Cosmological Constraints from the Redshift Dependent of the Alcock-Paczynski Test

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WITH Changbom Park &

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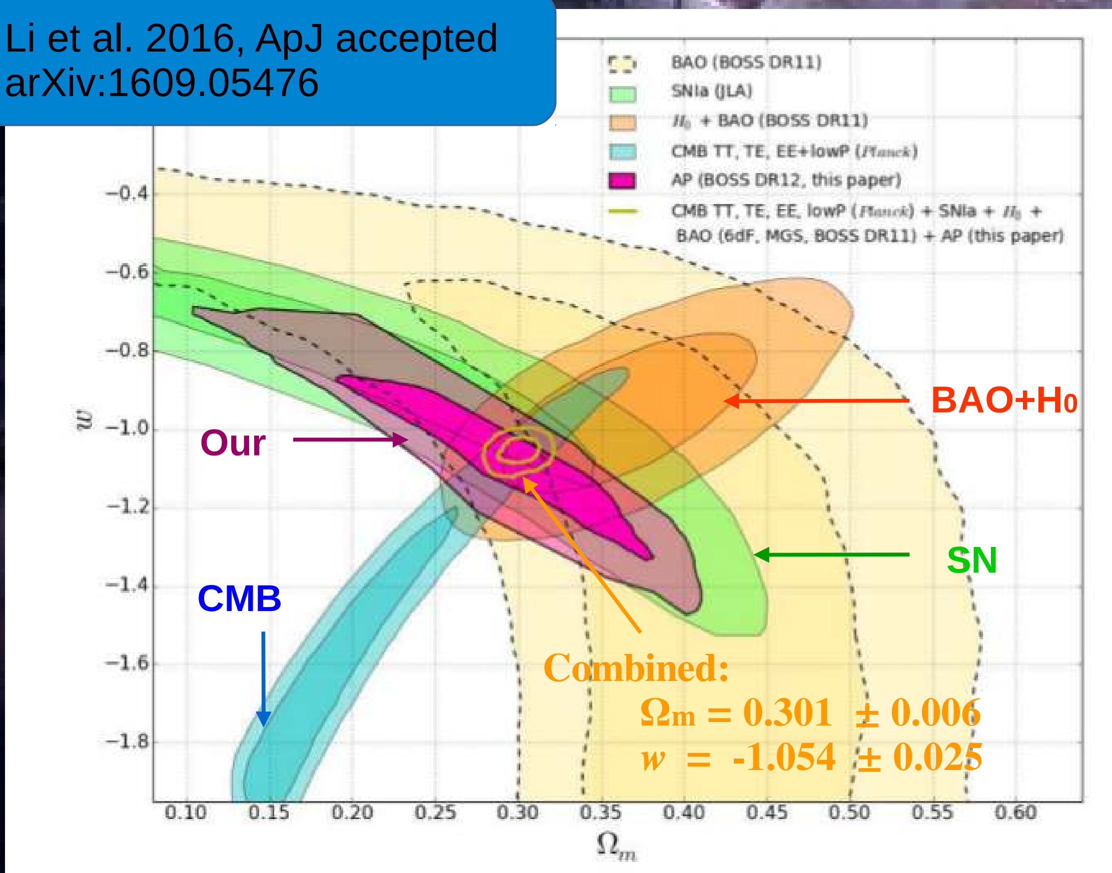
The 7th KIAS Workshop on Cosmology and Structure Formation

What: AP, the shape distortion of objects/structures, due to wrong cosmology (adopted to compute $r(z)$)

How: AP distortion is less significant than RSD, but more evolves with redshift. We focused on the redshift dependence, to probe AP and avoid RSD.

Result: We applied our idea to BOSS DR12 galaxies and obtained very tight cosmological constraint.

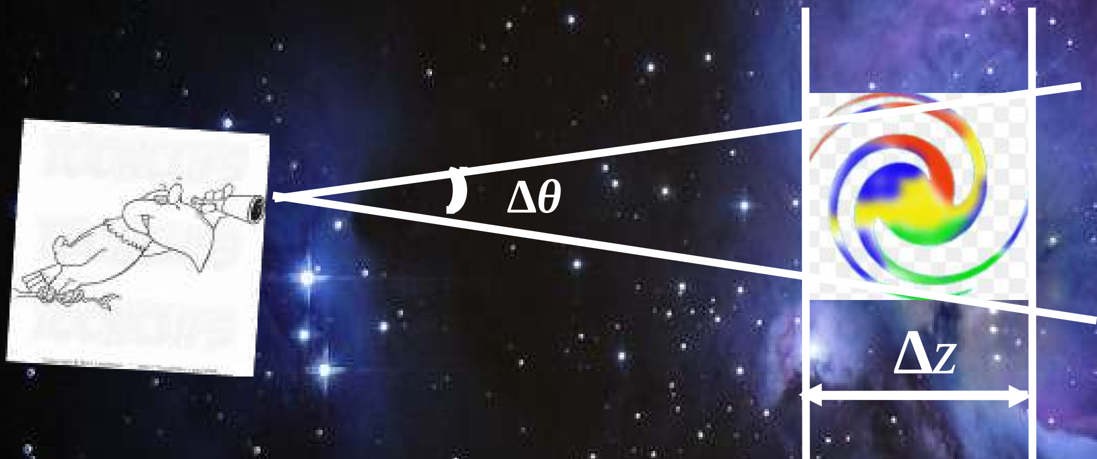
Li et al. 2016, ApJ accepted
arXiv:1609.05476



The Alcock-Paczynski Test

Alcock & Paczynski, Nature 281, 358 (1979)

The Alcock-Paczynski (AP) effect refers to the geometirc distortion when incorrect cosmological models are adopted for transforming redshift to comoving distance.



$$\Delta r_{LOS} = \frac{c}{H(z)} \Delta z$$

$$\Delta r_{\perp} = (1+z) D_A(z) \Delta\theta$$

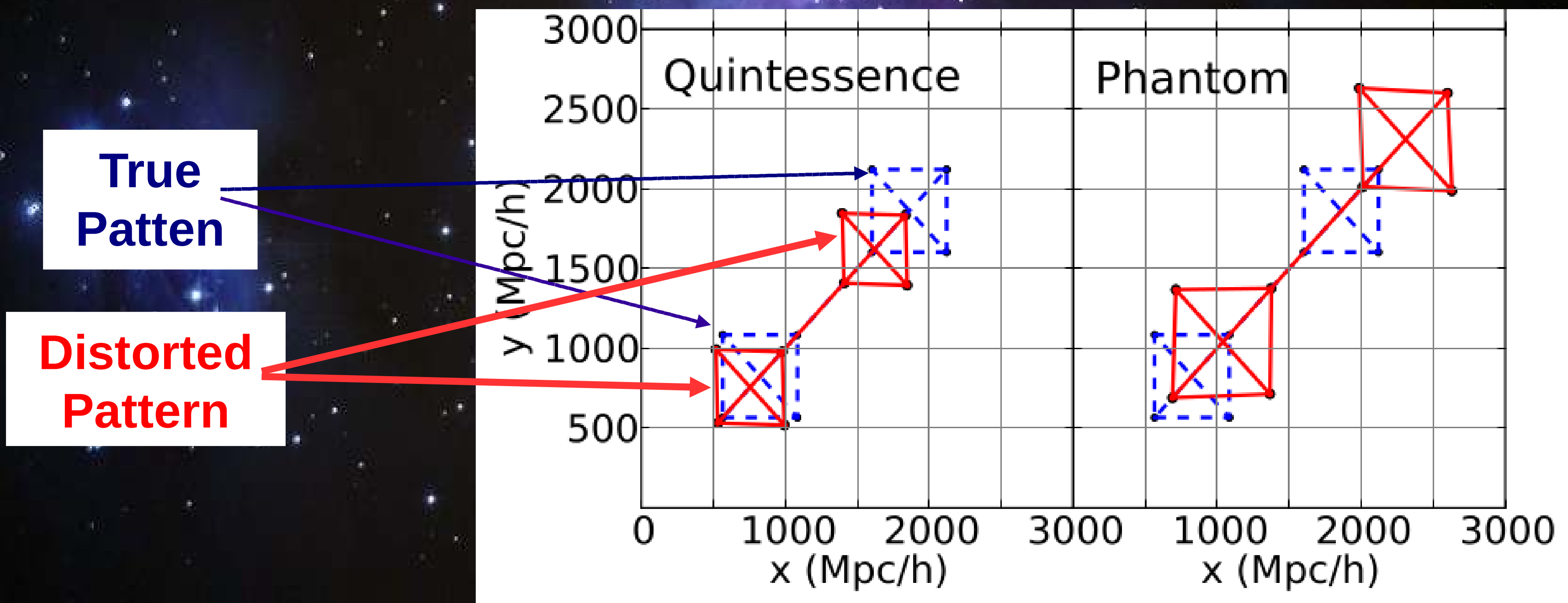
$$H(z) = H_0 \sqrt{\Omega_m a^{-3} + (1-\Omega_m) a^{-3(1+w)}}$$

$$D_A(z) = \frac{c}{1+z} r(z) = \frac{c}{1+z} \int_0^z \frac{dz'}{H(z')}$$

AP = Apparent shape distortion if H, D_A are wrong.

The Alcock-Paczynski Test

Incorrect cosmology → shape distortion
– and, the distortion is redshift dependent



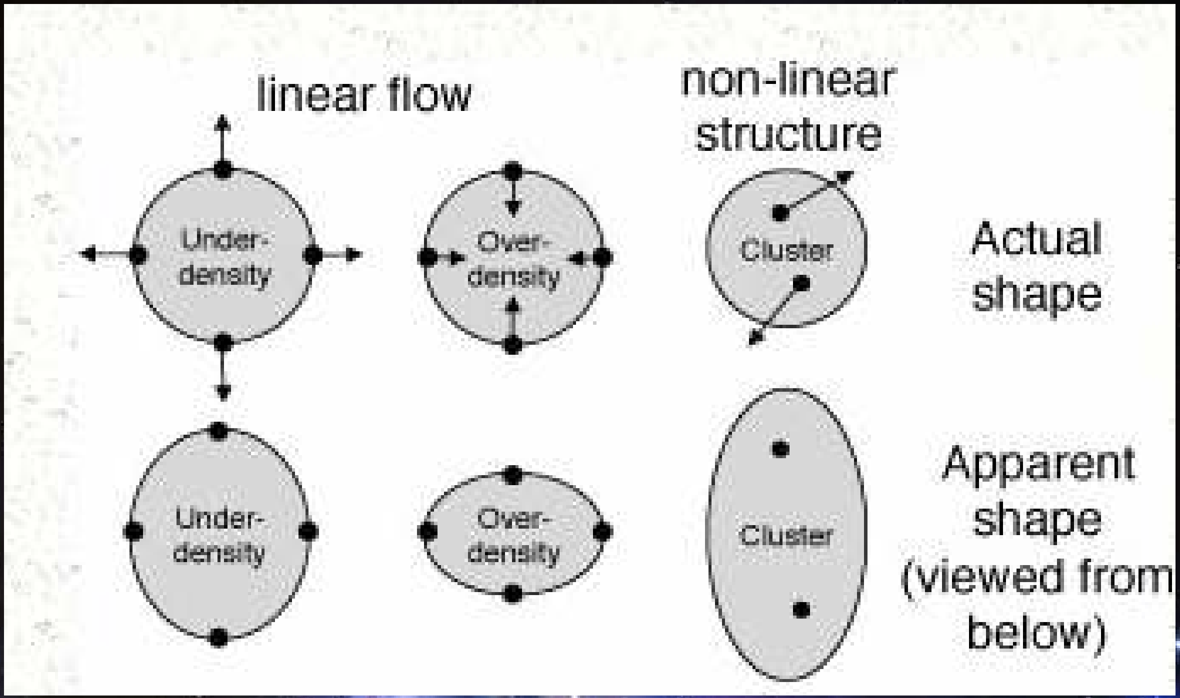
Viewpoint from ΛCDM observer

Q: How can we find isotropic objects in the Universe?

A: Large scale distribution of galaxies!

Credit: Sloan Digital Sky Survey.

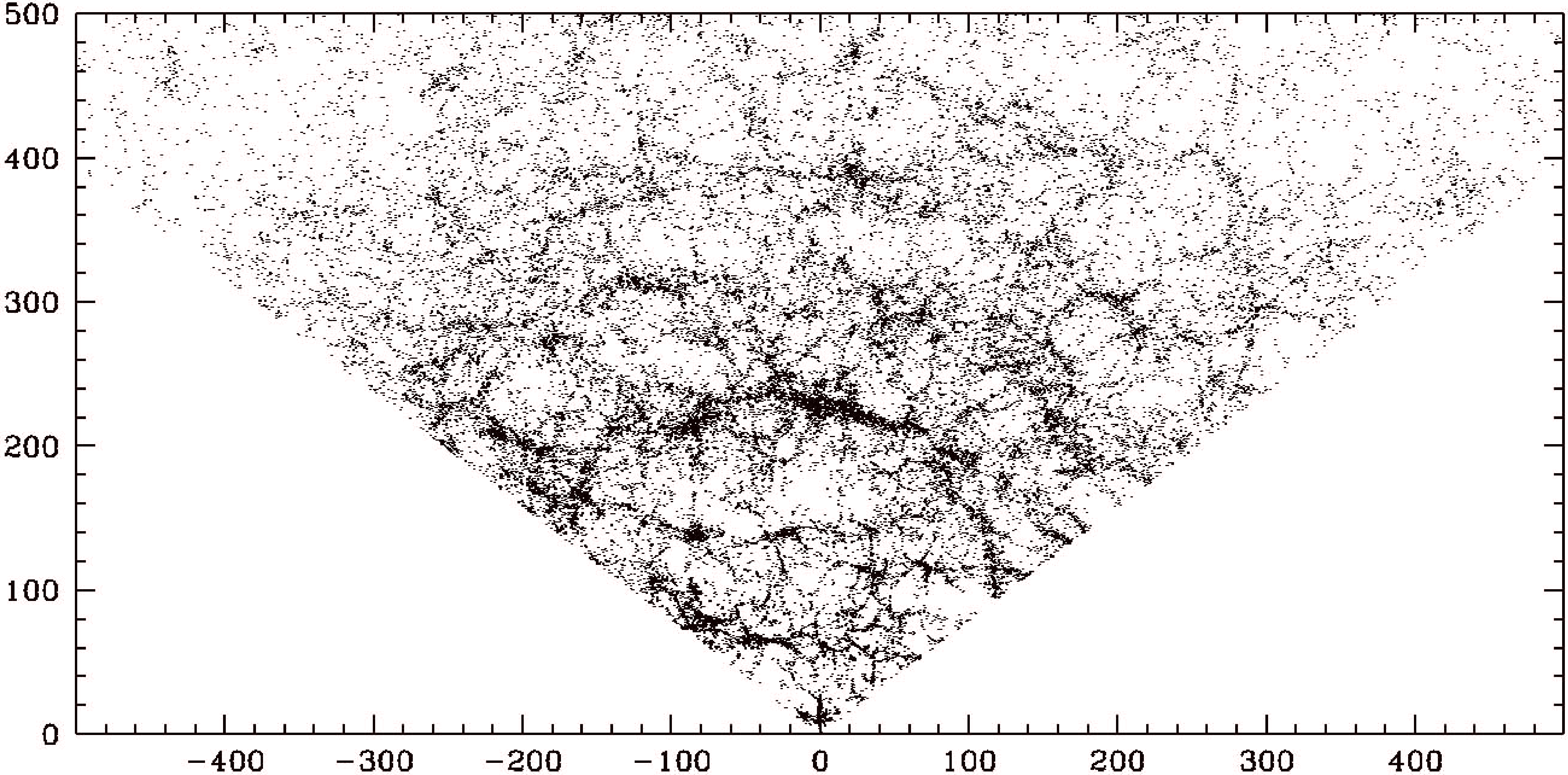
Problem of RSD



Redshift Space Distortion (RSD) produces serious anisotropy

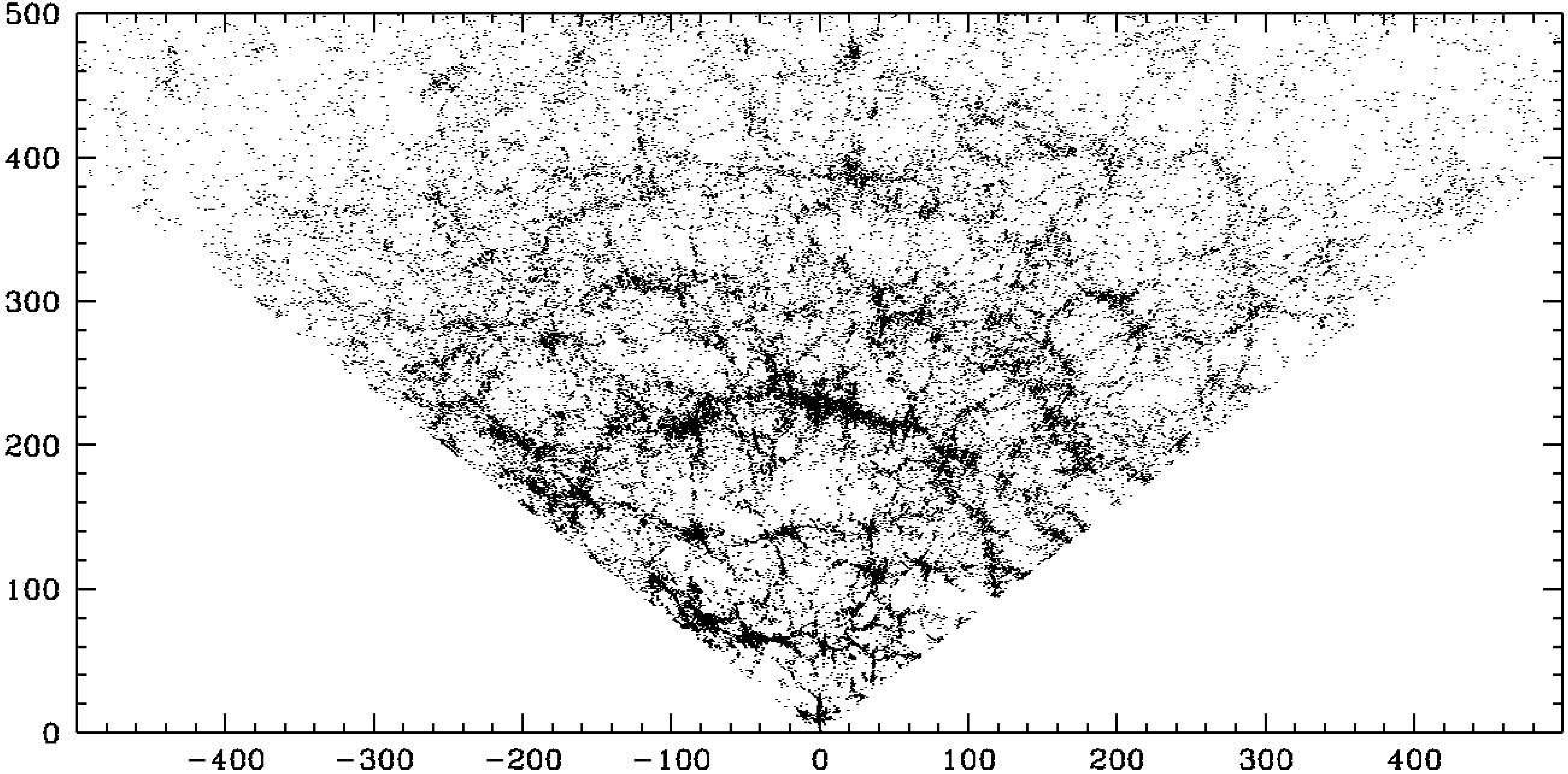
$$r = \int_0^{z_{\rm cosmo}+\Delta z} \frac{dz'}{H(z')}, \ \Delta z = \frac{v_{\rm LOS}}{c}(1+z_{\rm cosmo})$$

Difficult modeling (NL clustering)



Galaxy distribution in real space

SDSS DR7 after FoF contraction. 8.8h<RA<15.7h, 0<DEC<6deg

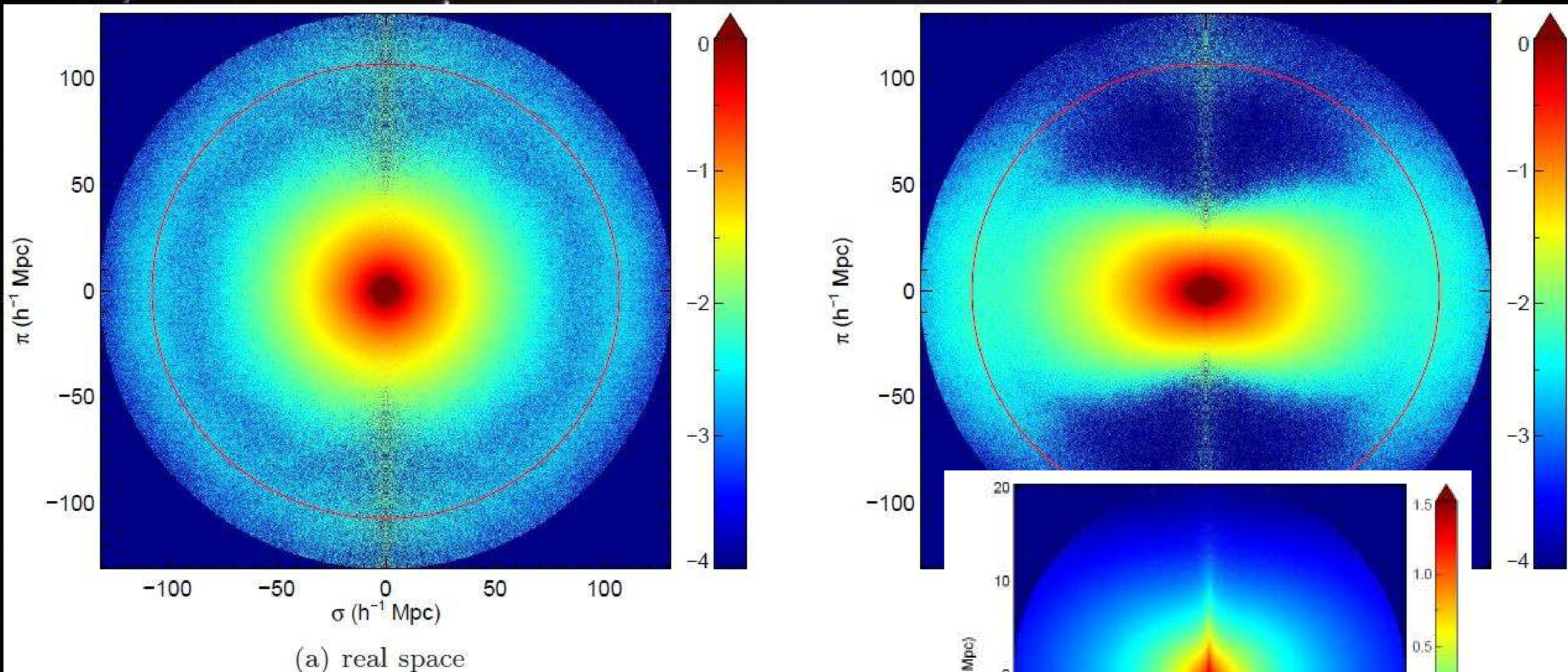


Galaxy distribution in redshift space

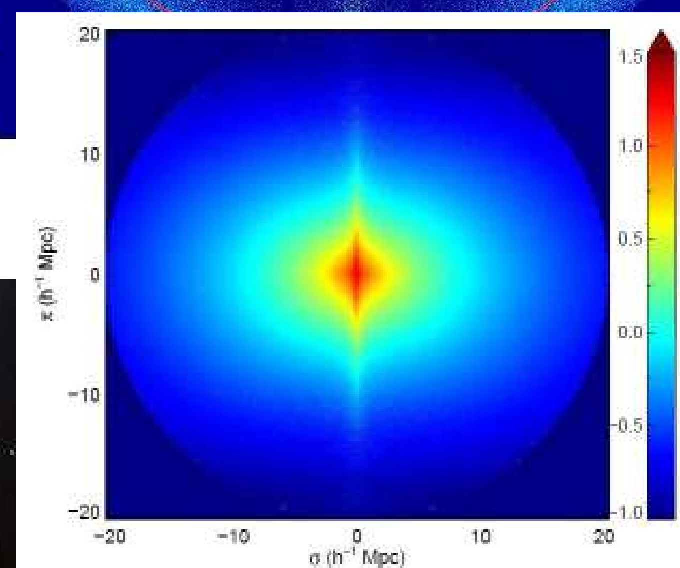
SDSS DR7 before FoF contraction. 8.8h<RA<15.7h, 0<DEC<6deg

RSD effects

on 2-point correlation function along (π) & across (σ) LOS

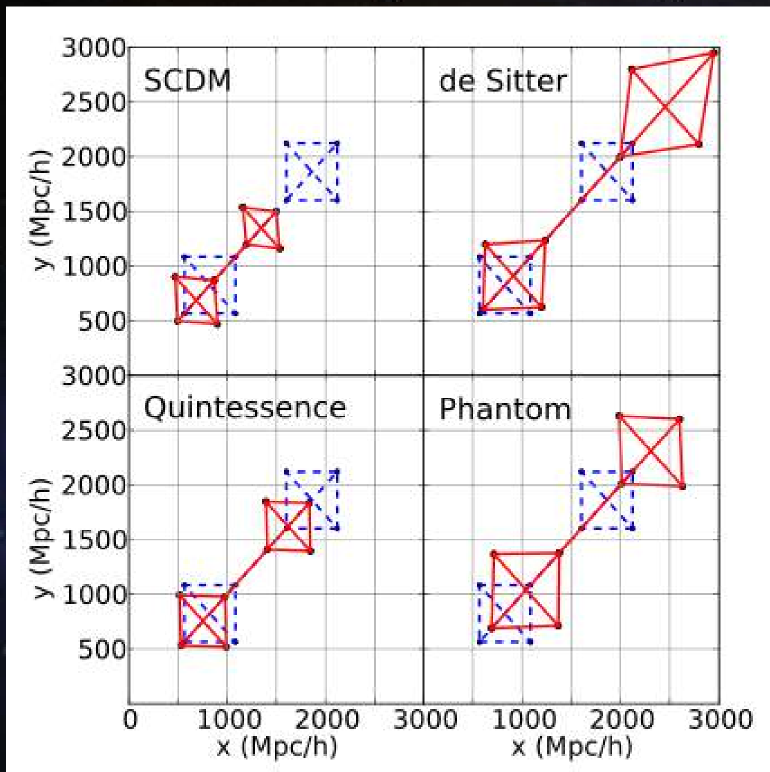


(a) real space



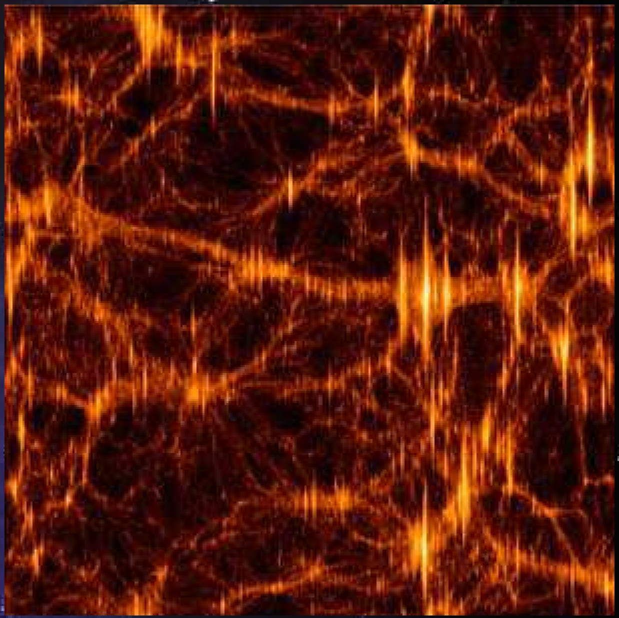
Horizon-Run 4 (Kim et al. 2015, JKAS, 48, 213)

Our Option: the redshift dependence



AP Distortion

Pattern evolves with distance



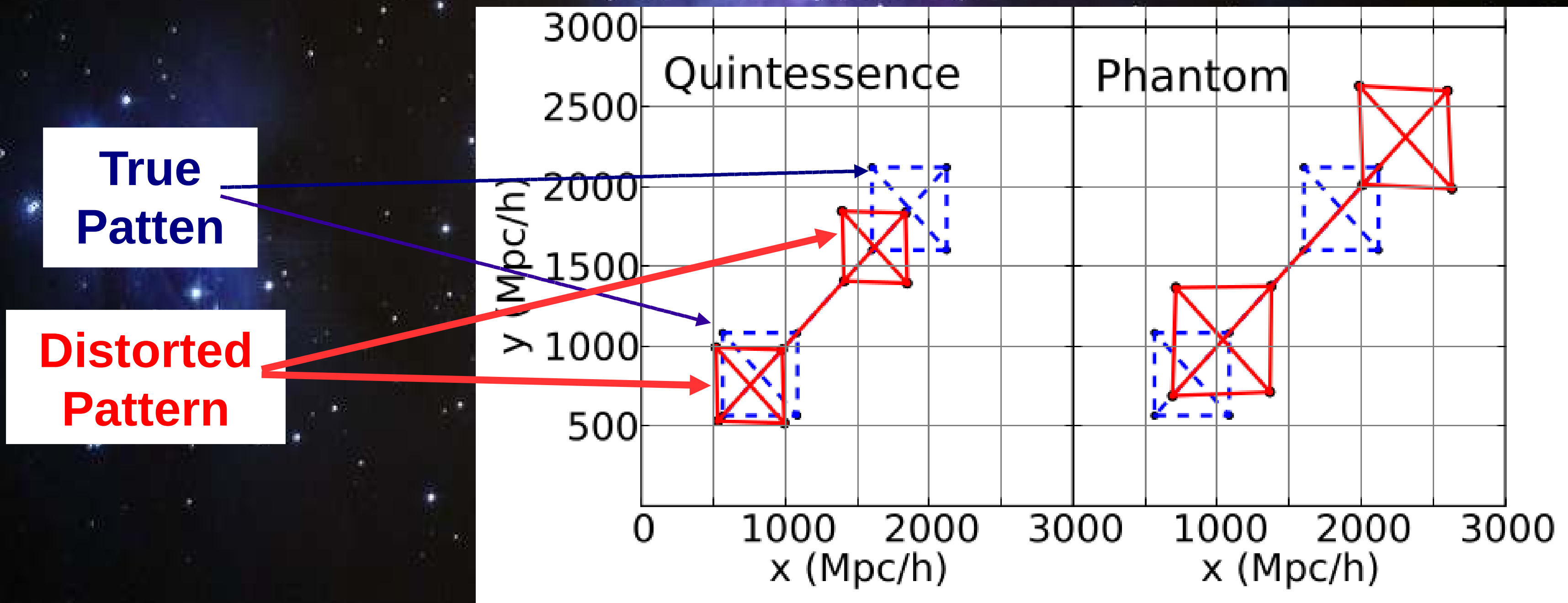
RSD

Kaiser effects on large scales and FoG effects on small scales
(pattern ~ independent of redshift)

The Alcock-Paczynski Test

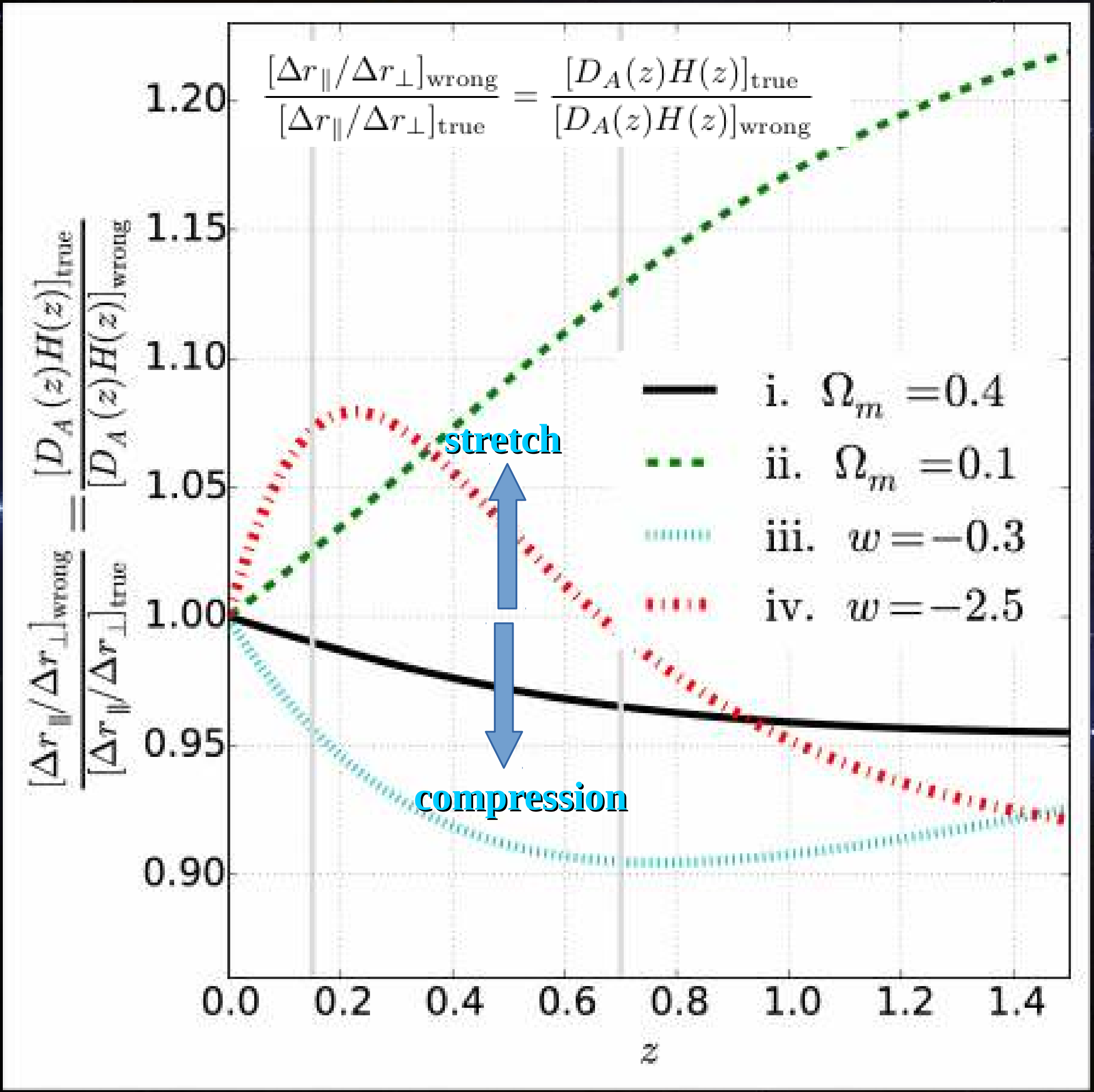
Incorrect cosmology → shape distortion

– and, the distortion is redshift dependent



Viewpoint from ΛCDM observer

Redshift Evolution of AP



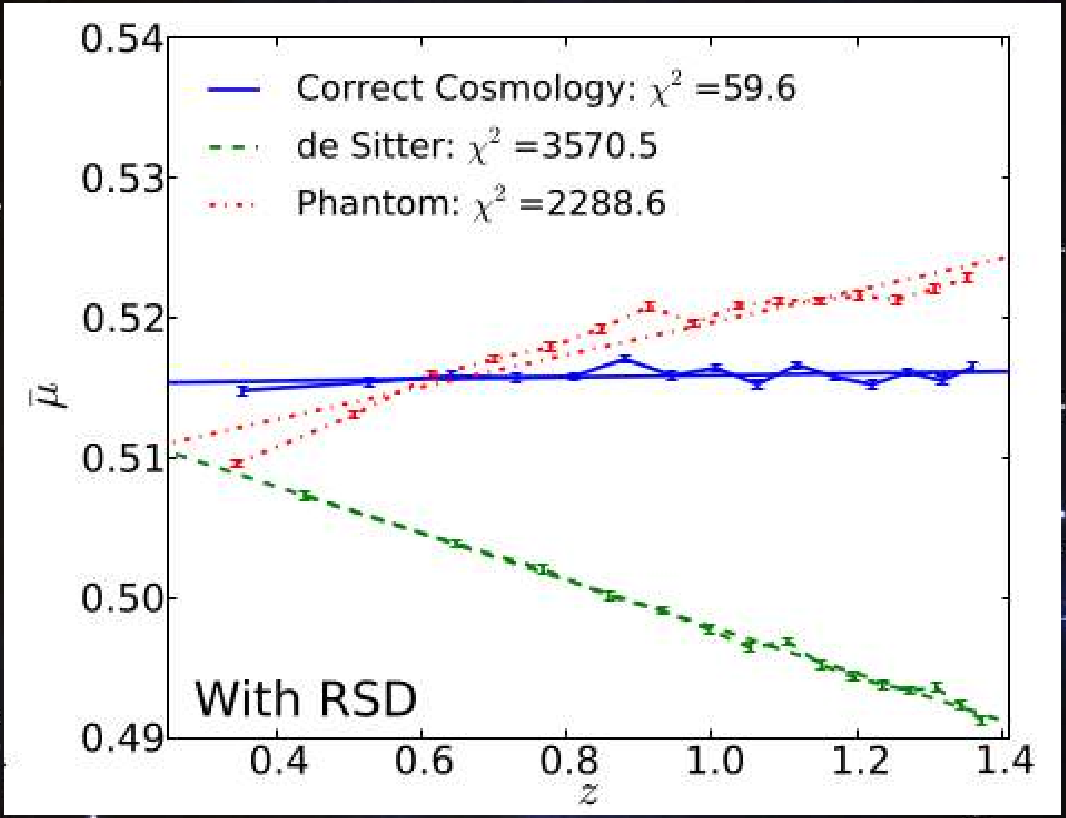
How much radial stretch at different z?

[Viewpoint from Ω_m=0.31 ΛCDM observer]

Proof-of-concept on HR3 N-body: Gradient Field

X.-D. Li, Changbom Park, J. E. Forero-Romero, Juhan Kim 2014 ApJ

Mean of cosine of vector direction

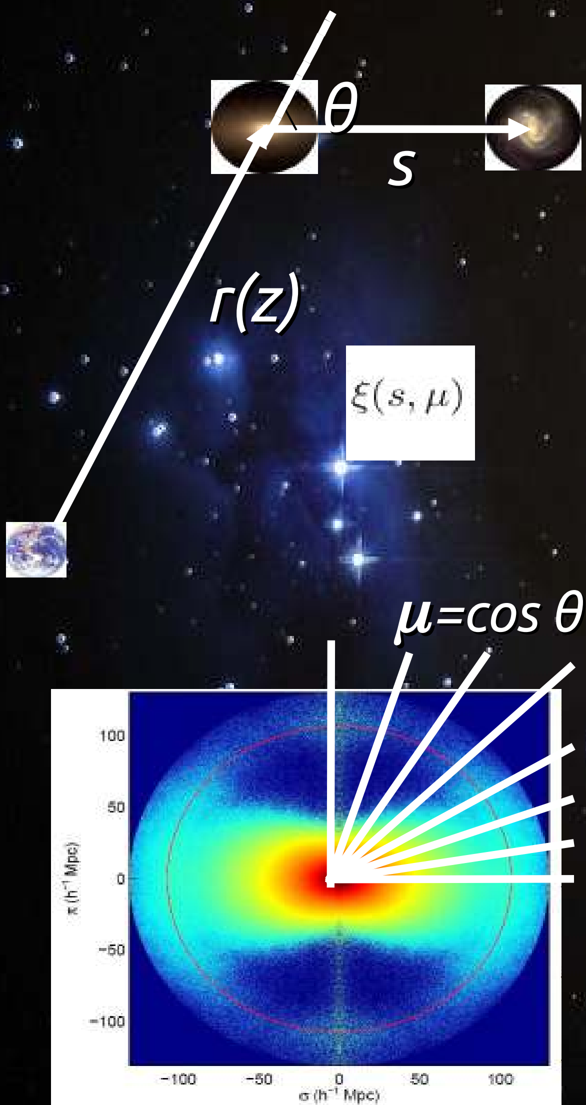


We study the gradient field of the spatial distribution of galaxies.

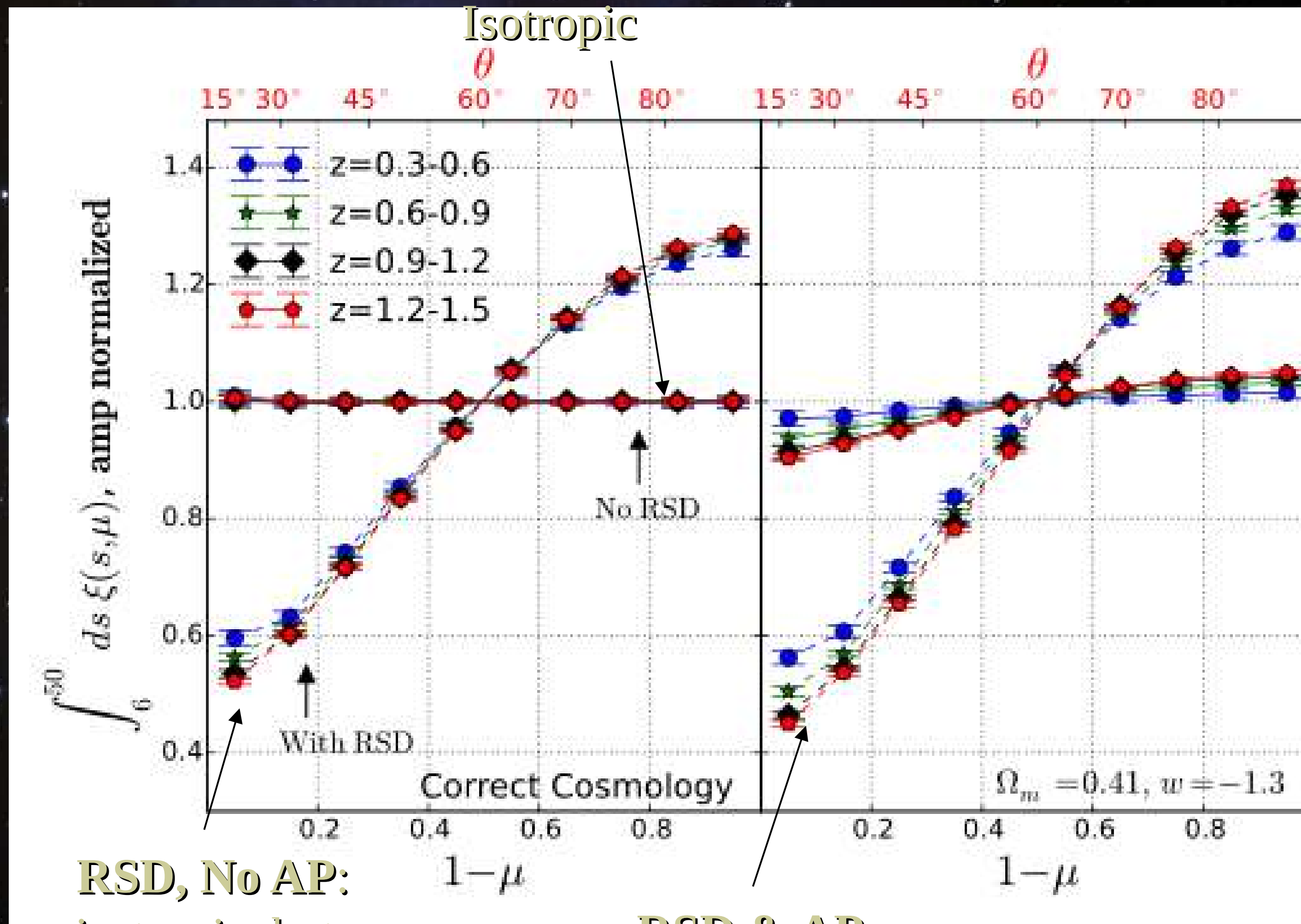
The anisotropy (quantified by the mean direction of gradient vectors) has redshift dependence in case of adopting wrong cosmologies.

Proof-of-concept on HR3 N-body: 2pCF

X.-D. Li, Changbom Park, Cris G. Sabiu, Juhan Kim 2015 MNRAS



No RSD, No AP:
Isotropic

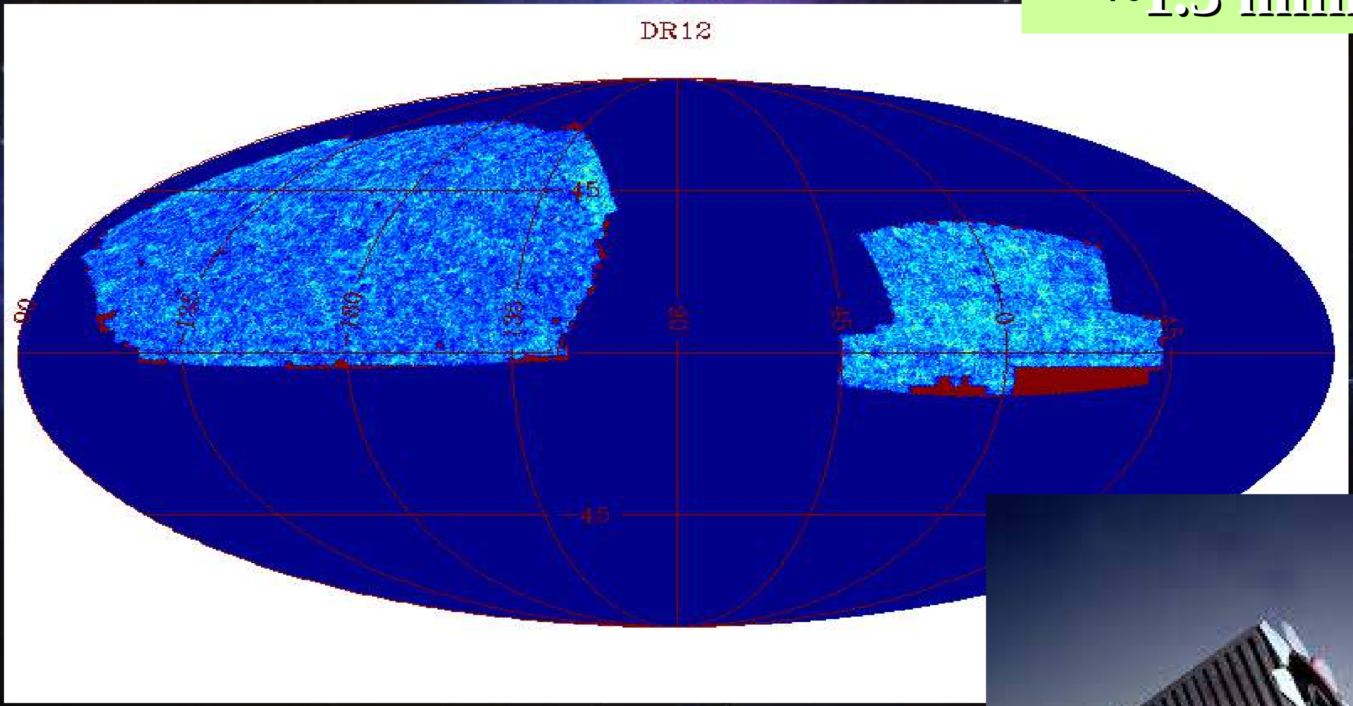


RSD, No AP:
anisotropic, but no significant redshift evolution

RSD & AP:
Redshift Evolution

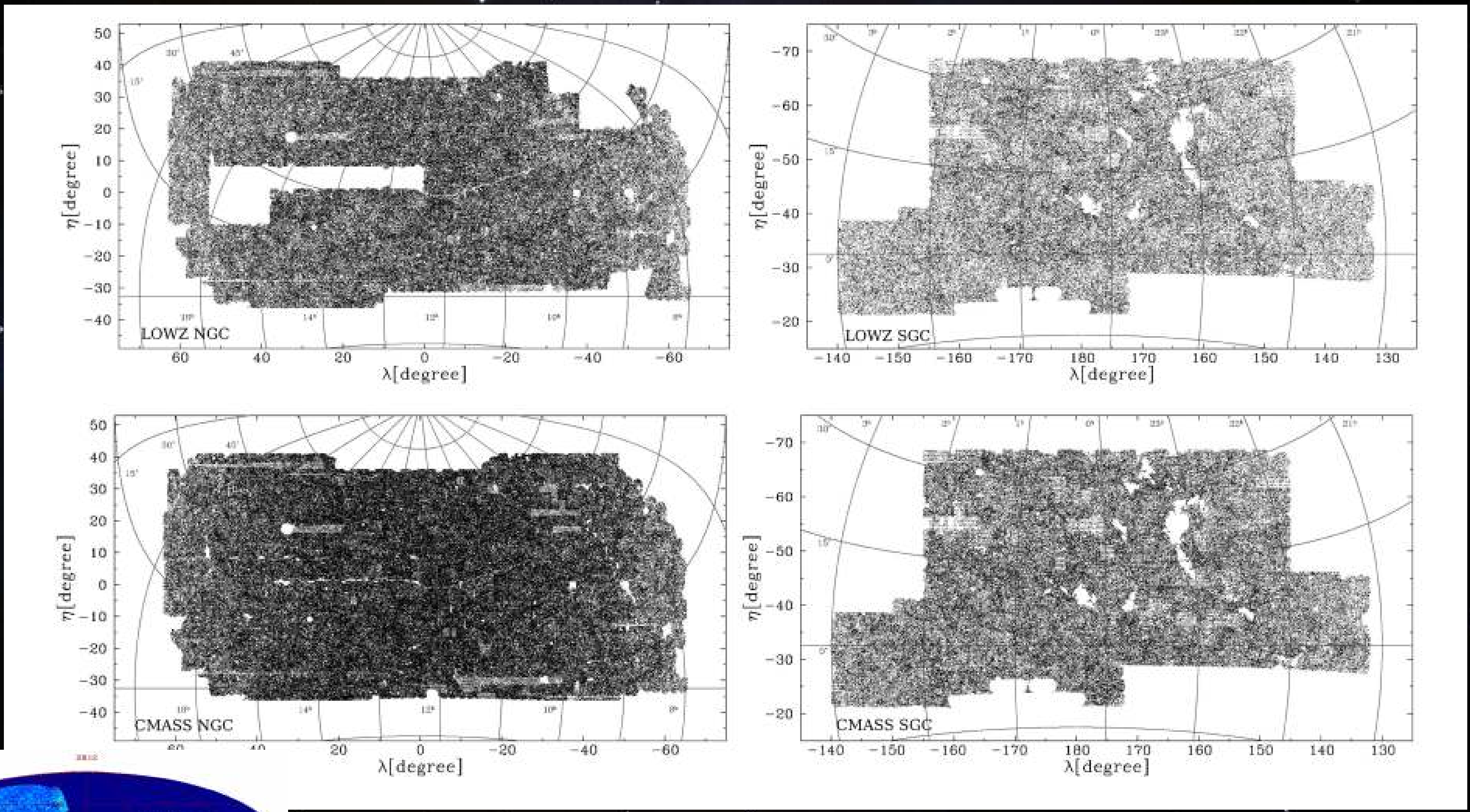
II. Application to BOSS DR12 Samples

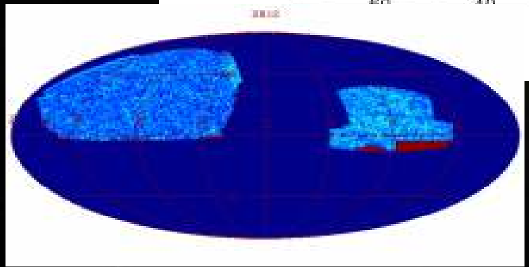
~1/4 sky, z ~ 0.15-0.7,
~1.3 million galaxies



Application to BOSS DR12 galaxies

X.-D. Li, Changbom Park, C.G. Sabiu, et al., to appear





LOWZ 8,337 deg ^{2} . CMASS 9,376 deg ^{2} (~1/4 sky)

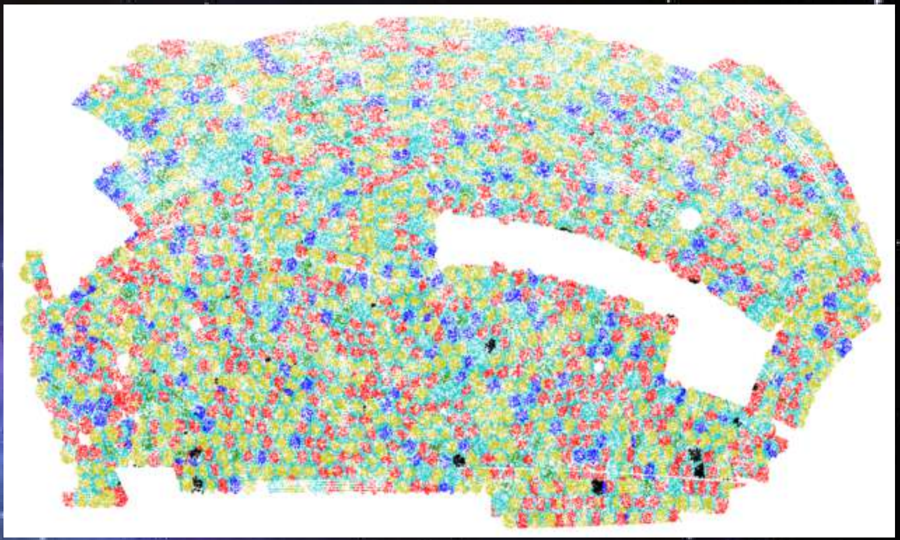
~1.13 M gals at $0.15 \le z \le 0.7$

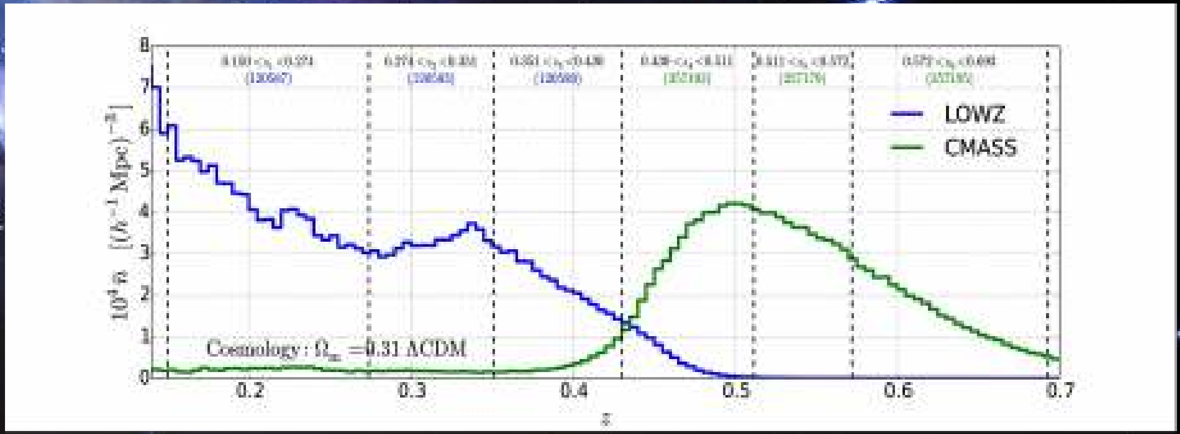
Systematics

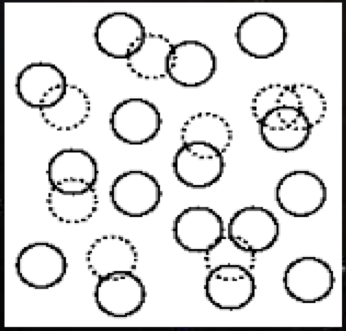
1. RSD
(still the most significant)

2. Galaxy bias
(affect clustering)

3. Angular variation
4. Radial variation
(incomplete LF coverage)
5. Fiber collision (high-density regions under-sampled)

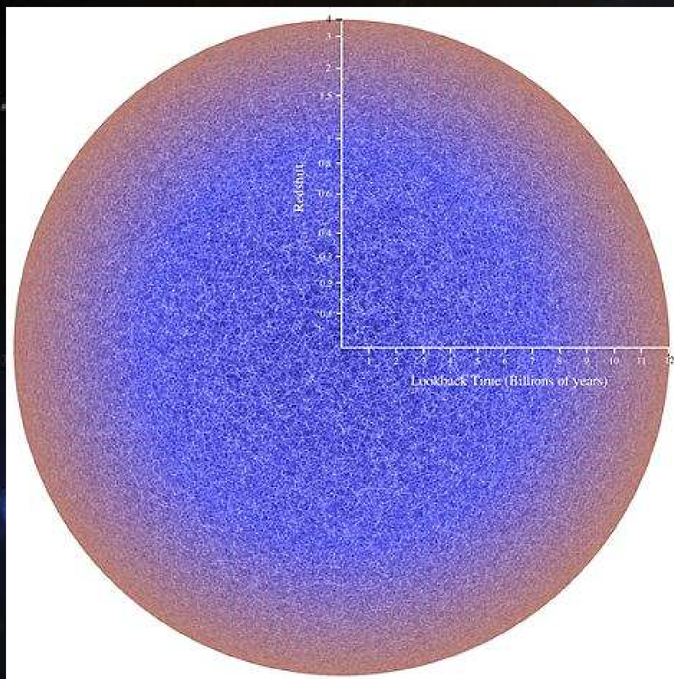


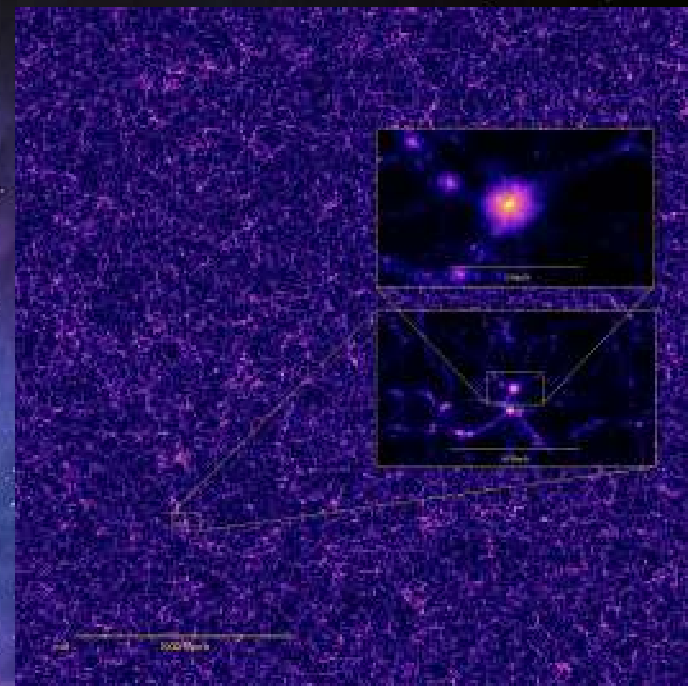




We create mock surveys to model the observational artifacts

Horizon run *N*-body





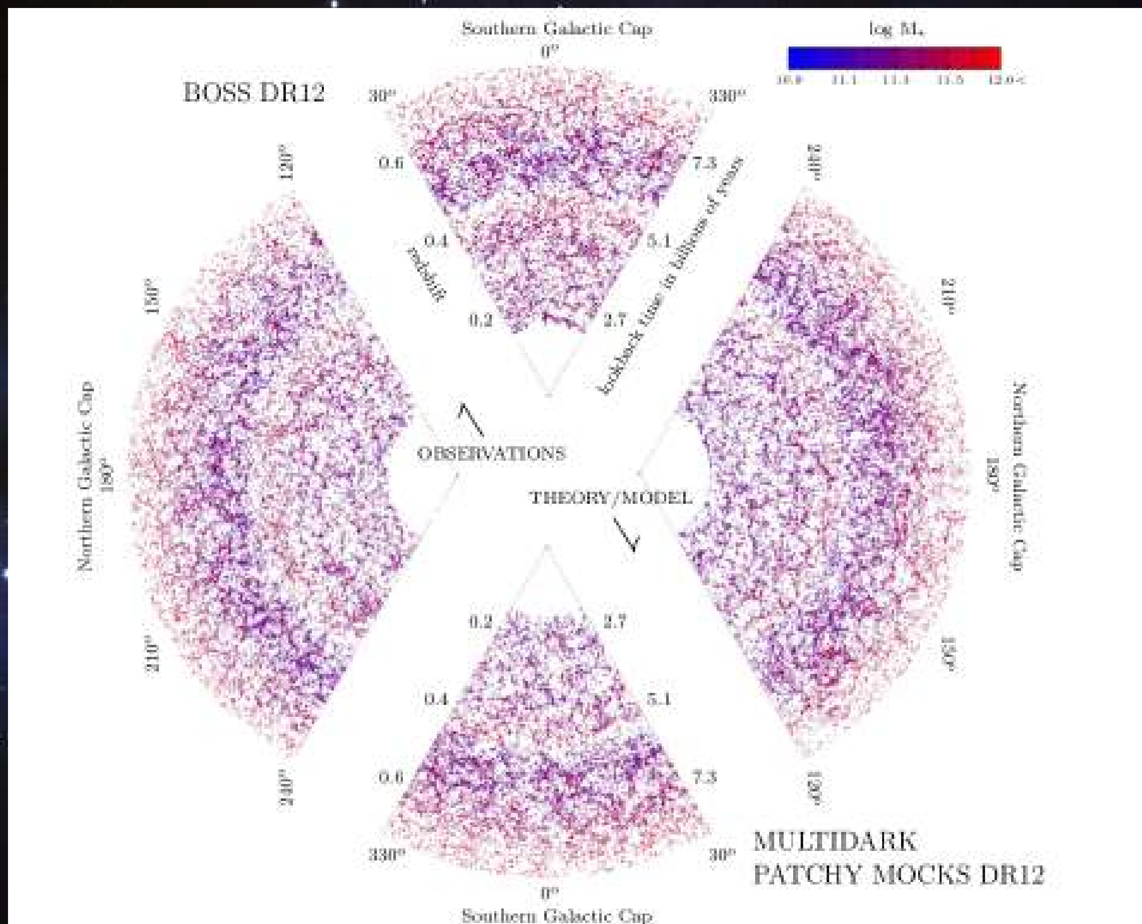
HR3 (Kim et al. 2012)
($10.815\ h^{-1}$ Gpc)^3
7120^3 particles
WMAP5 Cosmology

HR4 (Kim et al. 2015)
($3.15h^{-1}$ Gpc)^3
6300^3 particles
WMAP5 Cosmology

72 mocks → covariance estimation

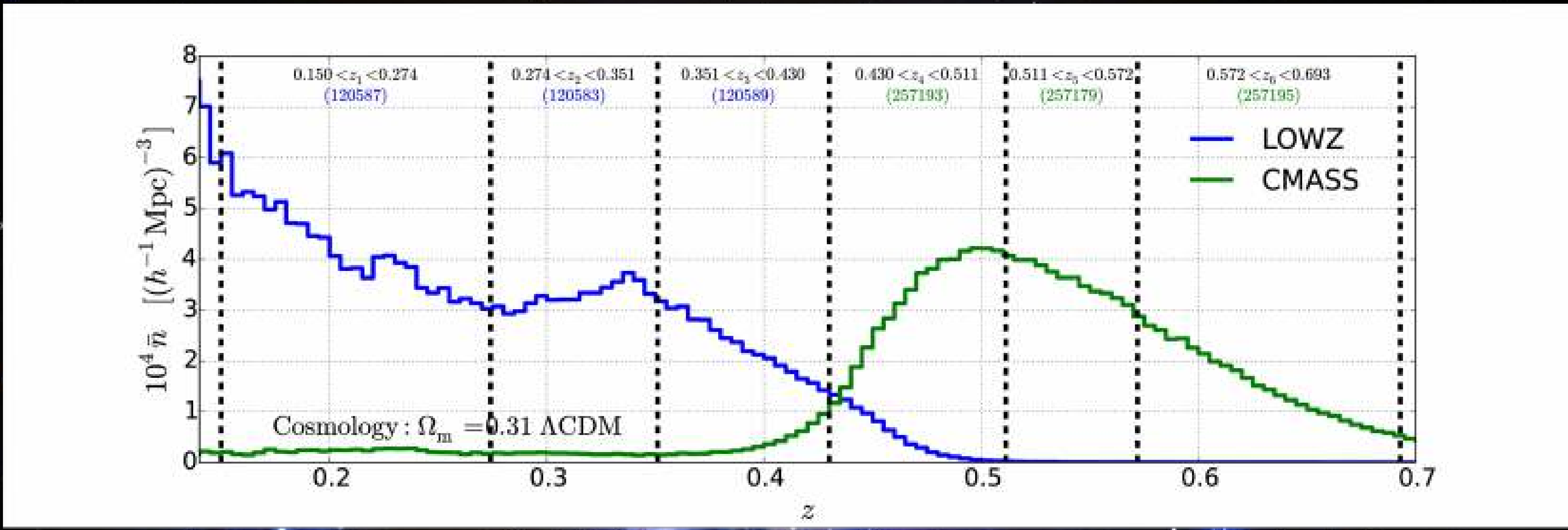
4 mocks → modeling systematic

MultiDark-Patchy Mocks



2048 mocks → covariance

Methodology



<u>0.15 < z < 0.7; Six *z*-bins</u>

1. Adopt a r(z) **[**in some cosmology], **construct 3D LSS**

2. Measure $\xi(s, \mu)$ **in each** z**-bin**

3. Quantify the evolution [ξ from 5 high-z bins compared to the lowest redshift**]**

Wrong Cos. → Large redshift evolution → Disfavored

4. Try different cosmologies and repeat 1-3 → Cosmological Constraints

Likelihood

Covariance from MDPatchy/HR3

$$\chi^2 \equiv \sum_{i=2}^{6} \sum_{j_1=1}^{n_\mu} \sum_{j_2=1}^{n_\mu} \mathbf{p}(z_i, \mu_{j_1}) \mathbf{Cov}_{i,j_1,j_2} \mathbf{p}(z_i, \mu_{j_2}),$$

where $\mathbf{p}(z_i, \mu_j)$ is the redshift evolution of clustering, $\hat{\xi}_{\Delta s}$, with systematic effects subtracted

$$\mathbf{p}(z_i, \mu_j) \equiv \delta\hat{\xi}_{\Delta s}(z_i, z_1, \mu_j) - \delta\hat{\xi}_{\Delta s,\mathrm{sys}}(z_i, z_1, \mu_j)$$

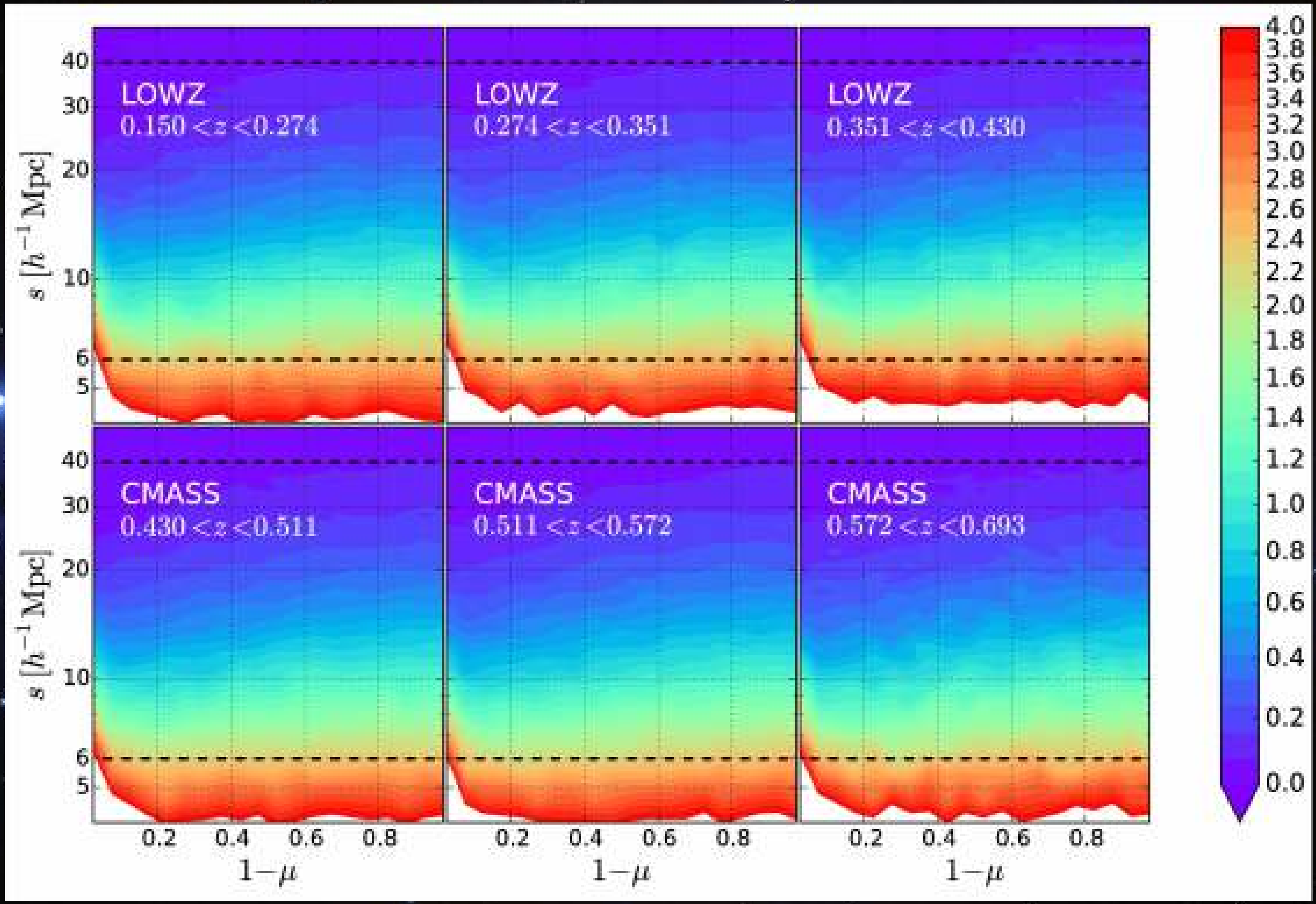
Redshift evolution of 2pCF

Sys. Correction from HR4

(comparing all redshift bins w.r.t. the lowest redshift bin)

2-d 2pCF in six redshift bins

$\Omega_m = 0.31\ \Lambda\text{CDM}$



FOG at $1 - \mu \to 0$ and Kaiser at $1 - \mu > 0.1$
Similar to each other: Small redshift evolution of RSD

1-d 2pCF as a function of angle

We follow the procedure of Li et al. (2015) and integrate the ξ over the interval 6 Mpc/h < s < 40 Mpc/h. We evaluate

$$\xi_{\Delta s}(\mu) \equiv \int_{s_{\min}}^{s_{\max}} \xi(s, \mu)\, ds.$$

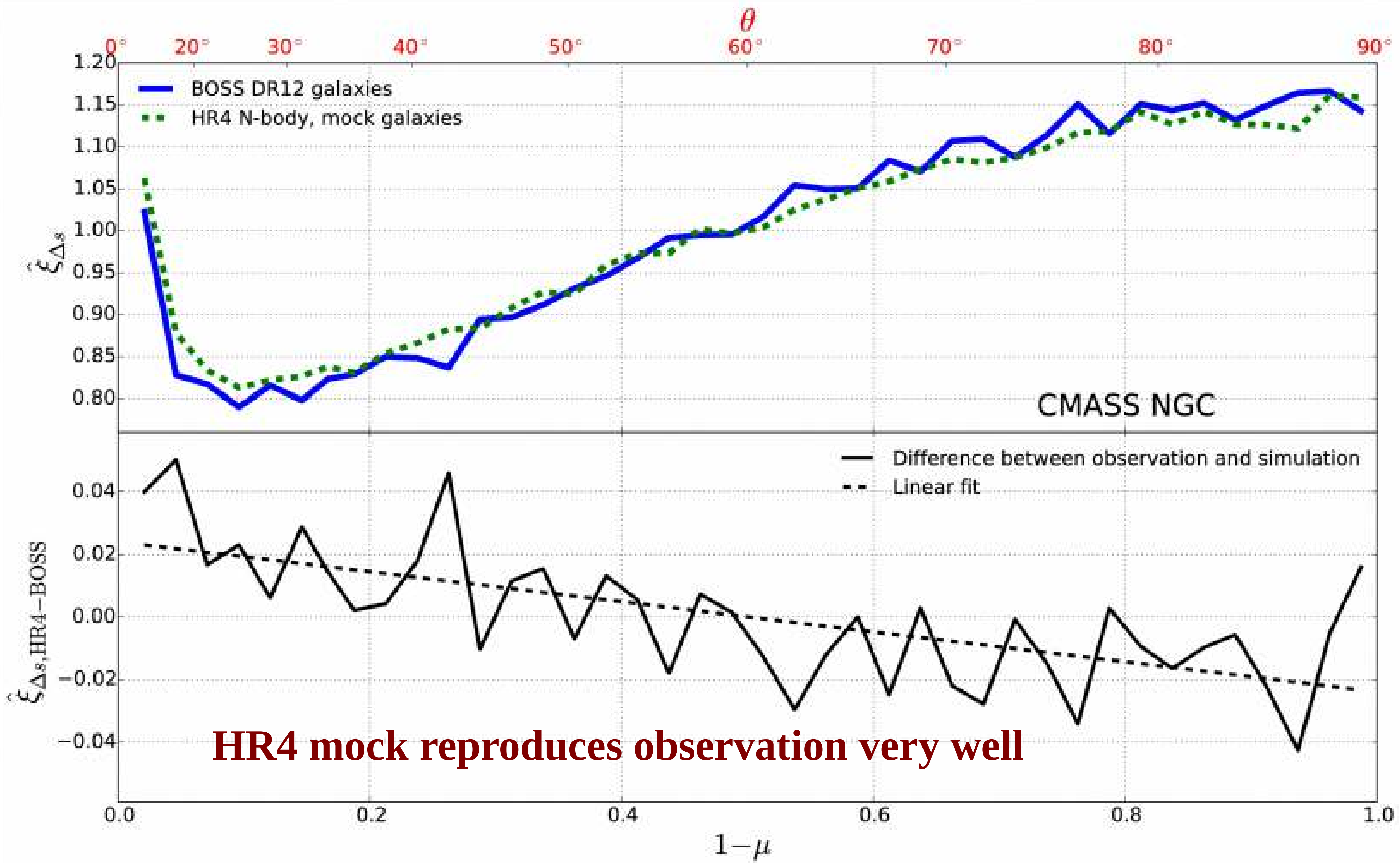
Focus on angular dependence

The redshift evolution of the bias of observed galaxies leads to redshift evolution of the strength of clustering, which is difficult to accurately model. To mitigate this systematic uncertainty we rely on the shape of $\xi_{\Delta s}(\mu)$, rather than its amplitude,

$$\hat{\xi}_{\Delta s}(\mu) \equiv \frac{\xi_{\Delta s}(\mu)}{\int_0^{\mu_{\max}} \xi_{\Delta s}(\mu)\, d\mu}.$$

Normalizing the amplitude; focus on shape [avoid sys from gal bias]

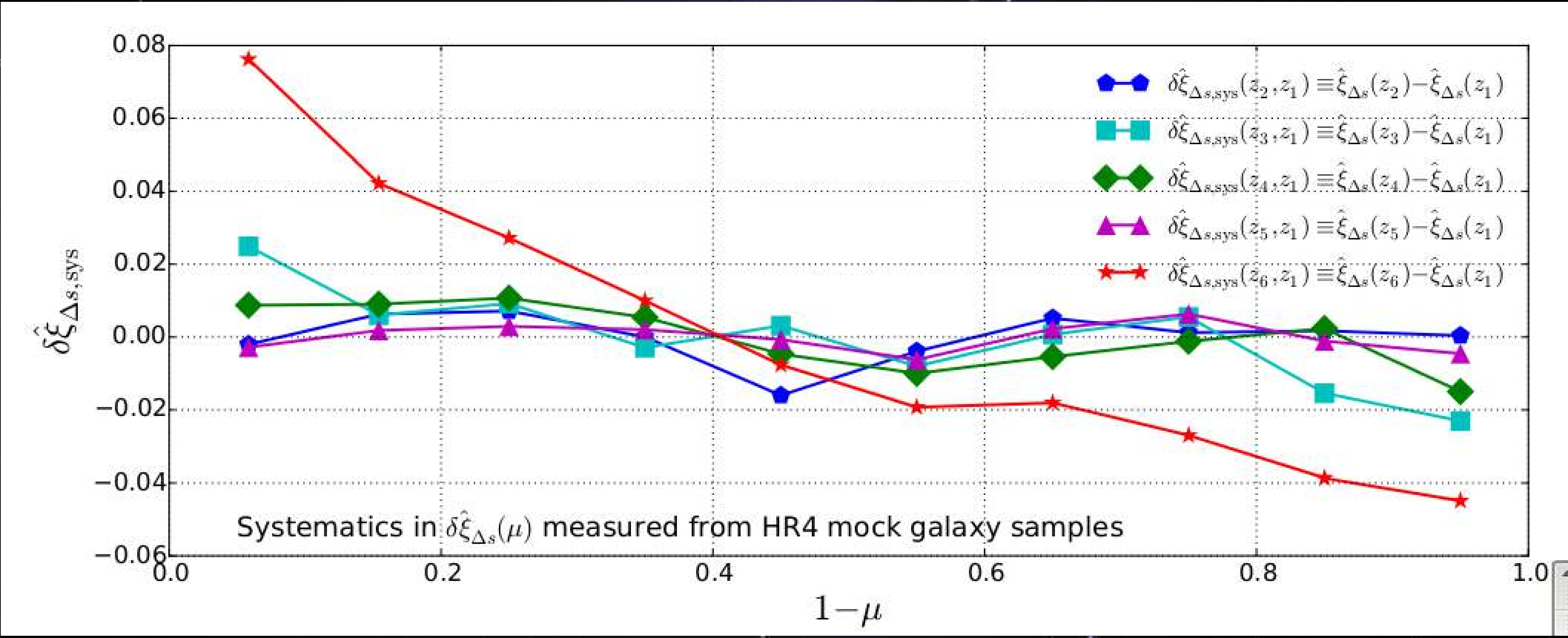
Observation VS Simulation



HR4 mock reproduces observation very well

Estimating systematic

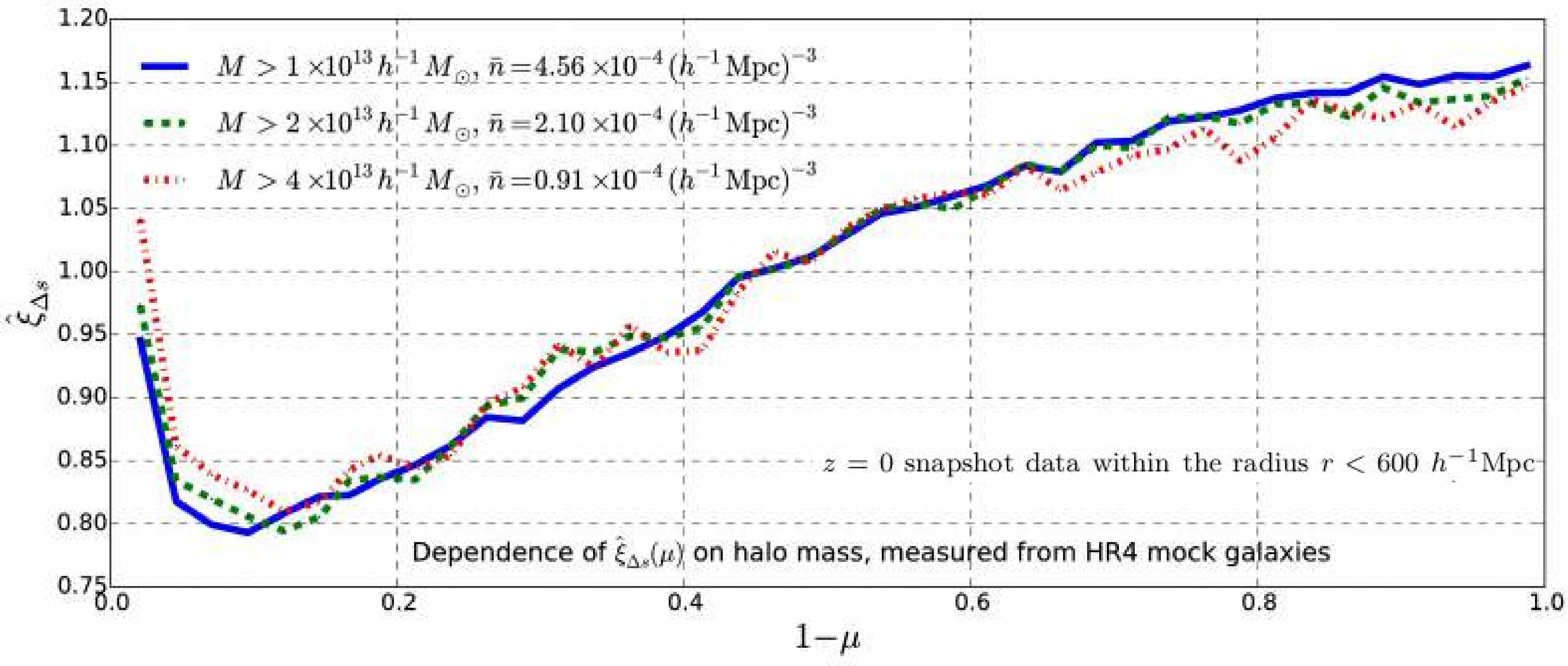
$$\delta\hat{\xi}_{\Delta s}(z_i, z_1, \mu_j) \equiv \hat{\xi}_{\Delta s}(z_i, \mu_j) - \hat{\xi}_{\Delta s}(z_1, \mu_j)$$



Redshift evolution from RSD, and so on

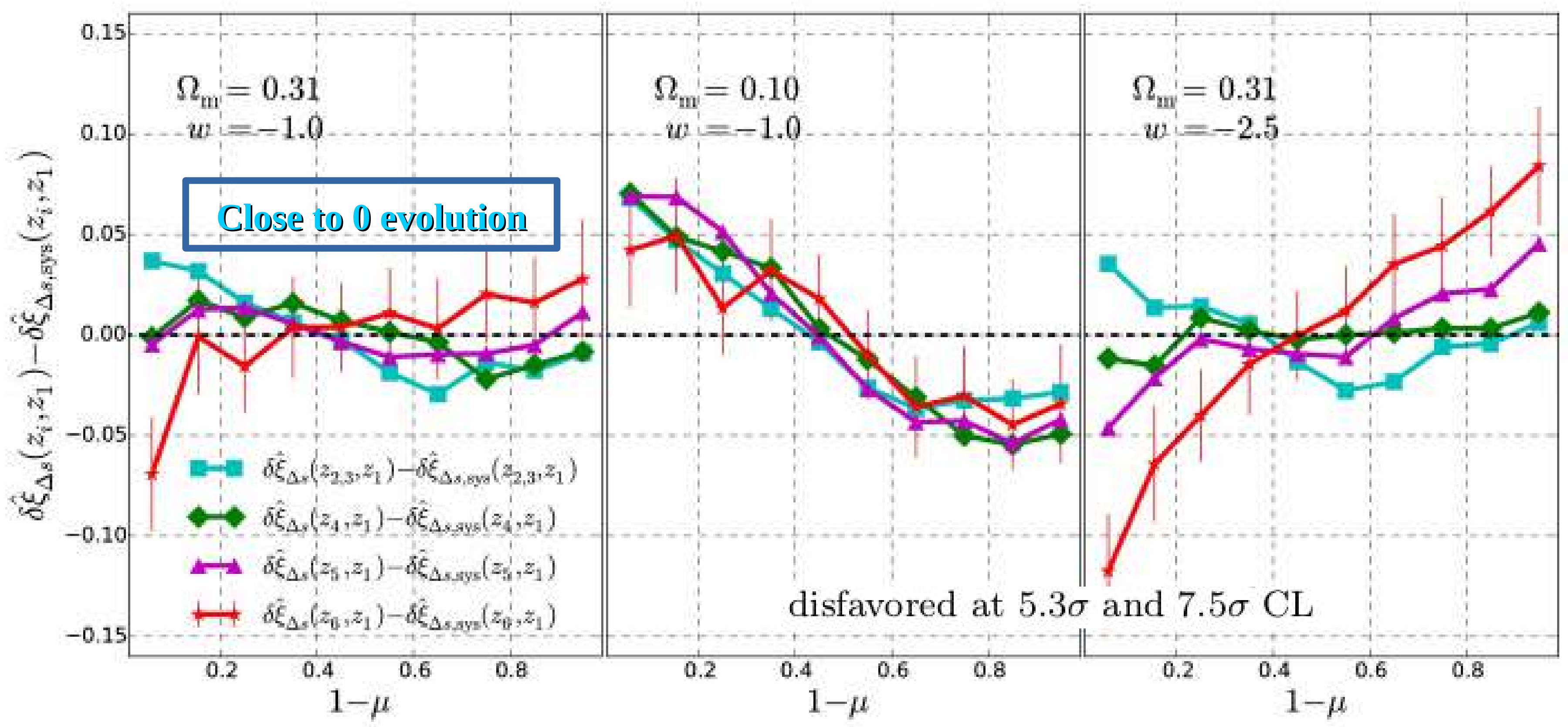
- Small in most redshift bins
- Relative large in the 6th bin but still correctable

Check gal bias



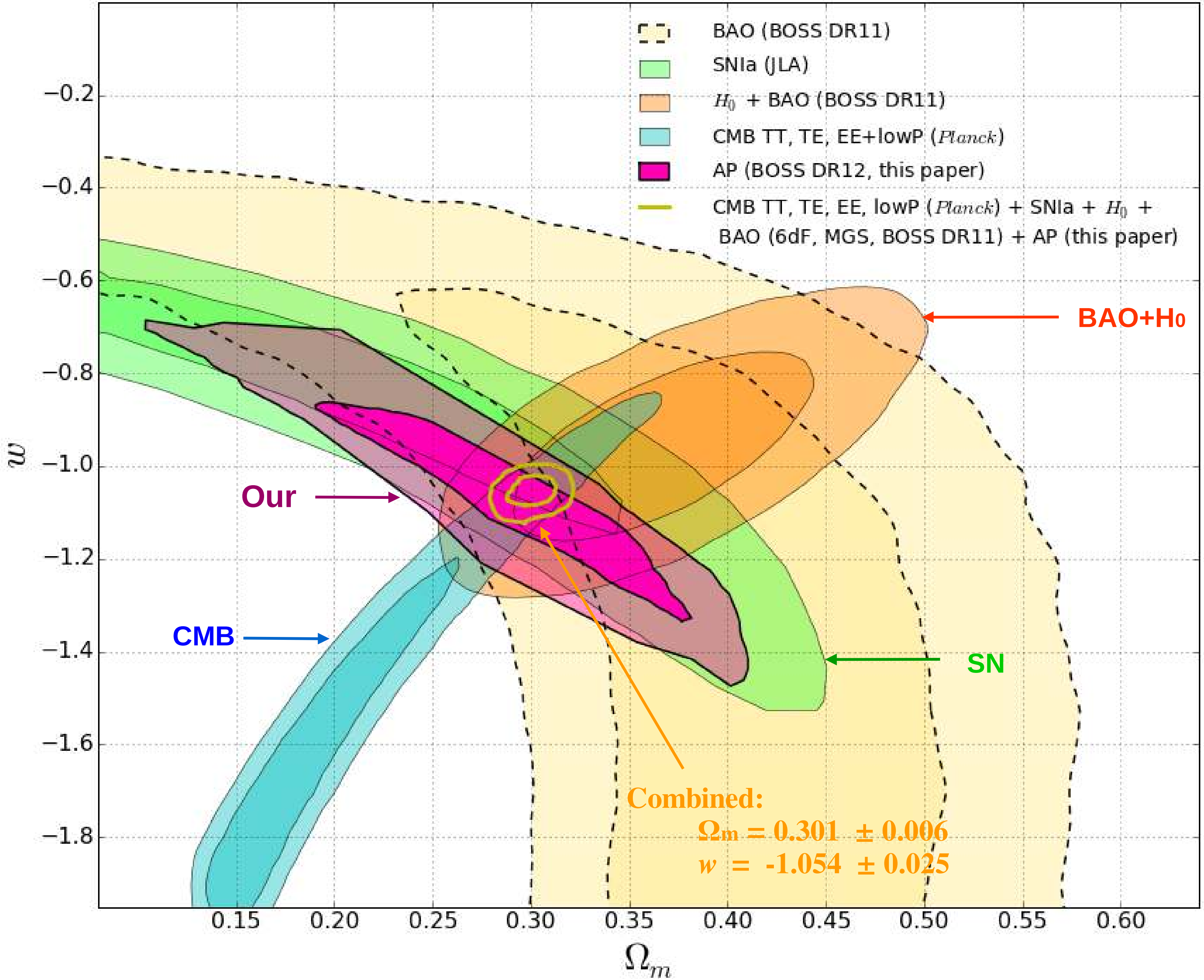
Considering the large variation of *M*, effect not significant

The Redshift Evolution

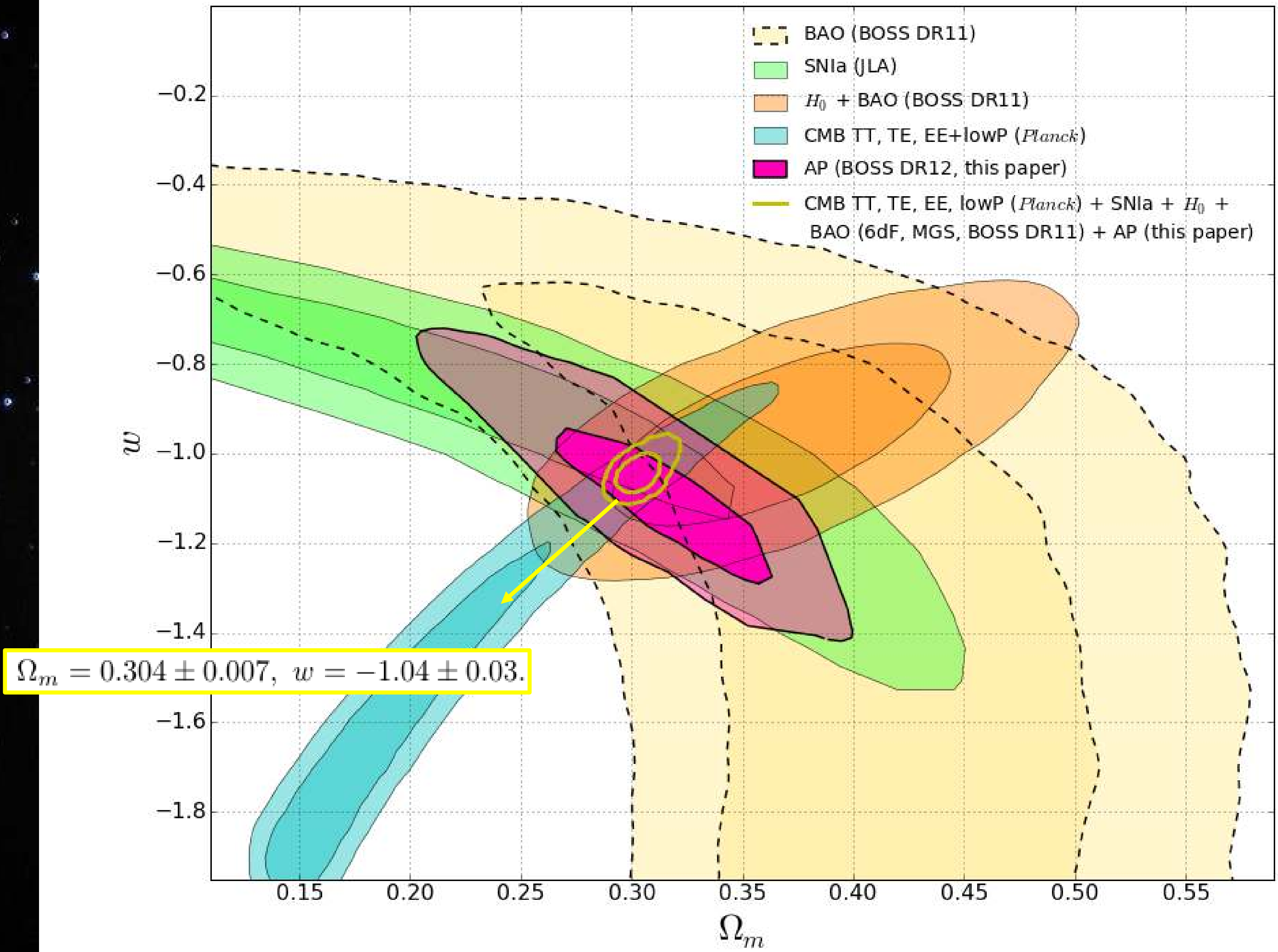


Redshift evolution from AP detected at high CL

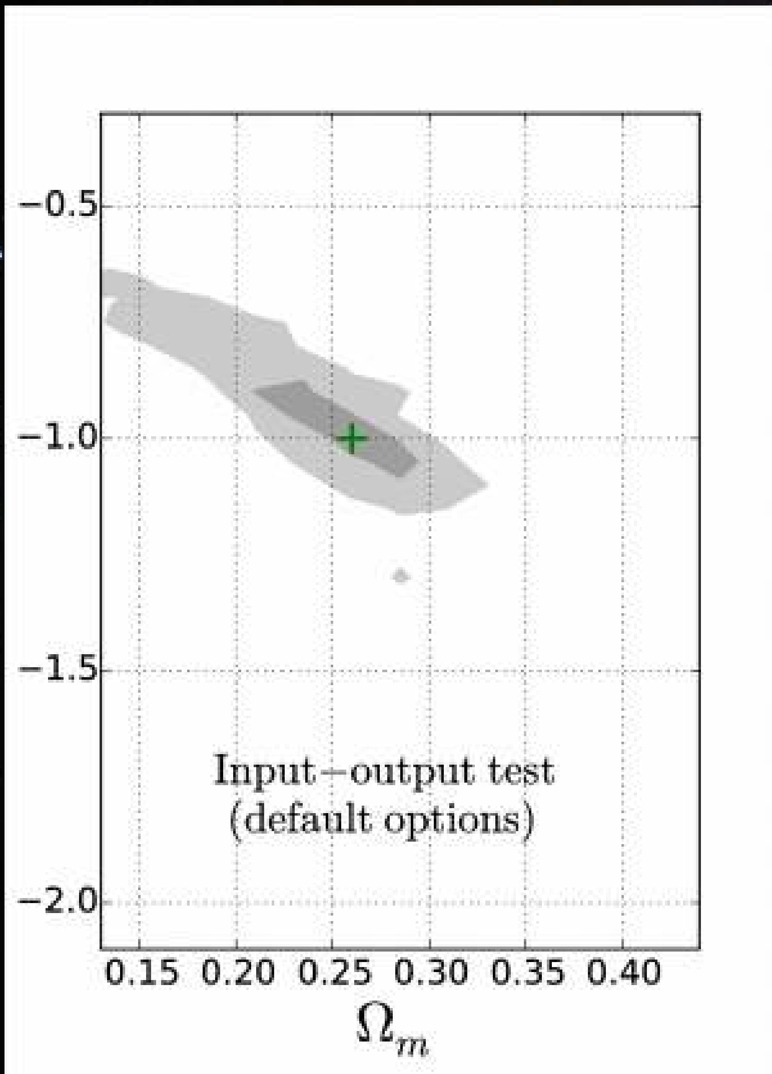
Cosmological constraint

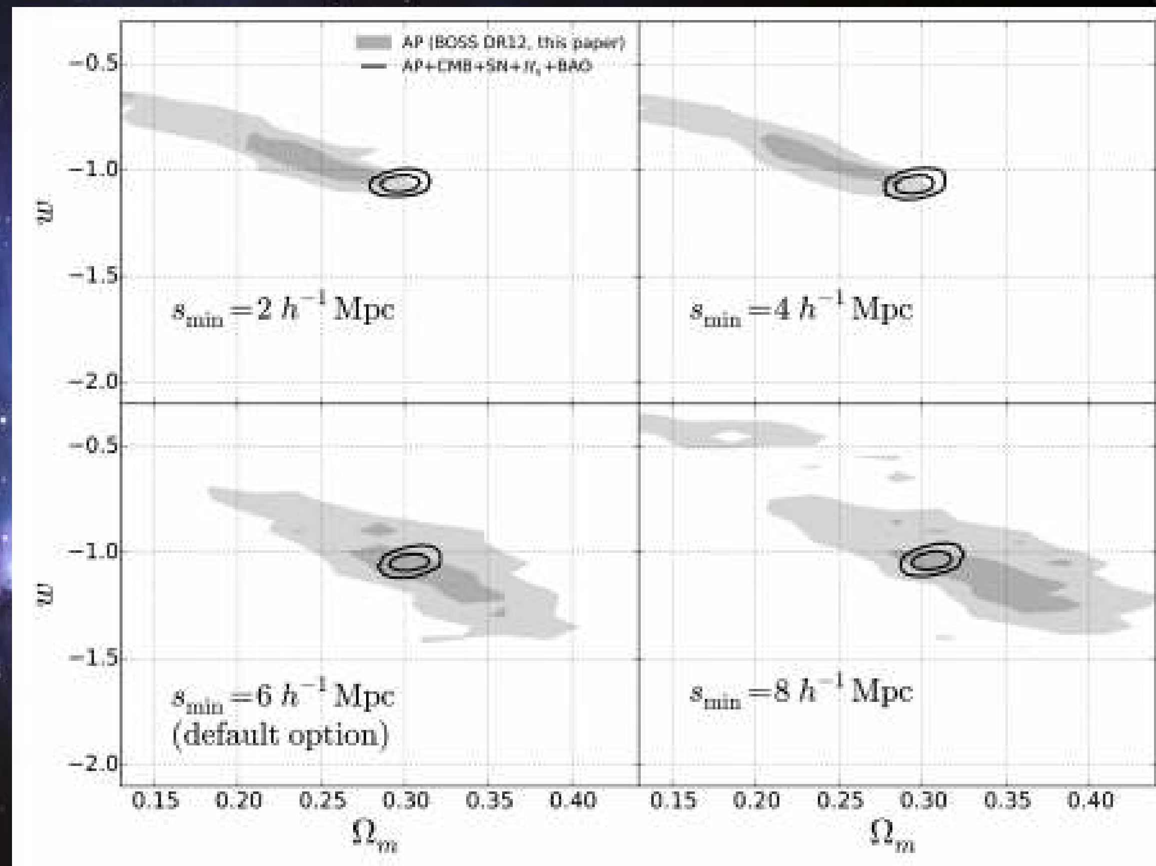


Cosmological constraint (HR3 N-body as Covmat)

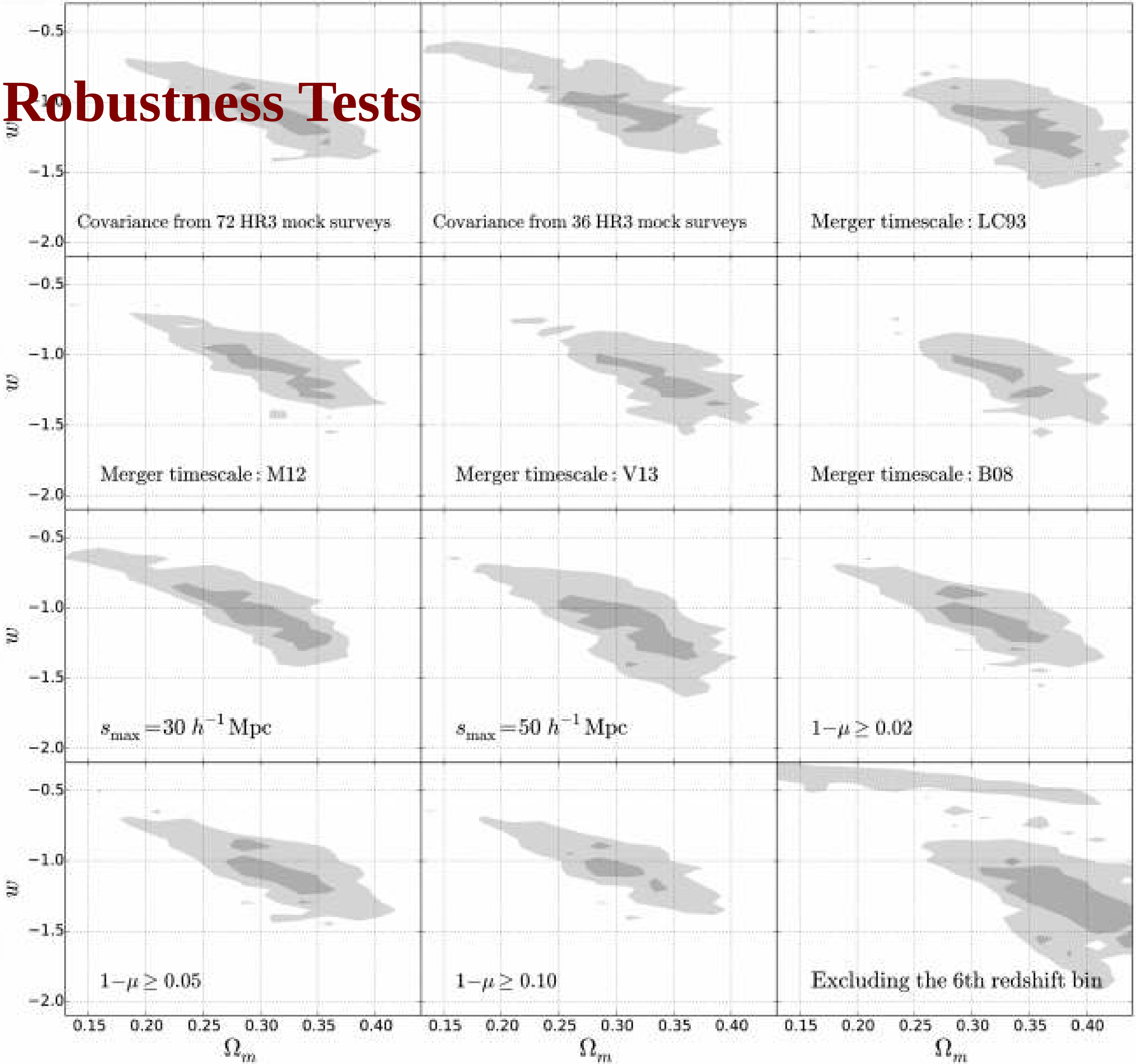


Robustness Tests

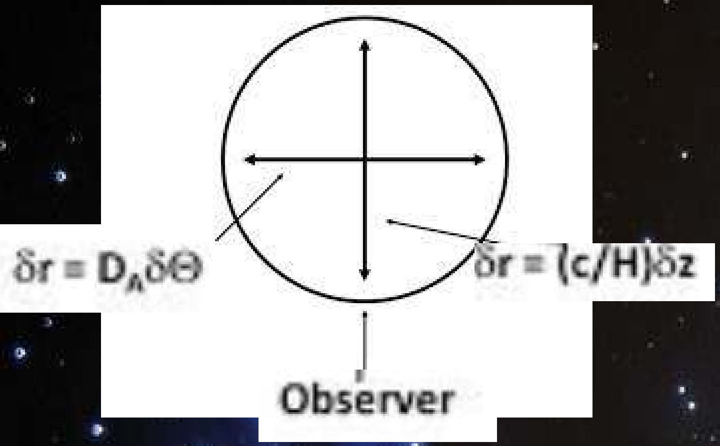




Robustness Tests



Comparing the different probes of geometry



BAO: $D_A(z)/r_d$, $H(z)*r_d$

AP: $D_A*H(z)$

SNIa: $D_L(z)$

Our: $\sim d\, D_A*H(z) / dz$

* Simple idea, successfully overcoming RSD, powerful

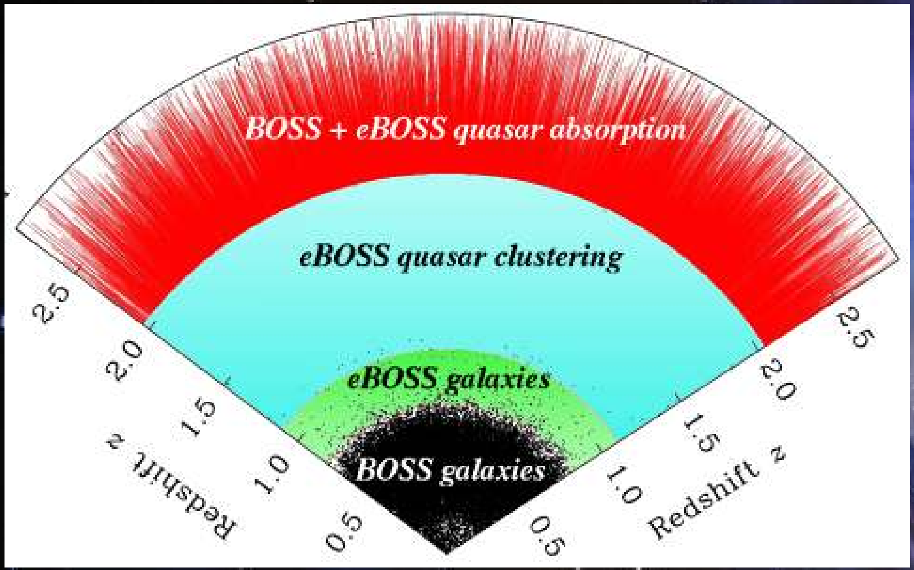
* ~Independent from other techniques (combinable)

* No complicate modeling

* Enter small scales (6 - 40 Mpc/*h*) difficult for most techniques

A lot of information encoded in small-scale clustering!

Promising application to future spectroscopic surveys

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Thank you.