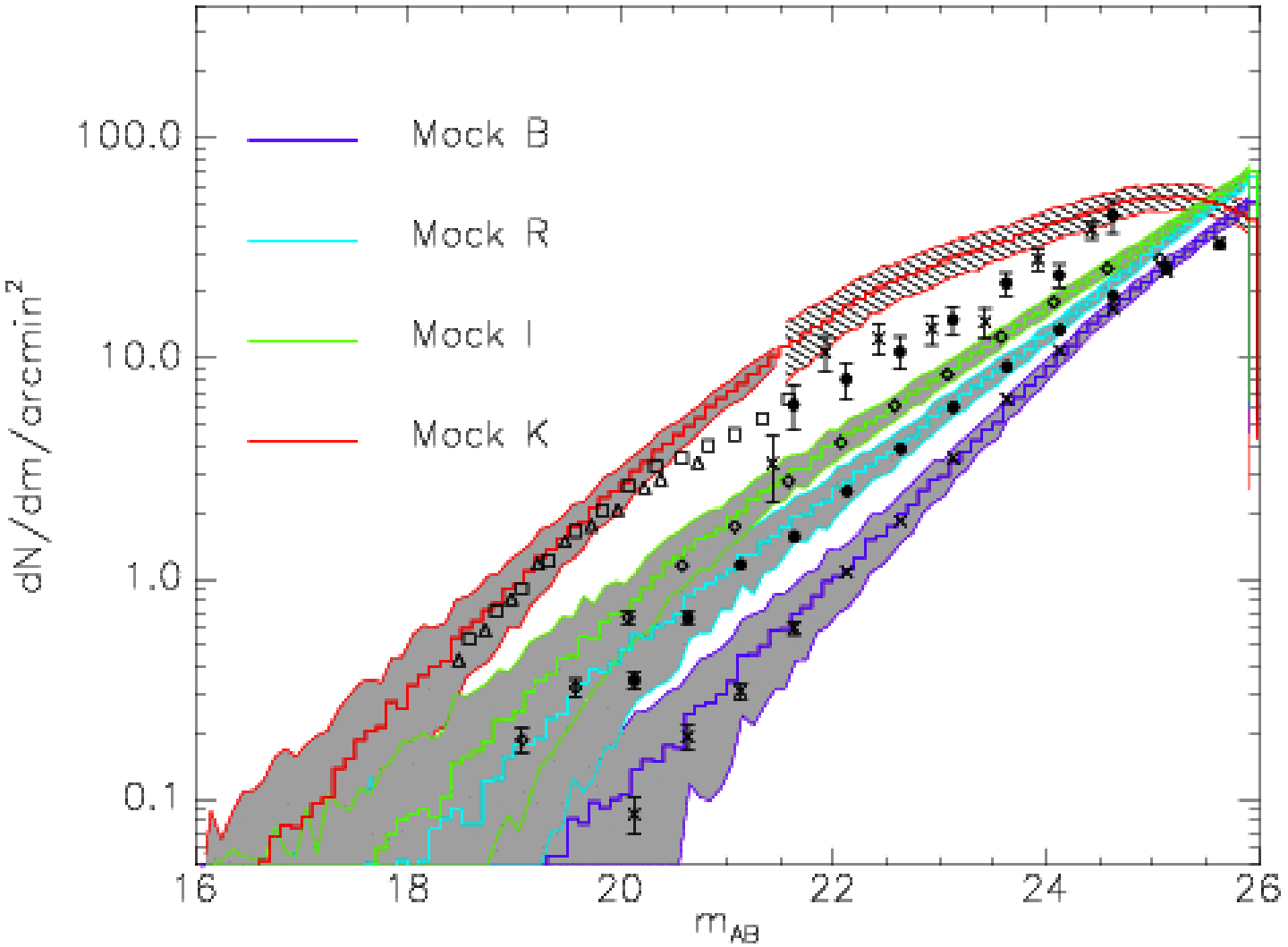



Counts agree in
the optical but
not in the K-band




Redshift distributions are
approximately OK but
numbers high at all z

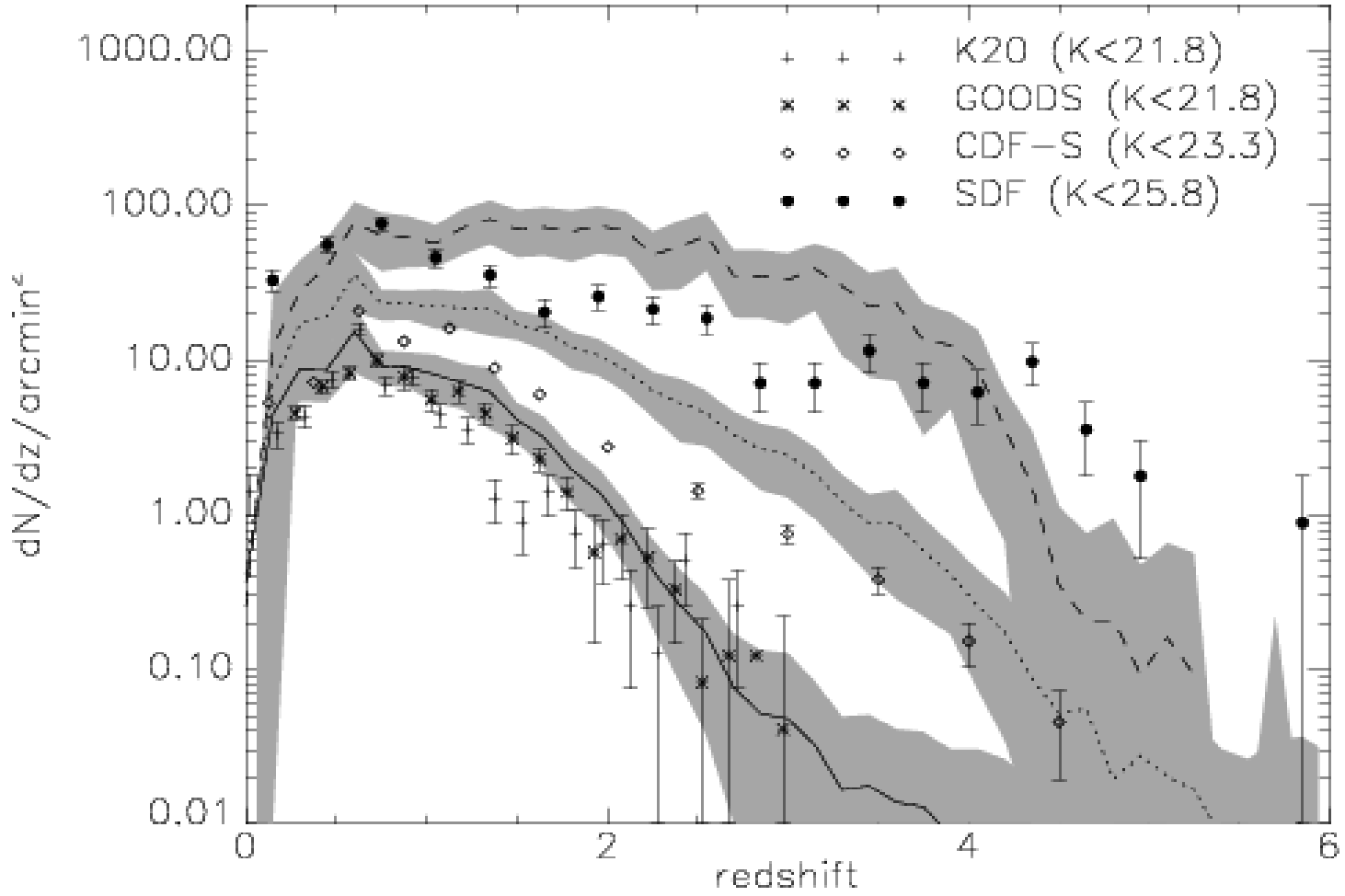
# Does the MS produce the right number of faint galaxies?




Counts agree in the optical but not in the K-band

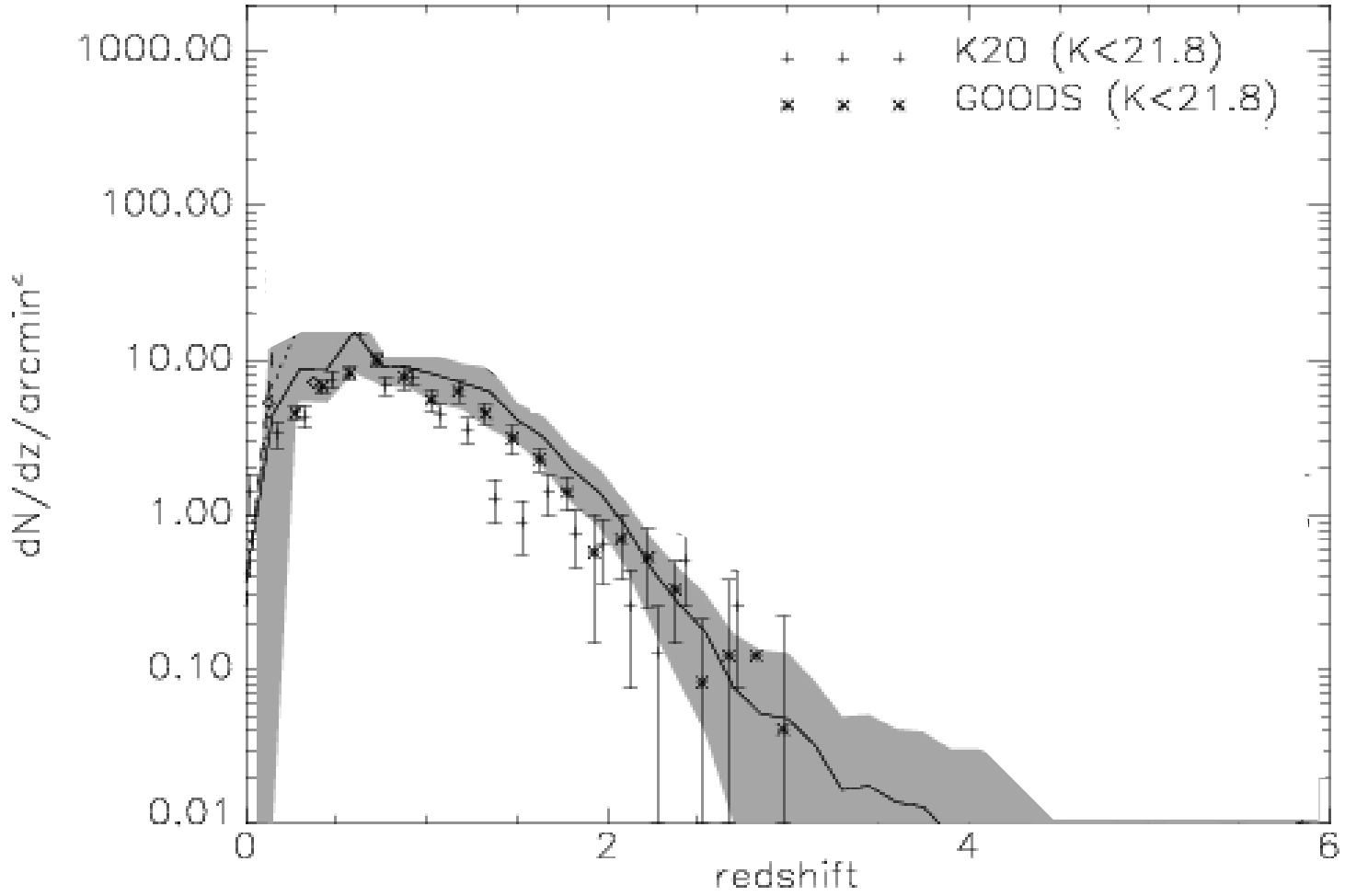
Too many faint red galaxies → galaxy formation too early?

# Does the MS produce the right number of faint galaxies?

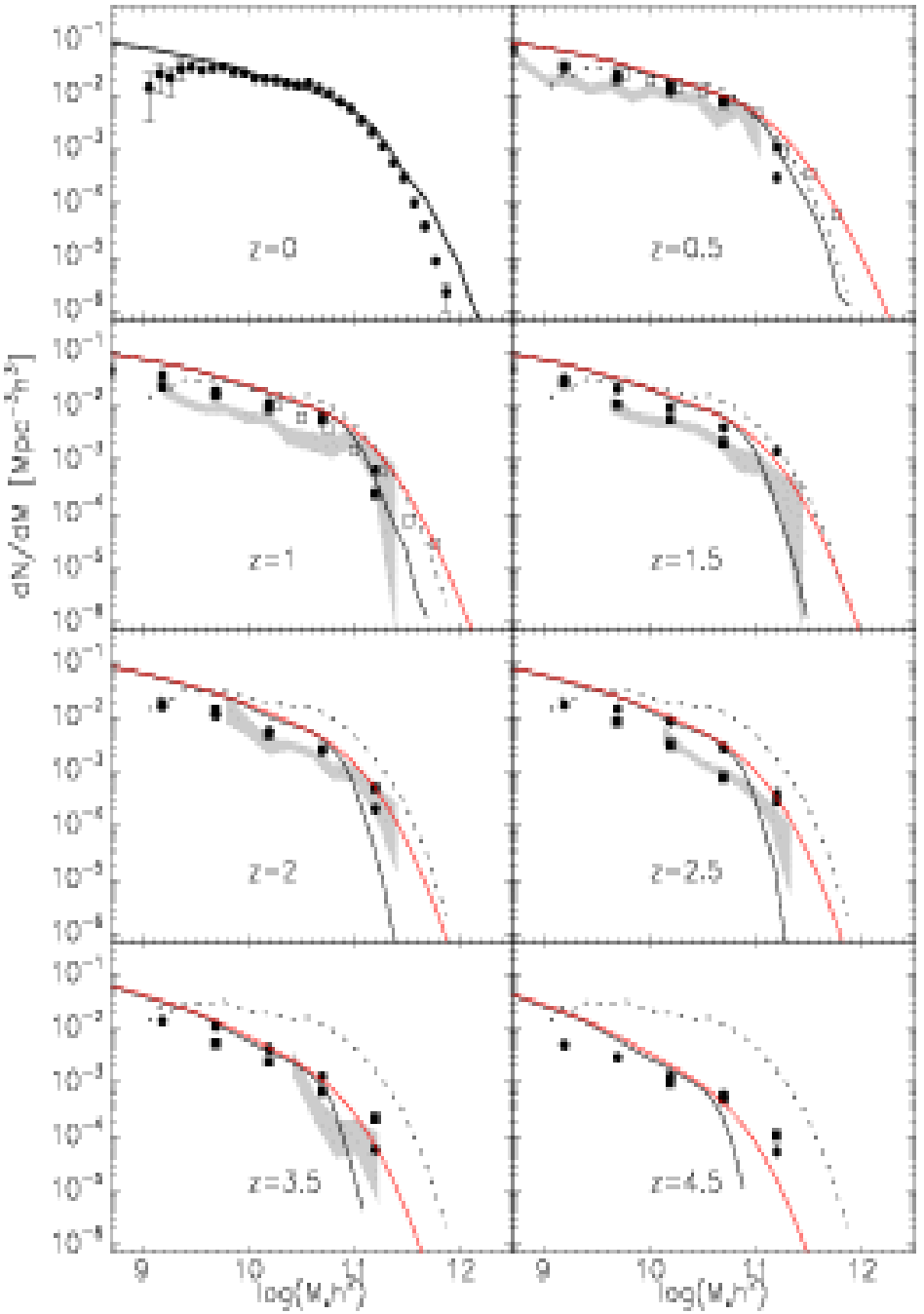



Redshift distributions are approximately OK but numbers high at all z

# Does the MS produce the right number of faint galaxies?

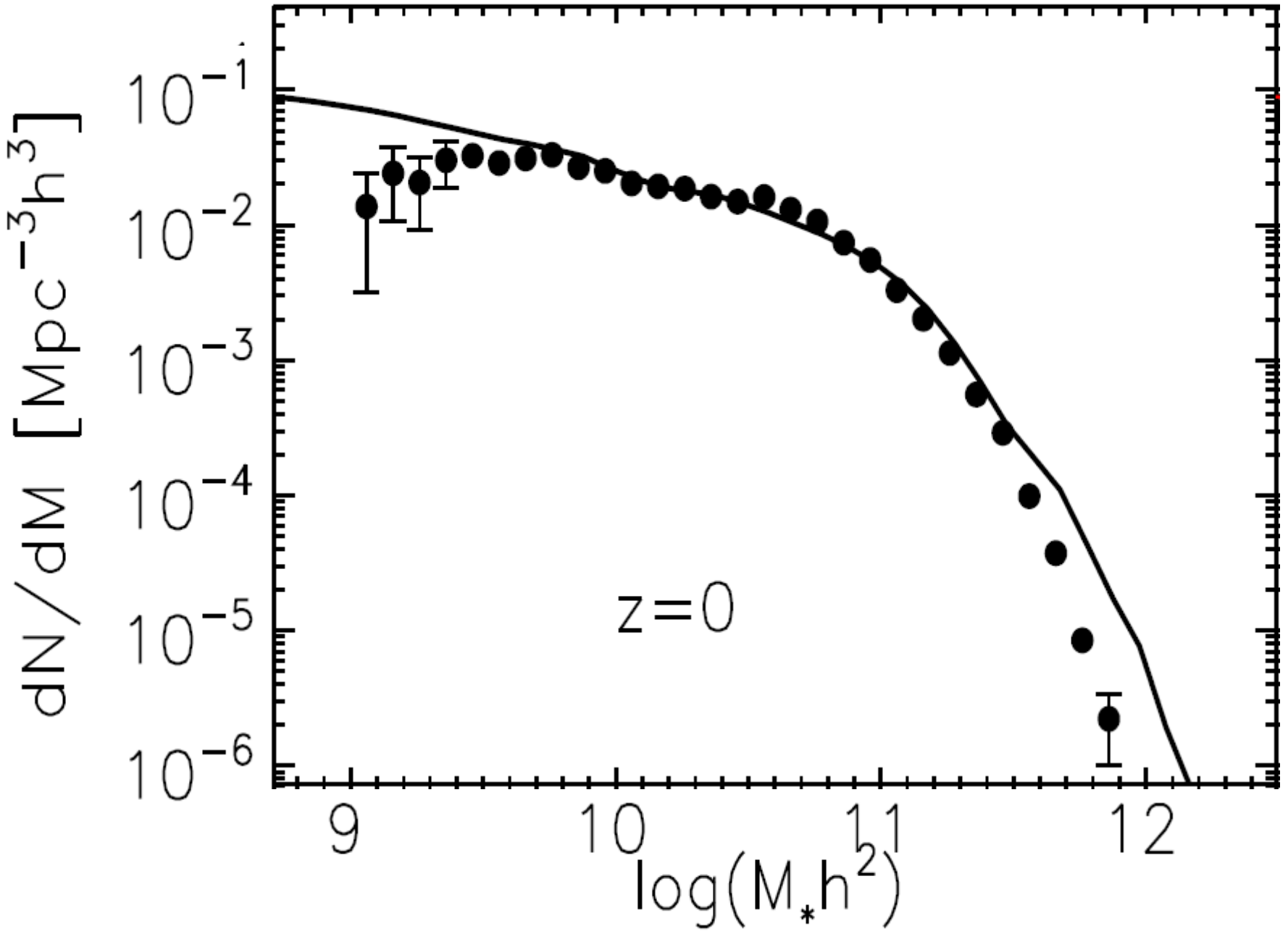



Redshift distributions are approximately OK but numbers high at all z

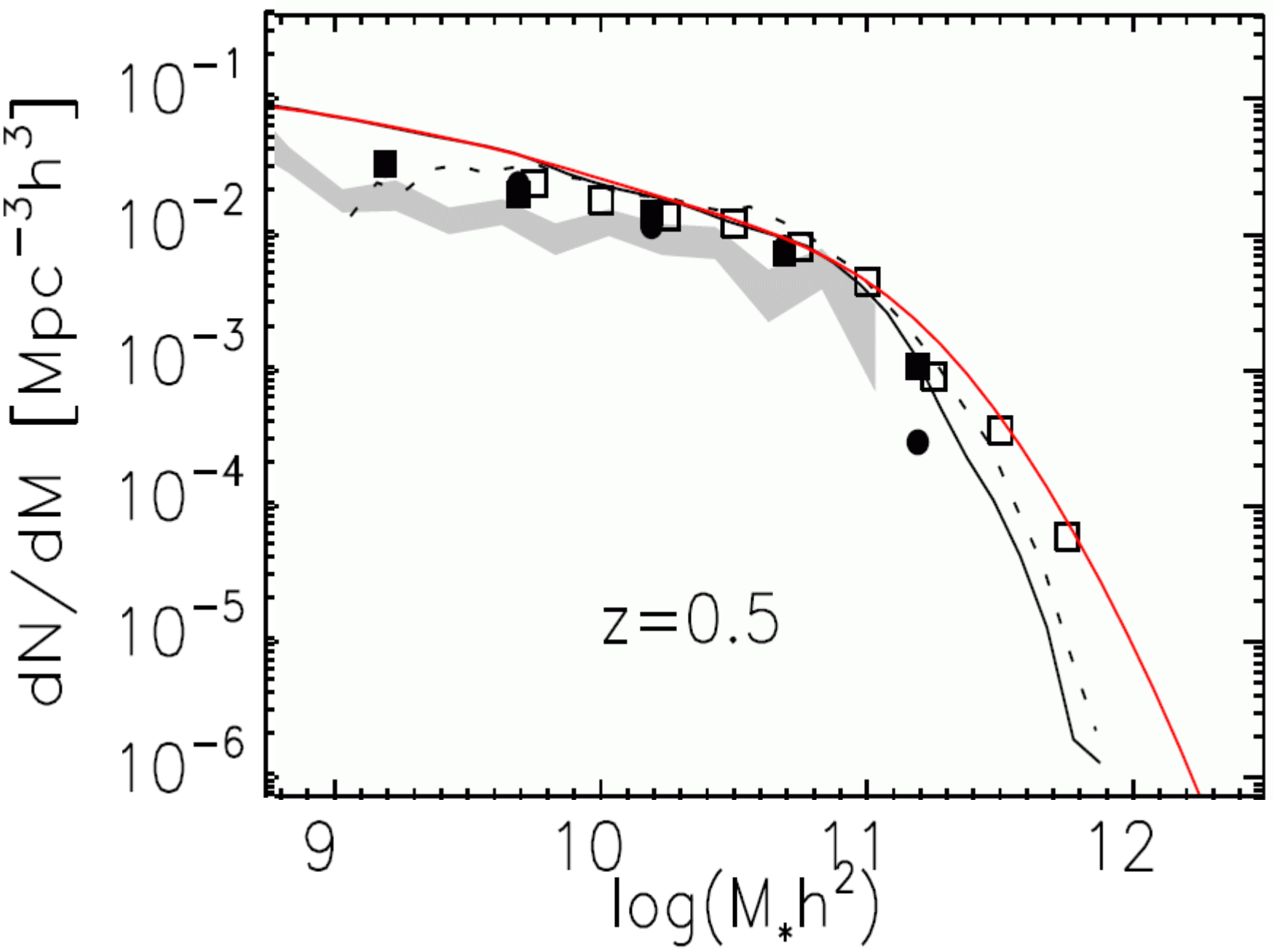



# Evolution of the mass function of galaxies in the MS compared to observation

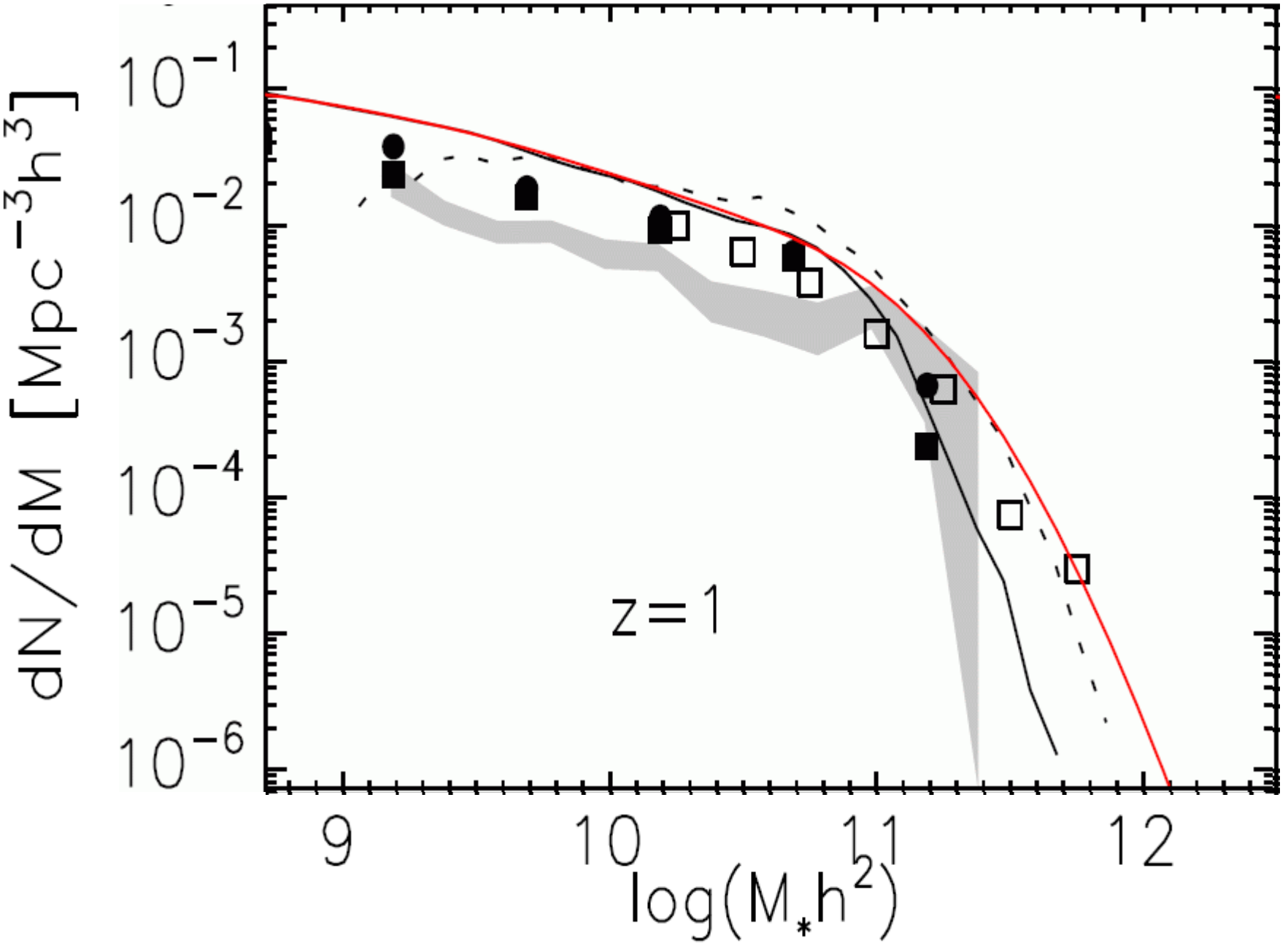
# Evolution of the mass function of galaxies in the MS compared to observation



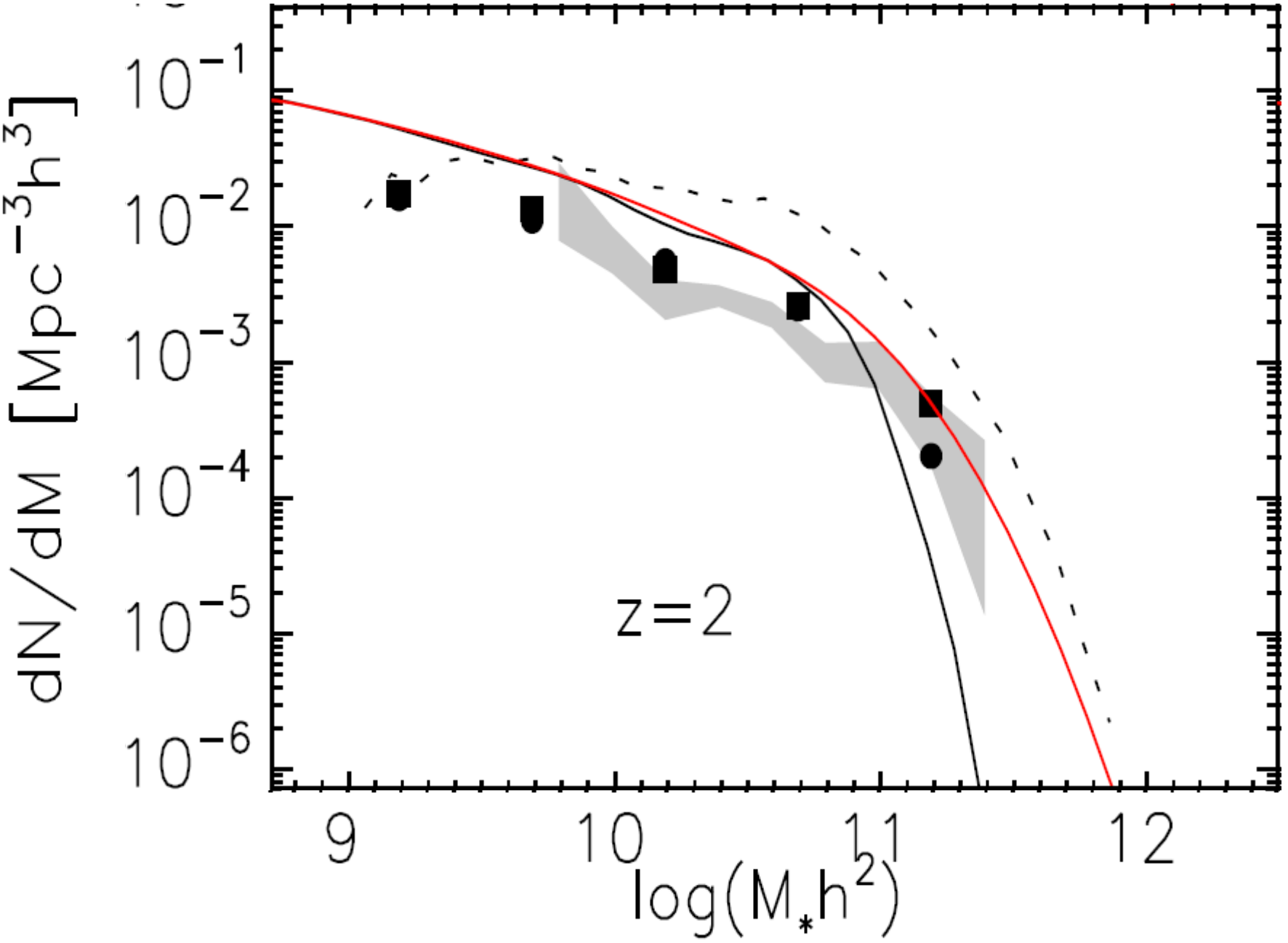
# Evolution of the mass function of galaxies in the MS compared to observation



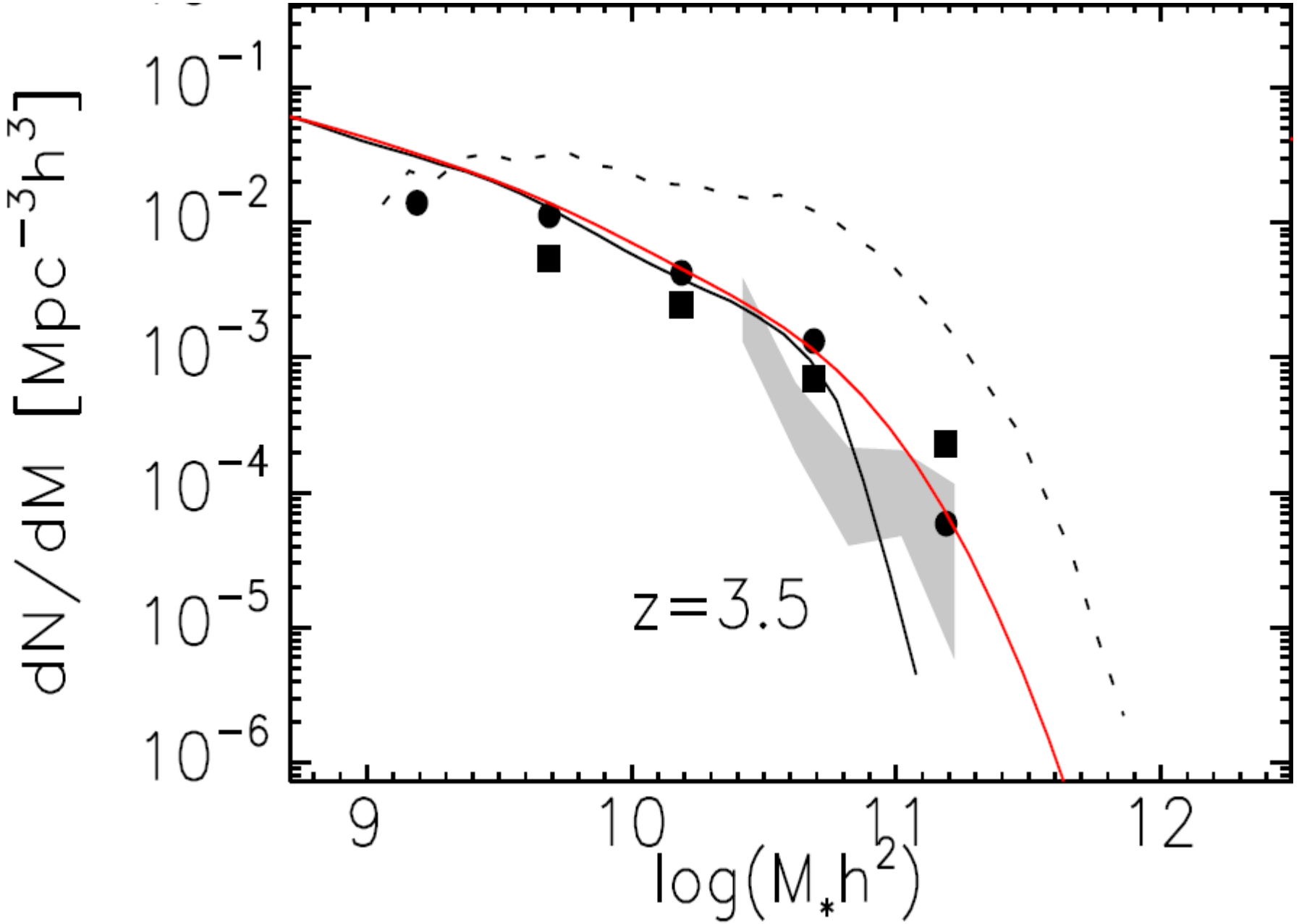
# Evolution of the mass function of galaxies in the MS compared to observation



# Evolution of the mass function of galaxies in the MS compared to observation



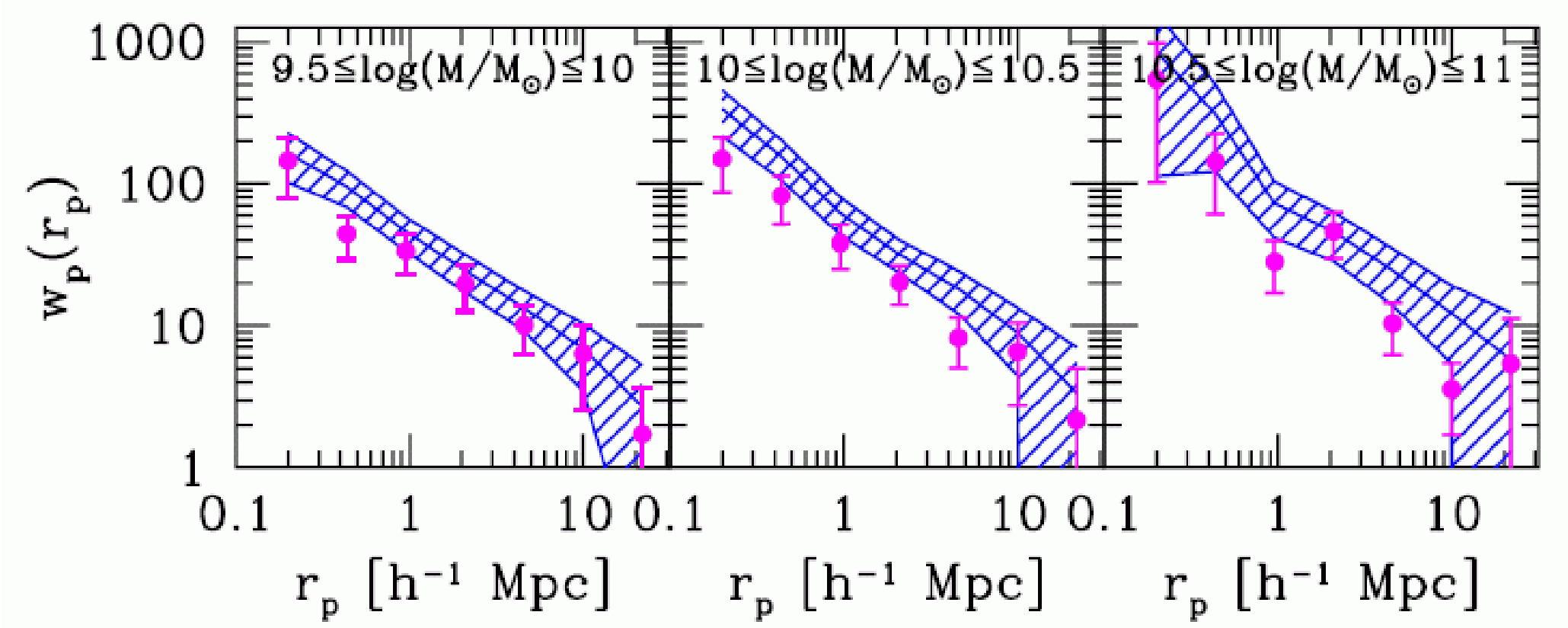
# Evolution of the mass function of galaxies in the MS compared to observation



# Comparison with VVDS survey $w_p(r_p)$

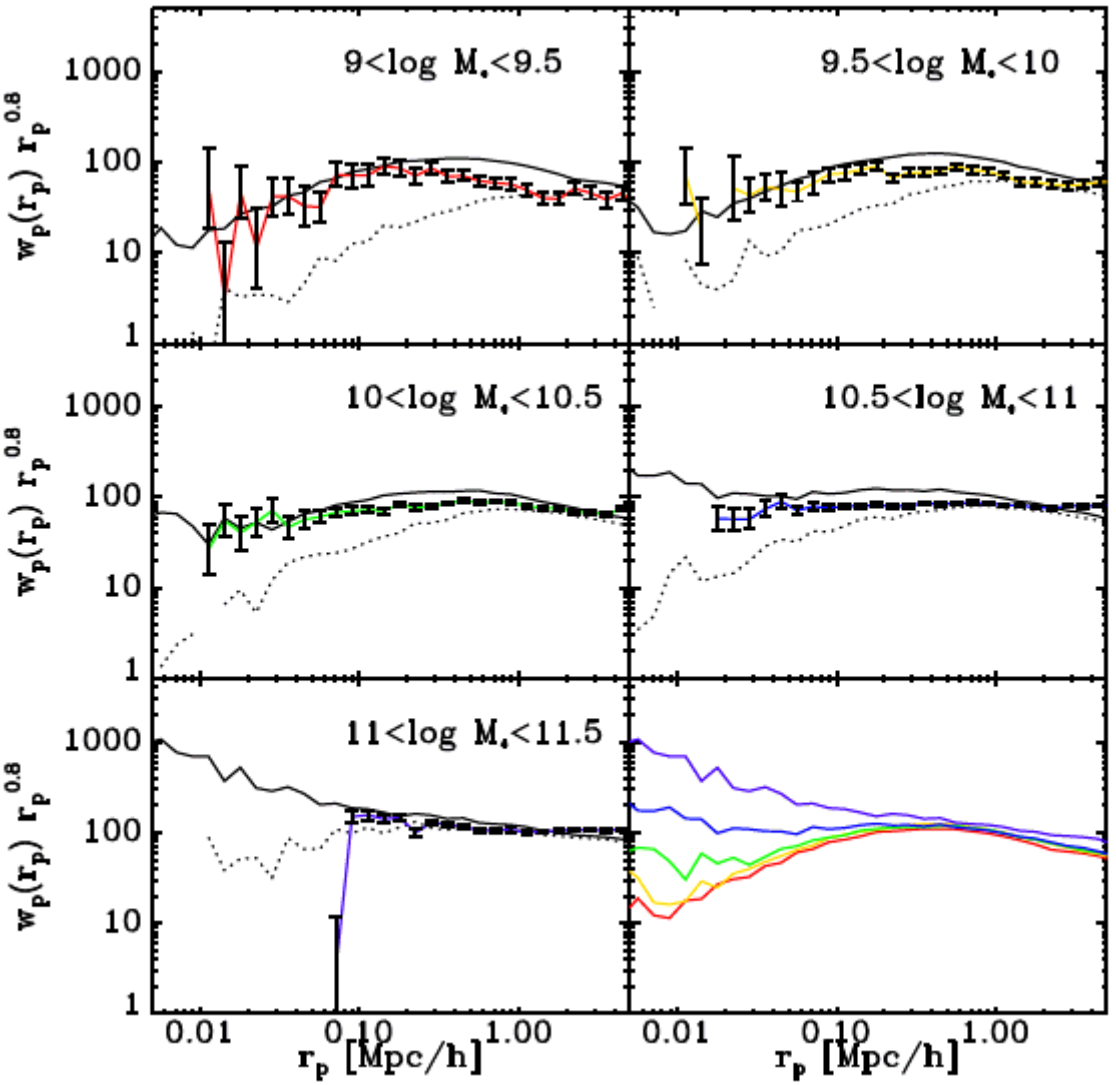
Meneux et al 2007

‹z› ~ 0.6



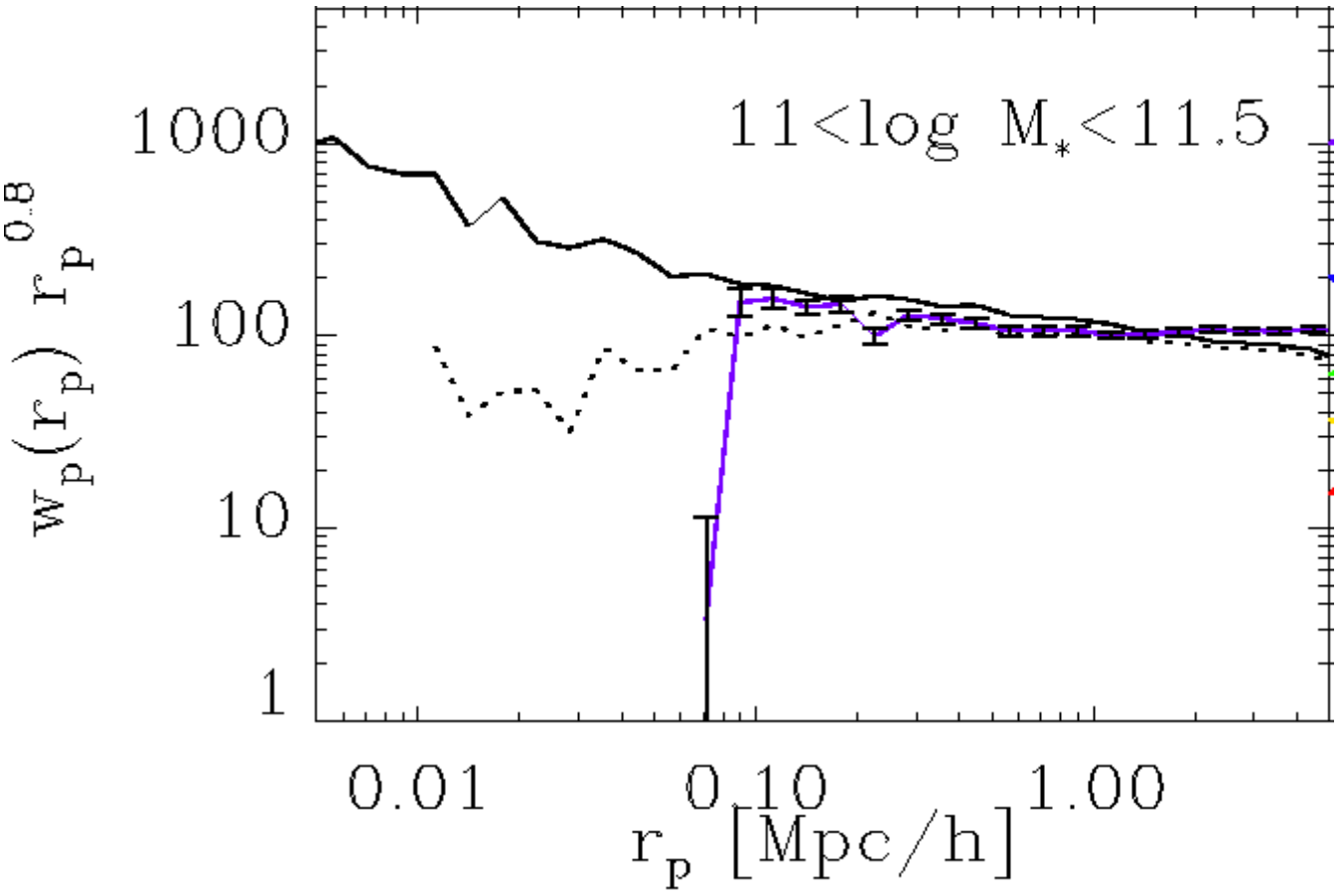

The Millennium Simulation approximately reproduces the observed abundance of pairs on scales ~ 200 kpc at z ~ 0.6

# Small-scale correlations in the MS versus SDSS

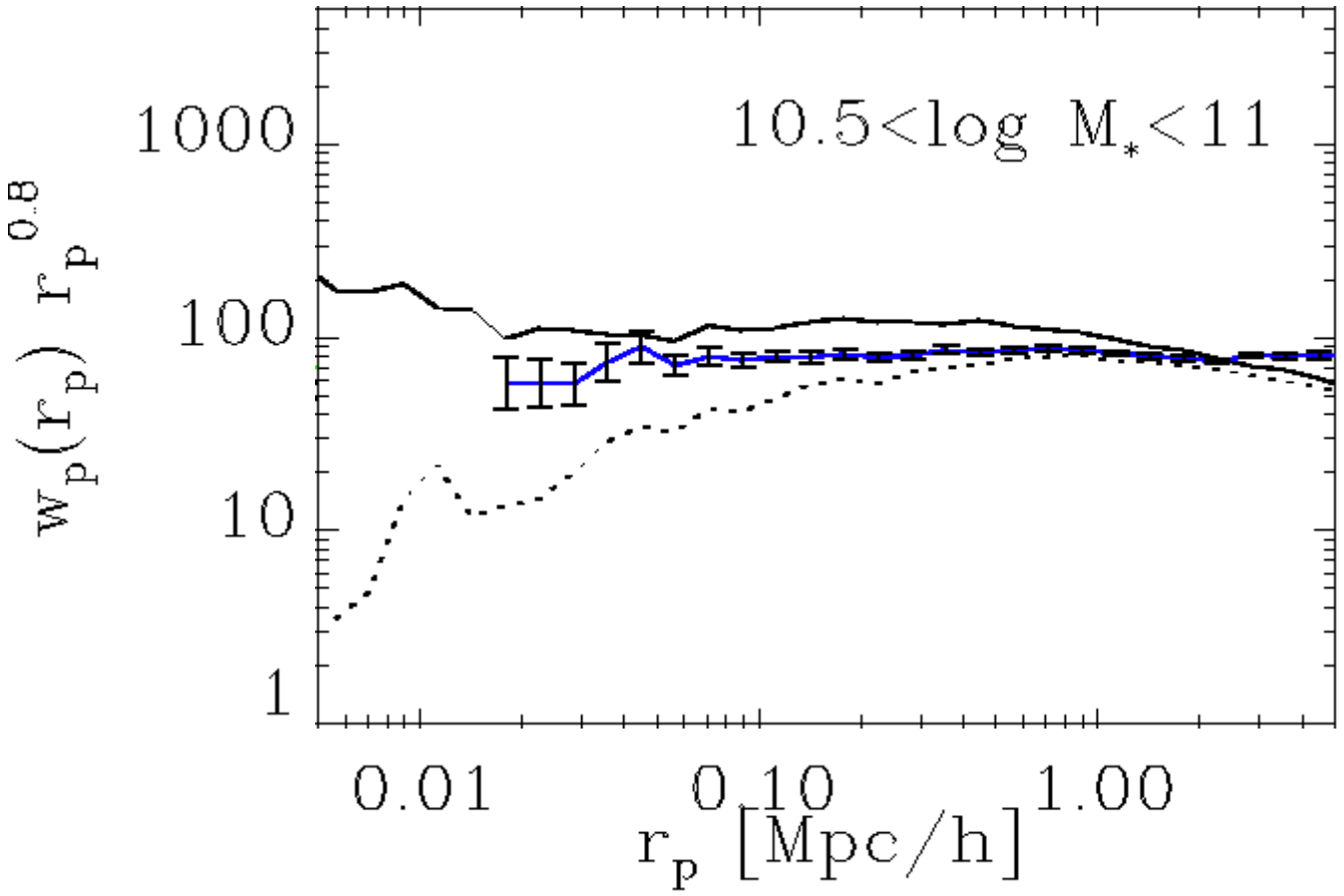



Kitzbichler & White 2008

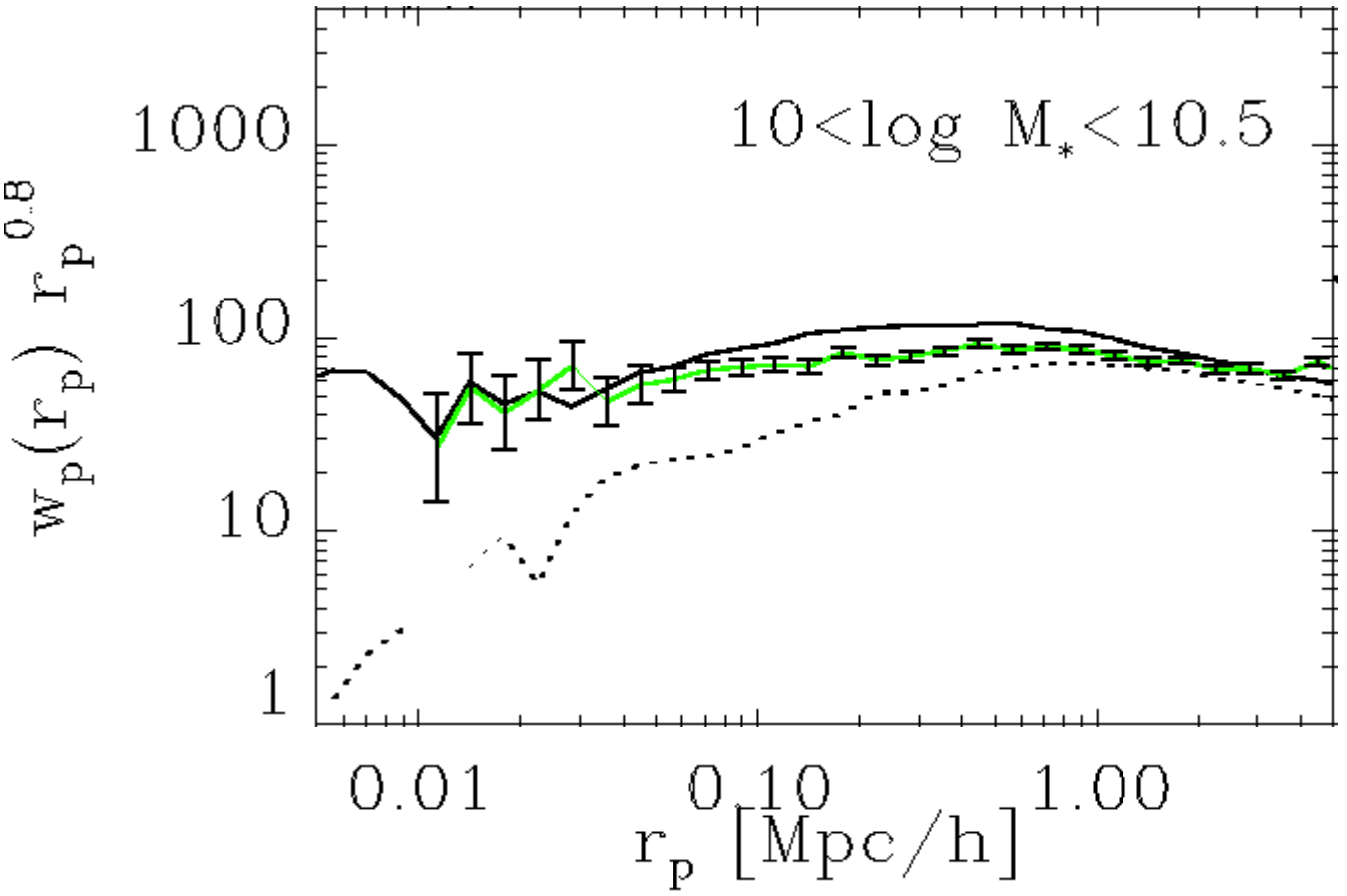
# Small-scale correlations in the MS versus SDSS



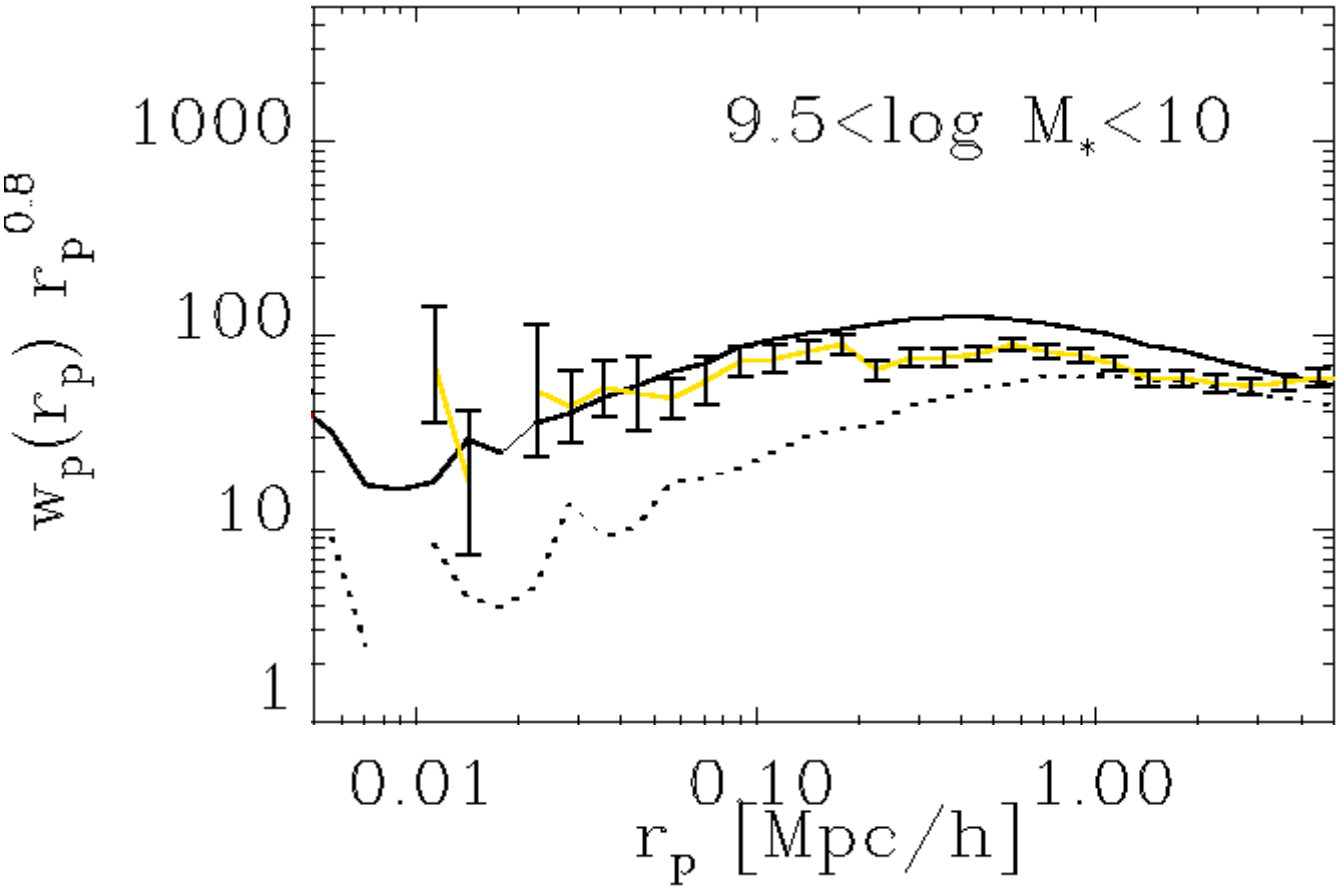
# Small-scale correlations in the MS versus SDSS



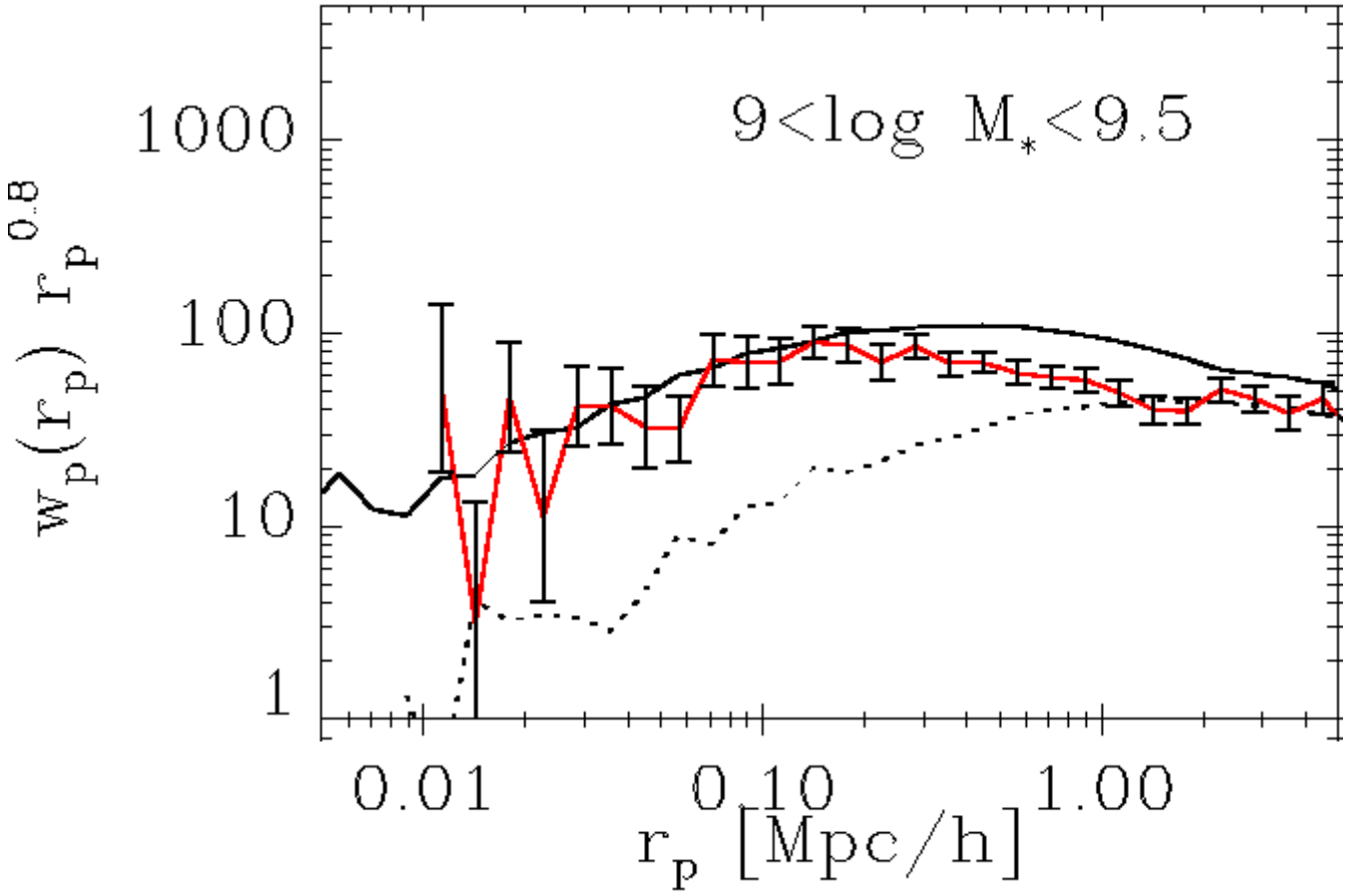
# Small-scale correlations in the MS versus SDSS



# Small-scale correlations in the MS versus SDSS

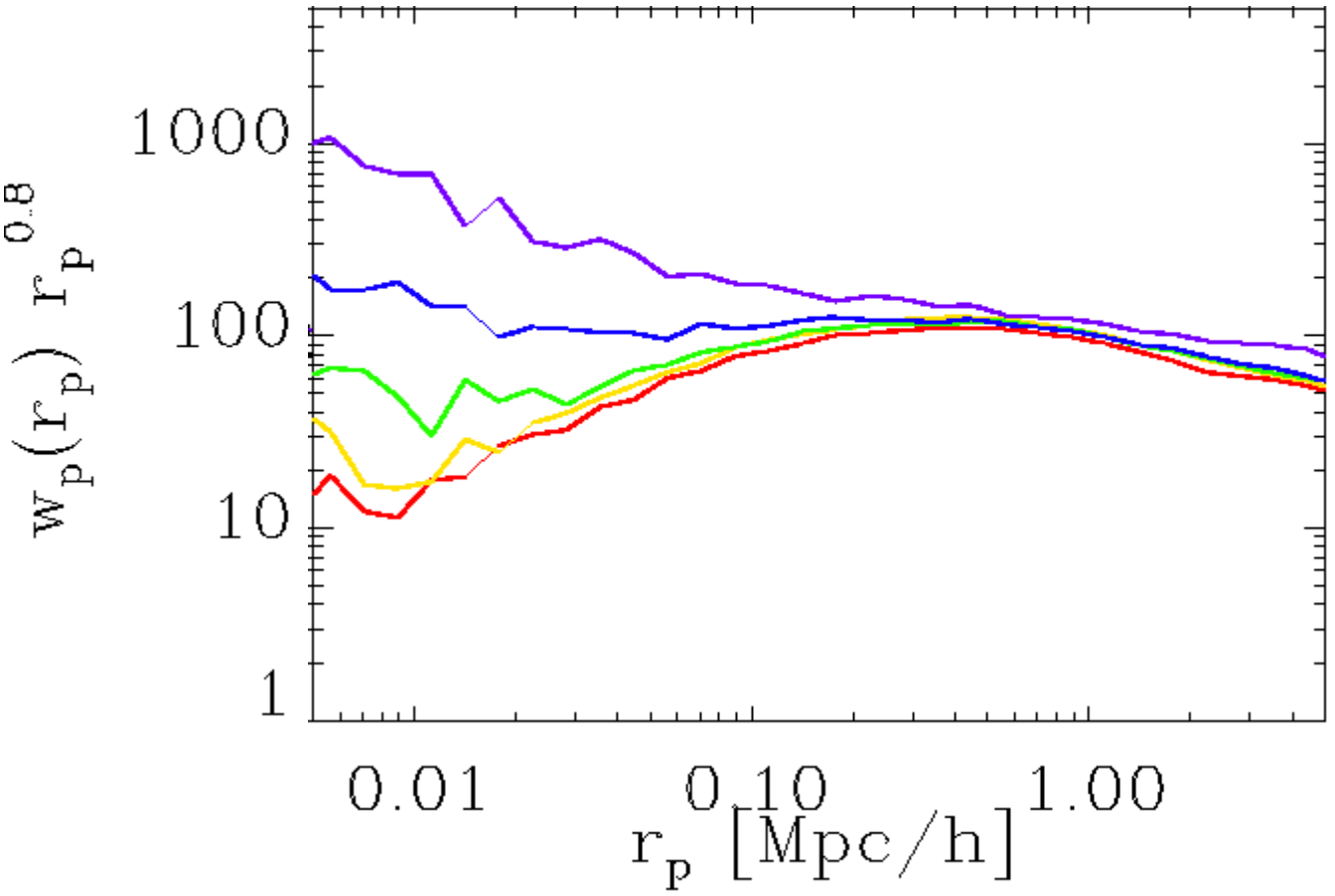


# Small-scale correlations in the MS versus SDSS




- The Millennium Simulation reproduces the observed abundance of pairs on 30 to 50 kpc scales at z ~ 0.1
- The "orphan" galaxies are critical to getting this right

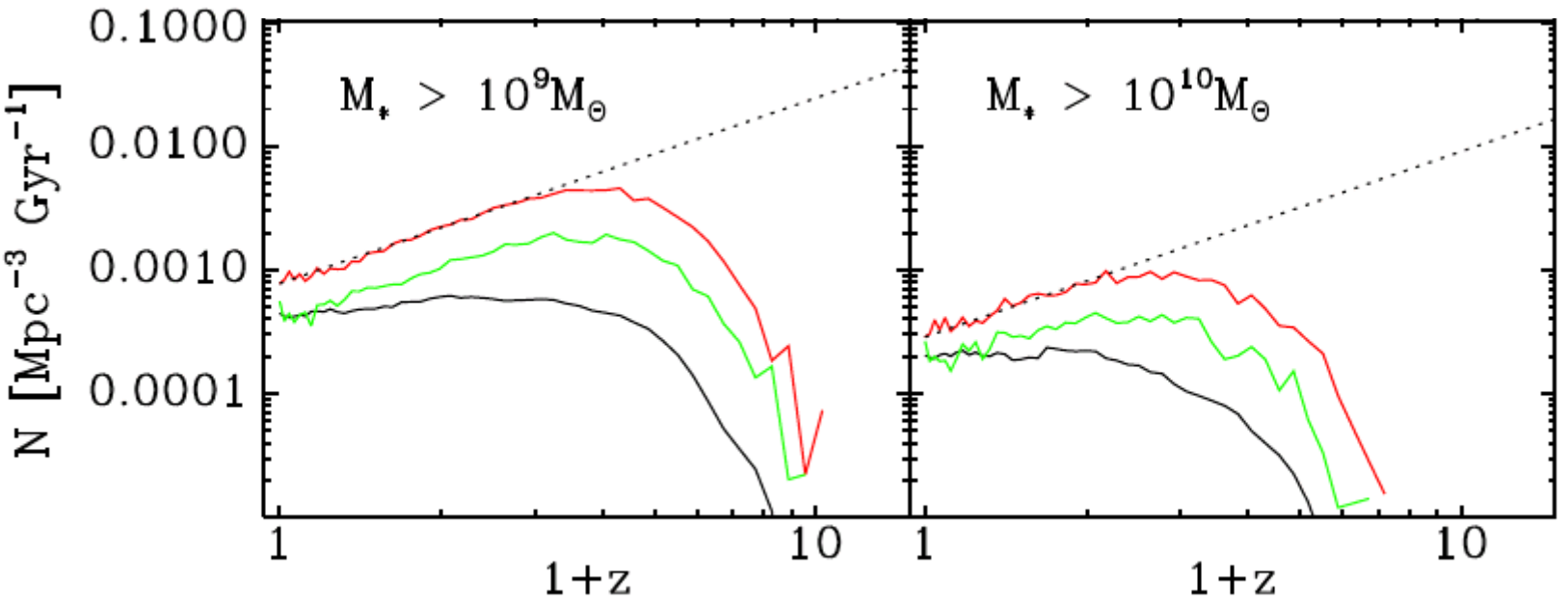
# Small-scale correlations in the MS versus SDSS




According to the simulation (and the data!) the small-scale shape of the correlation function depends strongly on stellar mass

# What constitutes a merger in the simulation?

- When two dark halos merge into a single halo?
- When the DM (sub)structure of one galaxy is disrupted within the halo of the other?
- When the code thinks dynamical friction has brought the visible galaxies together?



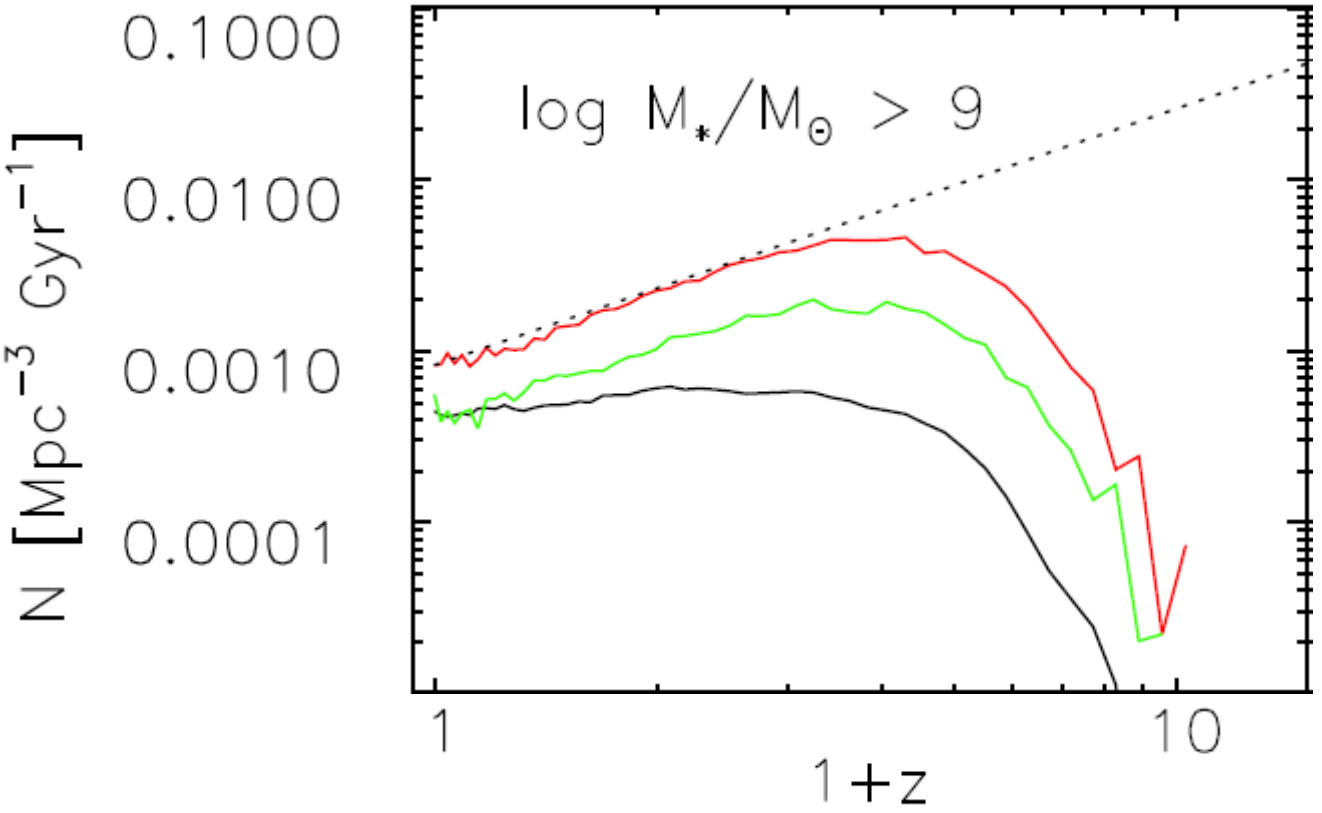

galaxy merger rate

halo merger rate

halo accretion rate

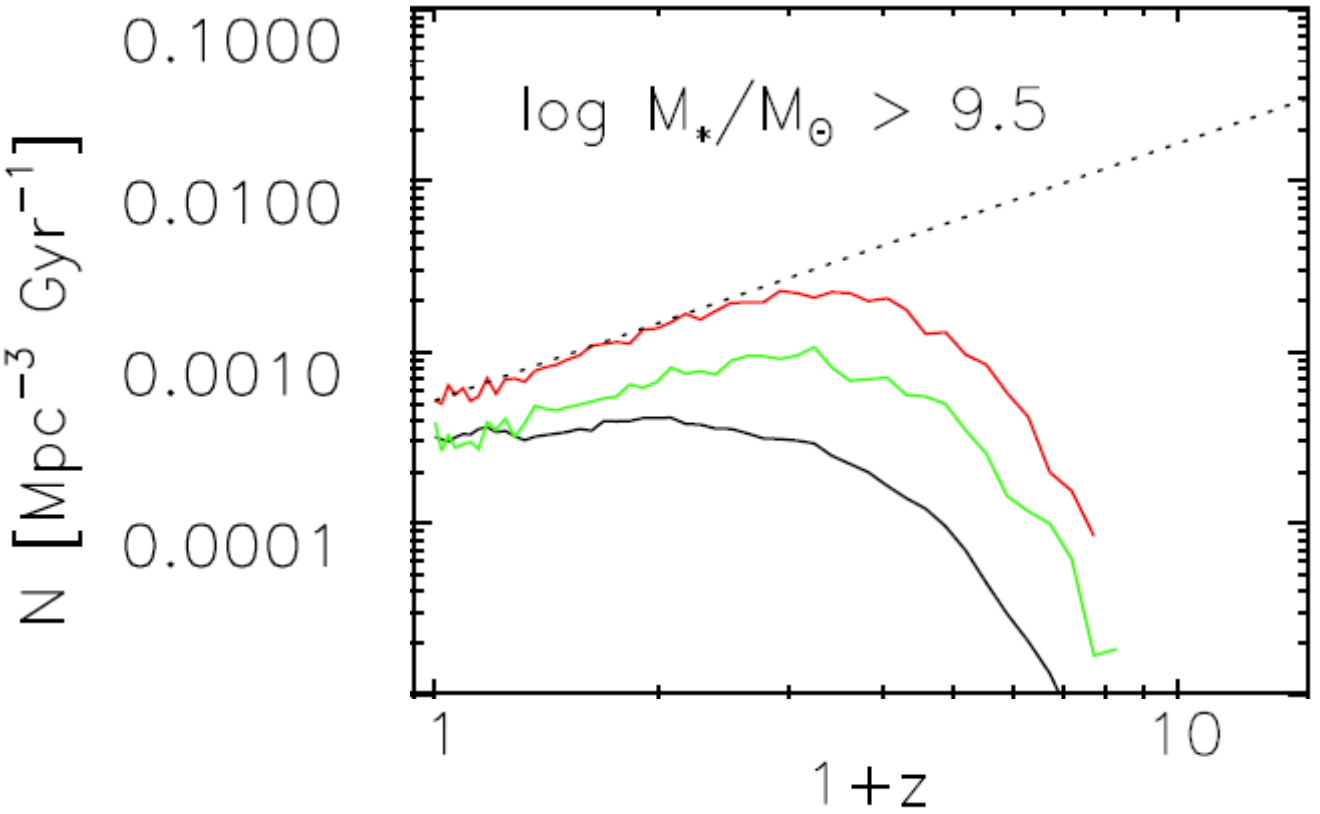
Kitzbichler & White 2008

# Merger rates as a function of stellar mass and redshift



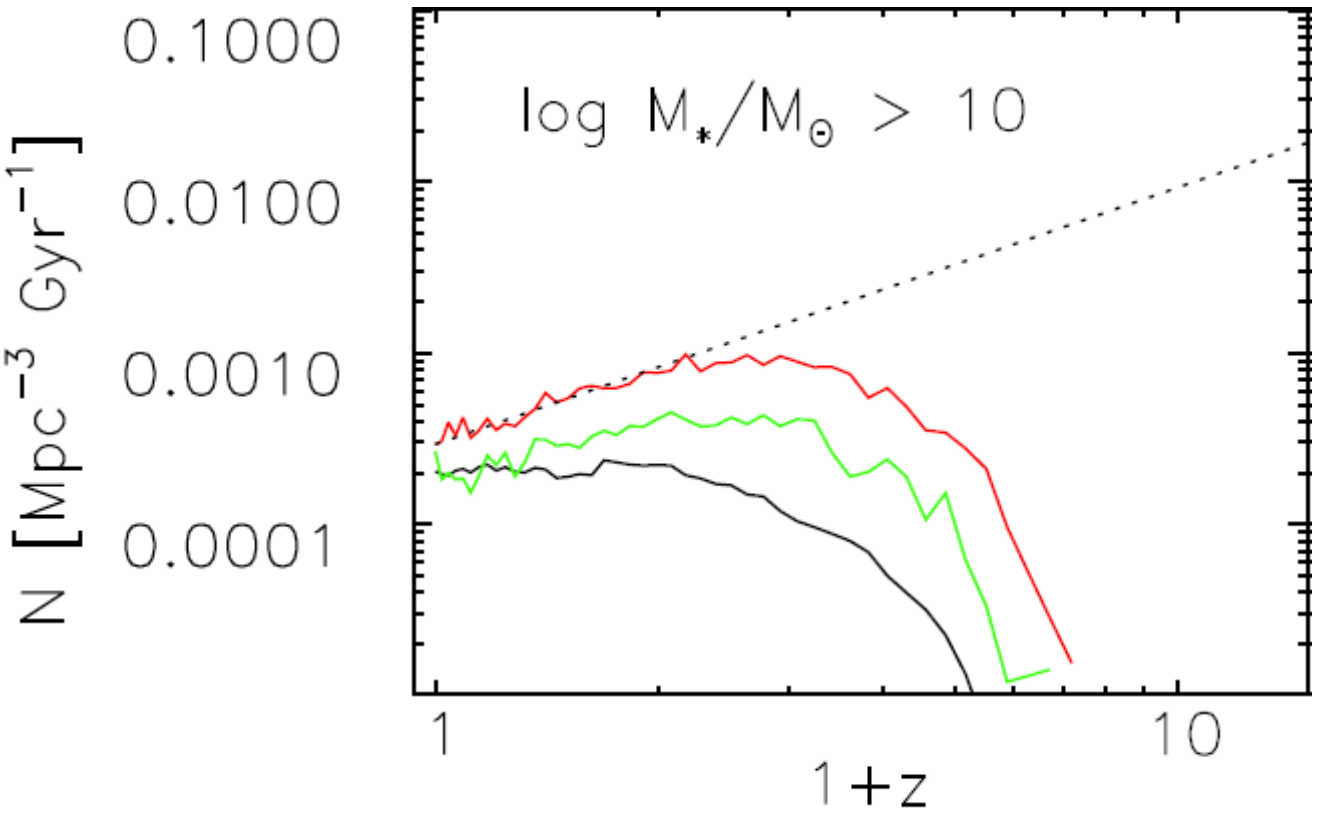

- Halo merger and disruption rates $\propto (1 + z)^{1.5}$ at low z, but galaxy merger rates are independent of z
- Halo merger rates are more than twice (sub)halo disruption rates

# Merger rates as a function of stellar mass and redshift



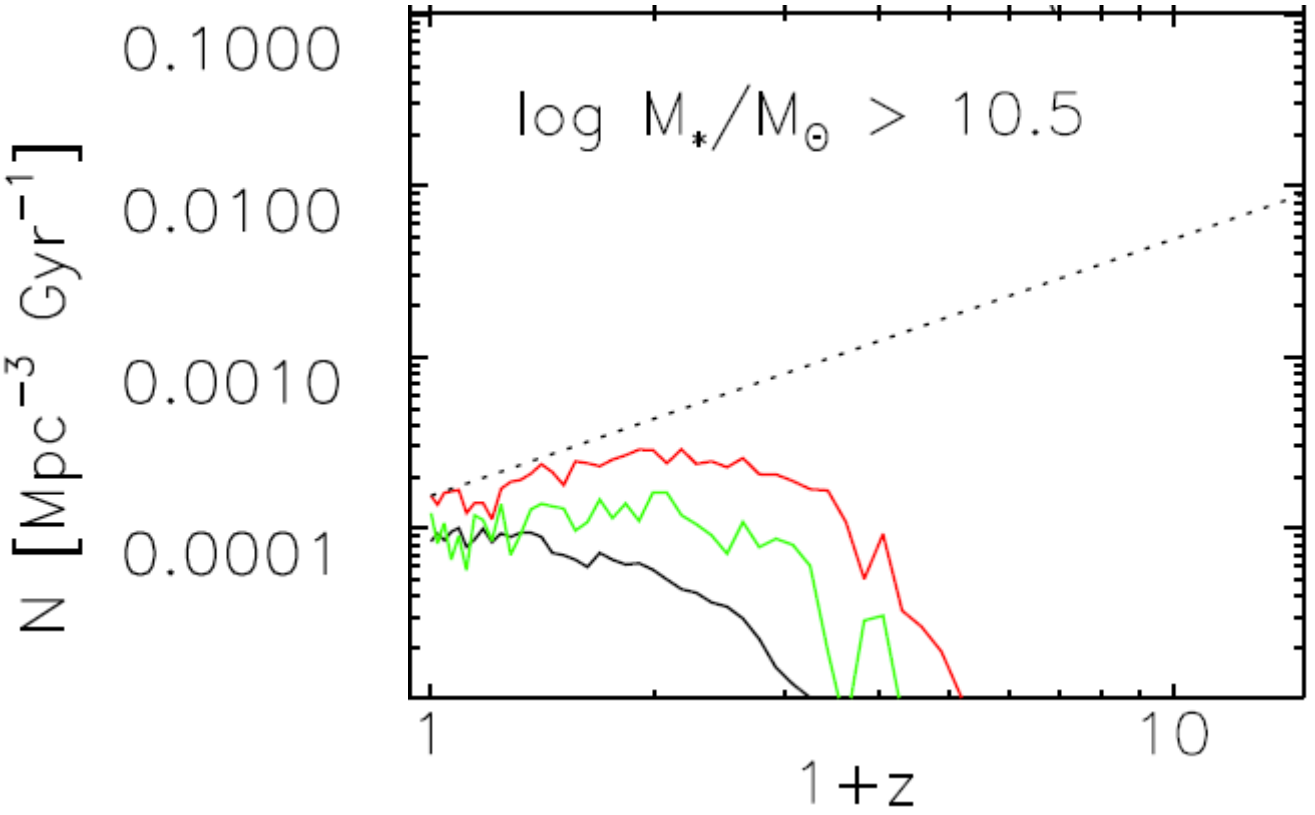

- Halo merger and disruption rates $\propto (1 + z)^{1.5}$ at low z, but galaxy merger rates are independent of z
- Halo merger rates are more than twice (sub)halo disruption rates
- All rates decrease with the minimum stellar mass of the galaxies

# Merger rates as a function of stellar mass and redshift



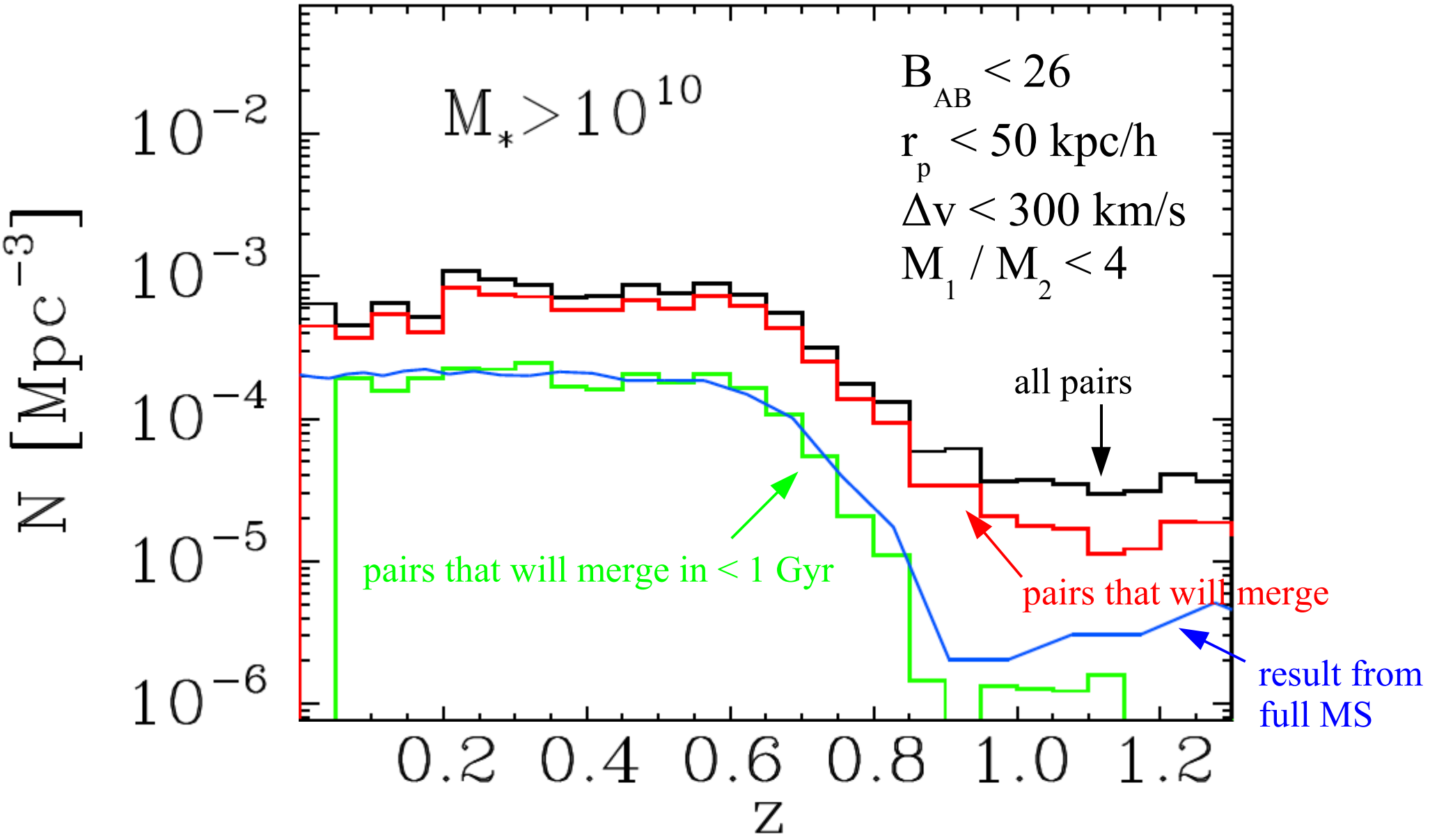

- Halo merger and disruption rates $\propto (1 + z)^{1.5}$ at low z, but galaxy merger rates are independent of z
- Halo merger rates are more than twice (sub)halo disruption rates
- All rates decrease with the minimum stellar mass of the galaxies

# Merger rates as a function of stellar mass and redshift



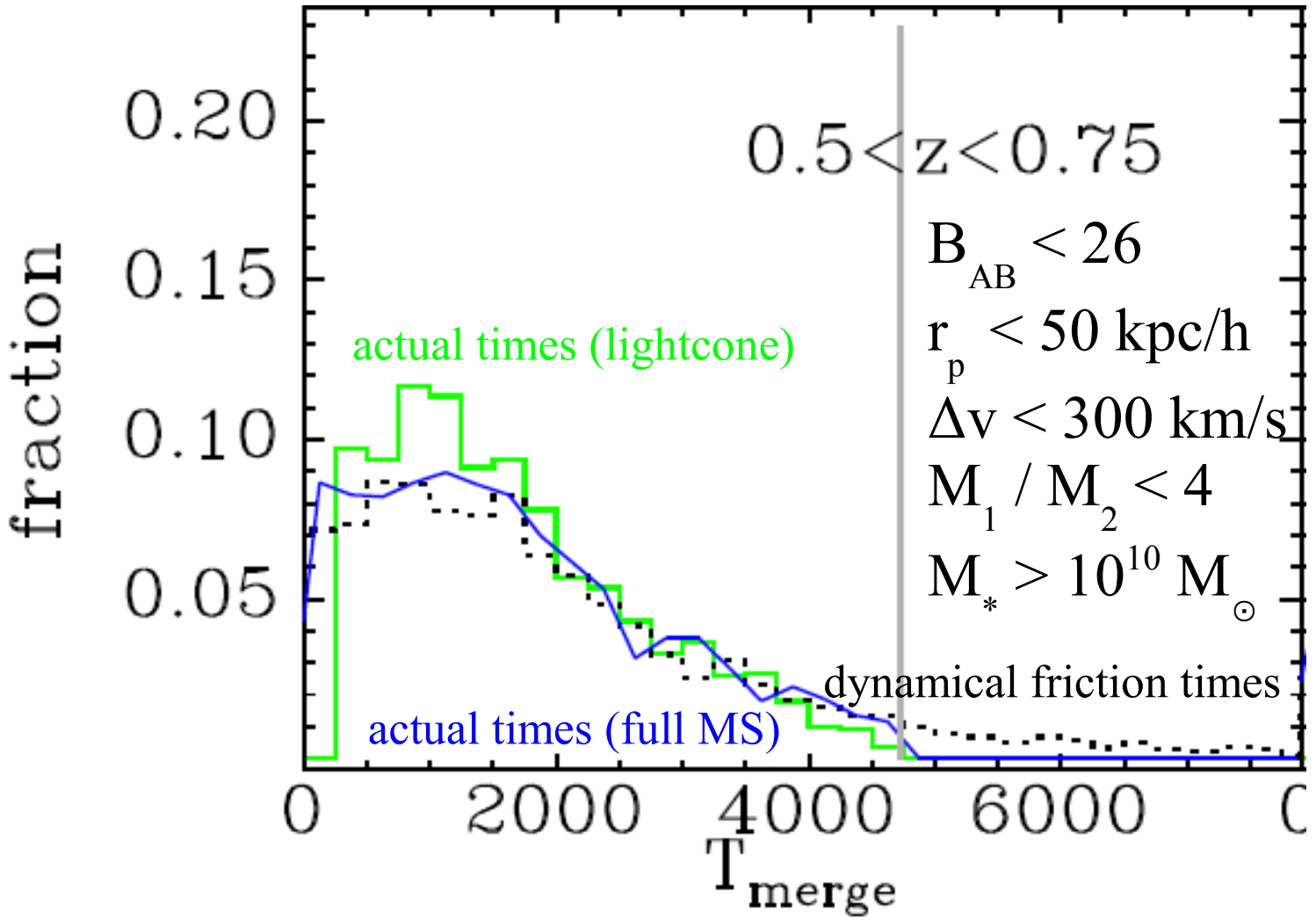

- Halo merger and disruption rates $\propto (1 + z)^{1.5}$ at low z, but galaxy merger rates are independent of z
- Halo merger rates are more than twice (sub)halo disruption rates
- All rates decrease with the minimum stellar mass of the galaxies

# Do observed close pairs actually merge?



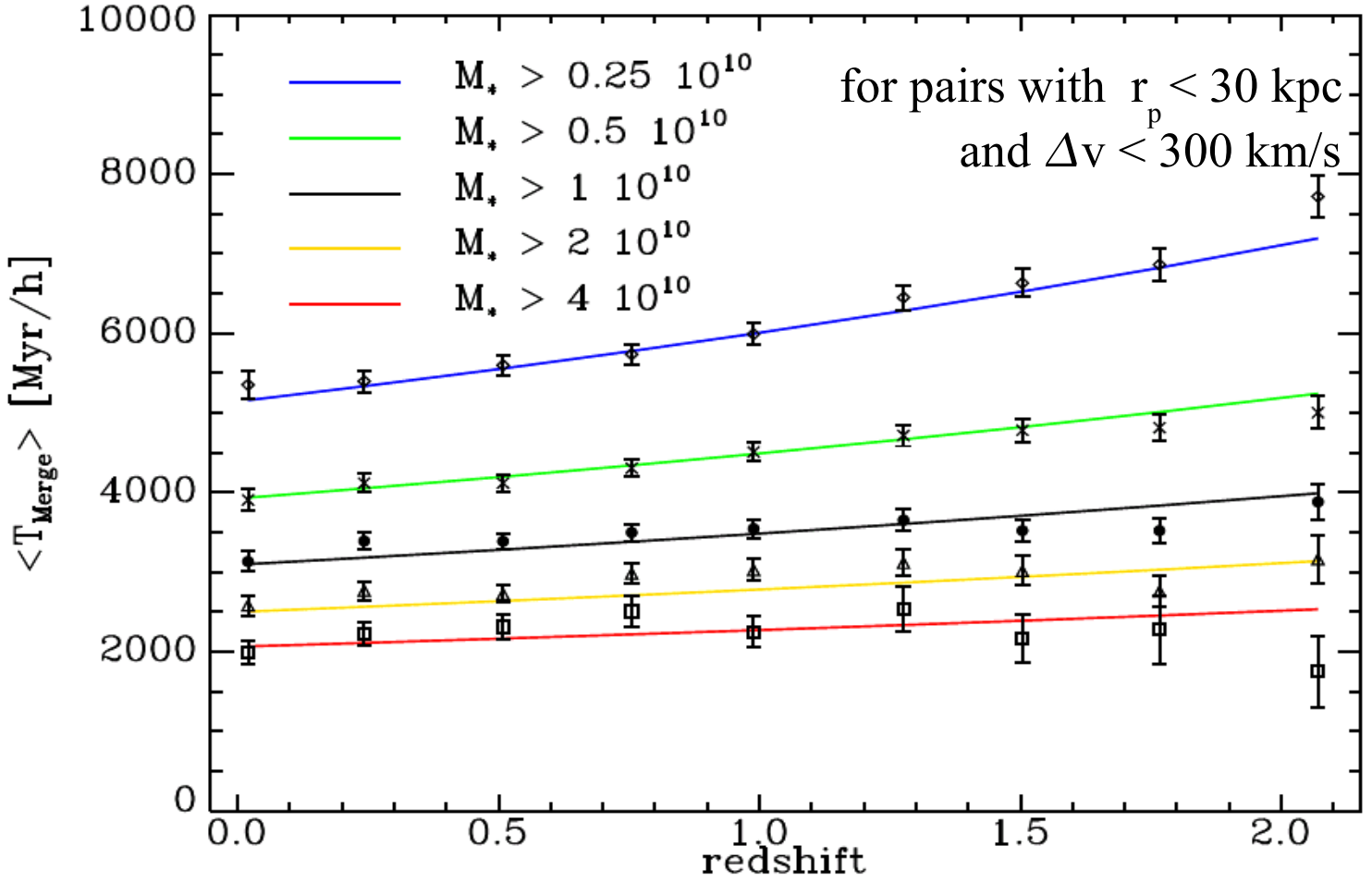

Most close pairs merge but they take a long time to do it!

# How long do close pairs take to merge?




The median merger time is about 2Gyr with a broad distribution

# Timescale for converting close pair counts into merger rates




$T_{merge}$ = (Abundance of projected close pairs) / (Merger rate of such pairs)

$\propto r_p M^{-0.3} (8 + z)$

Kitzbichler & White 2008

# How to estimate merger rates from pair counts

1 Count close pairs ( $r_p$ < 50 *or* 30 kpc) with well defined criteria on magnitude difference, stellar mass, etc.

2 Make completeness and background corrections to estimate abundance of pairs of chosen type at known z

3 Divide close pair abundance by the merger timescale to get merger rate (per unit volume) of the chosen pair type

e.g. for pairs of $\sim 10^{10}\ M_\odot$ galaxies at $z \sim 1$ with

$$r_p \leq 30 \text{ kpc/h (physical) and } \Delta v < 300 \text{ km/s}$$

$$T_{merge} = 2.0 \text{ Gyr/h}$$

# IN CONCLUSION

- Do NOT use morphologically selected samples to estimate merer rates
- Most close ($r_p$ <50 kpc) pairs will merge
- The time they take to merge varies widely
- The appropriate average time is around 2 Gyr
- Merger rates are not expected to vary much with z
- Most previous observational estimates are too high