The Information Content Encoded in the Clustering of Galaxies

Ashley J Ross
(University of Portsmouth)
Collaborators:
Will Percival, Shirley Ho, Hee-Jong Seo, Roland de Putter, Lado Samushia, BOSS Galaxy Clustering/ Evolution and DES LSS working groups

Outline

- Observing LSS
- Measuring clustering statistics
  - using photometric redshifts (photoz)
- Physical information
  - Color, environment and galaxy evolution
  - Rate of structure growth
  - Baryon Acoustic Oscillations
  - (Matter density, neutrino mass, primordial non-Gaussianity)
- BOSS Photometric vs. Spectroscopic redshifts

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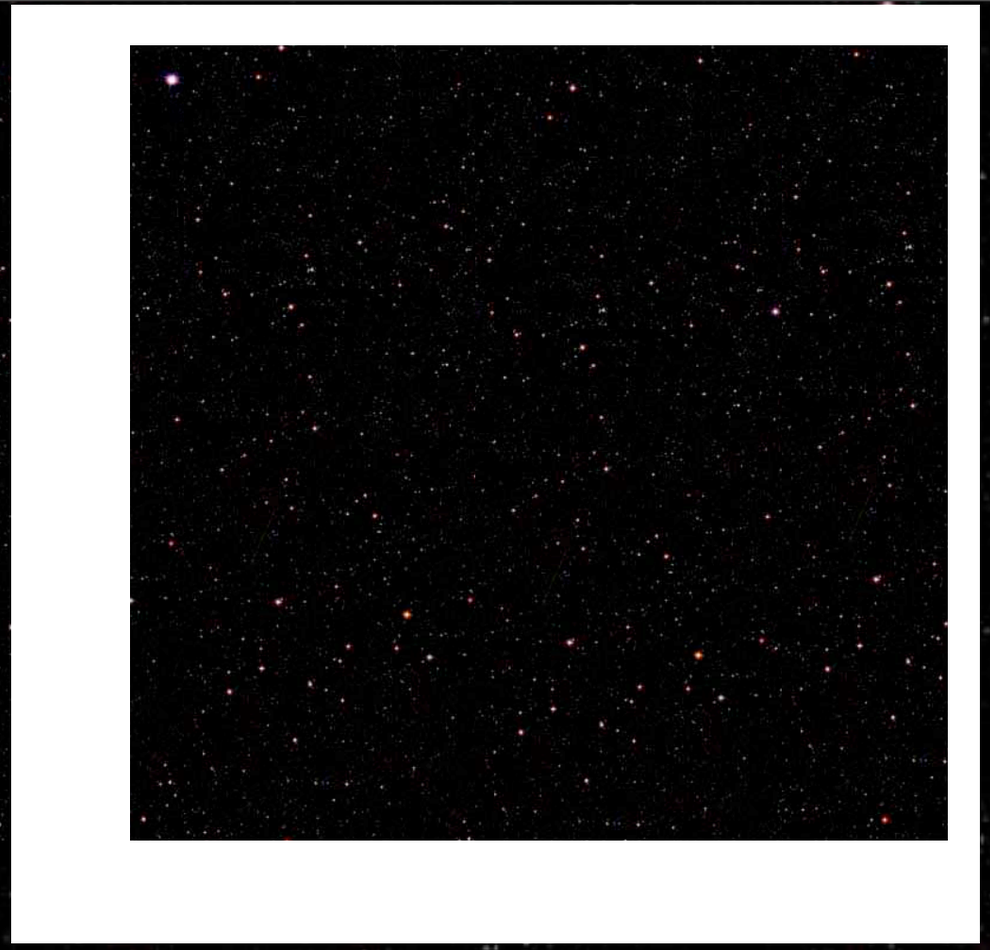

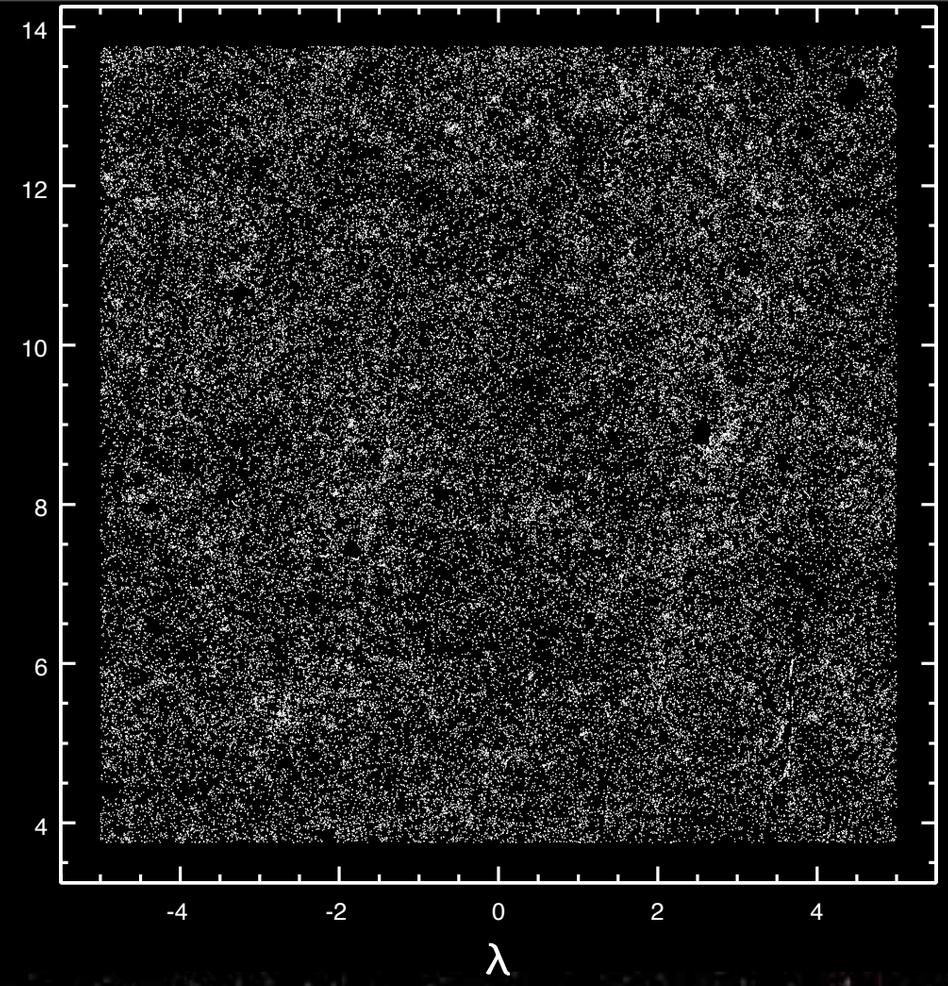

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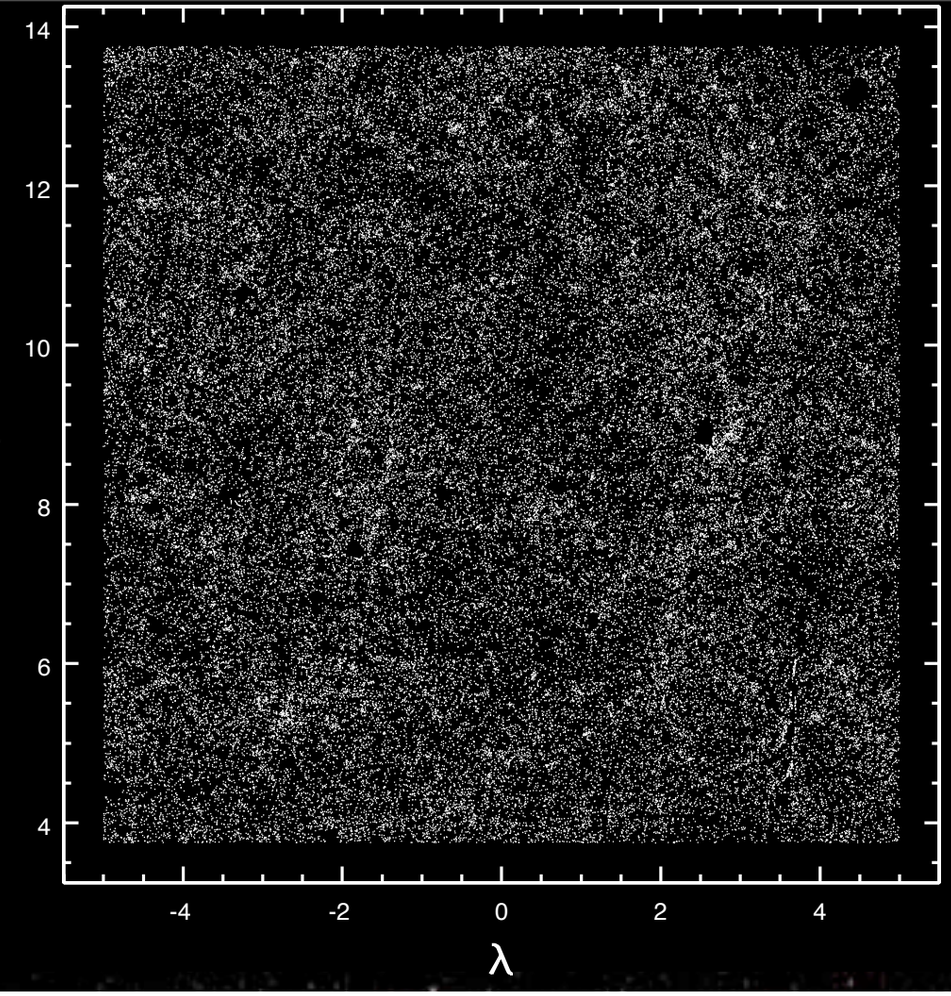
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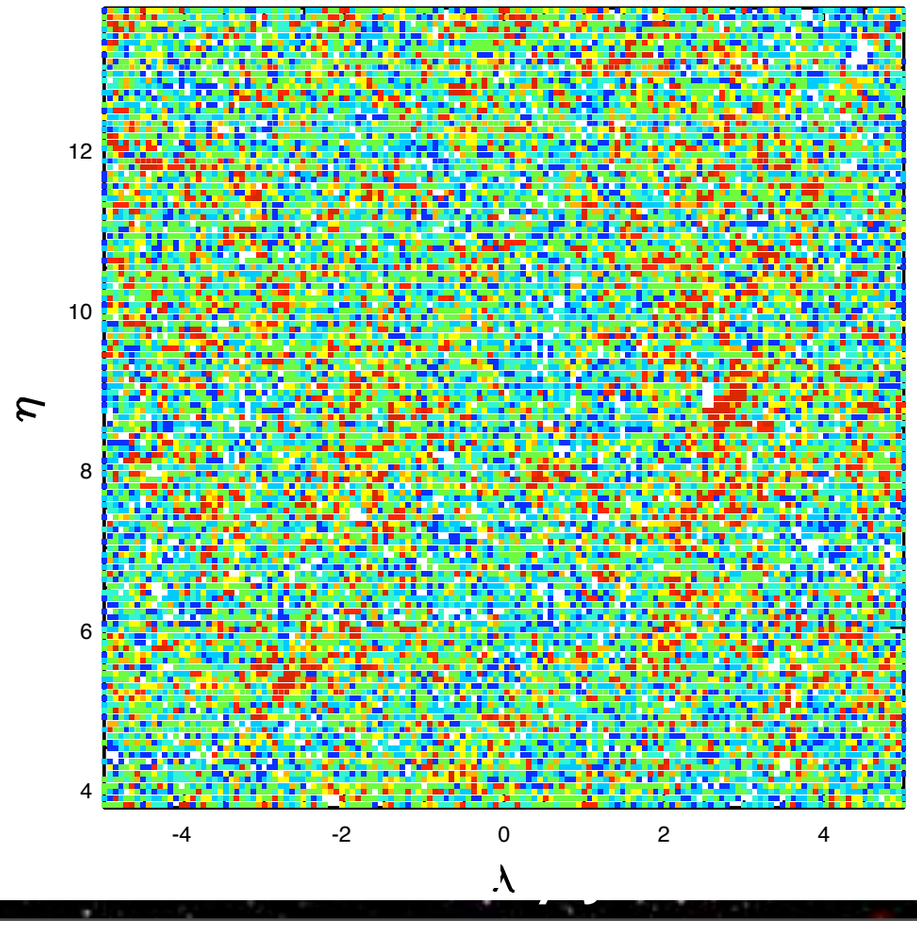
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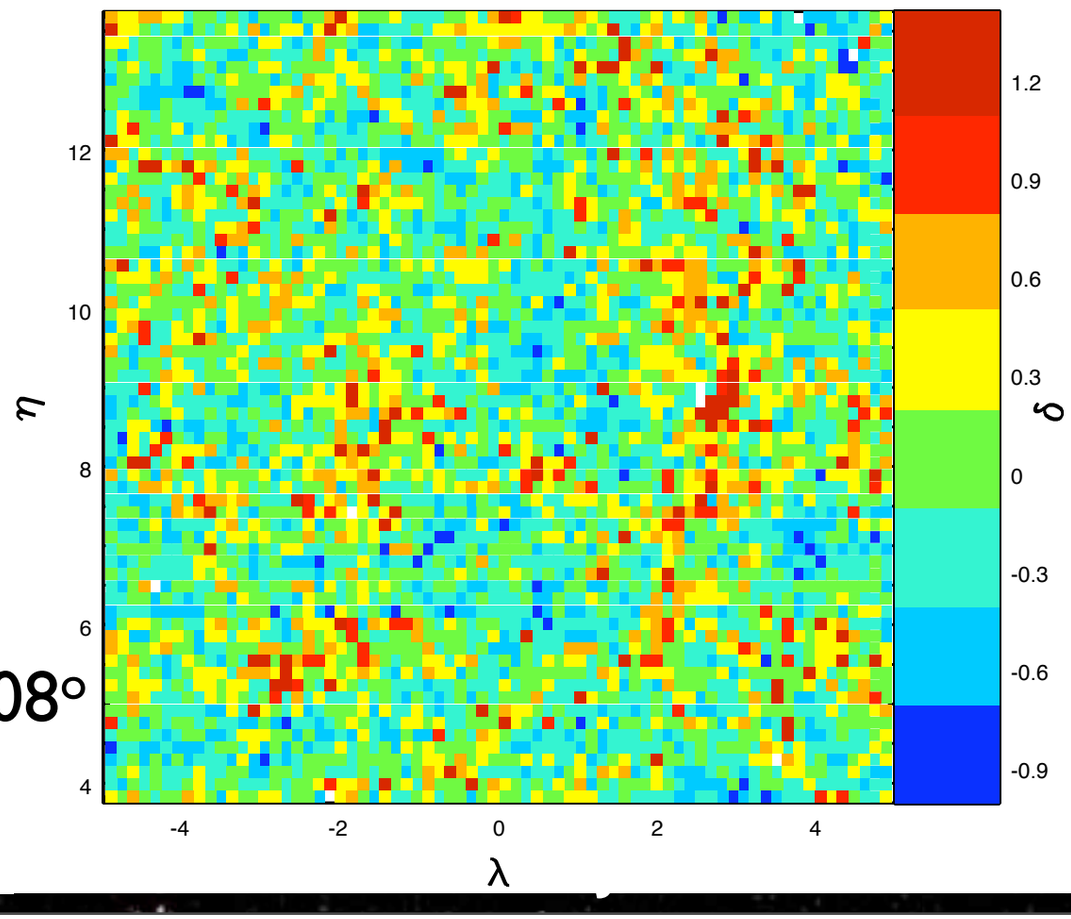
~0.04°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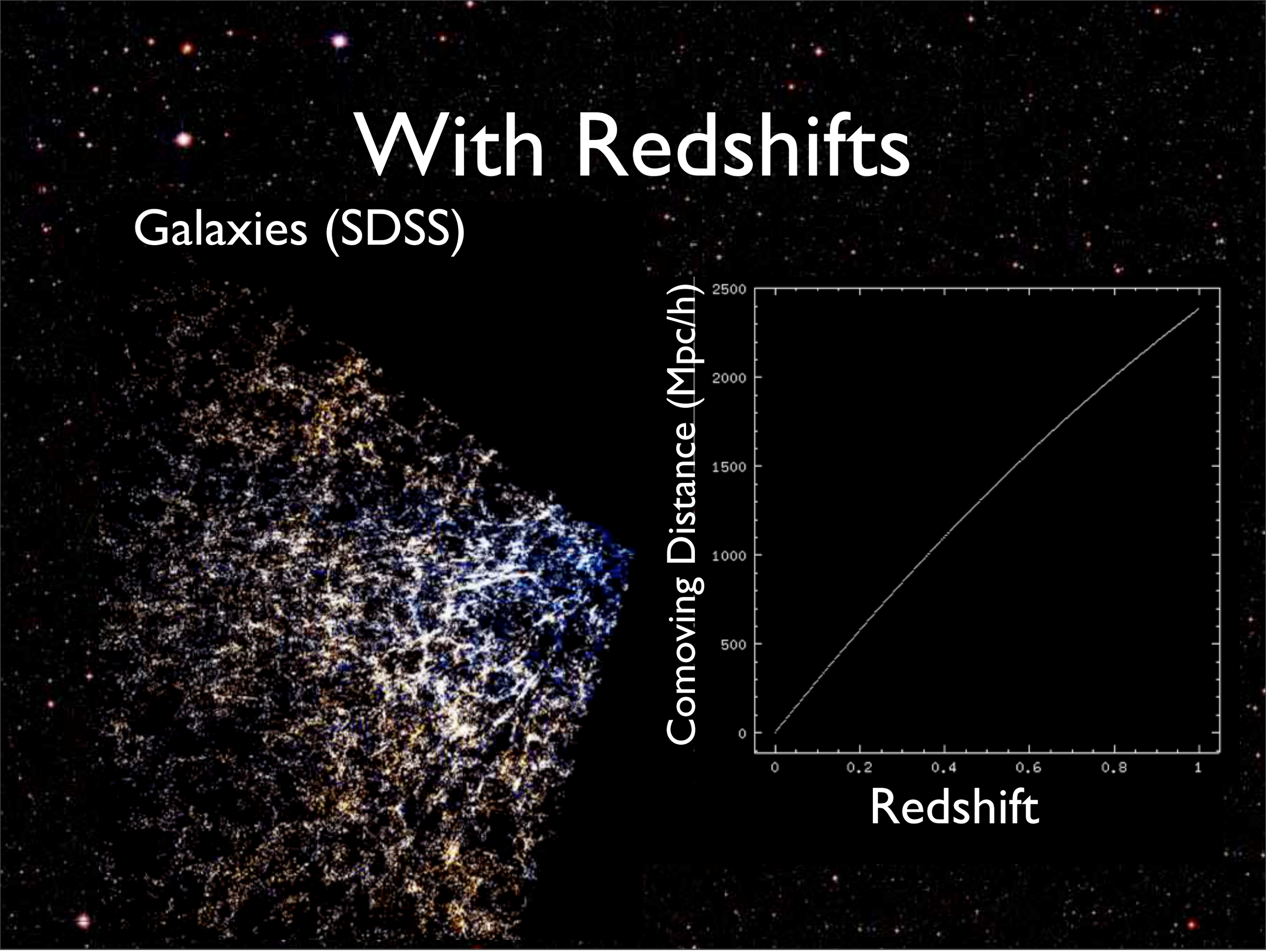
~0.08°

With Redshifts

Galaxies (SDSS)



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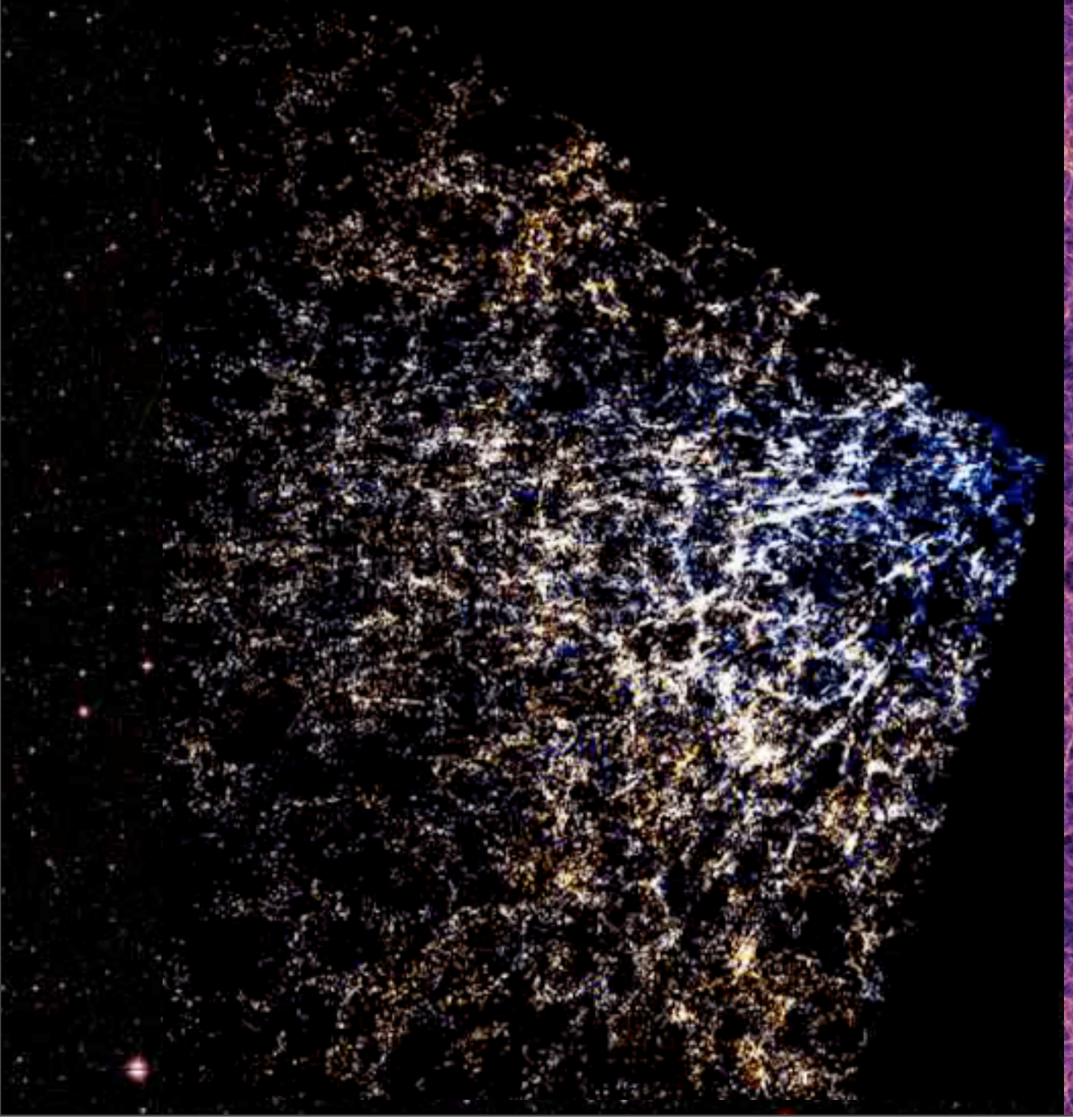
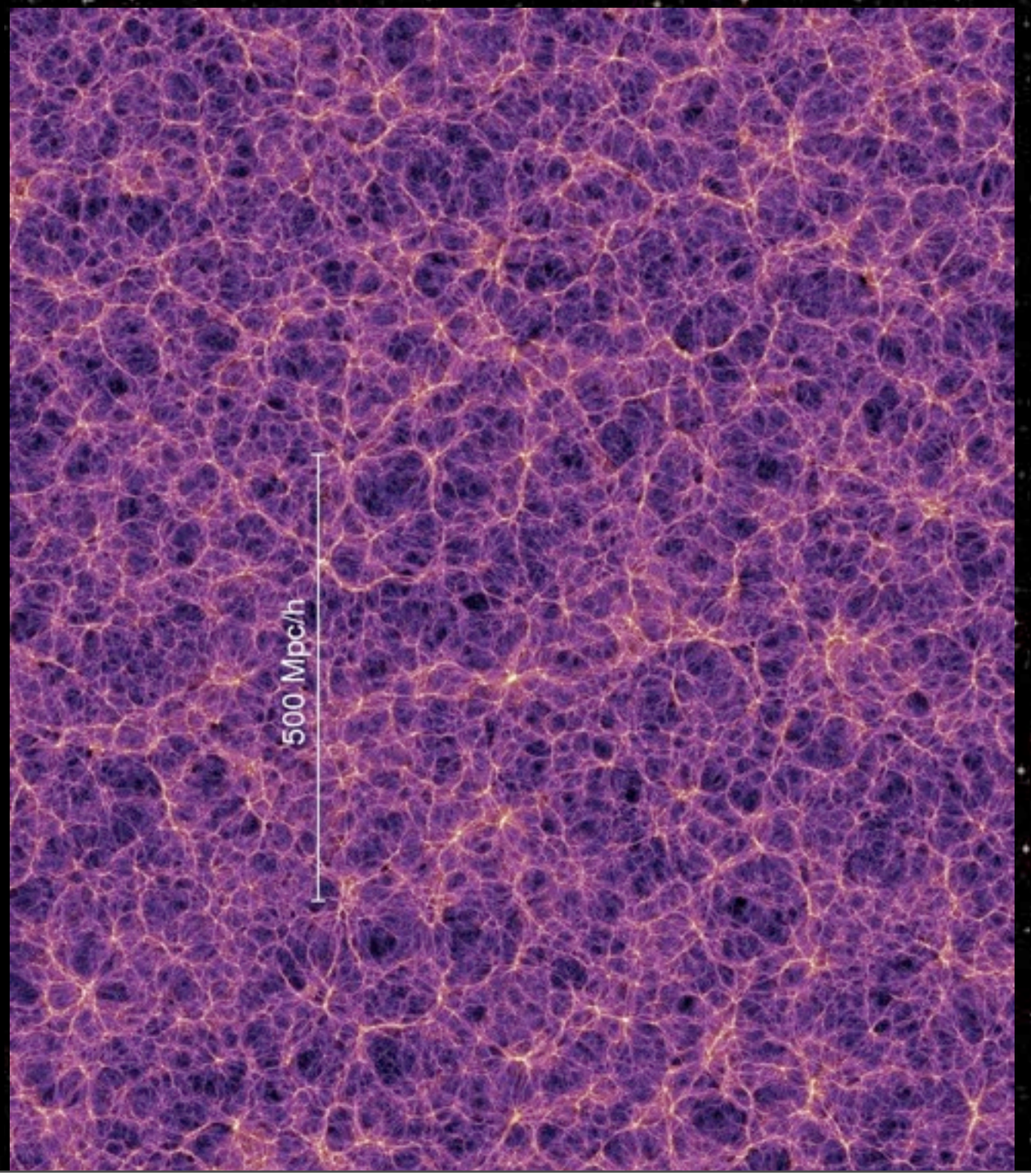


Millennium Simulation



Clustering Measurements

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

$$w(\theta) = \langle \delta_i \delta_j \Theta_{i,j} \rangle$$

  - Alternatively:

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

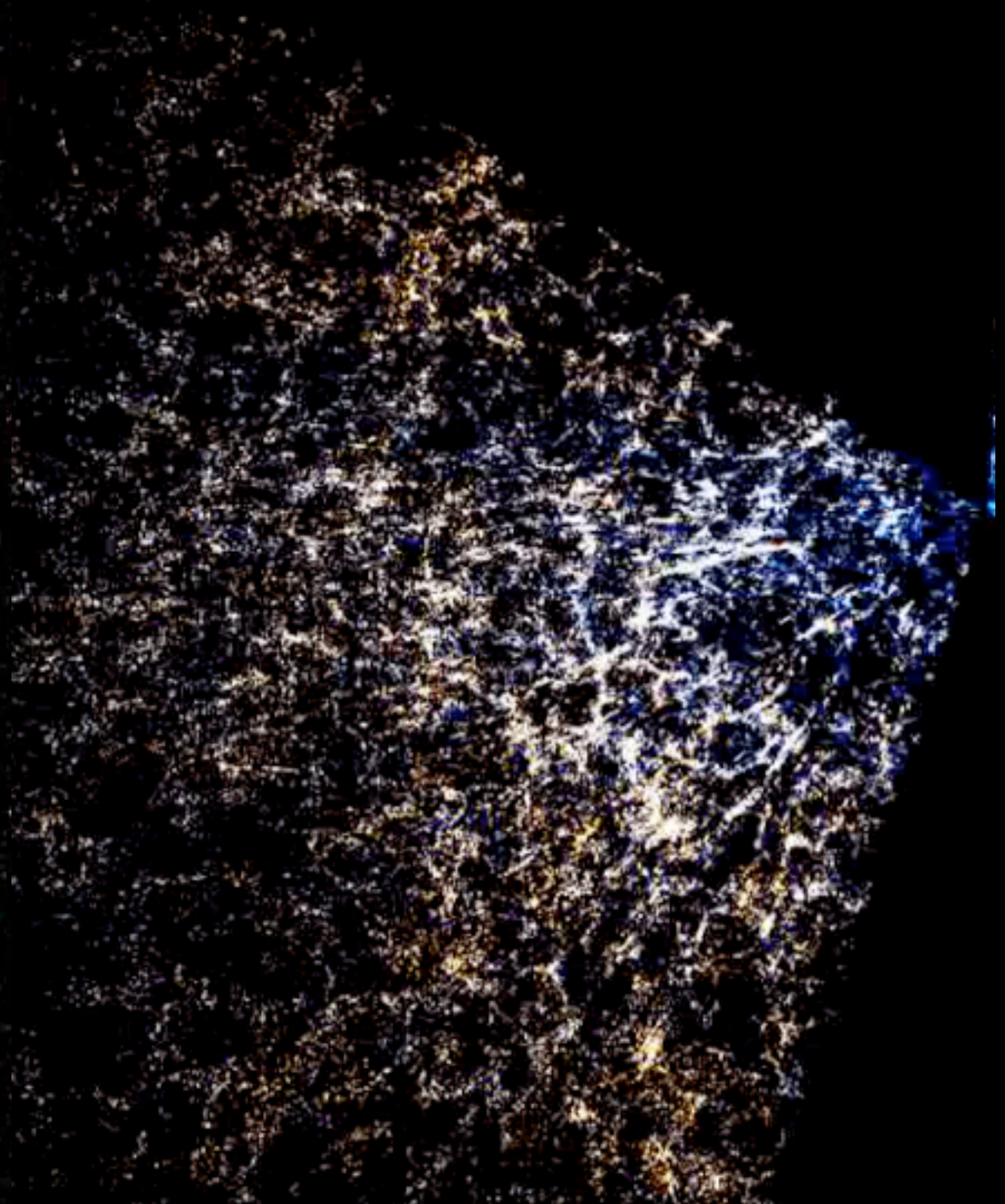
  - Real-space denoted

$$\xi_2(r)$$

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

Clustering Measurements

Galaxies (SDSS)



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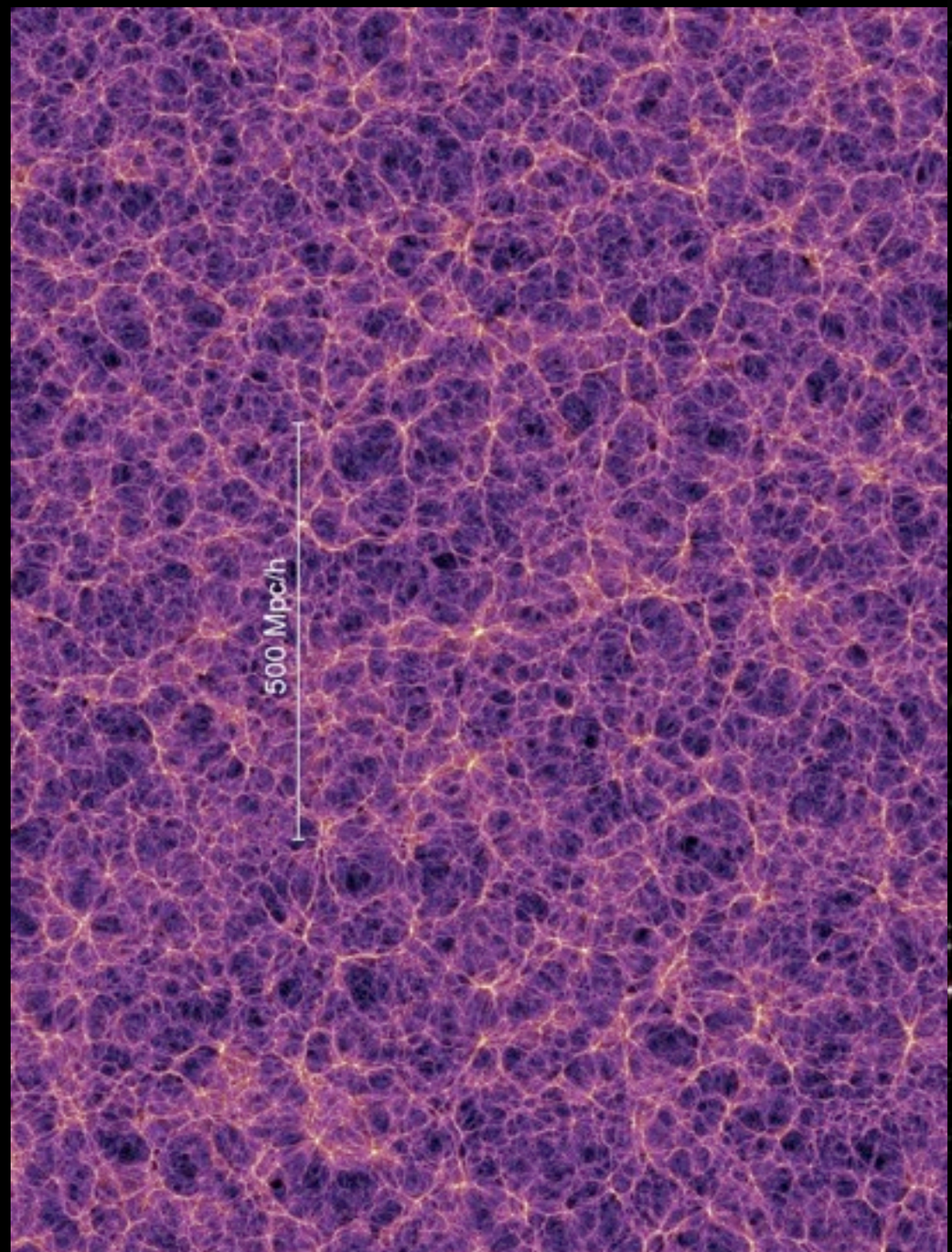

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The Dark Sector

- Agreement between simulation, observation
- Job done?

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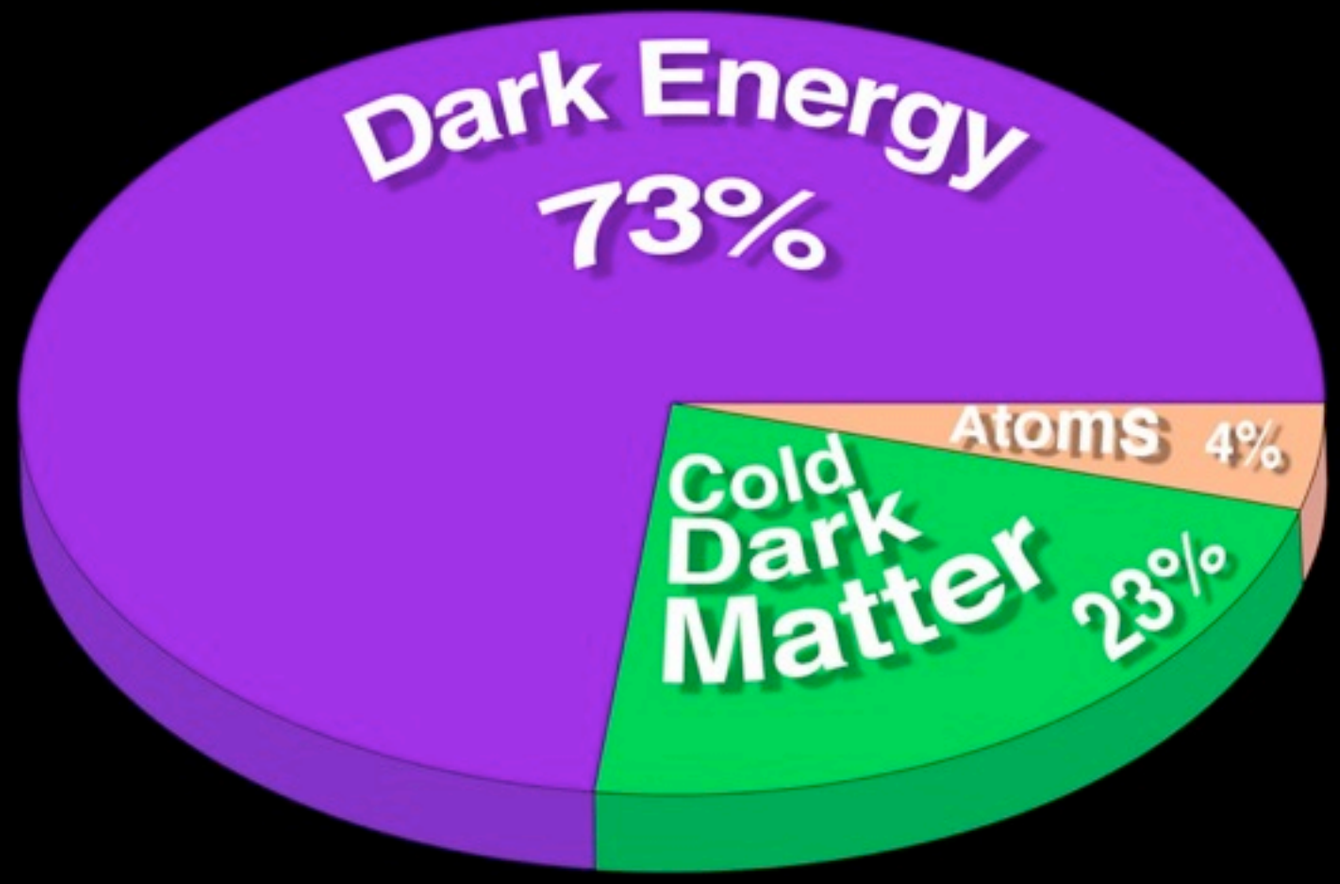
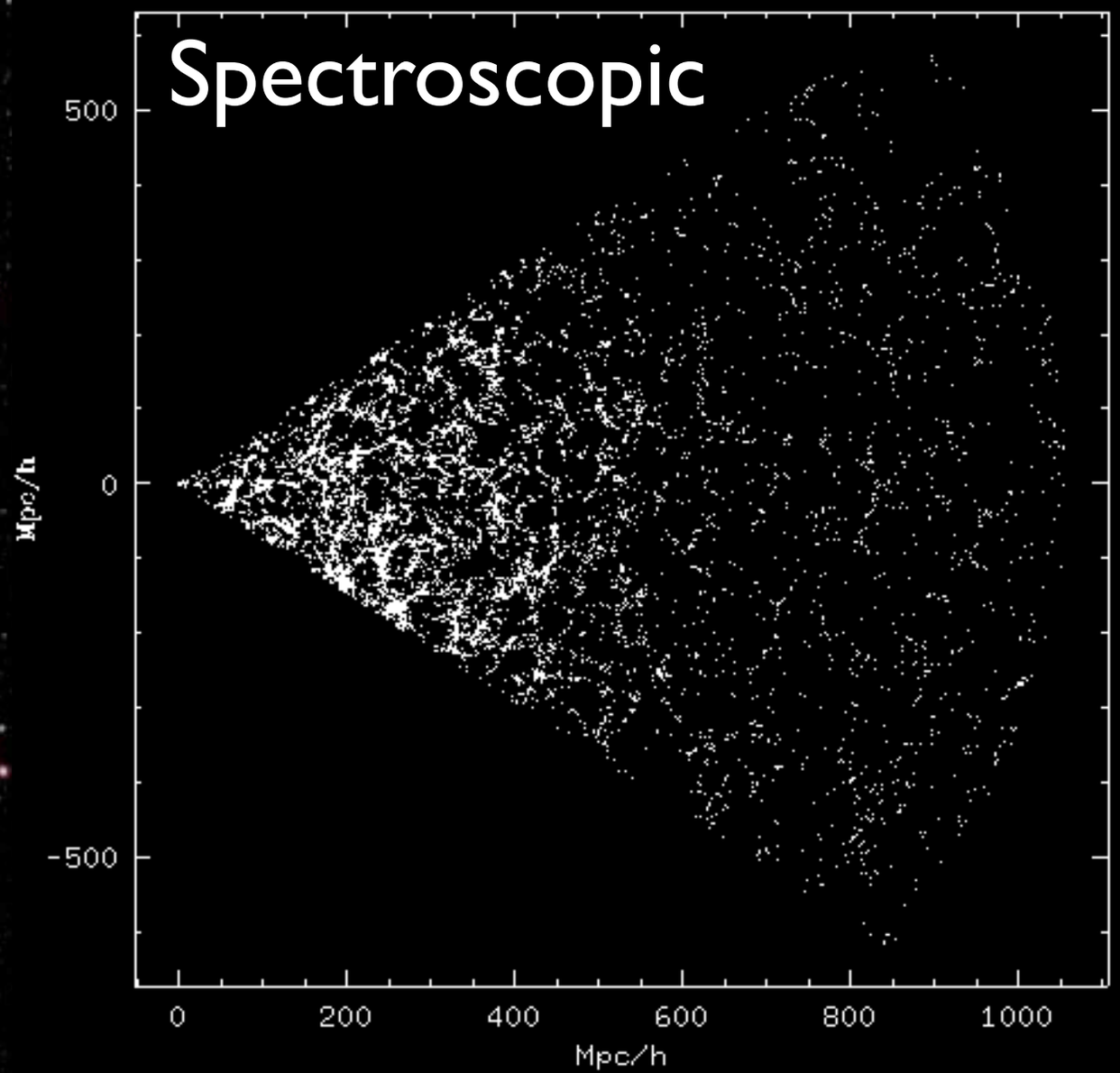
- Job done?
- Need to quantify amounts and properties* of dark sector, test GR

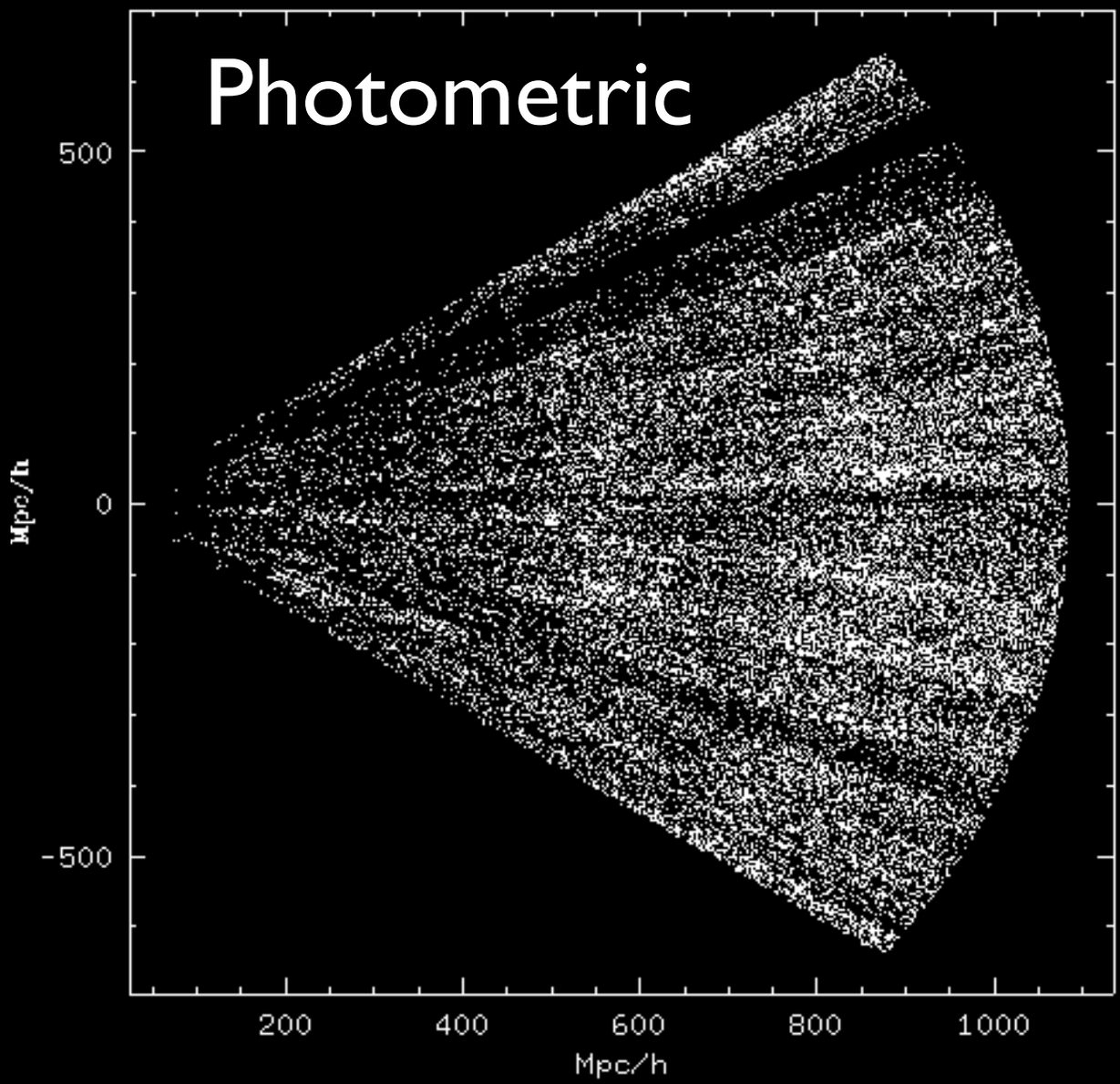


Photometric Redshifts

- *(u)griz(y)* imaging surveys allow $\Delta z_{phot} \sim 0.03(1 + z)$, or about 100 Mpc/h
- Radial clustering nearly wiped out

Photometric Redshifts





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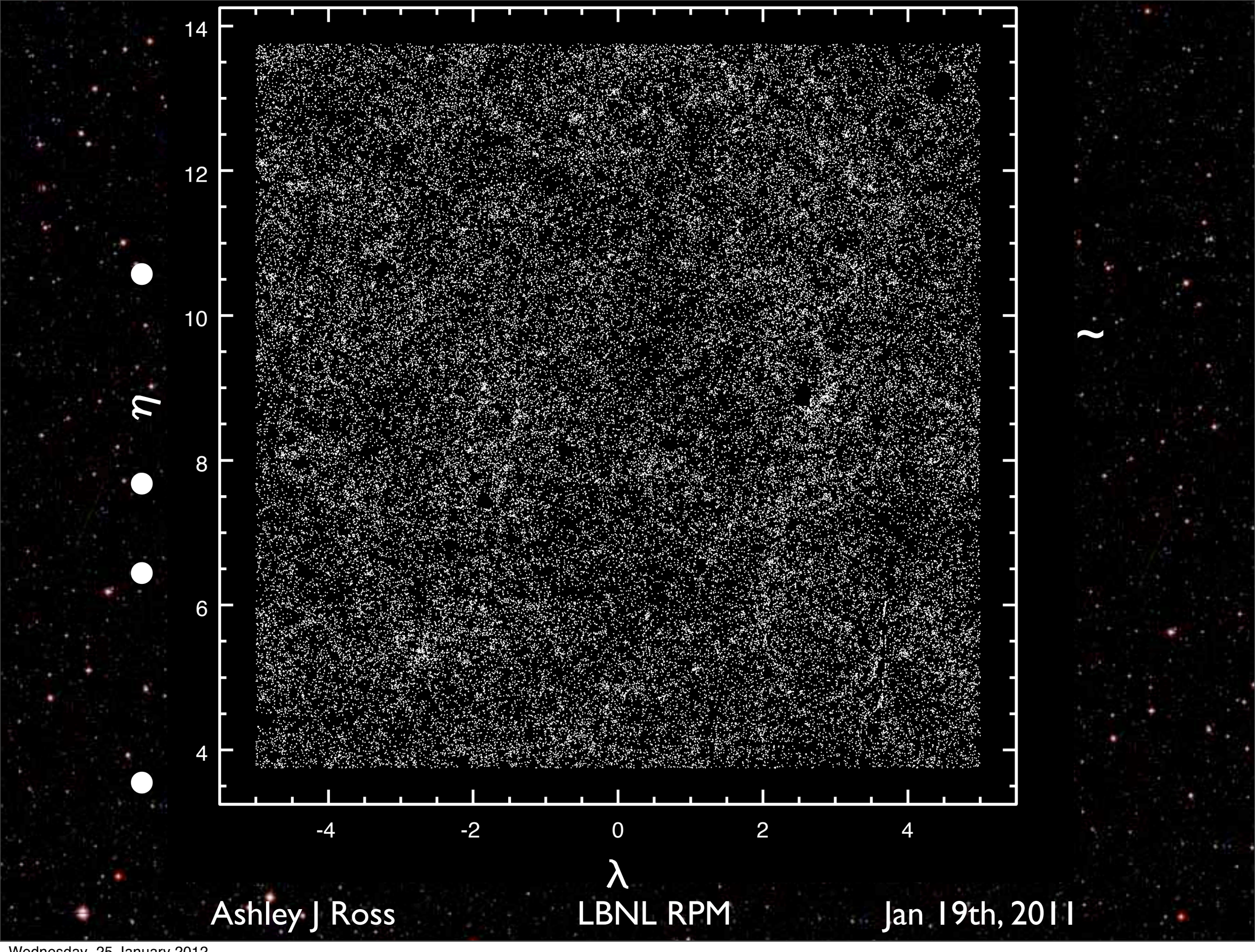
Why Photometric Surveys?

- More objects at higher redshifts (SDSS has ~2×10^7 photoz galaxies; $L*$ observable to $z \sim 0.4$)
- Extremely precise measurements
- Upcoming, deeper, wide-field surveys will rely primarily on photometry (e.g, Dark Energy Survey)
- (Lensing needs high density of background sources)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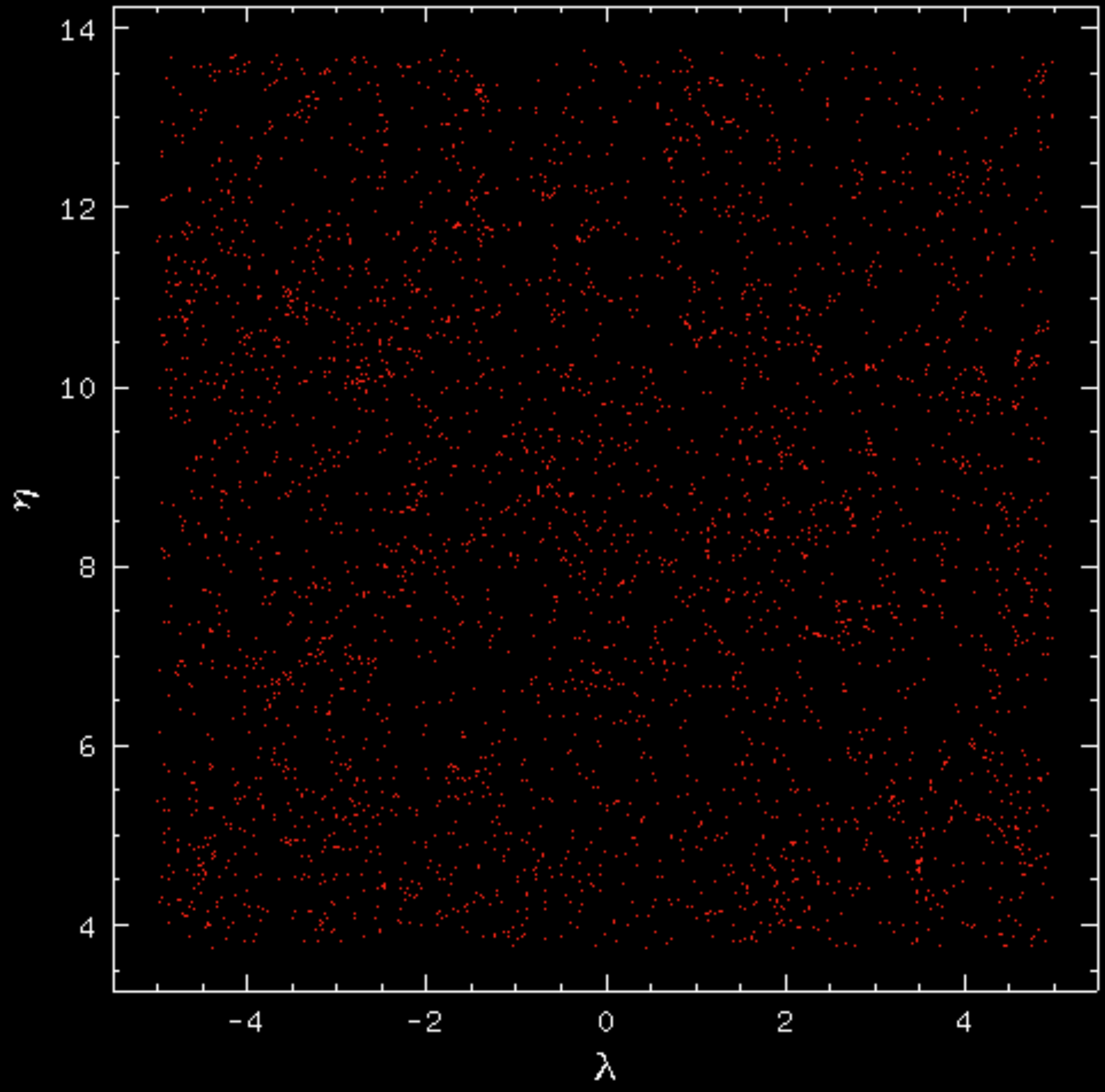

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Clustering with Photometric Redshifts

- "2+1" dimensions": make measurements in photoz bins ~ as wide as photoz error $w(\theta)$,
- project over redshift distribution

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

- Accurate measurements require careful treatment of observational systematics

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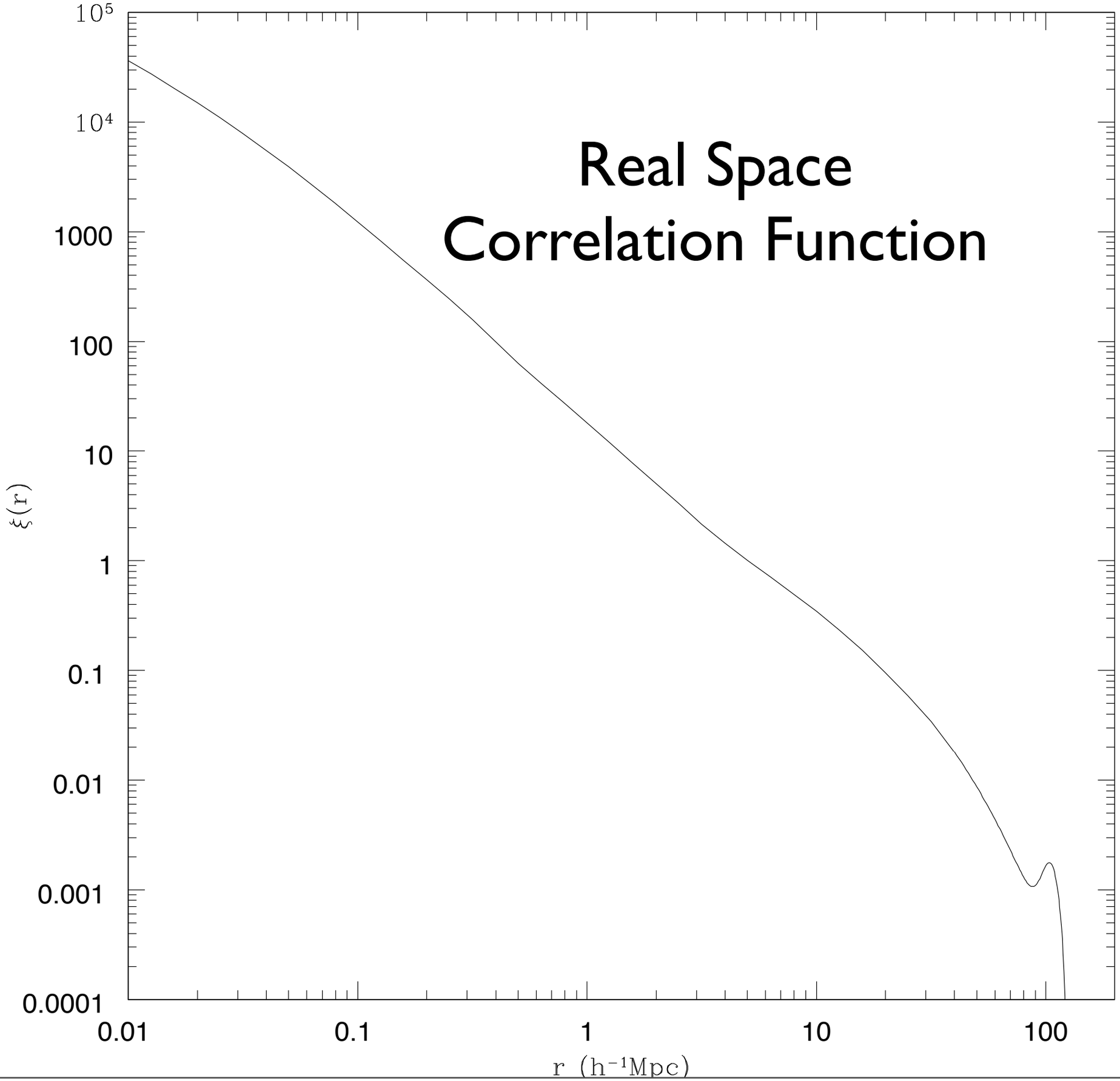
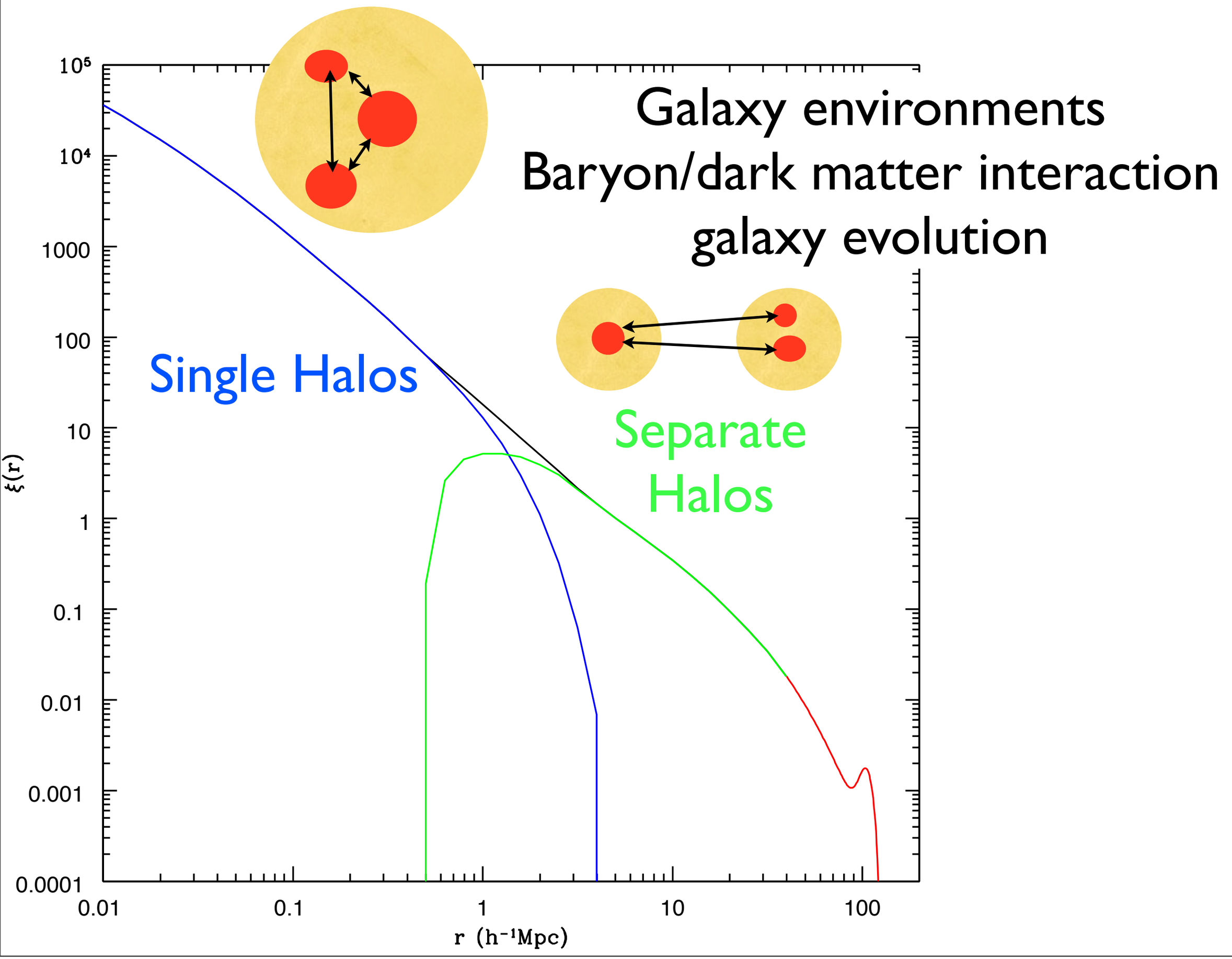
Real Space Correlation Function




Galaxy environments
Baryon/dark matter interaction
galaxy evolution
Single Halos
Separate
Halos
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

Clustering depends on Color

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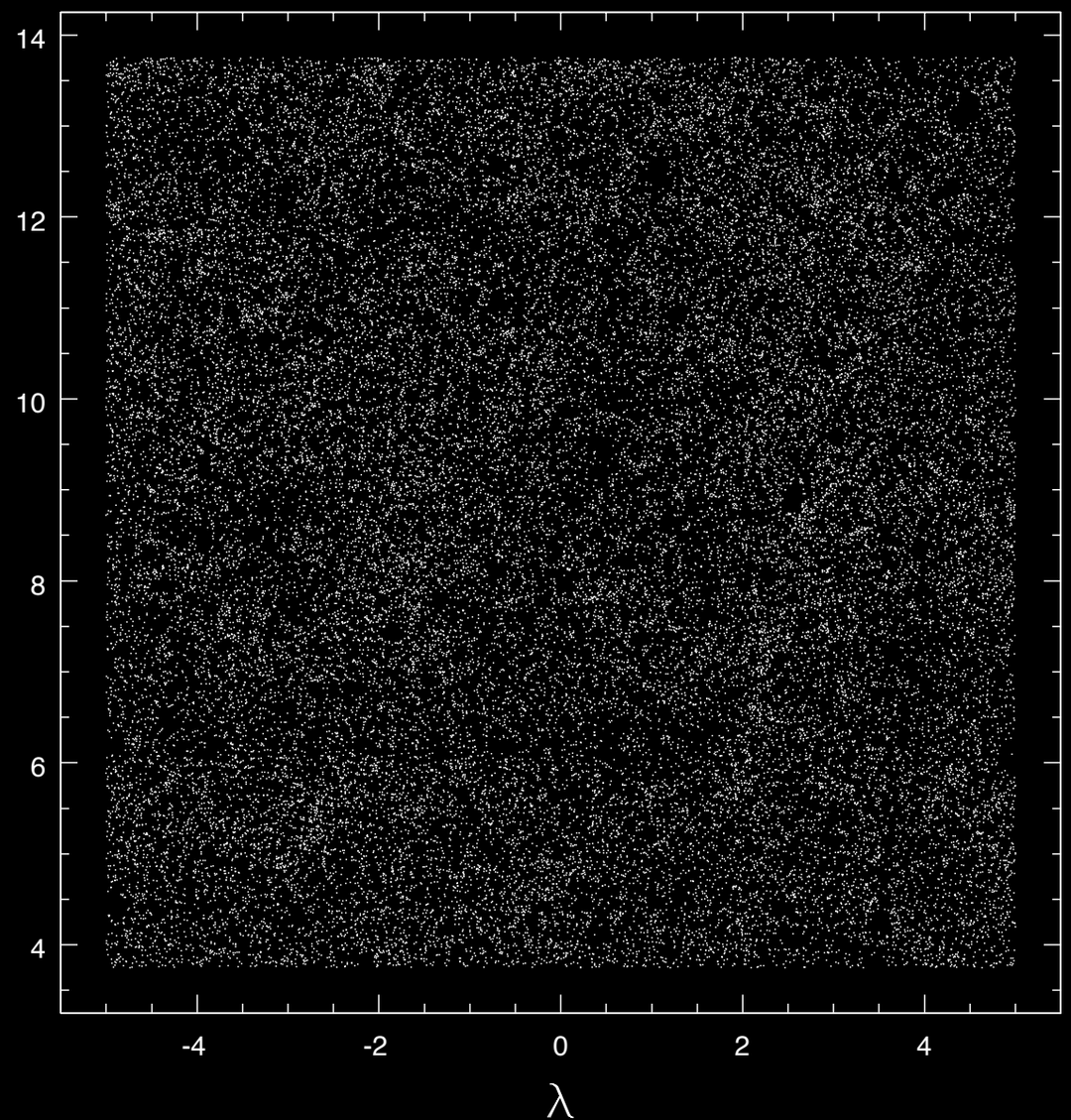
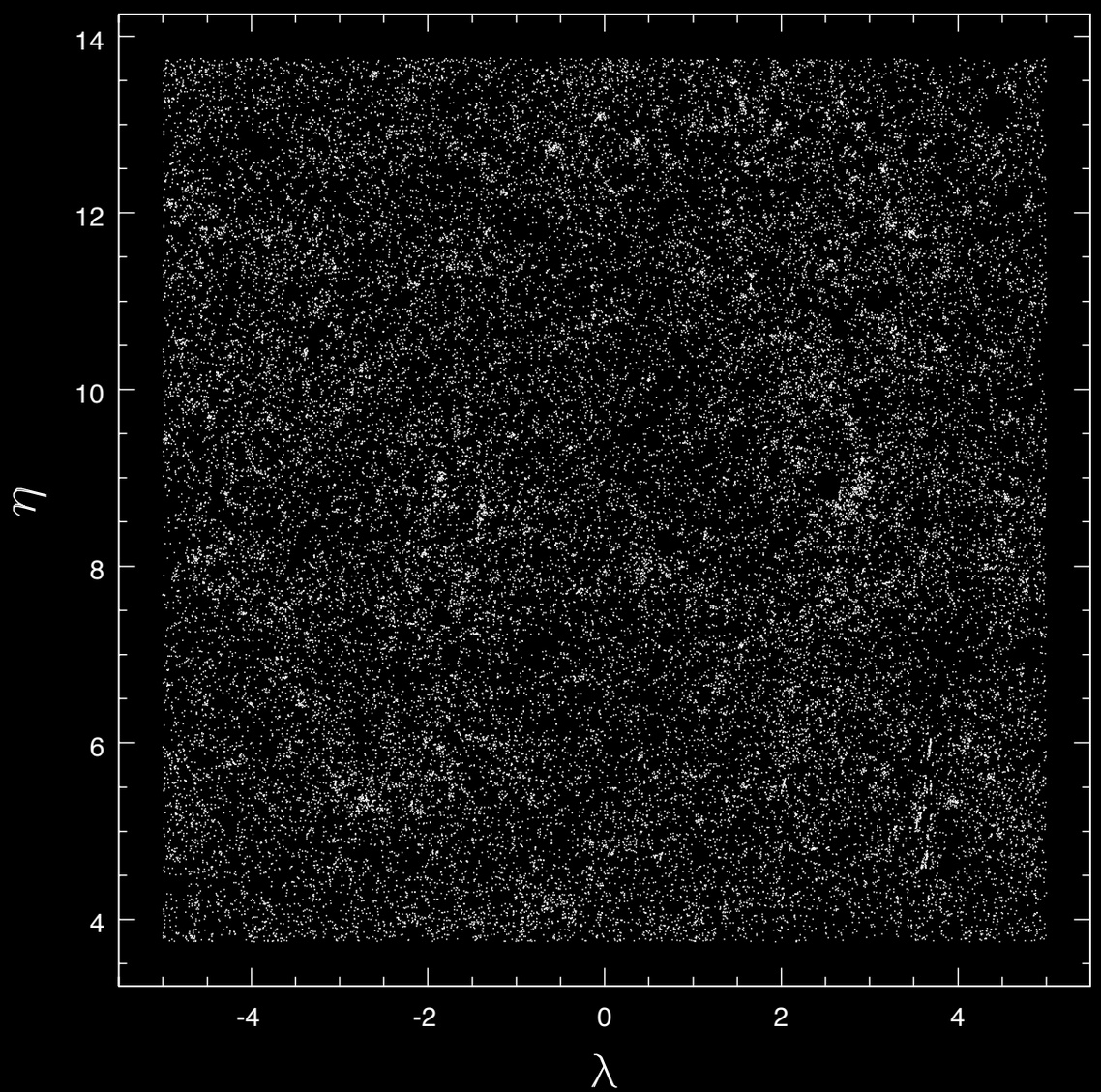


Blue



Red

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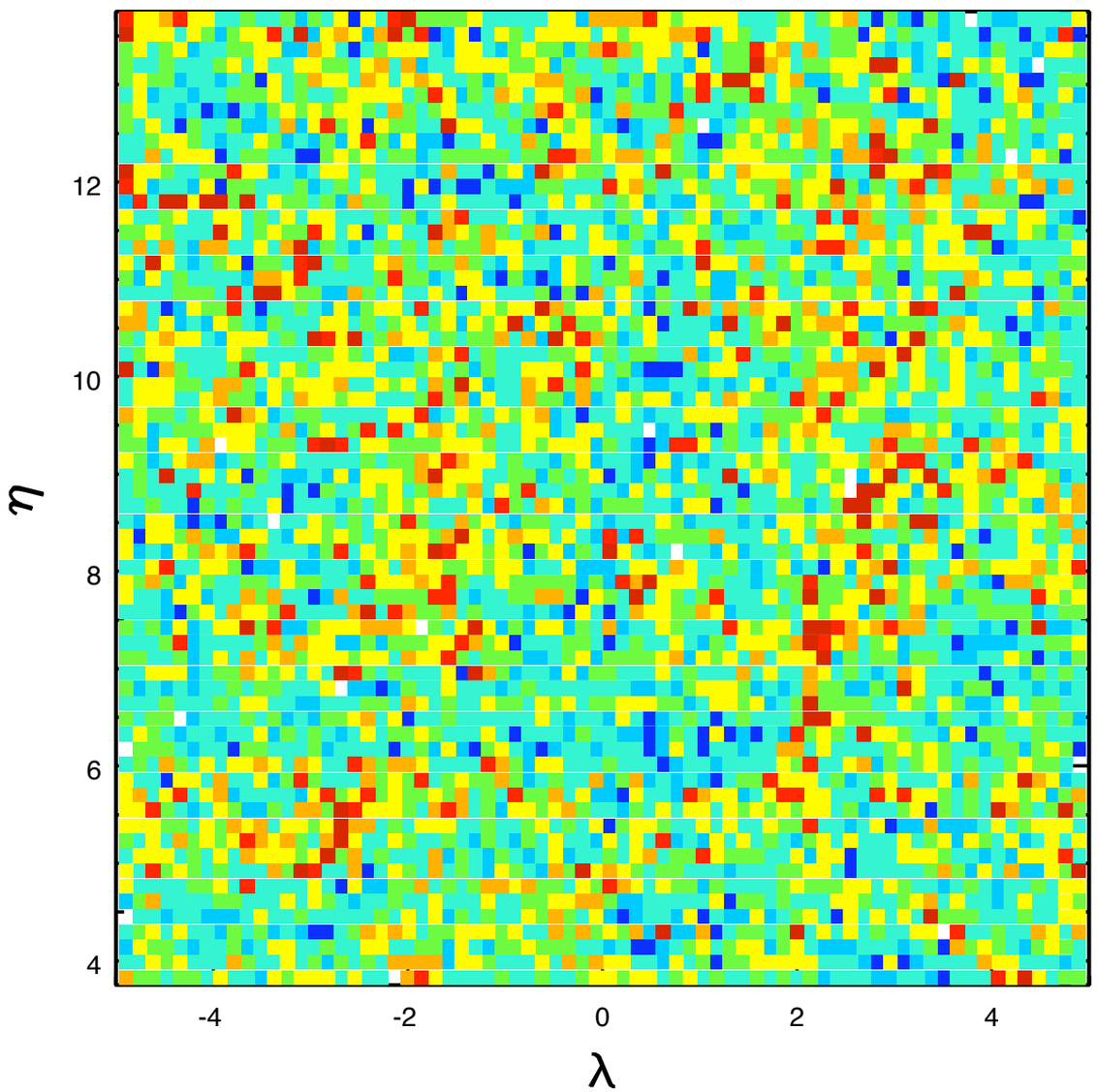
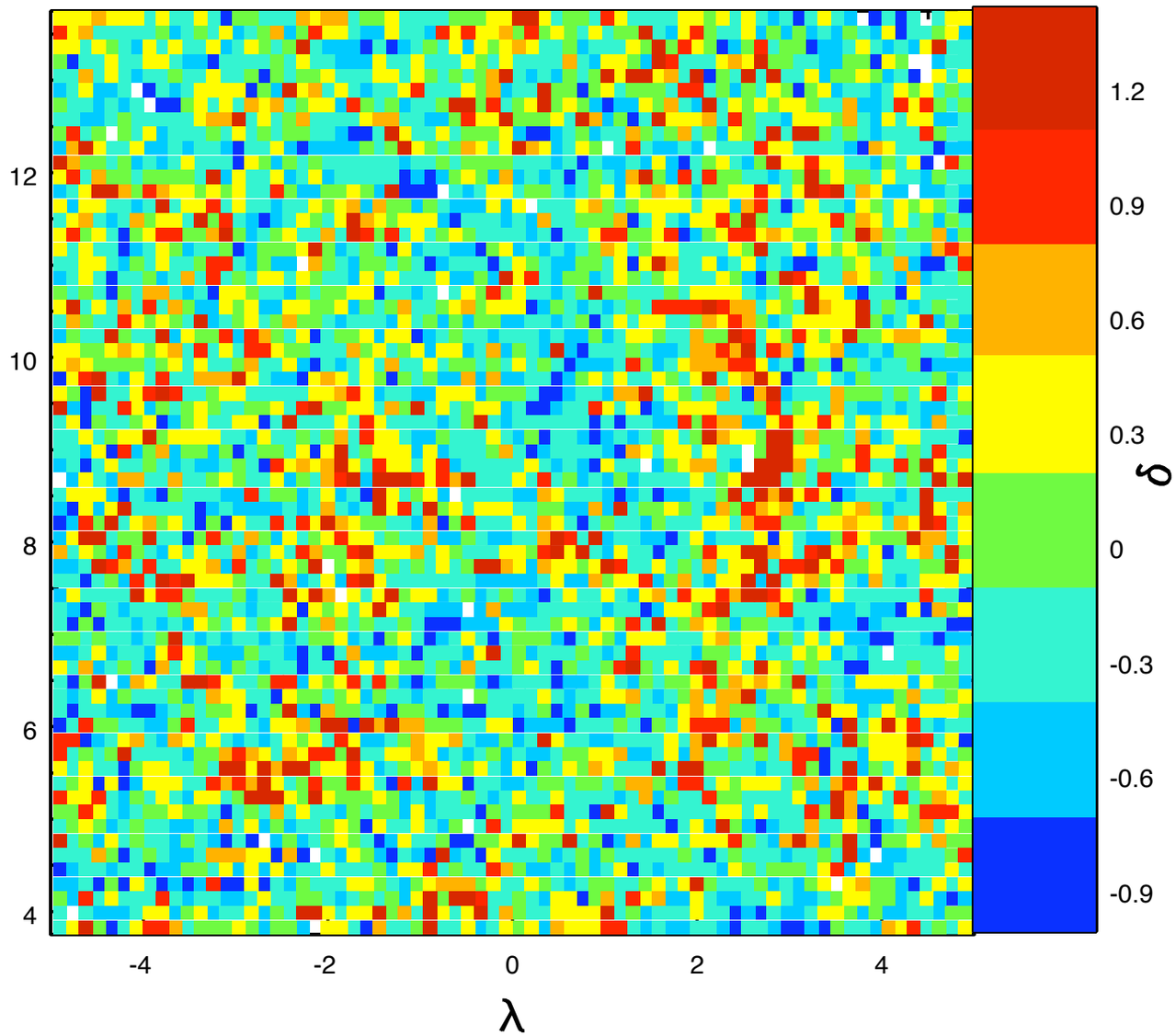
Clustering depends on Color



Blue



Red

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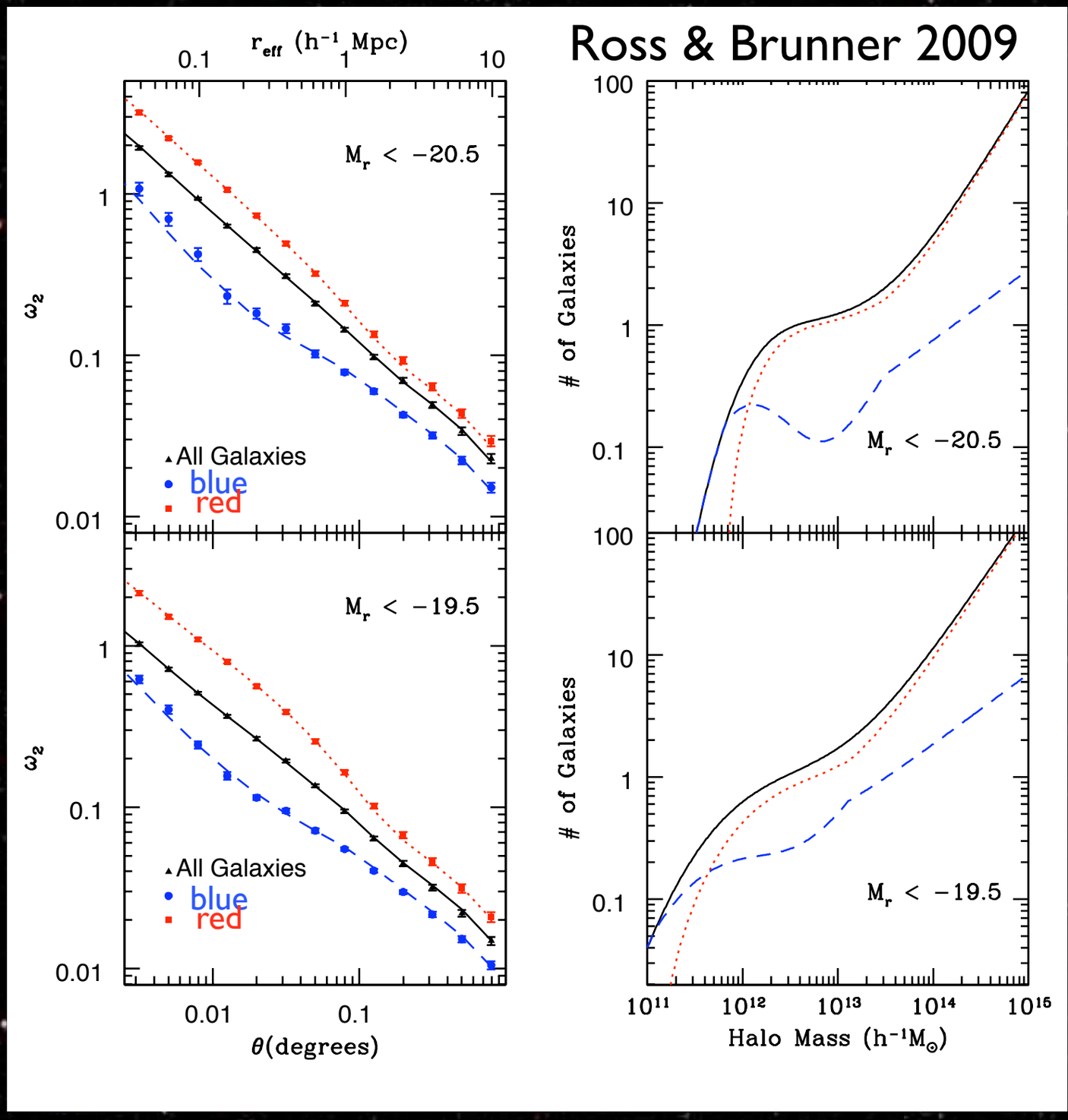
Clustering of Red and Blue Galaxies

- SDSS DR5 photozs
- measurements fit by parametric halo model
- +Segregation of blue/red galaxies



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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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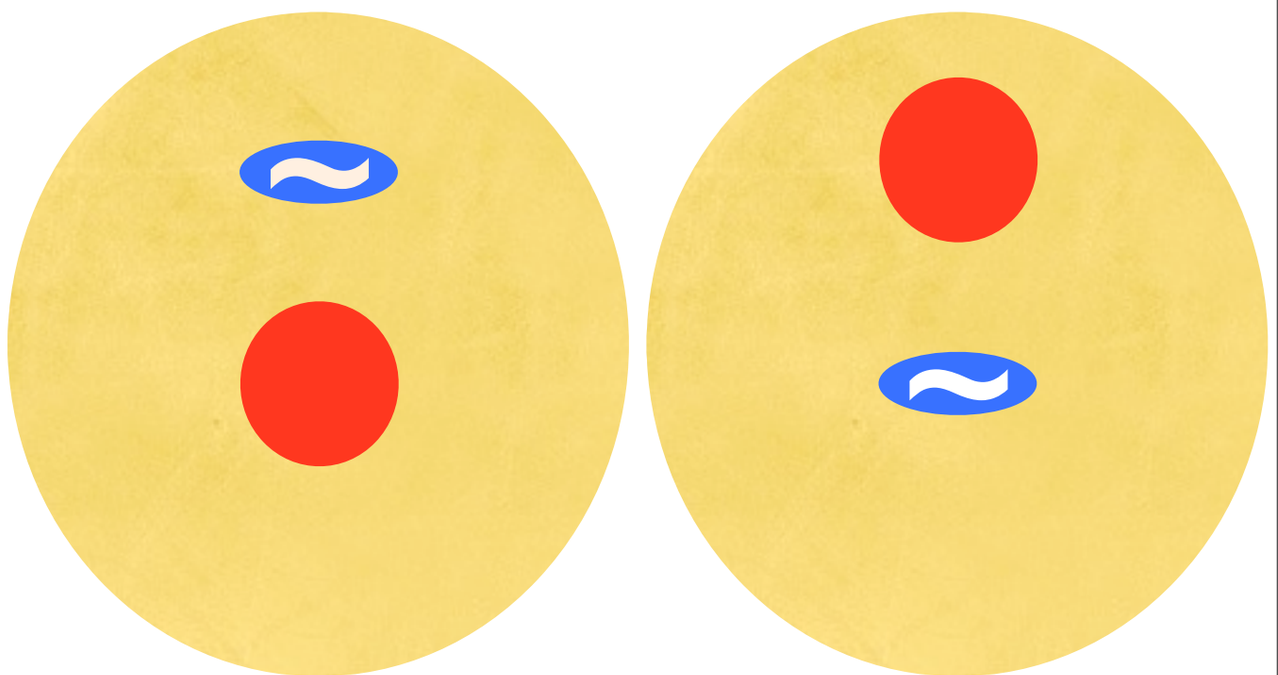
Mixing (old model)



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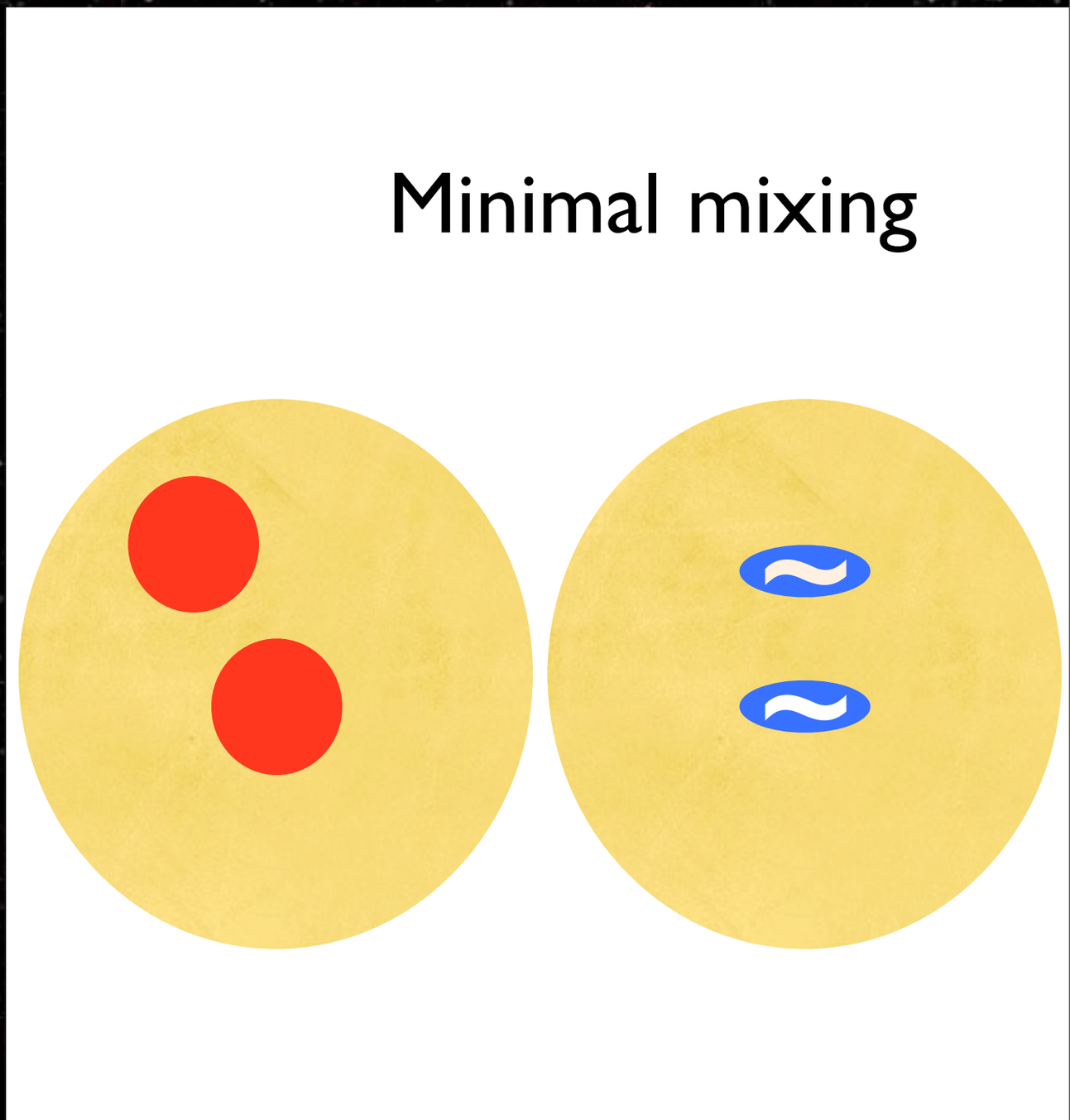

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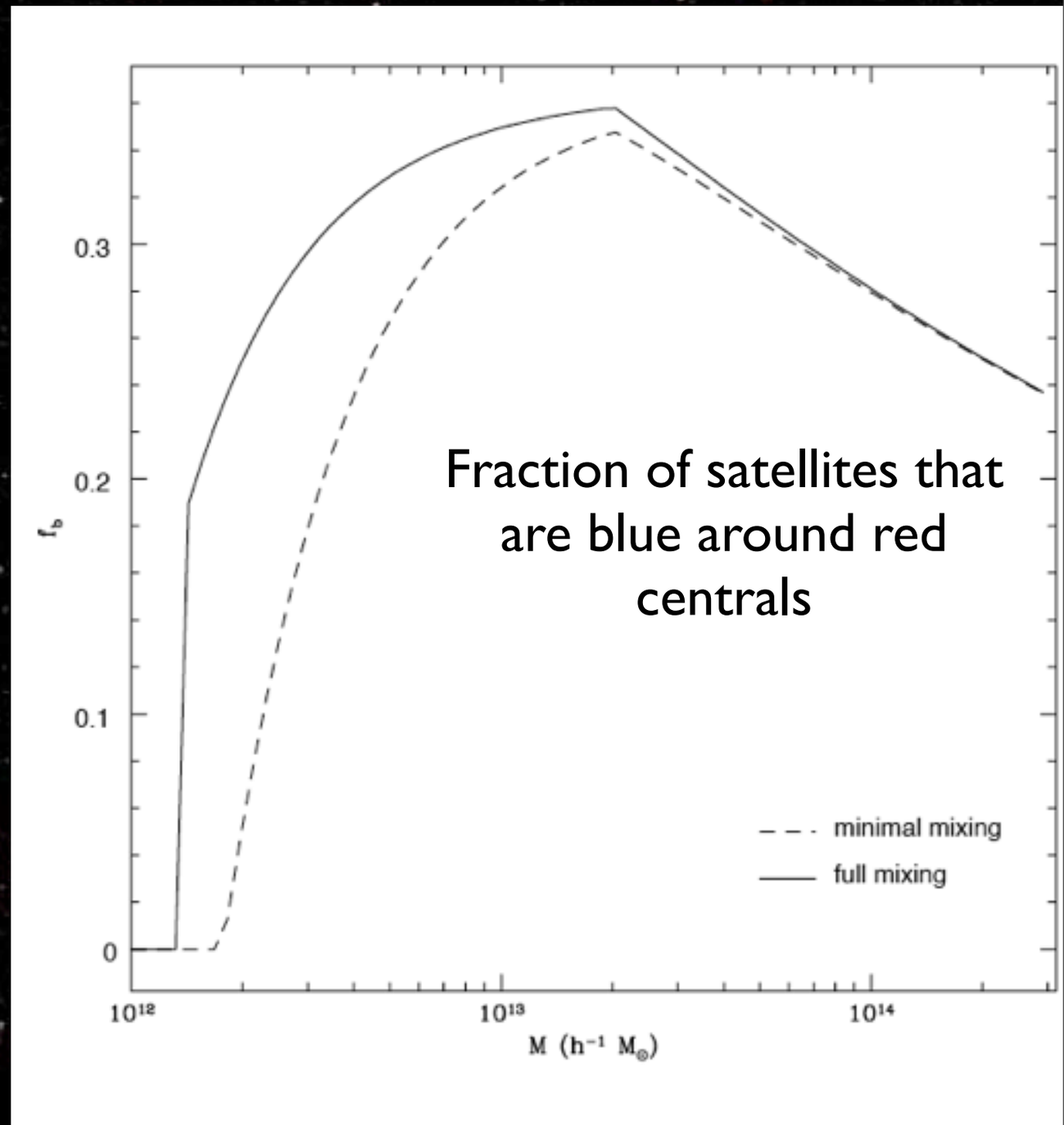
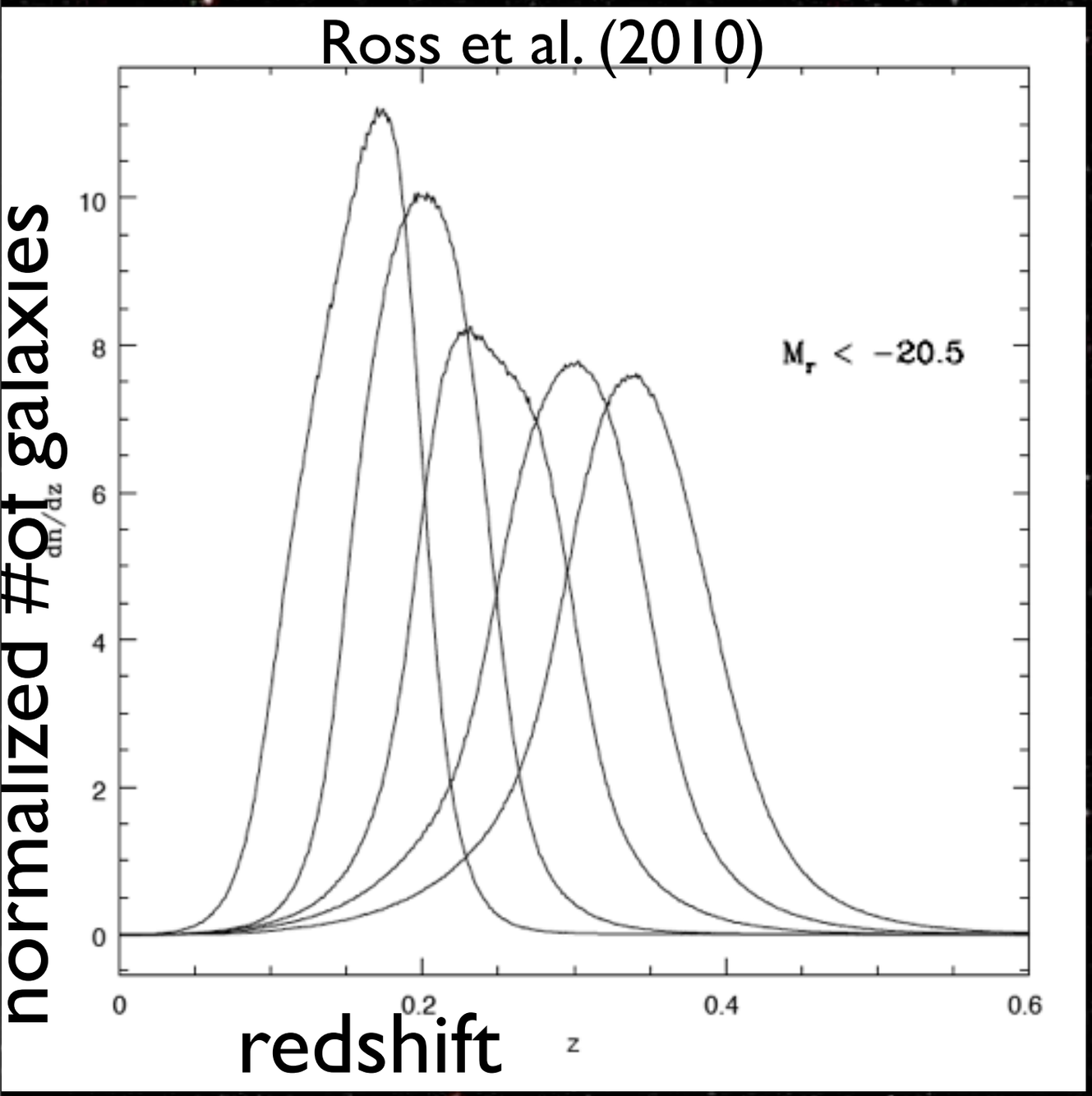


Fraction of satellites that are blue around red centrals

Evolution

Ross et al. (2010)



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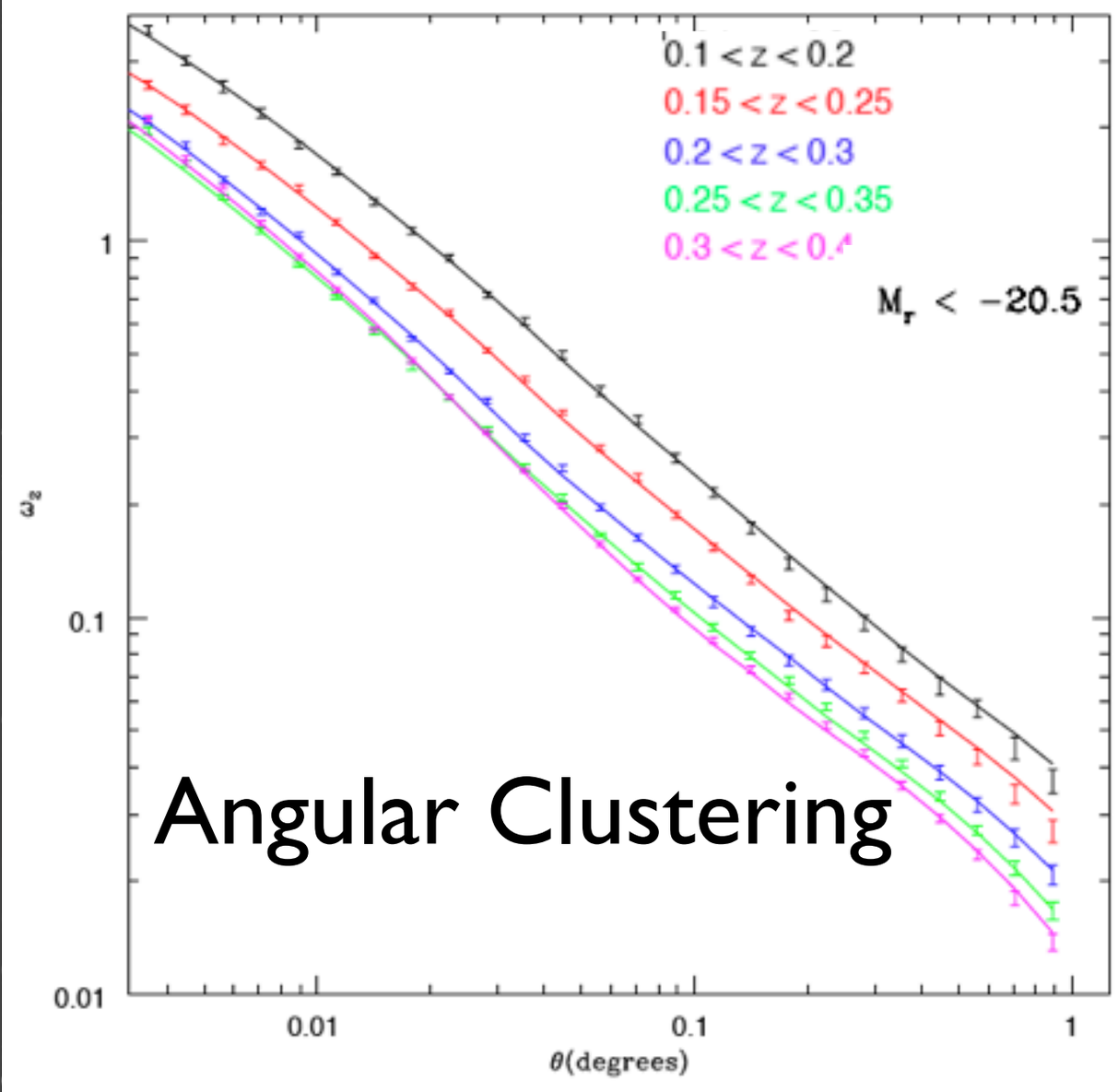
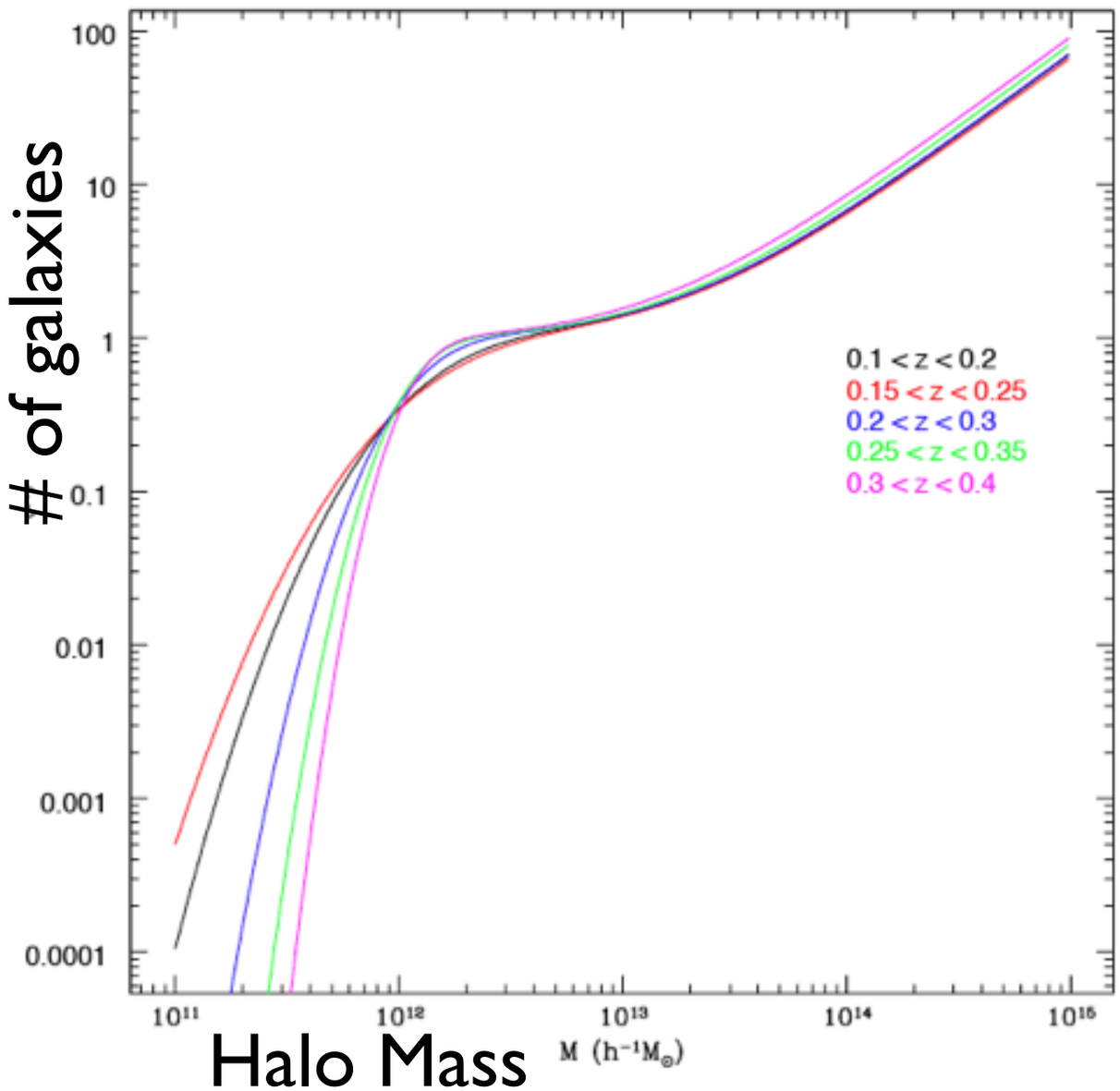


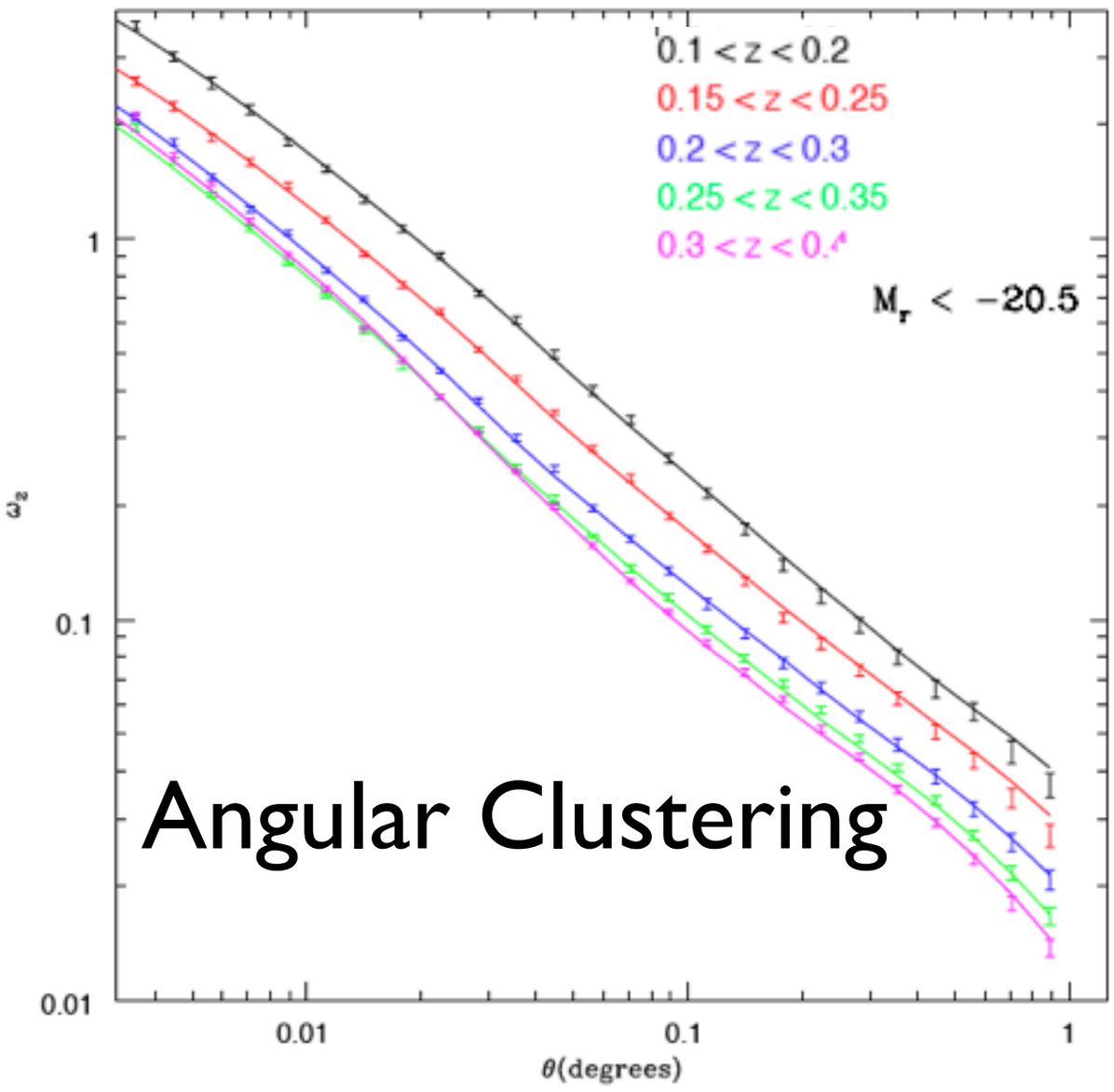
Angular Clustering



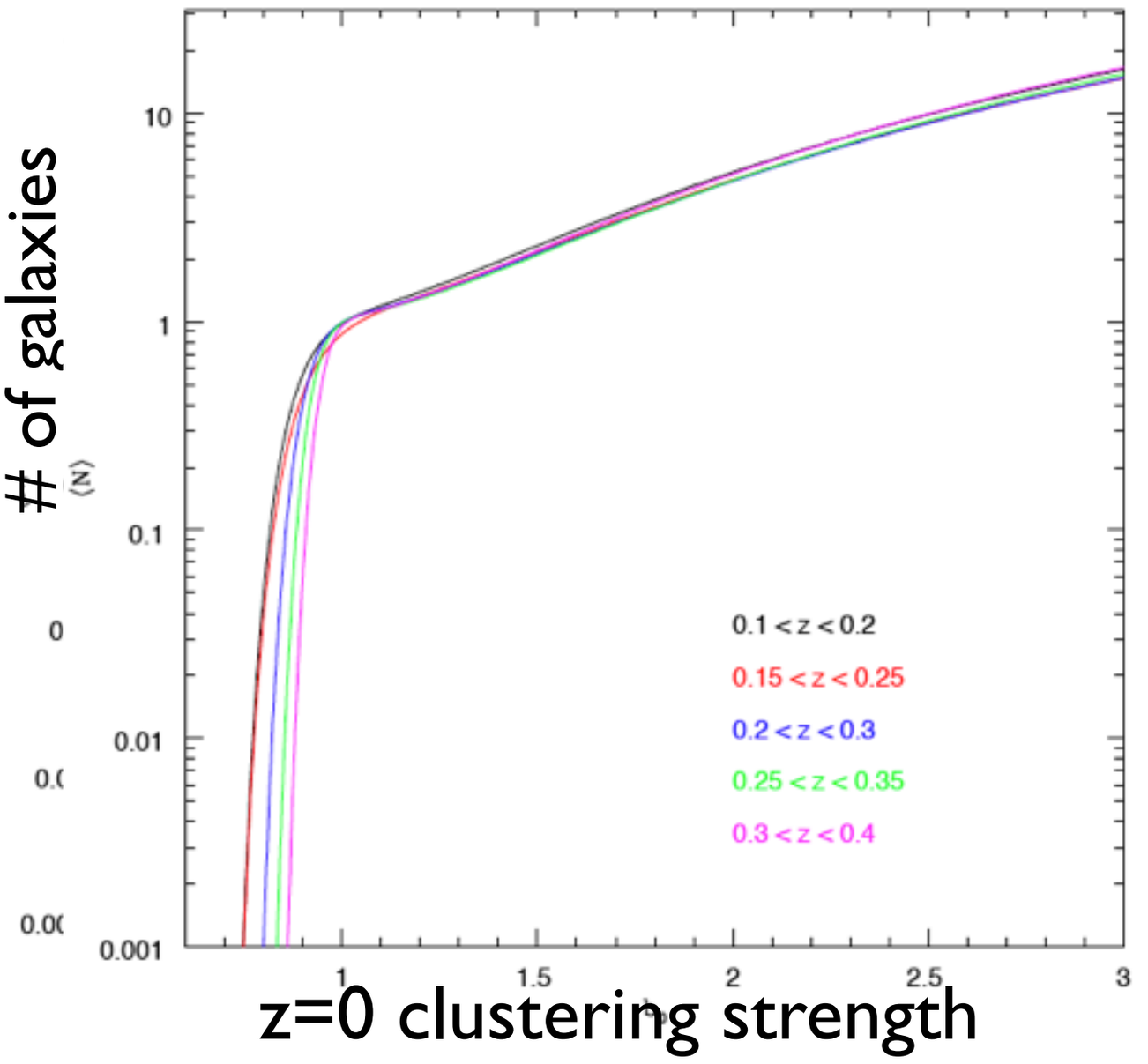
Halo Mass

Evolution

Ross et al. (2010)



Angular Clustering



z=0 clustering strength

Evolution

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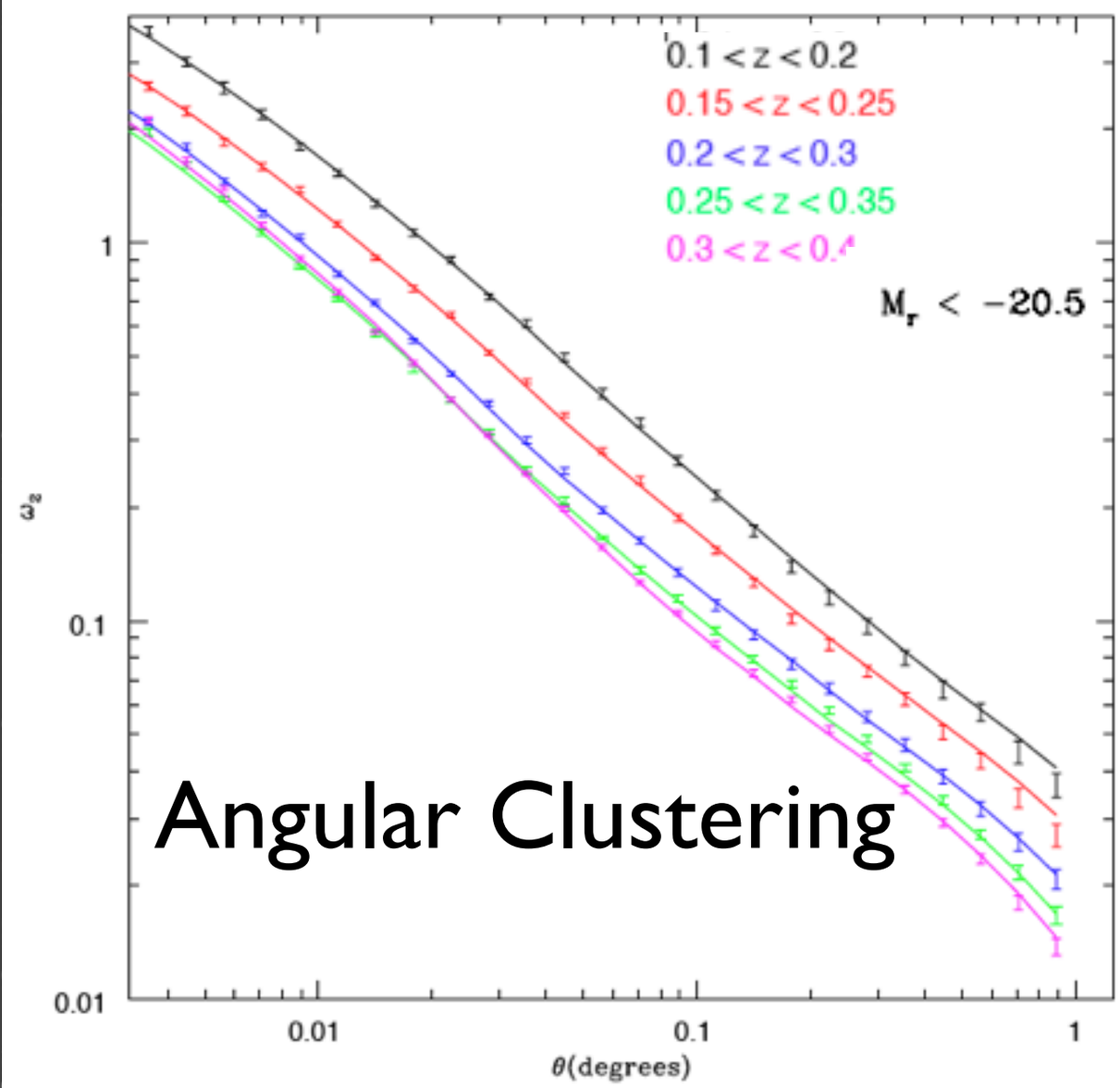

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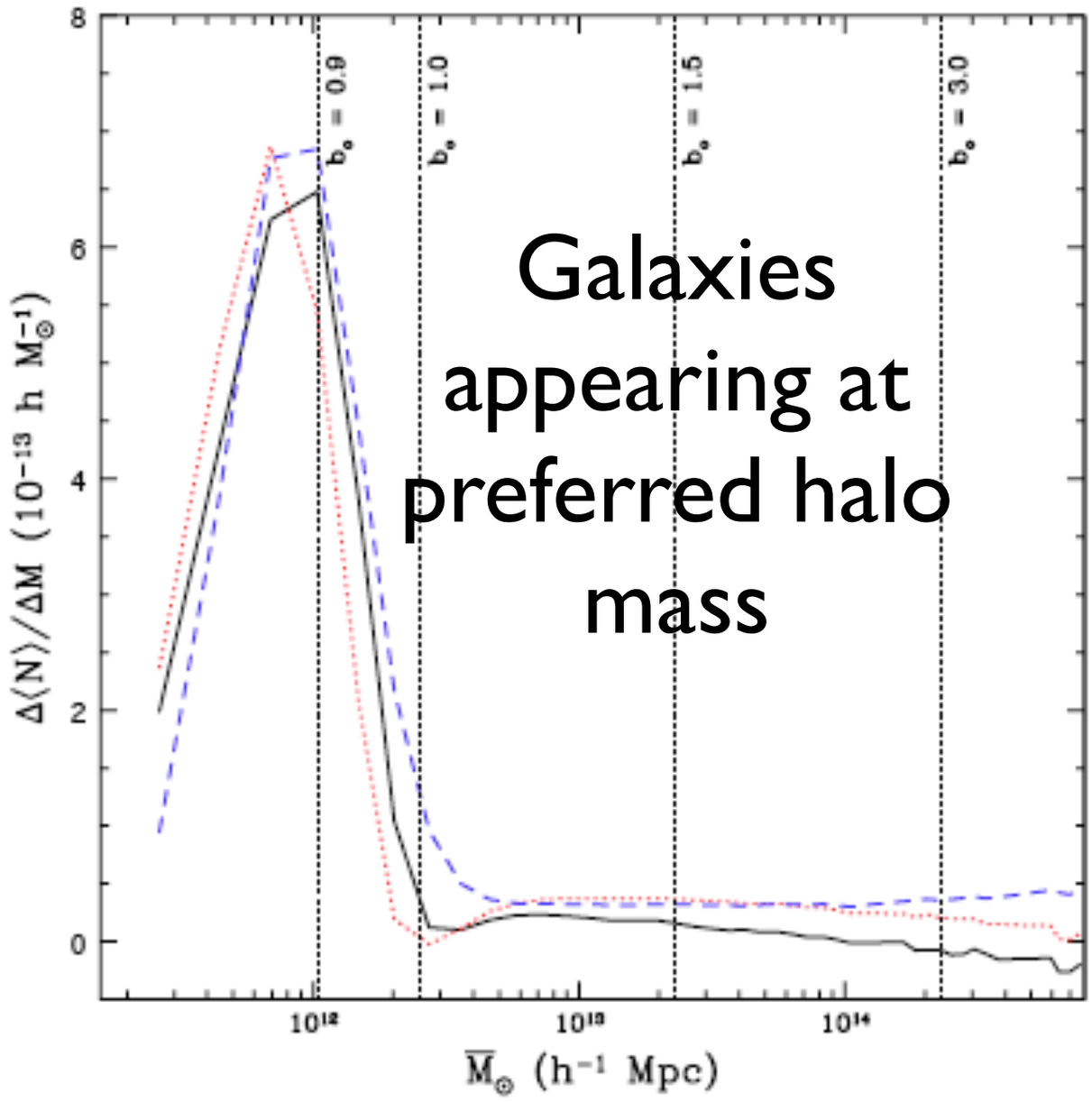
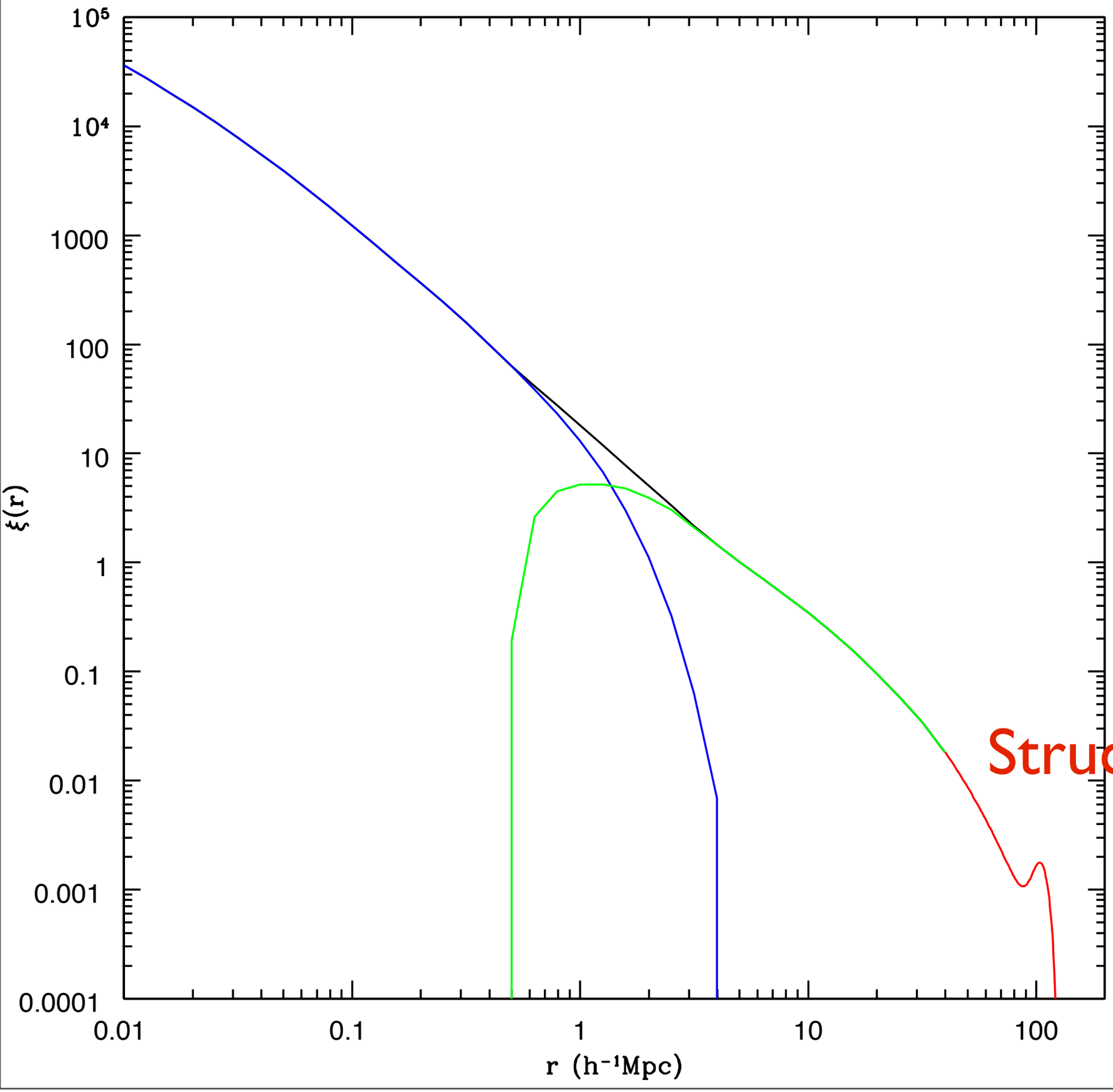


Galaxies appearing at preferred halo mass

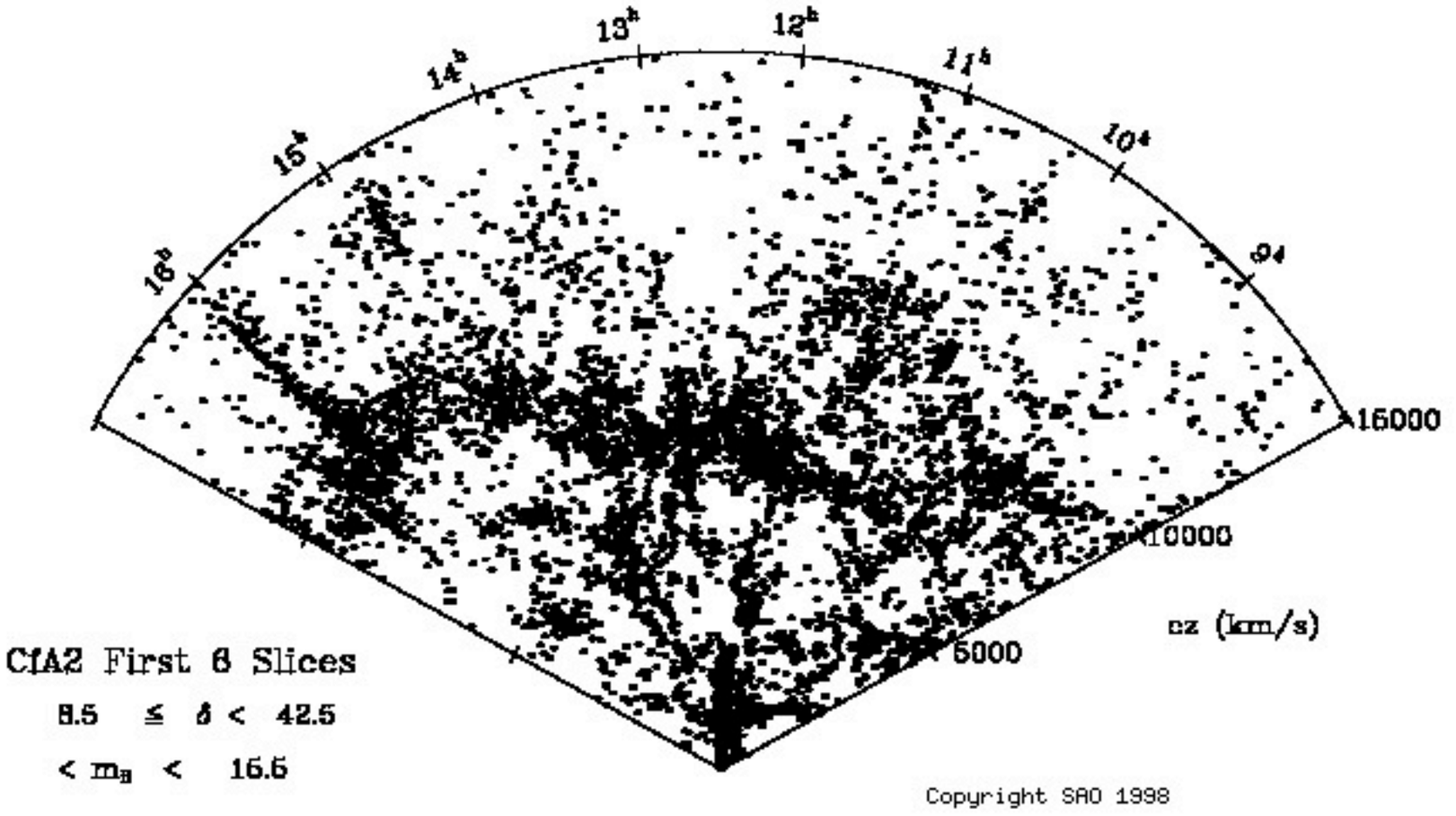


Structure Growth

Structure Growth with Redshift Space Distortions (RSD)

- Intrinsic velocities of galaxies imply redshift space is distorted from real-space
- Small scales - finger of God effect
- Large scales - infall onto clusters

Structure Growth with Redshift Space Distortions (RSD)

- 

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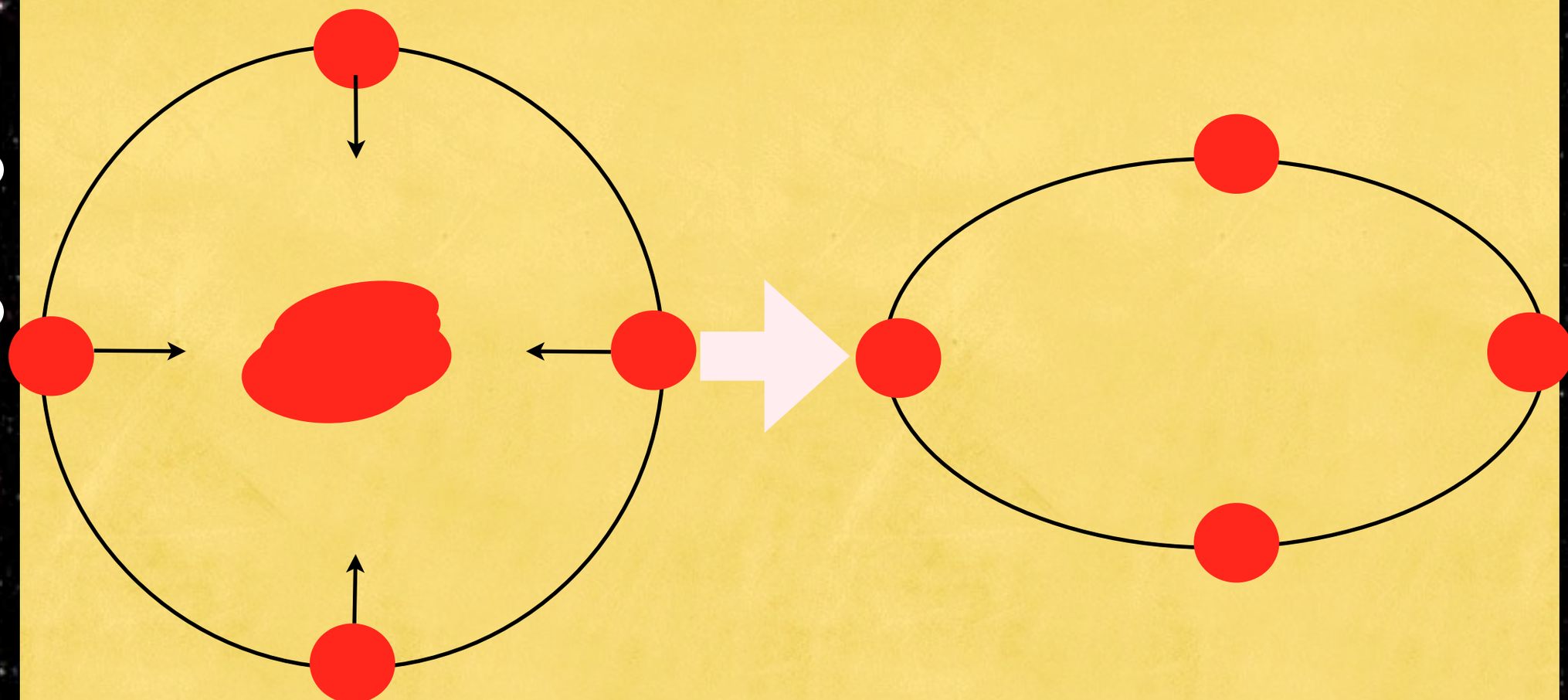
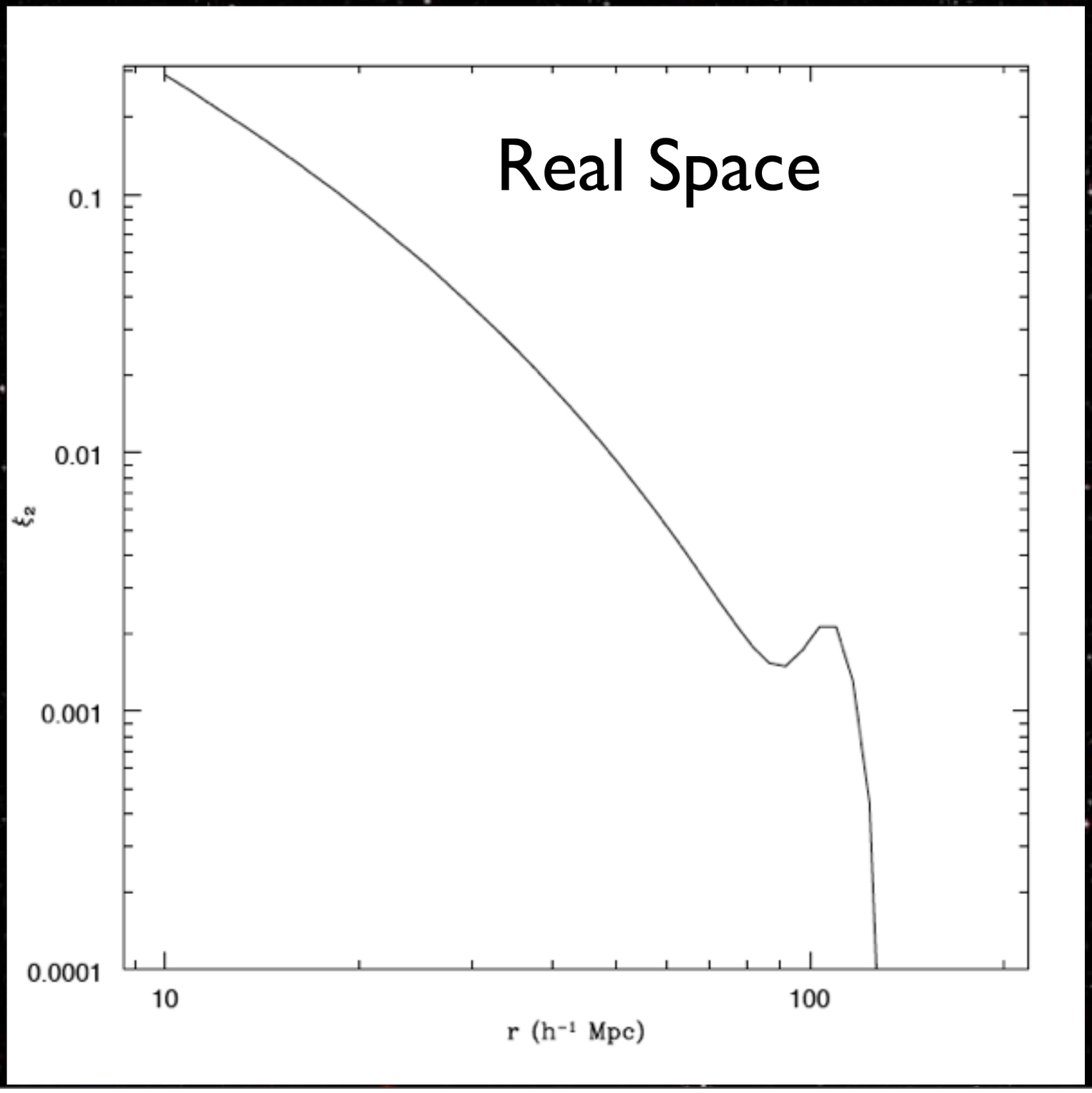
Structure Growth with Redshift Space Distortions (RSD)

- Real Space

Redshift Space



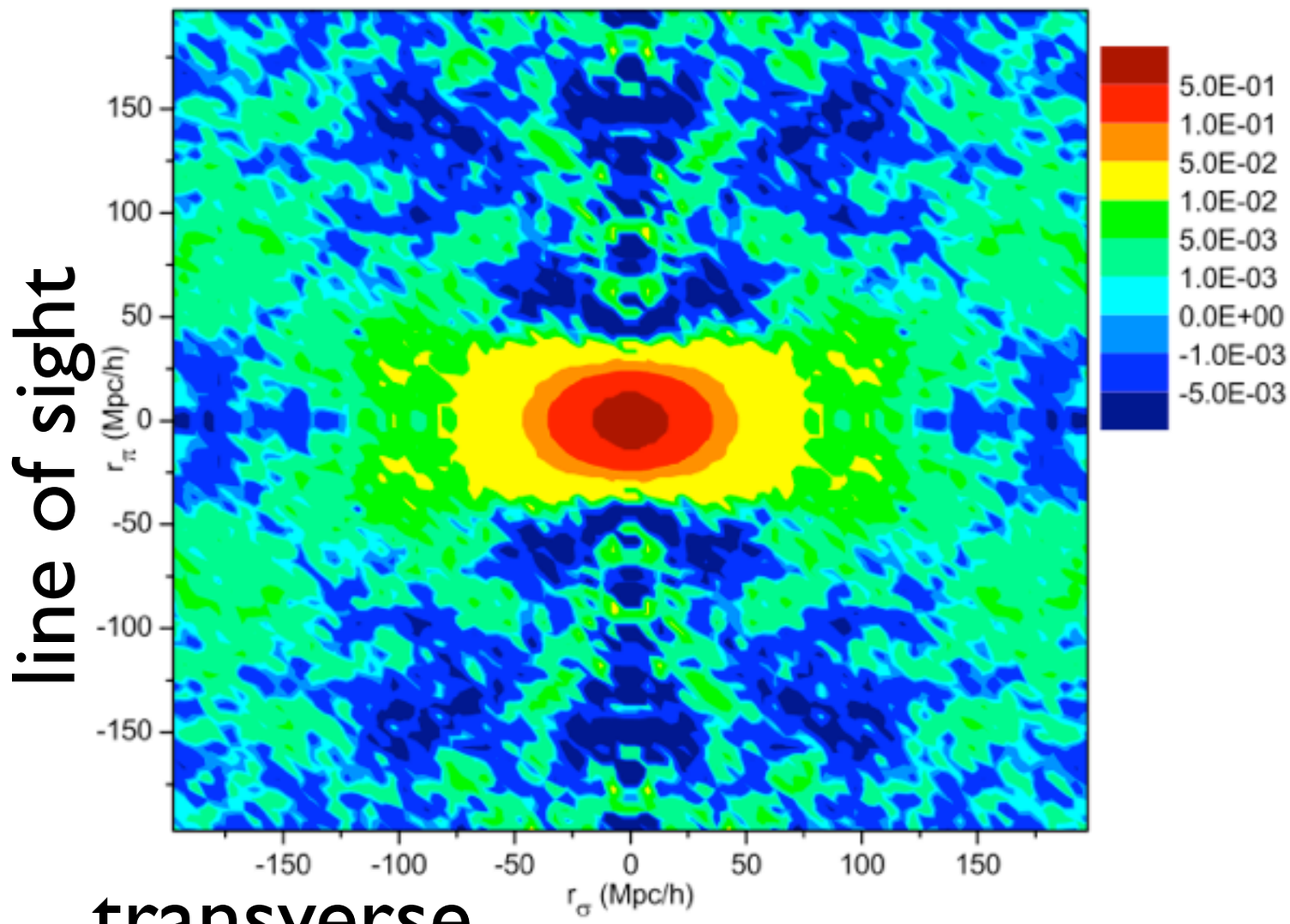
Real/Redshift Space Clustering



Real/Redshift Space Clustering

Reid, Samushia et al. (in prep.)

Redshift Space



Redshift Space Clustering

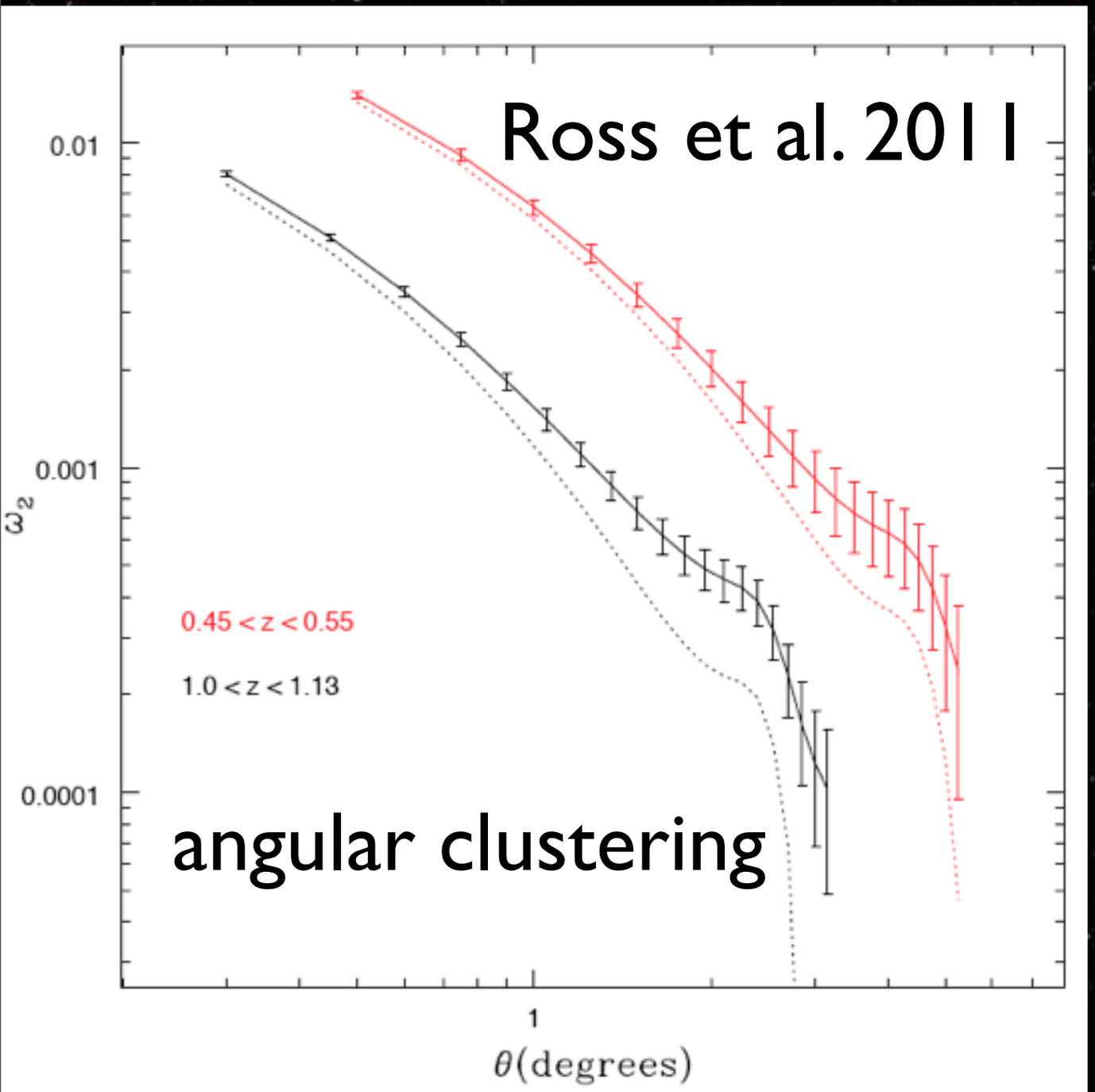
- Large scale distortions can be modeled with linear theory:

$$P(k,\mu) = (1 + f\mu^2)^2 P(k)$$

$$\mu = \cos(\theta); f = \mathrm{dln}(D)/\mathrm{dln}(a) \sim \Omega_{matter}^{\gamma}$$

- GR predicts γ = 0.557

RSD with Photozs?



- Projections for Dark Energy Survey
- Implies DES can measure f

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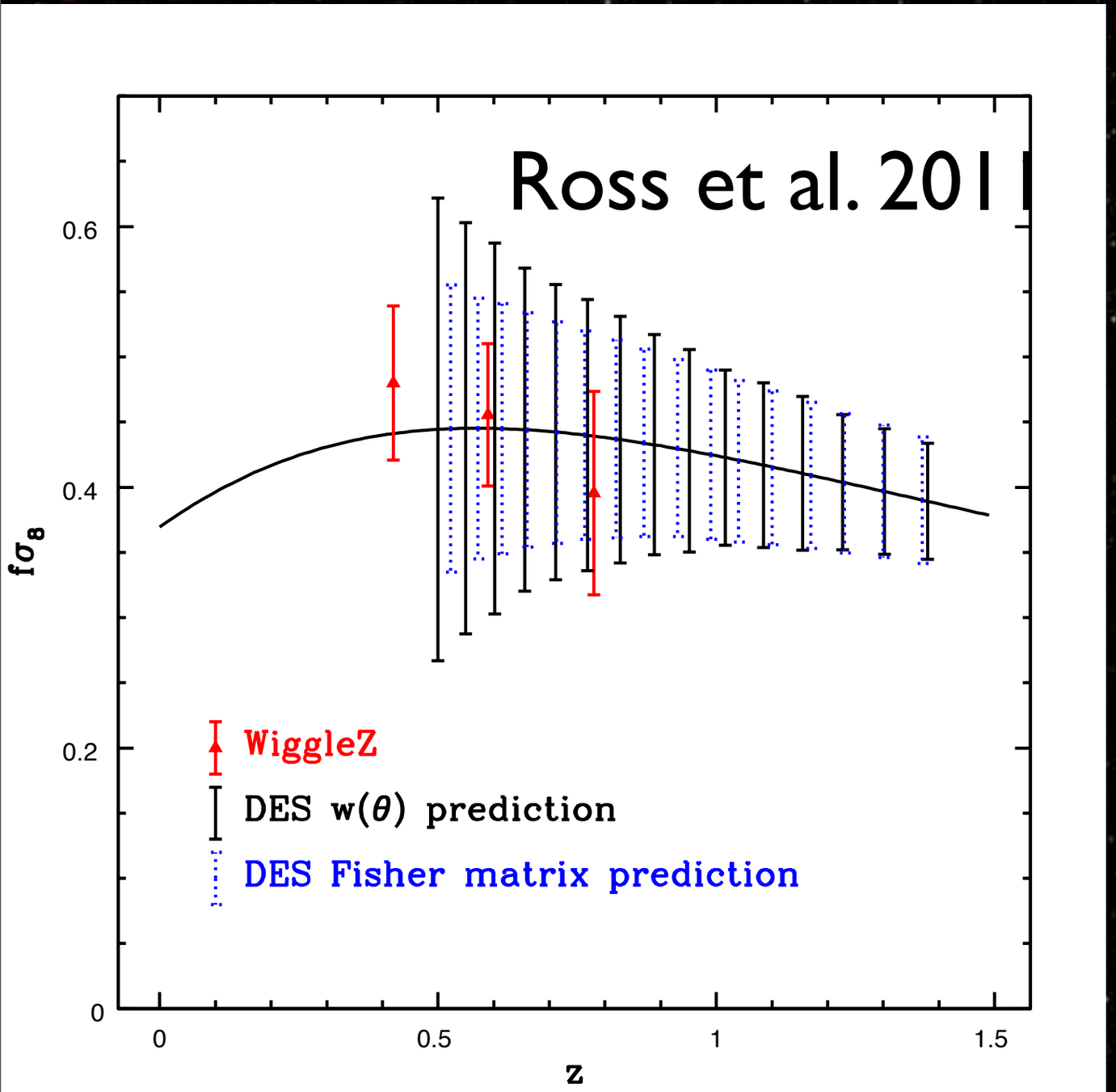

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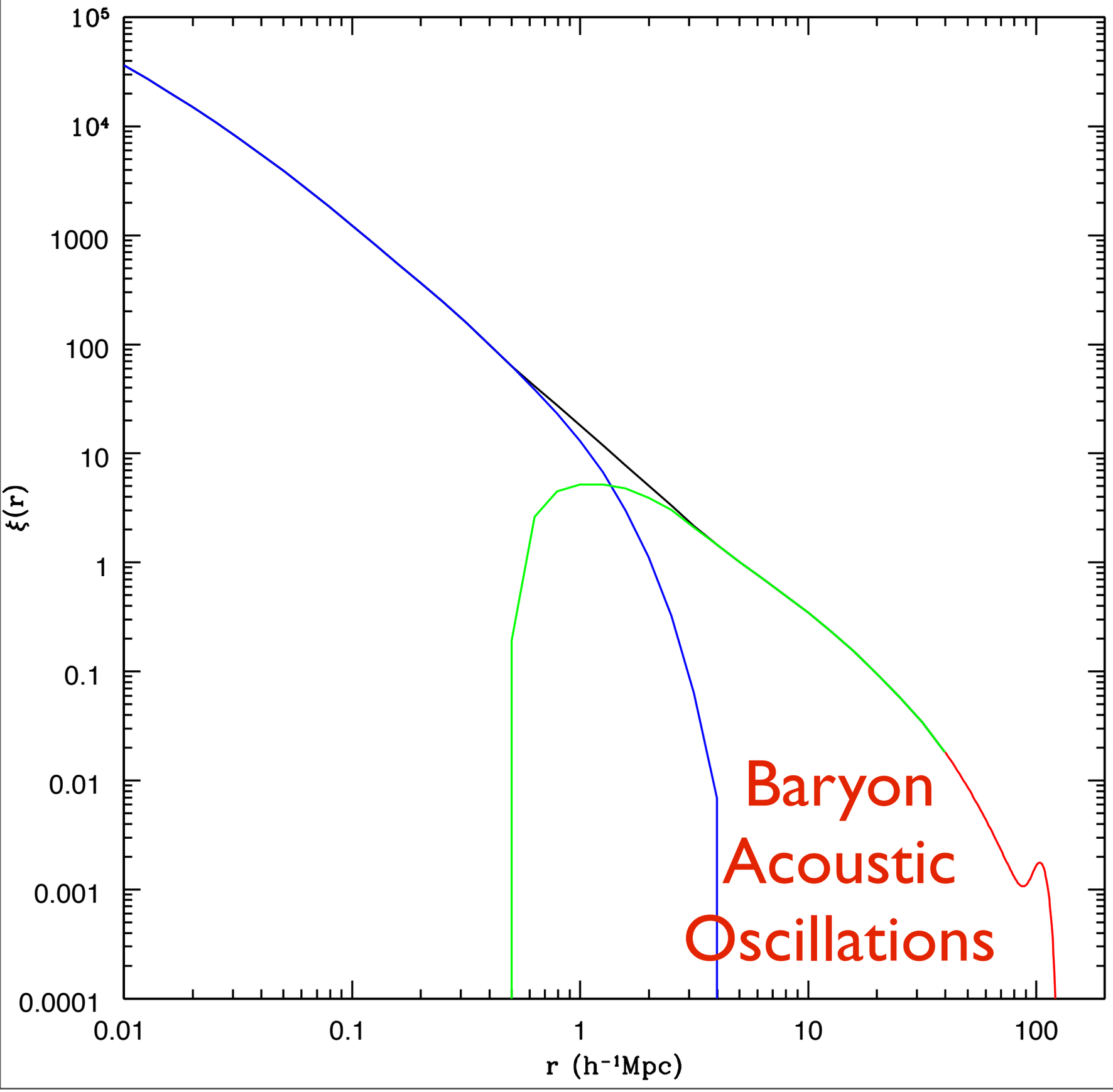
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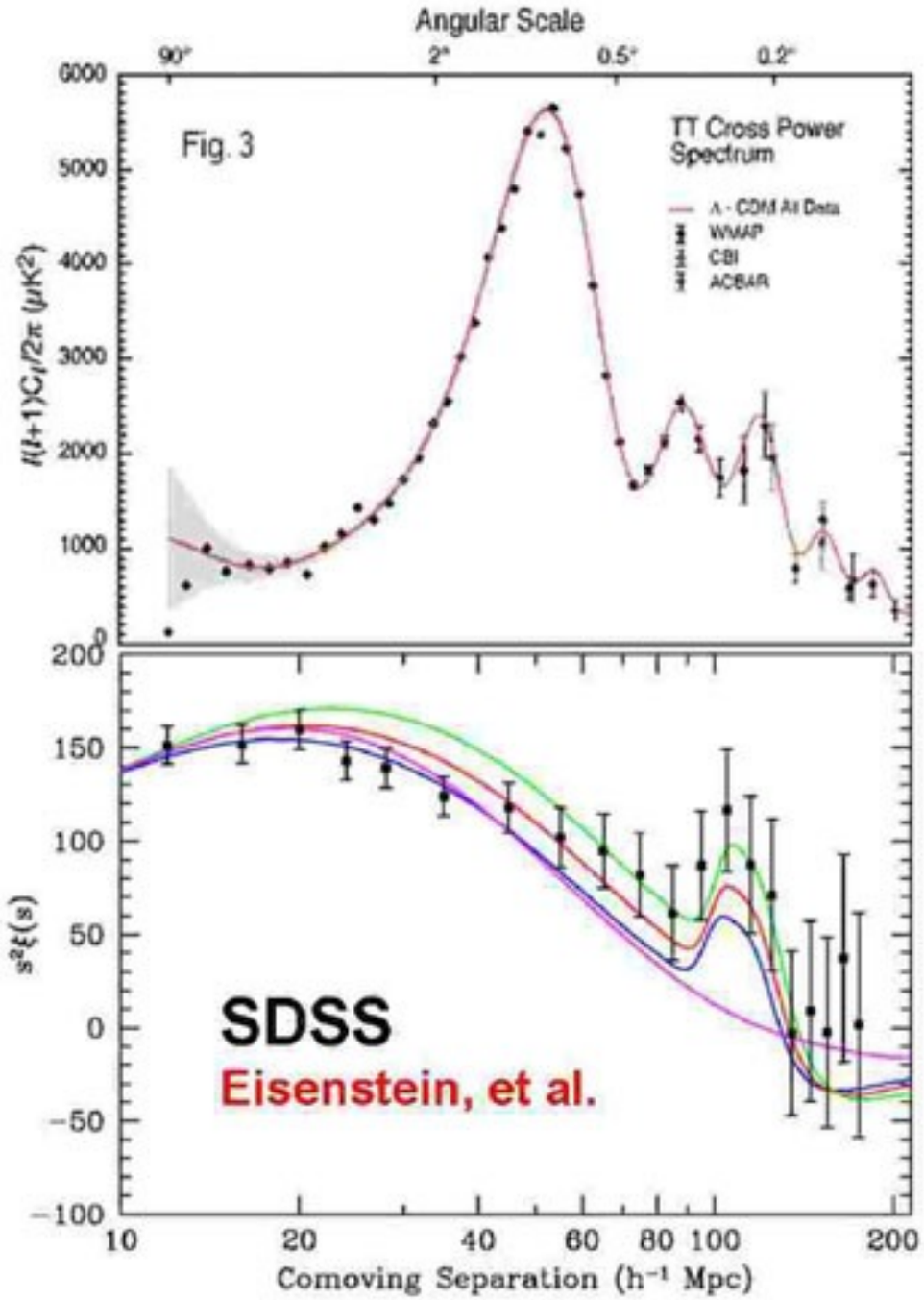
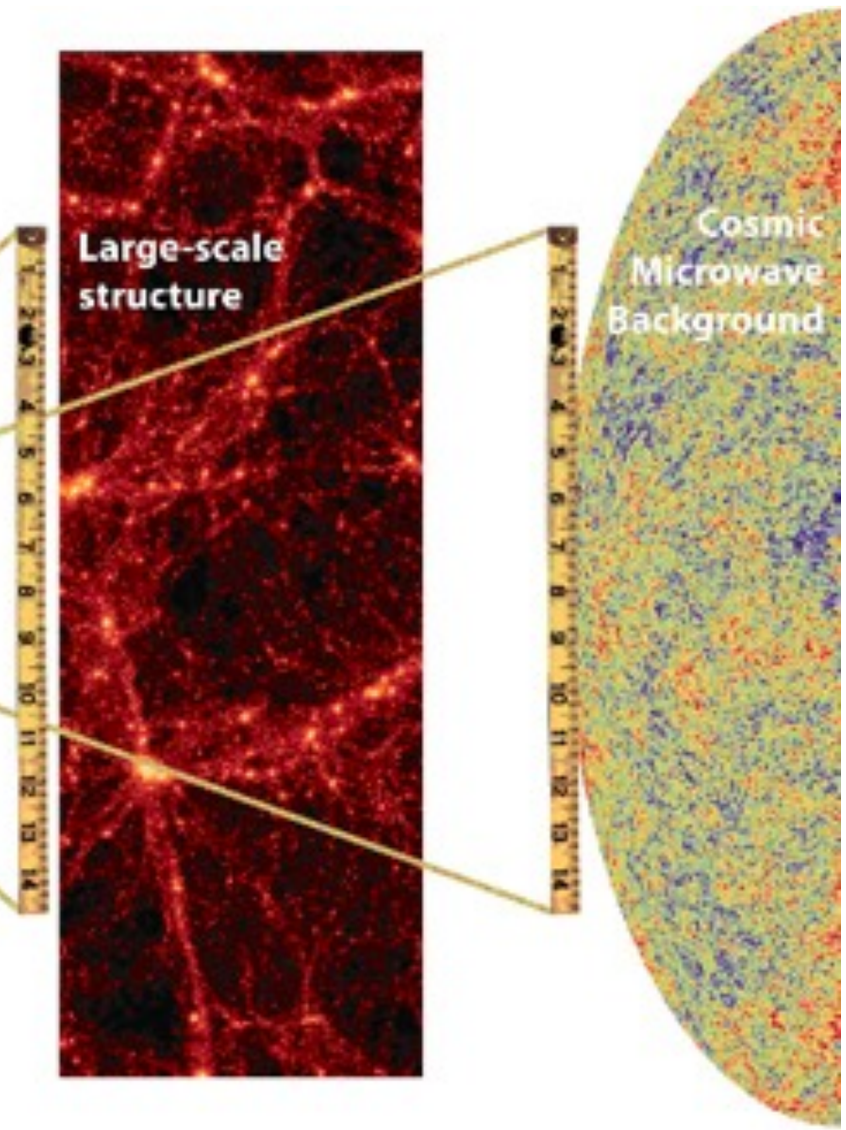
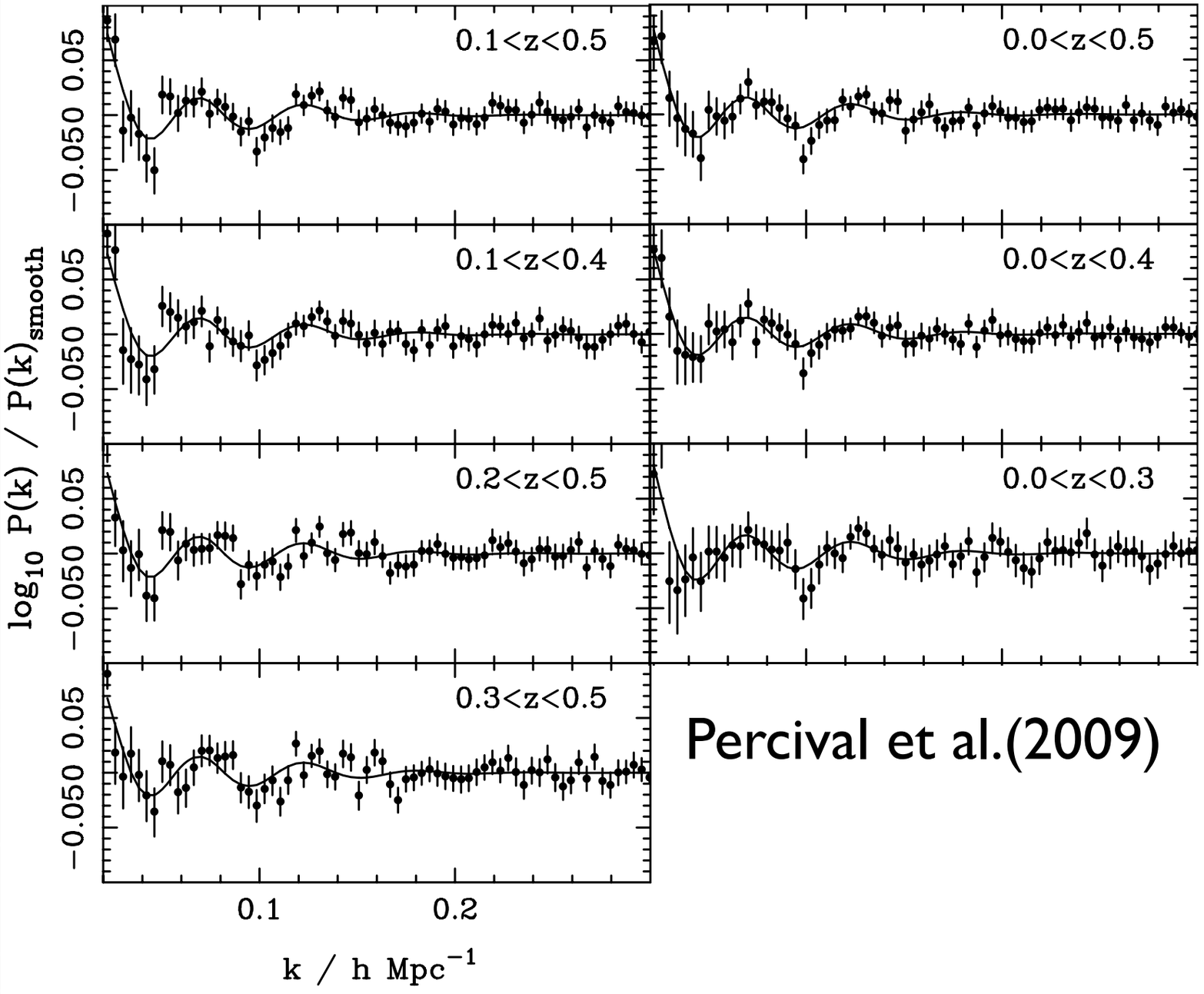
Baryon
Acoustic
Oscillations

Baryon Acoustic Oscillations (BAO)

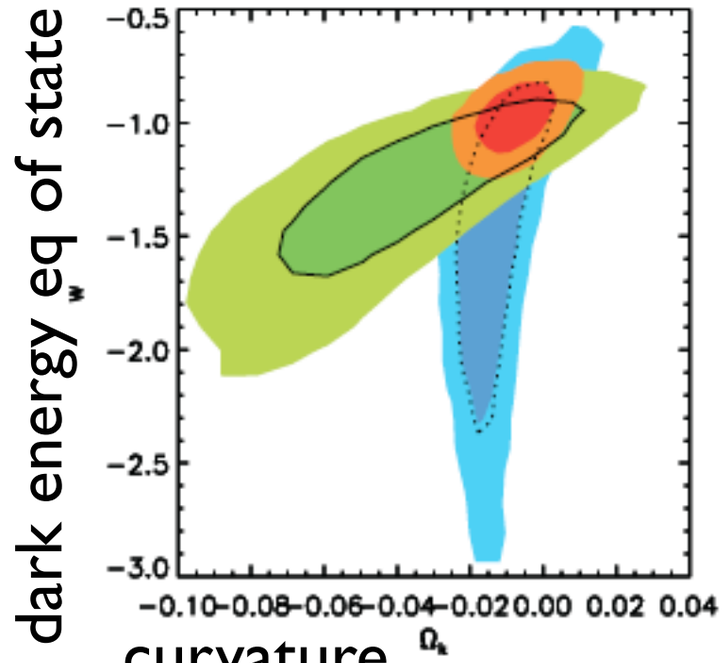


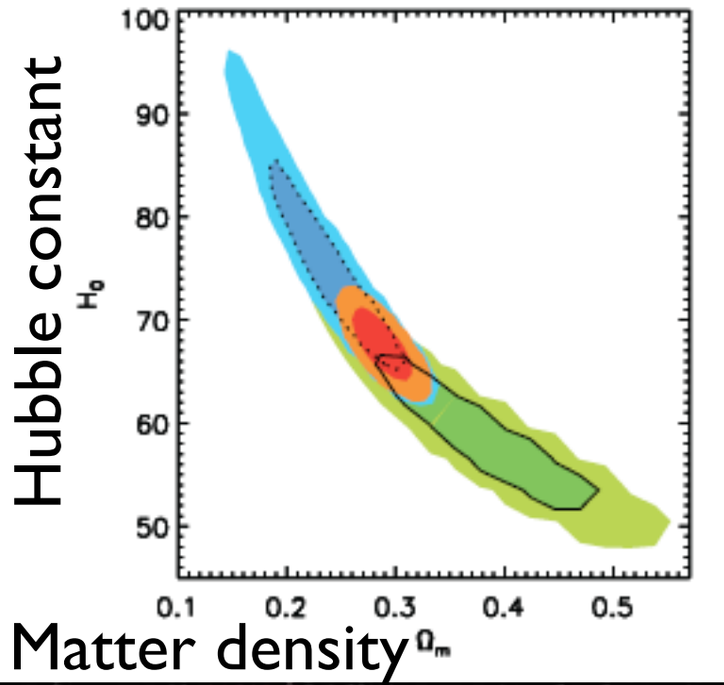


Baryon Acoustic Oscillations



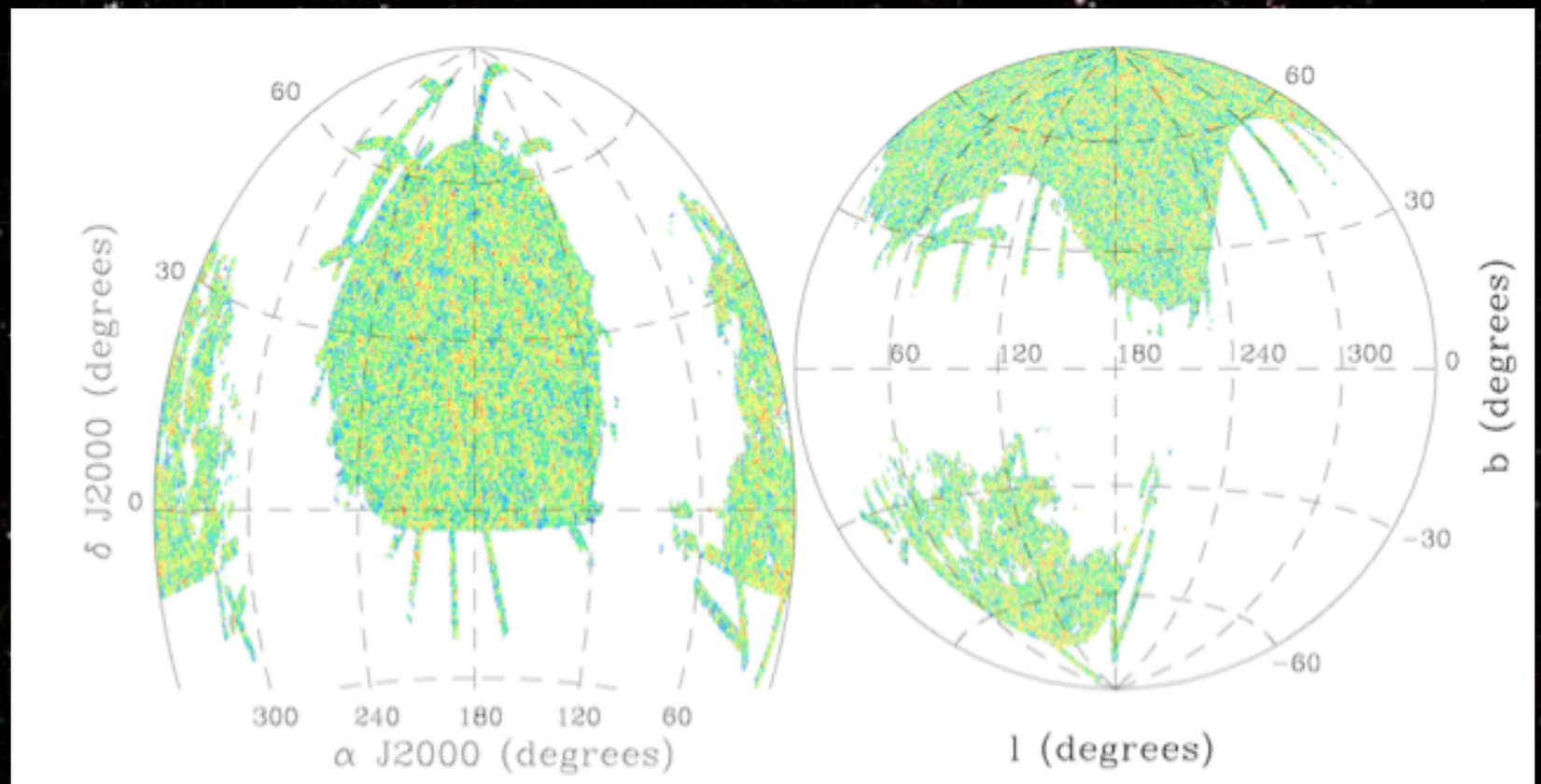
Percival et al.(2009)





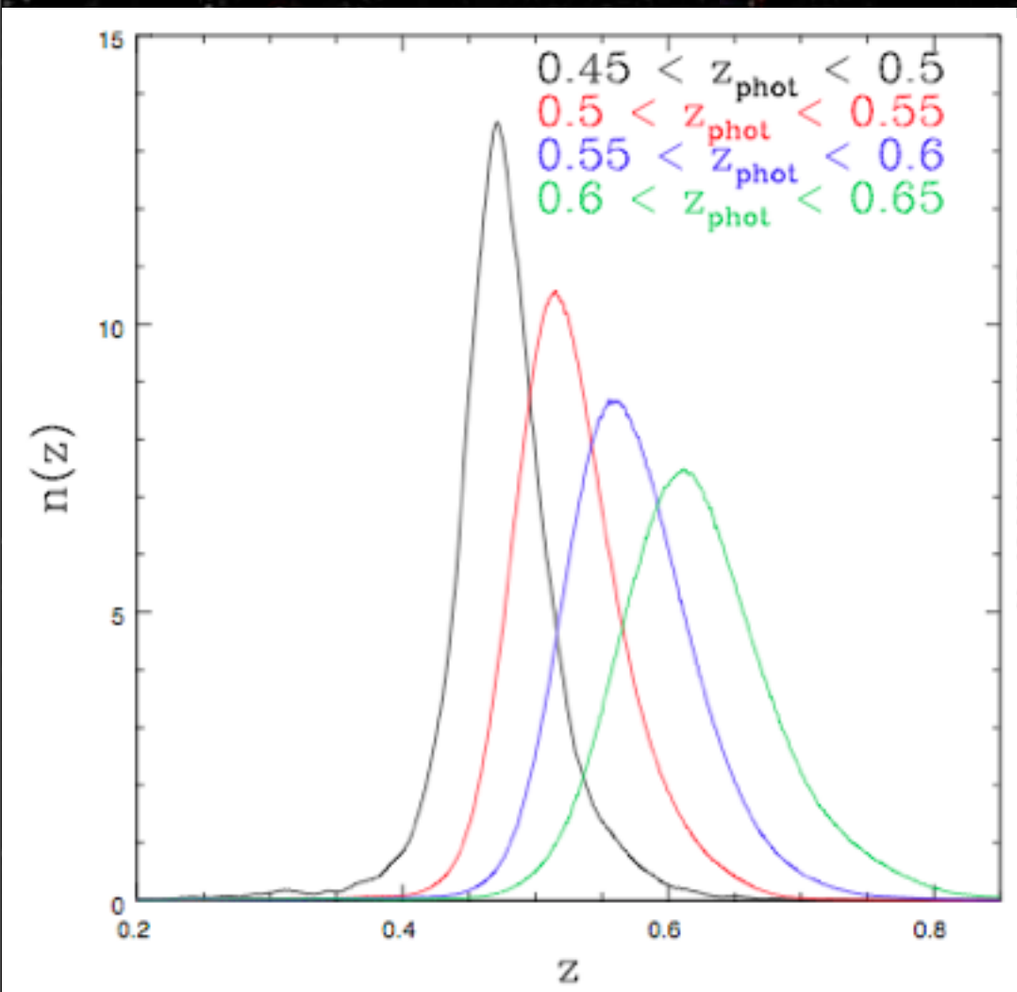
BOSS-trained DR8 Photozs

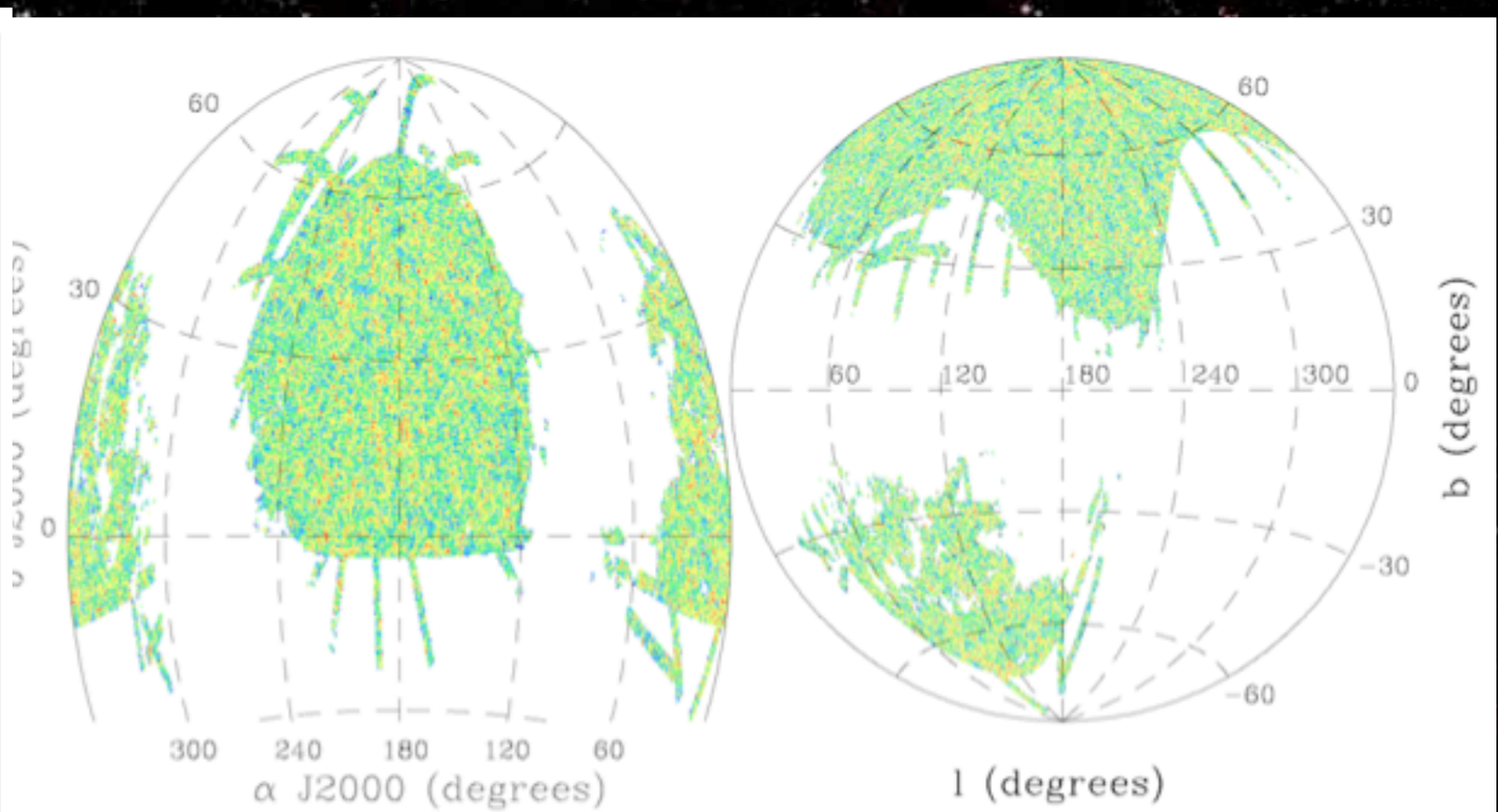
- Used over 100,000 BOSS spectra
- Over 1,000,000 photozs over 10,000 sq degrees



Ross, A. J. et al. 2011 (ArXiv:1105:2320)
Ho, S. et al. 2012 (ArXiv:1201:2137)
Seo, H. et al. 2012 (ArXiv: 1201:2172)
de Putter, R. et al. 2012 (ArXiv: 1201:1909)

BOSS-trained DR8 Photozs





Ross, A. J. et al. 2011 (ArXiv:1105:2320)
Ho, S. et al. 2012 (ArXiv:1201:2137)
Seo, H. et al. 2012 (ArXiv: 1201:2172)
de Putter, R. et al. 2012 (ArXiv: 1201:1909)

Ashley J Ross LBNL RPM Jan 19th, 2011

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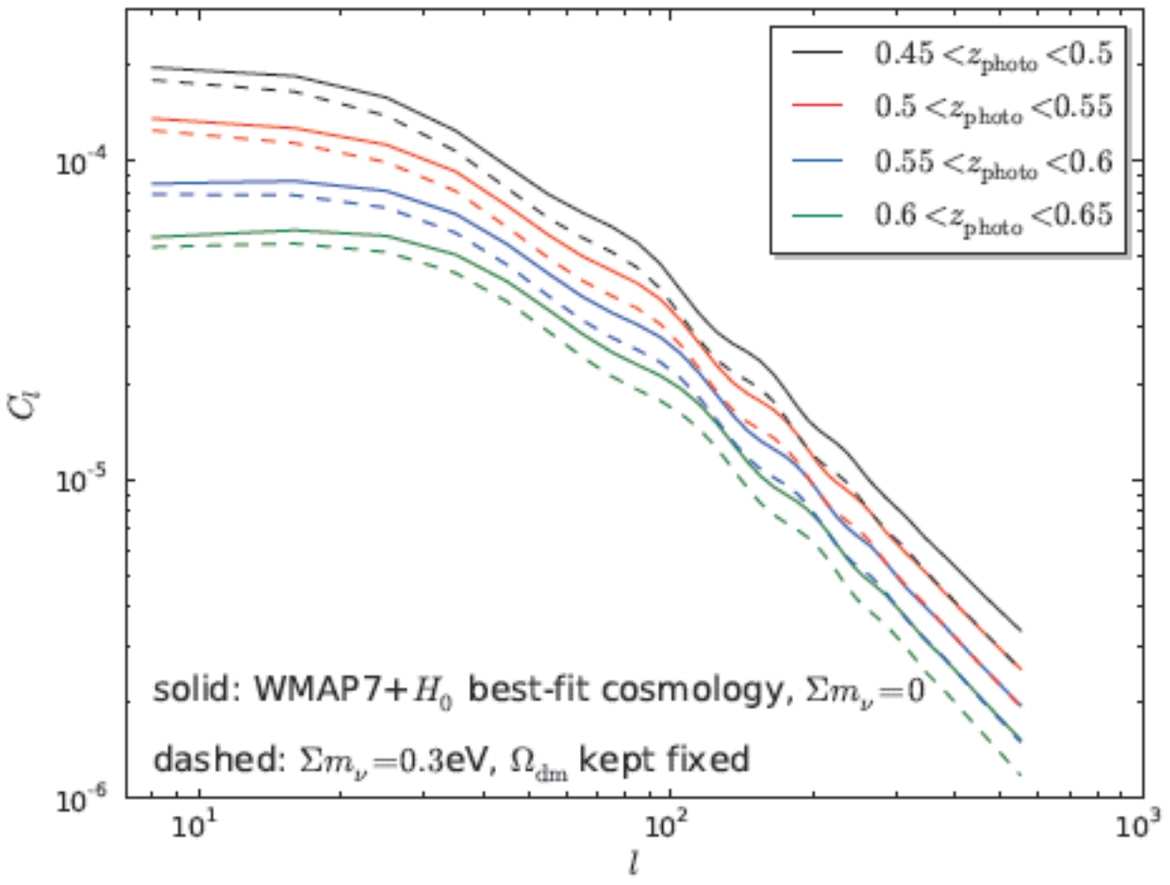
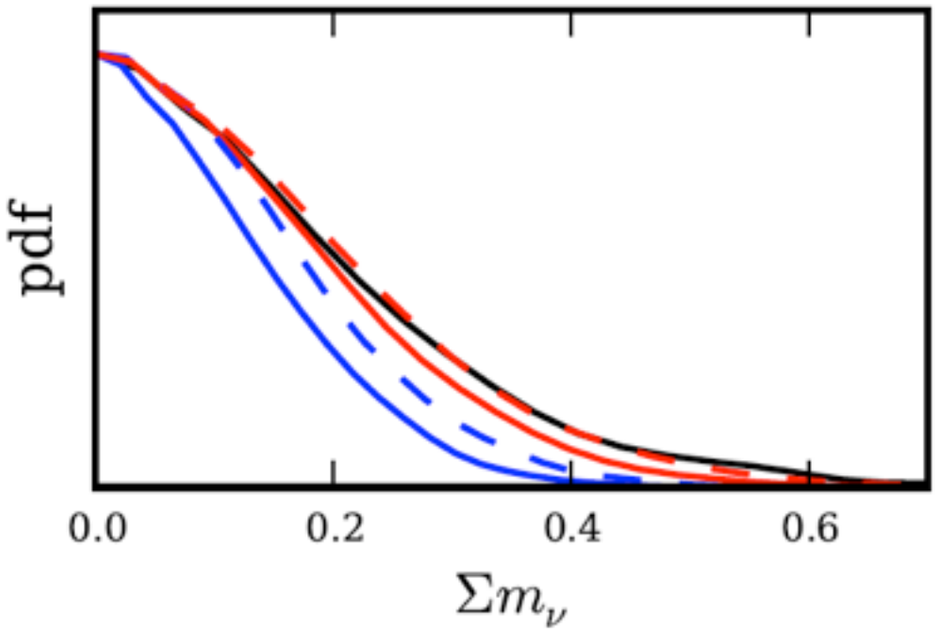
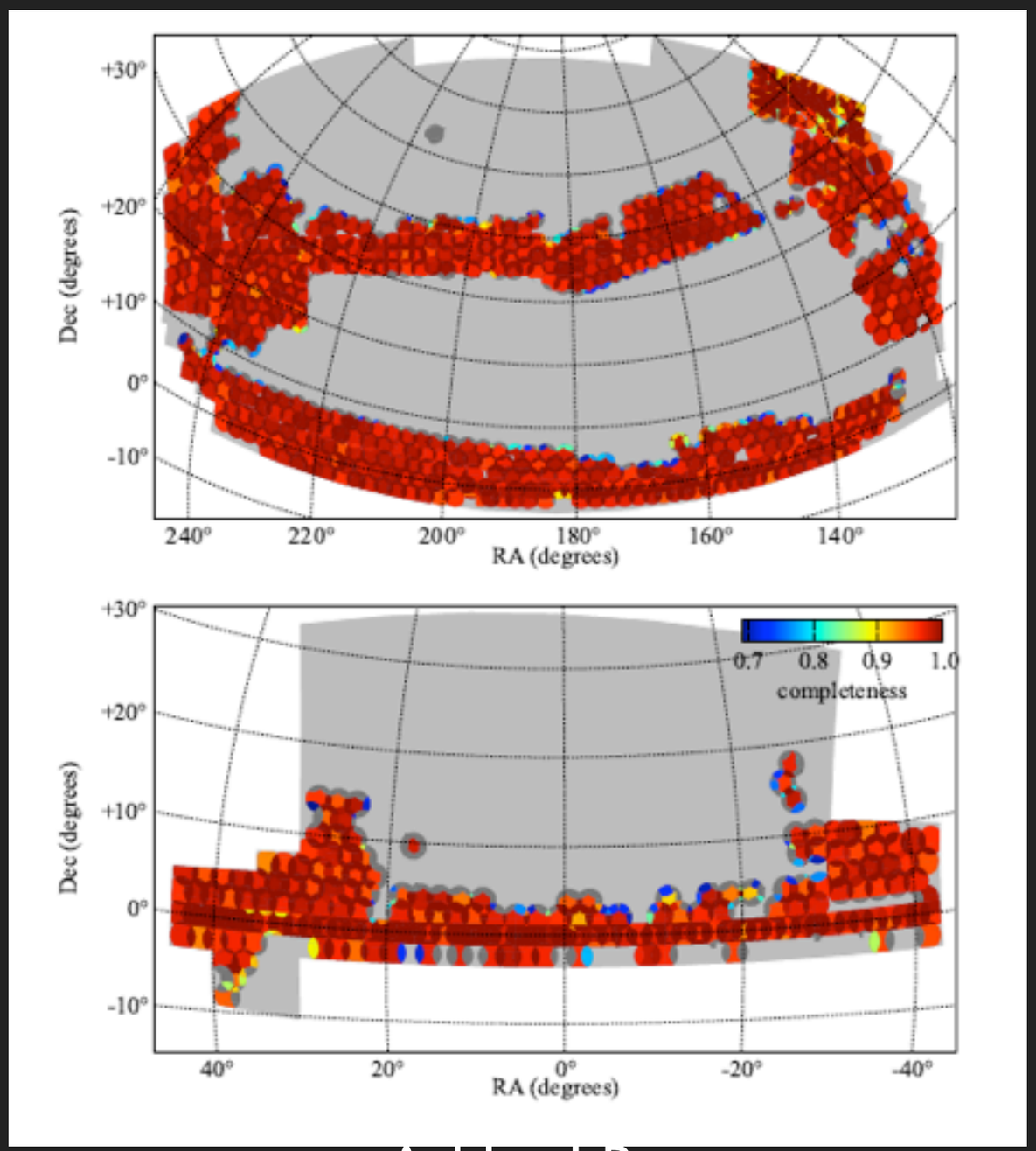




$$\sum m_\nu < 0.26 \text{ eV}, \ 95\%\text{CL}$$

de Putter, R. et al. 2012 (ArXiv: 1201:1909)

SDSS DR9 BOSS Specz 'CMASS' Sample



- Targeted 1 million galaxies
  8600 sq degrees of NGC
  3100 sq degrees of SGC
- DR9 footprint 3345 sq. deg
  21% in Southern galactic cap
- 270,000+ redshifts $0.43<z<0.7$
- Redshift completeness >98%
- Public July 2012

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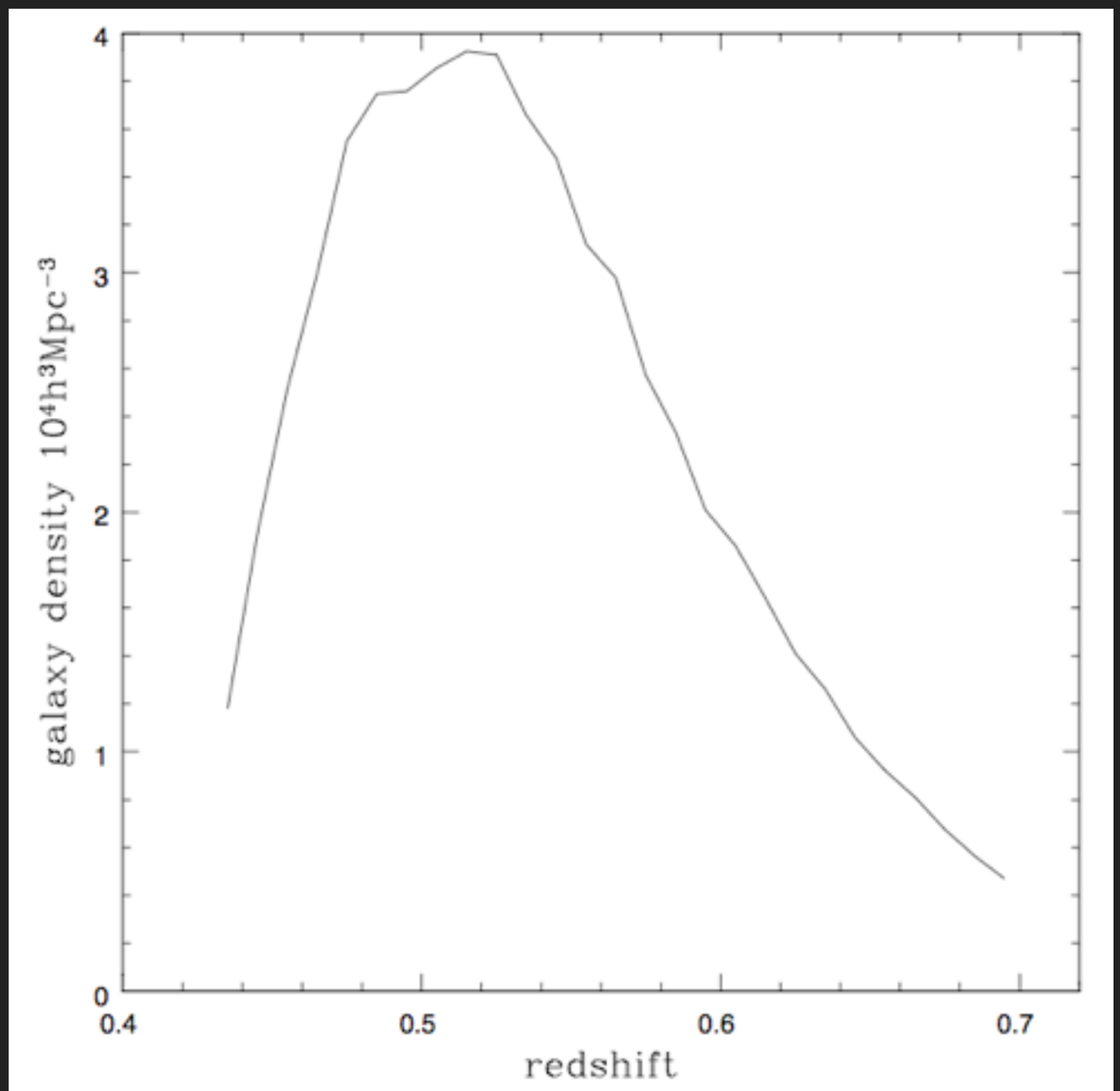

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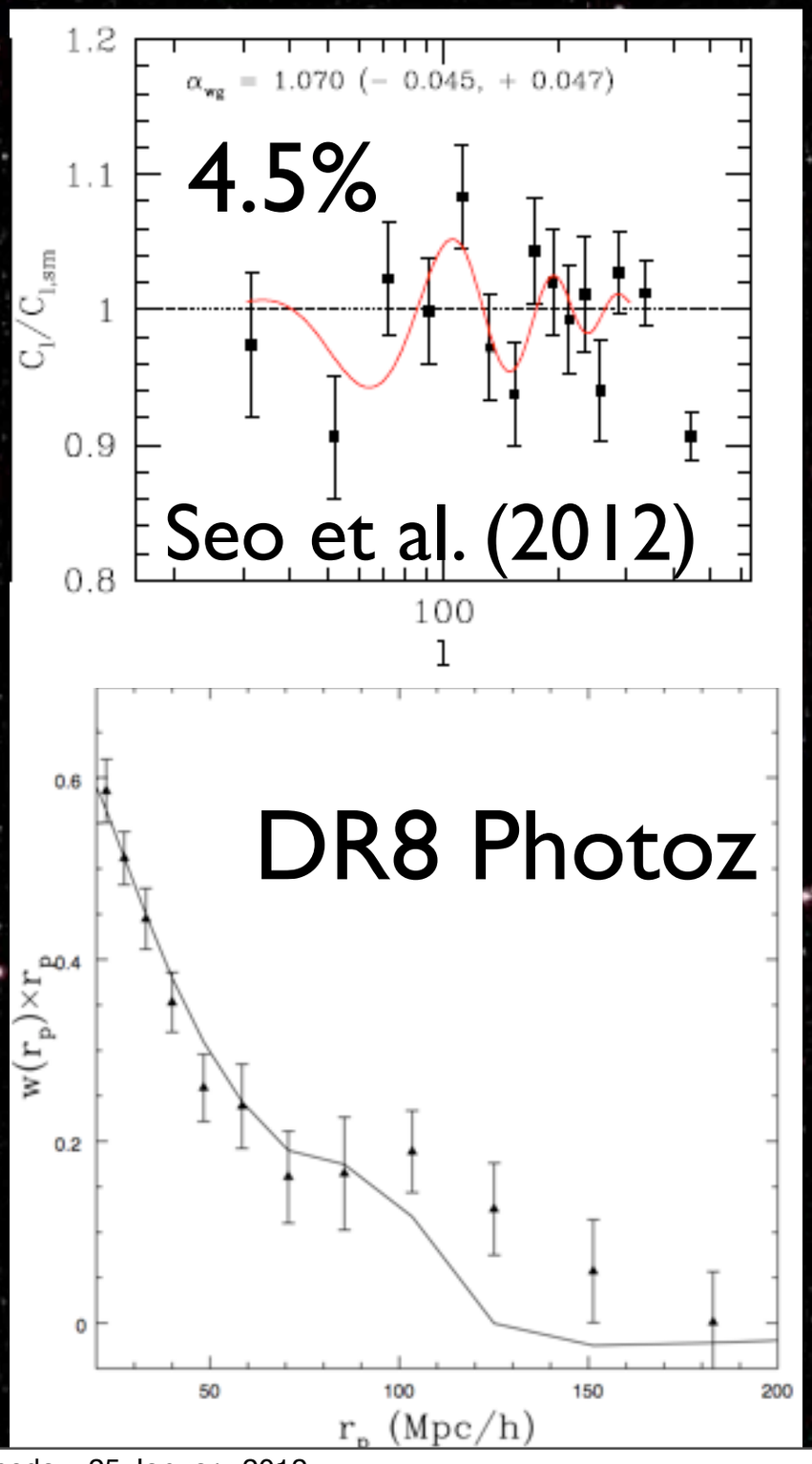
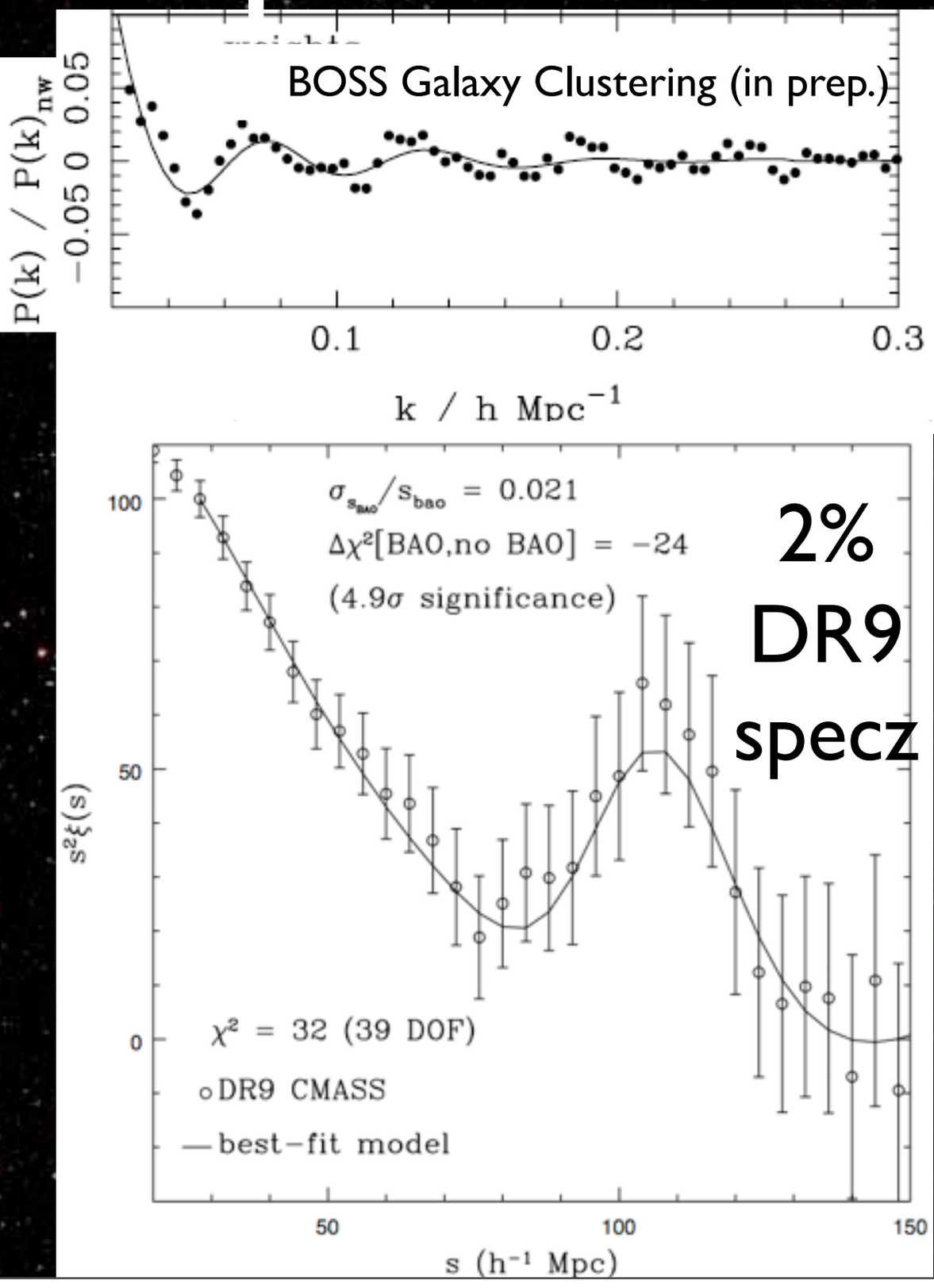
BAO Comparison



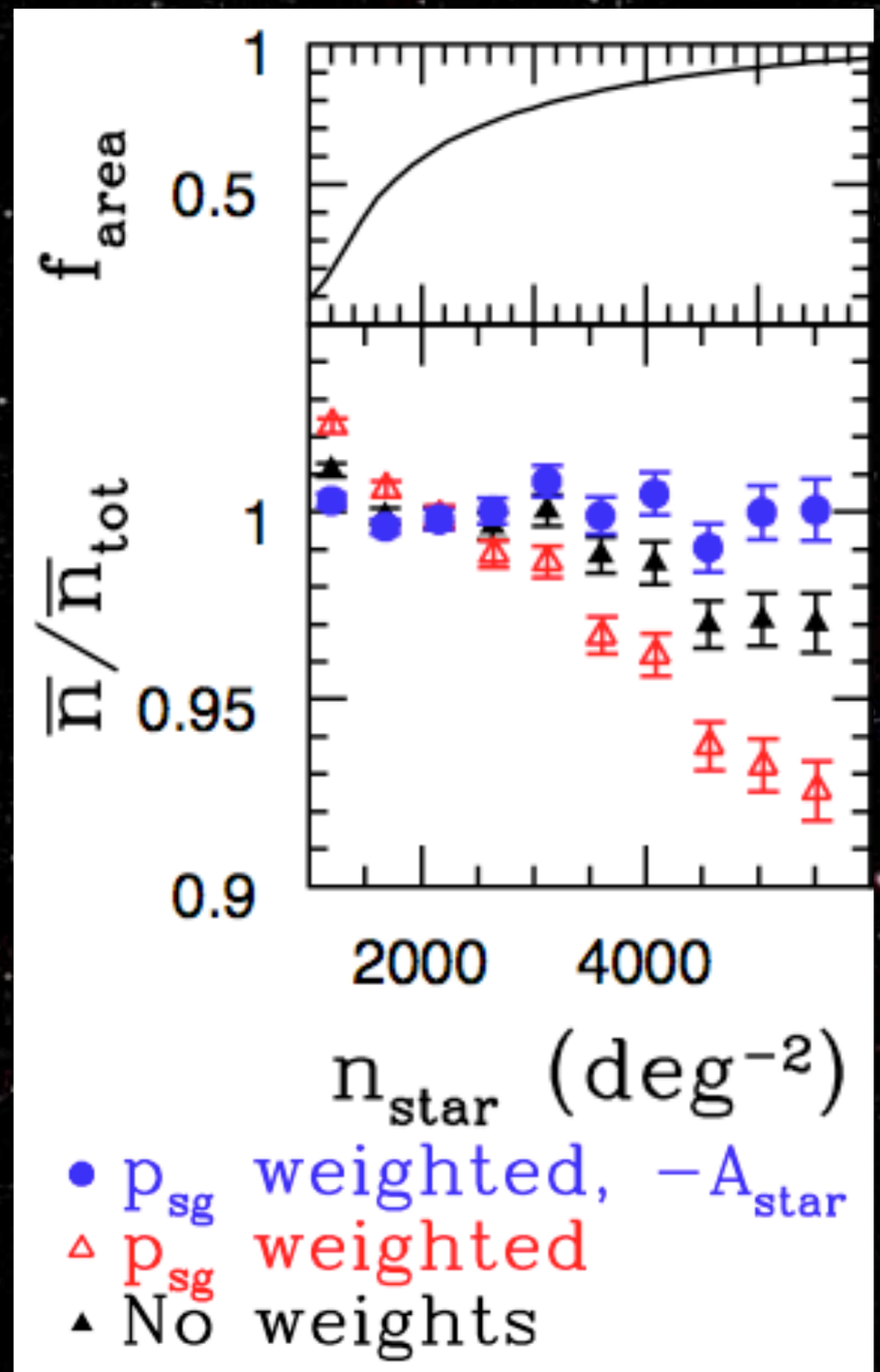


Observational Systematics

- Object classification
  - Star/galaxy/quasar
  - Use probabilities
- Galactic foregrounds
  - Stars, Galactic Extinction
- Observing conditions
  - Seeing, Sky Background, Airmass
- Photometric offsets, varying dust law?
  - See Schlafly et al. (2011a,b)

Stars

- ~3% stellar contamination → n_{CMG} should increase with n_{star}
- Opposite is observed
- "removing" stellar contamination → huge anti-correlation



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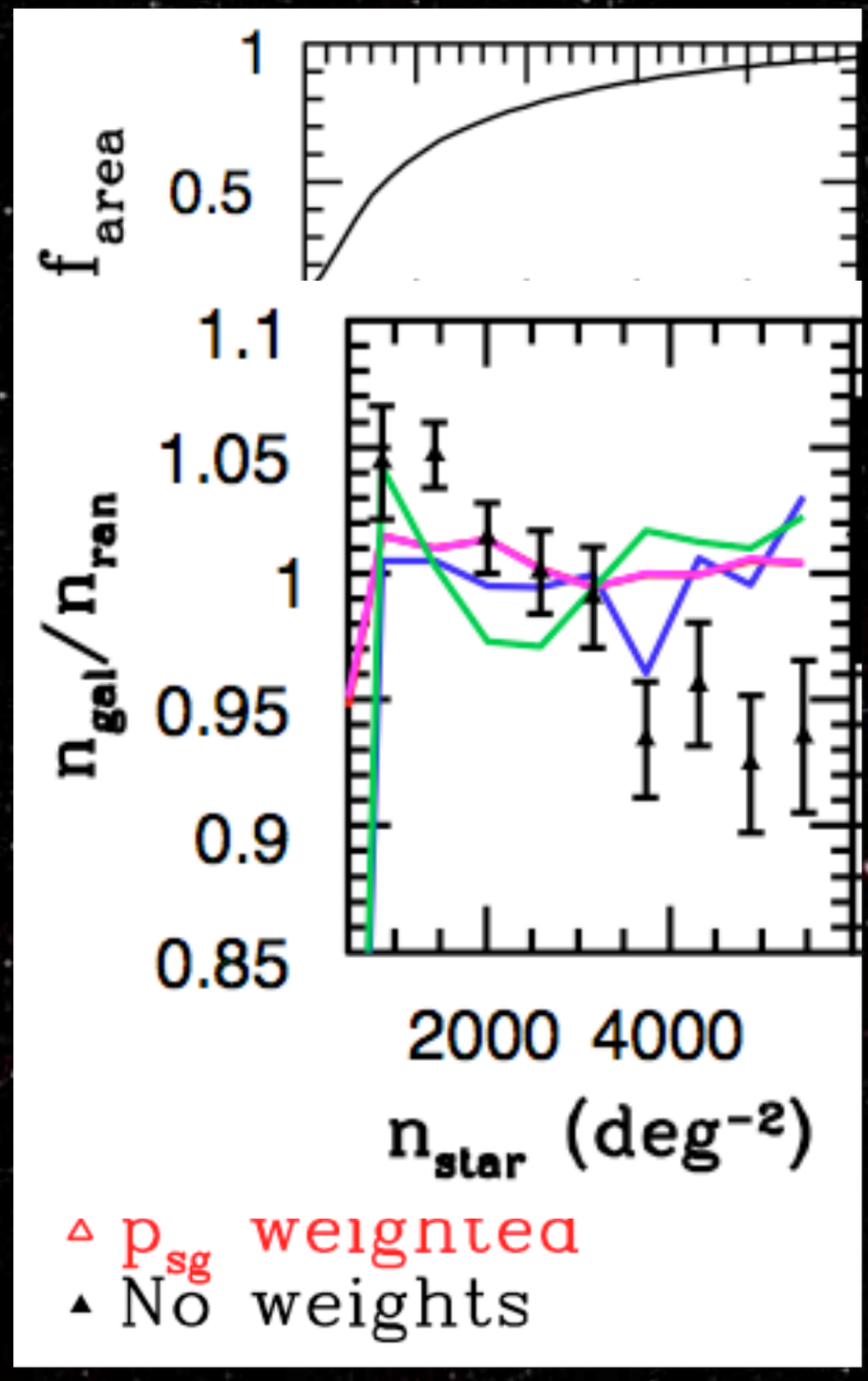
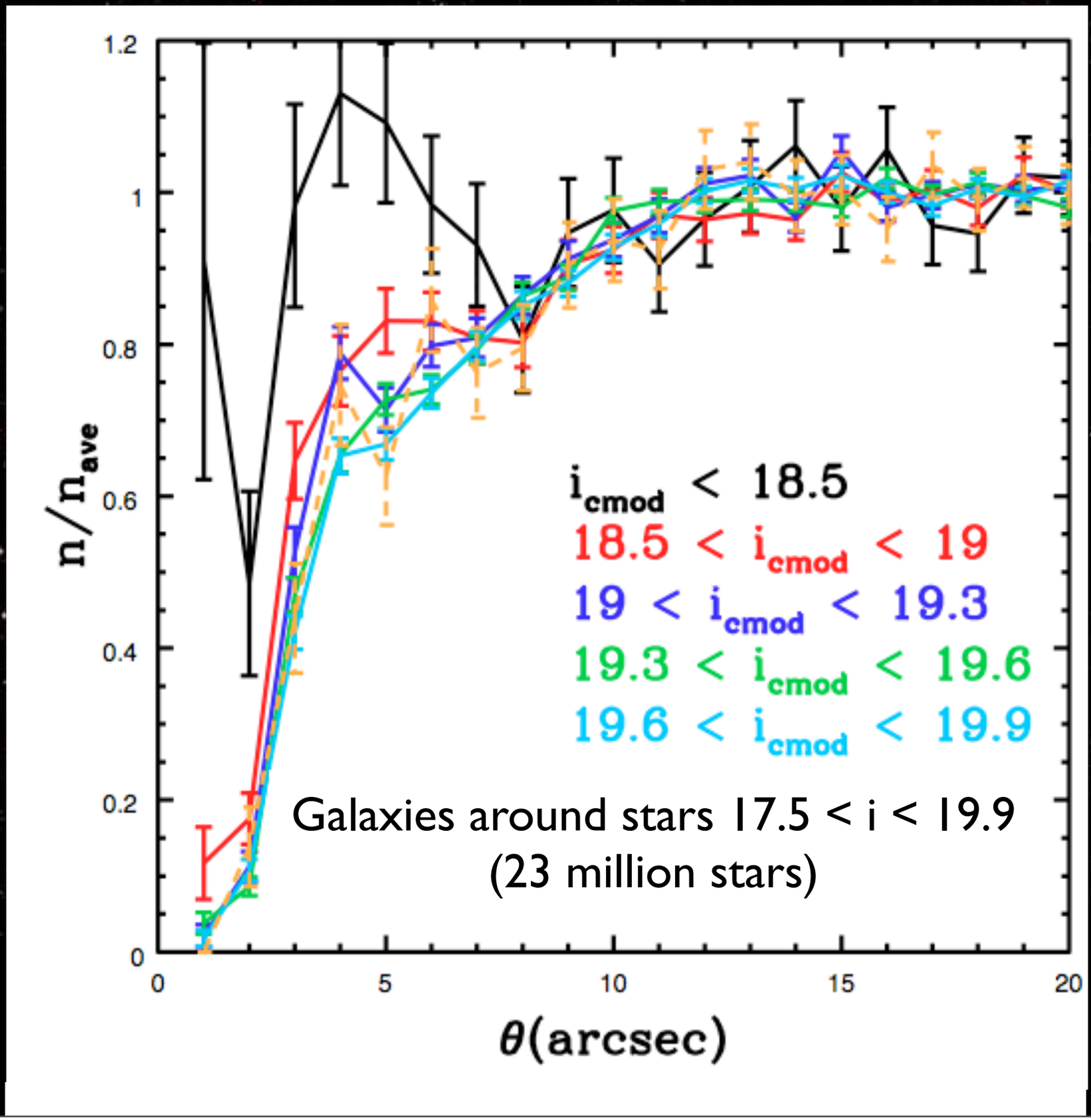


Stars Occult Area



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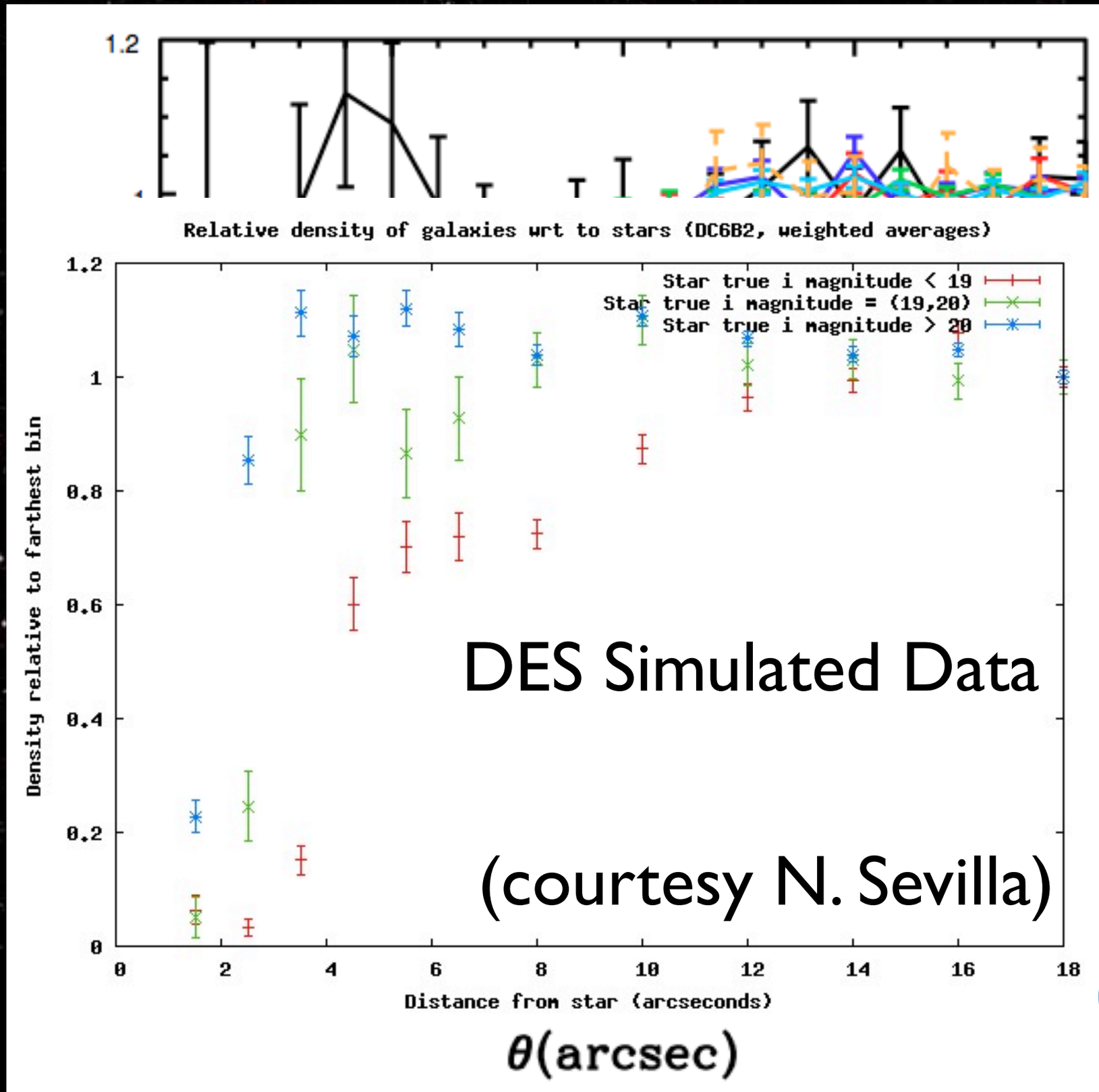
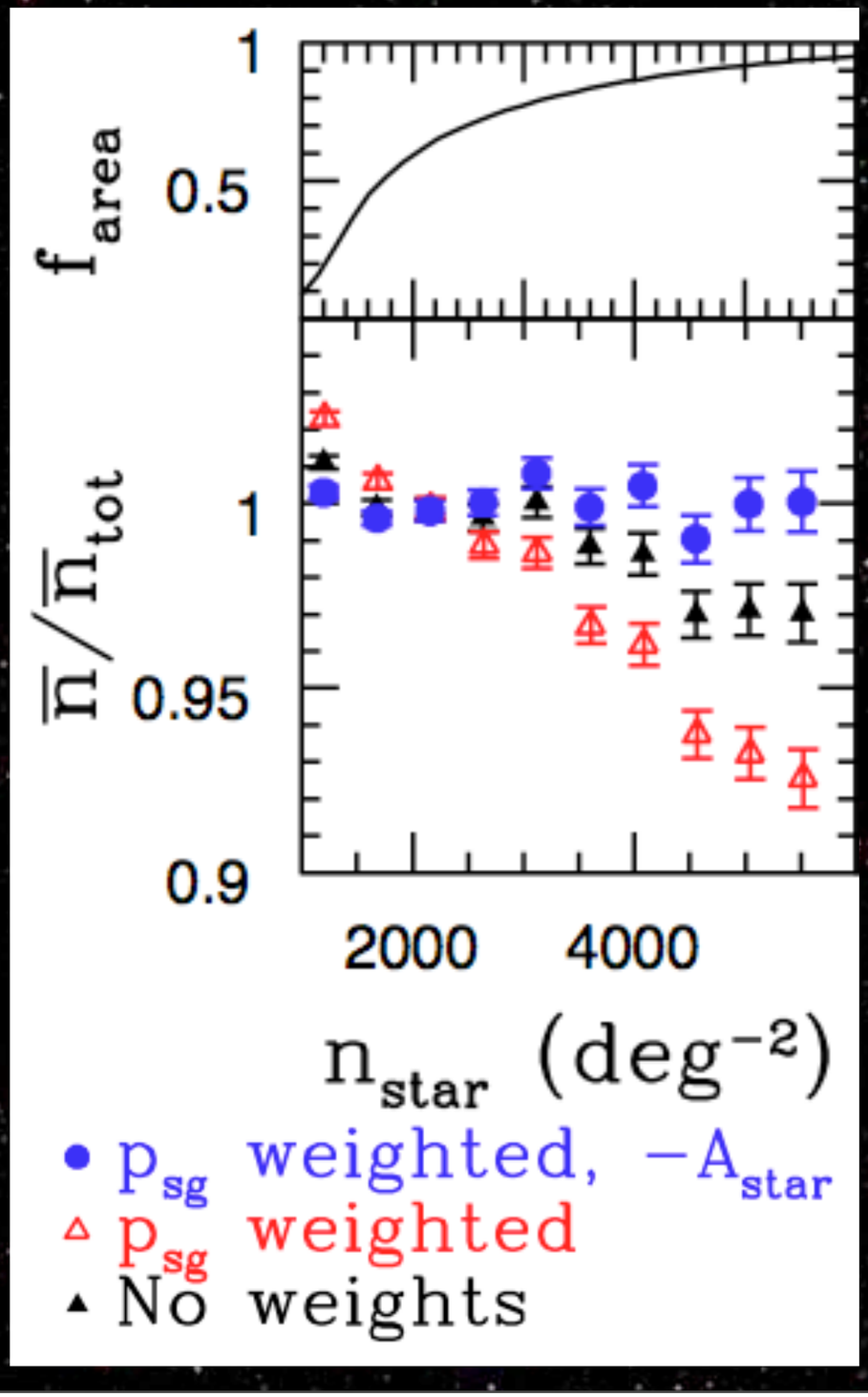
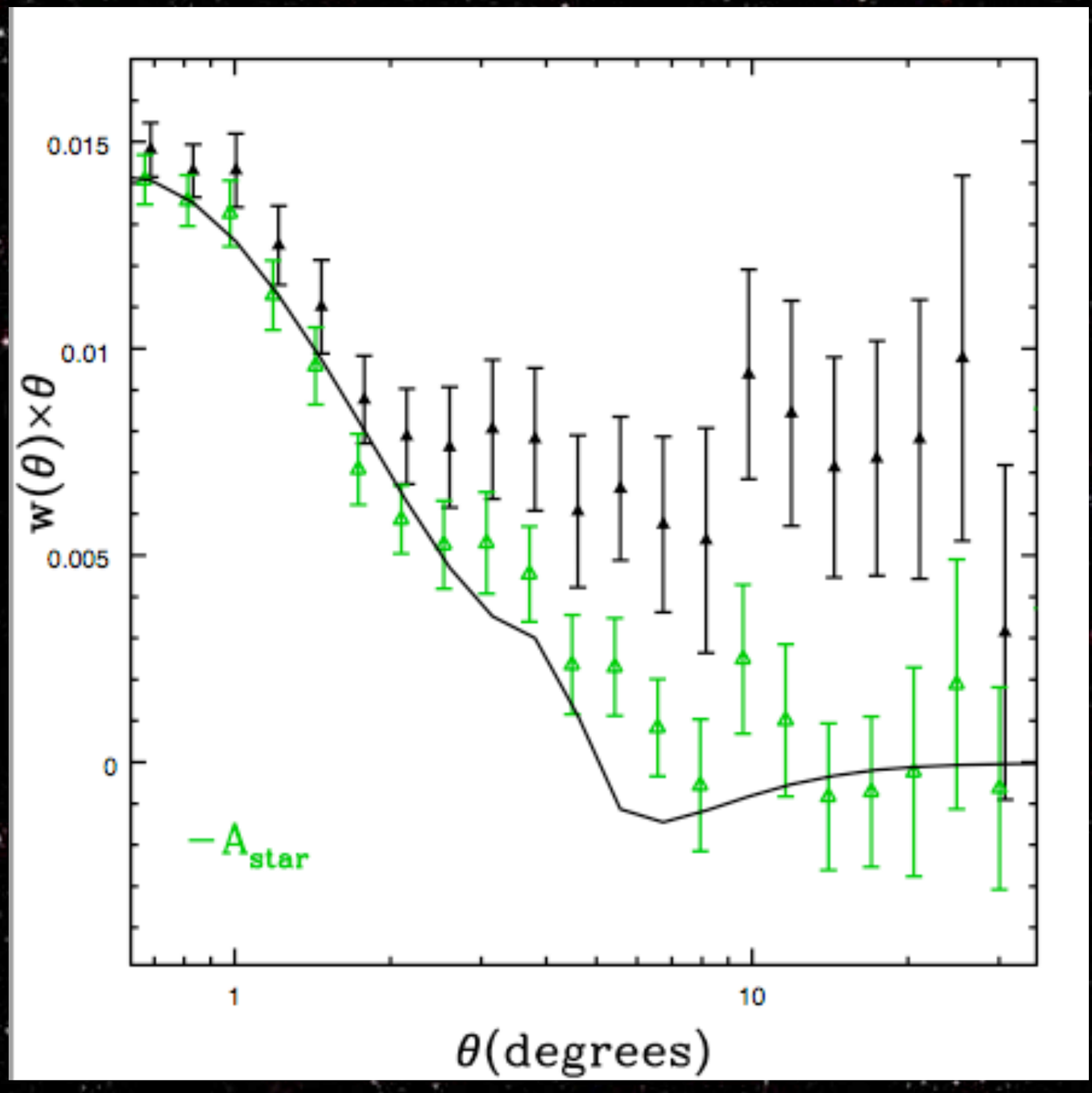


DES Simulated Data

(courtesy N. Sevilla)

Correcting for Stars



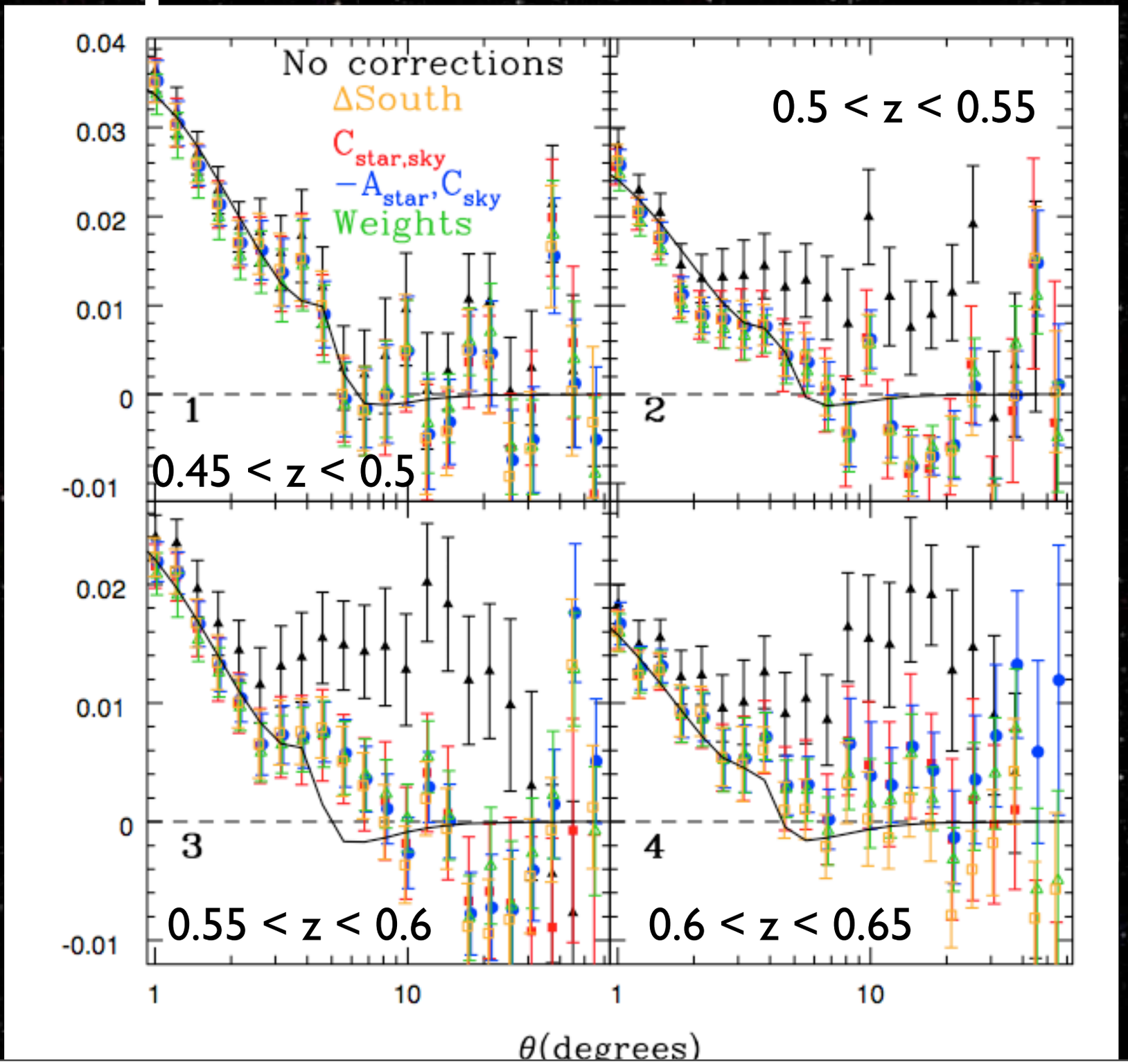


General Solution

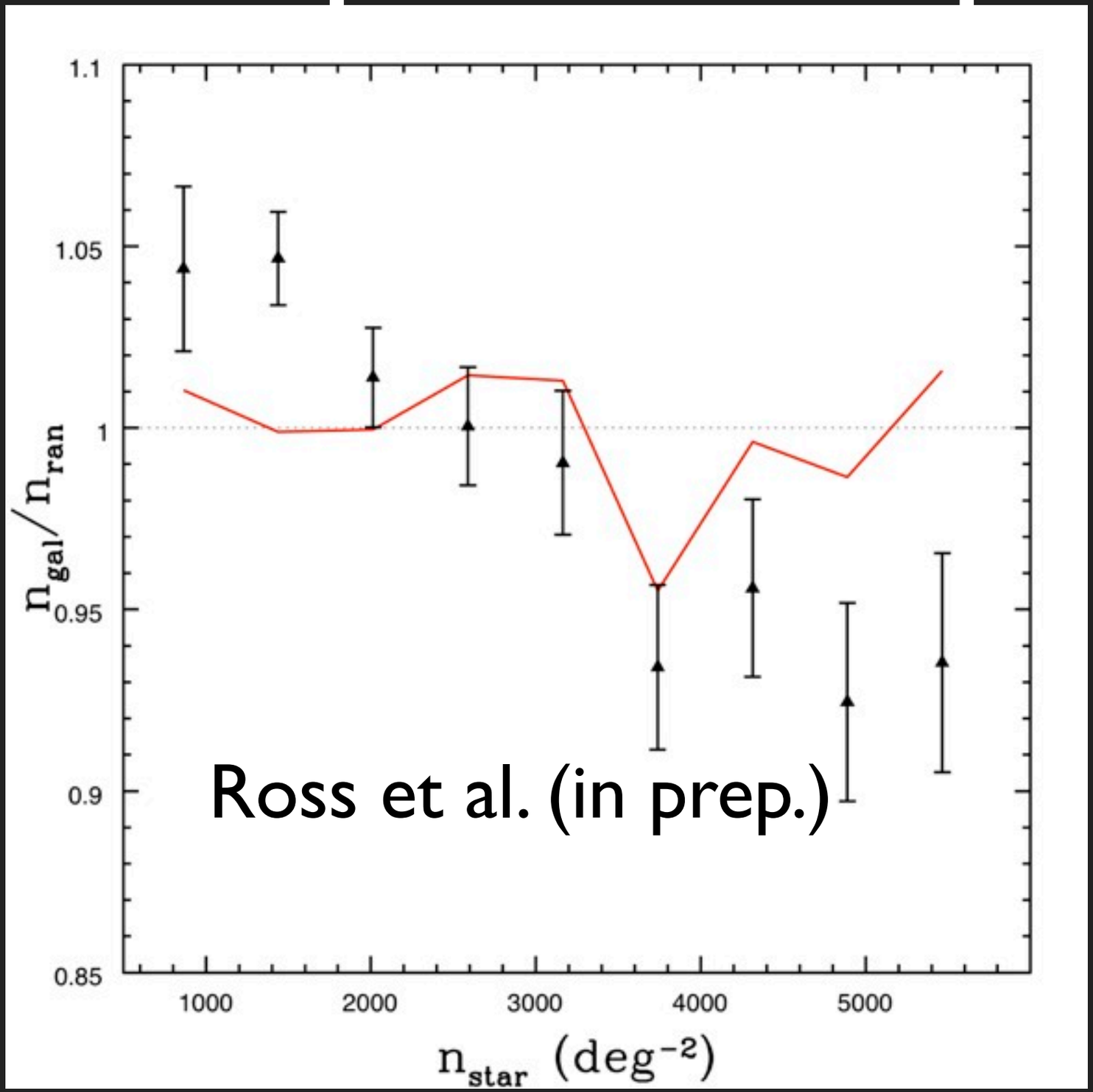
- If you can make a map
- 1) Assume intrinsic cross-correlations are 0, subtract measured contribution
- 2) Assume intrinsic no local relationship, weight appropriately

w(θ) for photoz shells

- fit for bias with basic ΛCDM model
- with corrections: χ^2/d.o.f = 0.79, 1.8, 0.99, 1.0
- without corrections: χ^2/d.o.f = 0.99, 3.9, 7.0, 6.4



Spectroscopic Sample



Ross et al. (in prep.)

- Again went through all potential systematics
- Most important: Correct for presence of stars via weights linear fit to $n_g(n_{star})$ relationship

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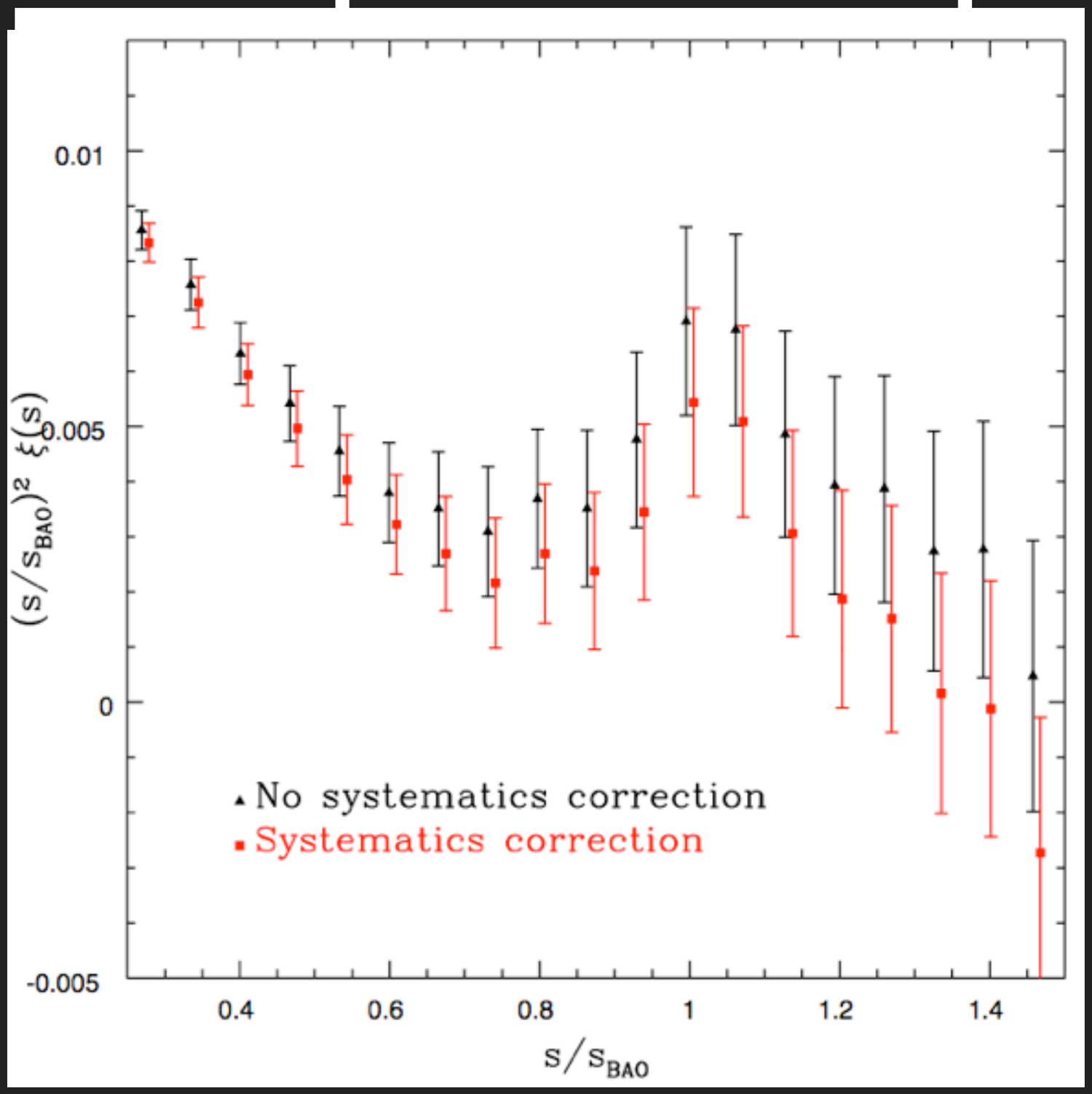
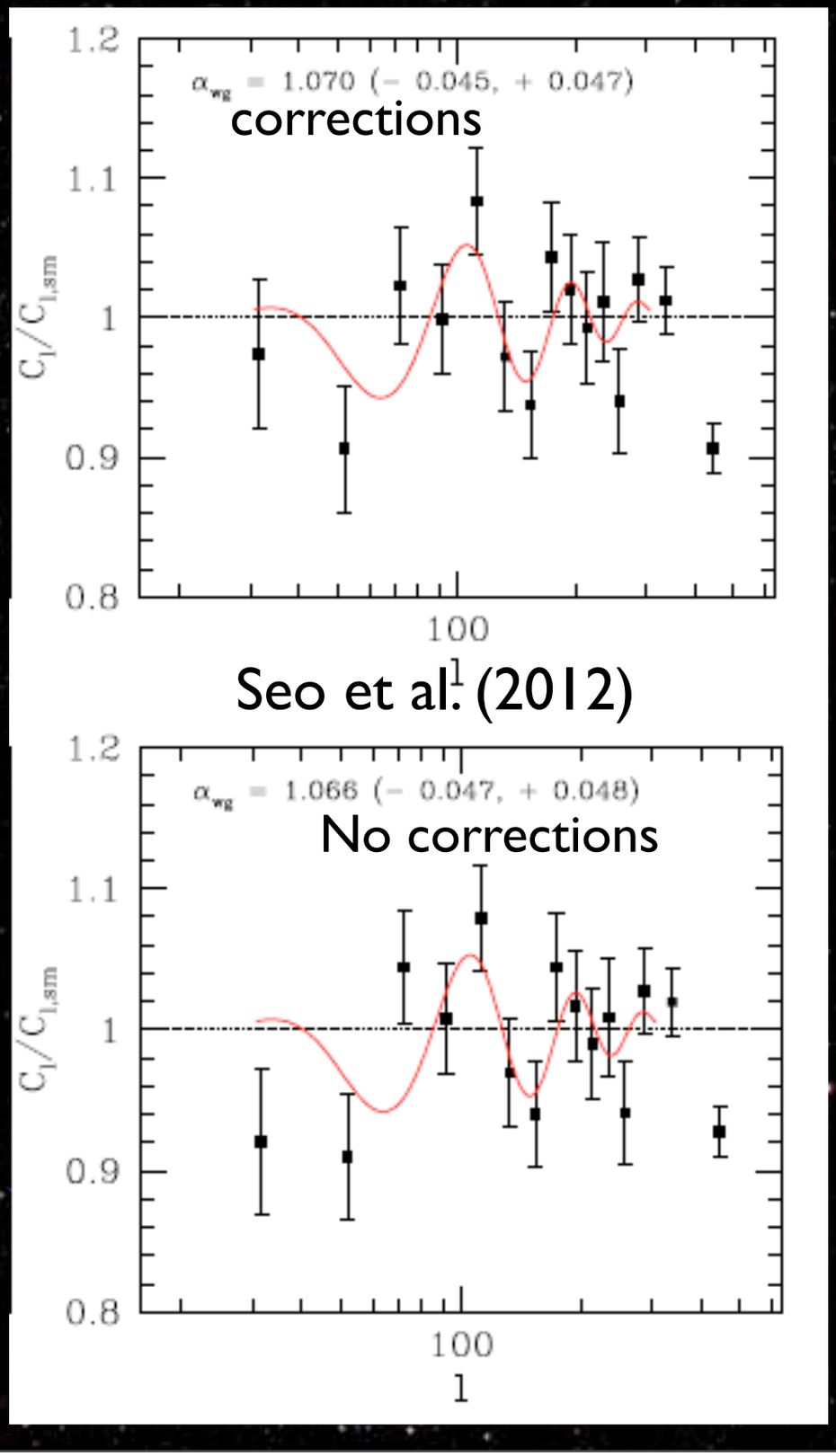


- Again went through all potential systematics
- Most important: Correct for presence of stars via weights linear fit to $n_g(n_{star})$ relationship

BAO position unaffected

- photoz: position changes by 0.1σ, χ^2/dof 1.2->1.1
- specz, ≪0.1σ (X. Xu, W. Percival)



Lessons for the future

- Approach DES carefully
  - Spectroscopic overlap
  - Fix object detection ahead of time
  - re-apply BOSS photoz methods
  - coordinate with weak lensing
- Issues in BigBOSS target catalog can be addressed ahead of time
  - BOSS systematics found during photoz project

Conclusions

- Galaxy clustering encodes a wealth of cosmological information!
- (faint) foreground stars present challenge for all forthcoming surveys
- Using photometric redshifts presents challenges
  - ...but the information is still there
- BAO position appears robust to observational systematics
- BOSS photoz sample is best existing sample...results came out this week!
- BOSS DR9 cosmological implications coming soon!