Theoretical perspectives on luminosity functions

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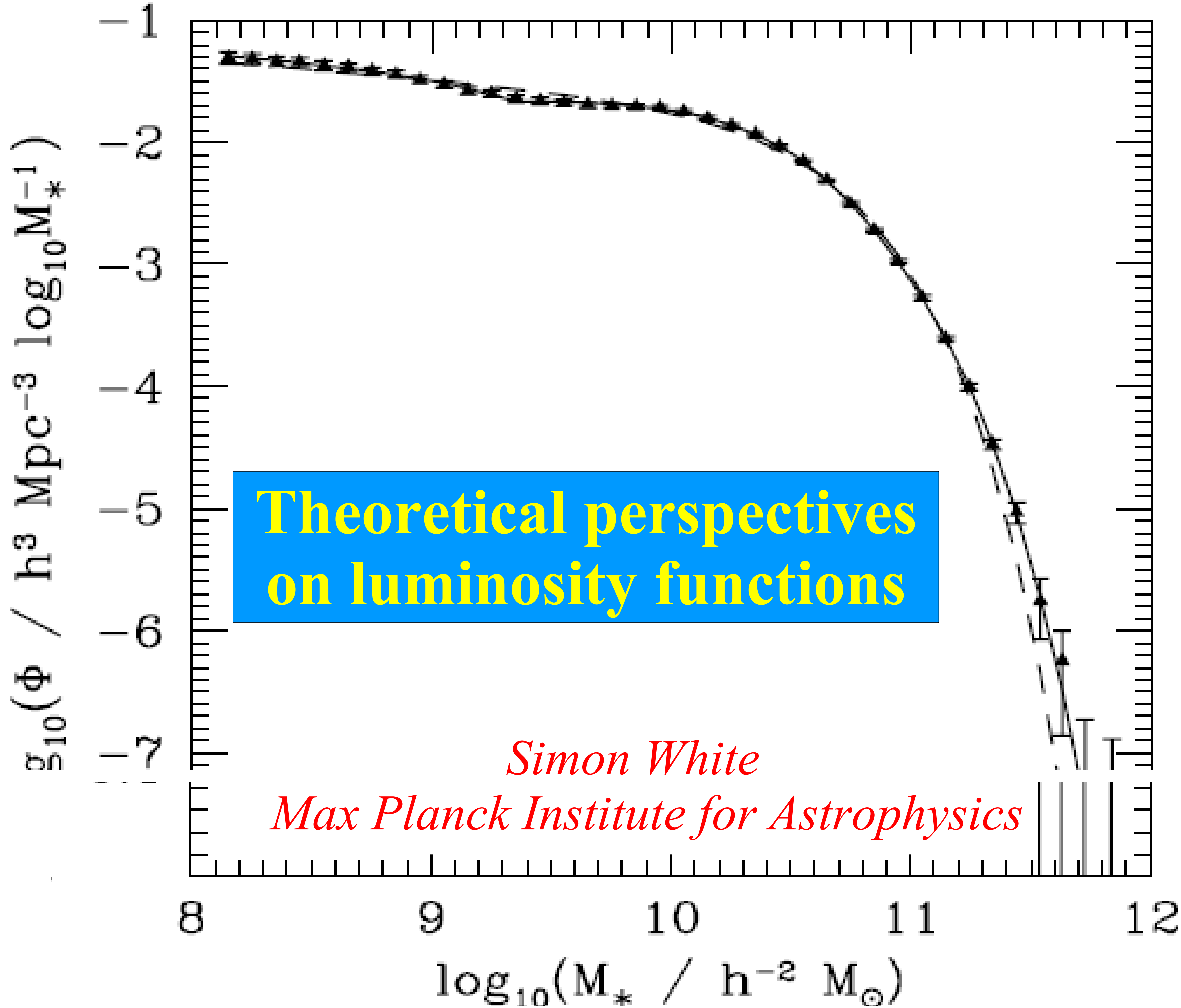

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This is not true!

It is one of the most *easily measurable* statistics but the luminosities depend on

- -- the λ sensitivity of telescope + filter + detector
- -- the redshift of the galaxy
- -- the way dust is mixed with the stars
- -- emission from HII regions and AGN
- -- the properties of minority populations (O/B or AGB stars)

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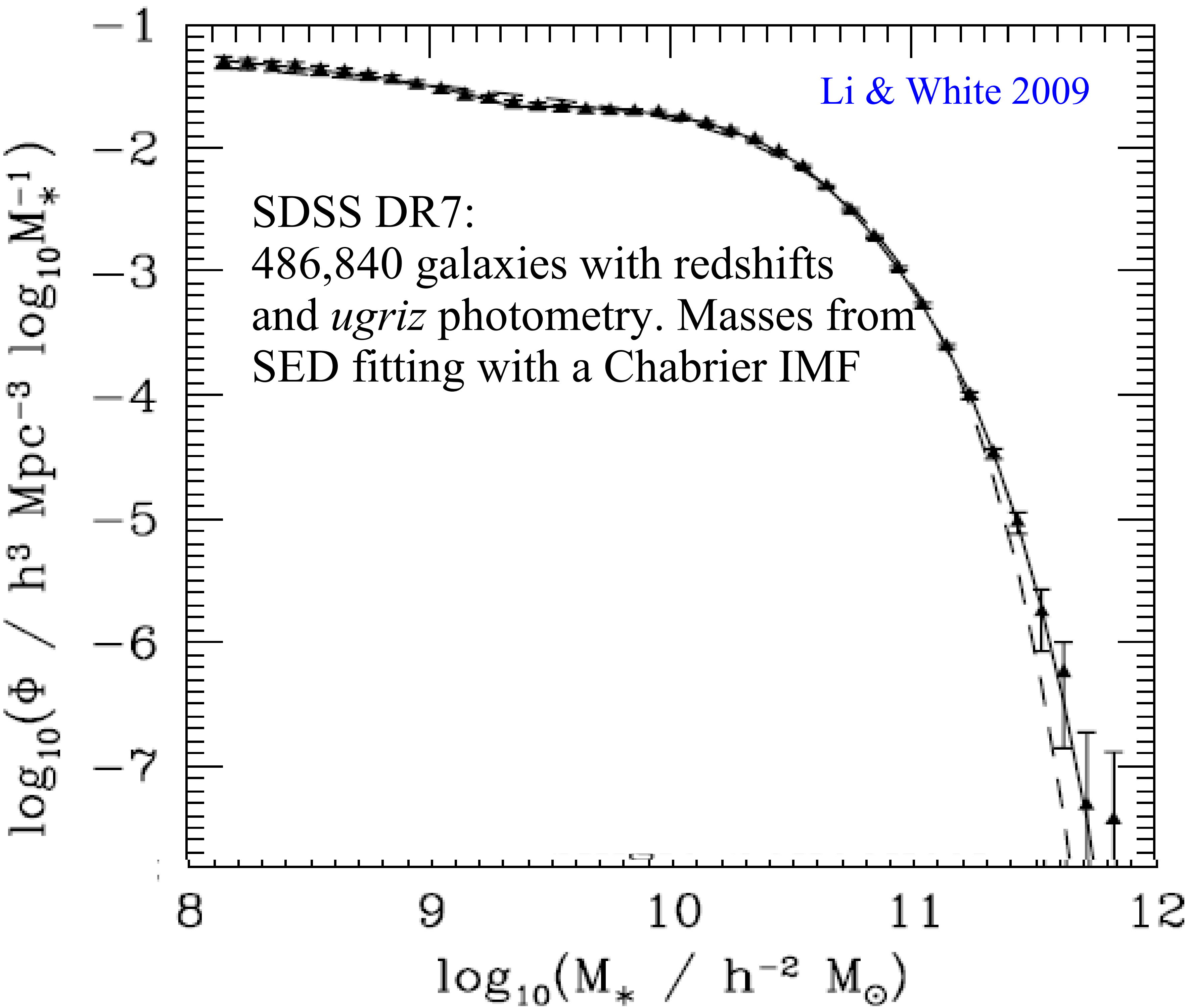
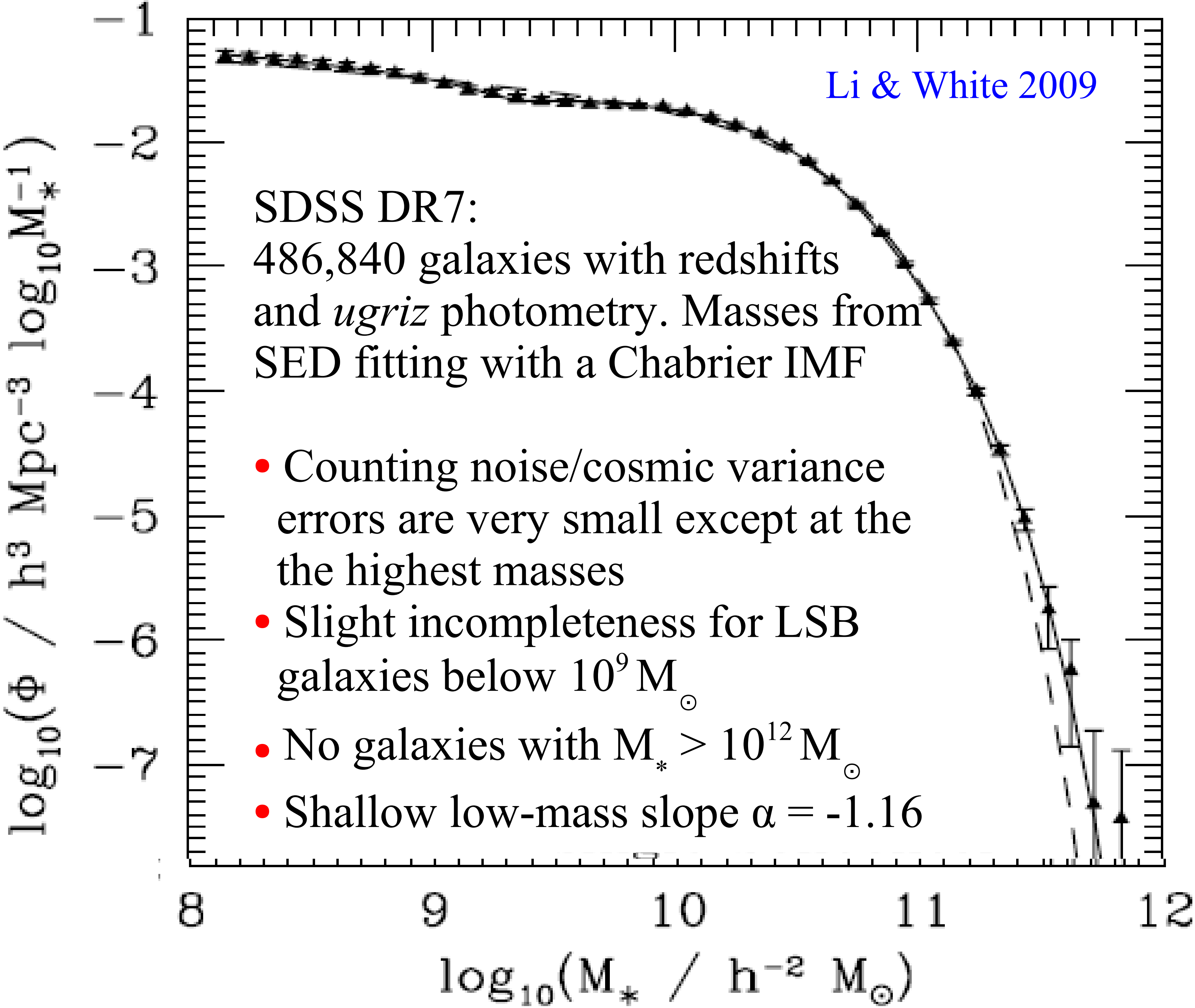
Stellar mass functions are almost as easily made from redshift surveys with good multi-colour photometry, but

- -- stars are a small and variable fraction of total galaxy mass...
- -- ... and also of the associated baryonic mass
- -- they are model-dependent


Li & White 2009
SDSS DR7:
486,840 galaxies with redshifts
and ugriz photometry. Masses from
SED fitting with a Chabrier IMF
$\log_{10}(\Phi\ /\ h^3\ \mathrm{Mpc}^{-3}\ \log_{10}M_*^{-1})$
$\log_{10}(M_*\ /\ h^{-2}\ M_\odot)$
−1
−2
−3
−4
−5
−6
−7
8
9
10
11
12


Li & White 2009
SDSS DR7:
486,840 galaxies with redshifts and *ugriz* photometry. Masses from SED fitting with a Chabrier IMF
• Counting noise/cosmic variance errors are very small except at the the highest masses
• Slight incompleteness for LSB galaxies below $10^9 M_\odot$
• No galaxies with $M_* > 10^{12} M_\odot$
• Shallow low-mass slope α = -1.16
−1
−2
−3
−4
−5
−6
−7
8
9
10
11
12
$\log_{10}(\Phi \ / \ h^3 \ \mathrm{Mpc}^{-3} \ \log_{10} M_*^{-1})$
$\log_{10}(M_* \ / \ h^{-2} \ M_\odot)$

The SDSS mass function is well fit by a Schechter model with

$$\log_{10}(m_* / h^{-2}\, M_\odot) = 10.525 \pm 0.005$$

$$\alpha = -1.155 \pm 0.008$$

$$\Phi_* = 0.0083 \pm 0.0002\ h^3\ \mathrm{Mpc}^{-3}$$

Counting noise and large-scale structure are no longer important sources of uncertainty. Incompleteness only affects the lowest masses. The principal remaining systematic uncertainties are:

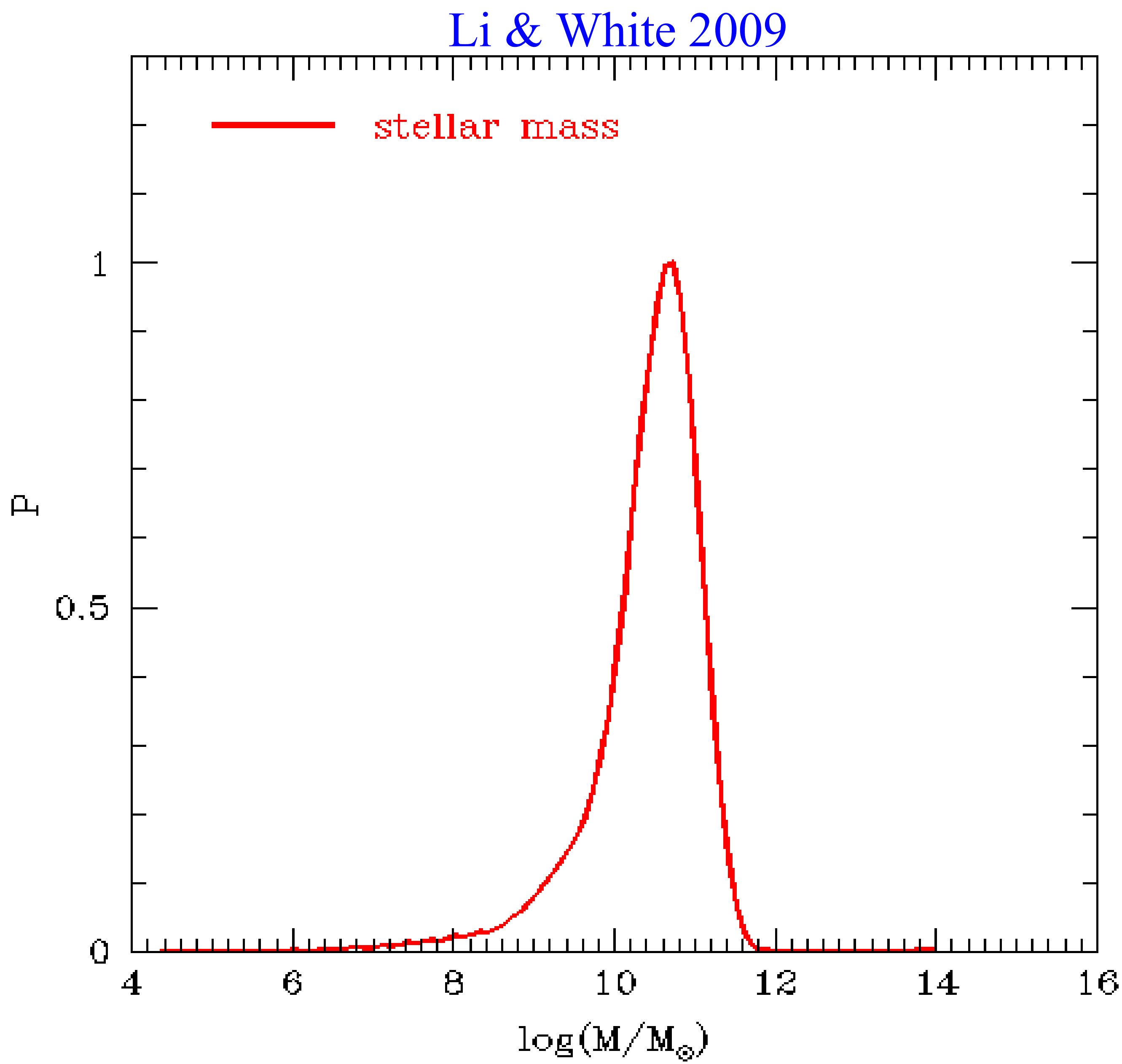
(i) the IMF
(ii) the conversion SED $\longrightarrow$ M/L

For given IMF (ii) appears small (systematic < 0.1 dex) as judged by agreement of different published conversion schemes.

This mass function $\longrightarrow$ $\rho_* = 3.14 \pm 0.10 \times 10^8\ h\ M_\odot\ \mathrm{Mpc}^{-3}$

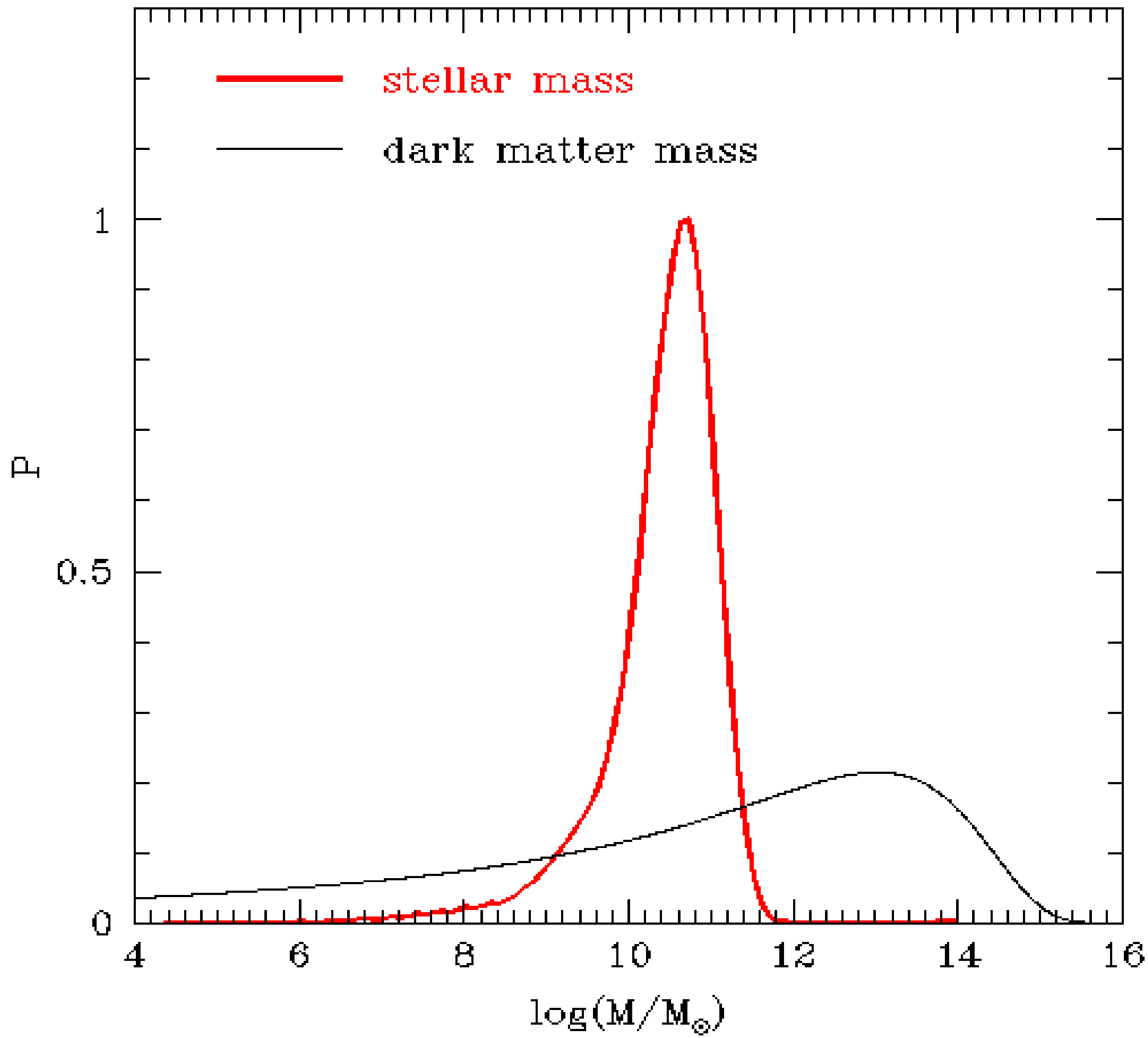
In the WMAP5 cosmology only 3.5% of baryons are in stars!

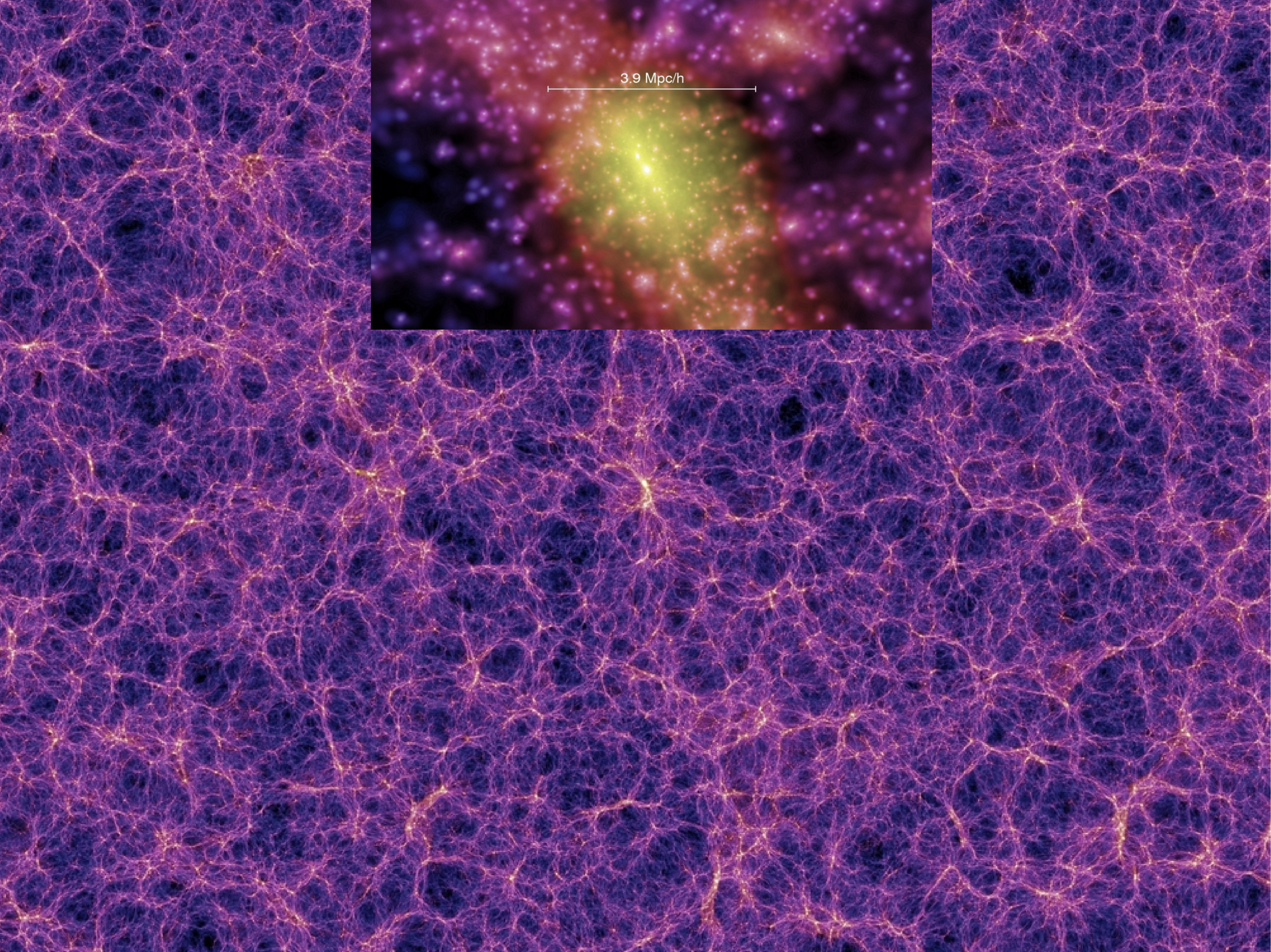
Most stars are in galaxies with similar stellar mass to the Milky Way



Most stars are in galaxies with similar stellar mass to the Milky Way
Dark matter (and baryons) are *much* more broadly distributed across halo mass in the WMAP5 cosmology

Li & White 2009




3.9 Mpc/h

A counting argument relating halo and galaxy masses

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

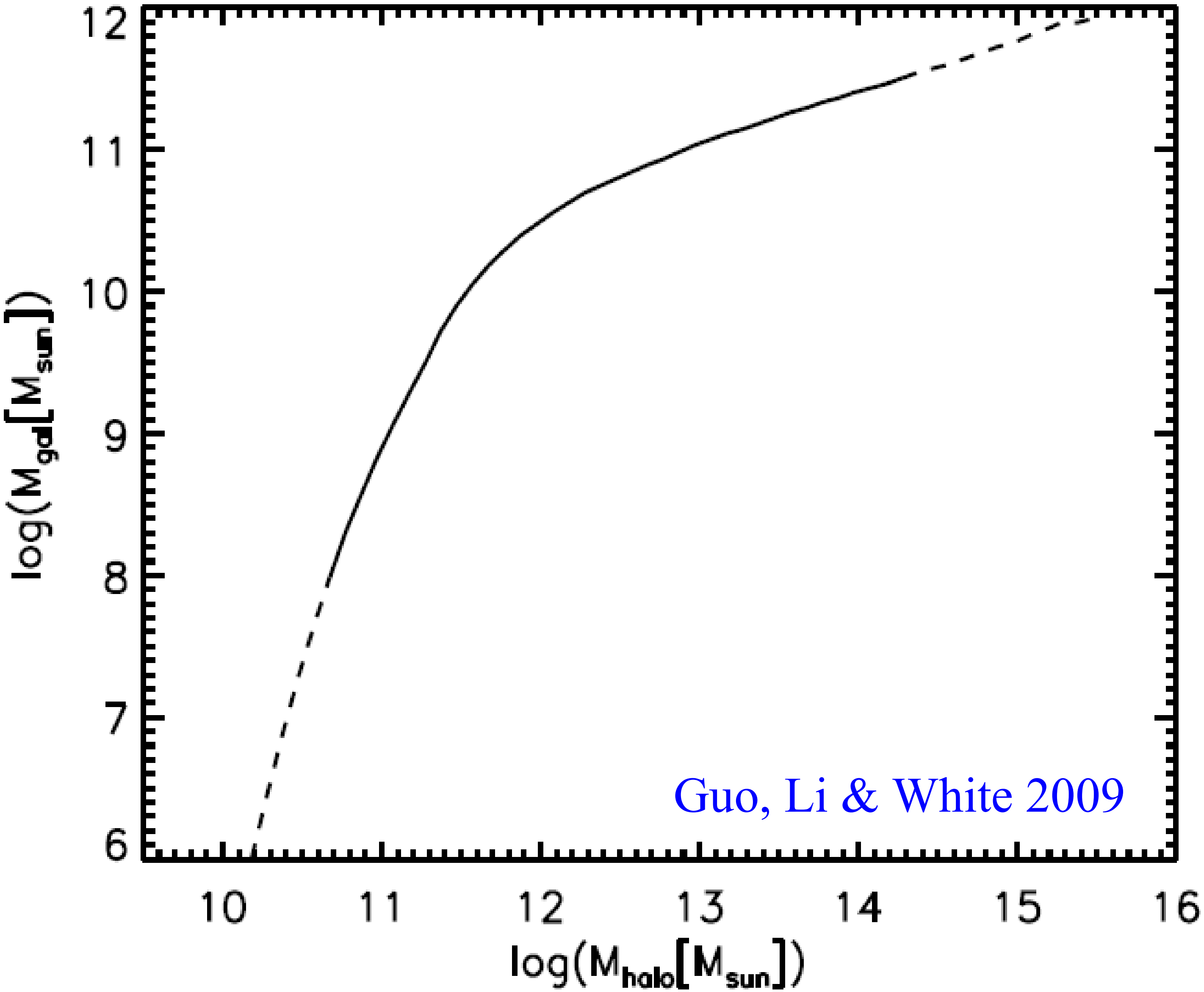
The Millennium and MS-II simulations allow all halos/subhalos massive enough to host z=0 galaxies to be identified

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

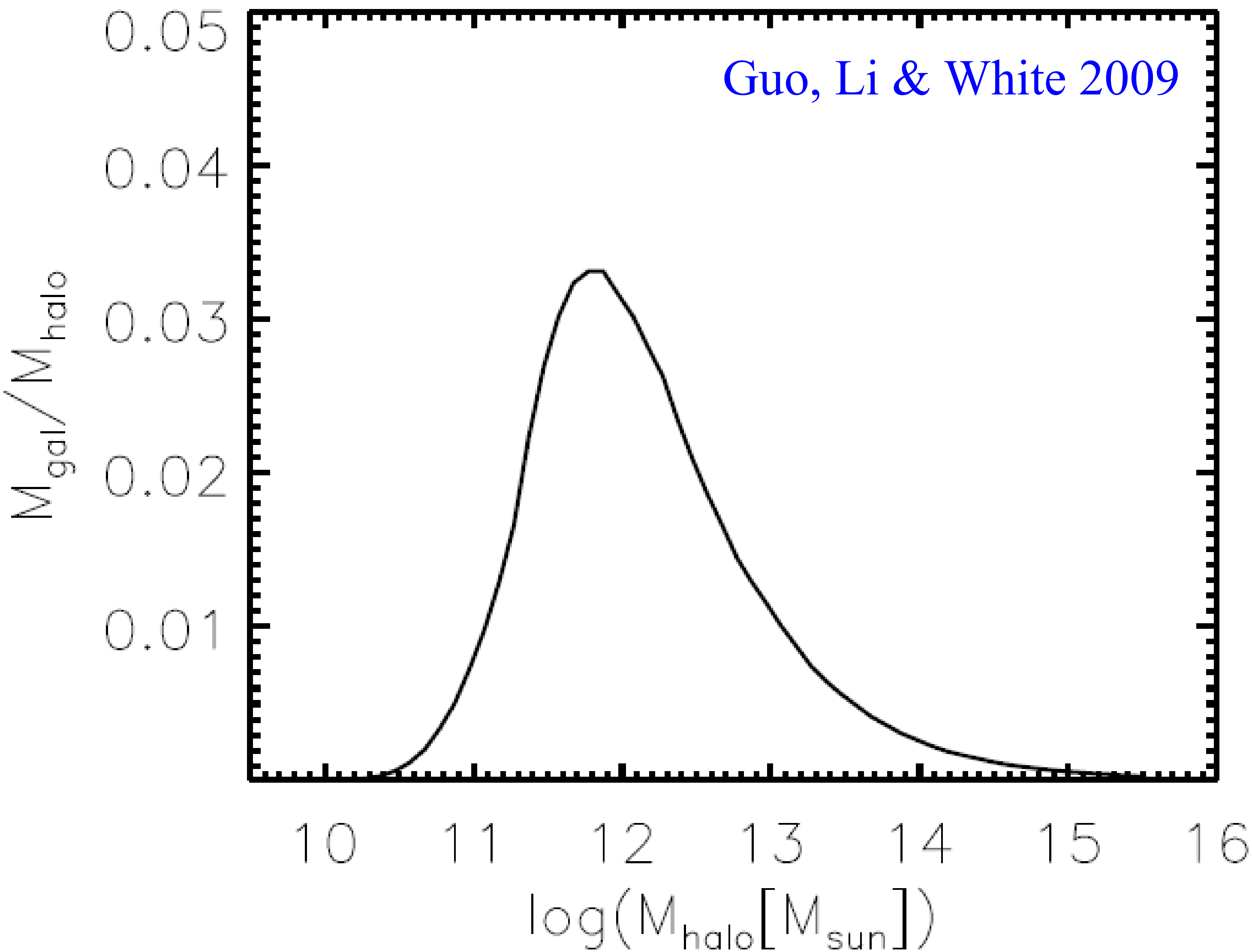
The simulations then give the halo/subhalo abundance, $n(>M_{h,max})$

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

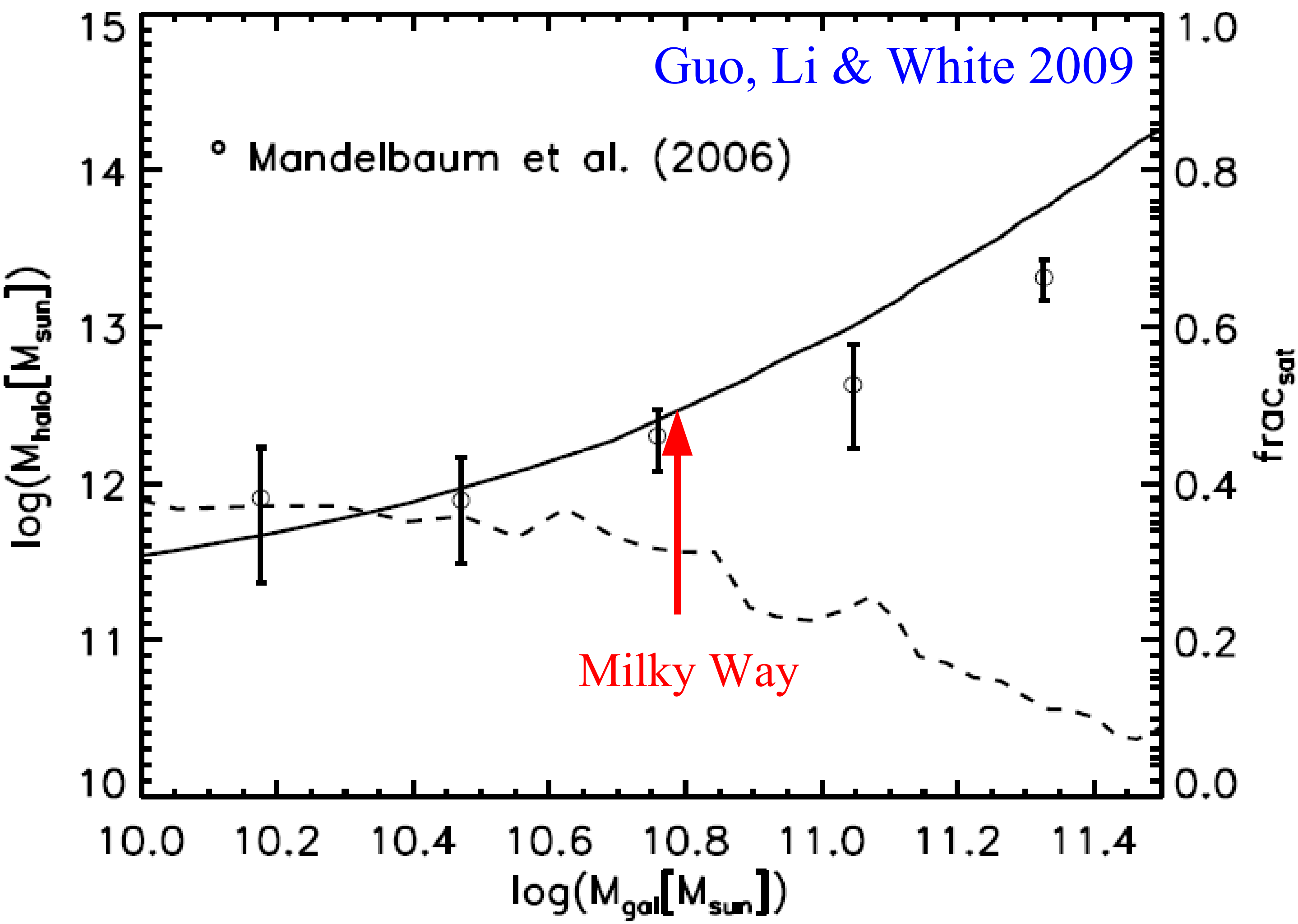
We can then derive $M_*(M_{h,max})$ by setting $n(>M_*) = n(>M_{h,max})$



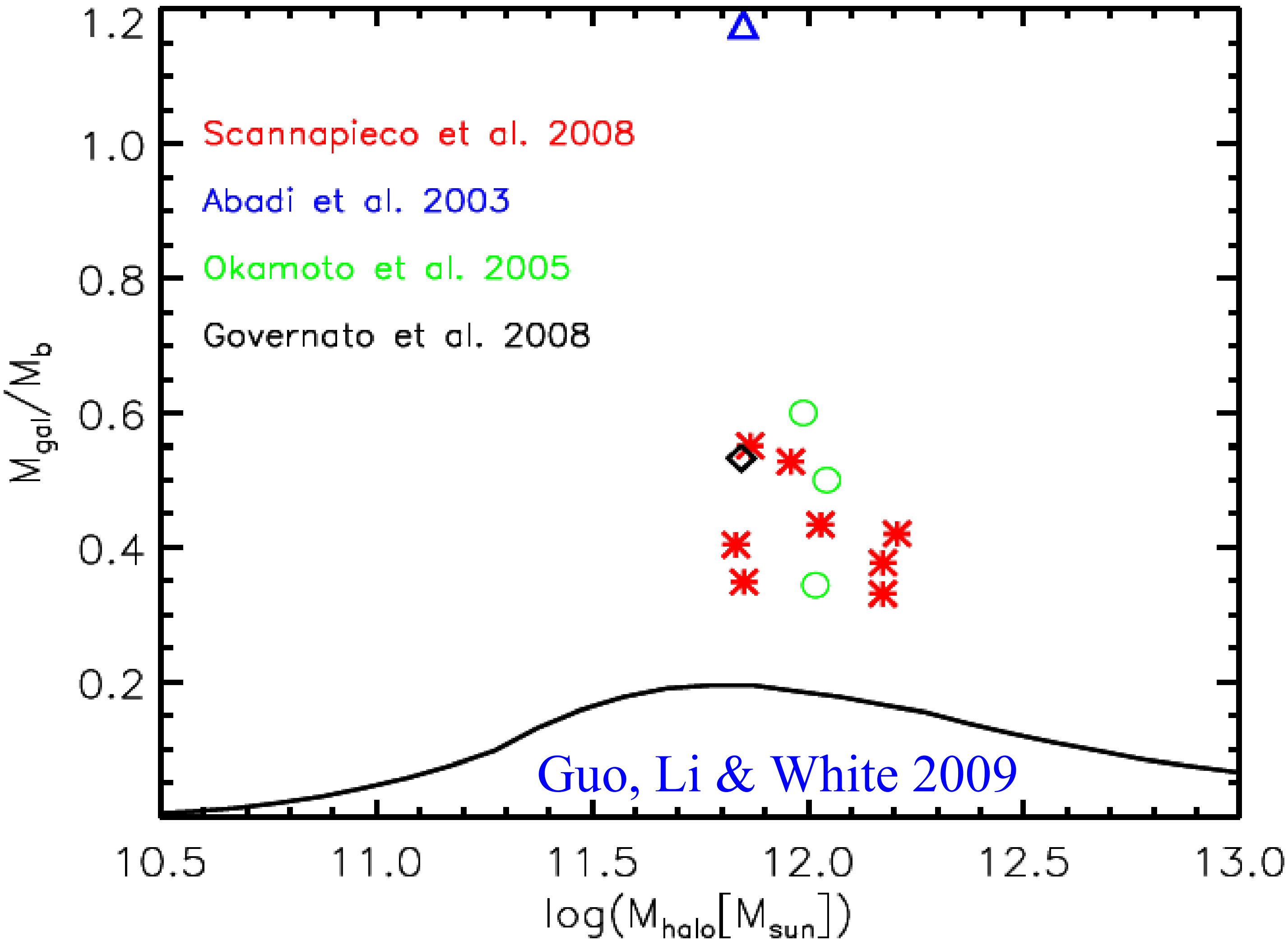
- The stellar mass of the central galaxy increases rapidly with halo mass at small halo mass, but slowly at large halo mass
- The characteristic halo mass at the bend is 5 x 10^{11} $M_{\odot}$



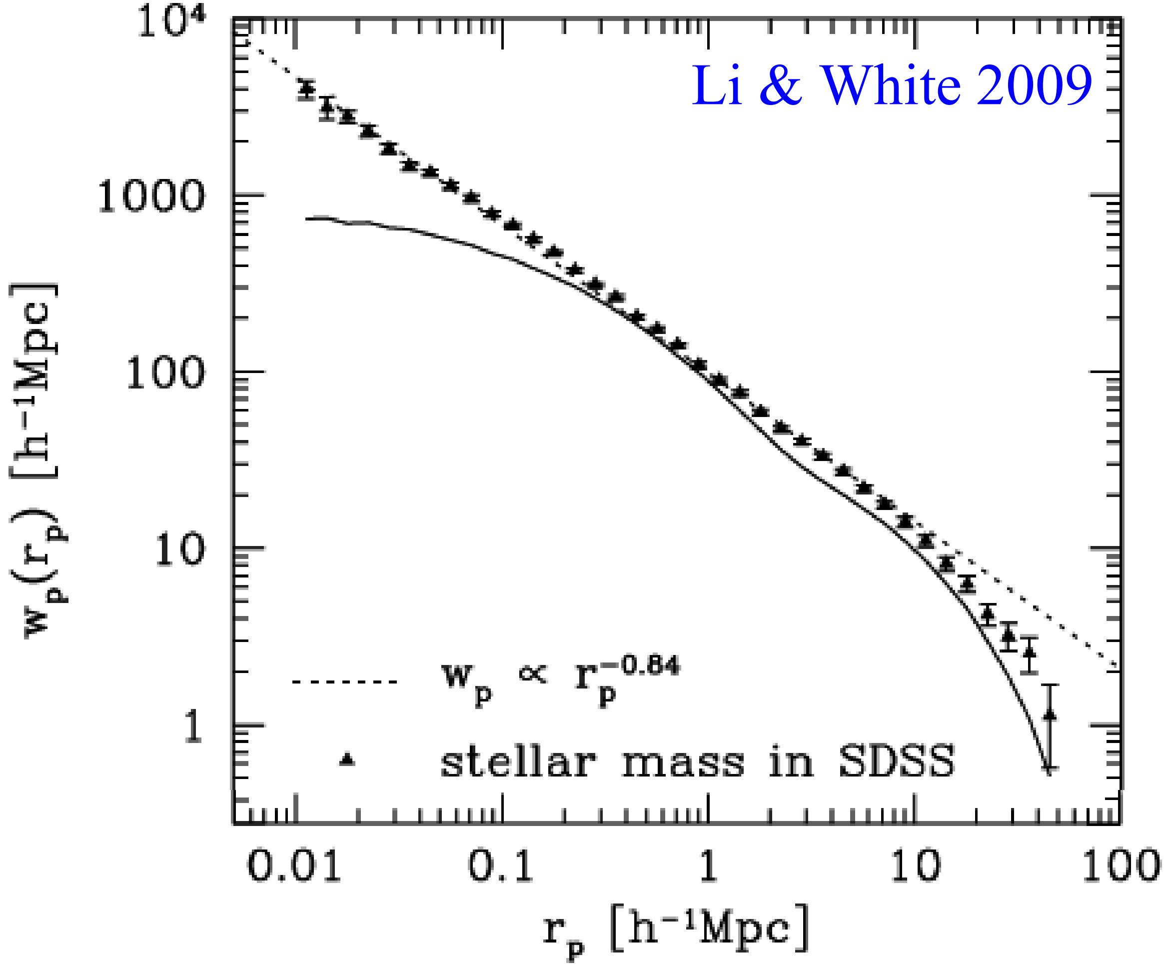
- The maximum halo mass fraction in central galaxy stars is 3.5%
- This is attained for halos similar in mass to the Milky Way's halo
- The fraction drops very rapidly to higher and lower masses



- The (maximum) halo masses inferred as a function of stellar mass agree well with those inferred from galaxy-galaxy lensing
- For $M_* = 6 \times 10^{10}\ M_\odot$ the Milky Way should have $M_h = 2 \times 10^{12}\ M_\odot$
- For $M_h = 1.0 \times 10^{12}\ M_\odot$ it should have $M_* = 3.5 \times 10^{10}\ M_\odot$



- Galaxy formation efficiency is: $\varepsilon = M_* / (\Omega_b M_{h,max} / \Omega_{bm})$
- This *maximises* at about 20%
- It is much lower than in all current galaxy formation simulations
- In the Milky Way about $2 \times 10^{11} M_\odot$ of baryons are "missing"



Stellar masses for all SDSS galaxies make it possible to measure the mass-weighted autocorrelation of *stars* in the local universe

- This is insensitive to the IMF or other mass scale uncertainties
- It has *rms* scatter of 7% about a power law for 10 kpc < r < 10 Mpc
- This is quite different than predicted for dark matter or baryons

Multi-colour local luminosity functions thus show

- that galaxy formation has been very *inefficient*. Only about 3.5% of all baryons have been turned into stars

- that this efficiency is a very *strong* function of halo mass. It maximises at about 20% for halos like the Milky Way's

- that $>10^{11}\ M_\odot$ of baryons are missing from the MW+halo system

- that even apparently realistic galaxy formation simulations fail to match the observed efficiencies by factors of 2 to 6

- that star formation processes cause $\xi(r)$ for the stars to be a power law, and so quite different in shape from $\xi(r)$ for mass or baryons