Measuring and Analysing Galaxy Clustering with SDSS Photometric Data

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Collaborators:
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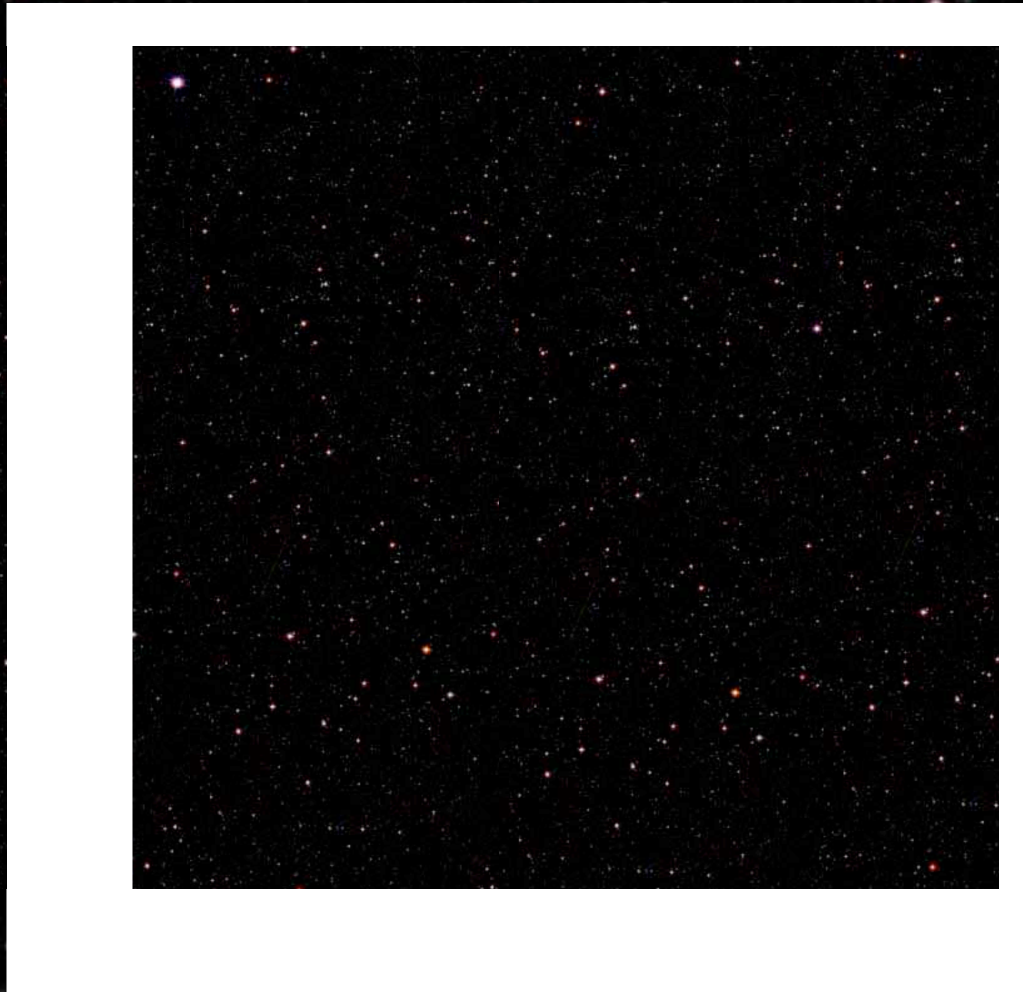
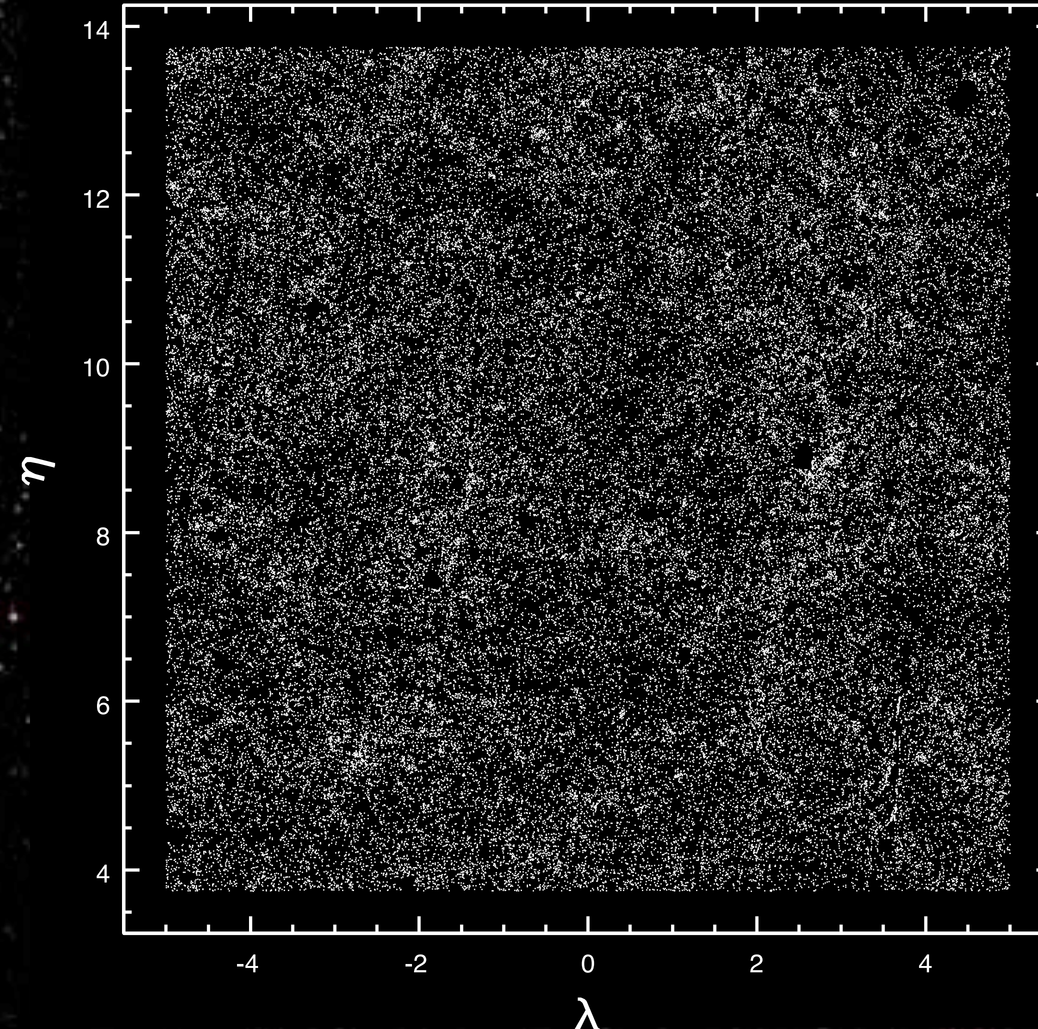
Outline

- Measuring clustering with photometric surveys
- Bias of red galaxies
- HOD constraints from SDSS data
- DES and beyond

Ashley J Ross LBNL April 1st, 2011





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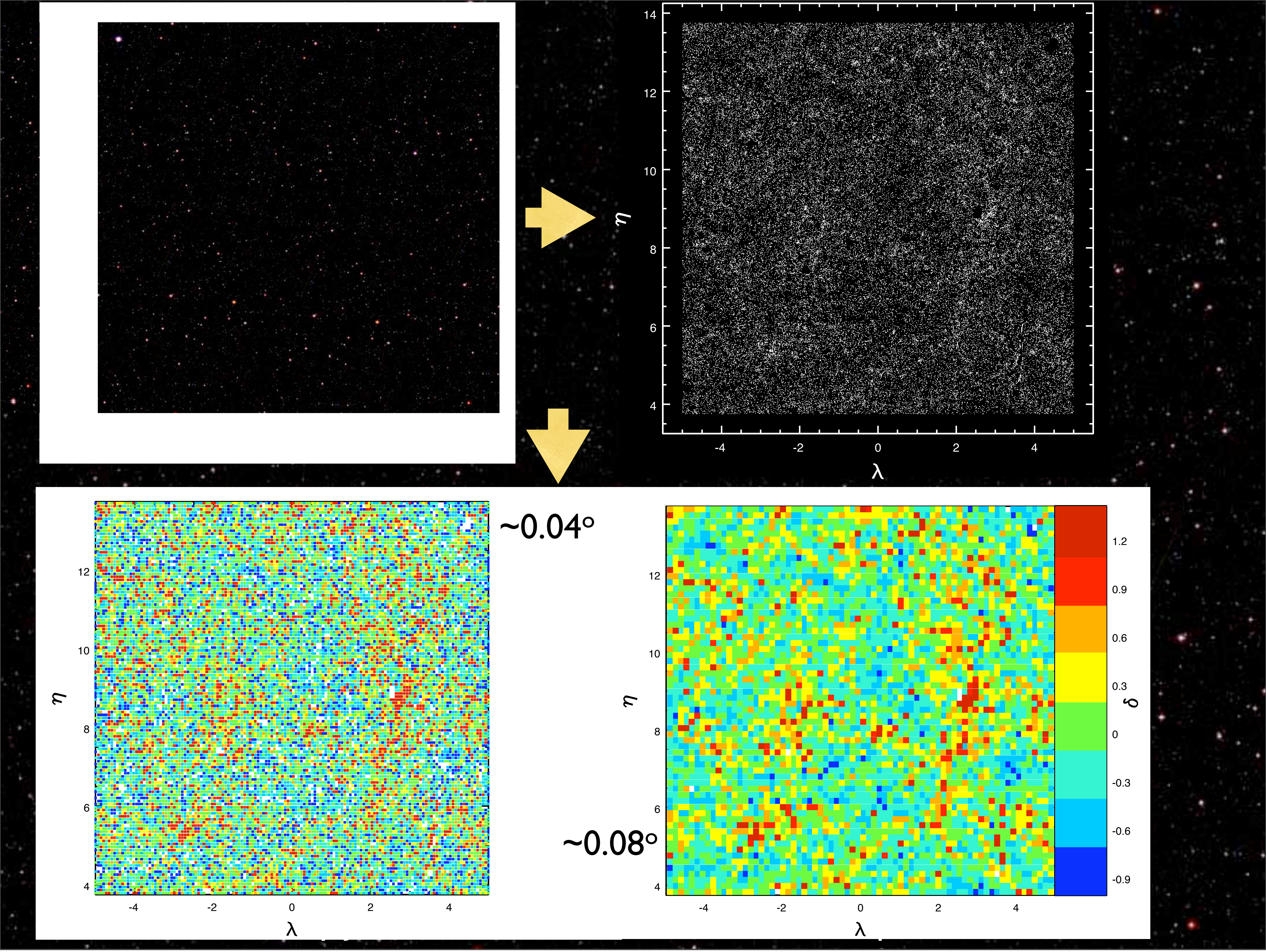


~0.04°
~0.08°
η
λ
δ
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9

Correlation Functions

- Overdensity, $\delta = \frac{N}{\langle N \rangle} - 1$
- 2-point angular correlation function, w:

  $w_2(\theta) = \langle \delta_i \delta_j \rangle$

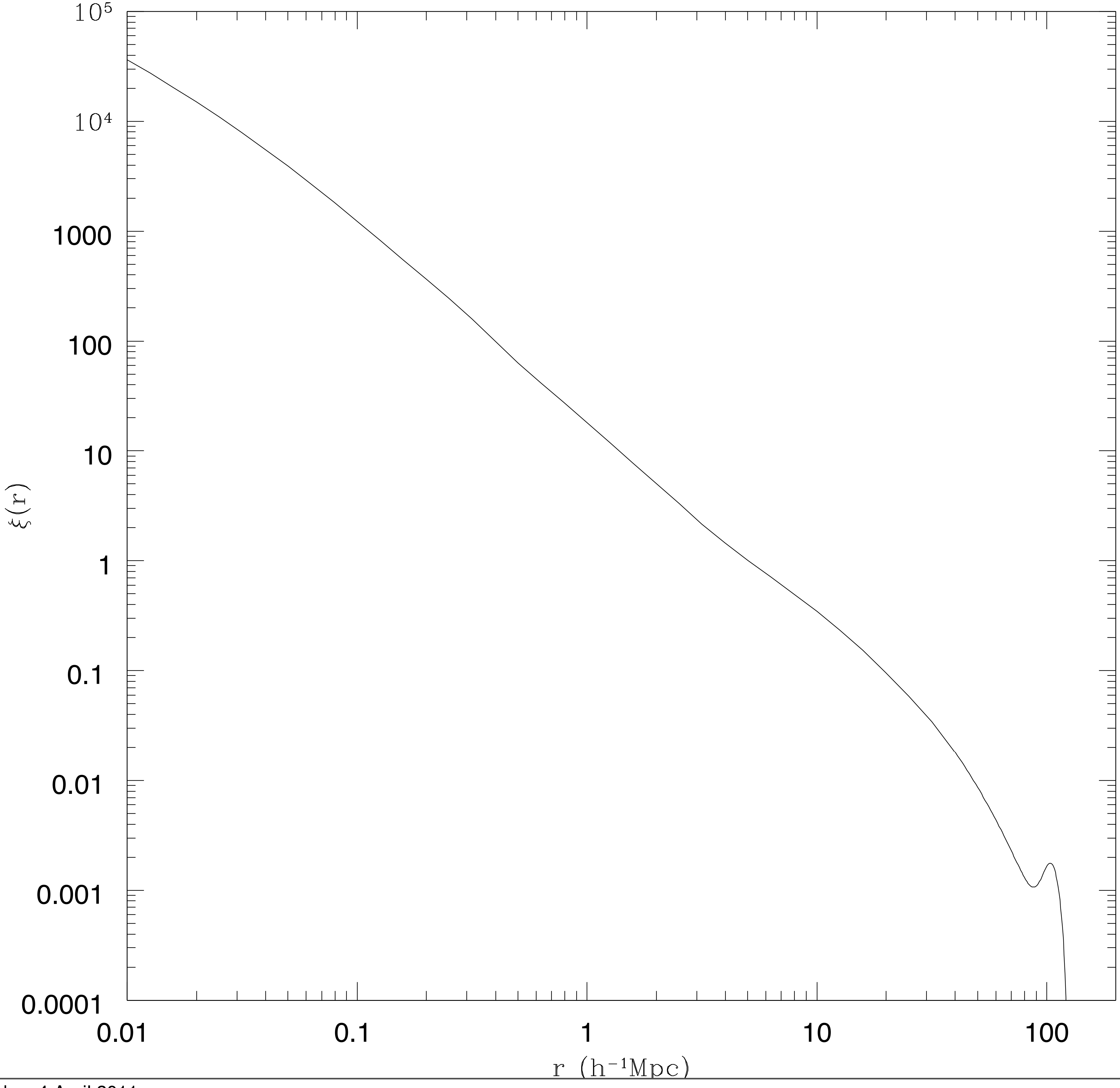
  - Alternatively:

    $w_2(\theta) = DD(\theta)/RR(\theta) - 1$

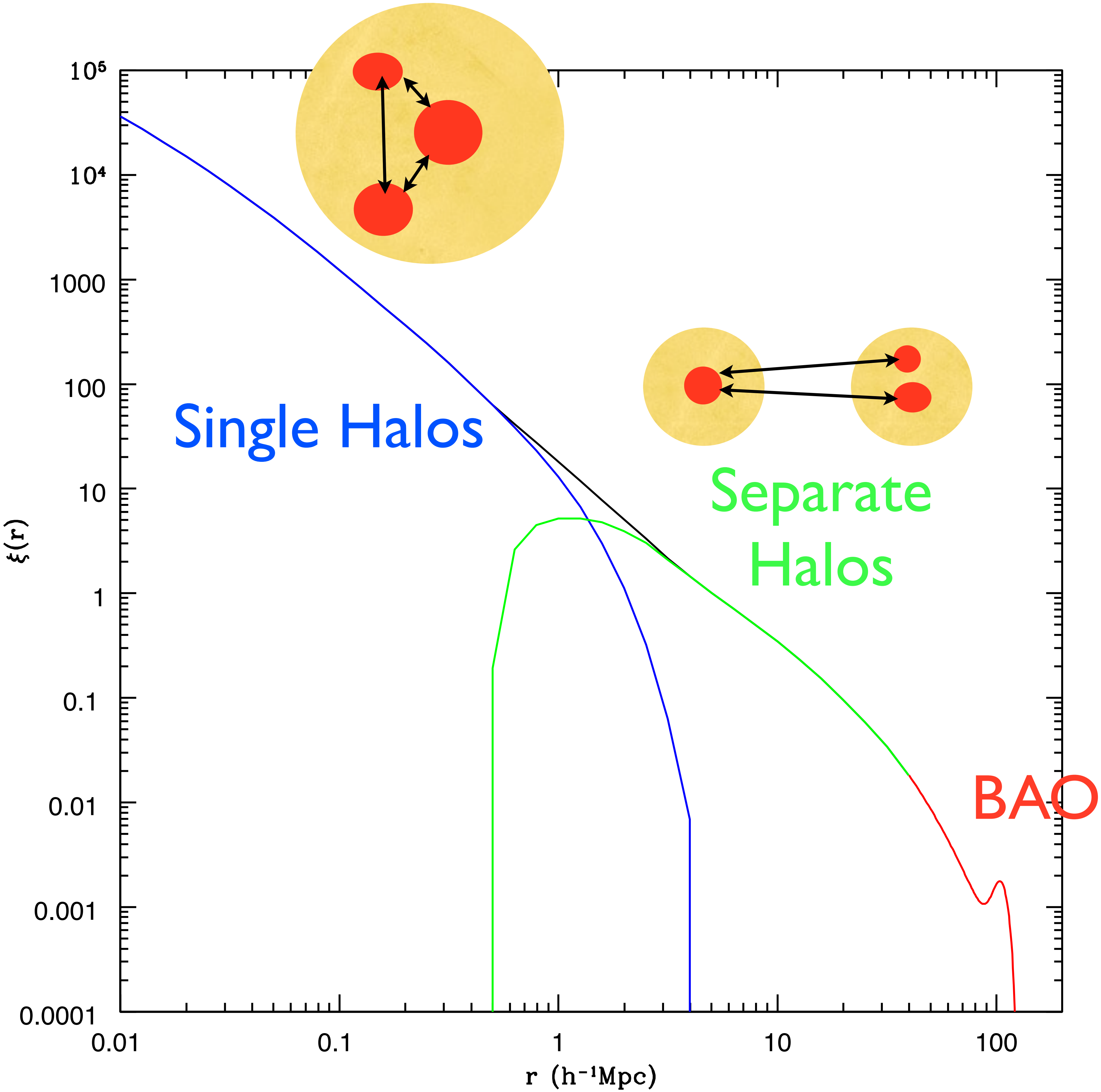
  - Real-space denoted

    $\xi_2(r)$

- Fourier transform $P(k)$, angular version C_ℓ



ξ(r)
10^5
10^4
1000
100
10
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
100
r (h^{-1}Mpc)



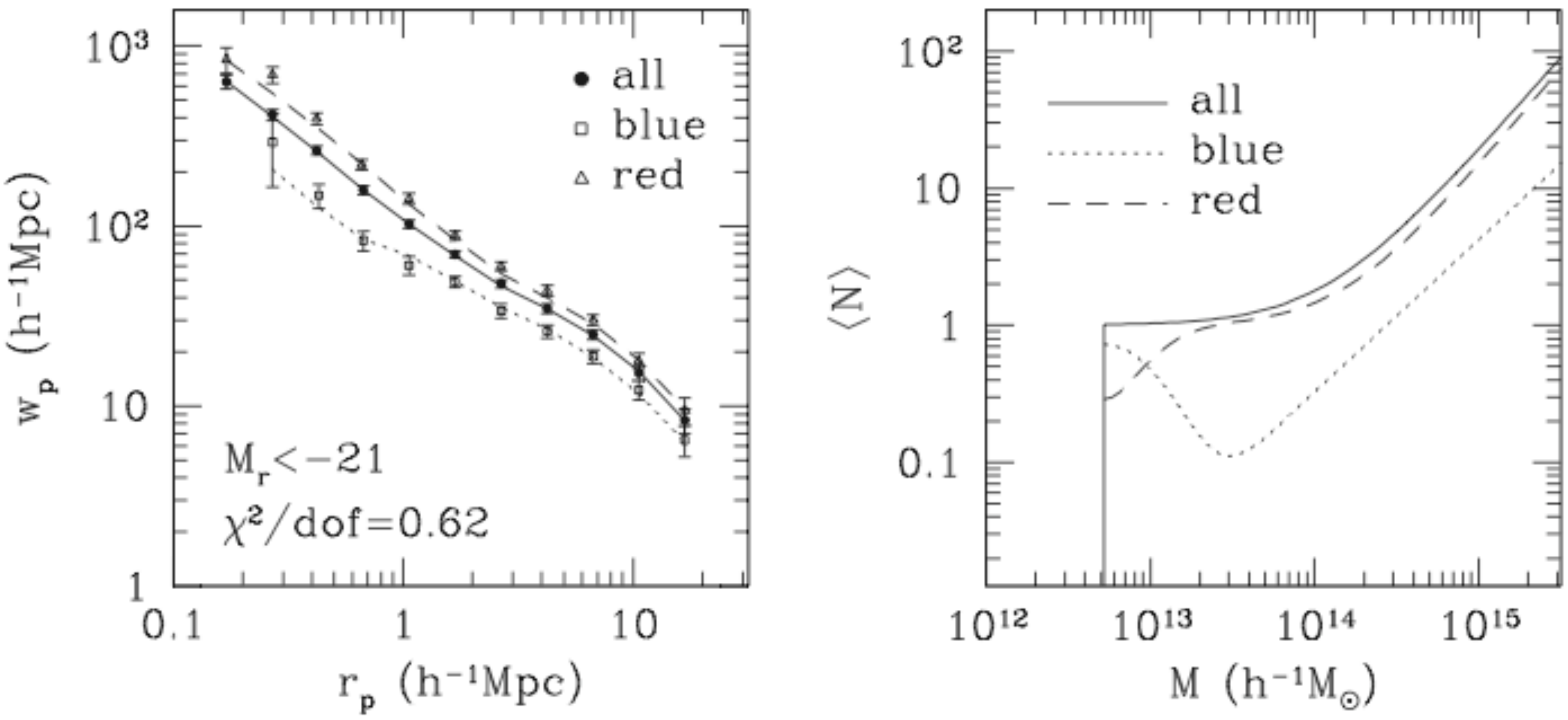
Single Halos
Separate Halos
BAO
ξ(r)
r (h⁻¹Mpc)
10⁵
10⁴
1000
100
10
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
100

Why Measure Galaxy Clustering?

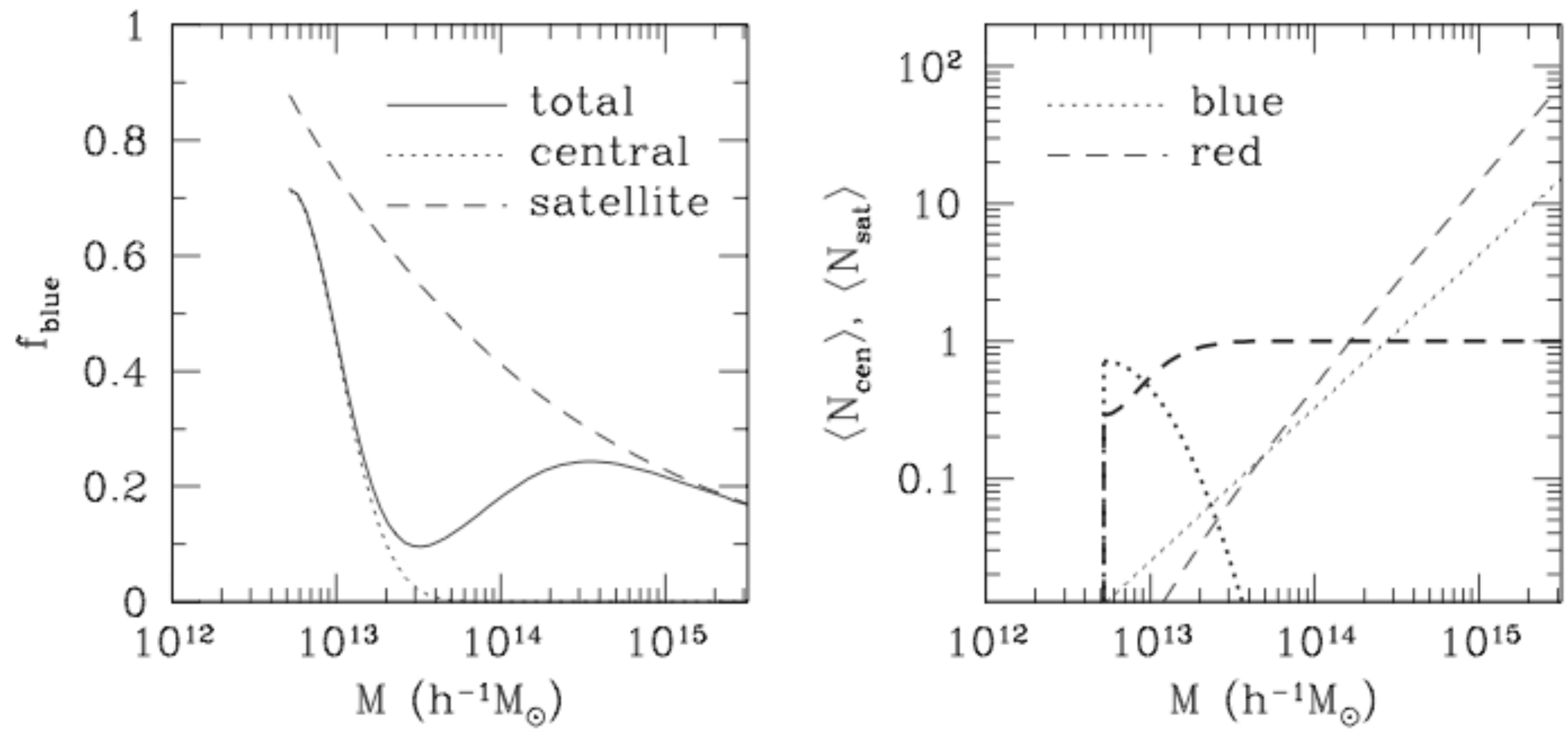
- Two main scientific pursuits:

  1) Study galaxies themselves

  2) Measure cosmological parameters



Zehavi et al. (2005)



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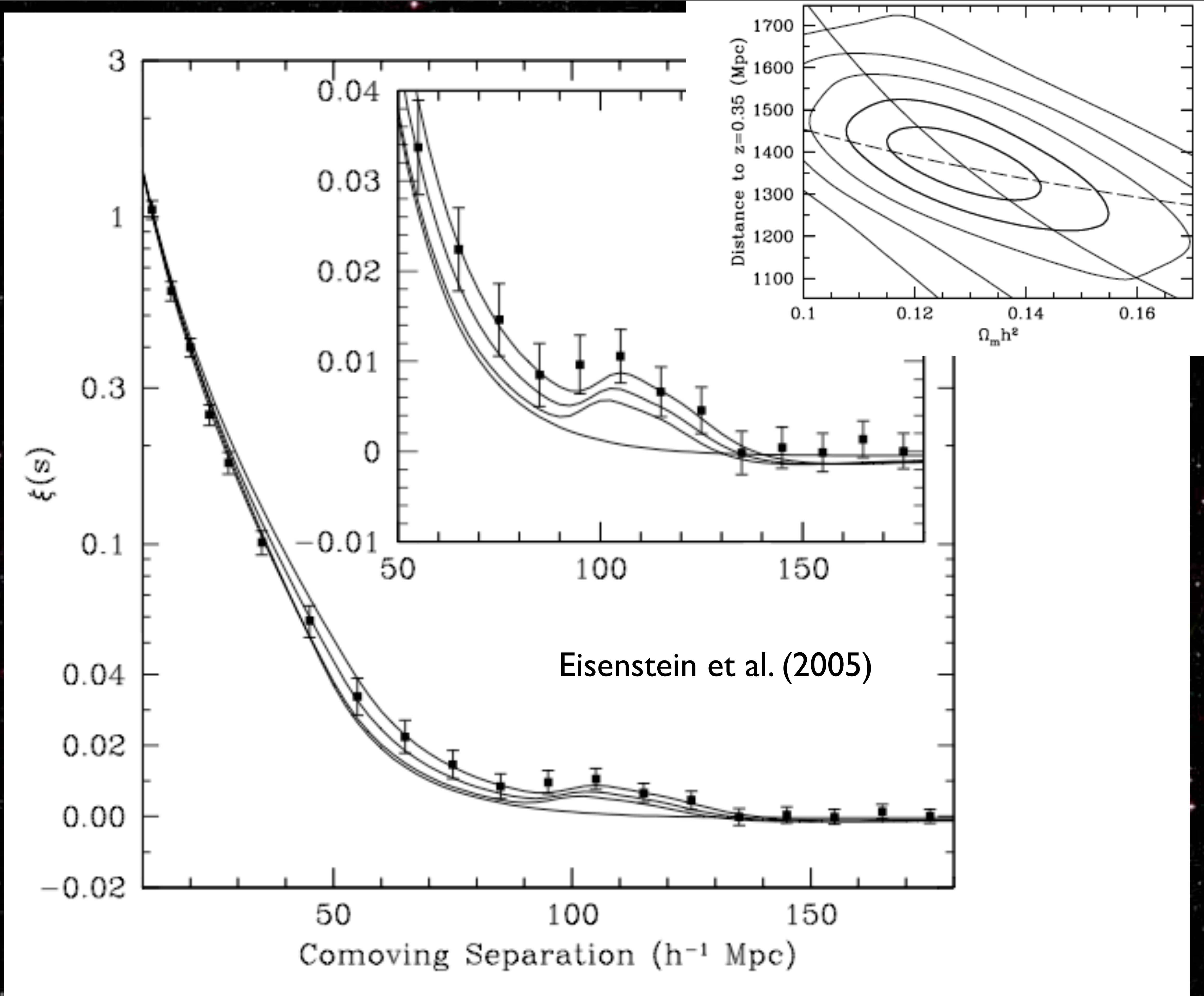
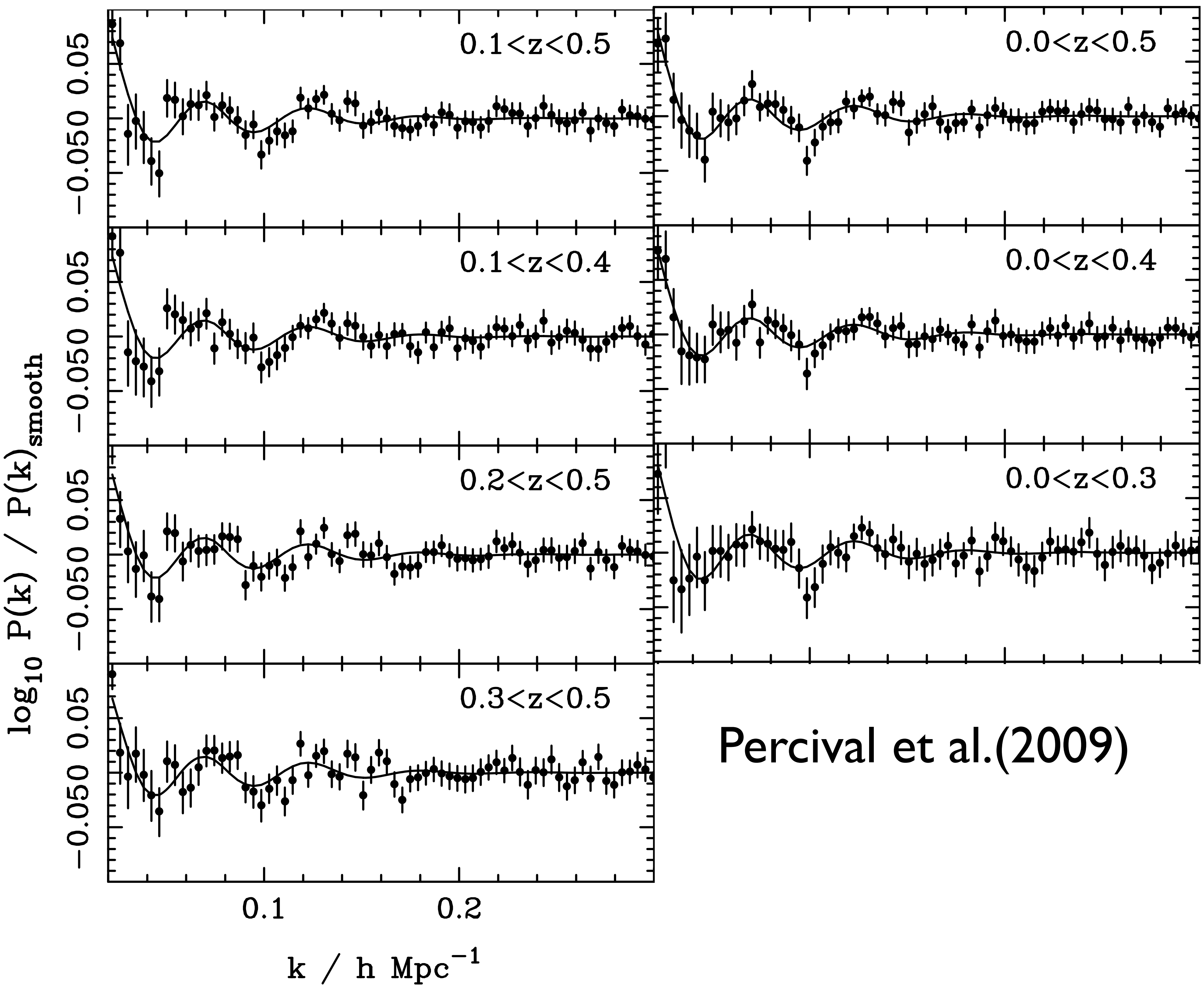
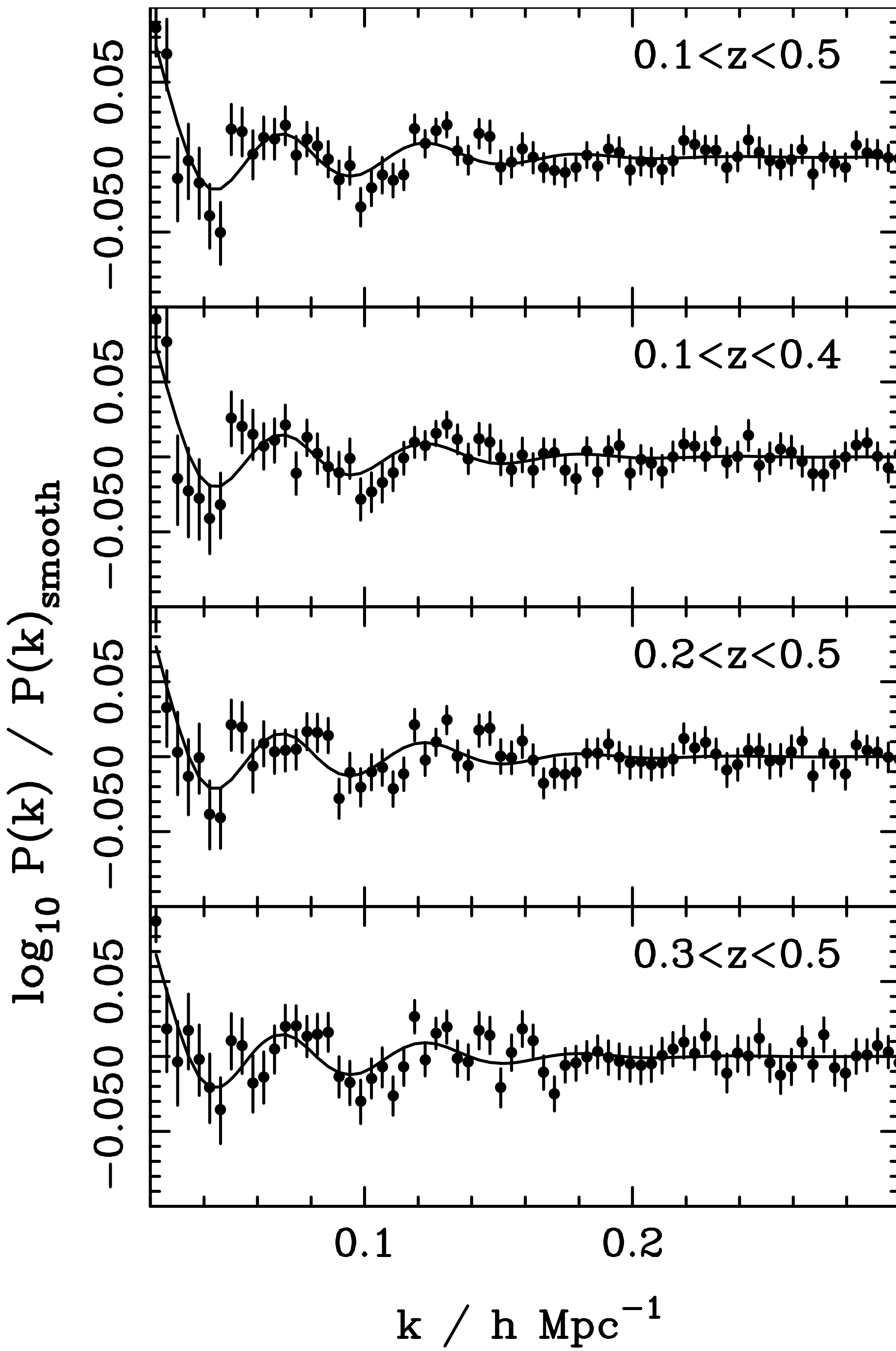
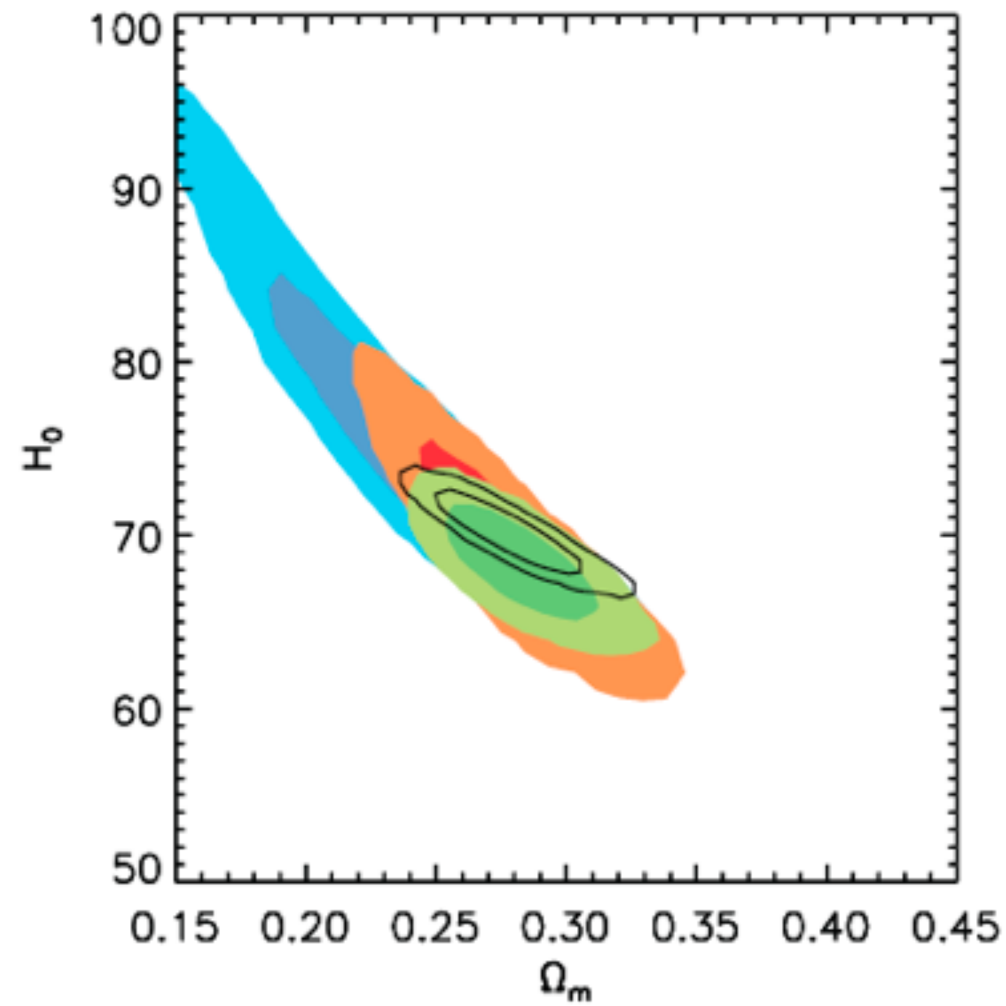


ξ(s)
Comoving Separation (h⁻¹ Mpc)
Eisenstein et al. (2005)
Distance to z=0.35 (Mpc)
$\Omega_m h^2$



Percival et al.(2009)

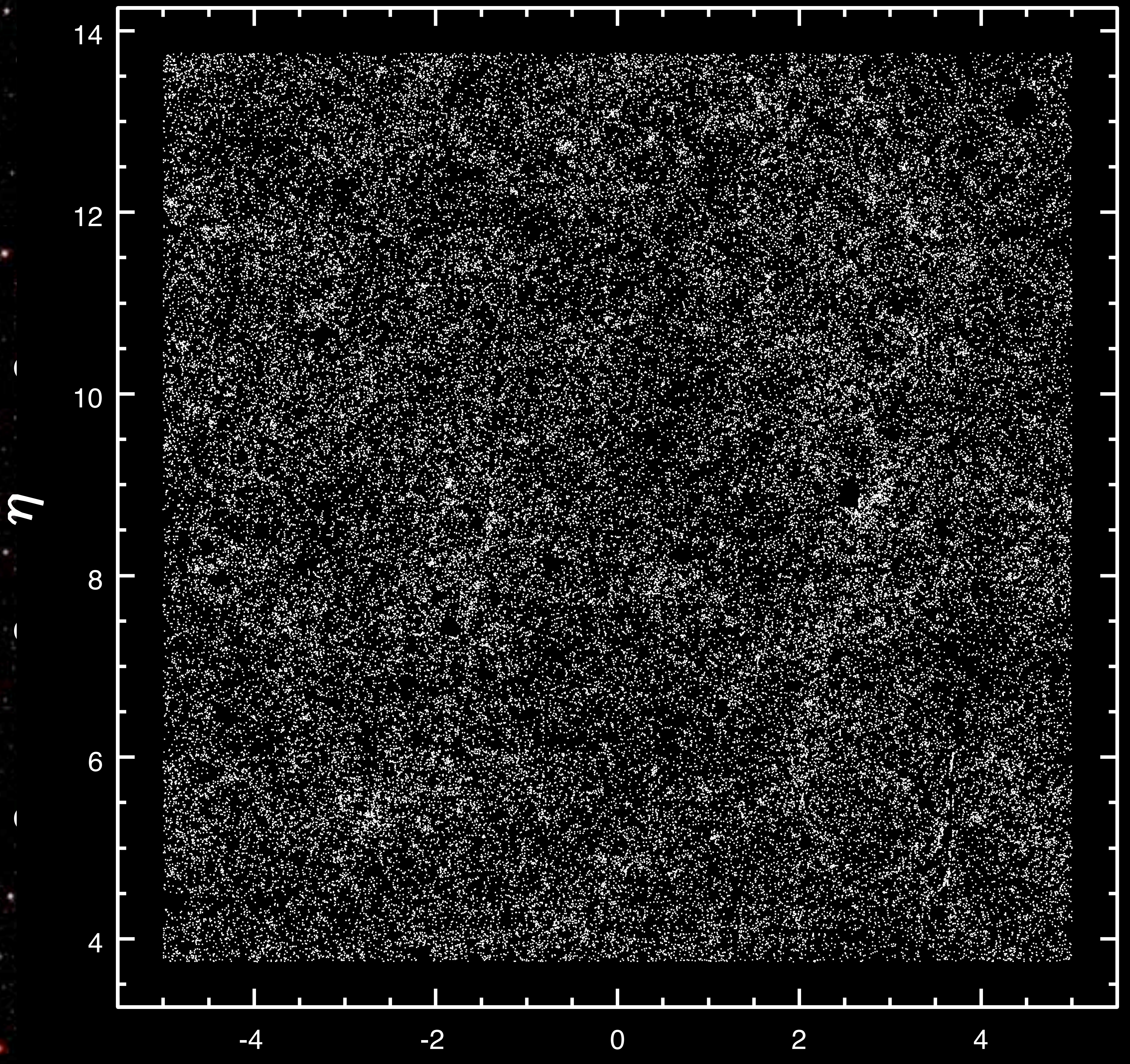




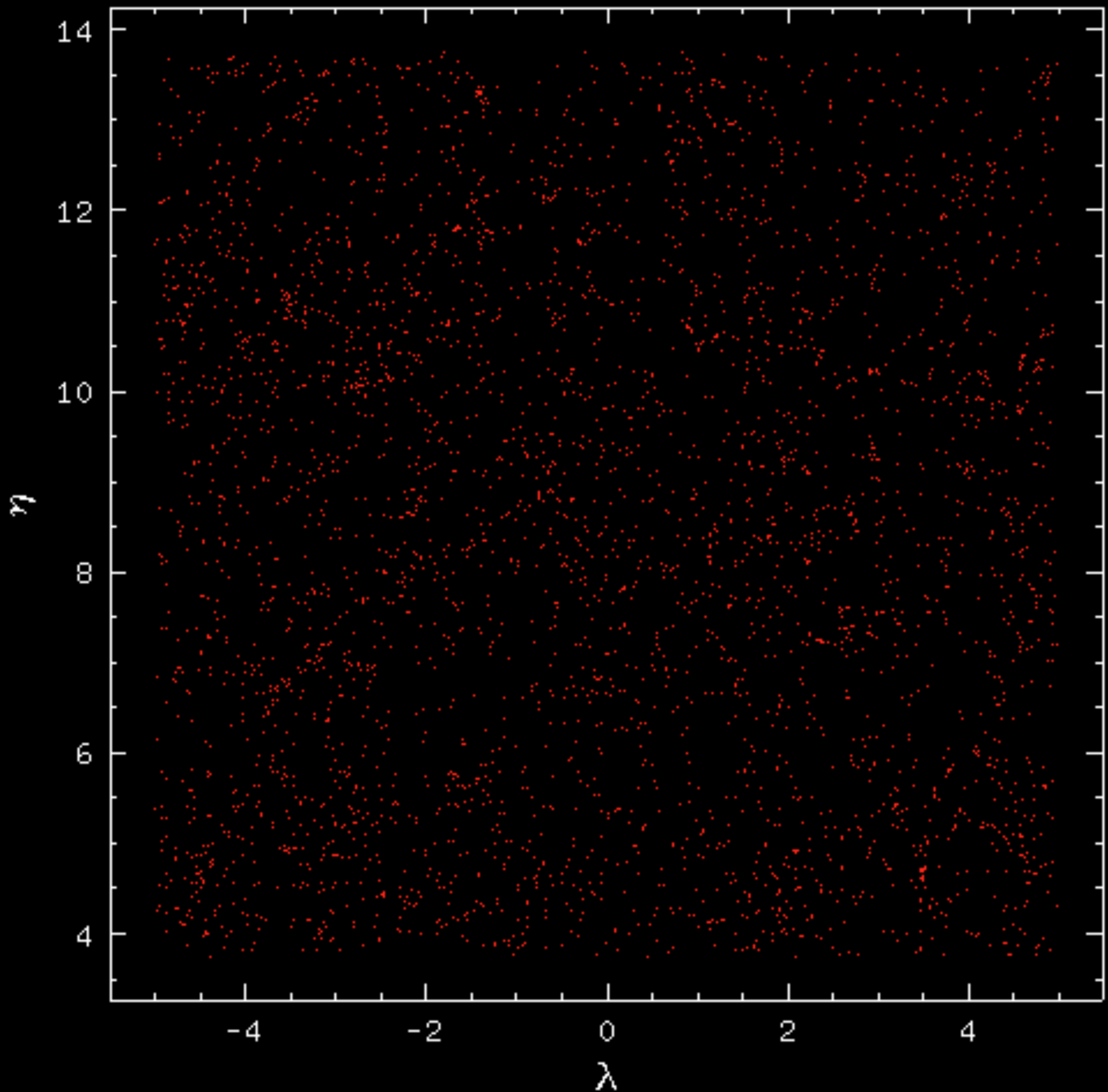
Percival et al.(2009)

Why Photometric Surveys?

- More objects at higher redshifts (SDSS has ~2x10^7 photoz galaxies; L_* observable to z ~ 0.4)
- Extremely precise measurements, no fibre collisions
- Upcoming, deeper, wide-field surveys will rely primarily on photometry (DES, Pan-STARRS, LSST)



η
14
12
10
8
6
4
-4
-2
0
2
4
λ



as

z

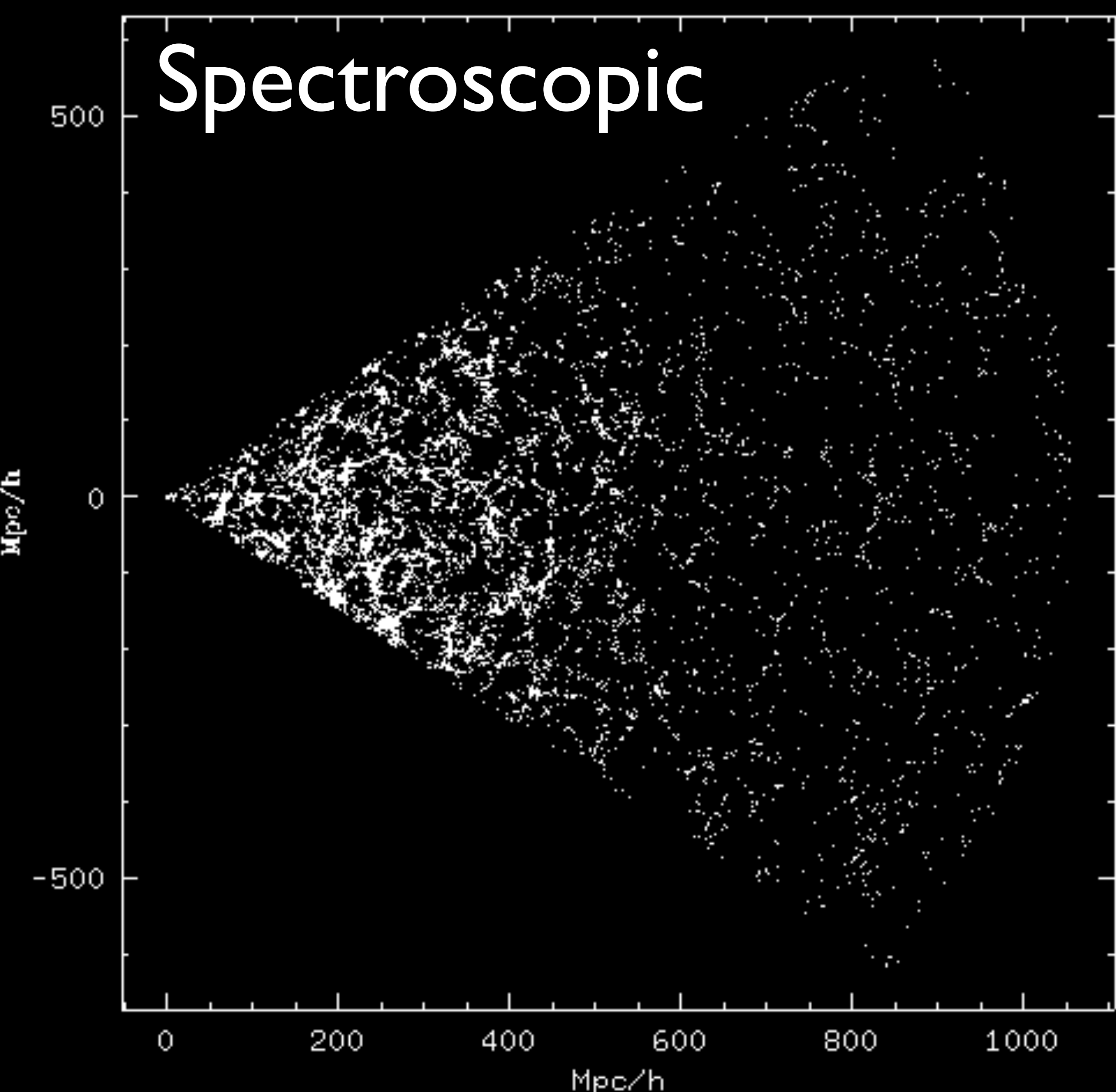
e

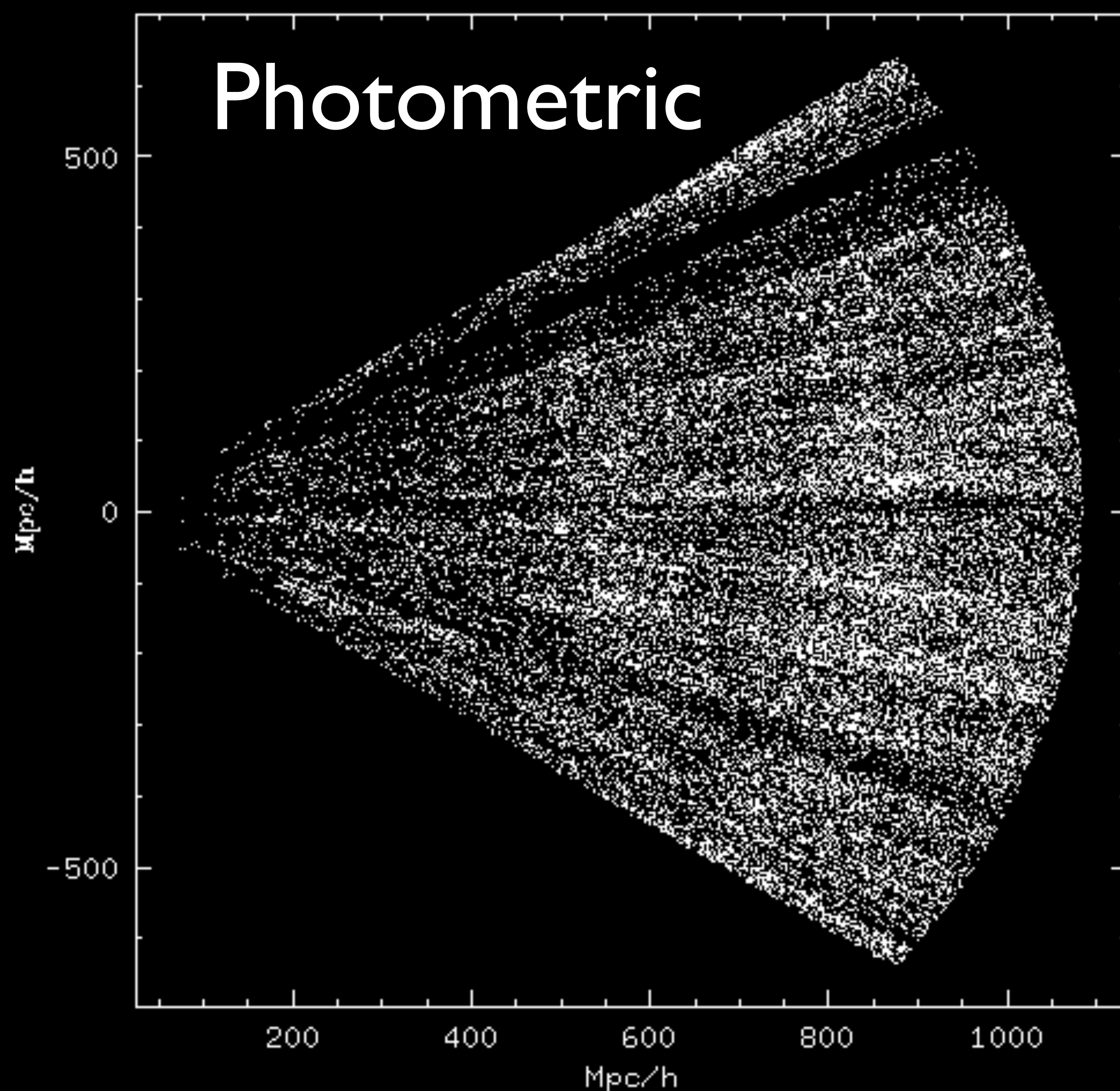
l

Photometric Redshifts

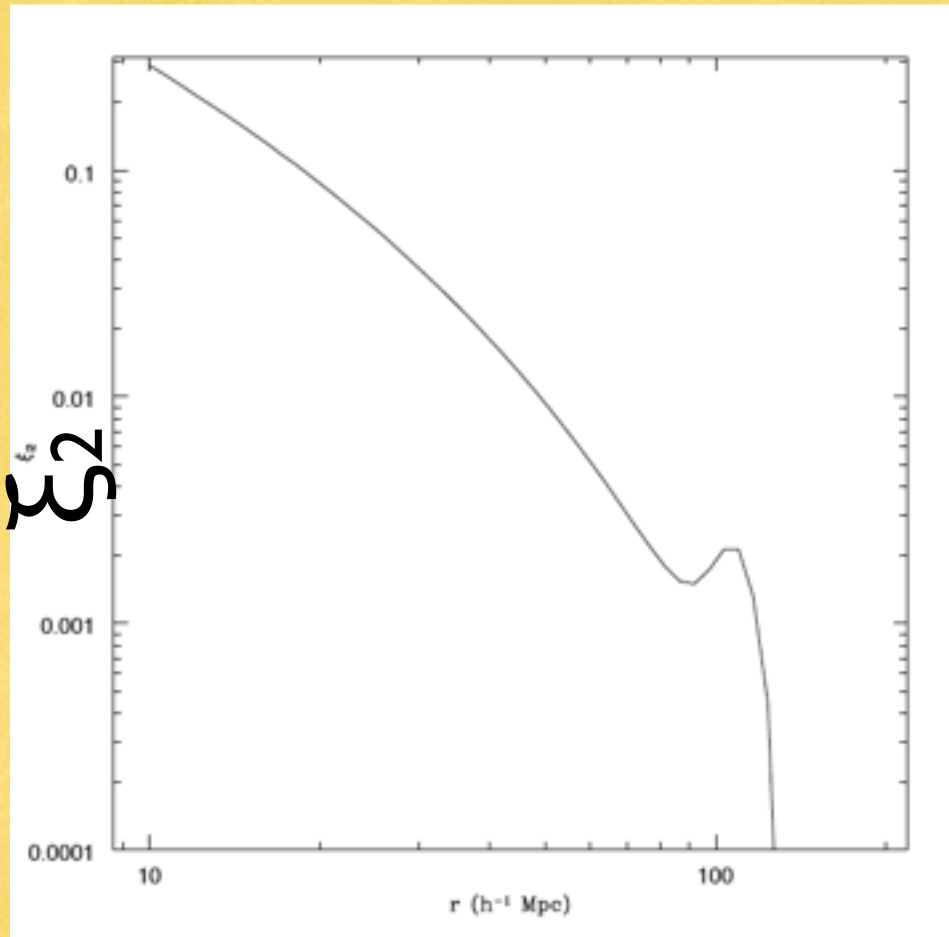
- *(u)griz(y)* imaging surveys allow $\Delta z_{phot} \sim 0.03(1 + z)$
- One can accurately recreate d*n*/dz if errors well understood
- Radial clustering nearly wiped out

Radial Clustering Wiped Out





BAO Peak Smeared



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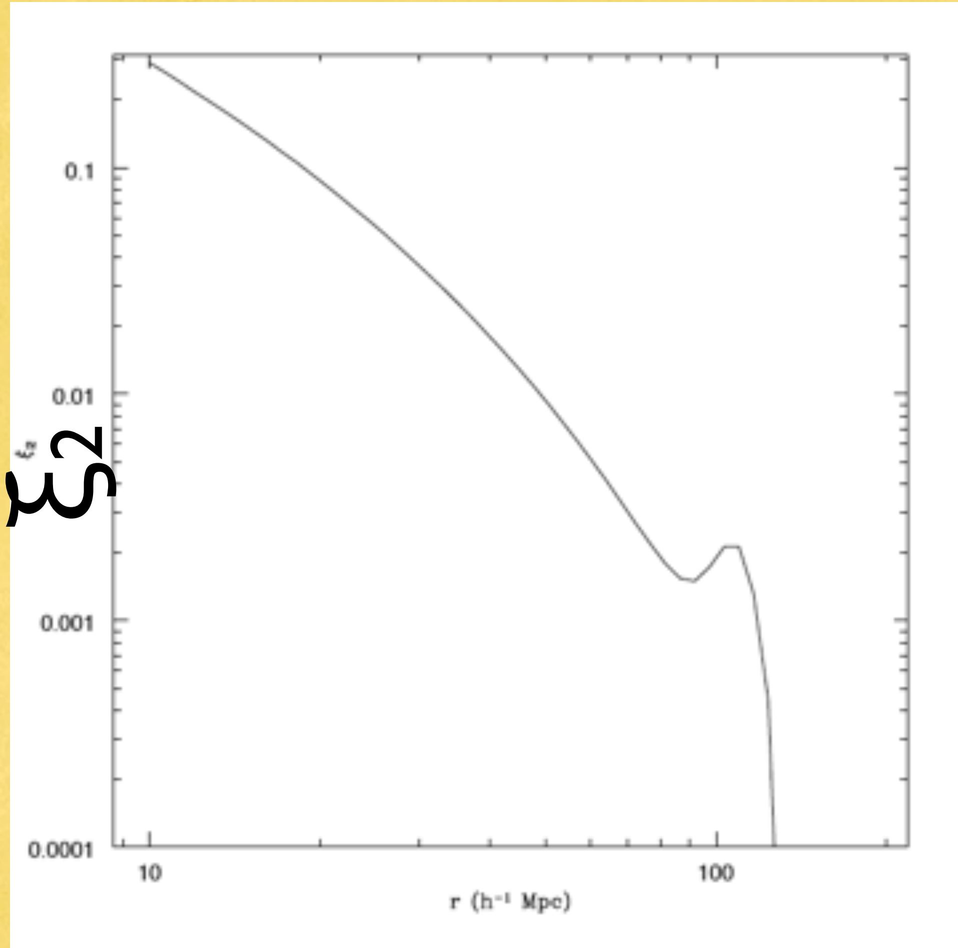

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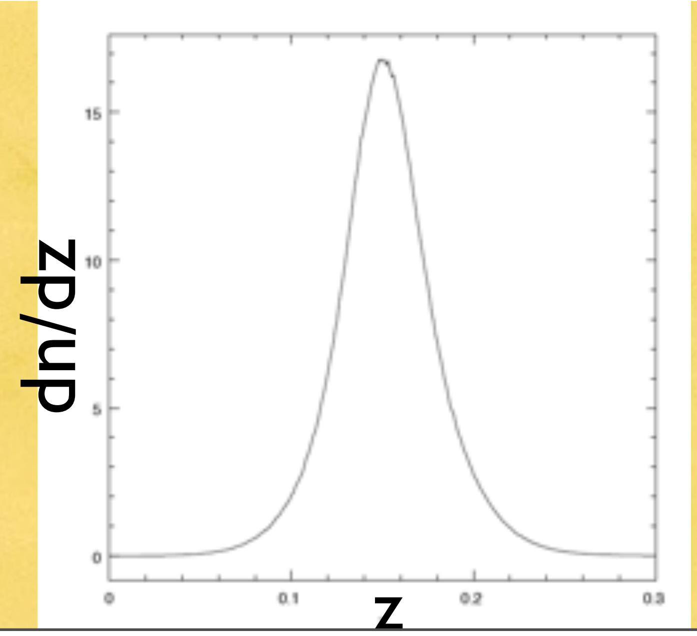

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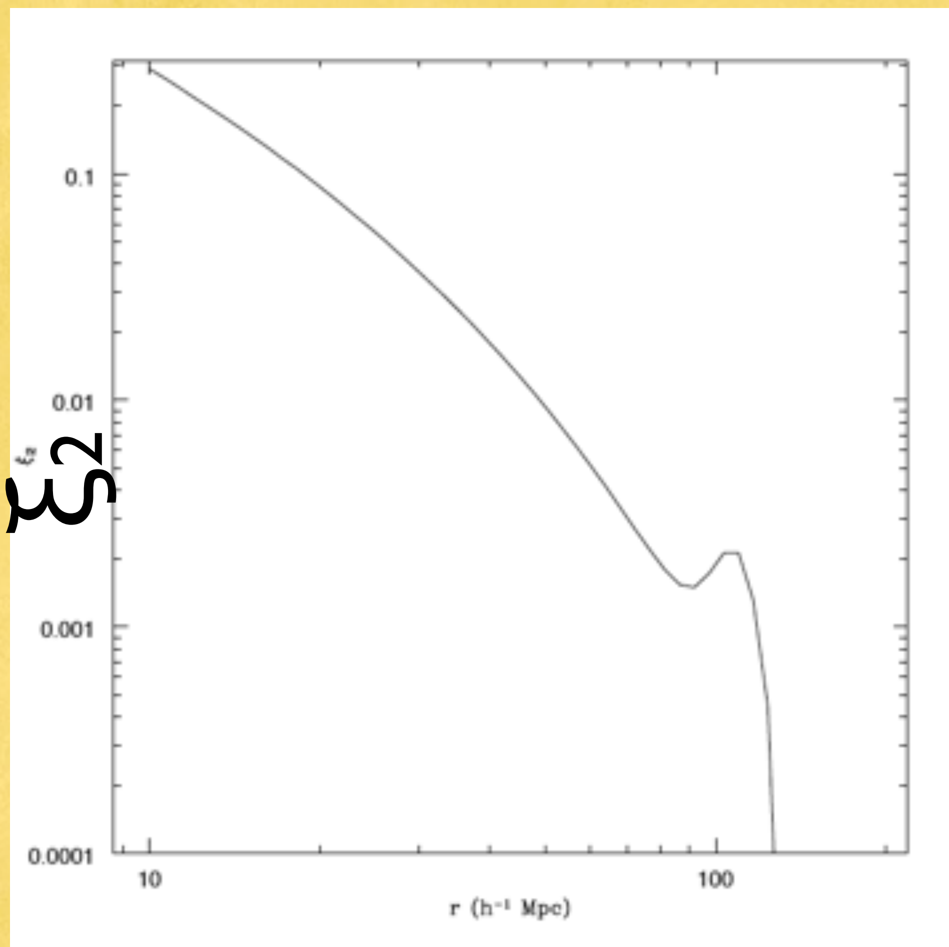

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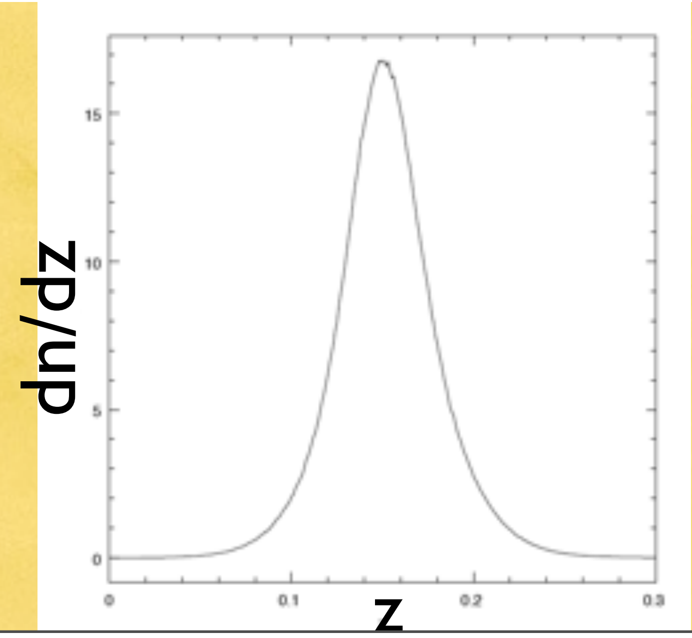
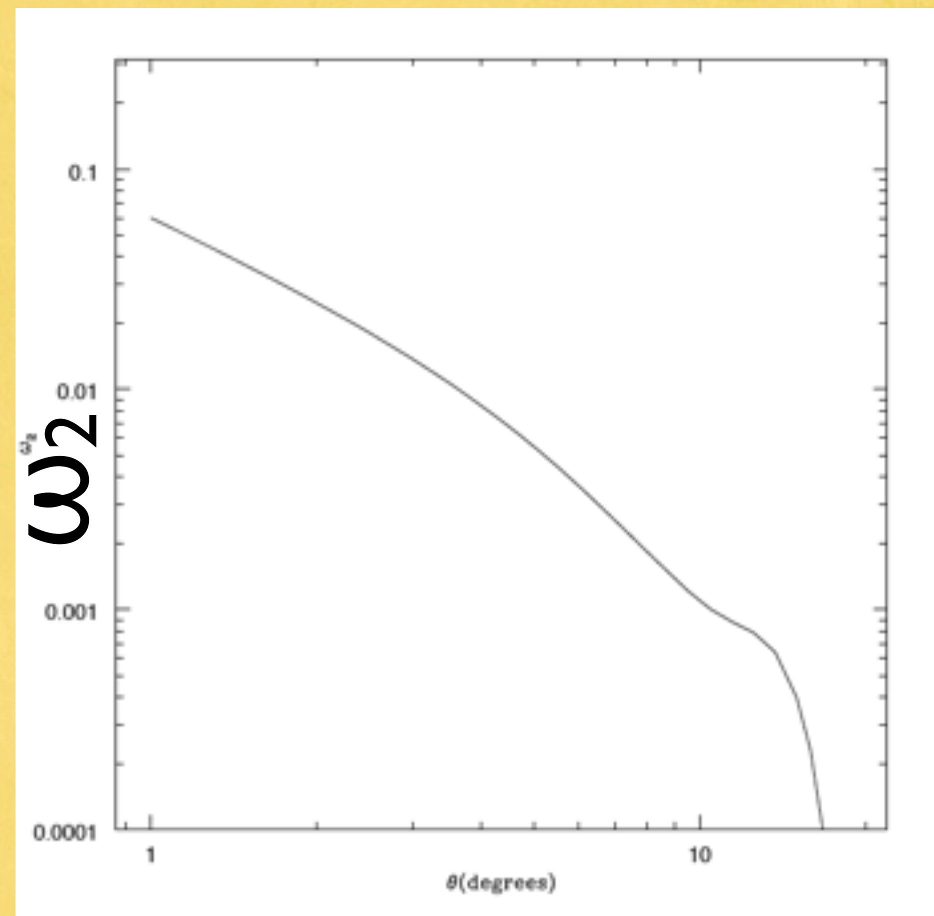
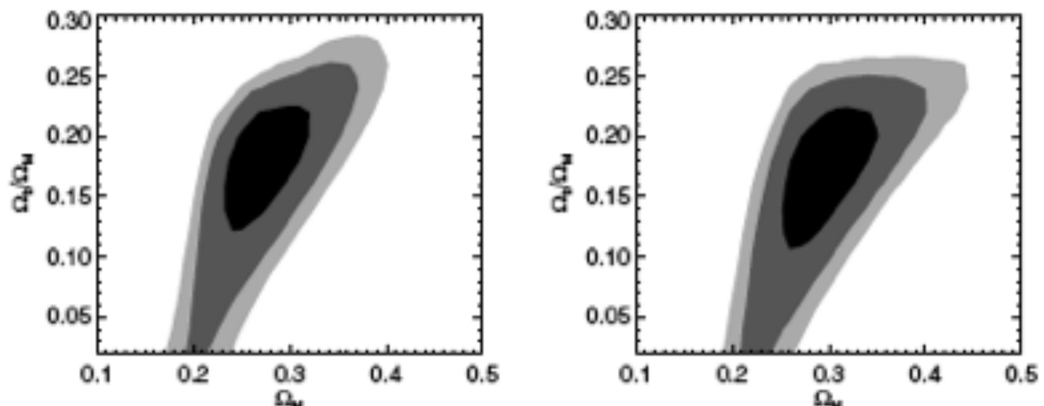
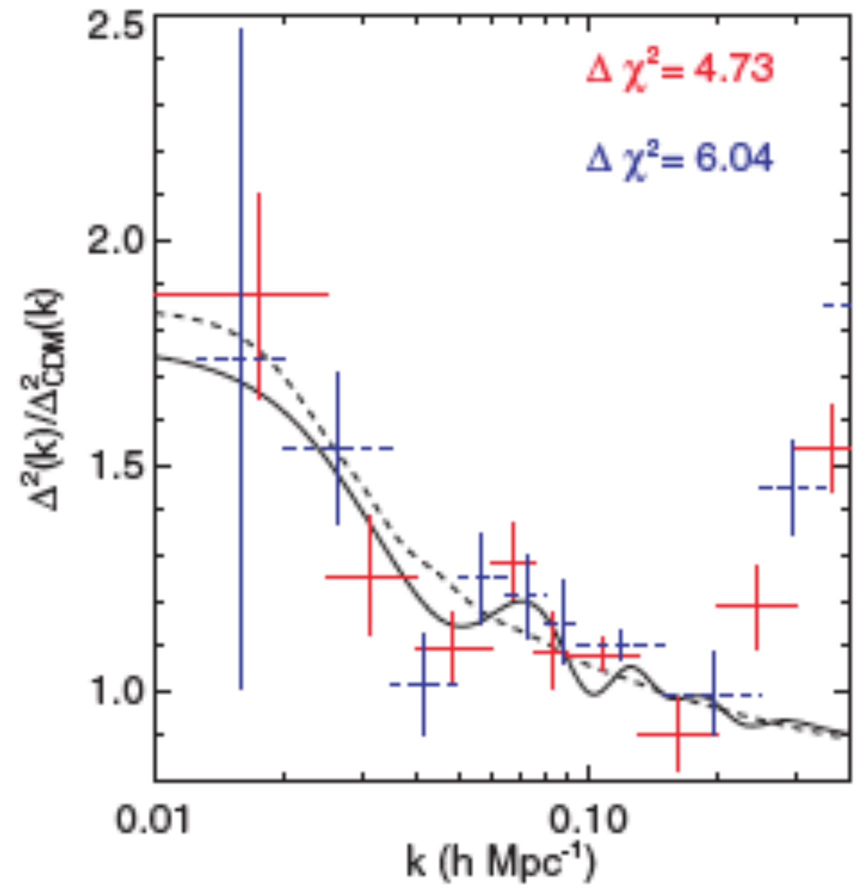


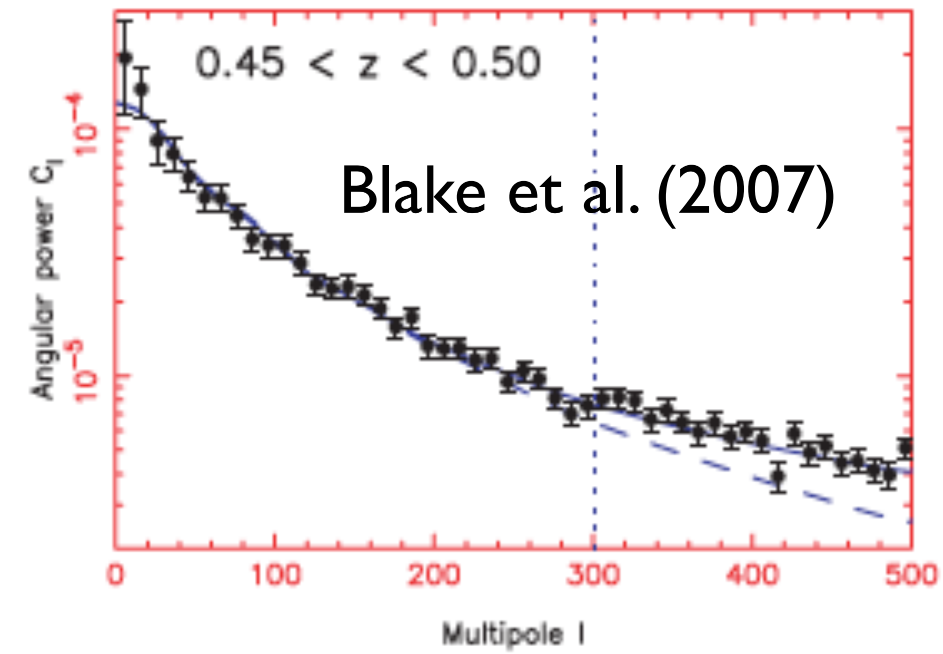


SDSS Results

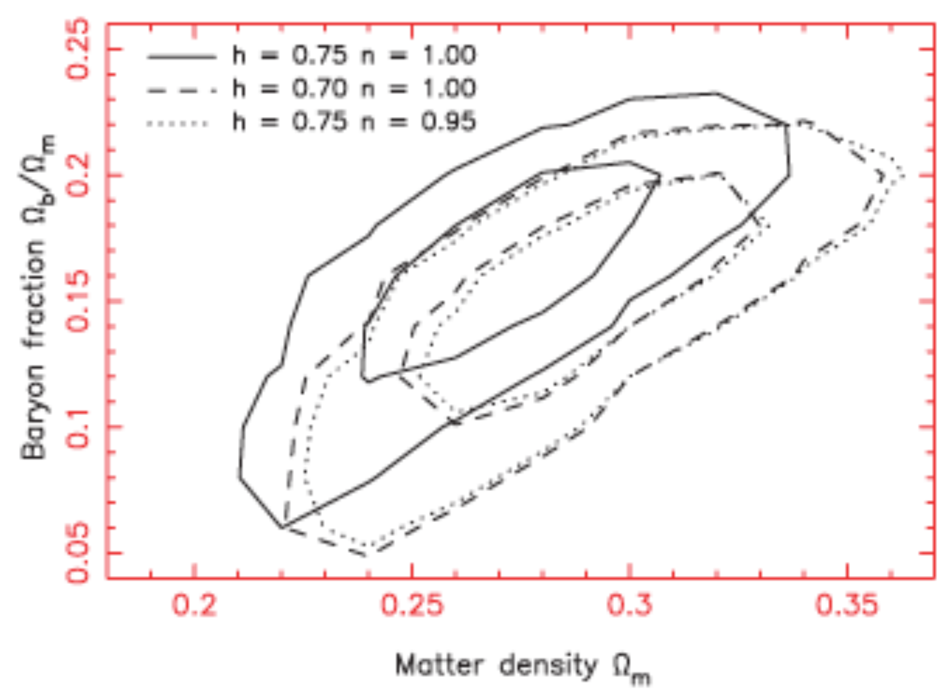


Padmanabhan et al. (2007)





Blake et al. (2007)



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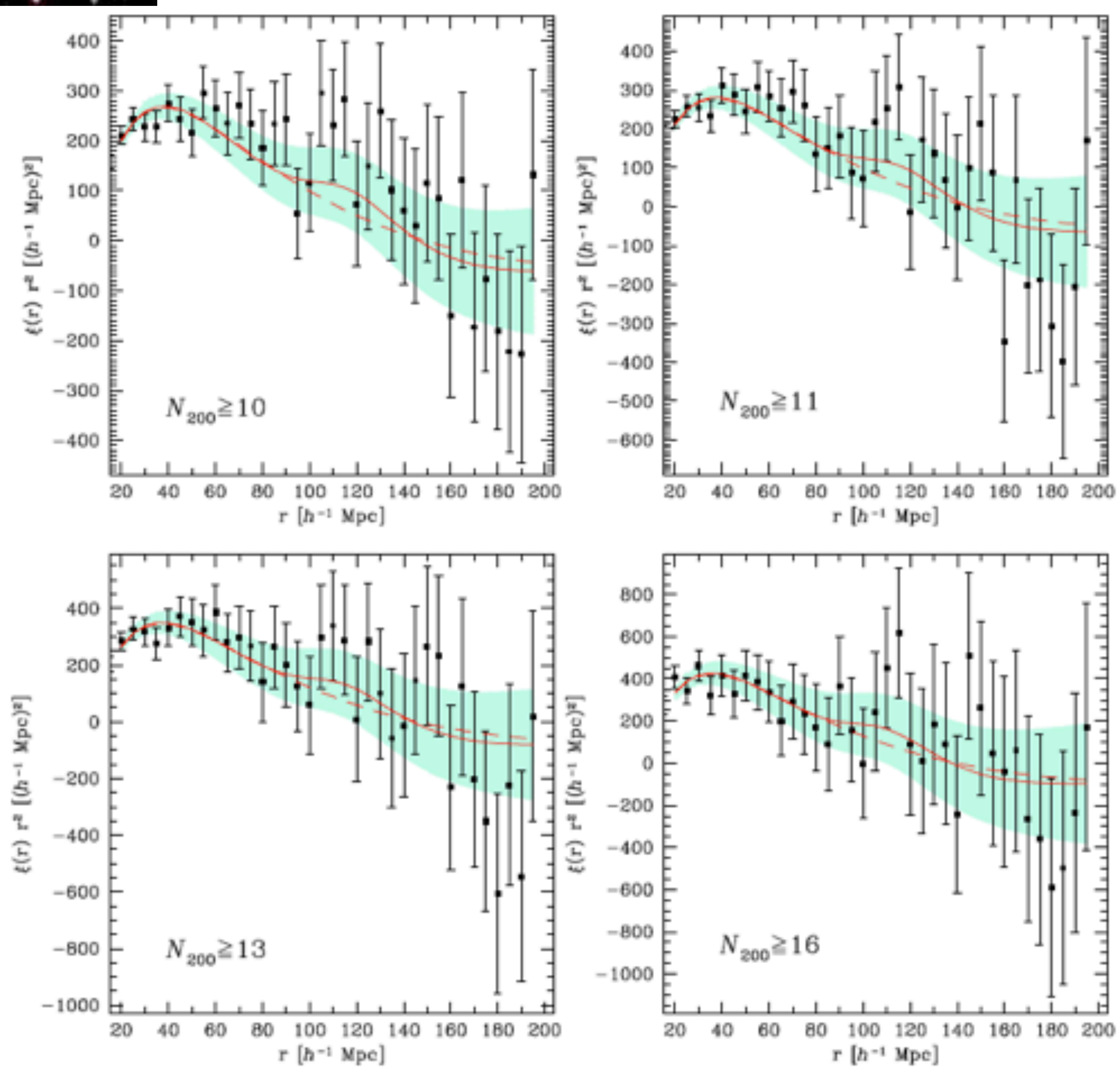
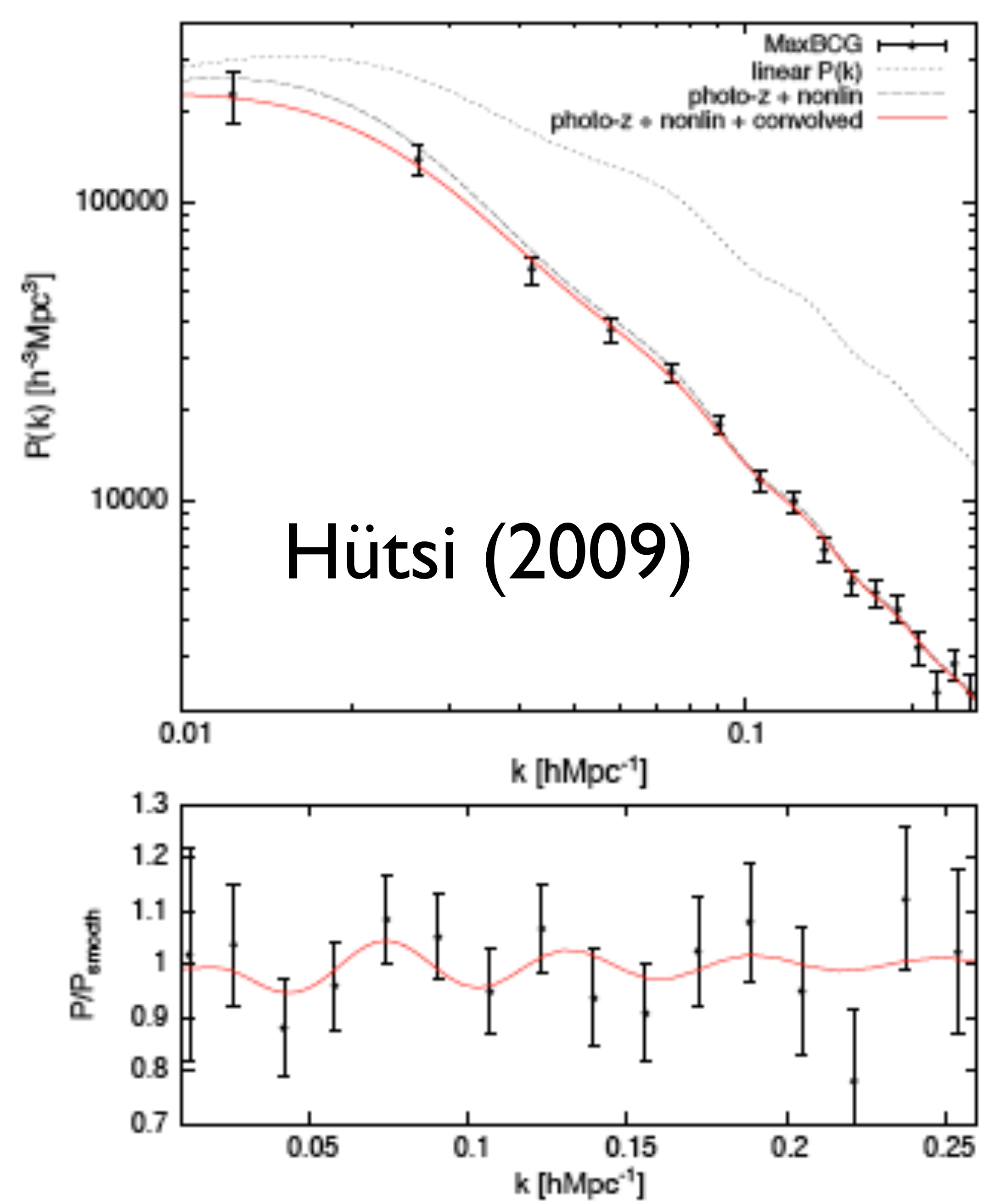


Estrada et al. (2009)

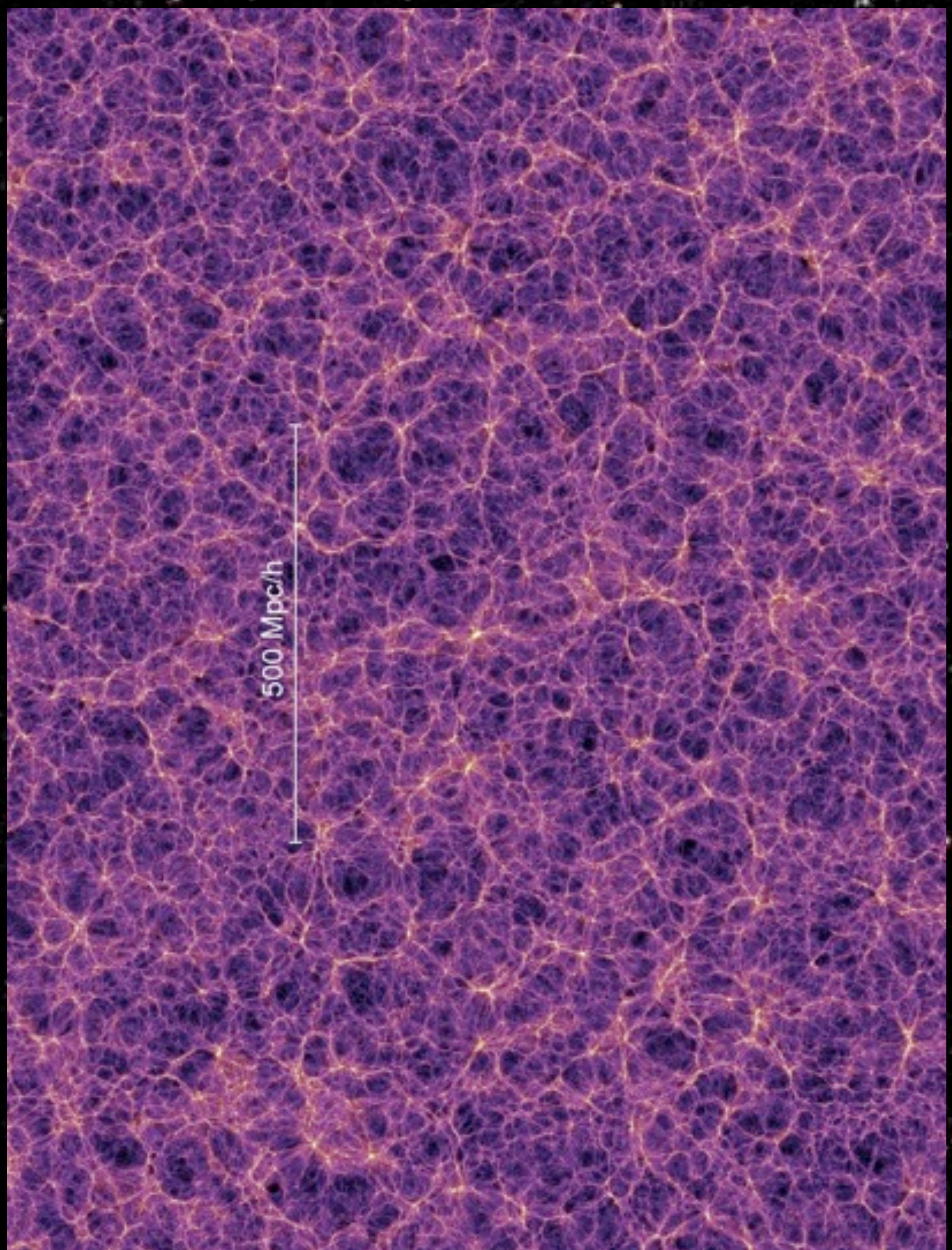


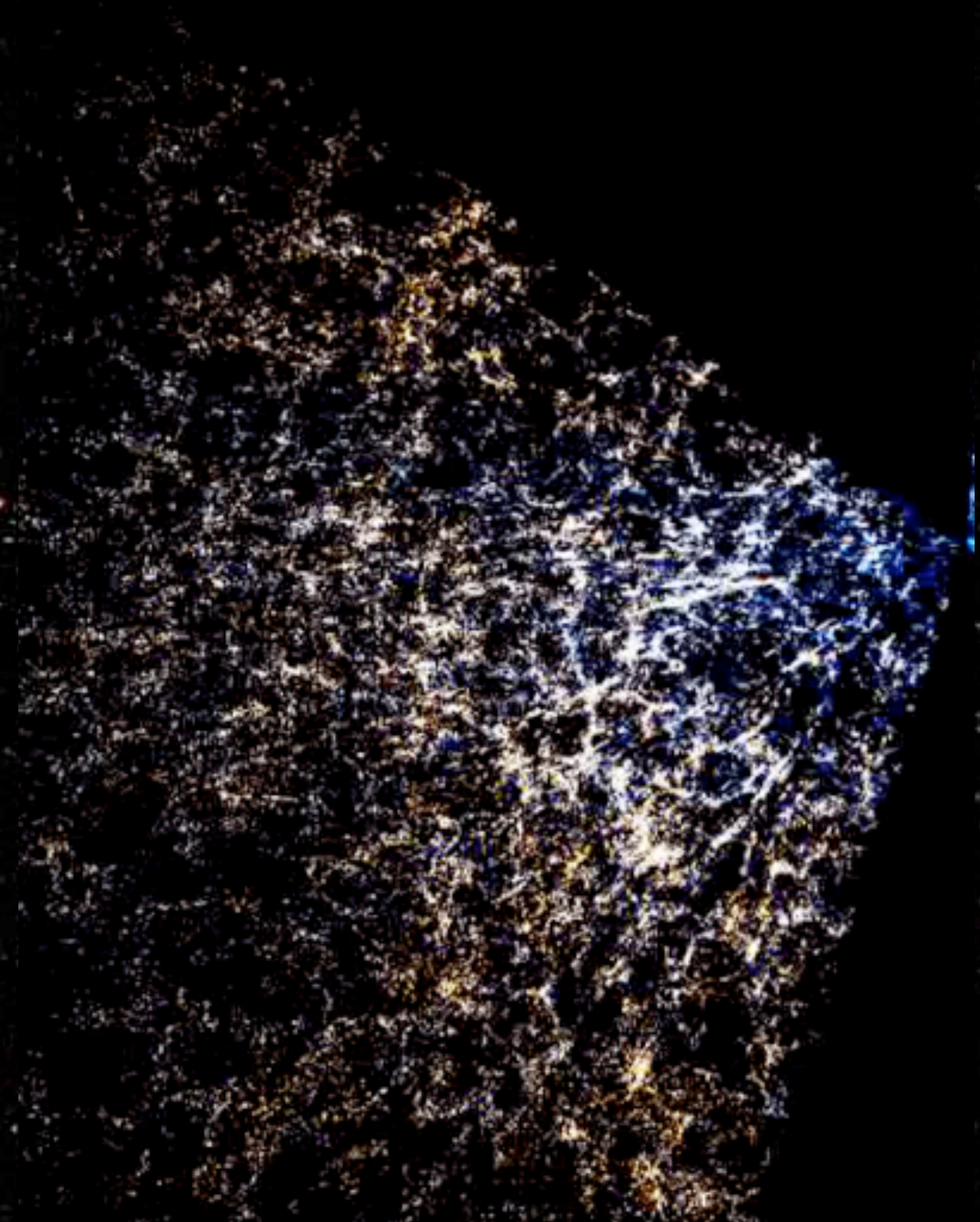
Hütsi (2009)

Dark Matter Vs. Galaxies

Dark Matter (Millennium)

Galaxies (SDSS)





Bias

- Bias relates galaxy clustering to dark matter clustering
- Local bias model:

$$\delta_g = F(\delta_{\rm DM}) \Rightarrow \delta_g = b_1\delta_{\rm DM} + 0.5b_2\delta^2_{\rm DM} + O(\delta^3_{\rm DM})$$

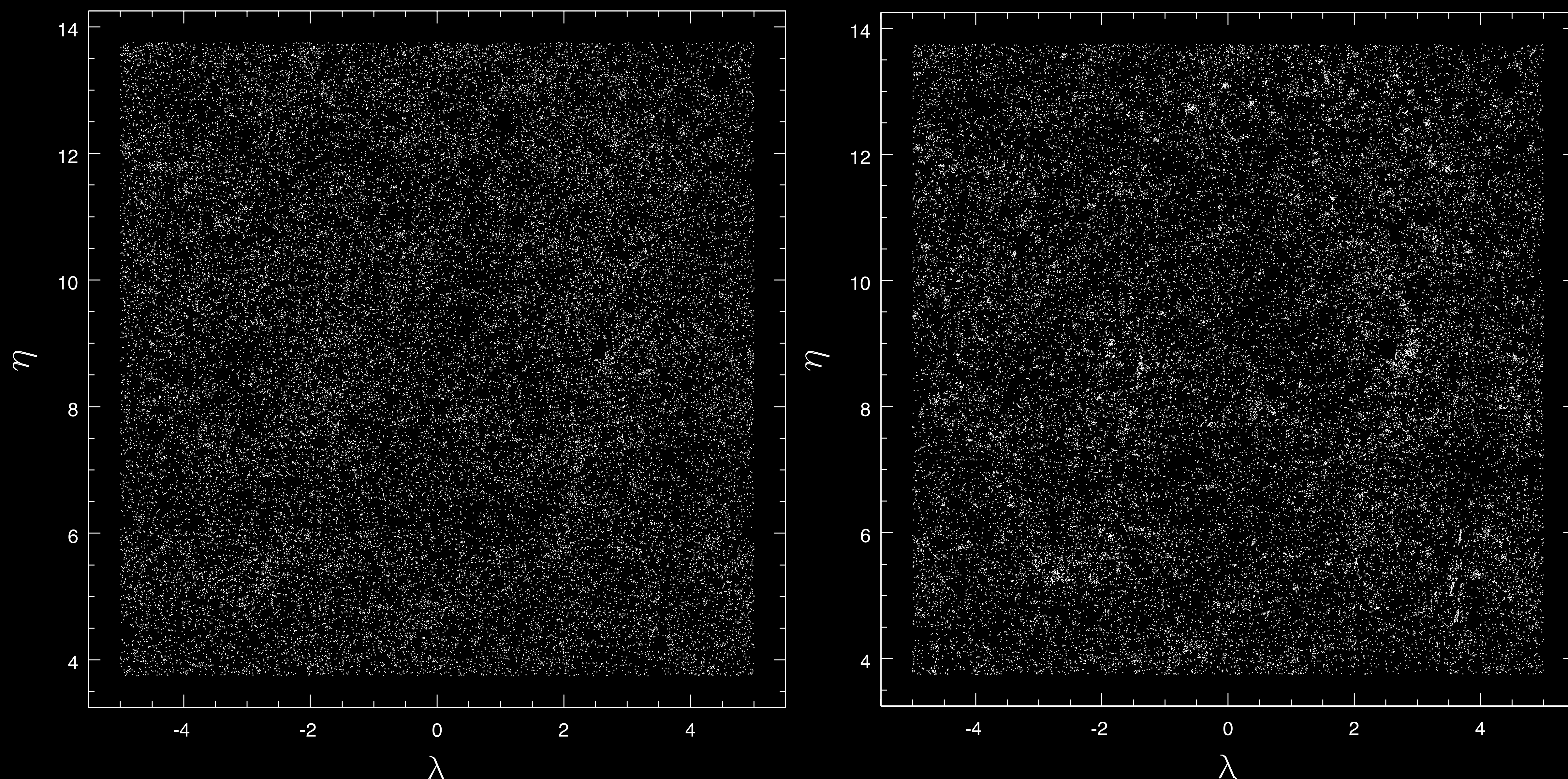
- For $r_{\rm eq} \gtrsim 10h^{-1}{\rm Mpc}$:

$$\omega_2 \cong b_1^2\omega_{2,{\rm DM}}$$

Bias depends on Colour

- Red (early-type) galaxies more clustered than blue (late-type) galaxies
  - Red found in clusters, more blue in field
  - Bias much larger for early-type

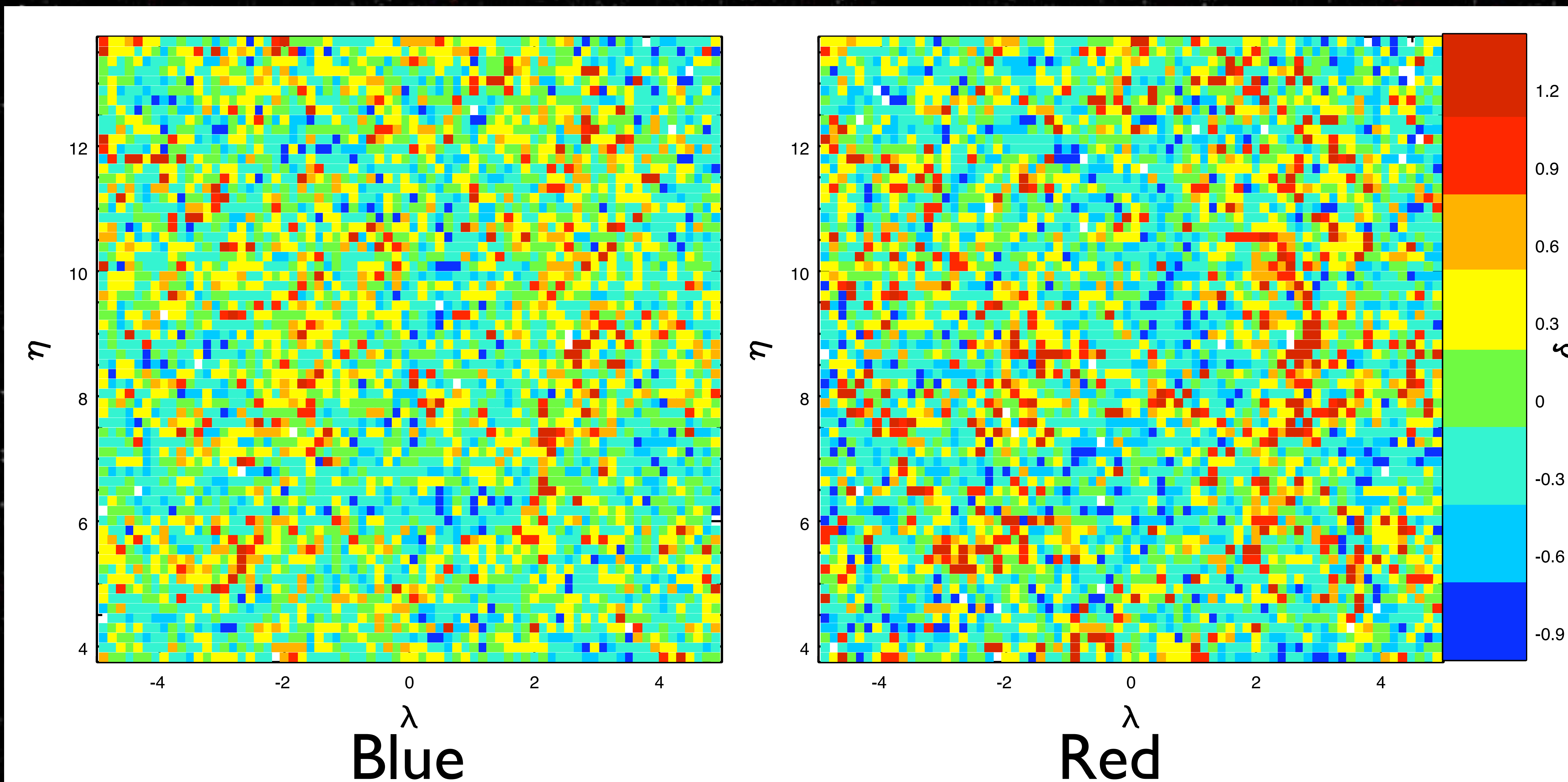
Bias depends on Colour



Blue

Red

Bias depends on Colour



Bias - Mass

- Galaxies exist in dark matter halos
- Clustering is due simply to gravity
- Galaxy bias should depend on the mass of the halos the galaxies occupy
- bias of galaxies relates to local environment

Model Correlation Functions

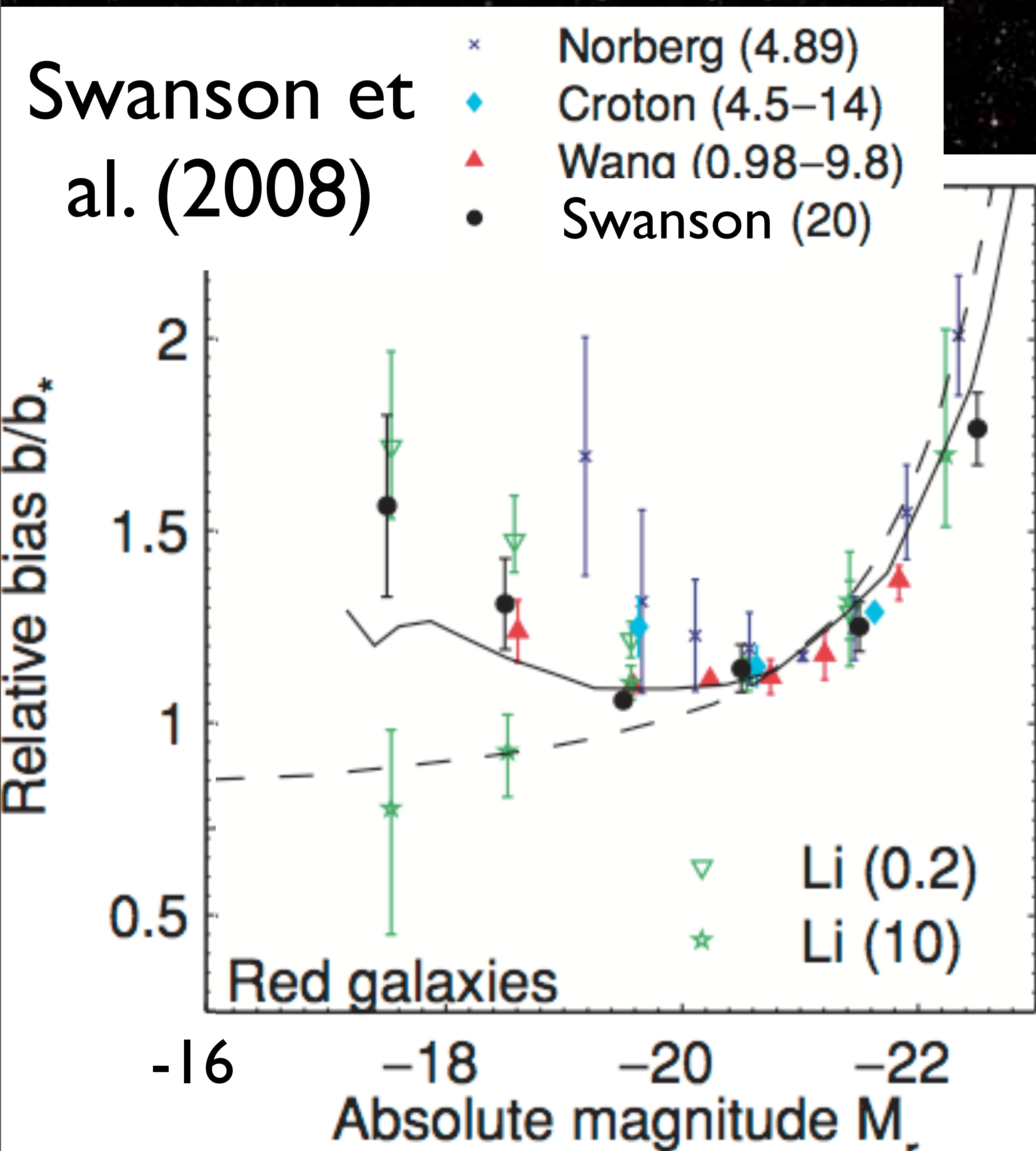
- redshift space correlation function (Halofit w/ linear RSD)
- *w*(θ), project over n(z)

$$w(\theta) = \int dz_1 \int dz_2 n(z_1) n(z_2) \xi^s(\mu, r_{ev}(\theta, z_1, z_2))$$

$$r_{ev}(\theta, z_1, z_2) = \sqrt{\chi^2(z_1) + \chi^2(z_2) - 2\chi(z_1)\chi(z_2)\cos\theta}$$

$$\mu = (\chi(z_1) - \chi(z_2))/r_{ev}$$

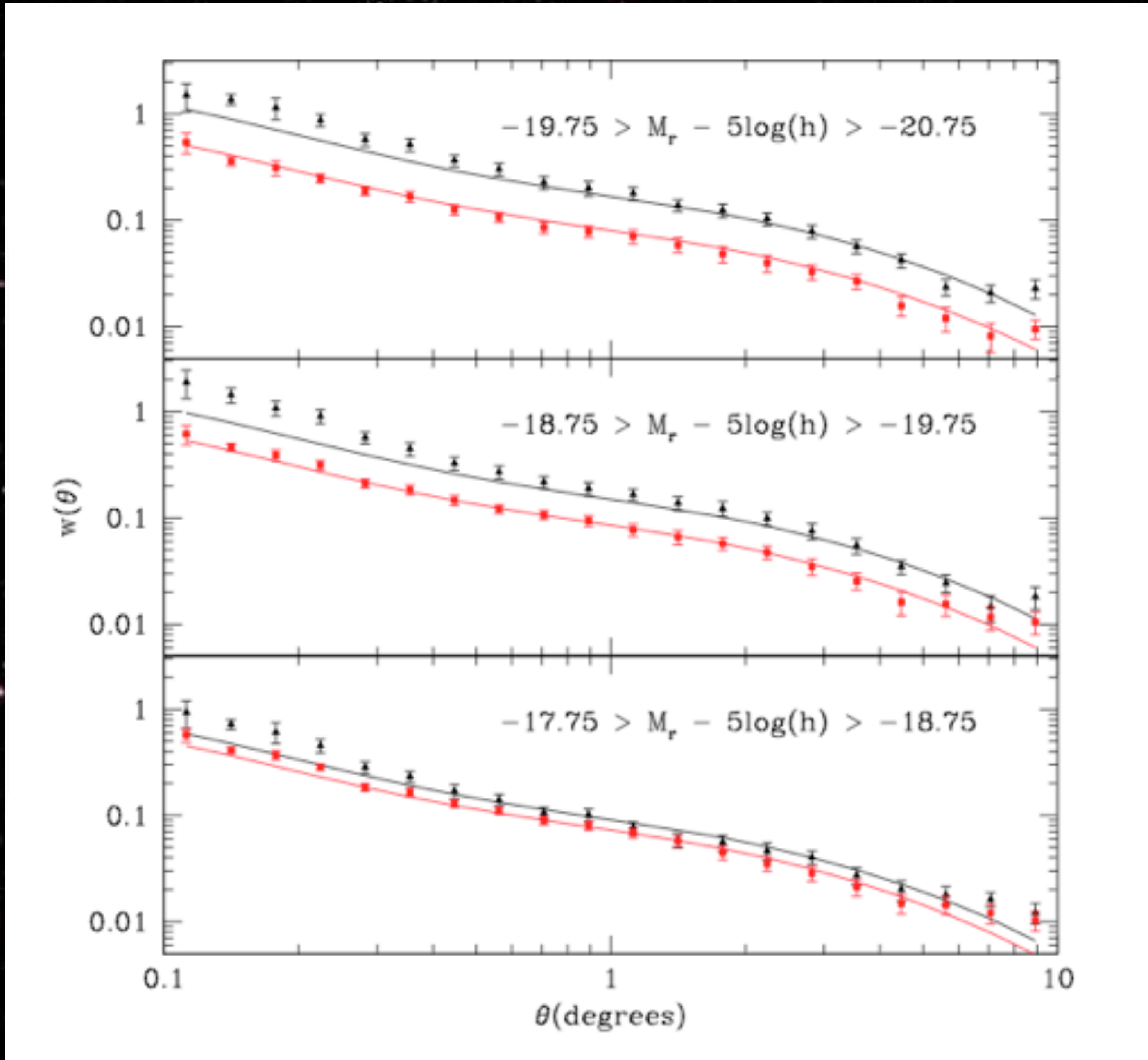
Red Galaxy Bias



- Implies low luminosity red galaxies ~ exclusively satellites
- Other studies (groups, LRG cross-correlations) inconsistent

SDSS DR7 Photometric Galaxies

- $z_{phot} < 0.1$, $r < 20$, $M_r < -17.75$, $u-r > 2.2$, $g-r > 0.8$
- auto-correlations, cross-correlations with $z < 0.15$ ($z < 0.1$, $0.1 < z < 0.15$) spectroscopic samples
- bias relation robust to changes in color selection, photozs, etc.



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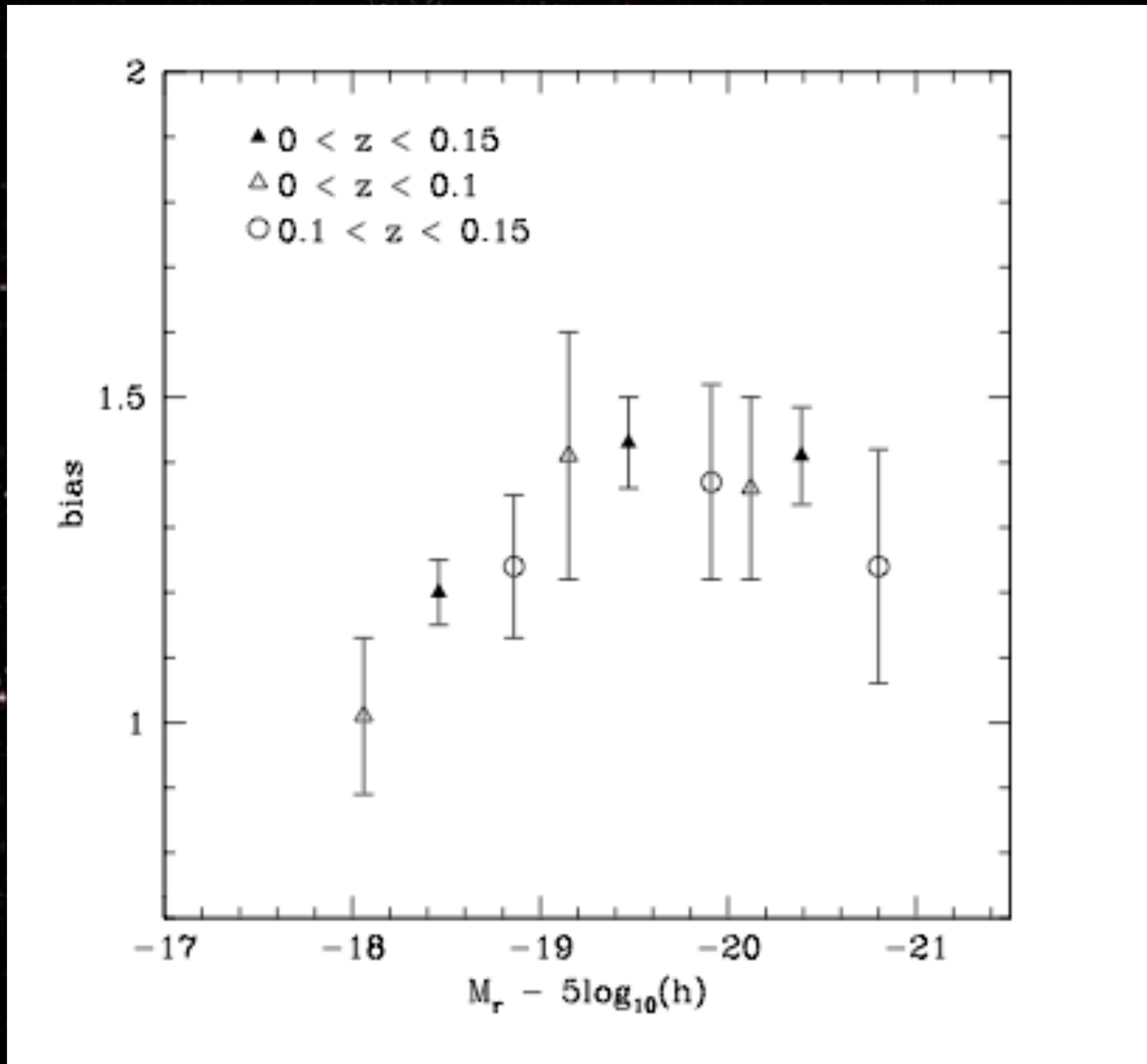

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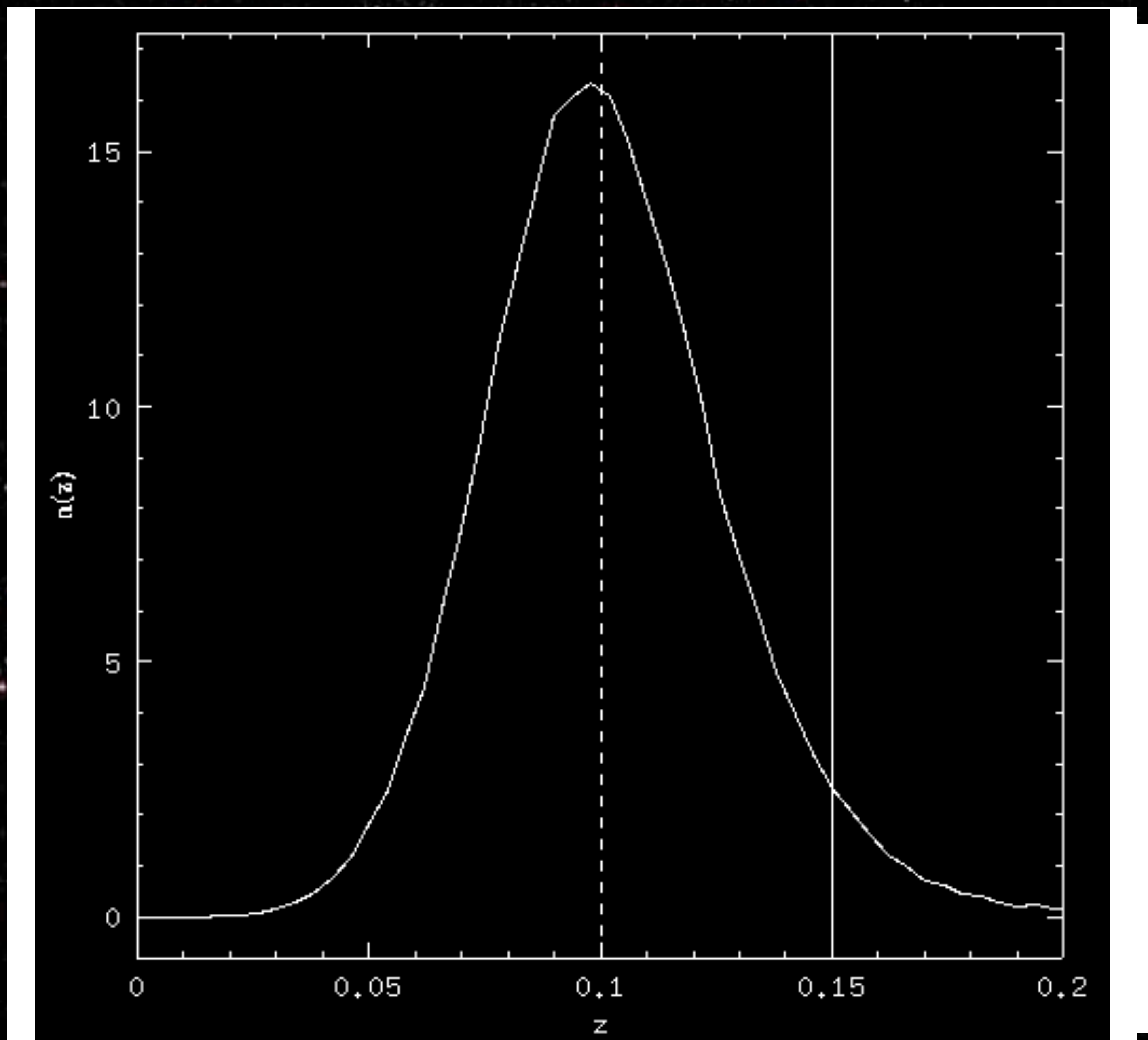

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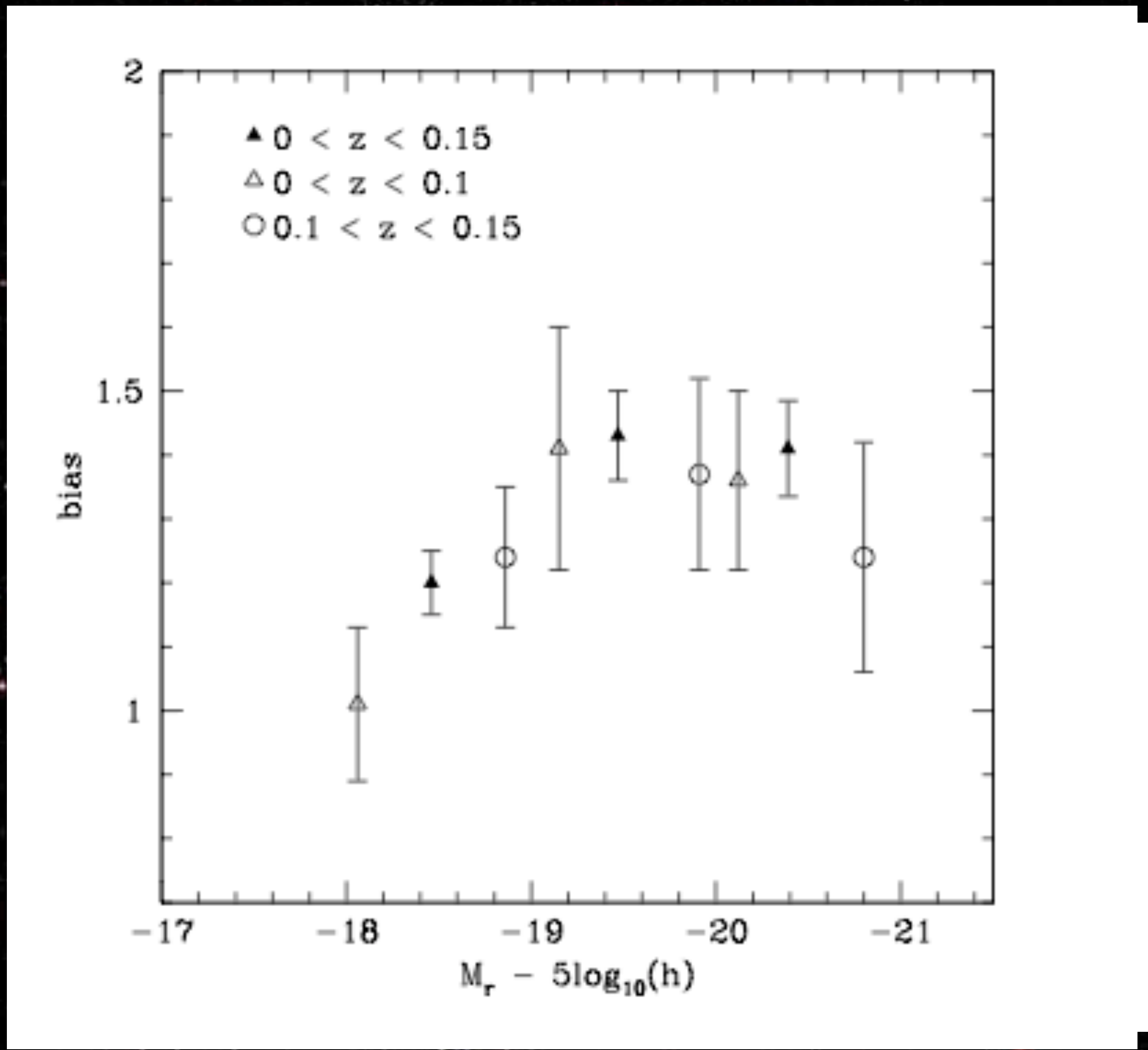
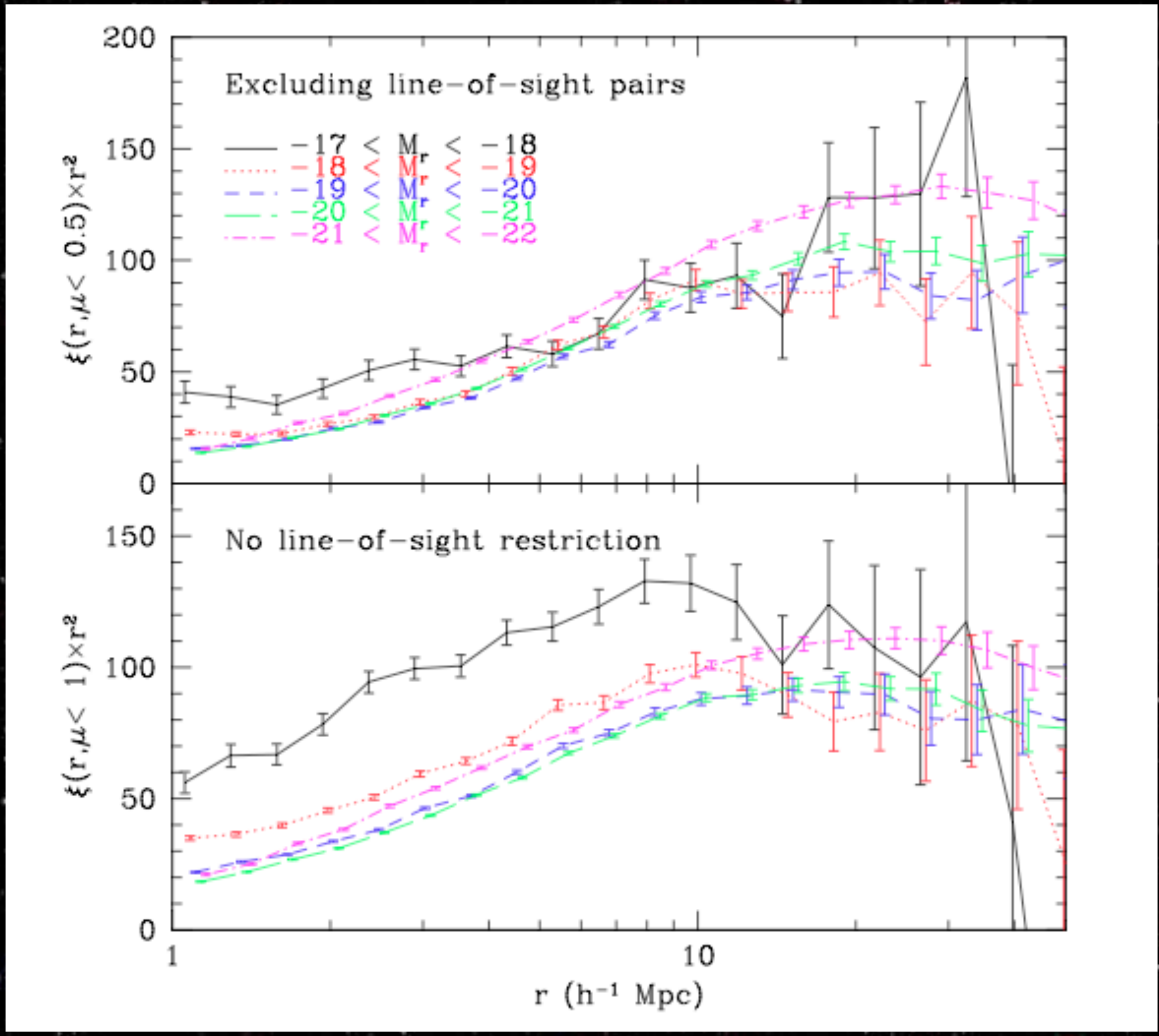


DR7 Spectroscopic Galaxies

- Strong dependence on angle to line-of-sight & scale



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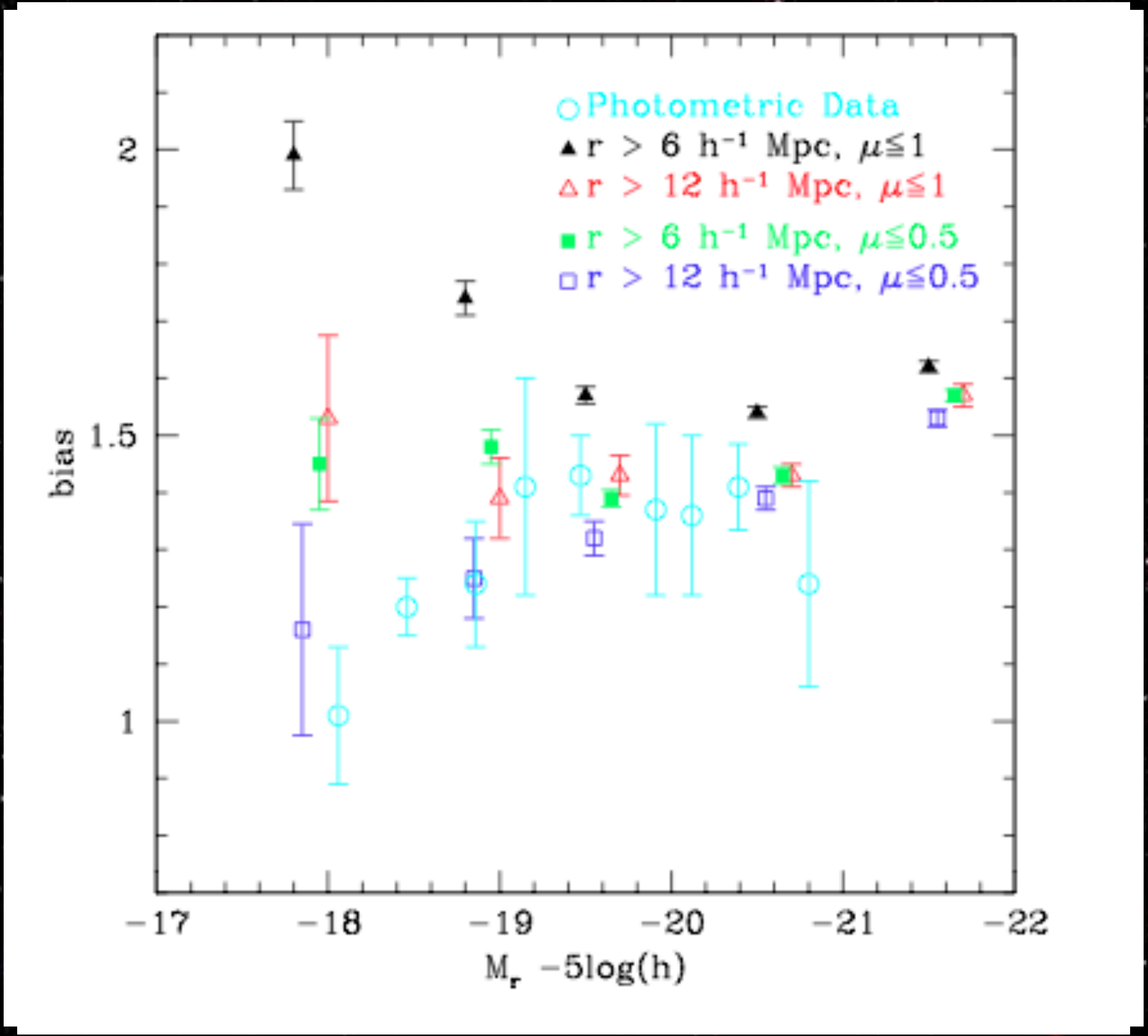
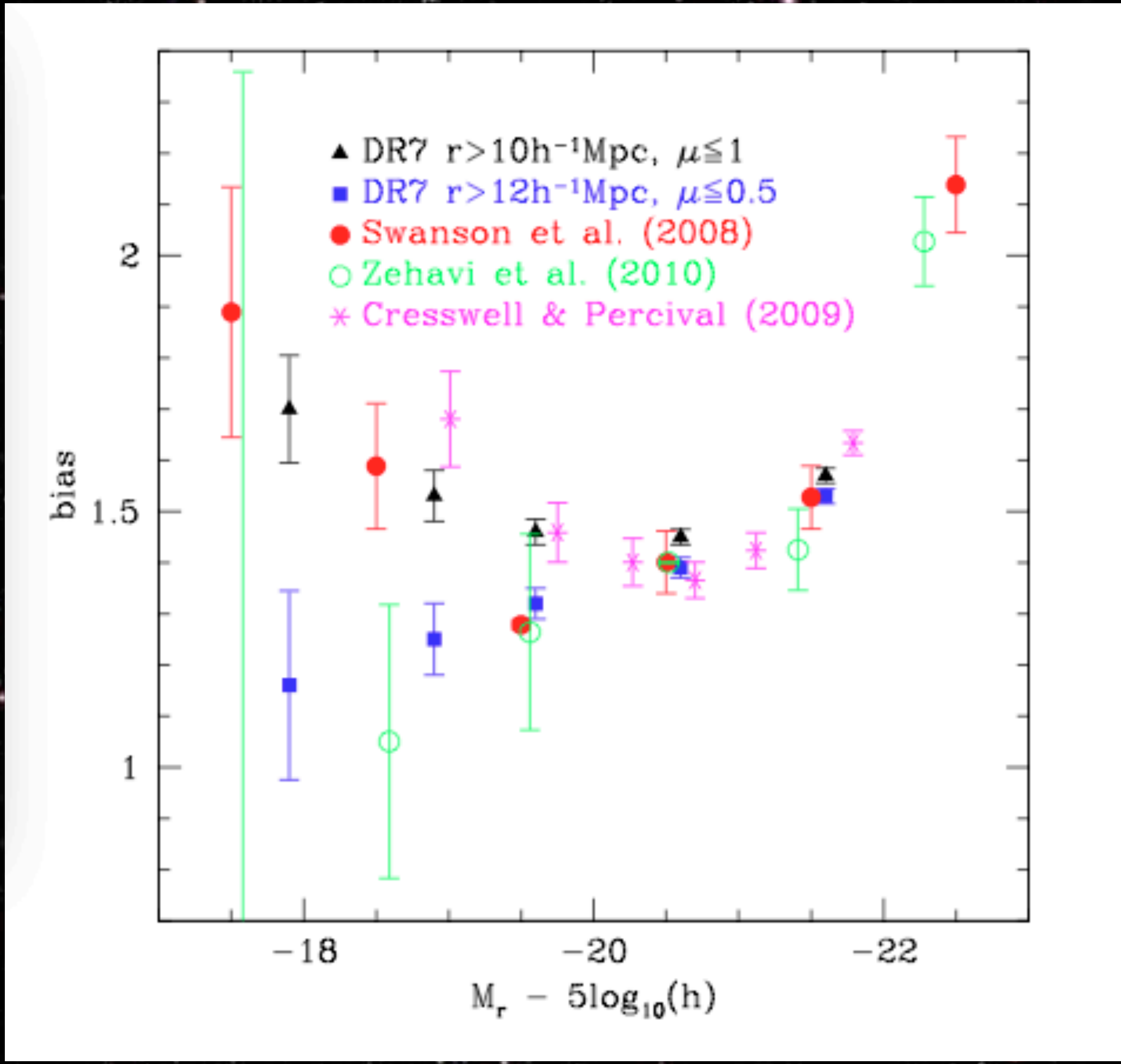


Implications

- Previous results recovered for small-scales and los clustering
- Most robust (large volume, minimal los contribution) -> monotonic increase in bias with luminosity



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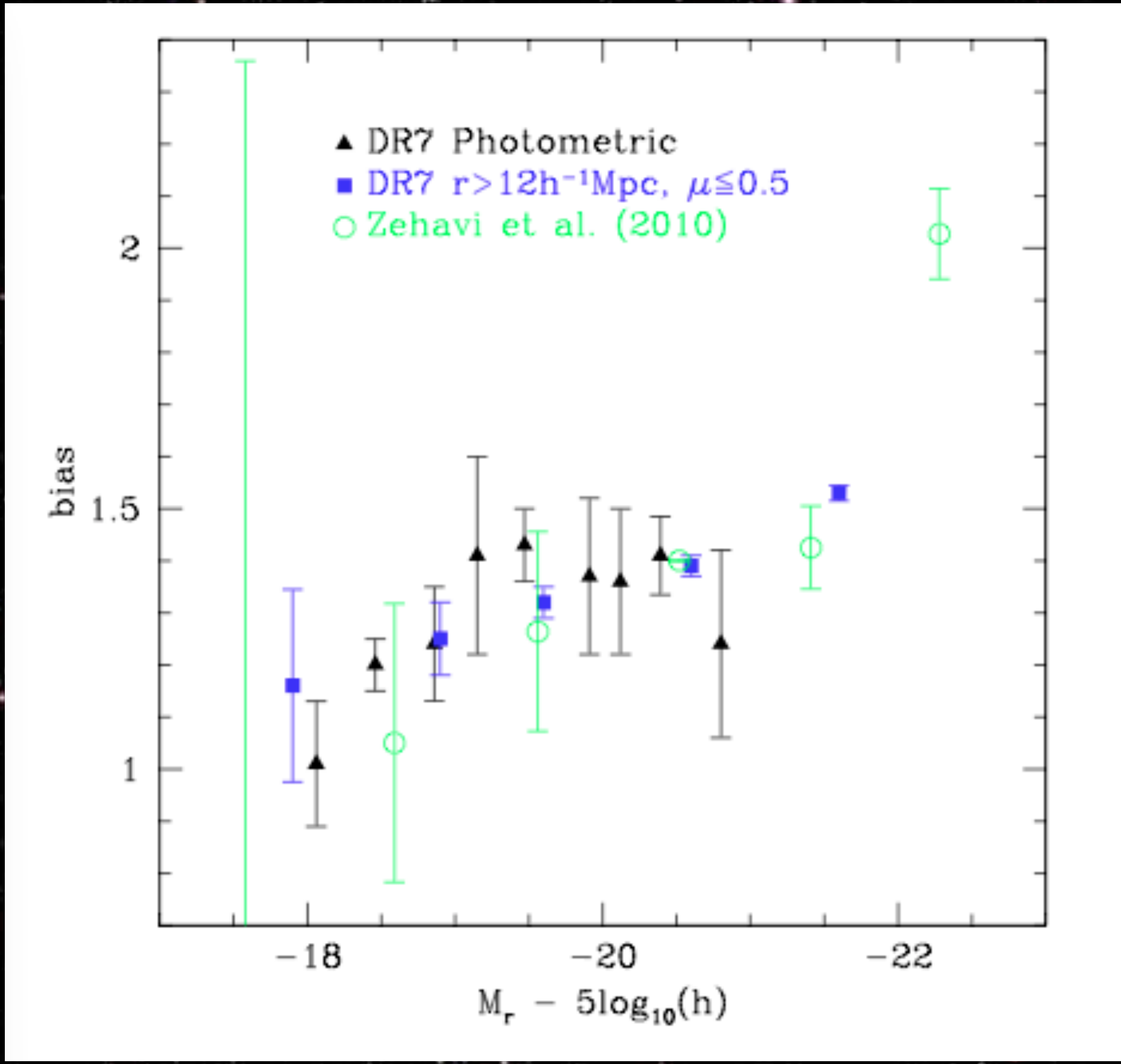


SDSS HOD modeling with photozs

- Huge SDSS data set allows precise ω_2 measurements - ideal for testing model
- Clustering measurements complementary to spectroscopic (larger range of scales, redshift range)

HOD Modeling

- Given model for DM halo number density as function of mass and redshift

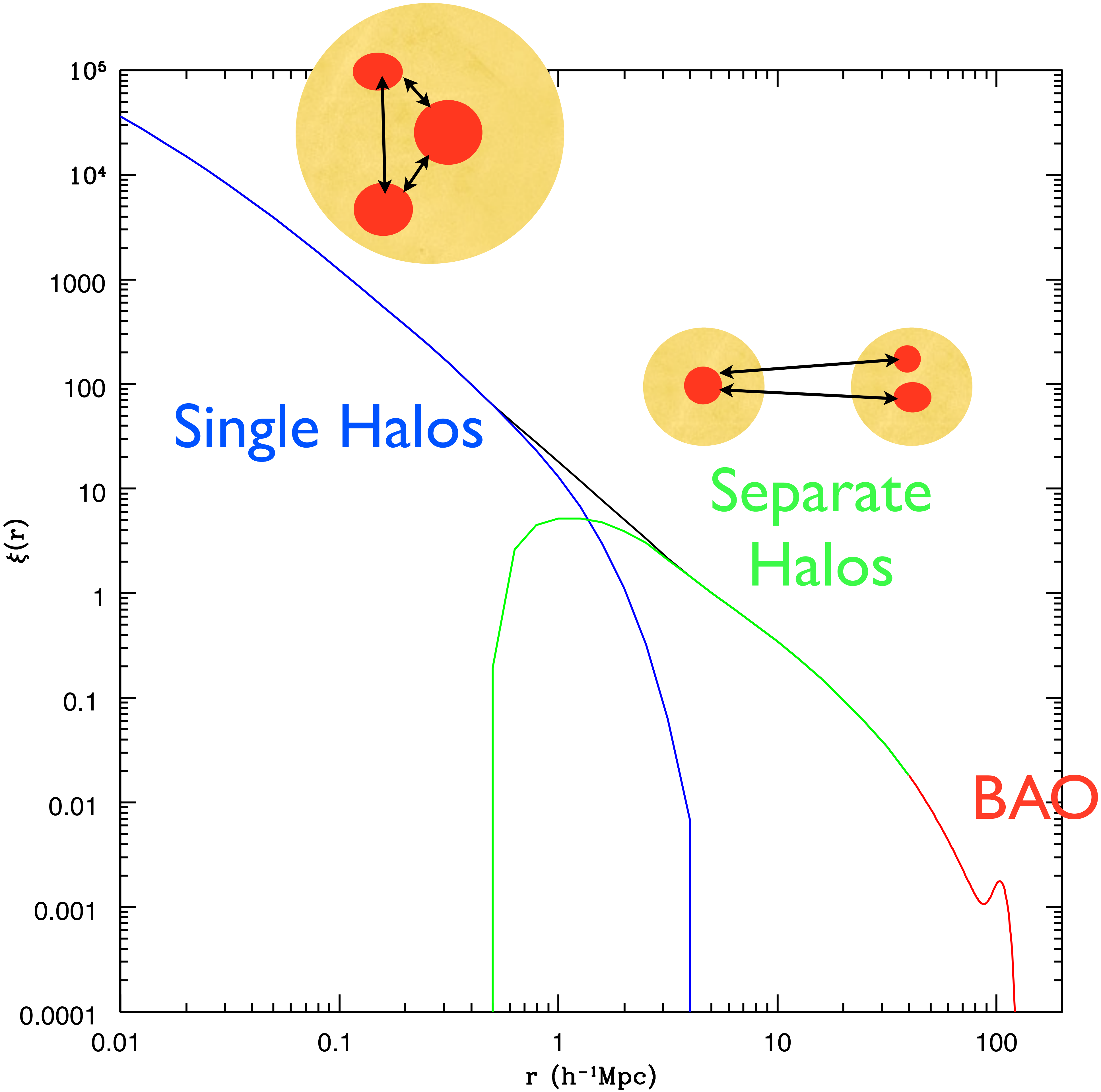
- Model $P(k)$ by modeling mean occupation of galaxies in dark matter halos

$$N(M) = N_{cen}(M) \times (1 + N_{sat}(M))$$

- Two "1-halo" terms

$$P_{cs} = \int_{M_{vir}(r)}^{\infty} dM n(M) N_{cen}(M) \frac{2N_{sat} u(k|M)}{n_g^2}$$

$$P_{ss} = \int_{M_{vir}(r/2)}^{\infty} dM n(M) N_{cen}(M) \left(\frac{N_{sat} u(k|M)}{n_g} \right)^2$$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“2-halo” term

- Essentially, determines bias given HOD model:

$$P_{2h}(k,r) = P_{matter}(k) \times \left[\int_0^{M_{lim}(r)} dMn(M)b(M,r)\frac{N(M)}{n'_g}u(k|M)\right]^2$$

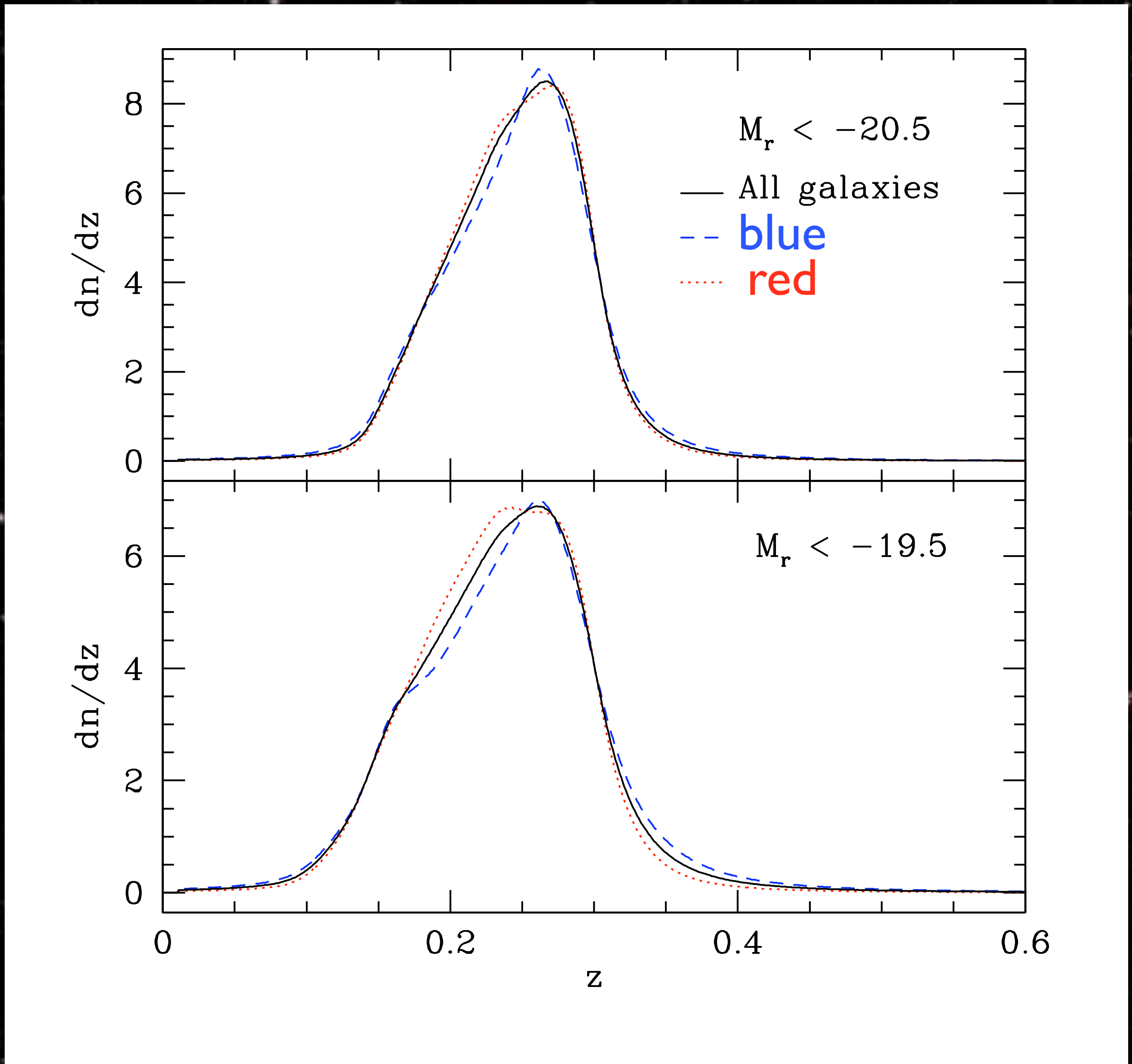
- so $P(k,r) = P_{cs}(k) + P_{ss}(k) + P_{2h}(k,r)$ =>

$$\xi(r) = \frac{1}{2\pi^2}\int_0^\infty dkP(k,r)k^2\frac{\sin\, kr}{kr}$$

$$\omega_2(\theta) = \frac{2}{c}\int_0^\infty dzH(z)(dn/dz)^2\int_0^\infty du\xi(r = \sqrt{u^2 + x^2(z)\theta^2}$$

SDSS DR5 Galaxies

- Template based $z_{phot} < 0.3$
- Two samples; M_r -5log$h$ < -19.5 (~4 million galaxies), < -20.5 (~1.3 million galaxies)
- Split into red/blue samples via type value



HOD constraints with SDSS DR5 Galaxies

- HOD model:

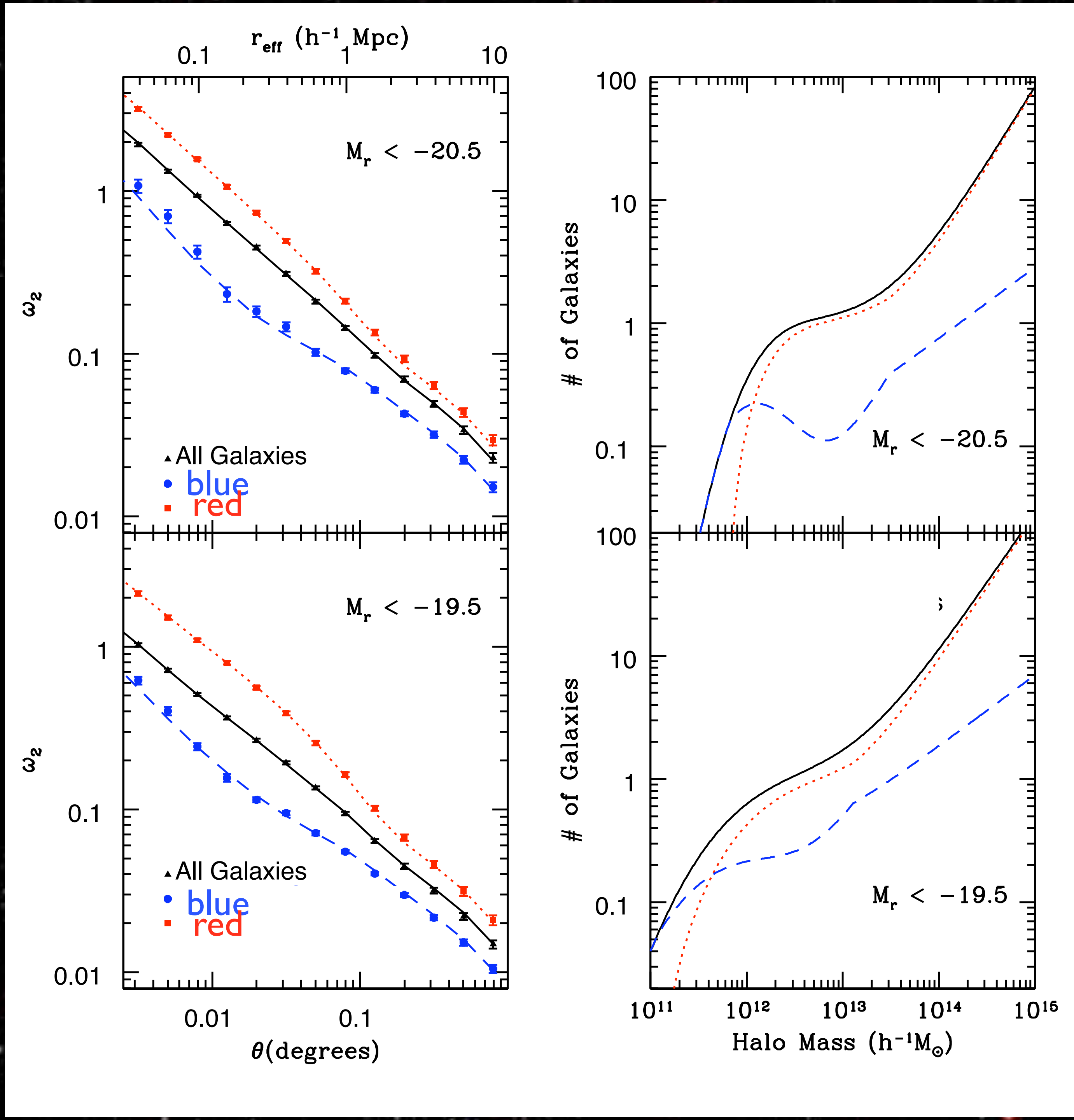
$$\langle N_c \mid M \rangle = 0.5 \left(1 + \mathrm{erf}\left(\frac{M/M_{cut}}{\sigma_{cut}}\right)\right)$$

$$\langle N_s \mid M \rangle = 0.5 \left(1 + \mathrm{erf}\left(\frac{M/M_{cut}}{\sigma_{cut}}\right)\right) \times (M/M_0)^{\alpha}$$

$$\langle N_c|M\rangle_{late} = \langle N_c|M\rangle \times f_{c0}\exp\left(\frac{-\log_{10}(M/M_{cut})}{\sigma_c}\right)$$

$$\langle N_s \mid M\rangle_{late} = \langle N_s \mid M\rangle \times fs_0\exp\left(\frac{-\log_{10}(M/M_0)}{\sigma_s}\right)$$

- +Segregation of blue/red galaxies



Red/blue Model

- New modeling for red/ blue galaxies
- Place galaxies into separate halos as much as statistics allow
- Means ~ no mixing in low mass halos, some mixing in high mass halos

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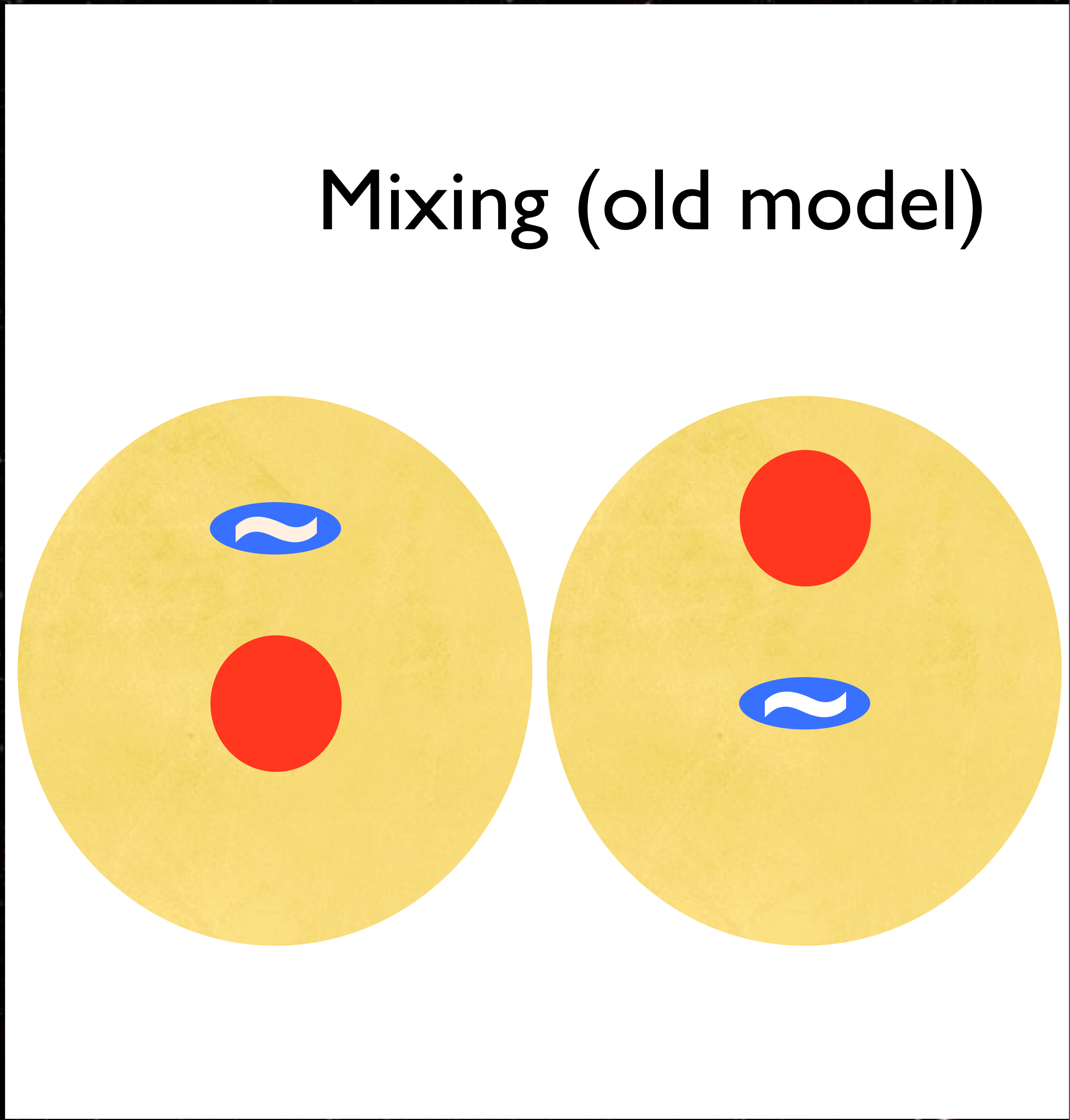

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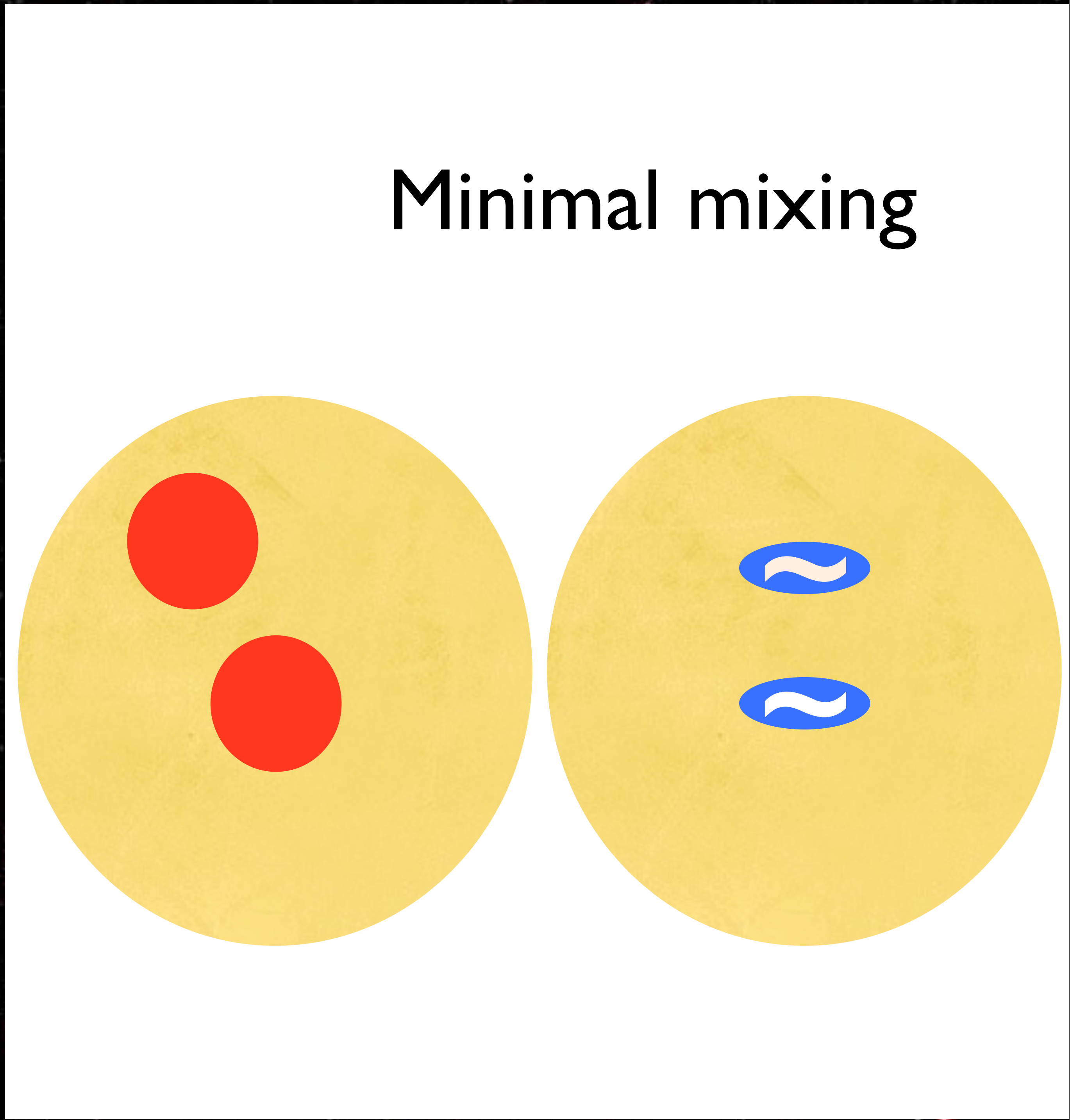

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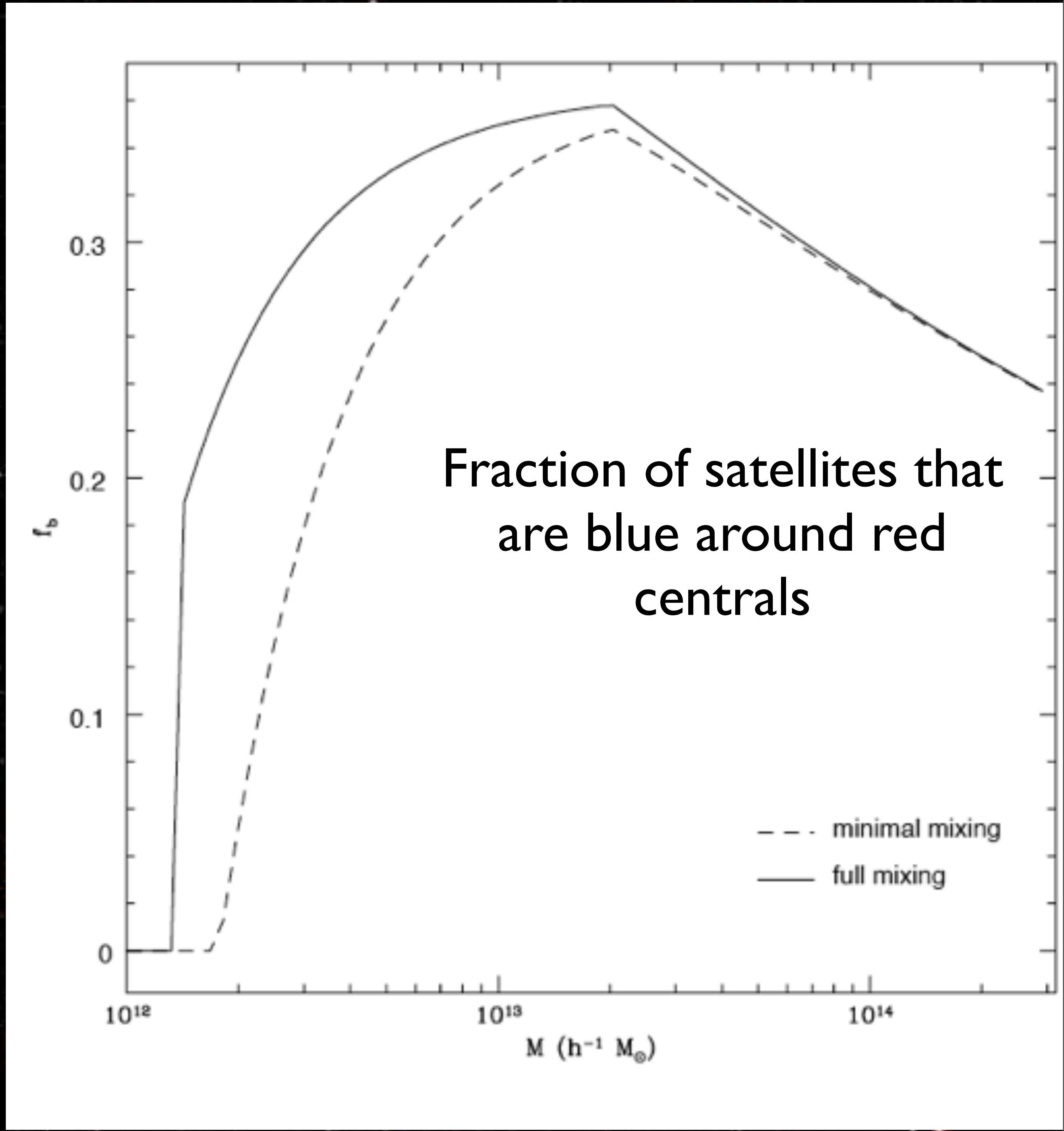
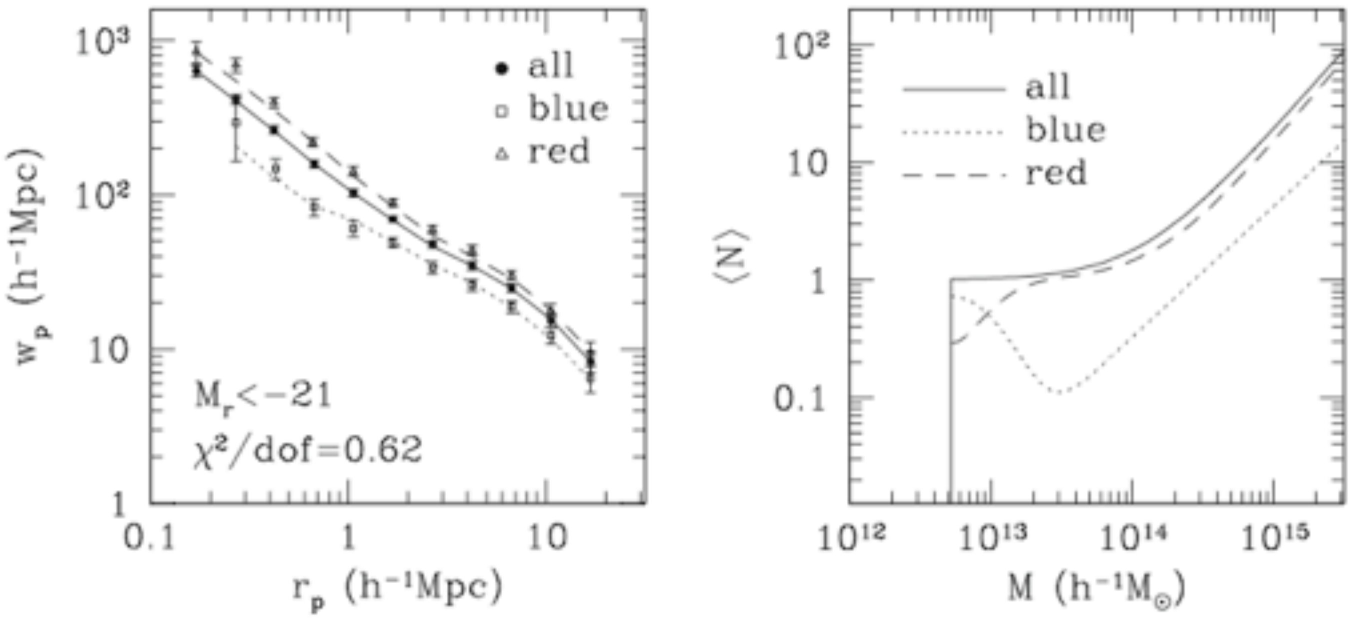
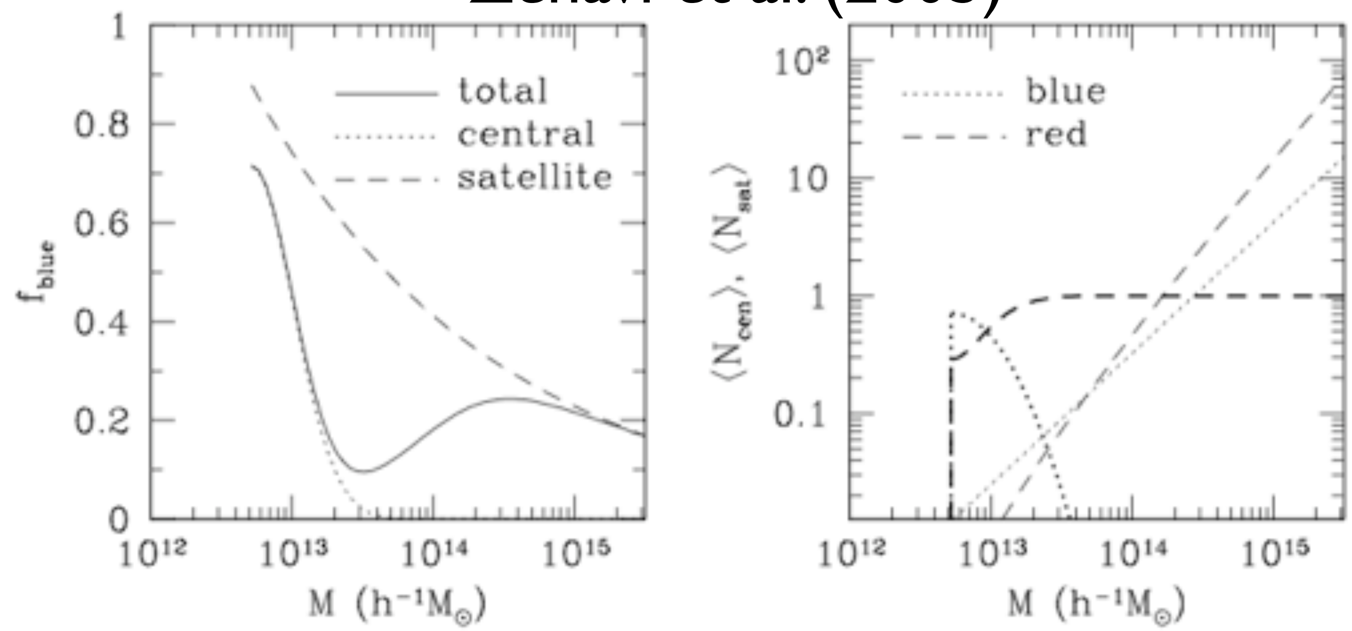
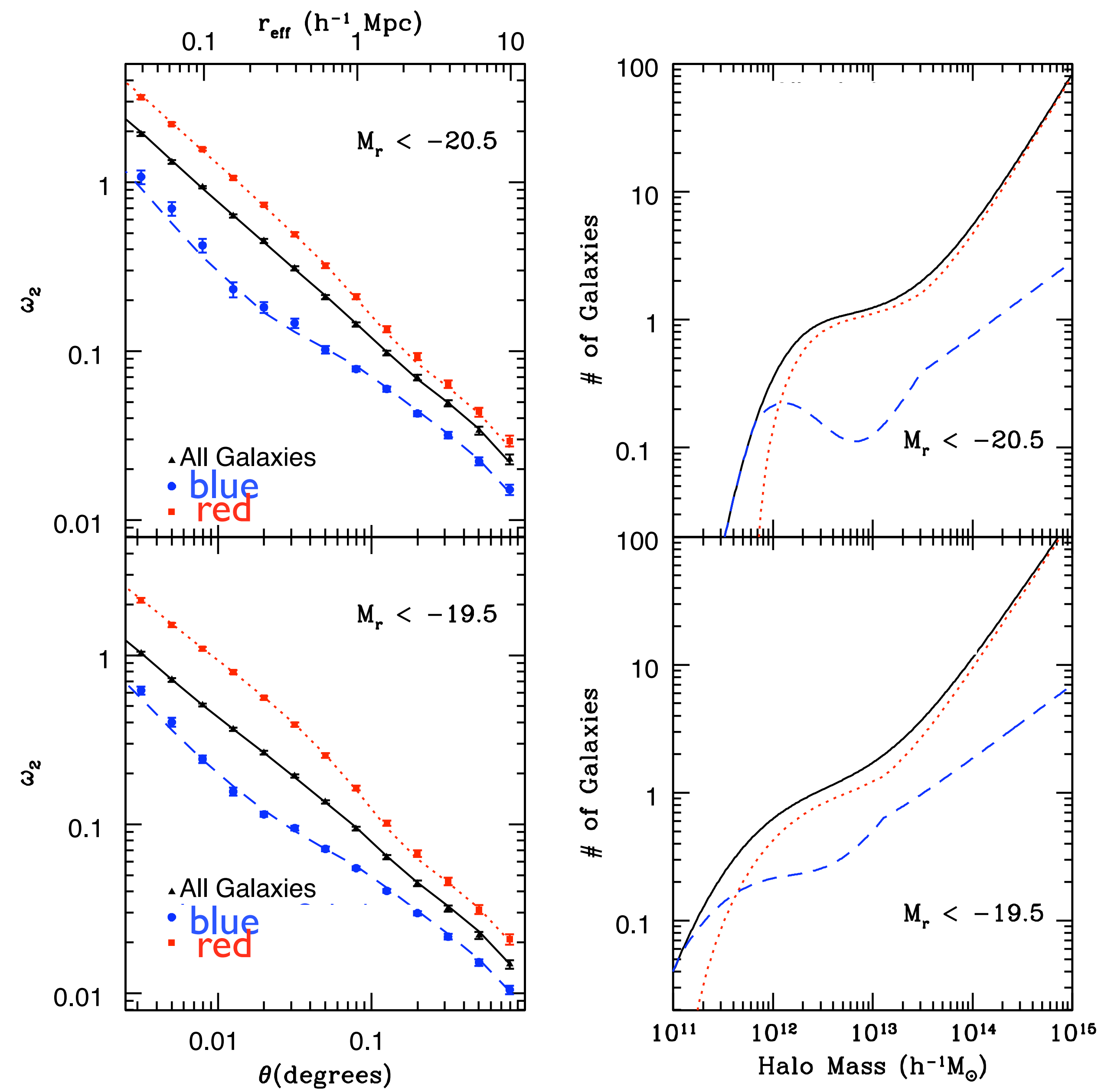


Comparison with Spectroscopic



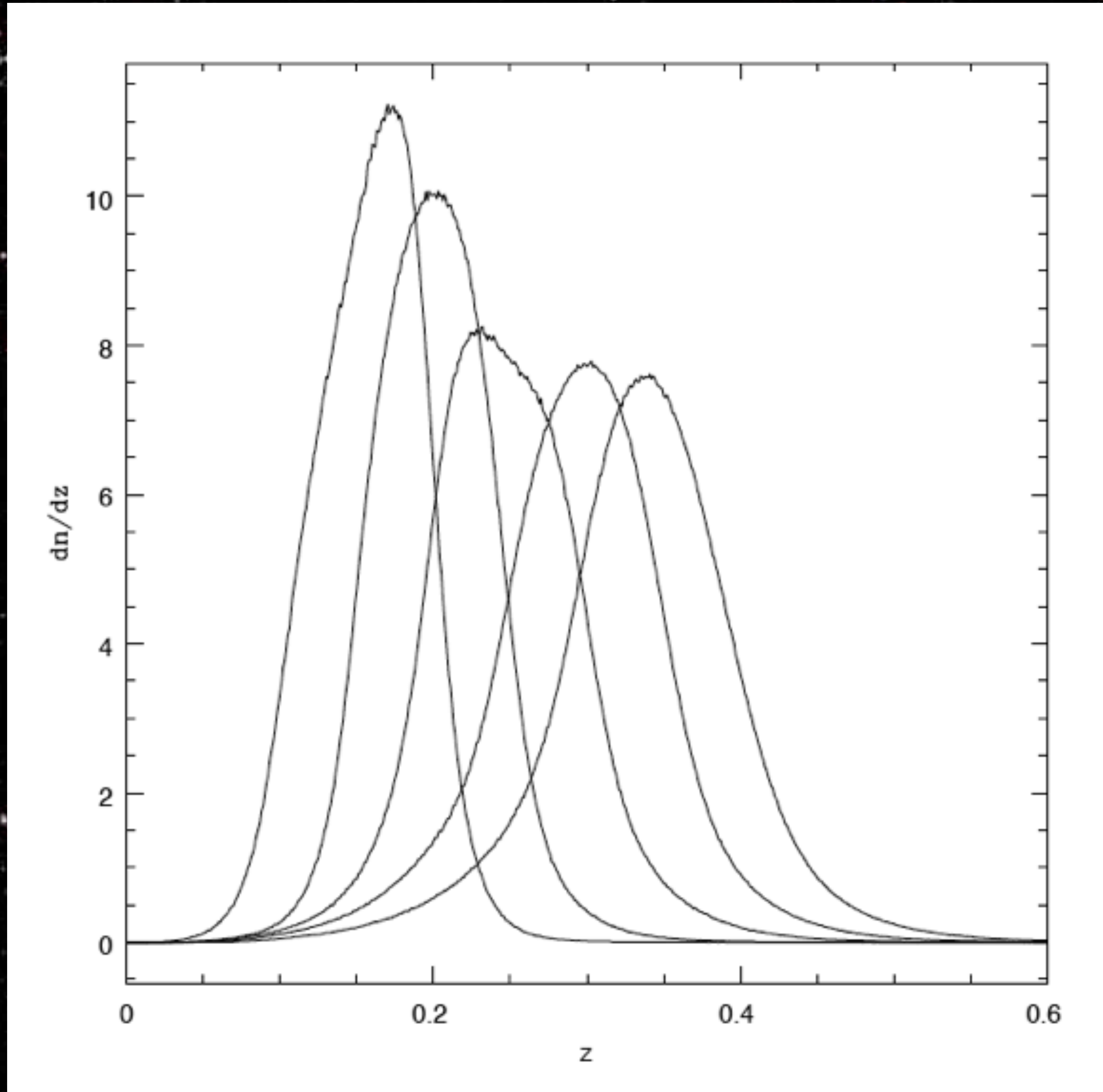
Zehavi et al. (2005)





Redshift Evolution

- Use DR7 galaxies with $0.1 < z < 0.4$, $M_r - 5\log h < -20.4$
- Split into 5 (overlapping) photoz shells
- b_l increases from 1.2 to 1.35



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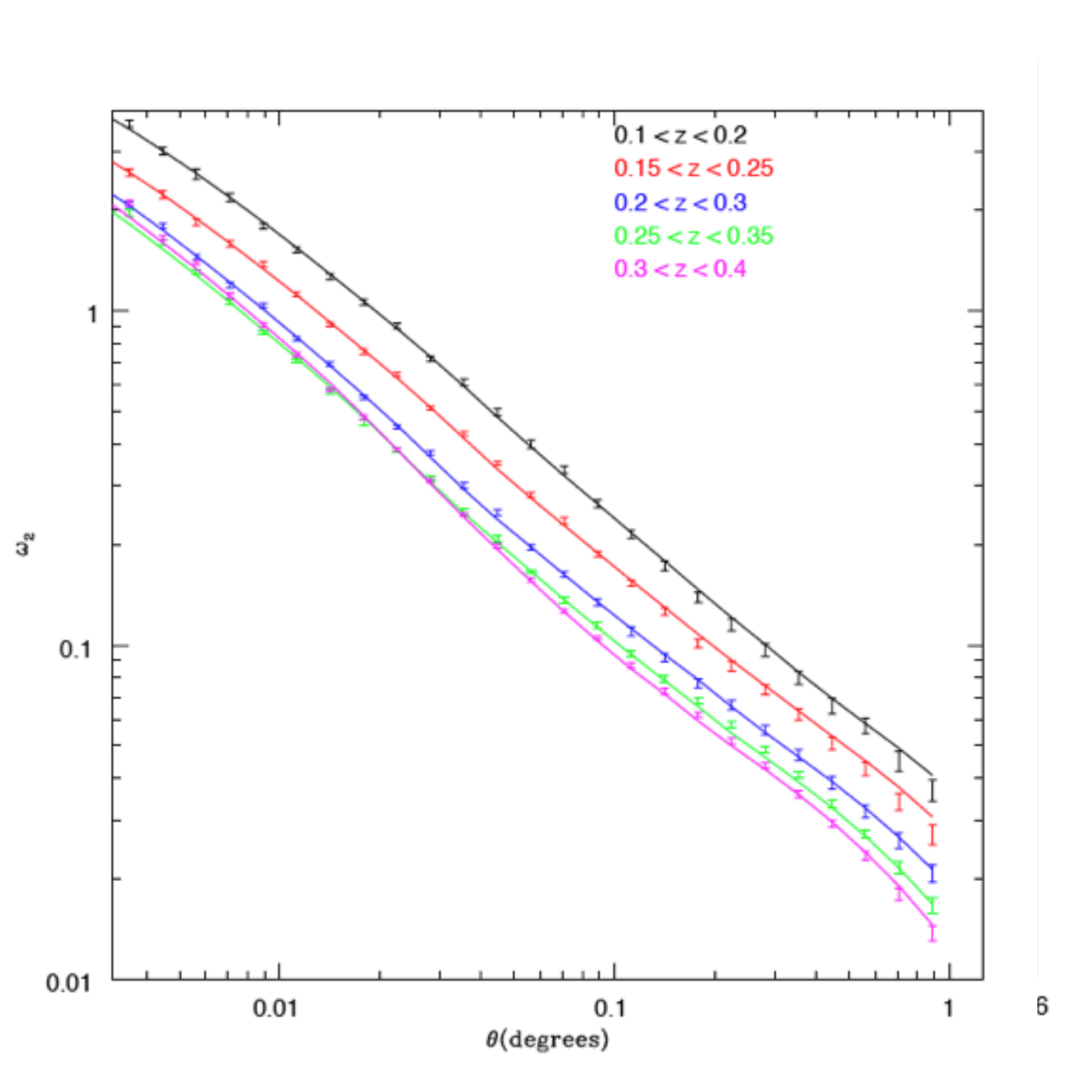

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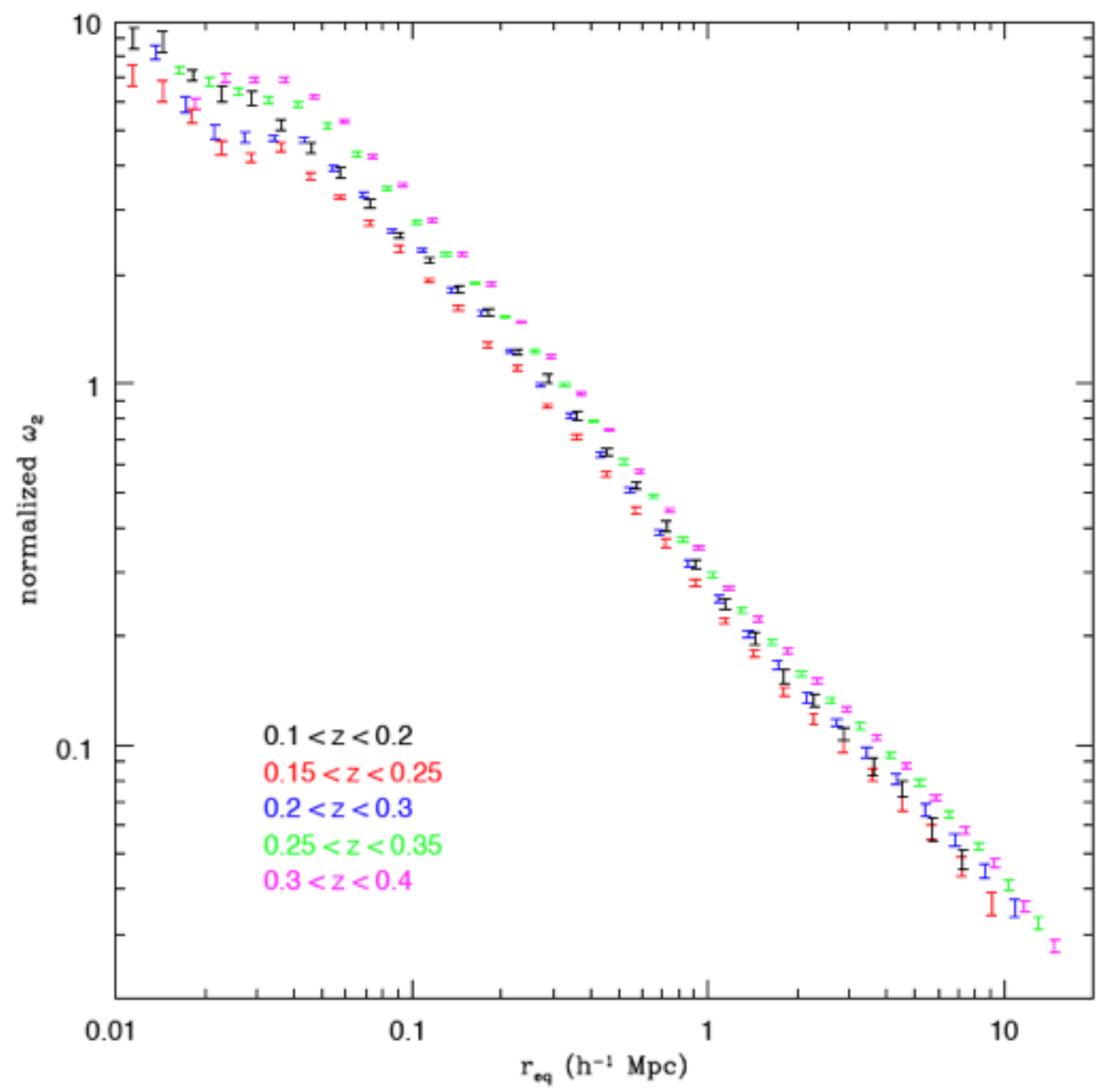
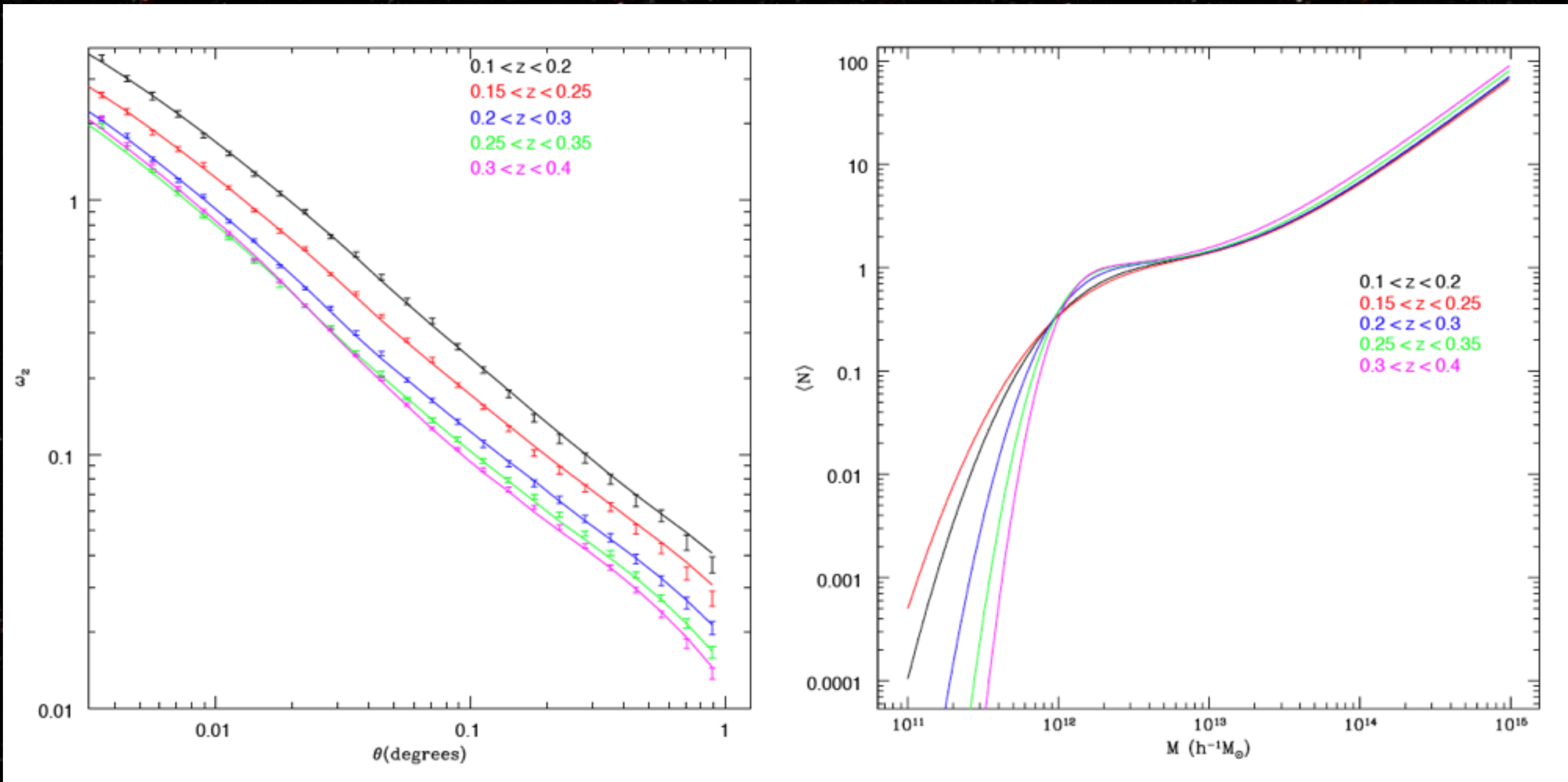


HOD Model Fits



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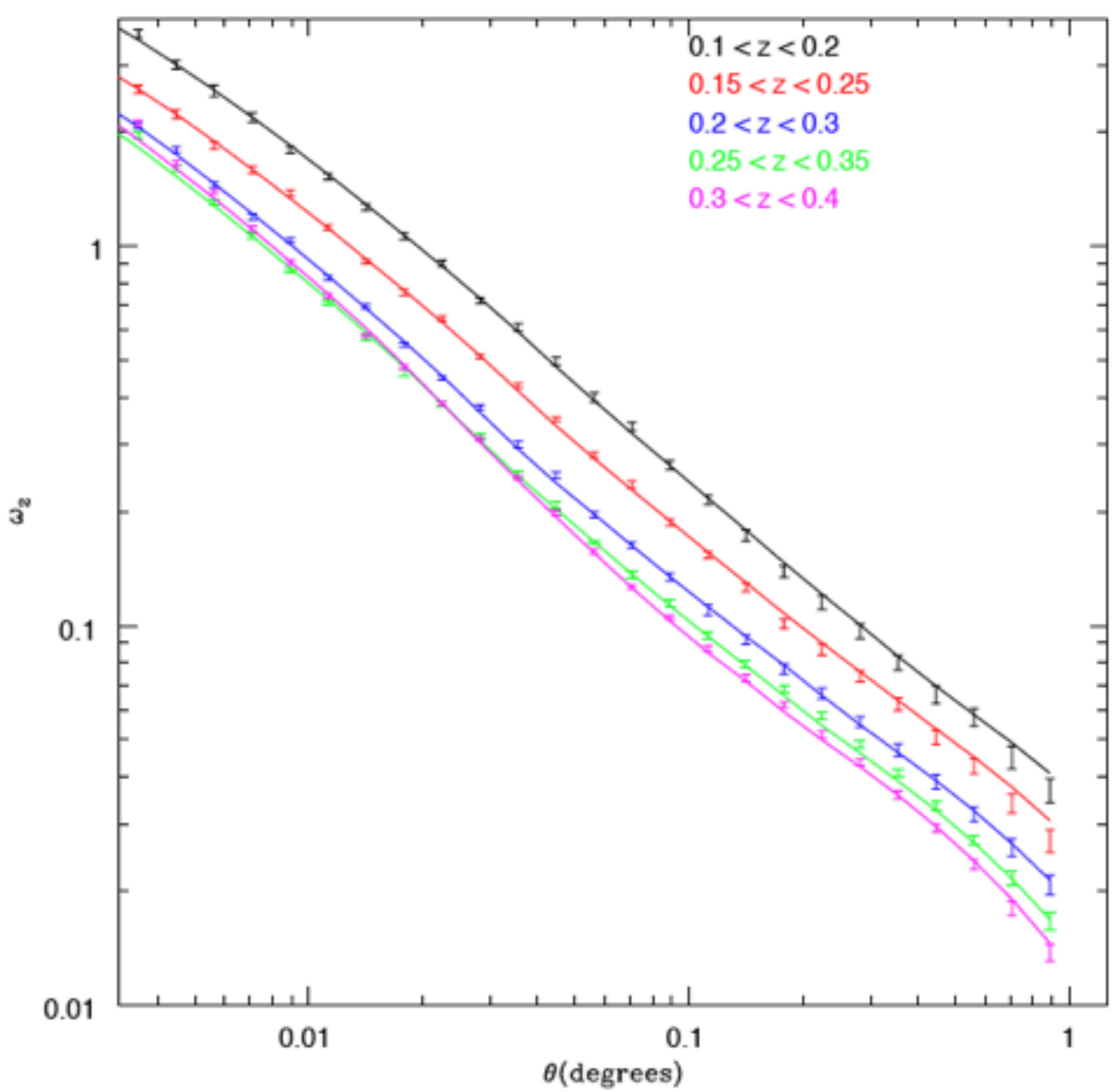

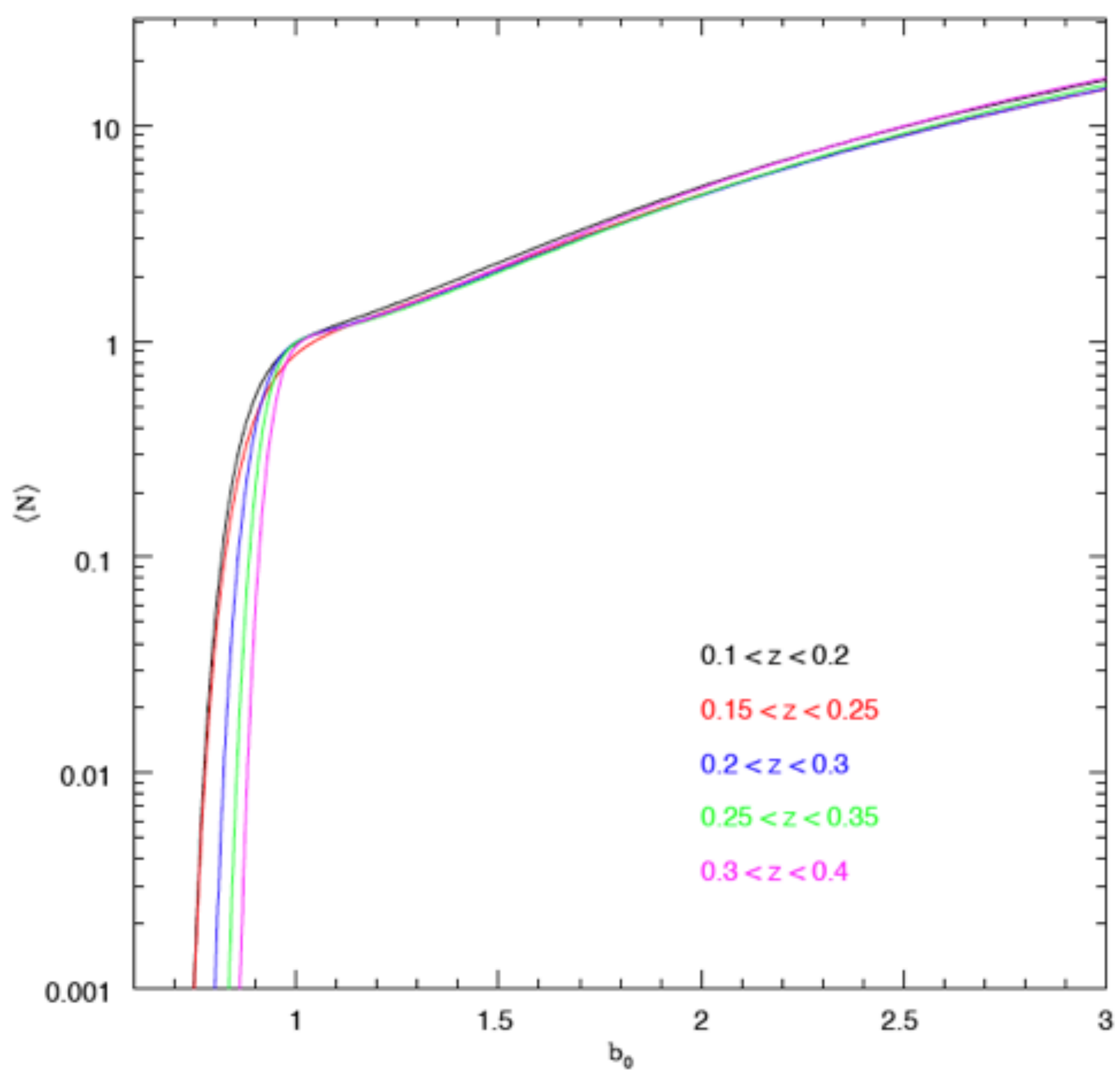

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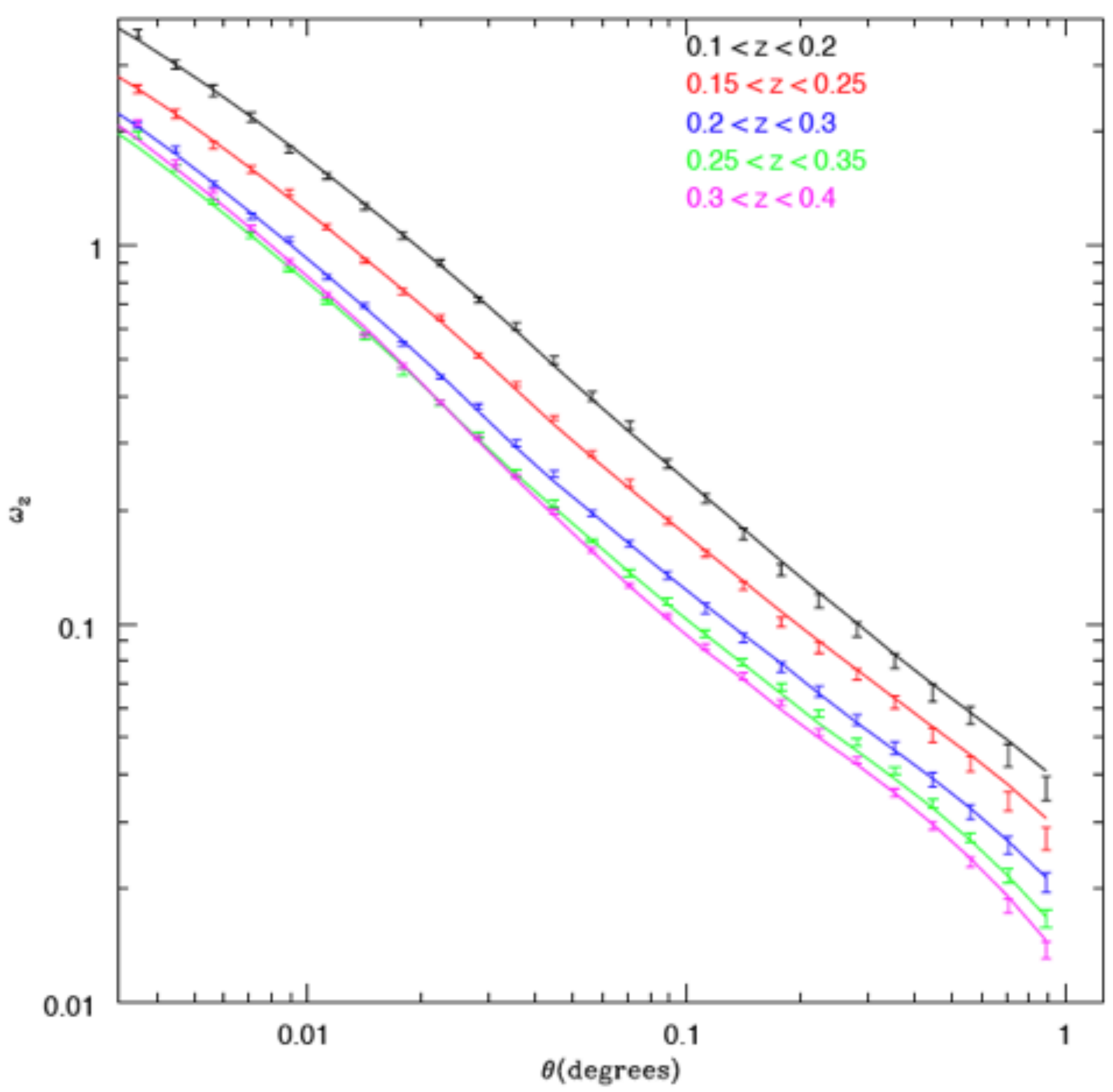
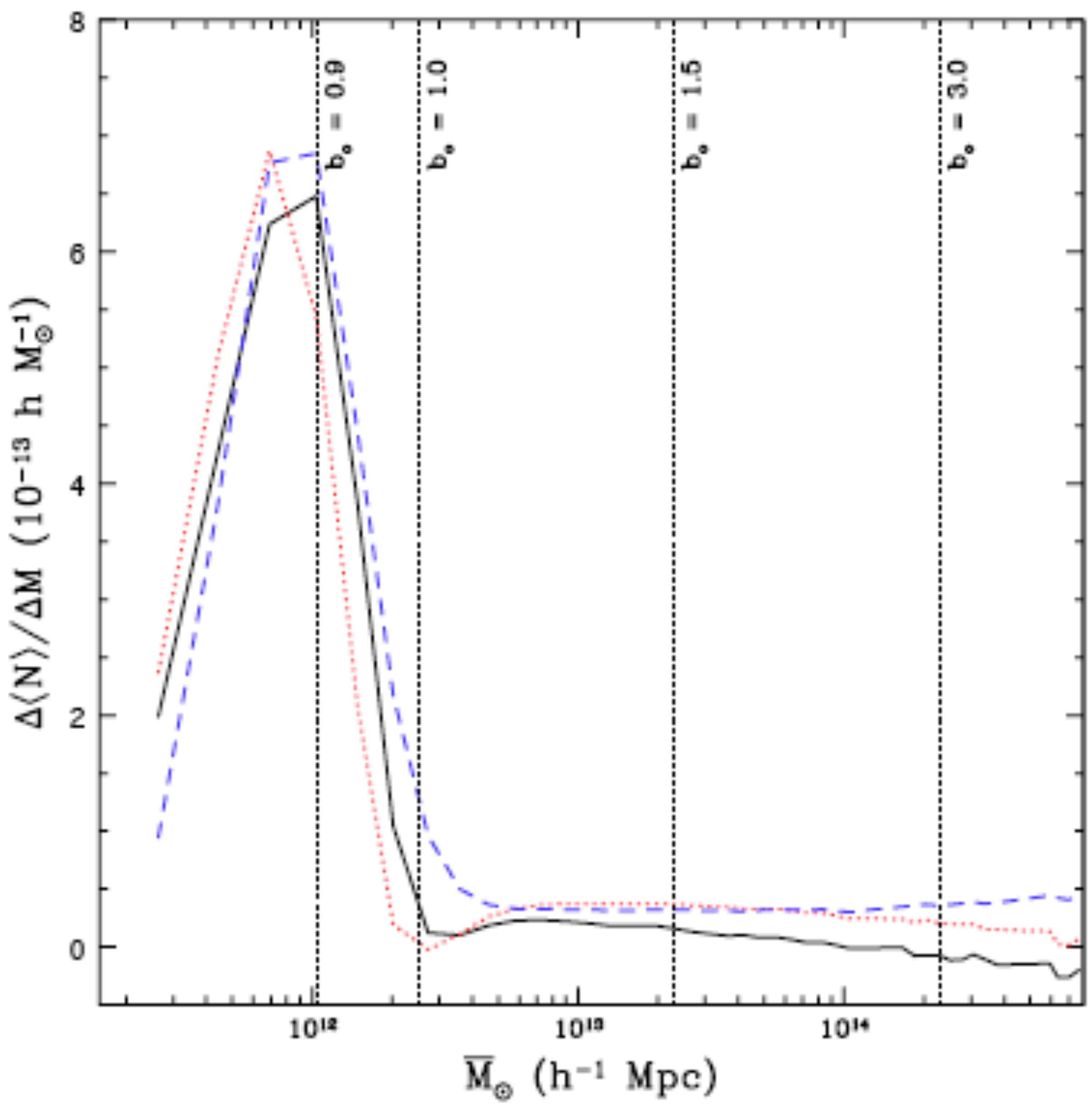
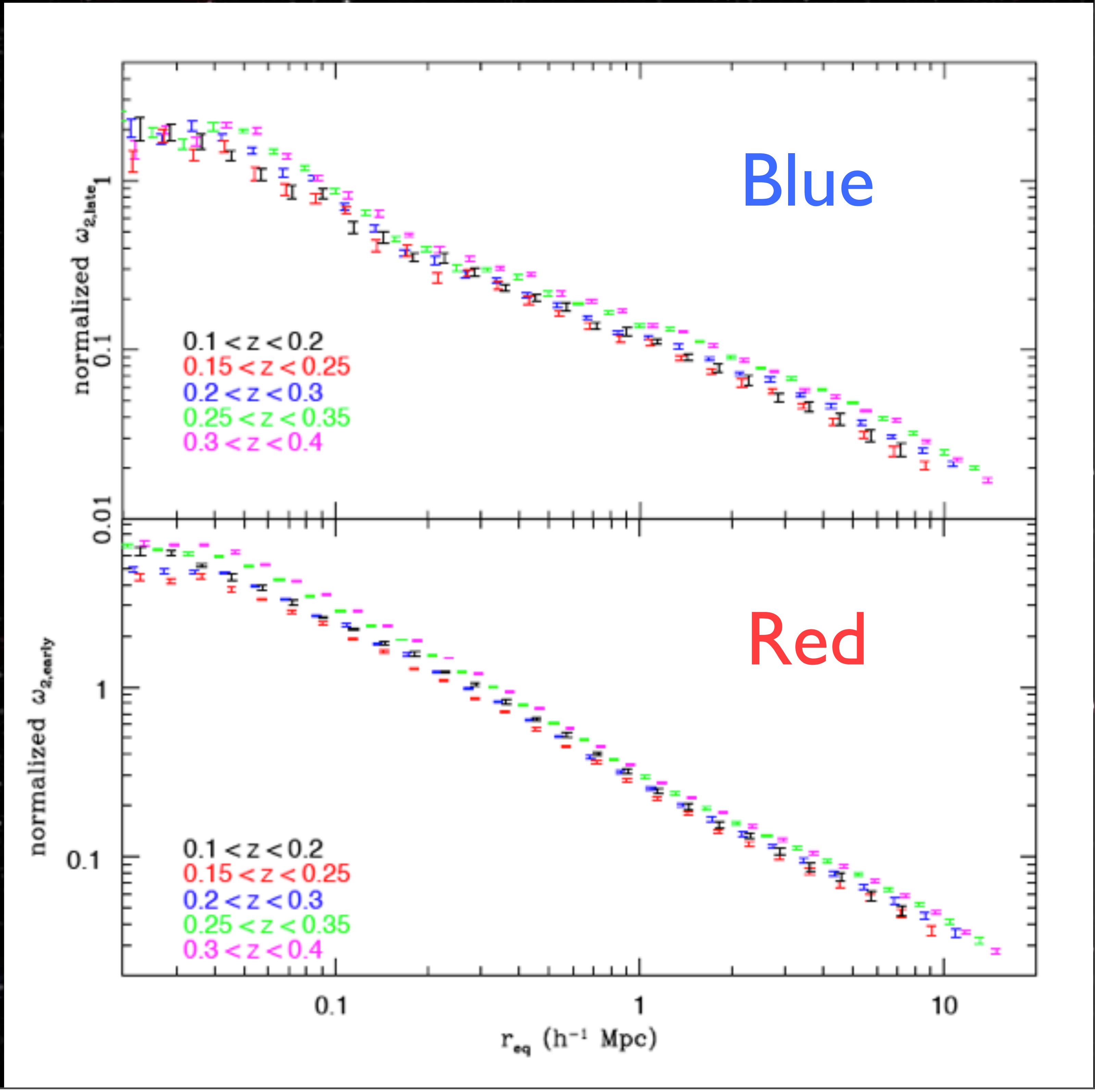




Red/Blue

- Increase in bias similar for red and blue
- HOD fits continue to favour minimal mixing



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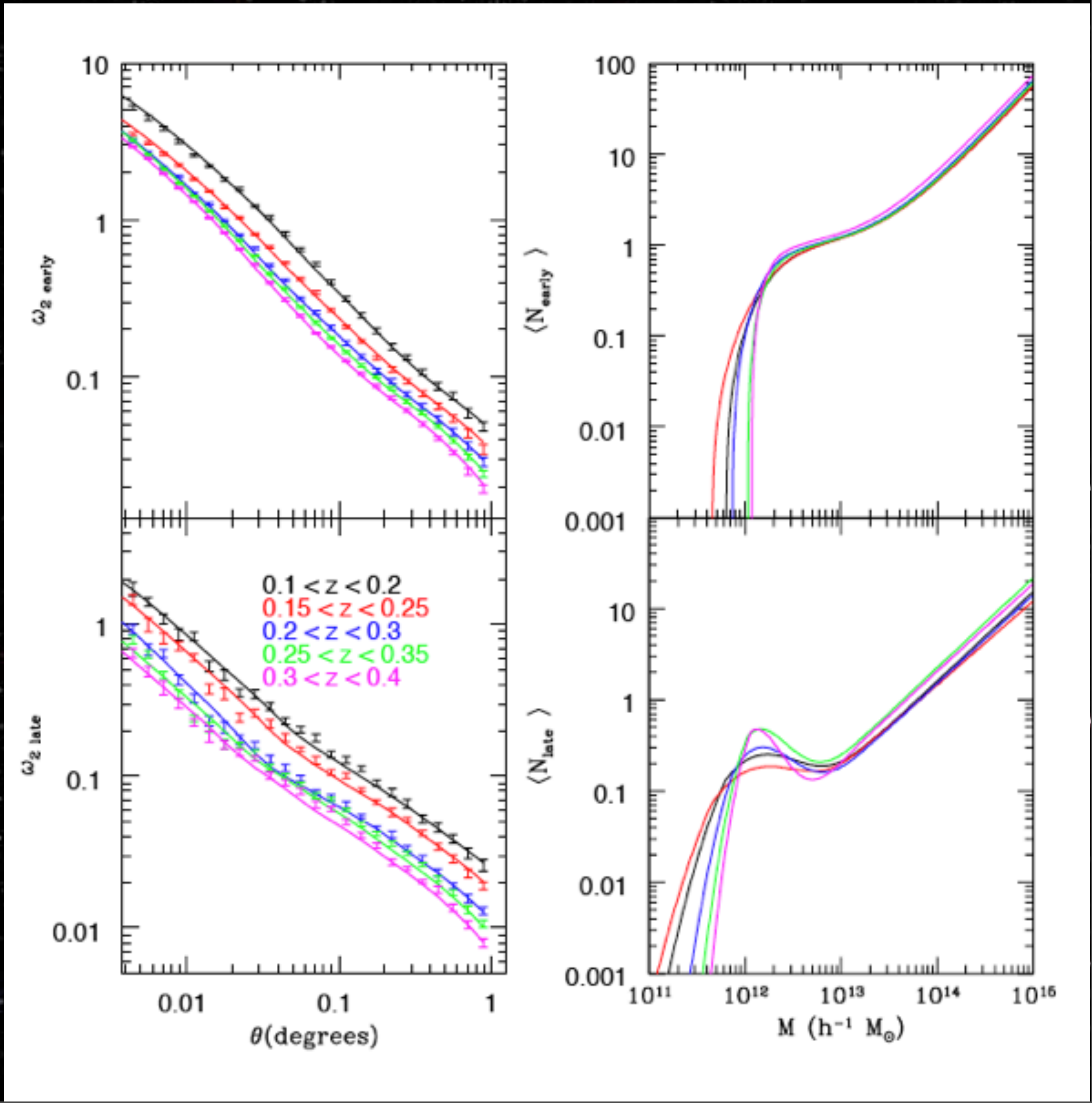

SDSS HOD modeling

- Early/late-type galaxies prefer to exist in separate DM halos
- ~L* Galaxies forming in 10^{12} M_{solar} halos
- Clustering measurements complementary to spectroscopic (larger range of scales, redshift range)
- DES will allow similar studies between z = 0 and z =1

Conclusions

- Much can be learned from SDSS photometric data
  - More robust measure of red galaxy bias/luminosity relationship
  - HOD model for red /blue improved
  - Evolution bias -> galaxy interaction in low mass halos
- Future surveys will rely on photometric data
  - Develop methods for determining best photoz samples, measurement techniques
  - Best results will come from combining ω_2, WL, and higher order measurements (will require focused collaboration!)