Modelling Galaxy-Galaxy Lensing with the Conditional Luminosity Function

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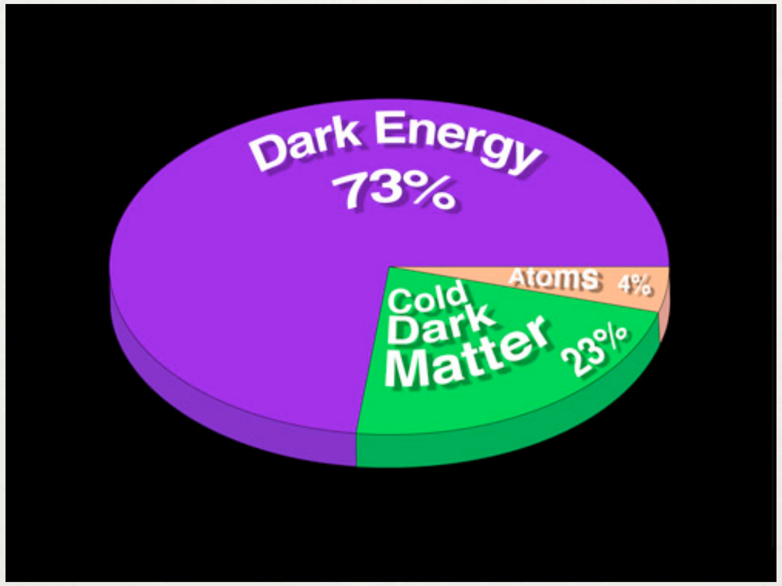
Outline

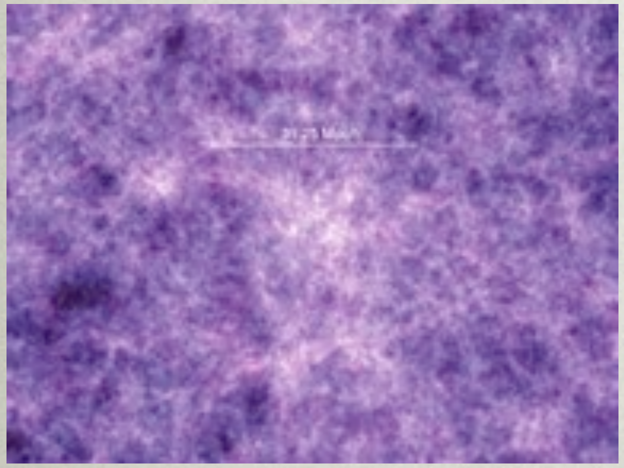
- INTRO
  - Standard Cosmological Model
  - Galaxy Formation
- GALAXY-GALAXY LENSING
  - Basics
  - Observational data
  - Modelling g-g lensing with CLF
- RESULTS
  - Comparison with data
  - Cosmology with g-g lensing

Cosmological Framework

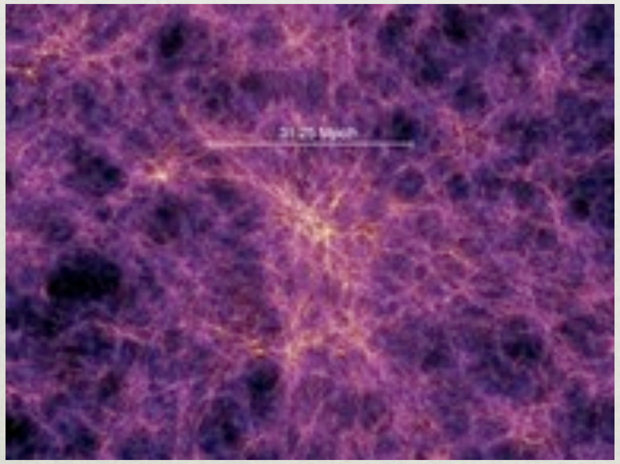
flat ΛCDM Universe



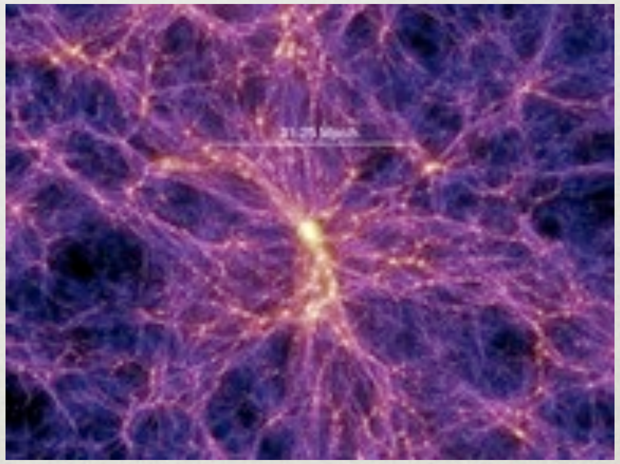
Structures form by the growth of small perturbations in the density field



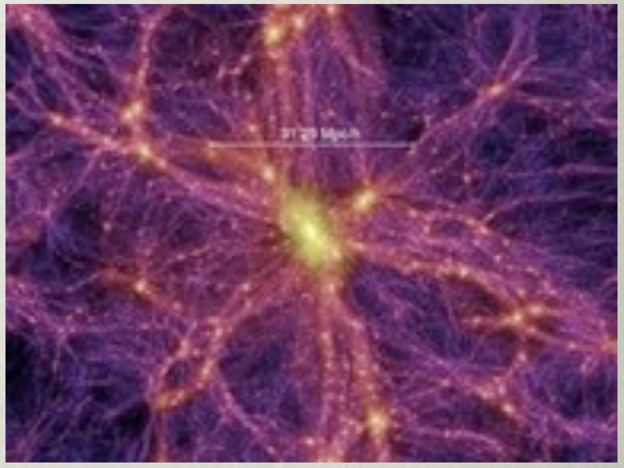
z = 18.3
t = 0.21 Gyr



z = 5.7
t = 1 Gyr



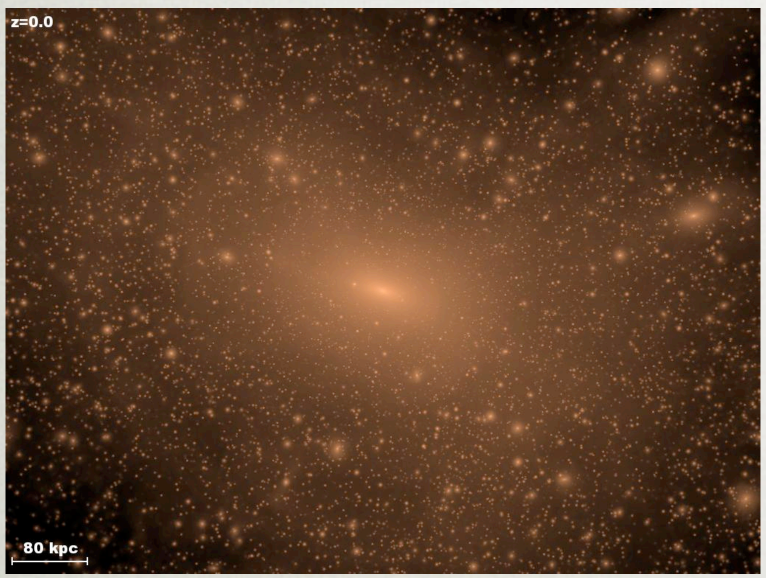
z = 1.4
t = 4.7 Gyr



z = 0
t = 13.6 Gyr

Millennium Simulation, Springel et al. 2005

Structure Formation Paradigm



Via Lactea simulation, Diemand et al 2007

Dark Matter Halo Formation

Gravitational Collapse

(fairly well understood)

"Gastrophysics"

baryonic processes involved

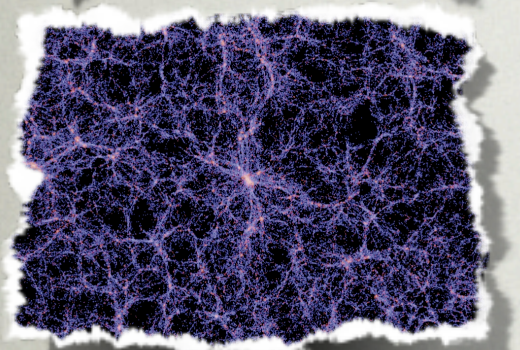
(far from a self consistent picture)

Starburst Galaxy M82

Different Approaches

Individual system

- e.g. lensing, kinematics, X-rays



Ab-initio

- e.g. SAMs, numerical simulations

Statistical

- Halo Occupation Statistics

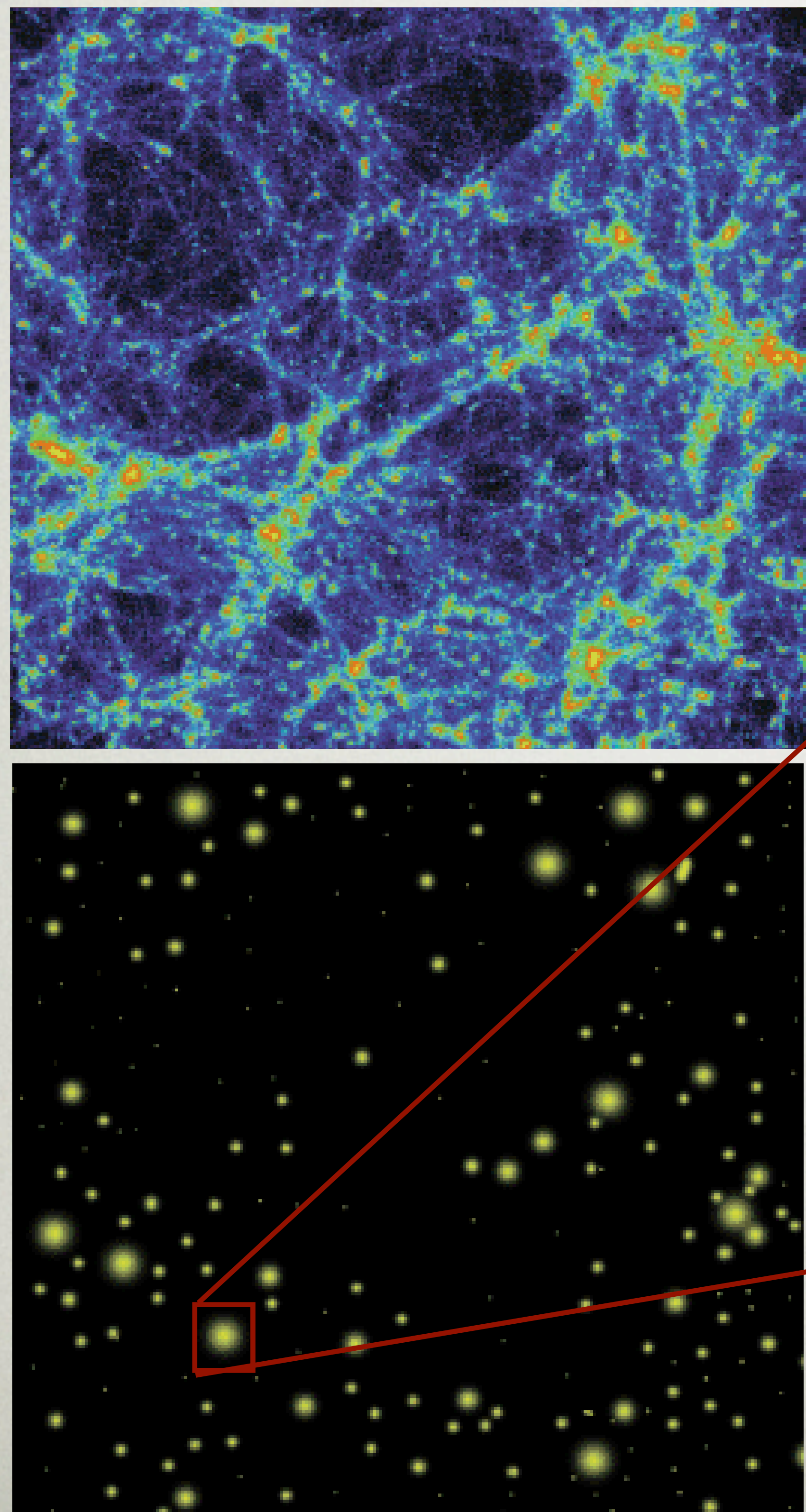
→ **Analytical description**

Halo Model

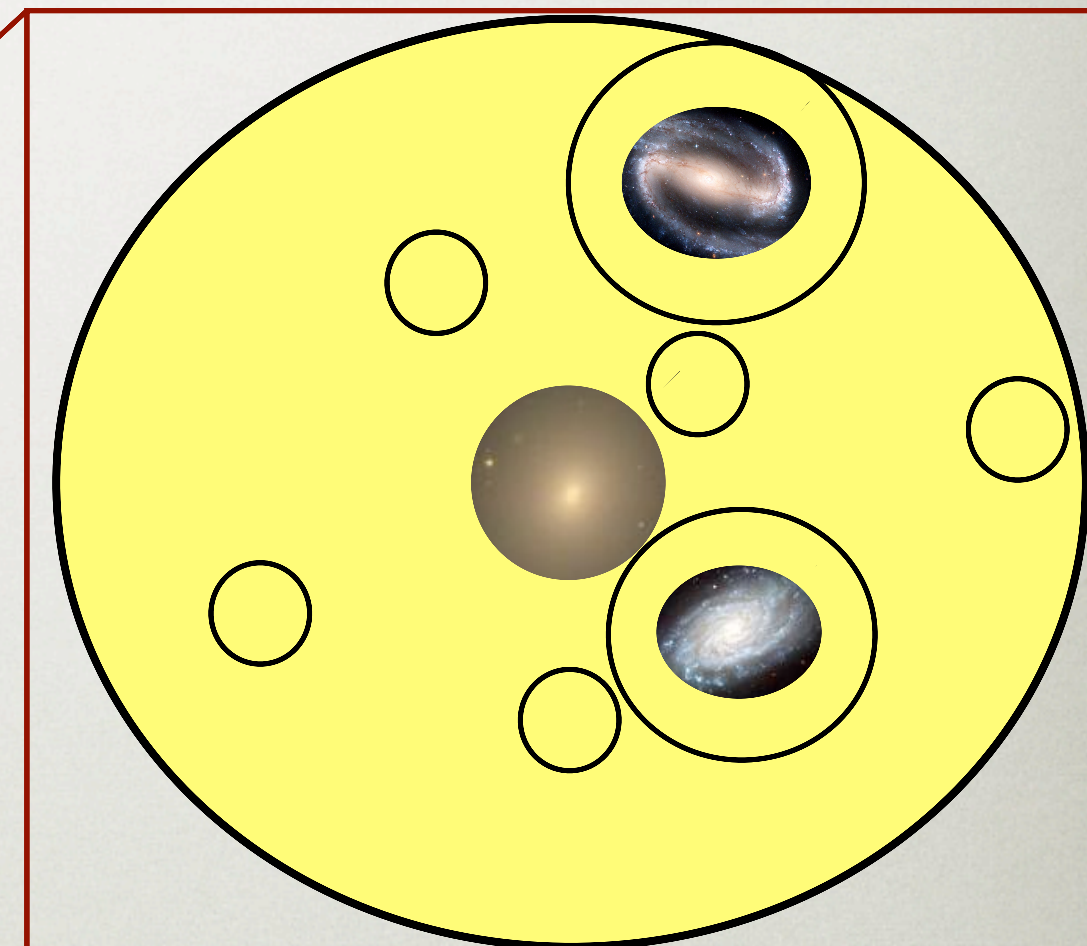
(every dm particle resides in virialized halo)

Numerical Simulation view

Halo Model view

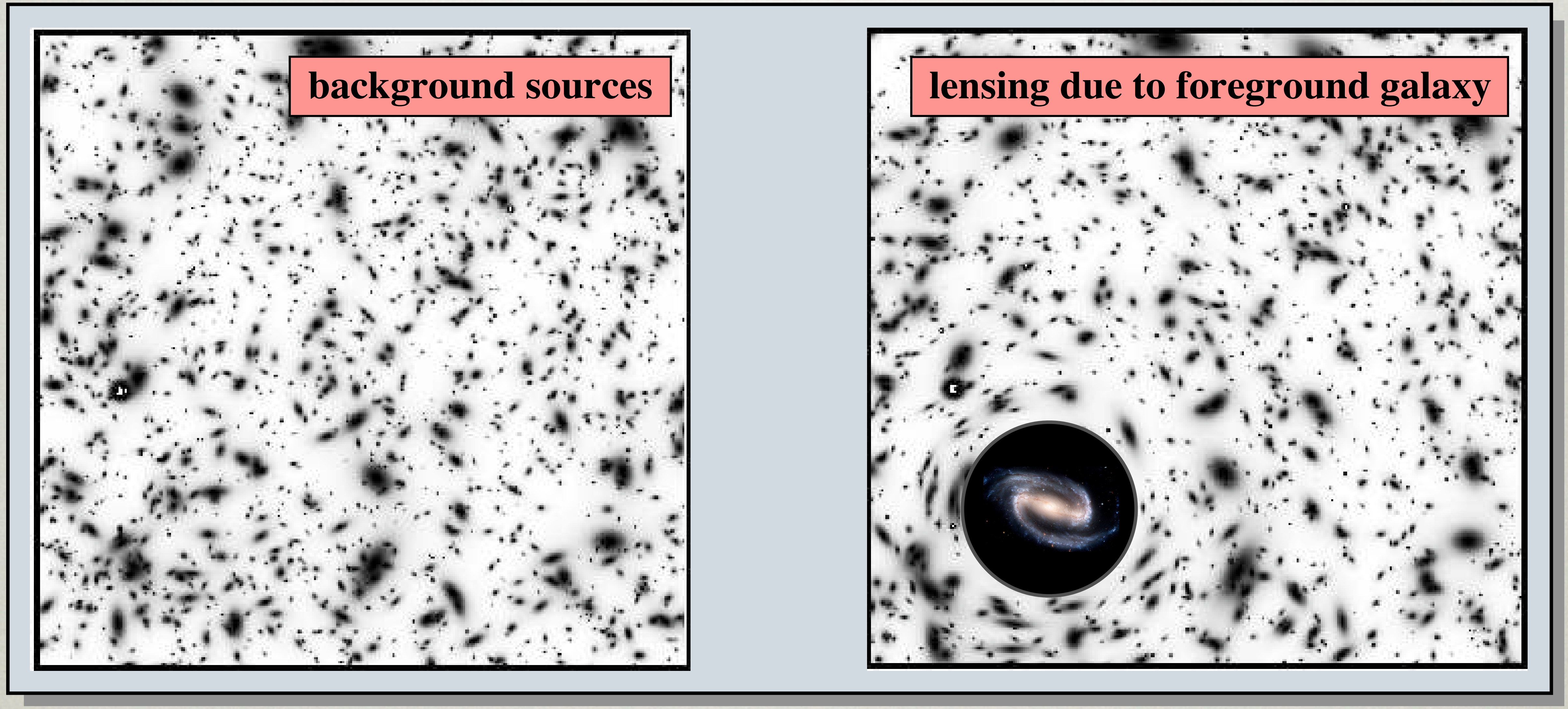


$$M = \frac{4\pi}{3}(180\bar{\rho})r^3$$



central and satellite galaxies

Weak Gravitational Lensing



small deformation of the background galaxy images

Galaxy-Galaxy Lensing

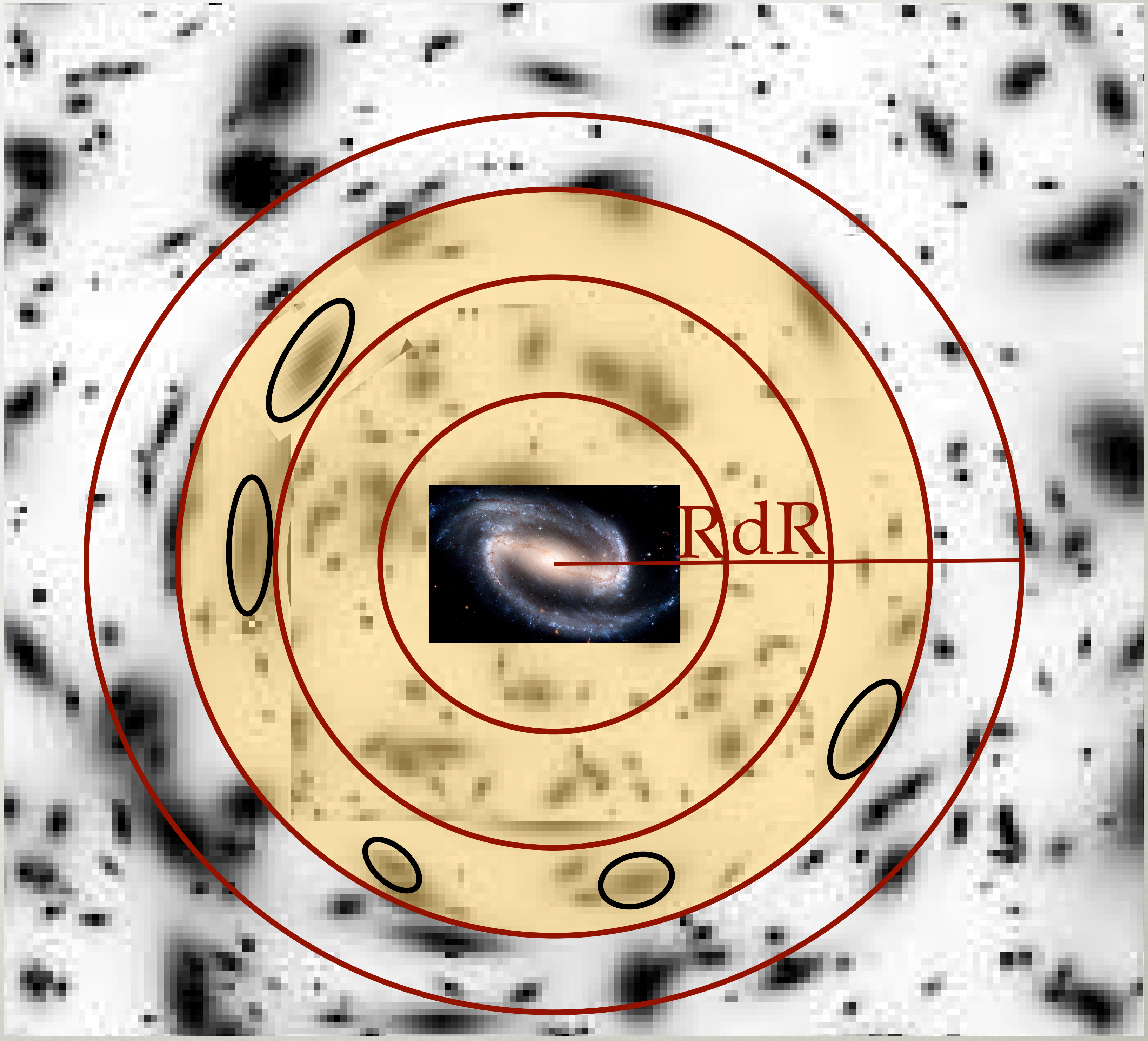
$$< \epsilon > (R; R + dR) = \gamma_t(R)$$

Shear
tells about
dark matter distribution
in the halo

BUT

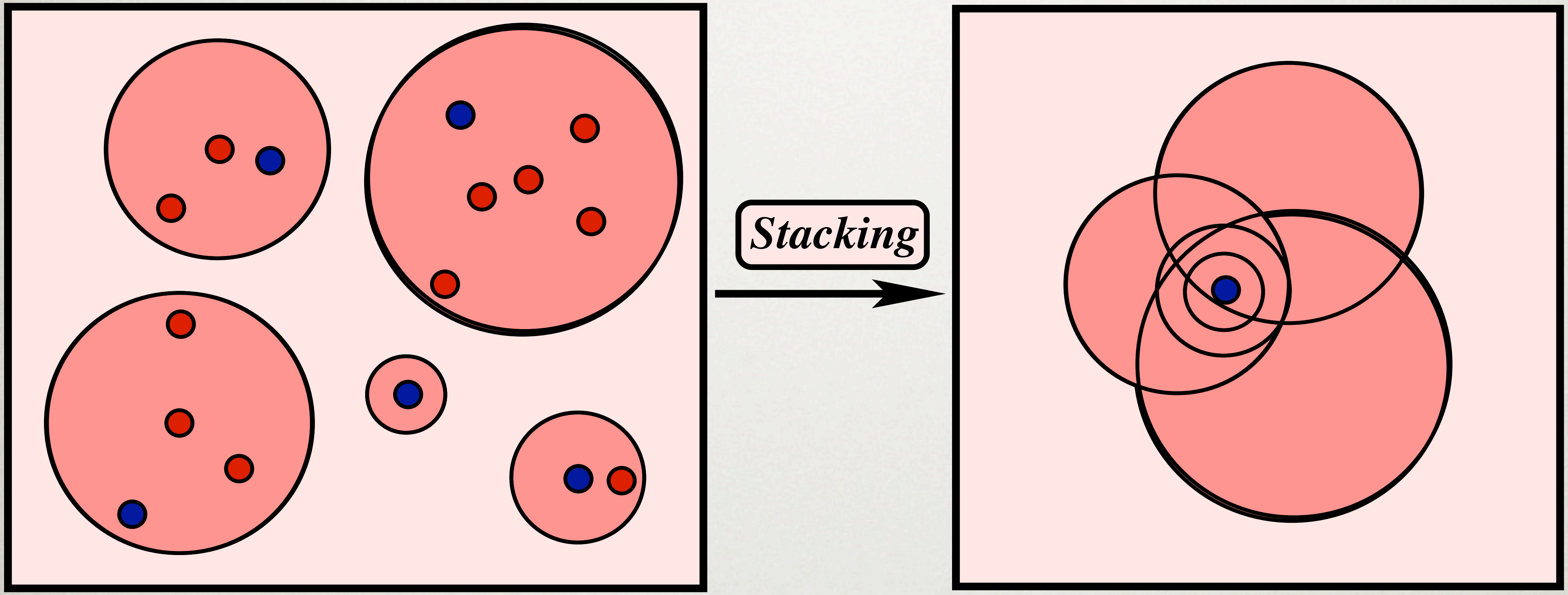
Too few
background galaxies

Need to stack
many foreground
galaxies



Stacking Procedure

Stacking according to an observed galaxy property (e.g. Luminosity)



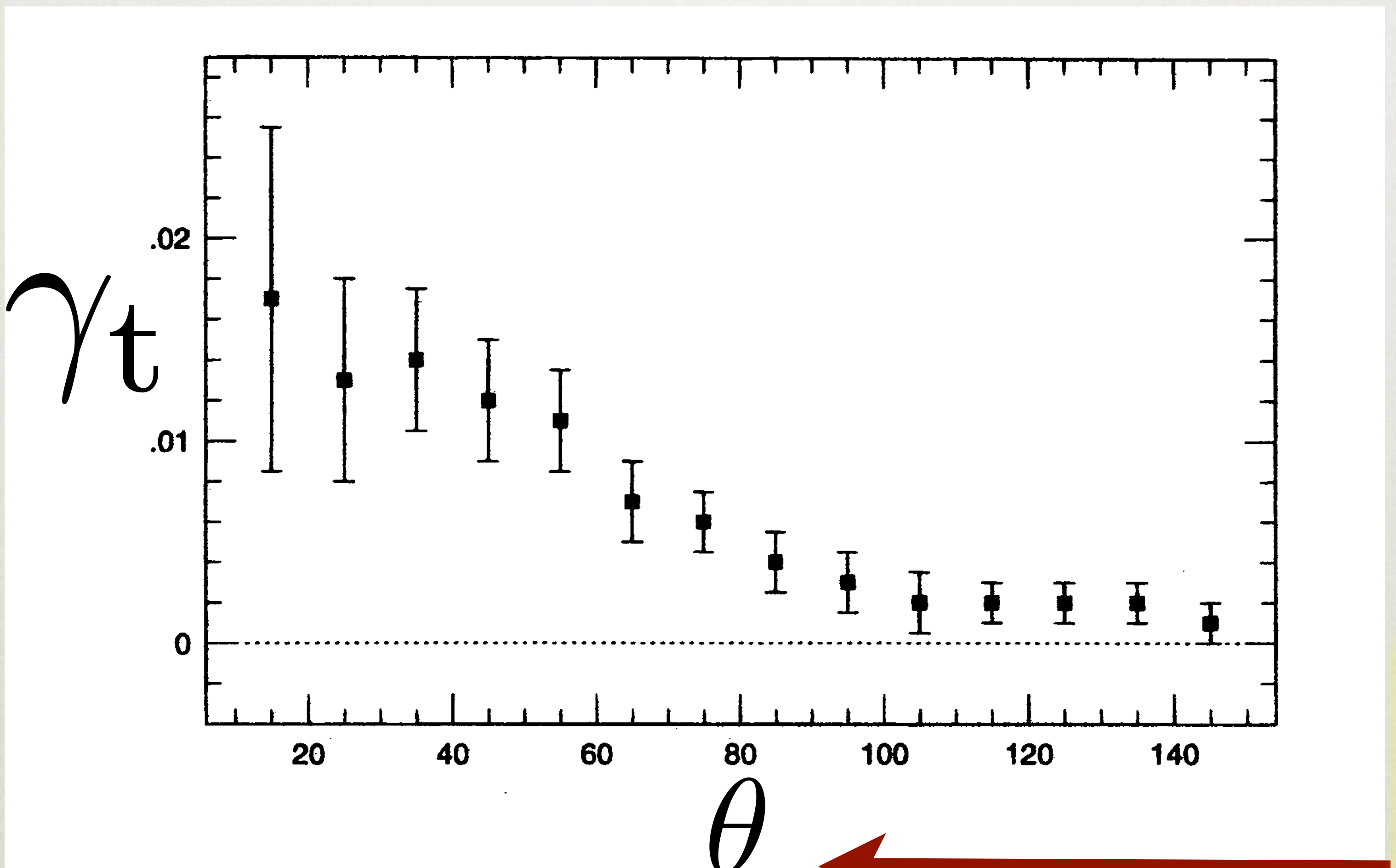
haloes of different masses
central and satellite galaxies } Mixed together

Difficult interpretation

First Measurement

(Brainerd, Blandford & Smail @ 5m Hale Telescope, Palomar, 1996)

Stacking according to the apparent magnitude



(arcsec)

No spectroscopic redshifts of the lenses

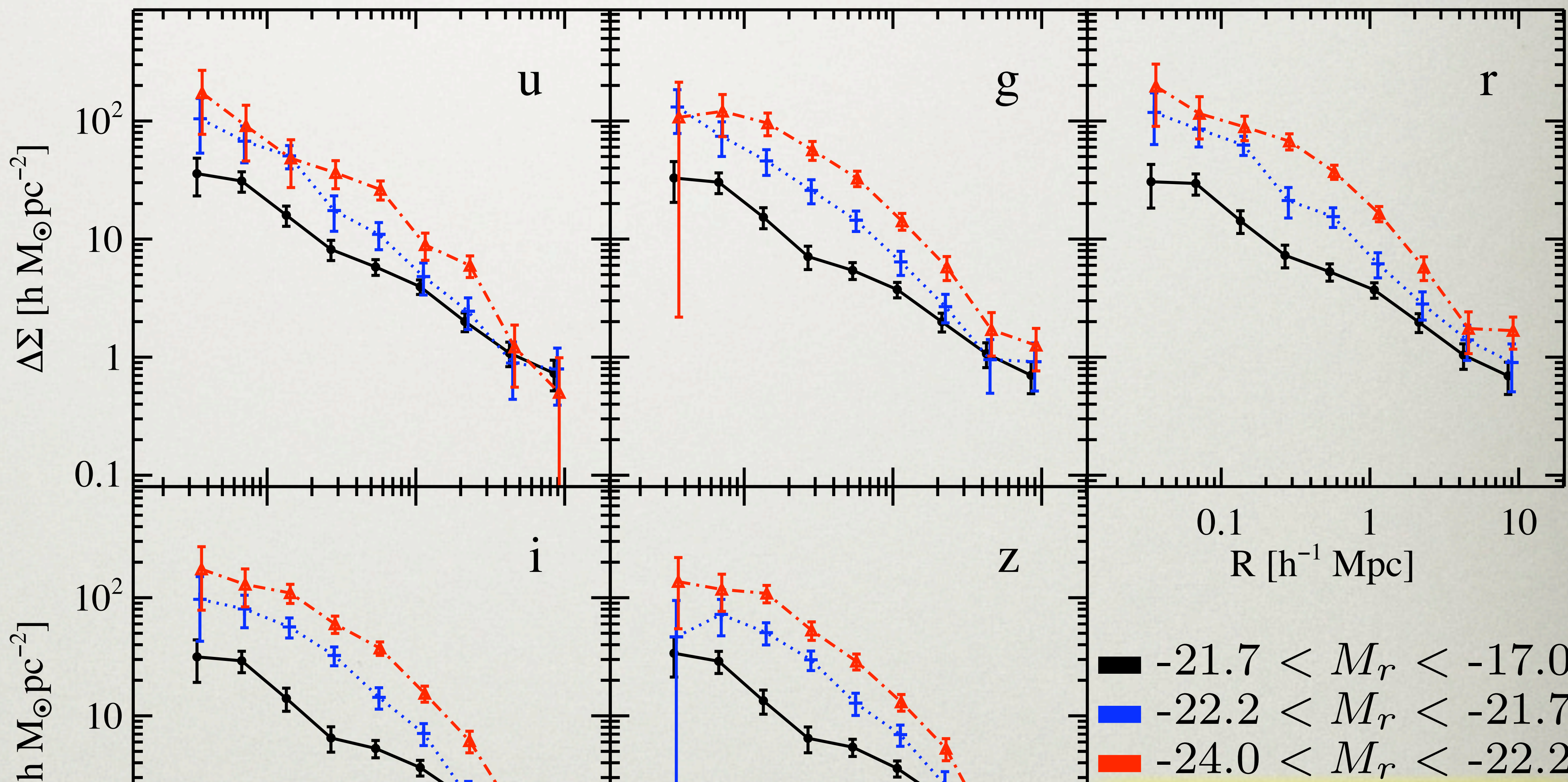
Things get better...

(Sheldon et al. @ Apache Point Observatory, New Mexico, SDSS, 2004)

Excess surface density $\Delta\Sigma(R) = \Sigma_{\rm crit}\gamma_{\rm t}(R)$

$$\Sigma_{\rm crit} = \frac{c^2}{4\pi G}\frac{D_{\rm S}}{D_{\rm L}D_{\rm LS}}$$

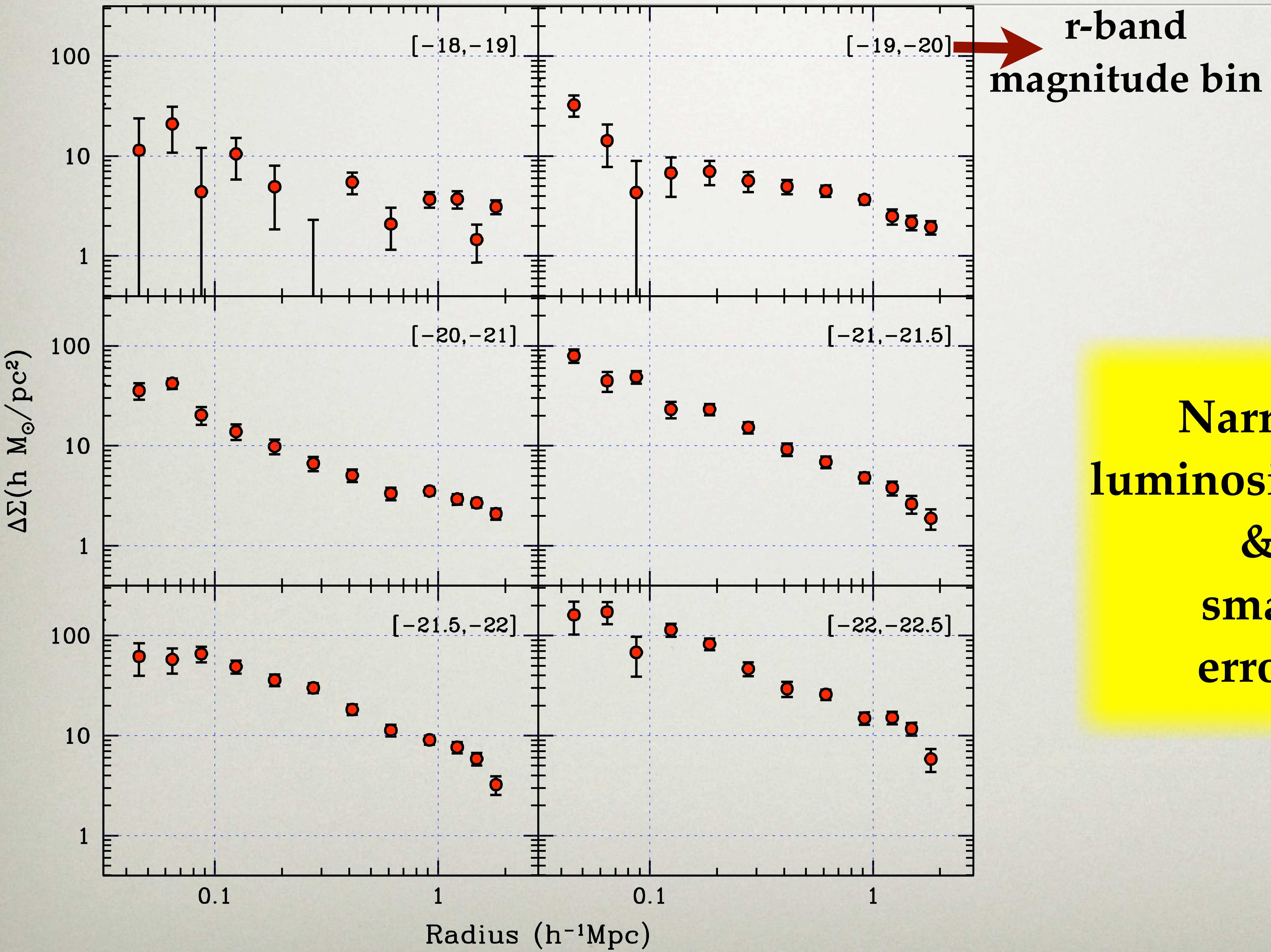
required spectroscopic redshifts of the lenses and photometric redshifts of the sources



Broad Luminosity Bins

State of the art

(Seljak et al., SDSS, 2005)



Narrow luminosity bins & small errors

Modelling g-g lensing

Excess surface density

$$\Delta\Sigma(R) = \bar{\Sigma}(< R) - \Sigma(R)$$

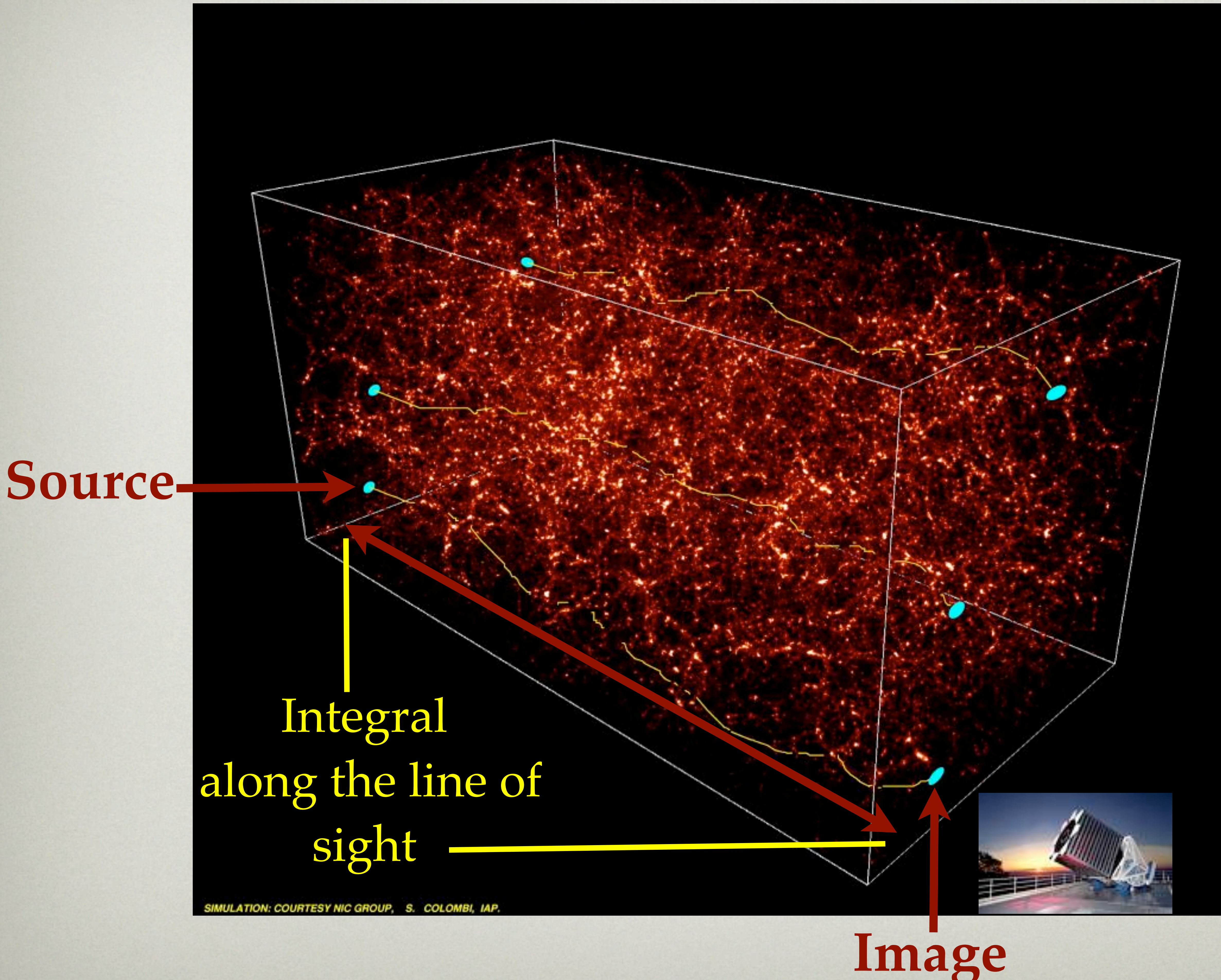
$$\bar{\Sigma}(< R) = \frac{2}{R^2} \int_0^R \Sigma(R')R'\mathrm{d}R'$$

Surface density

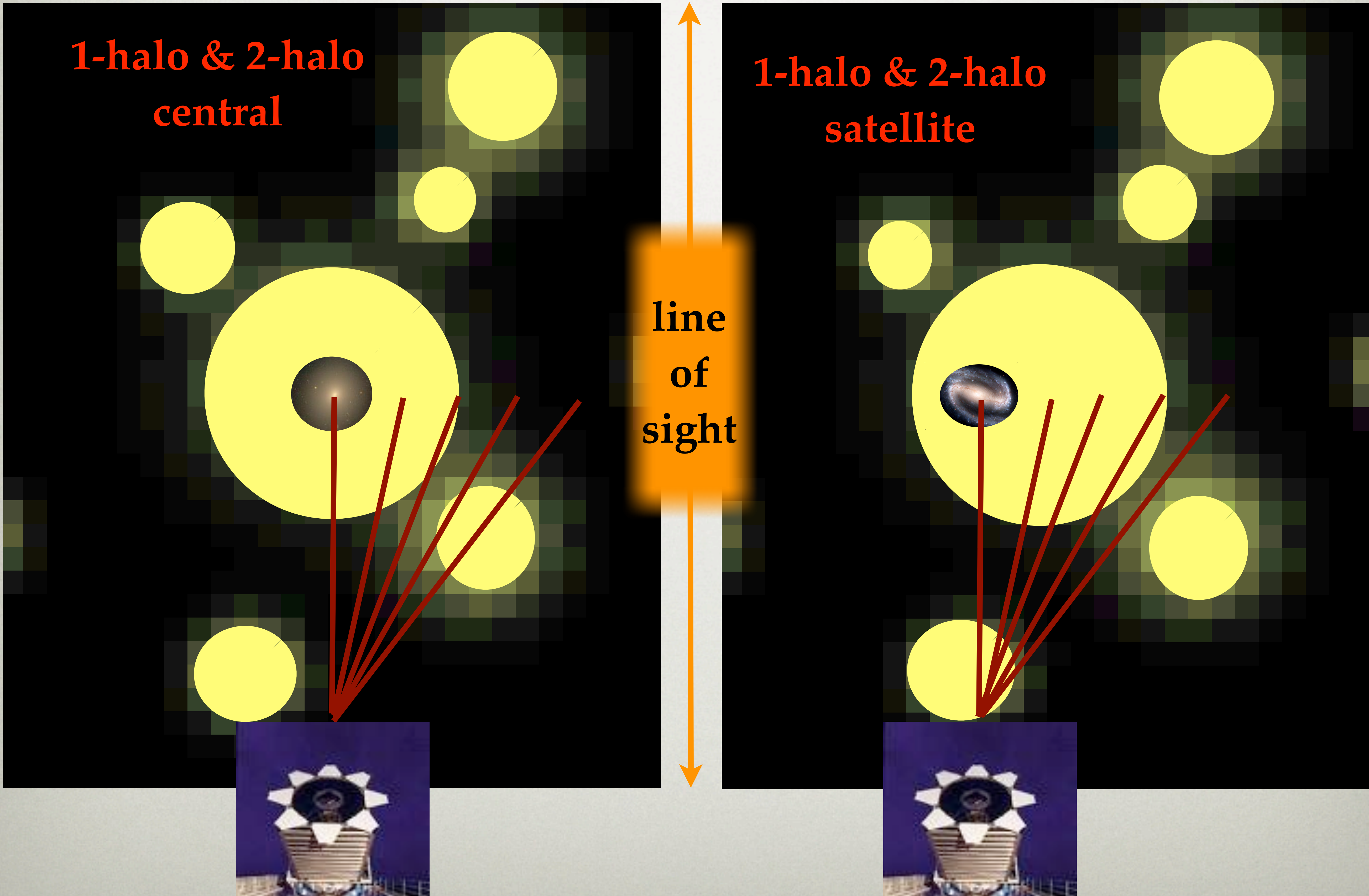
$$\Sigma(R) = \bar{\rho} \int_0^{\chi_\mathrm{S}} [1 + \xi_{\mathrm{g,dm}}(r)] \, \mathrm{d}\chi$$

Galaxy-dark matter cross correlation function

Excess of dark matter around a galaxy (it can be modelled)


Source
Integral
along the line of
sight
Image
SIMULATION: COURTESY NIC GROUP, S. COLOMBI, IAP.

Galaxy-Dark Matter Cross Correlation



Modelling the stacking procedure

$$\Delta\Sigma(R|L) = \int \mathcal{P}^{\rm c}(M|L)\Delta\Sigma^{\rm c}(R|M)\mathrm{d}M + \int \mathcal{P}^{\rm s}(M|L)\Delta\Sigma^{\rm s}(R|M)\mathrm{d}M$$

$$\Delta\Sigma^{\rm c}(R|M) \longleftrightarrow \rho_{\rm dm}(r|M)$$

Dark matter halo density profile (NFW)

$$\Delta\Sigma^{\rm s}(R|M) \longleftrightarrow \rho_{\rm dm}(r|M) \otimes n_{\rm s}(r|M)$$

Convolution of the halo density profile and the number density distribution of galaxies

The knowledge of the probability functions is required !!!

Probability Functions

Bayes' theorem:

$$\mathcal{P}^{\rm c}(M|L)\mathrm{d}M = \frac{\Phi^{\rm c}(L|M)n(M)}{\phi^{\rm c}(L)}\mathrm{d}M \qquad \mathcal{P}^{\rm s}(M|L)\mathrm{d}M = \frac{\Phi^{\rm s}(L|M)n(M)}{\phi^{\rm s}(L)}\mathrm{d}M$$

where

$$\phi^{\rm c}(L) = \int \Phi^{\rm c}(L|M)n(M)\mathrm{d}M \qquad \phi^{\rm s}(L) = \int \Phi^{\rm s}(L|M)n(M)\mathrm{d}M$$

with $n(M)$ **the halo mass function (Warren et al. 2007)**

$\Phi^{\rm c}(L|M)$

$\Phi^{\rm s}(L|M)$

→ **Central and satellite term of the** ***Conditional Luminosity Function***

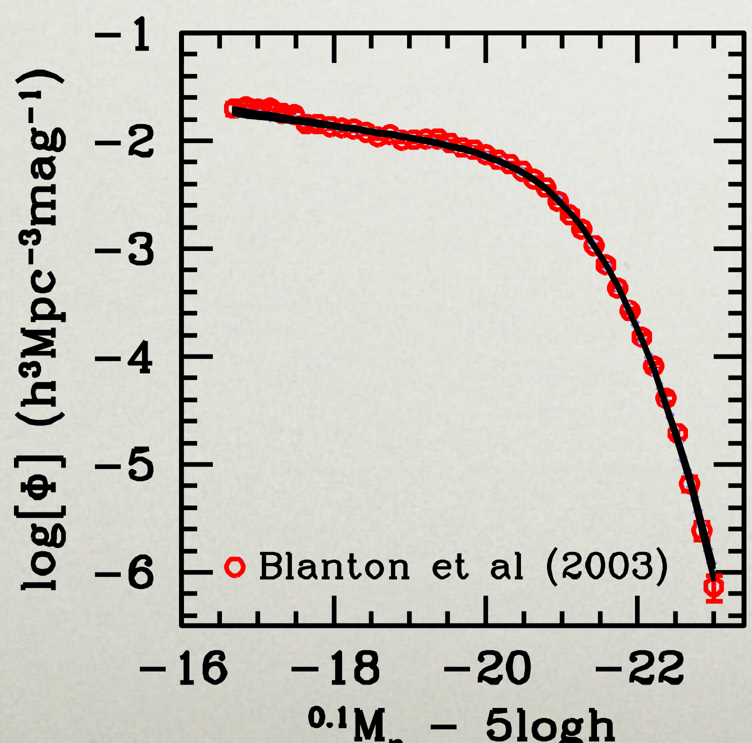
Conditional Luminosity Function

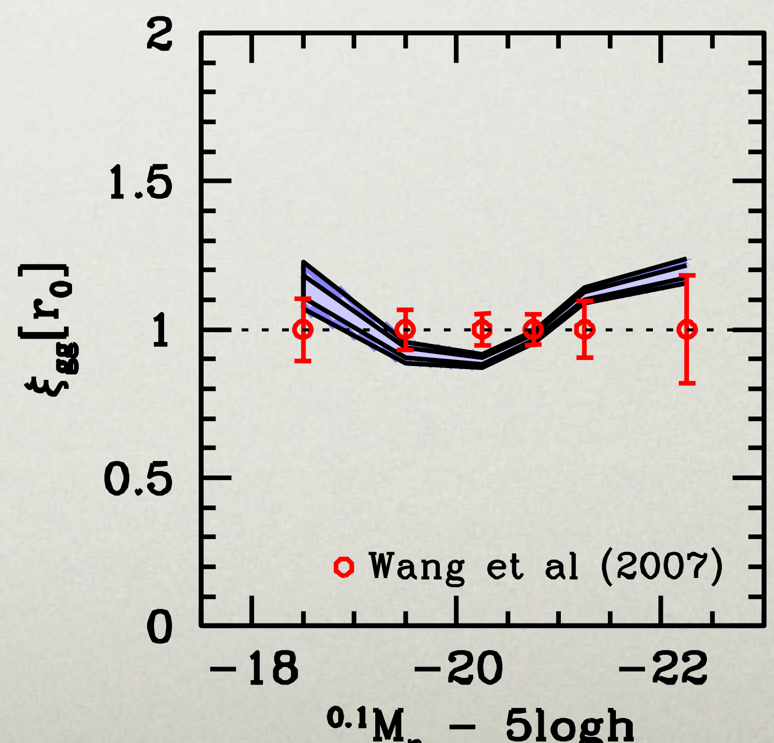
Number of galaxies with luminosity L living in a halo of mass M

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

assumed functional form with parameters constrained by

Luminosity Function





Correlation Length

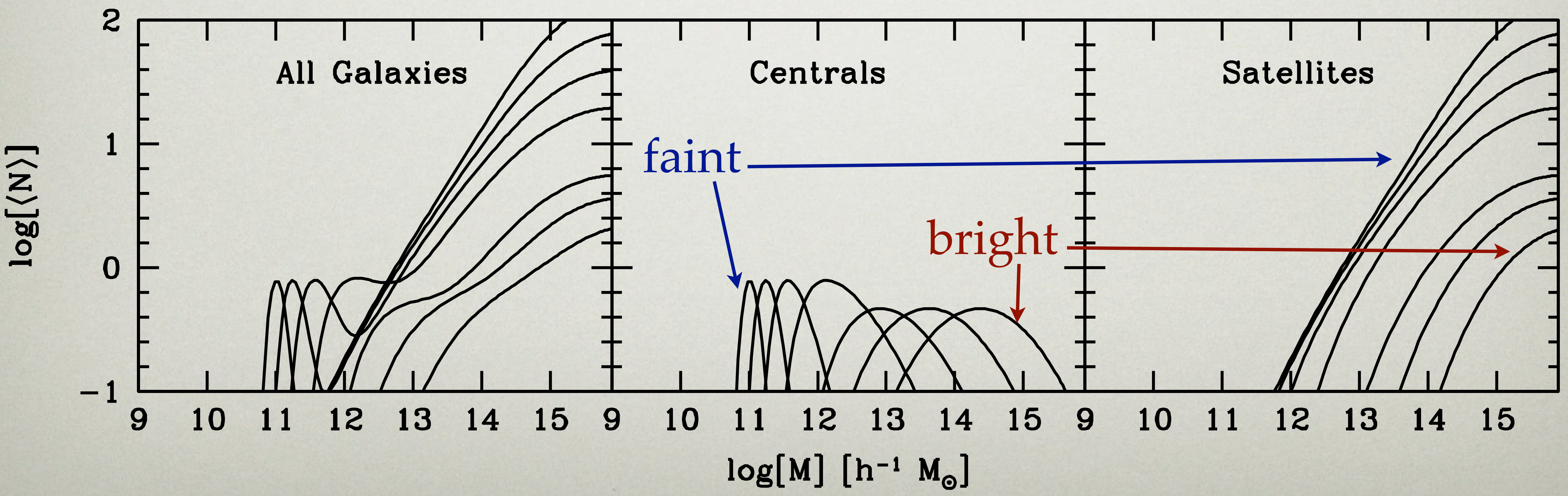
Probability Functions

$$\mathcal{P}_{\rm c}(M|L_1, L_2)\,{\rm d}M = \frac{\langle N_{\rm c}\rangle_M(L_1,L_2)}{\overline{n}_{\rm c}(L_1,L_2)}\, n(M){\rm d}M$$

$$\langle N_{\rm c}\rangle_M(L_1, L_2) = \int_{L_1}^{L_2} \Phi_{\rm c}(L|M)\,{\rm d}L$$

$$\mathcal{P}_{\rm s}(M|L_1, L_2)\,{\rm d}M = \frac{\langle N_{\rm s}\rangle_M(L_1,L_2)}{\overline{n}_{\rm s}(L_1,L_2)}\, n(M){\rm d}M$$

$$\langle N_{\rm s}\rangle_M(L_1, L_2) = \int_{L_1}^{L_2} \Phi_{\rm s}(L|M)\,{\rm d}L$$



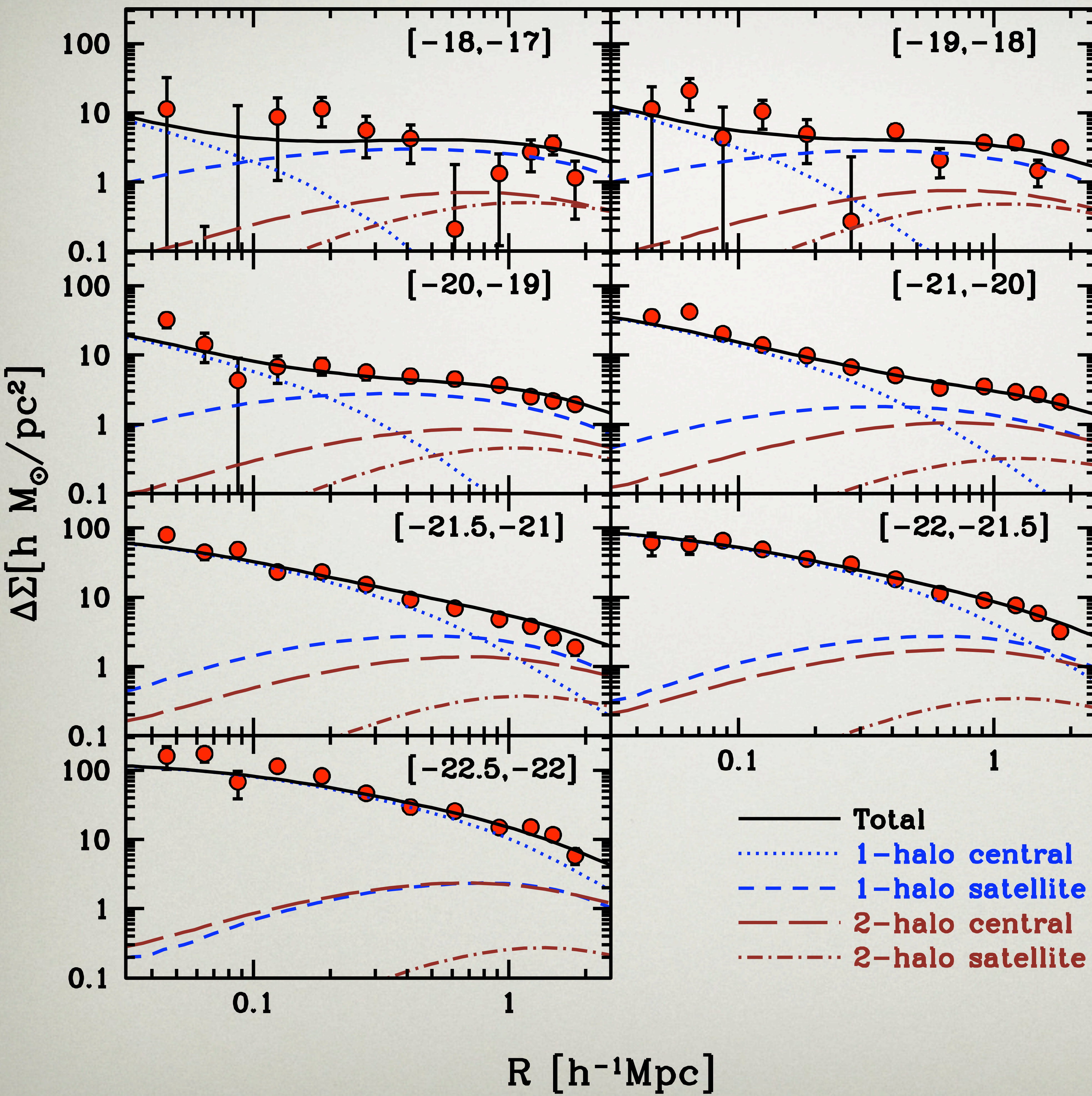
Putting all together...

- Galaxy clustering used to constrain the ***conditional luminosity function*** (CLF)

- The corresponding ***halo occupation statistics*** used to carefully model the lensing signal

- ***Theoretical predictions*** can be provided
    - and directly ***compared with data***

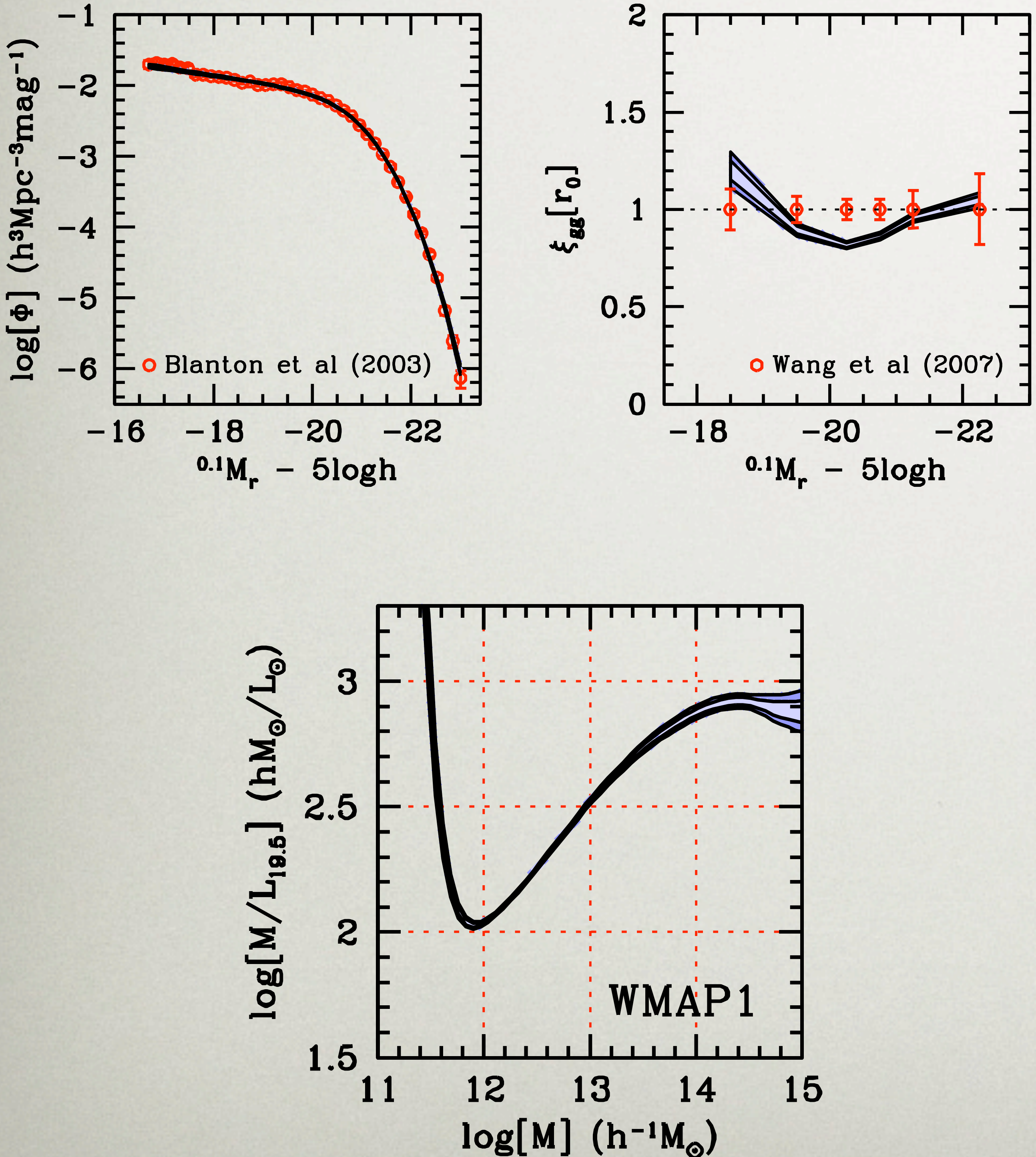

Results



NO FIT!!!

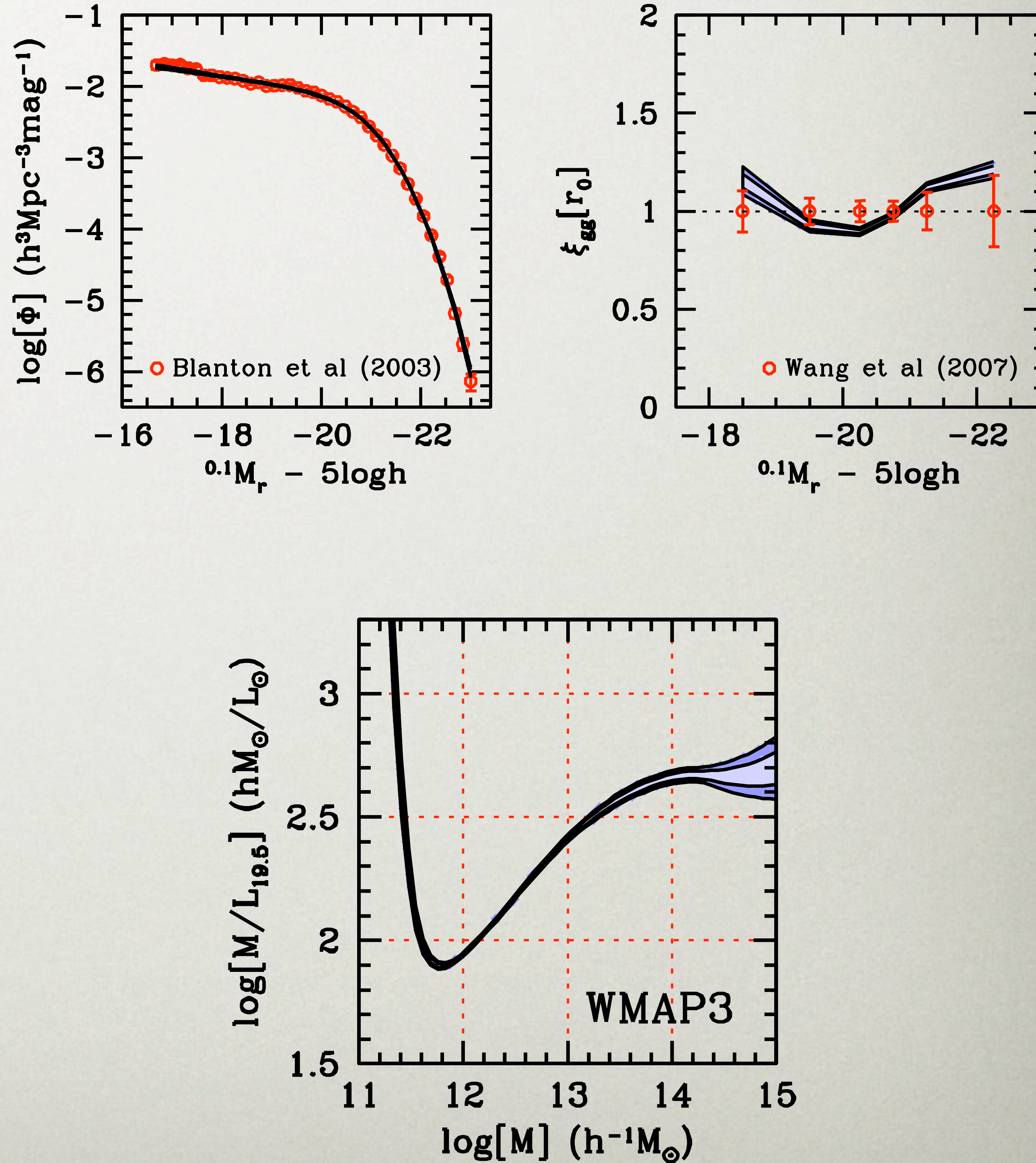
SIGNAL COMPLETELY PREDICTED BY CLF

WMAP1



Blanton et al (2003)
log[Φ] (h³Mpc⁻³mag⁻¹)
0.1Mr − 5logh
Wang et al (2007)
ξgg[r0]
0.1Mr − 5logh
log[M/L19.5] (hM⊙/L⊙)
log[M] (h⁻¹M⊙)
WMAP1

WMAP3



Blanton et al (2003)
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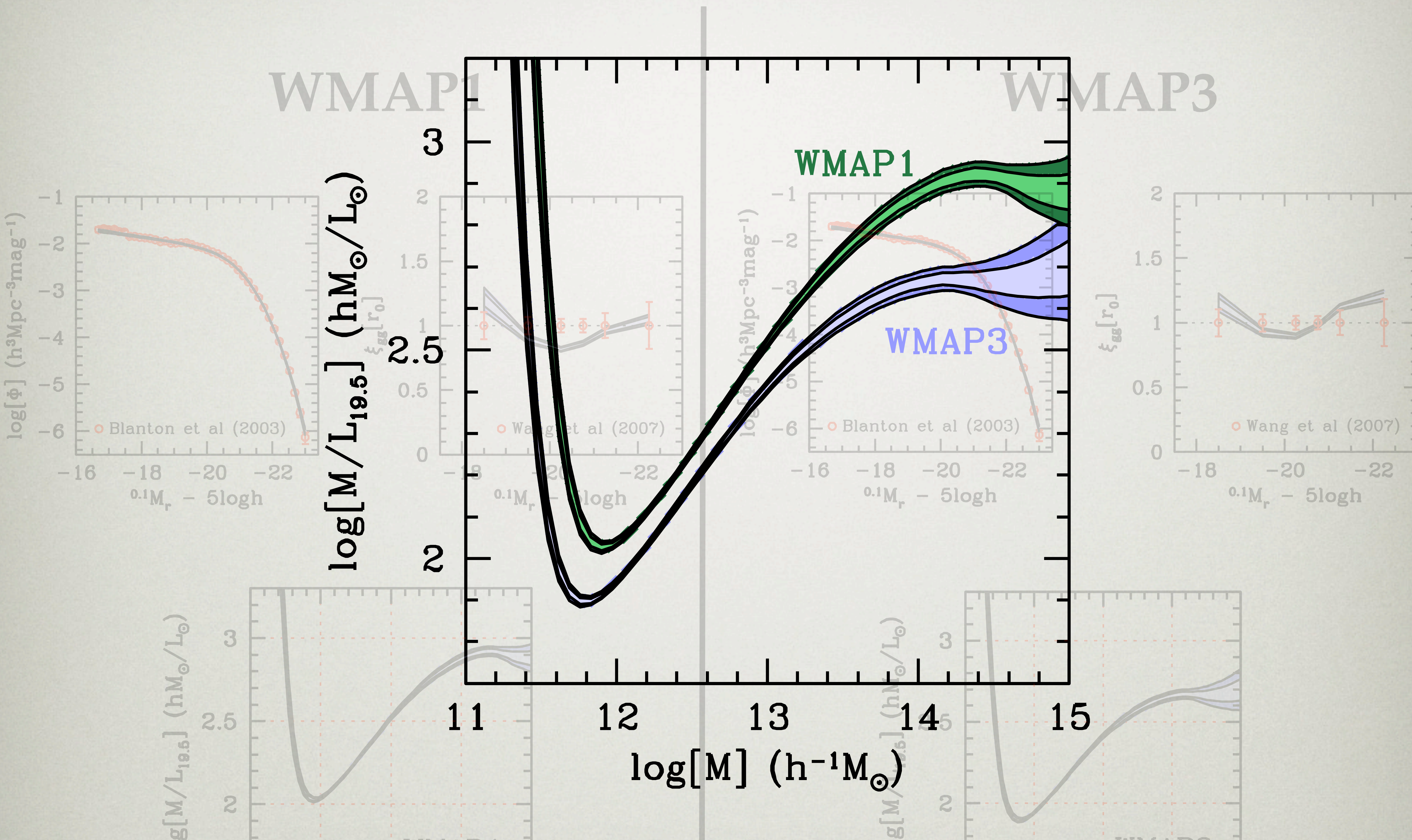
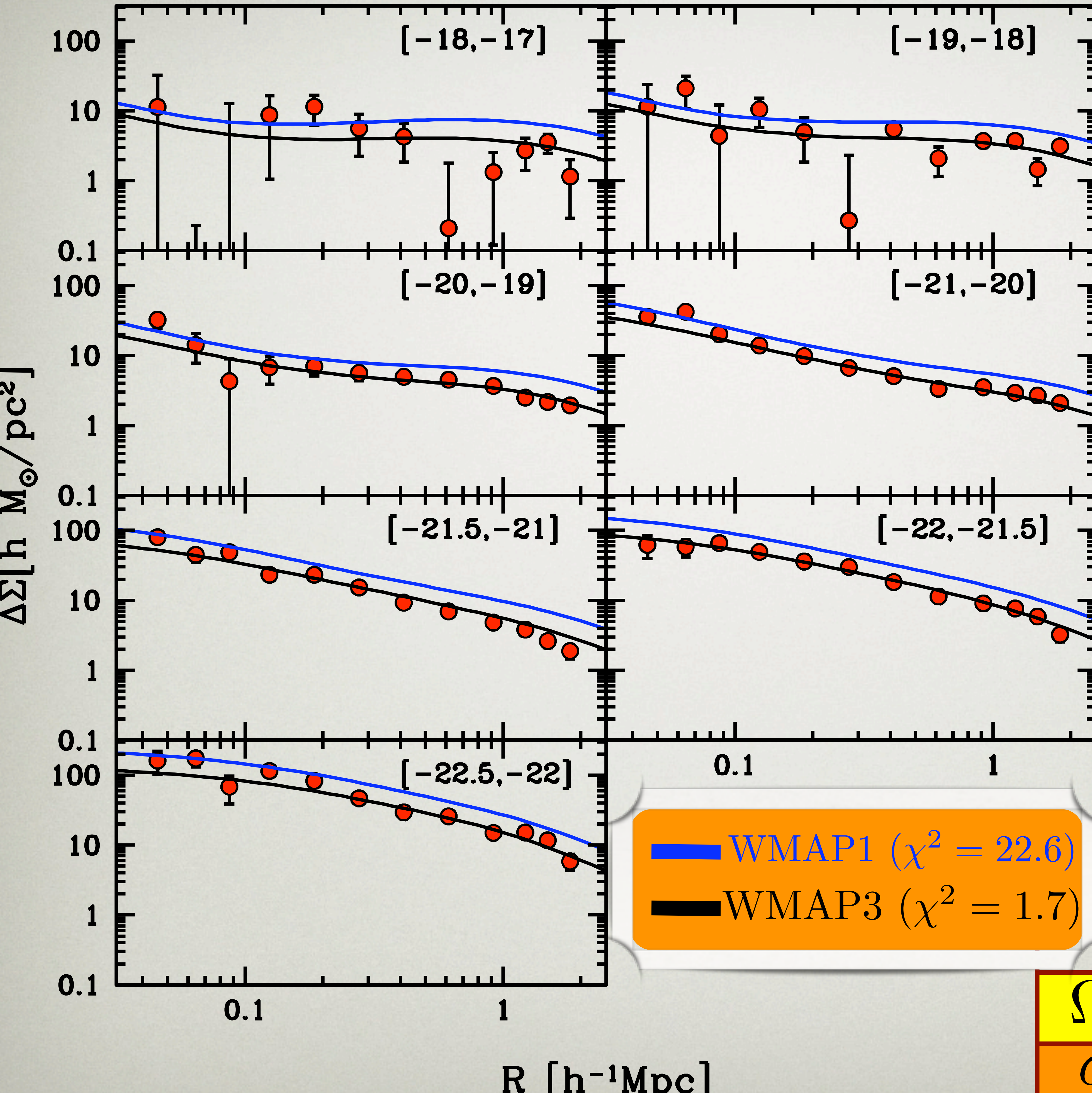
ξgg[r0]
0.1Mr − 5logh
log[M/L19.5] (hM⊙/L⊙)
log[M] (h⁻¹M⊙)
WMAP3



CLF alone cannot constrain cosmology but ...



WMAP3 CLEARLY PREFERRED

	WMAP1	WMAP3
Ω_m	0.3	0.27
σ_8	0.9	0.74

Conclusions

- G-G Lensing is a powerful technique to constrain the galaxy-dark matter relation
- The stacking procedure, required to achieve accurate measurements, complicates the physical interpretation
- The CLF provides a realistic model for the galaxy-dark matter connection
- By using the CLF, the g-g lensing is modelled with great level of detail
- Predictions are in excellent agreement with SDSS data
- The joint analysis of galaxy clustering and g-g lensing can be used "to constrain" cosmology

Thanks