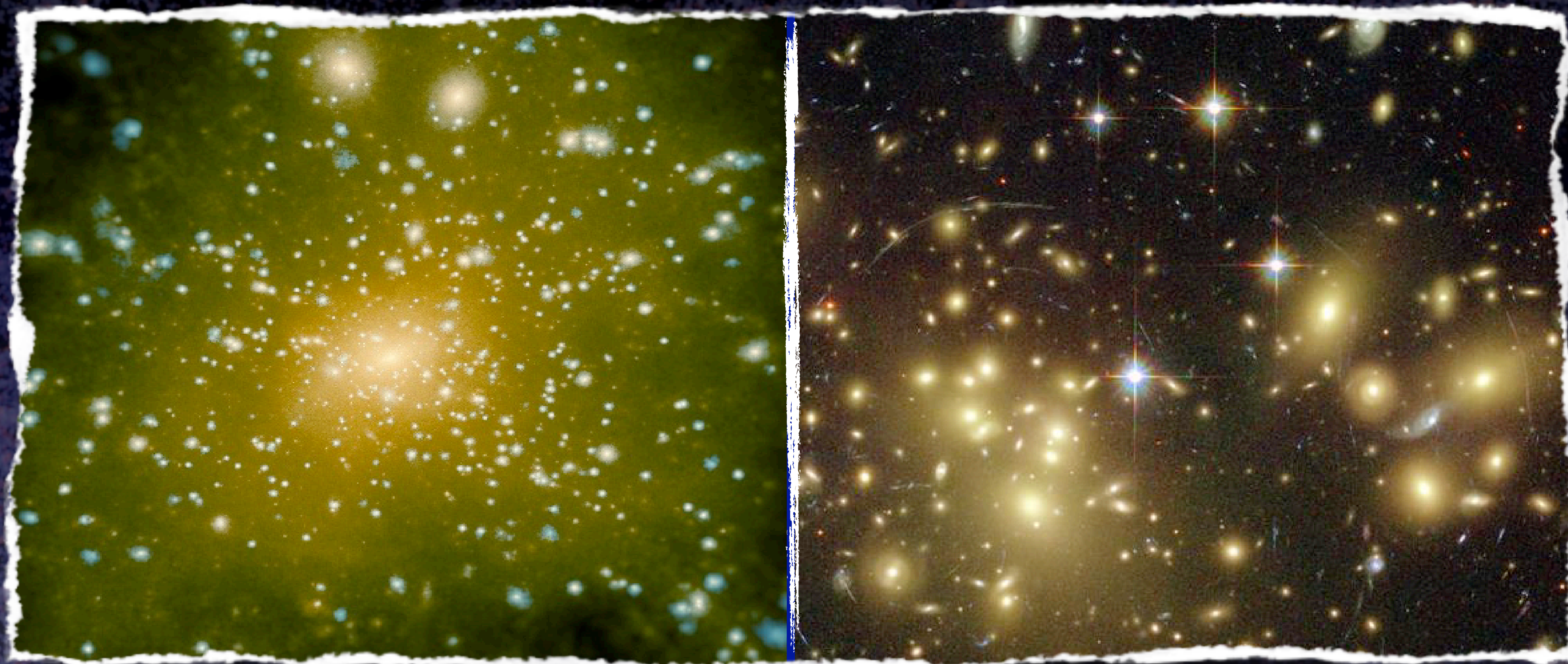
Constraining Cosmological Parameters with Galaxy Clustering and Galaxy-Galaxy Lensing



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In collaboration with:
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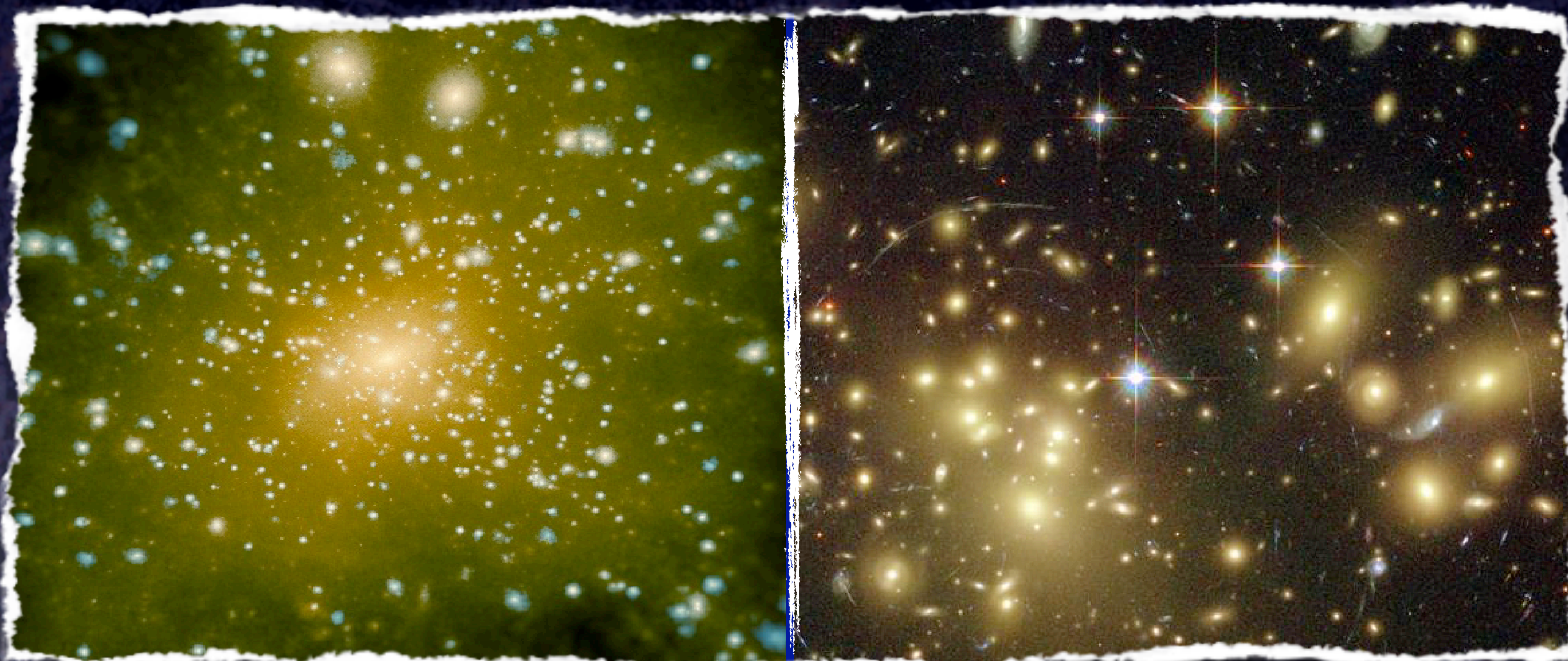
Houjun Mo (UMass), Xiaohu Yang (SHAO)

Introduction: Motivation & Goal

Our main goal is to study the Galaxy-Dark Matter connection;
i.e., what galaxy lives in what halo?

- To constrain the physics of Galaxy Formation
- To constrain cosmological parameters



Different Methods to Constrain Galaxy-Dark Matter Connection:

- Large Scale Structure
- Galaxy-Galaxy Lensing
- Satellite Kinematics
- Abundance Matching

The Conditional Luminosity Function

The CLF $\Phi(L|M)$ describes the average number of galaxies of luminosity L that reside in a halo of mass M.

$$\Phi(L) = \int \Phi(L|M)\, n(M)\, \mathrm{d}M$$

$$\langle L \rangle_M = \int \Phi(L|M)\, L\, \mathrm{d}L$$

$$\langle N \rangle_M = \int_{L_{\rm min}}^{\infty} \Phi(L|M) \mathrm{d}L$$

- Describes occupation statistics of dark matter haloes
- Is direct link between galaxy luminosity function and halo mass function
- Contains information on average relation between light and mass

see Yang, Mo & vdBosch 2003

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Galaxy luminosity function

Halo mass function

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The CLF Model

We split the CLF in a central and a satellite term:

$$\Phi(L|M) = \Phi_c(L|M) + \Phi_s(L|M)$$

For centrals we adopt a log-normal distribution:

$$\Phi_c(L|M)\mathrm{d}L = \frac{1}{\sqrt{2\pi}\sigma_c} \exp\left[-\left(\frac{\ln(L/L_c)}{\sqrt{2}\sigma_c}\right)^2\right] \frac{\mathrm{d}L}{L}$$

For satellites we adopt a modified Schechter function:

$$\Phi_s(L|M)\mathrm{d}L = \frac{\phi_s}{L_s}\left(\frac{L}{L_s}\right)^{\alpha_s} \exp\left[-(L/L_s)^2\right]\mathrm{d}L$$

Note: $\{L_c, L_s, \sigma_c, \phi_s, \alpha_s\}$ all depend on halo mass

Free parameters are constrained by fitting data.

Use Monte-Carlo Markov Chain to sample posterior distributions of free parameters, and to put confidence levels on derived quantities

Large Scale Structure: Definitions

Distribution of galaxies is conveniently parameterized via the two-point correlation function, $\xi(r)$, which can be measured using large galaxy redshift surveys (2dFGRS, SDSS, etc.)

$$\xi(r) = \frac{DD(r)\mathrm{d}r}{RR(r)\mathrm{d}r} - 1$$

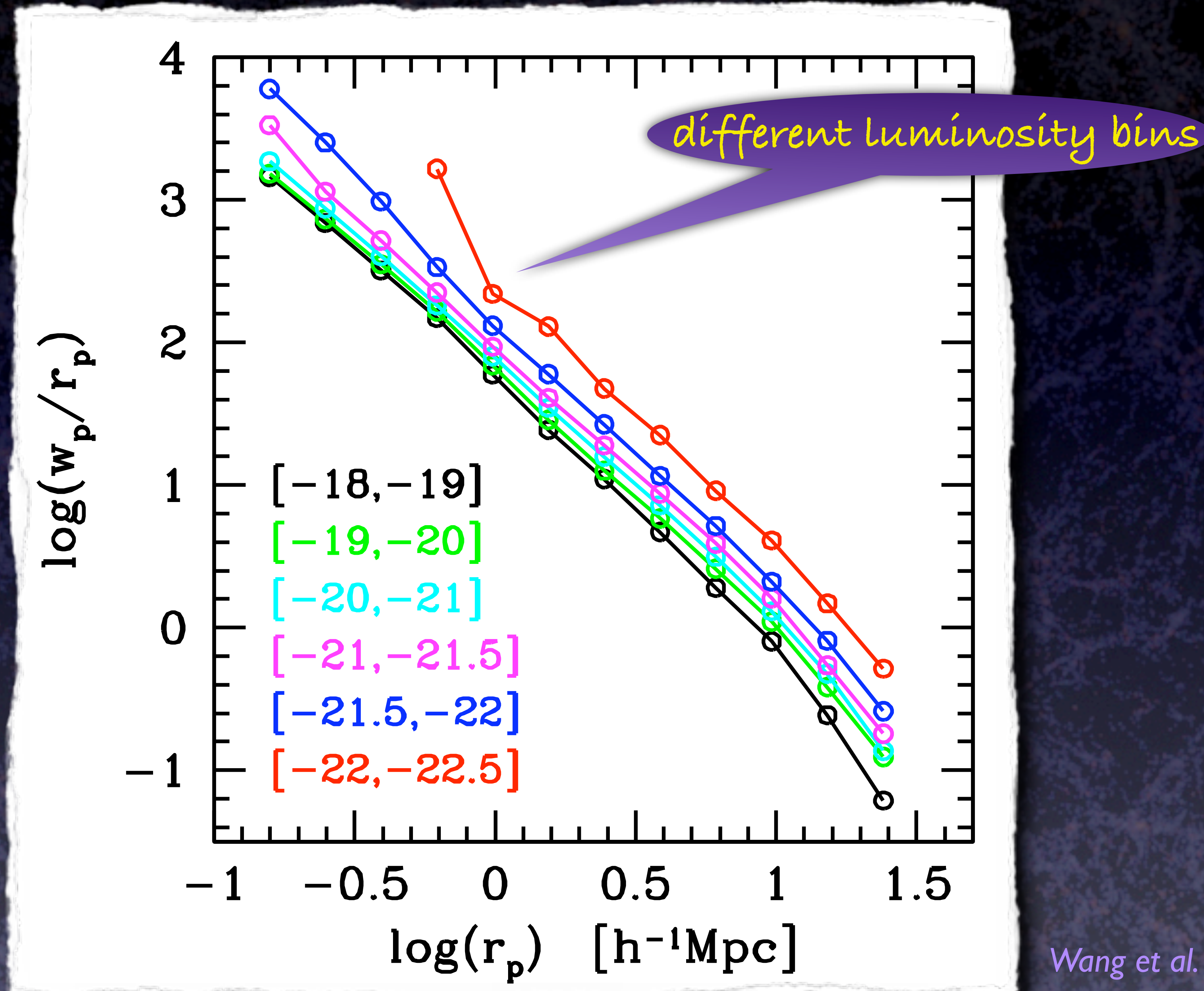
$\xi(r)$ is the Fourier Transform of the power spectrum

Clustering strength is typically expressed via the correlation length, r_0, defined by $\xi(r_0) = 1$

Because of redshift space distortions, what one actually measures is the projected two-point correlation function,

$$w_{\mathrm{p}}(r_{\mathrm{p}}) = 2\int_{r_{\mathrm{p}}}^{\infty} \xi(r)\, \frac{r\,\mathrm{d}r}{(r^2 - r_{\mathrm{p}}^2)^{1/2}}$$

Large Scale Structure: The Data

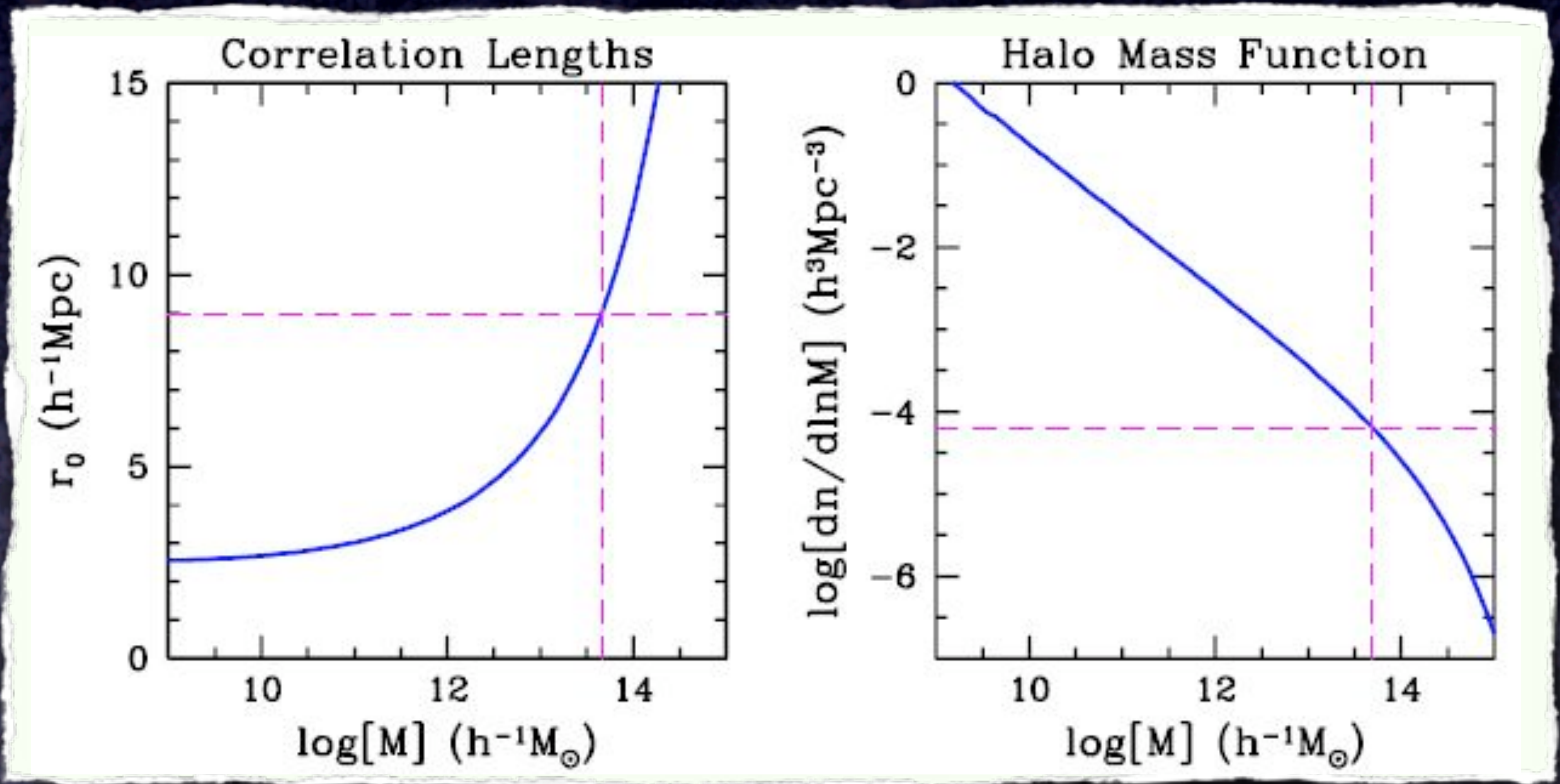


Wang et al. (2007)

More luminous galaxies are more strongly clustered

Occupation Statistics from Clustering

- Galaxies occupy dark matter halos
- CDM: more massive halos are more strongly clustered
- Clustering strength of given population of galaxies indicates the characteristic halo mass



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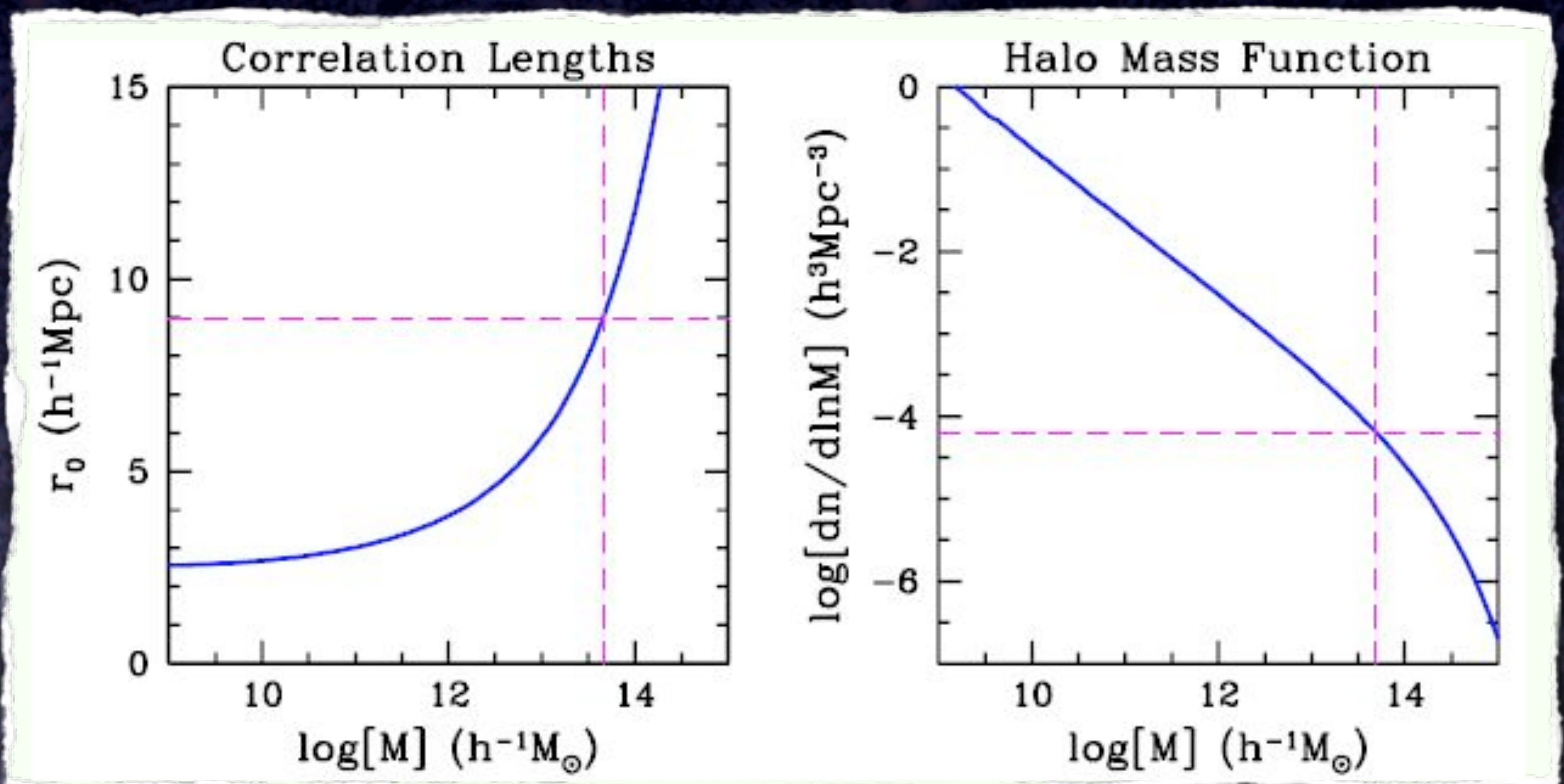

Measurements of $w_{\rm p}(r_{\rm p})$ constrain $\Phi(L|M)$

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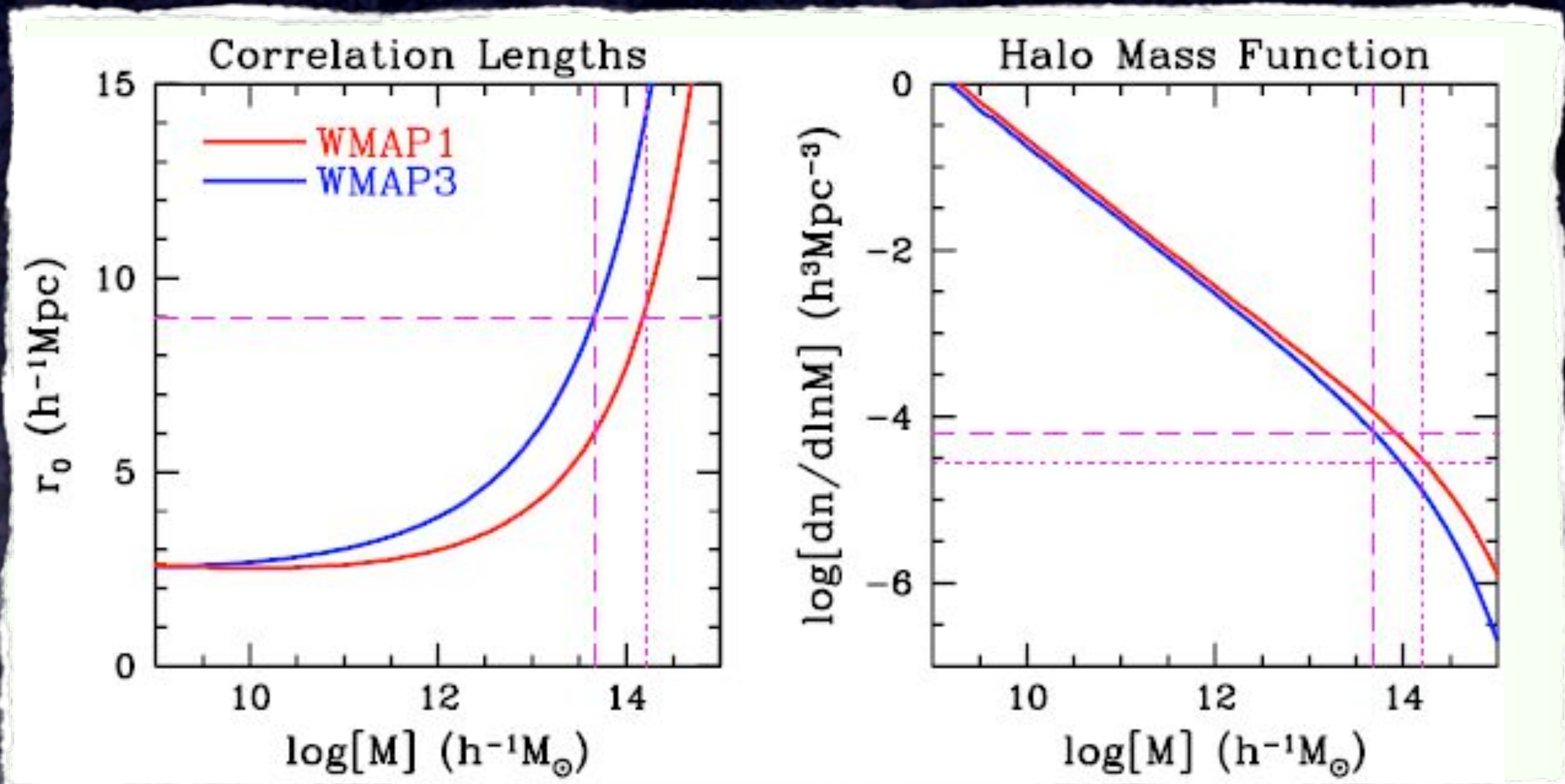


WMAP1

$\Omega_m = 0.30$

$\Omega_\Lambda = 0.70$

$\sigma_8 = 0.90$

WMAP3

$\Omega_m = 0.24$

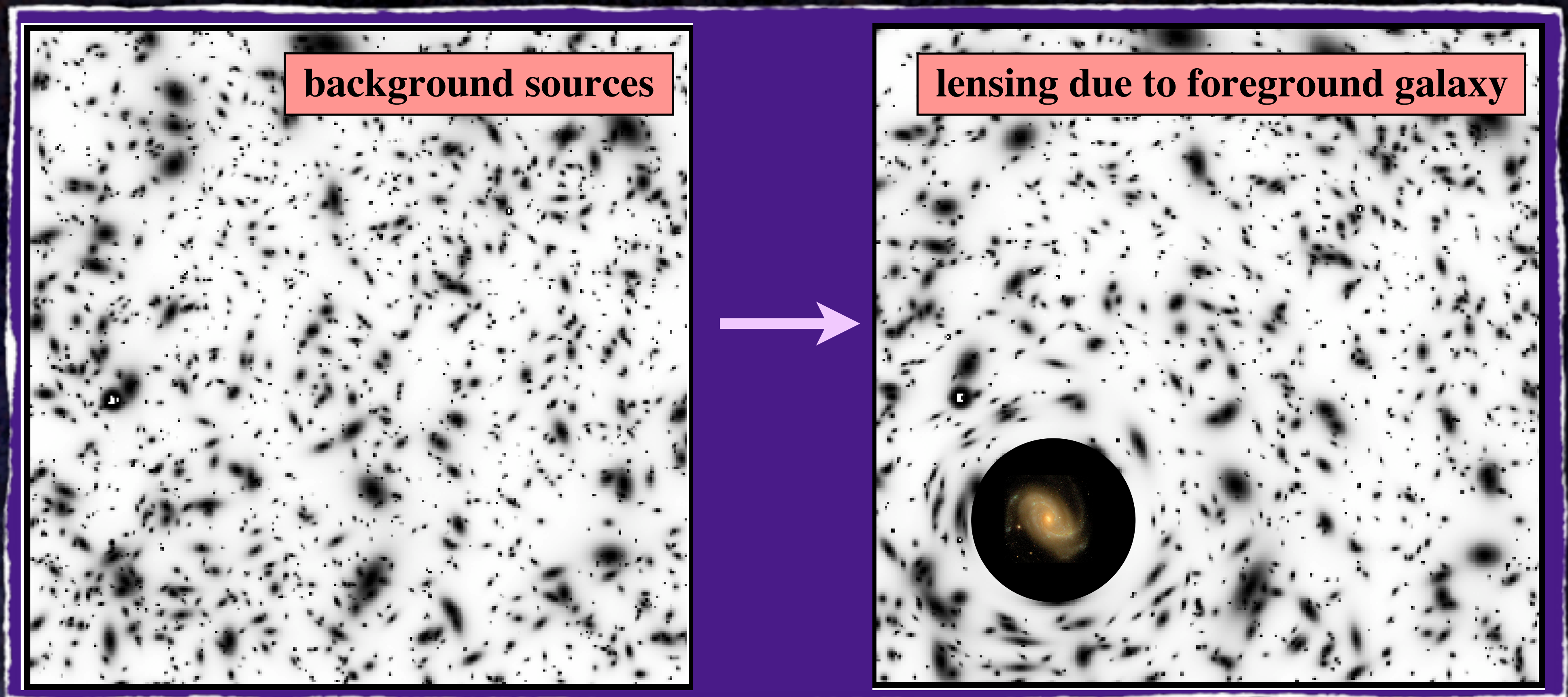
$\Omega_\Lambda = 0.76$

$\sigma_8 = 0.74$

...but, results depend strongly on cosmology.

Galaxy-Galaxy Lensing

The mass associated with galaxies lenses background galaxies



Lensing causes correlated ellipticities, the tangential shear, $\gamma_{\rm t}$, which is related to the excess surface density, $\Delta\Sigma$, according to

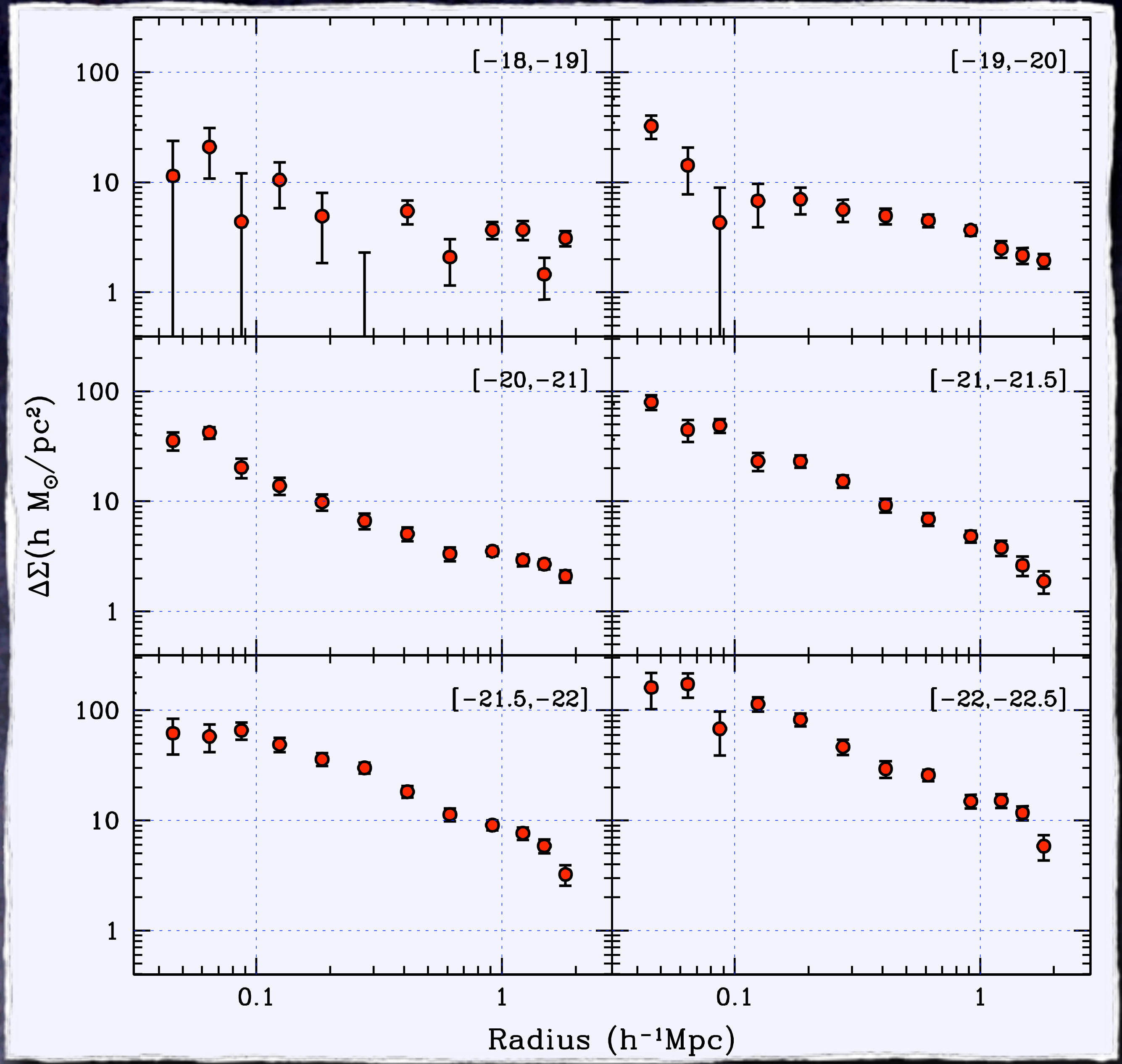
$$\gamma_{\rm t}(R)\Sigma_{\rm crit} = \Delta\Sigma(R) = \bar{\Sigma}(< R) - \Sigma(R)$$

$\Delta\Sigma$ is line-of-sight projection of galaxy-matter cross correlation

$$\Sigma(R) = \bar{\rho} \int_0^{D_{\rm s}} [1 + \xi_{\rm g,dm}(r)]\, {\rm d}\chi$$

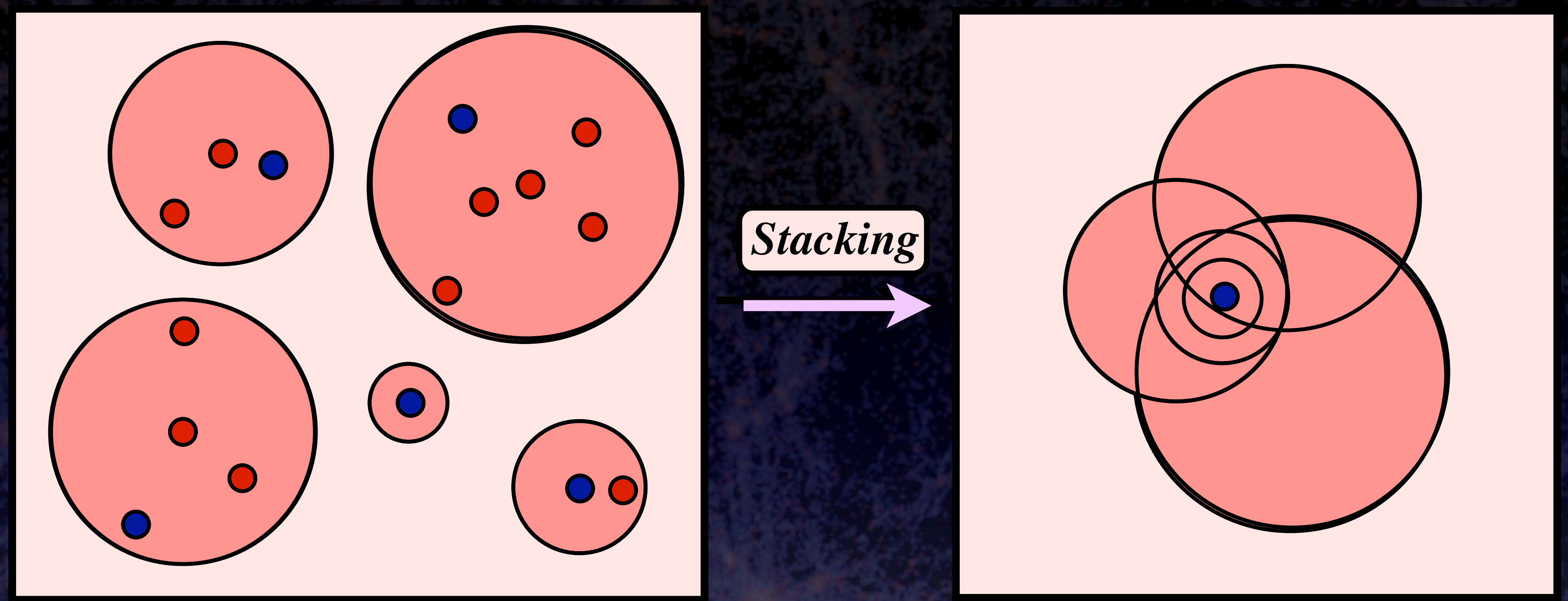
Galaxy-Galaxy Lensing: The Data

- Number of background sources per lens is limited
- Measuring shear with sufficient S/N requires stacking of many lenses
- $\Delta\Sigma(R|L_1, L_2)$ has been measured using the SDSS by Mandelbaum et al. 2006, using different bins in lens-luminosity



Mandelbaum et al. (2006)

How to interpret the signal?



Because of stacking the lensing signal is difficult to interpret

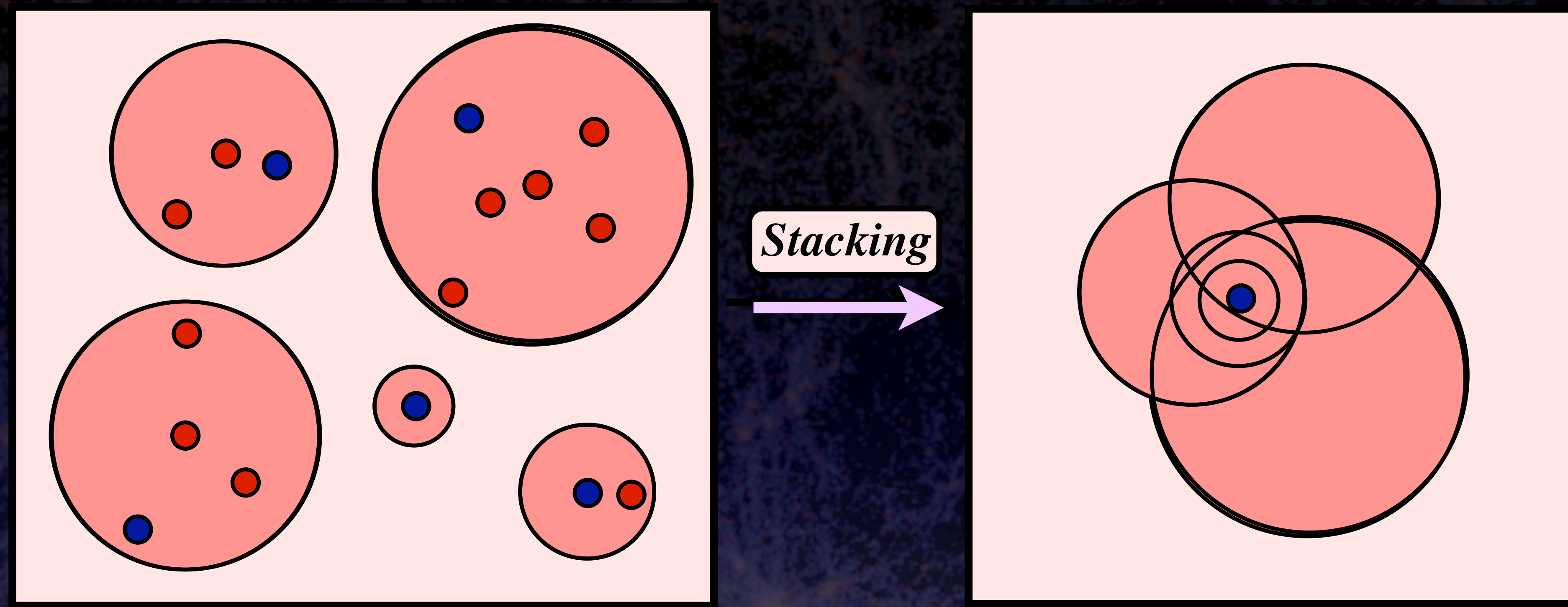
In order to model the data, what is required is:

$P_{\rm cen}(M|L)$ $P_{\rm sat}(M|L)$ $f_{\rm sat}(L)$

These can all be computed from the CLF...

For a given $\Phi(L|M)$ we can predict the lensing signal $\Delta\Sigma(R|L_1, L_2)$

How to interpret the signal?



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For a given $\Phi(L|M)$ we can predict the lensing signal $\Delta\Sigma(R|L_1, L_2)$

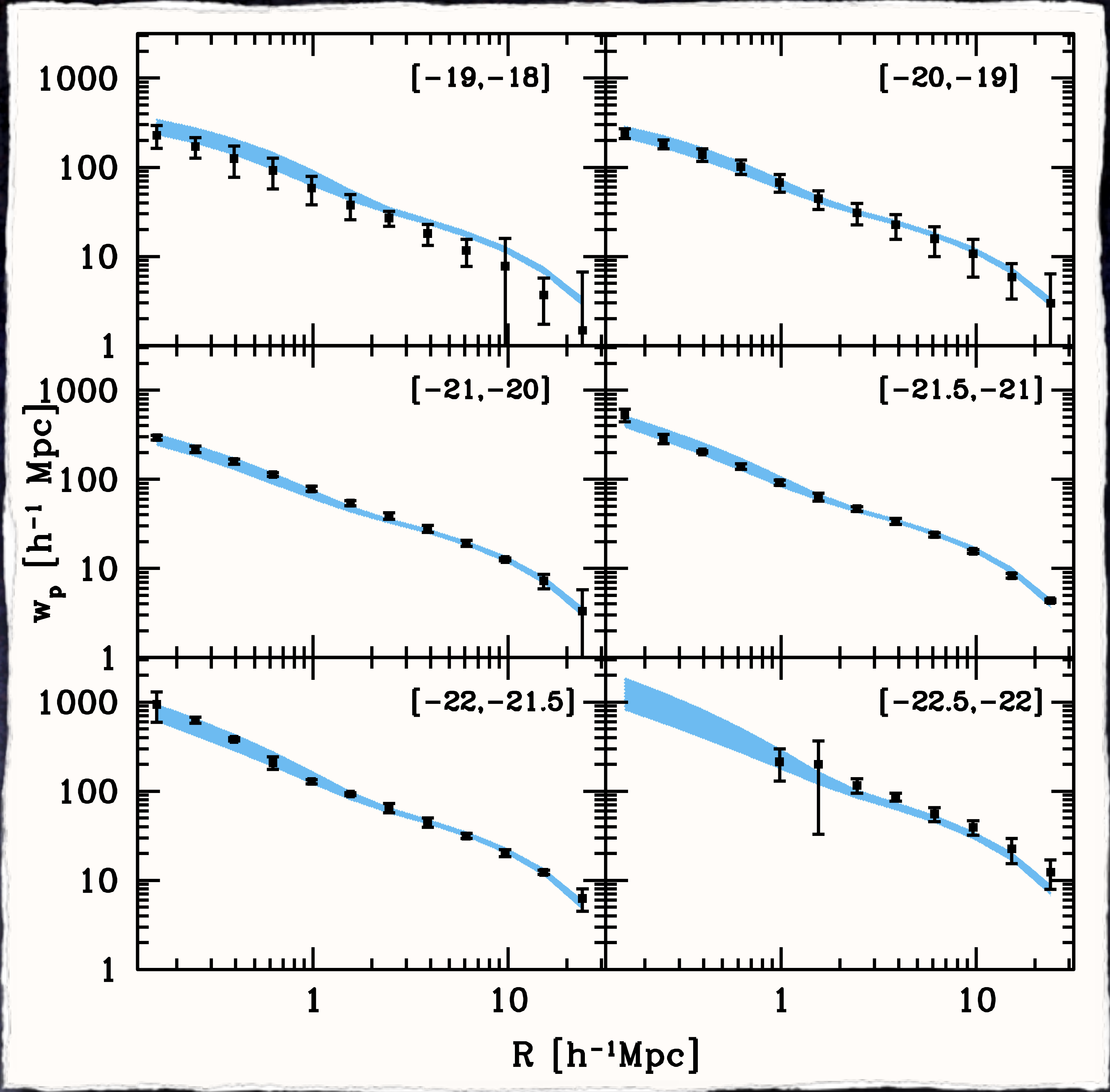
Combination of $w_{\rm p}(r_{\rm p})$ and $\Delta\Sigma(R|L_1, L_2)$ can constrain cosmology!

Fiducial Model

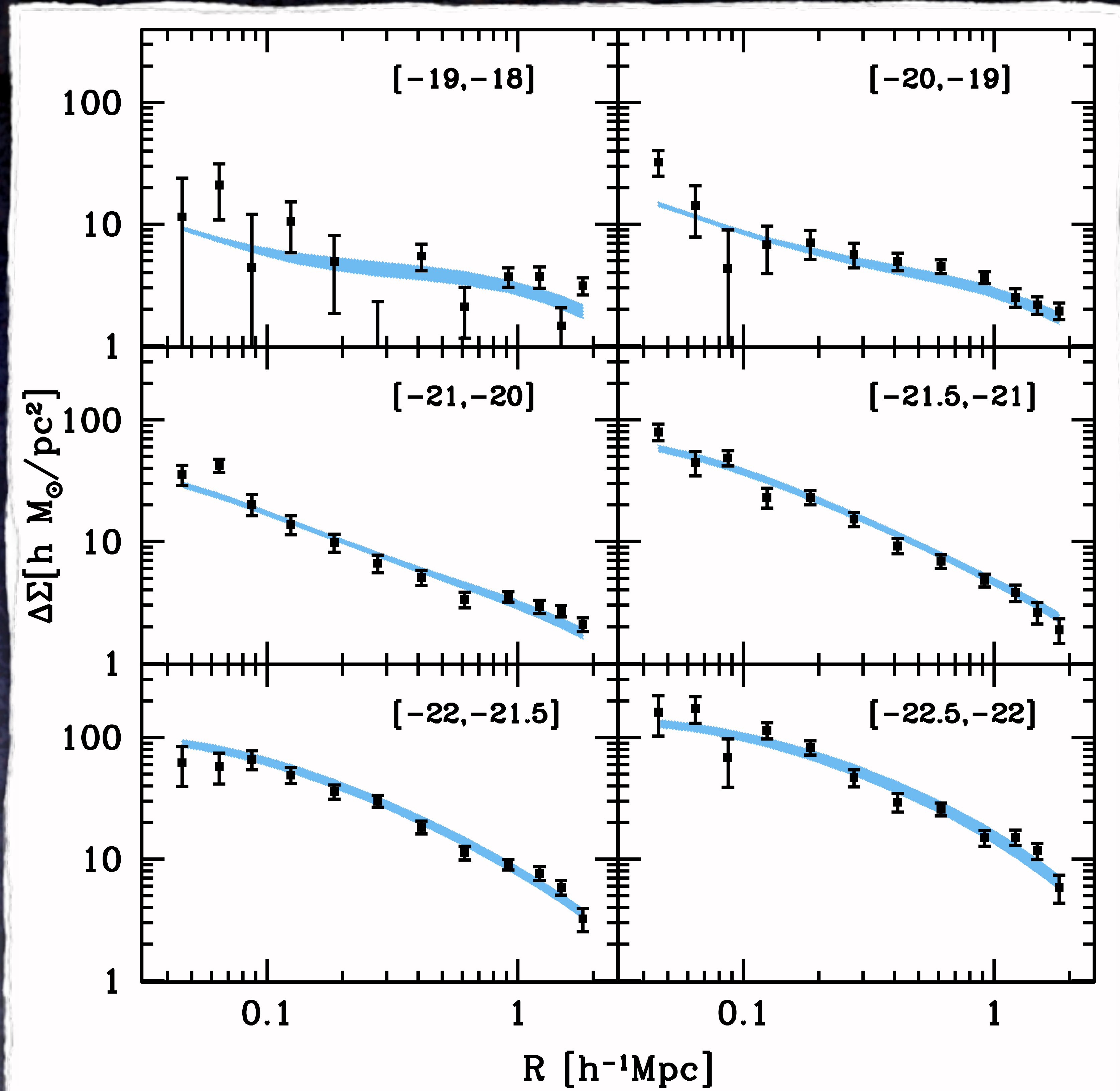
- Total of 13 free parameters:
  - 11 parameters to describe CLF
  - 2 cosmological parameters; $\Omega_{\rm m}$ and σ_8

  Total of 172 data points.
- All other cosmological parameters kept fixed at the best-fit WMAP5 values.
- Dark matter haloes follow NFW profile.
- Radial number density distribution of satellites follows that of dark matter particles.
- Halo mass function and halo bias function of Sheth & Tormen (1999).

Results: Clustering Data

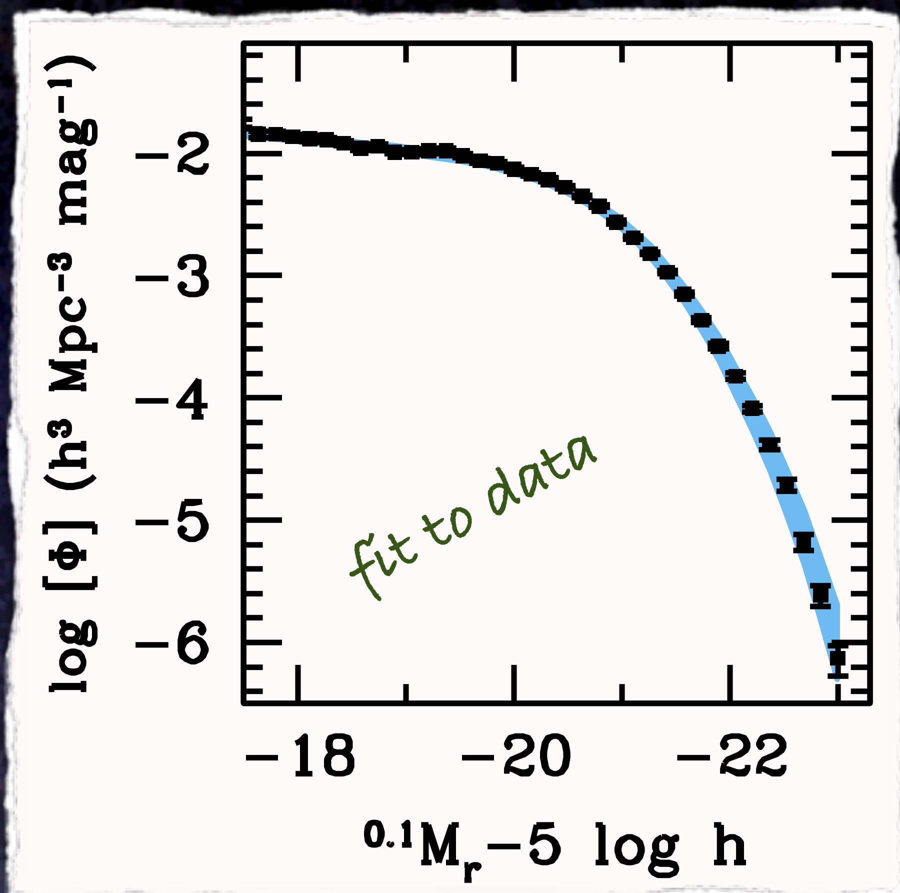


Results: Lensing Data

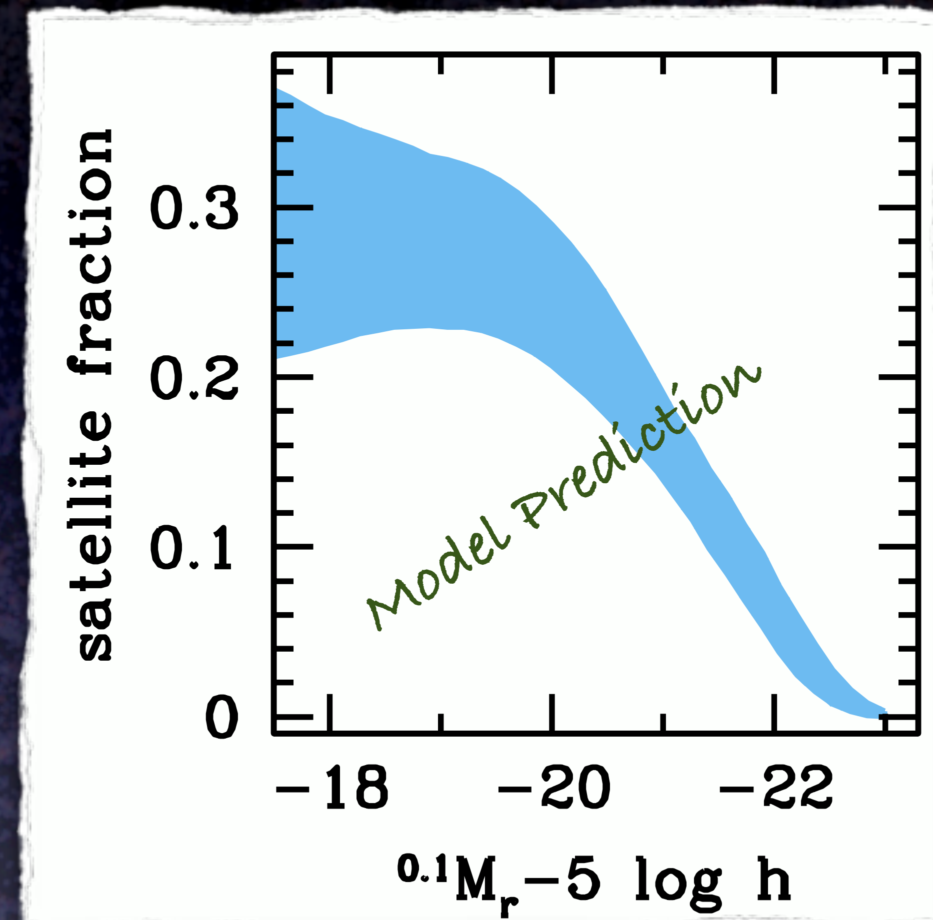


Luminosity Function & Satellite Fractions

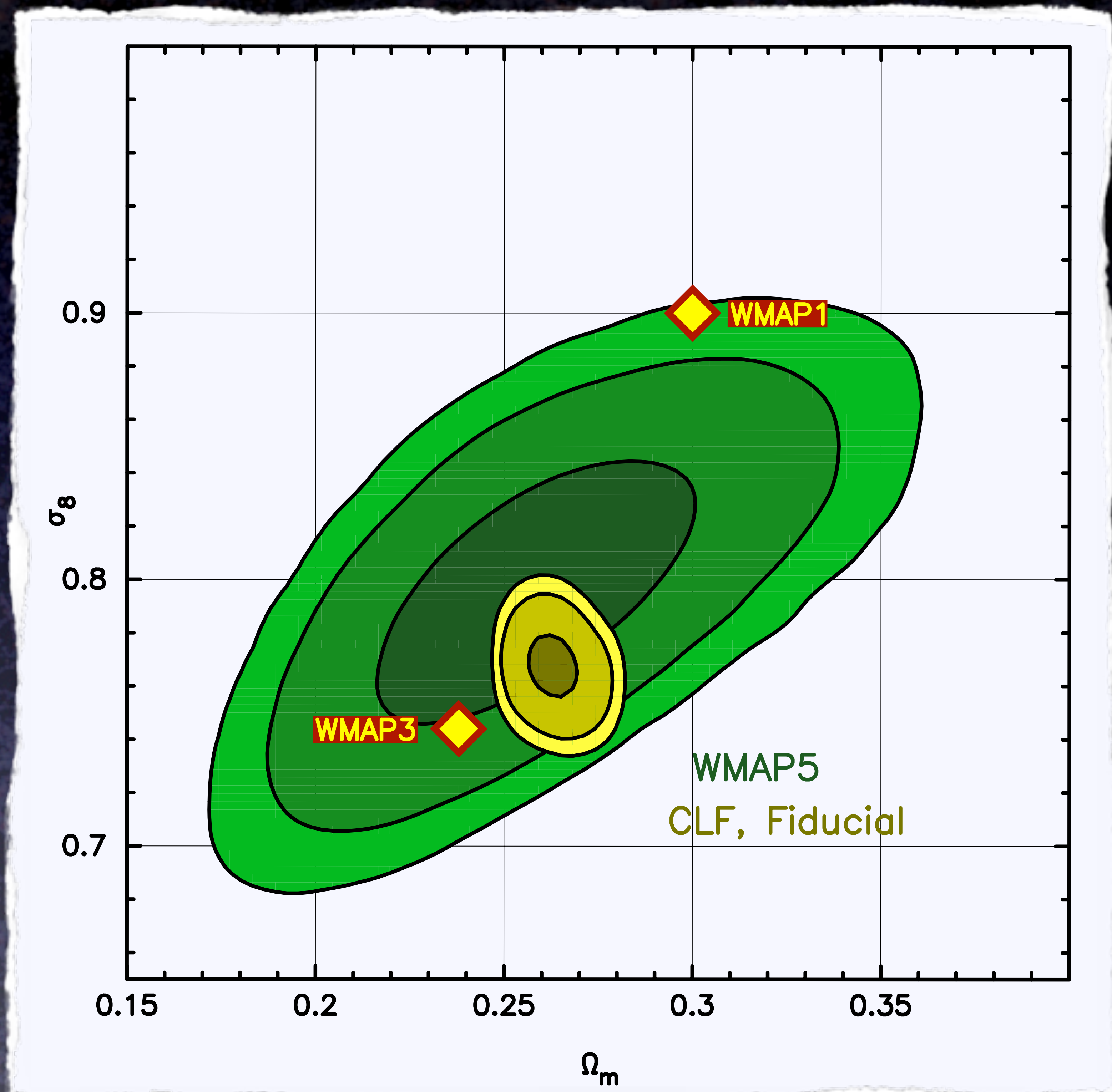
Luminosity Function



Satellite Fractions



Cosmological Constraints



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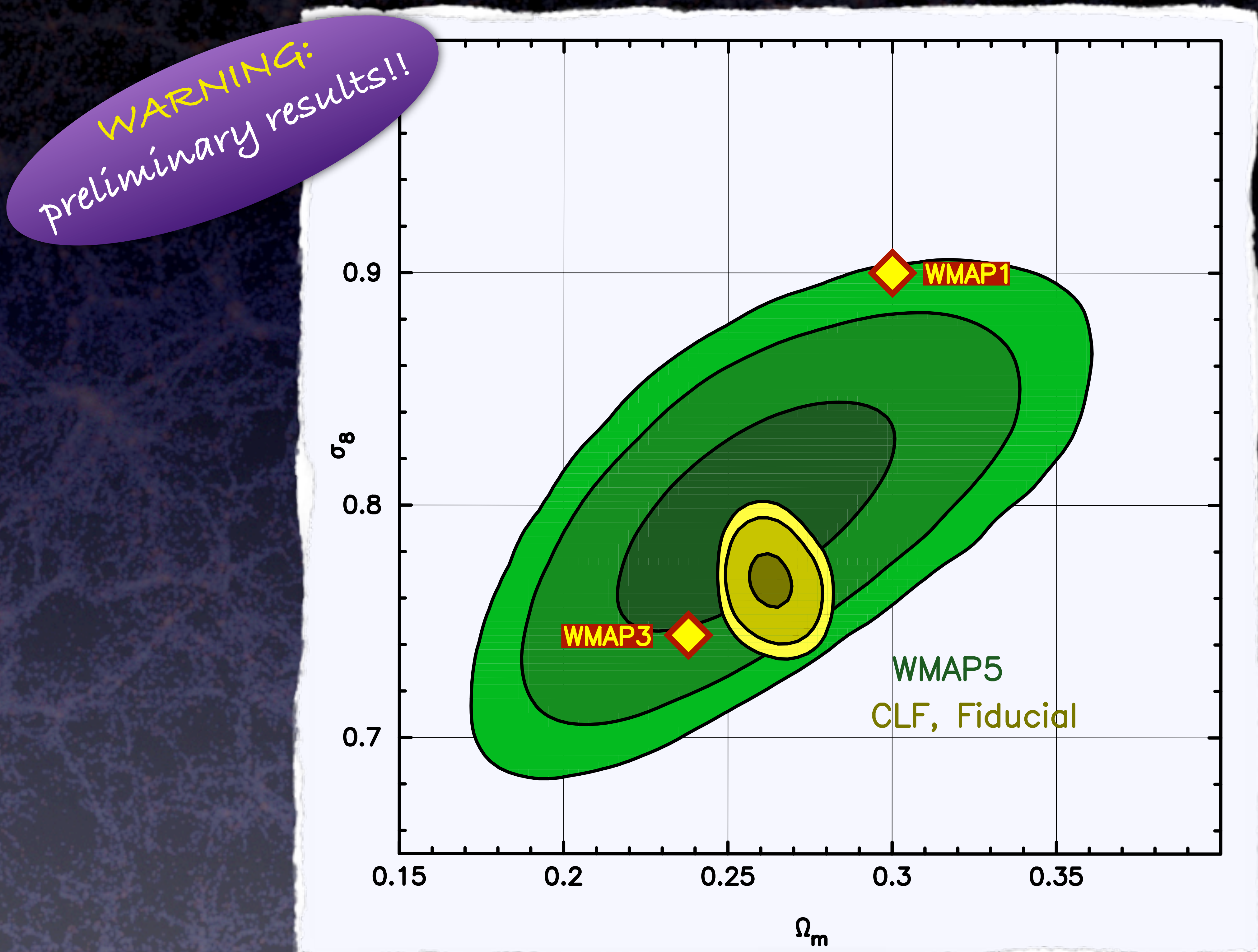
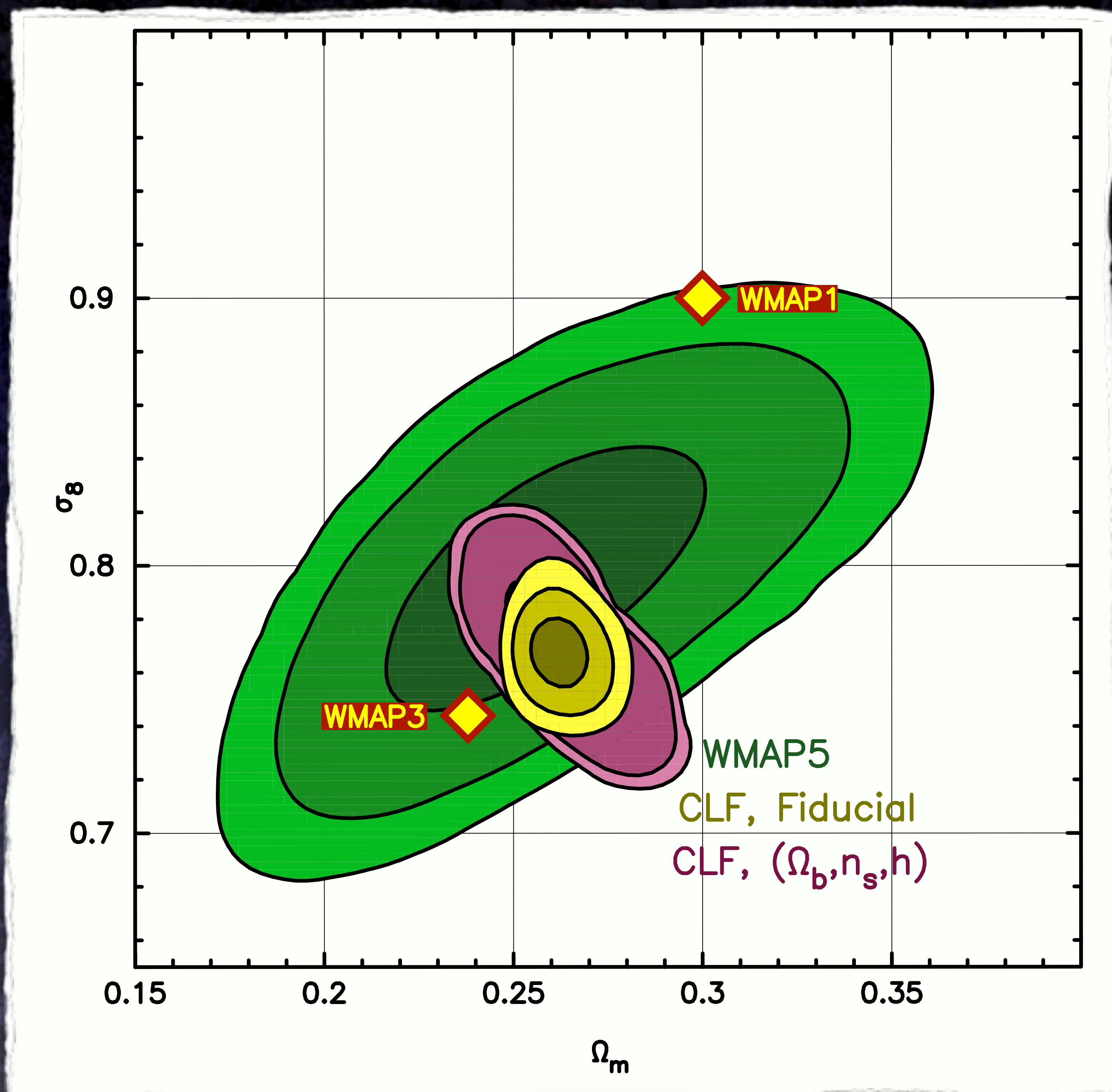


WMAP5 Gaussian Priors



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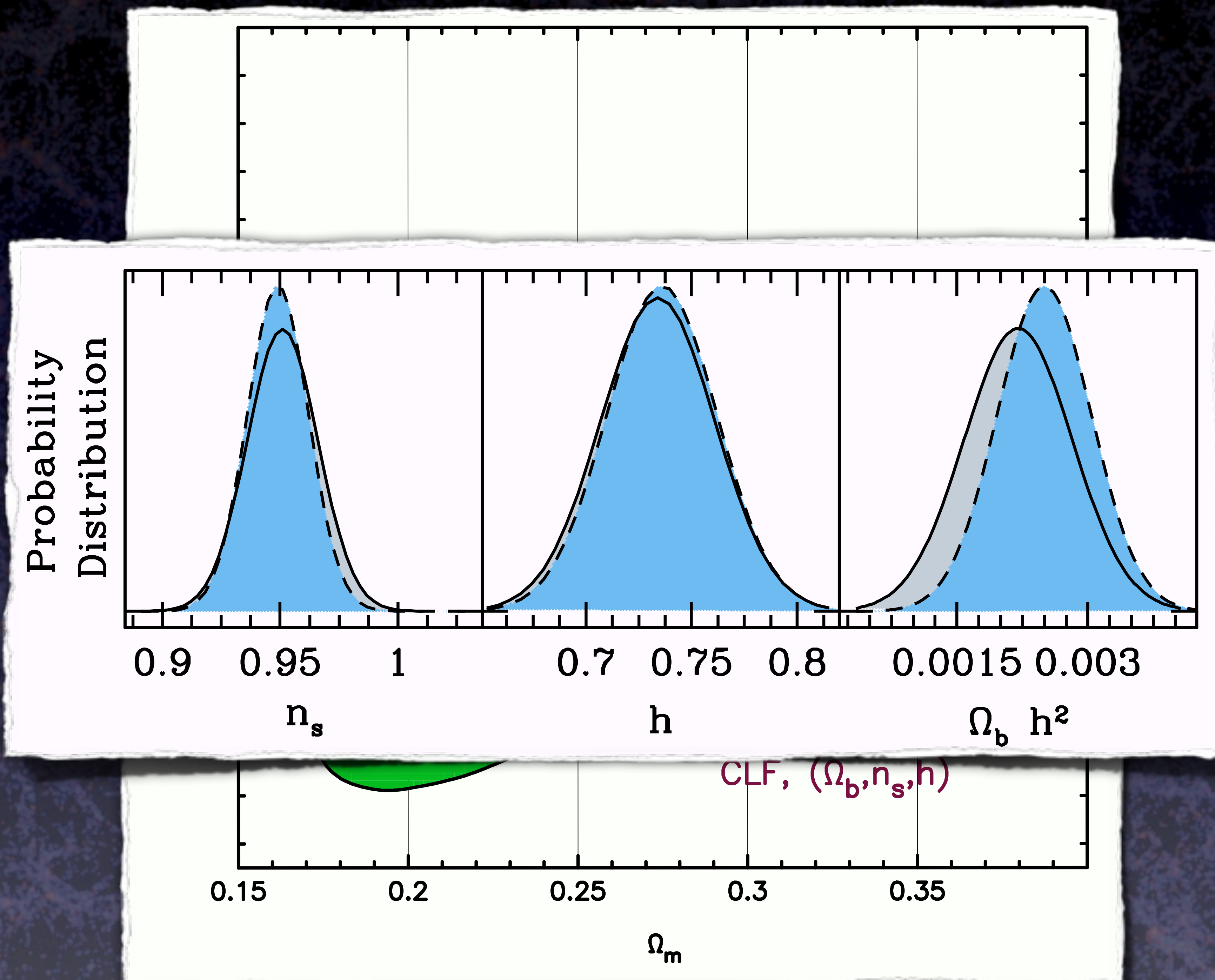
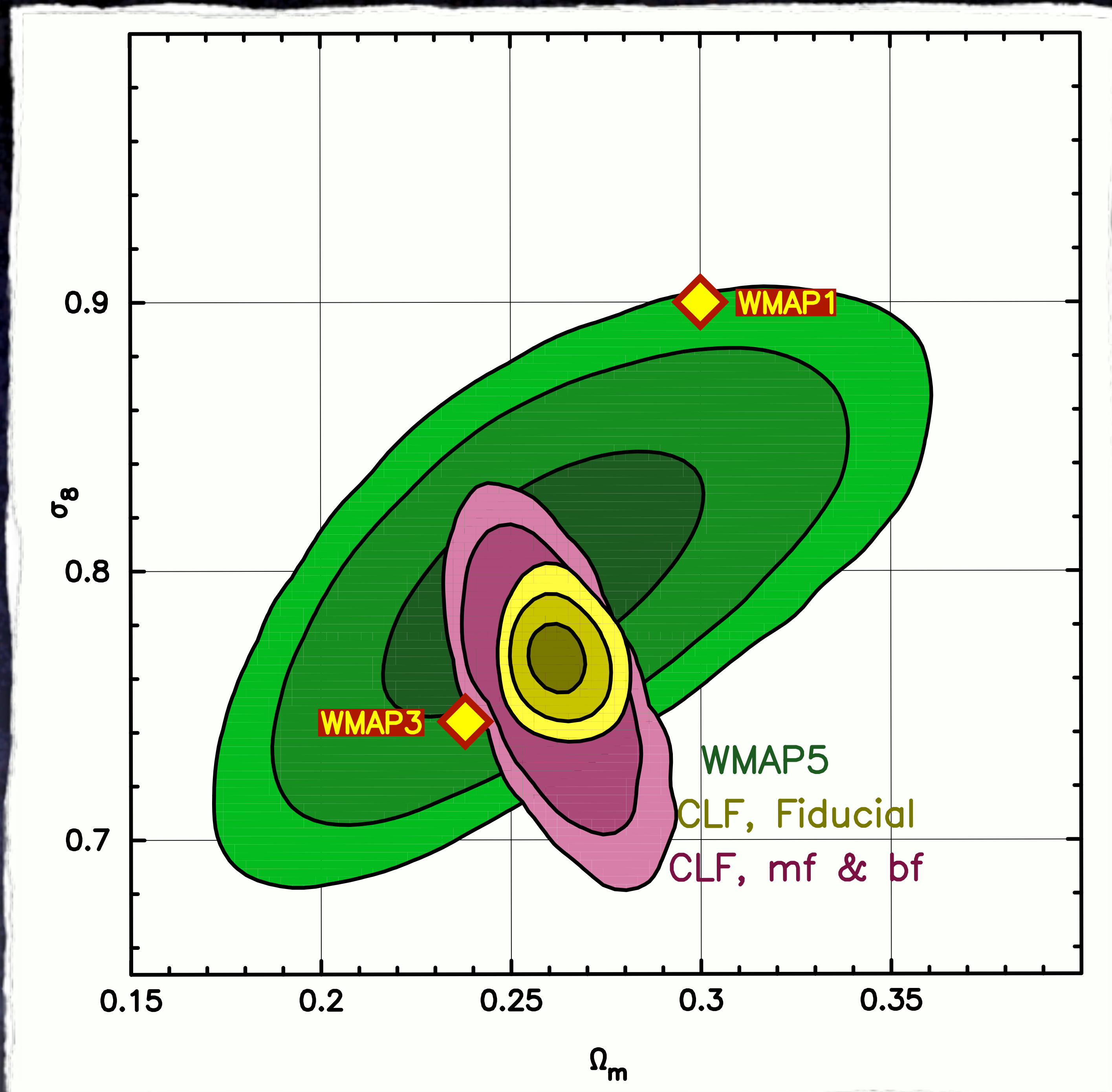
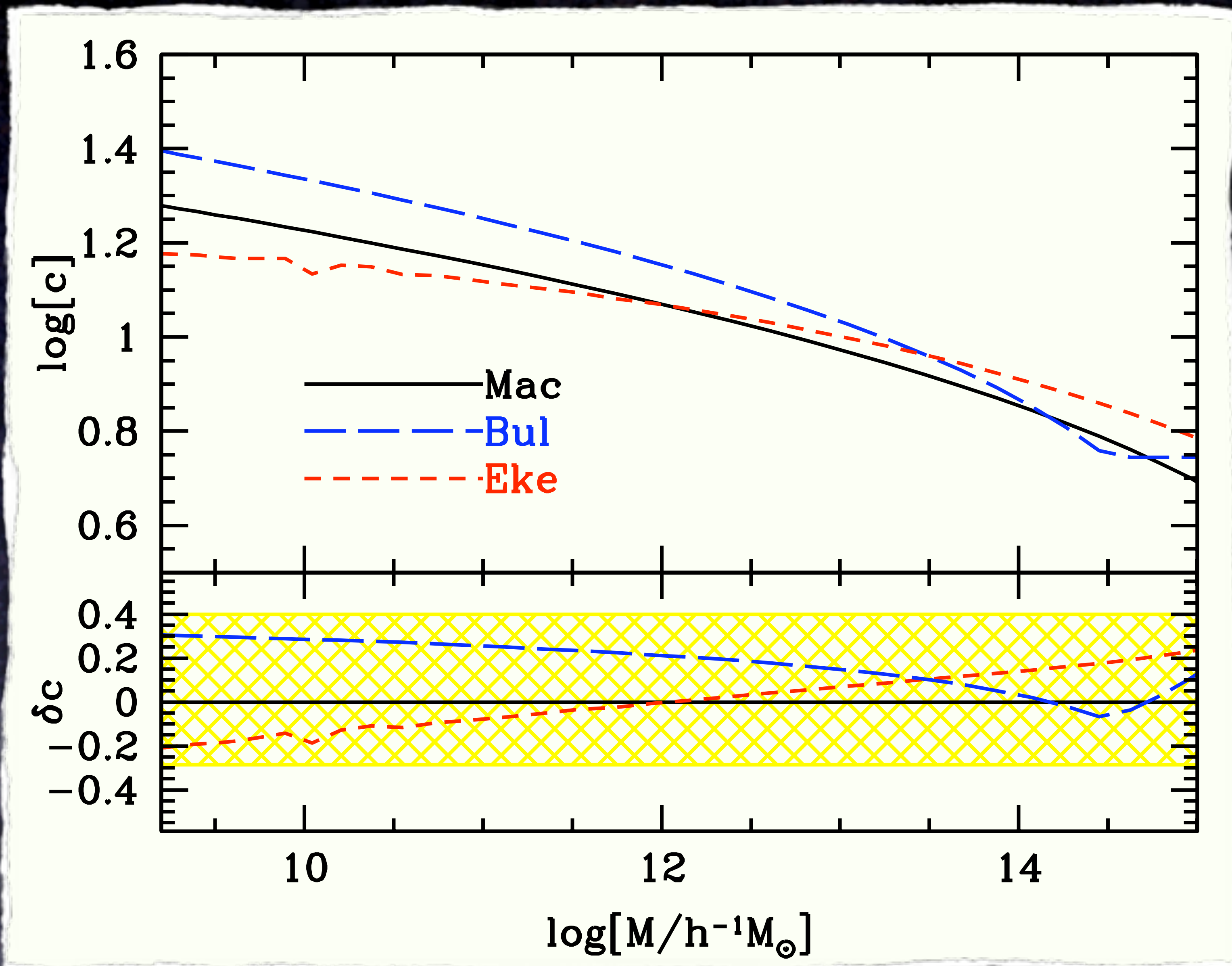


Systematic Errors in Mass & Bias Functions



Systematic Errors in Halo Concentrations



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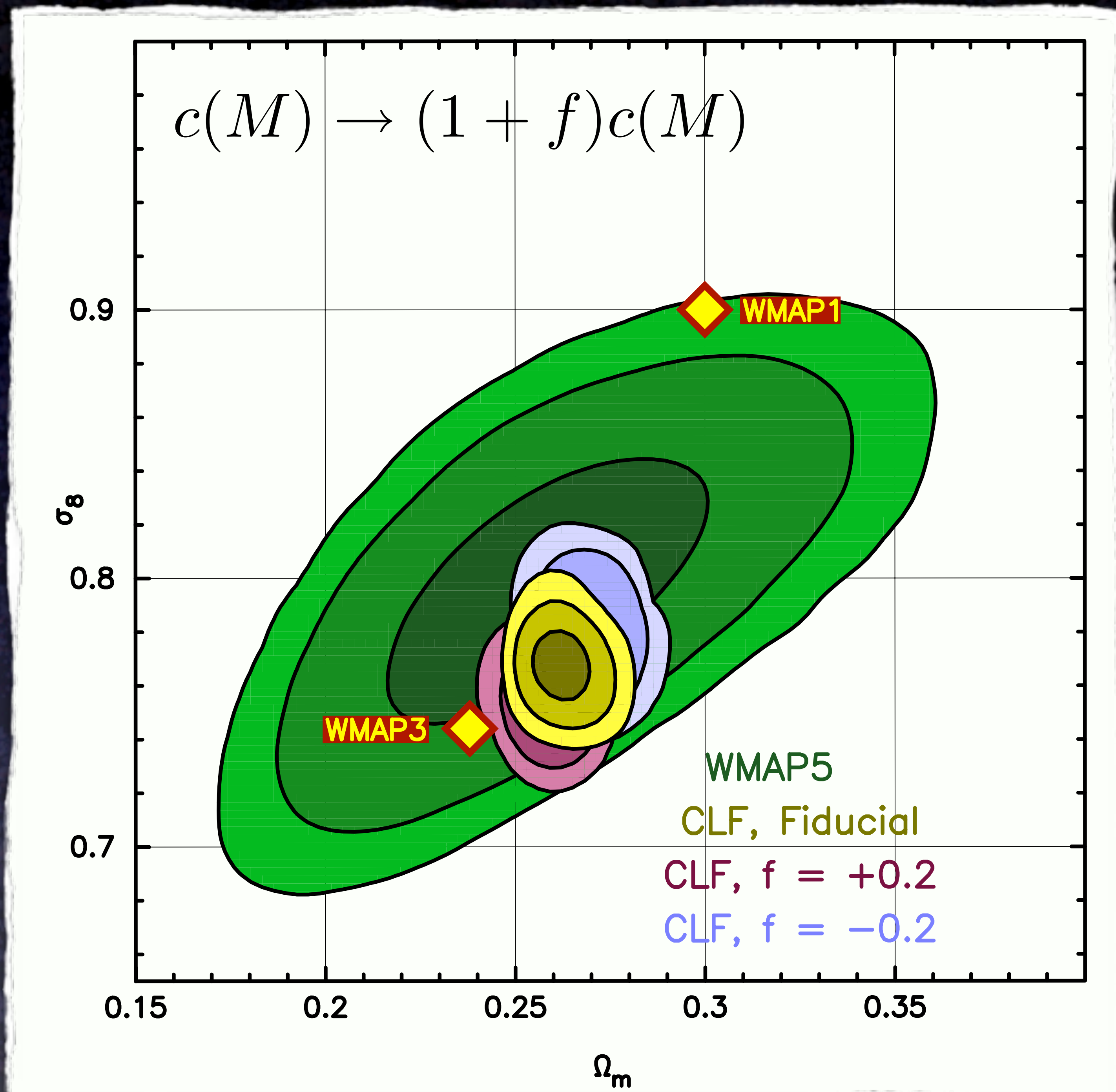
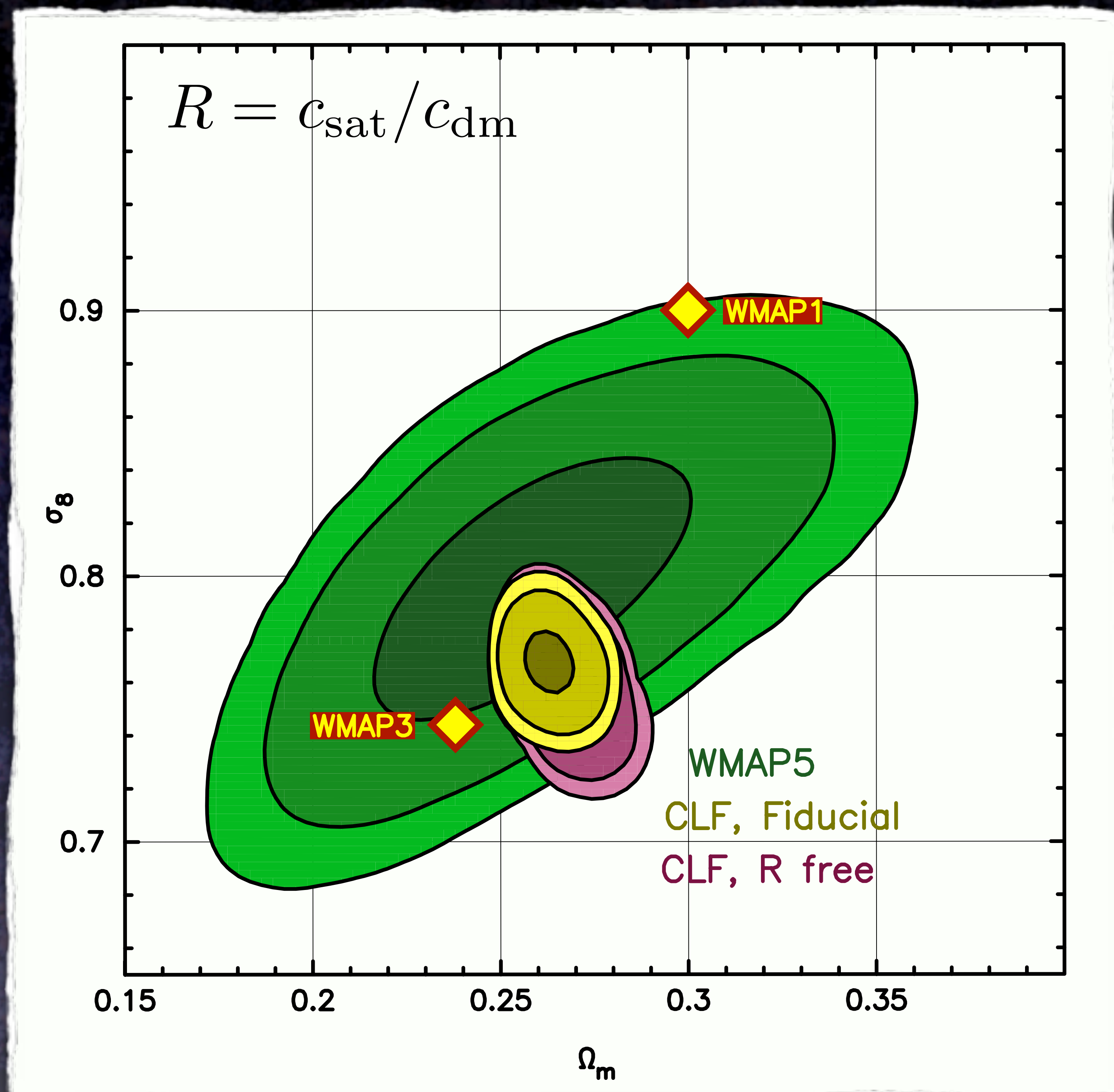
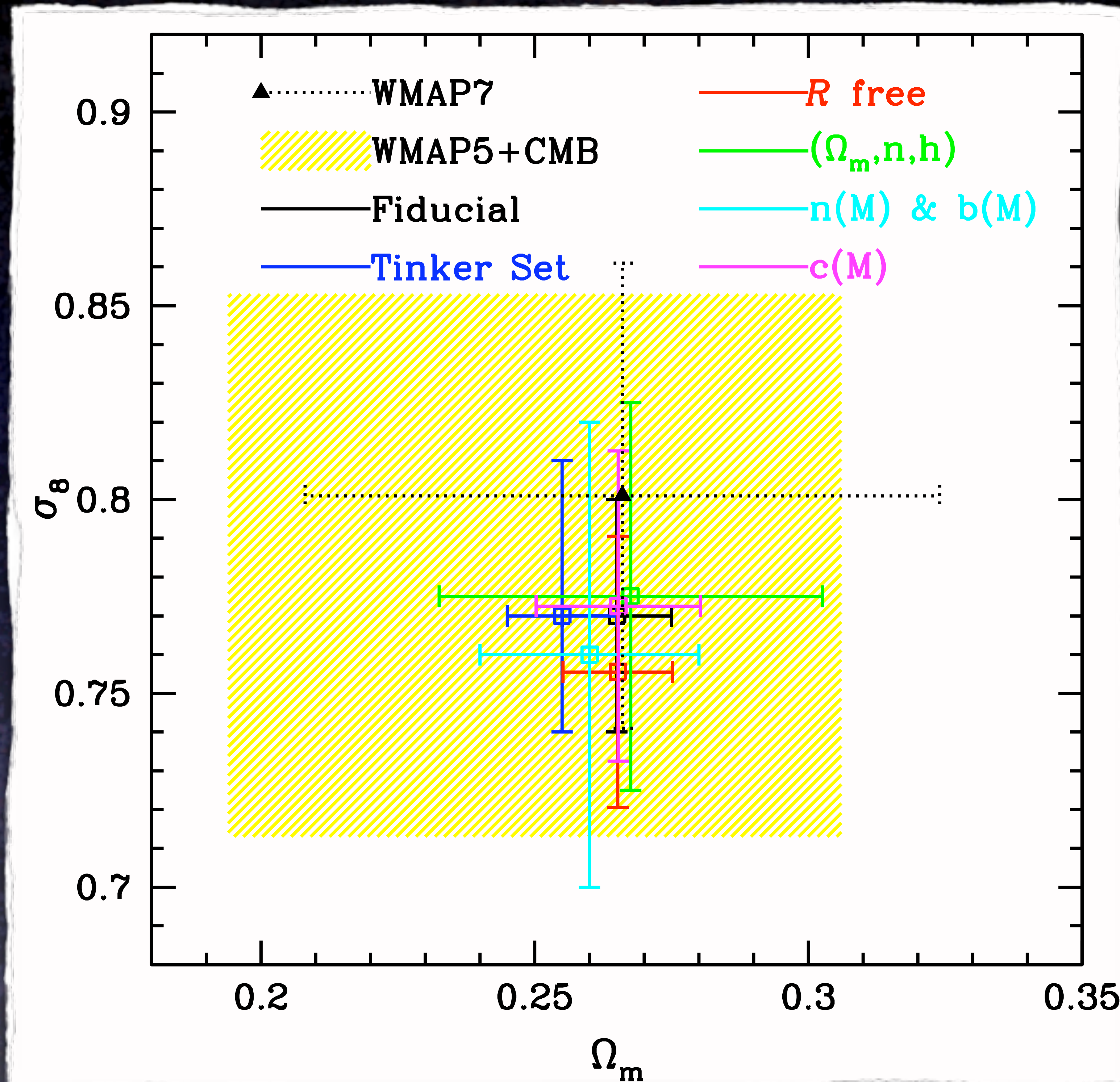


The Radial Distribution of Satellite Galaxies



Summary Plot



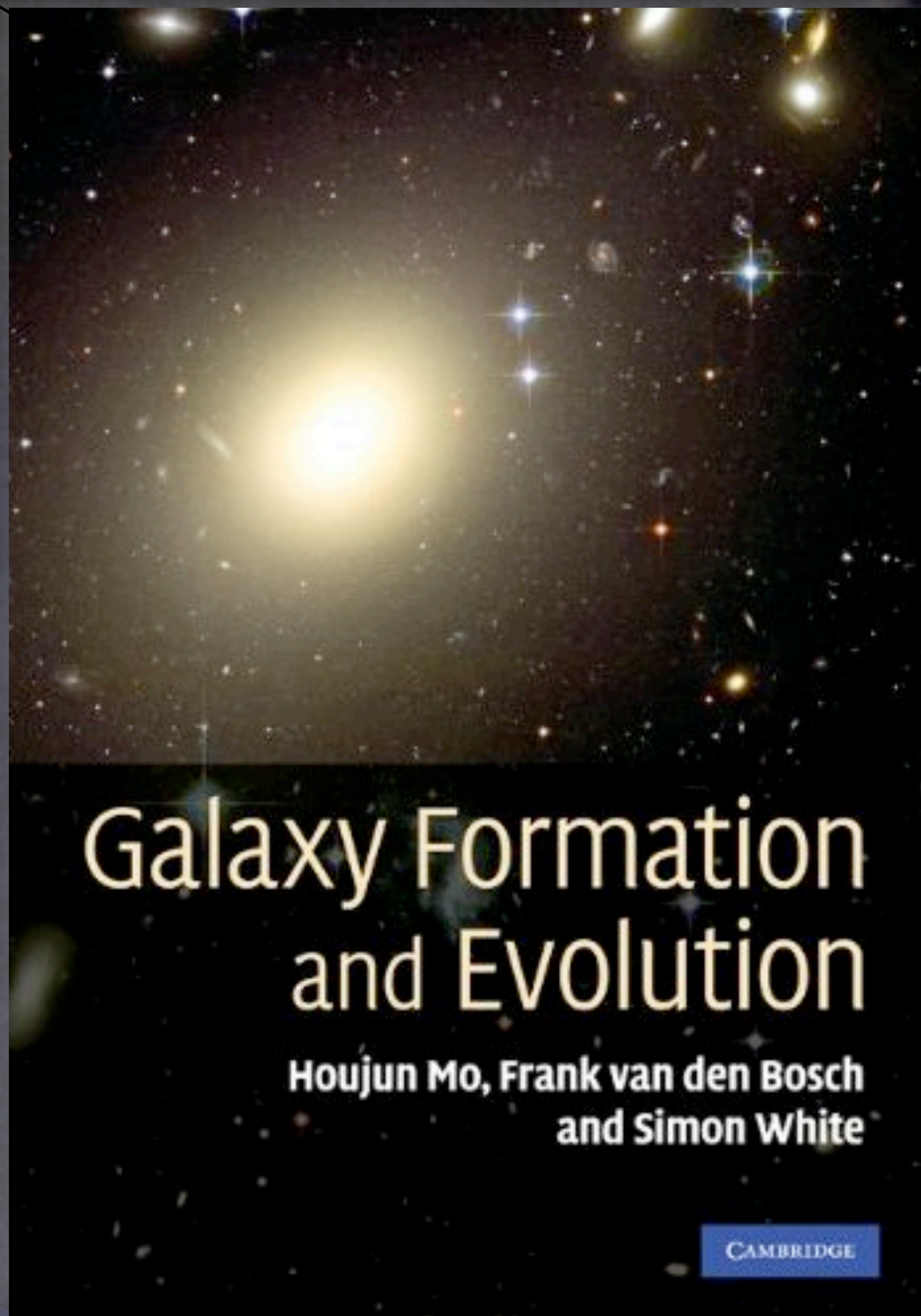
Overall excellent agreement with WMAP constraints.

Conclusions

- Conditional Luminosity Function (CLF) is powerful statistic to describe galaxy-dark matter connection.
- Combination of galaxy clustering and galaxy-galaxy lensing can constrain cosmological parameters.
- This method is complementary to and competitive with BAO, cosmic shear, SNIa & cluster abundances.
- Preliminary results are in excellent agreement with CMB constraints from WMAP5

The End

New Graduate Text Book



Release expected in May/June 2010

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cosmology
structure formation
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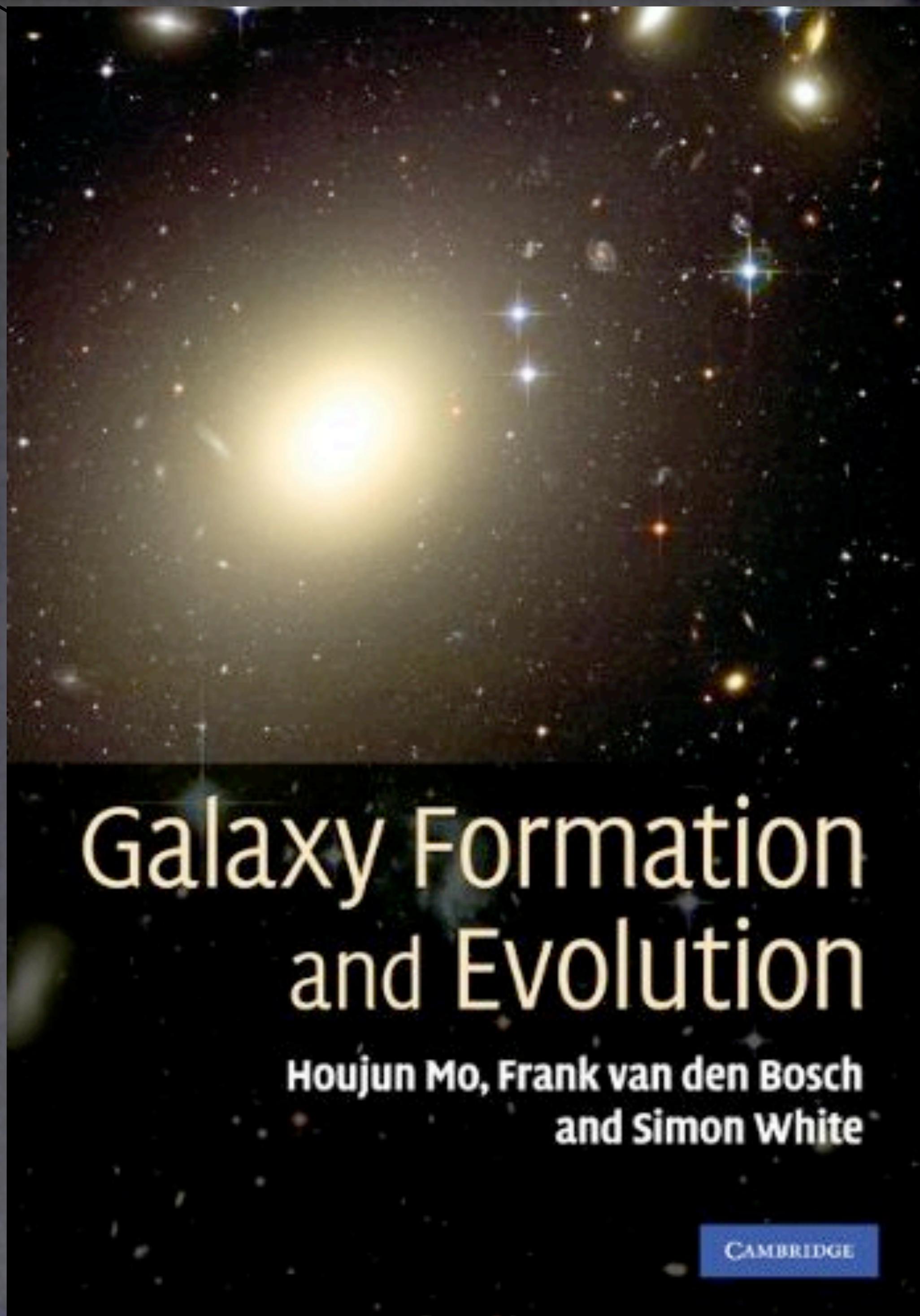

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