Cosmological Constraints from SDSS-III BOSS: the Alcock-Paczynski Test

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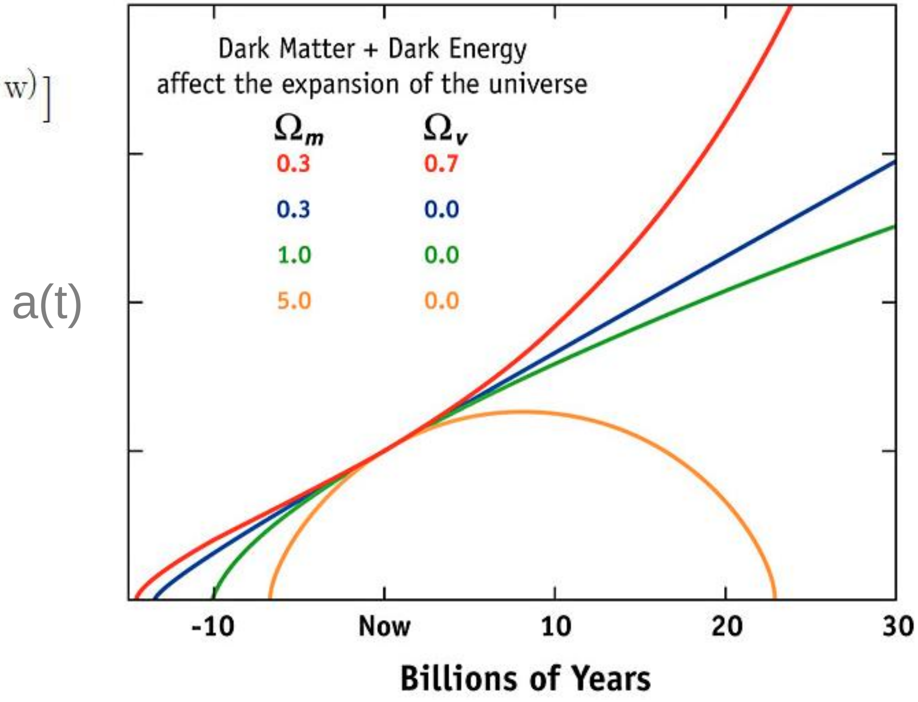
Expansion History of the Universe

Observation: The Universe is expanding (1929), and the expansion has been accelerating recently (1998).

General relativity connects the properties of spacetime with the amount and type of the energy contents in the universe.

$$\left(\frac{\dot{a}}{a}\right)^2 = H_0^2[\Omega_k a^{-2} + \Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_{DE}\ a^{-3(1+w)}]$$

$$r(z) = c\int\frac{dt}{a(t)} = c\int\frac{dz}{H(z)}$$



A Test for the Cosmic Expansion History based on Geometrical Shape of Cosmic Structures

An evolution free test for non-zero cosmological constant

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The cosmological constant has recently been questioned because of difficulties in fitting the standard $\Lambda = 0$ cosmological models to observational data[1,2]. We propose here a cosmological test that is a sensitive estimator of Λ. This test is unusual in that it involves no correction for evolutionary effects. We present here the idealised conception of the method, and hint at the statistical problem that its realisation entails.

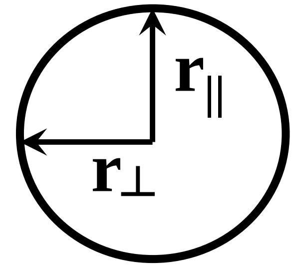
(Alcock & Paczynski, 1979, Nature, 281, 358)

Cosmological effects on the observed geometrical shape of cosmic structures

Comoving sizes

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

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



$$\frac{r_{\|}}{r_{\perp}} = \frac{c\Delta z}{(1+z)\Delta\theta \cdot H(z) D_A(z)}$$

where $D_A(z) = \frac{c}{1+z}\int_0^z \frac{dz}{H(z)}$ (flat universe)

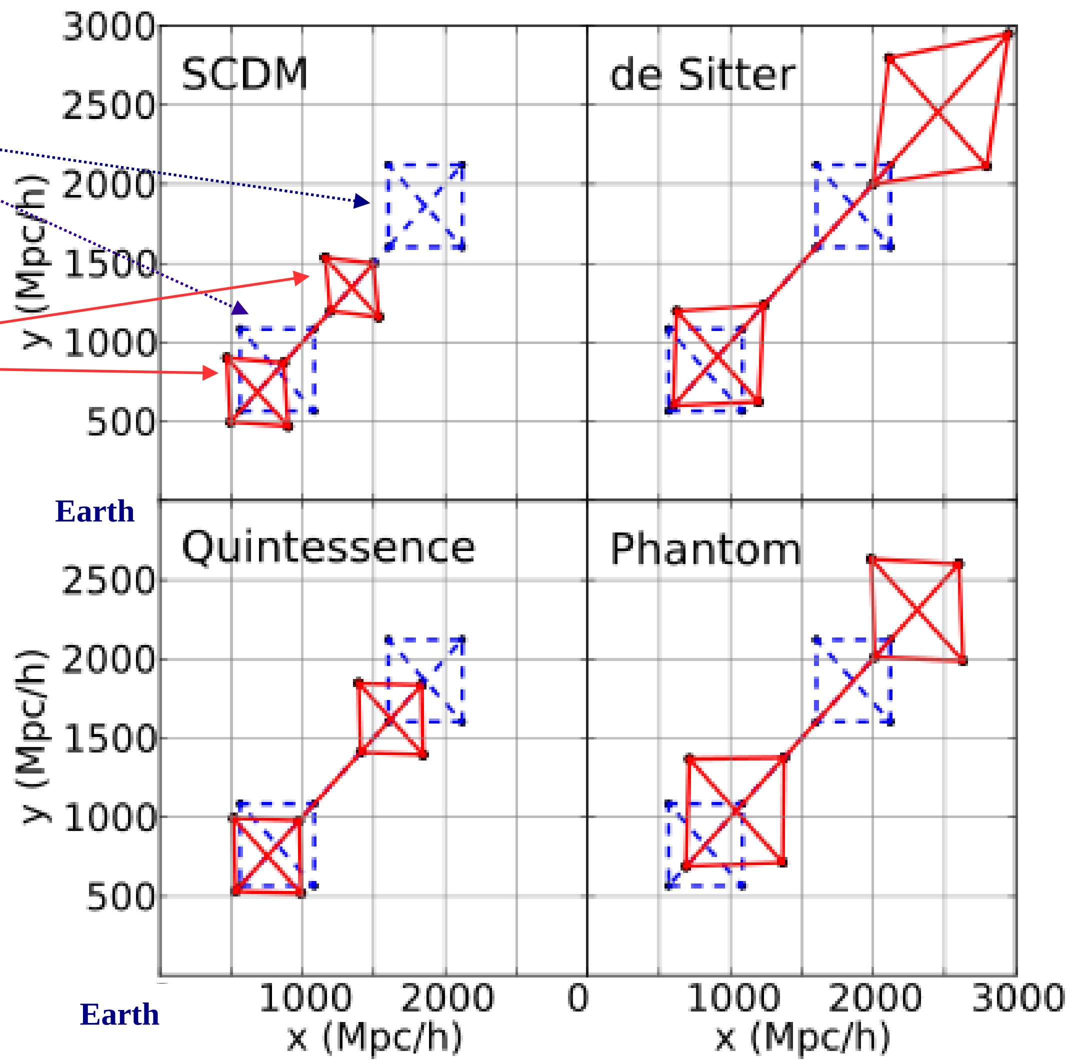
$$H(z) = H_0[\Omega_m (1+z)^3 + \Omega_X \exp(3\int_0^z \frac{1+w(z)}{1+z})dz]$$

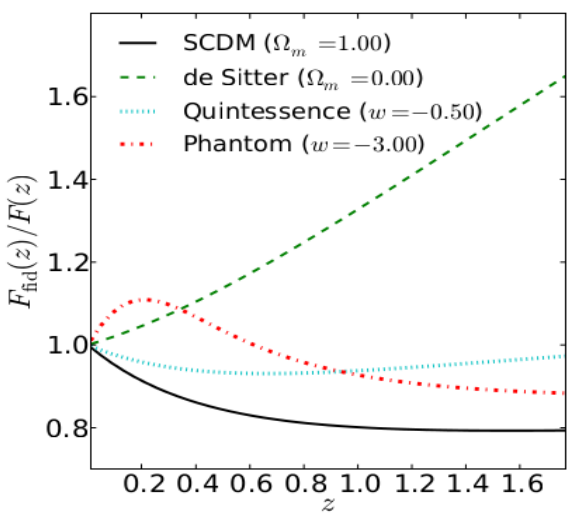
Shape of structures in the comoving space

in true (Ω_m=0.26 ΛCDM) and wrong cosmologies

Real Shape

Apparent Shape

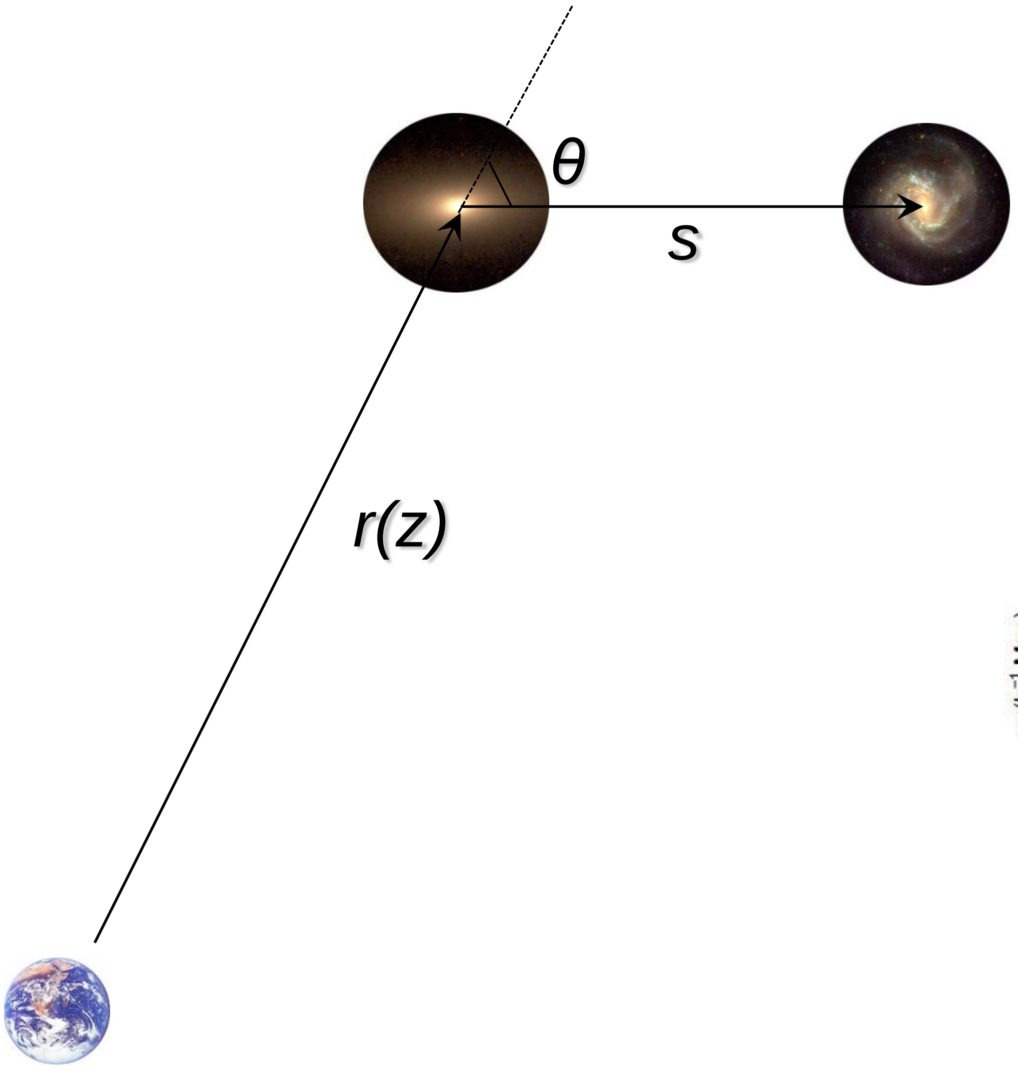


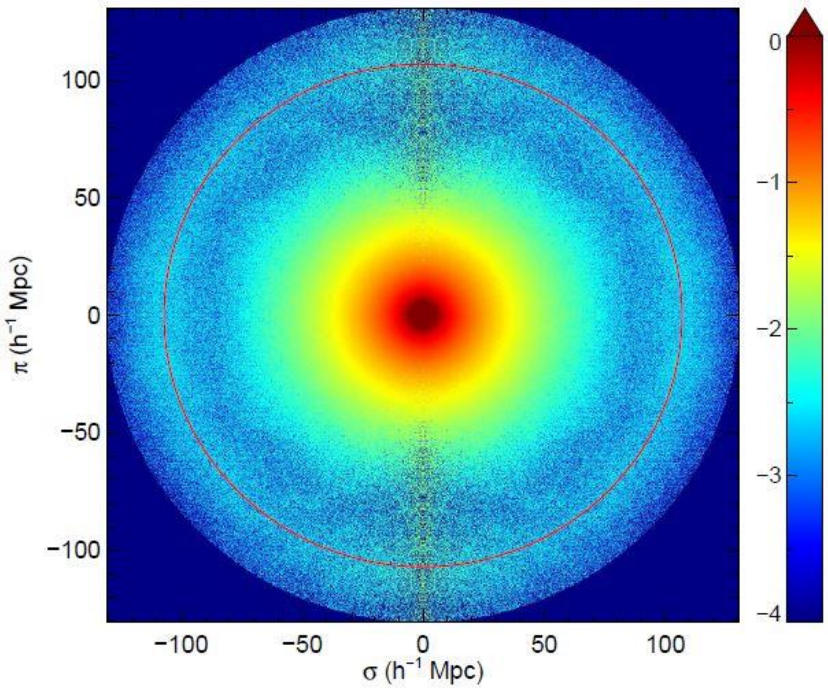


What can we use for the geometry test?

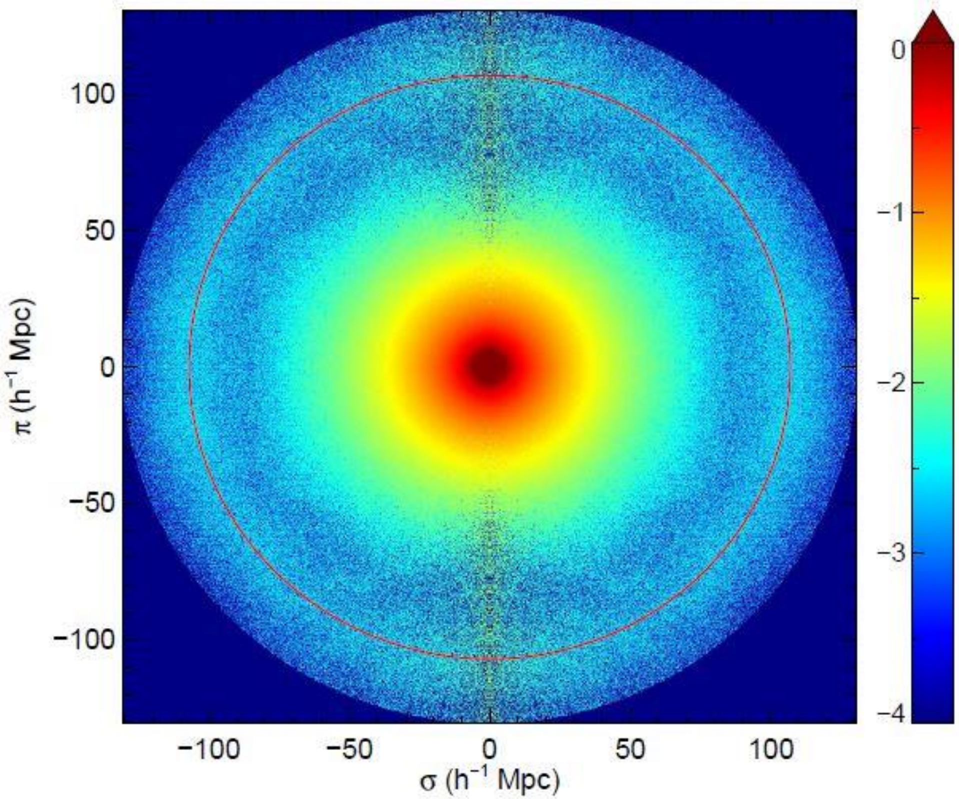
Clustering of Galaxies/Quasars!

2pCF as a measure of clustering anisotropy $\xi(s, \mu)$

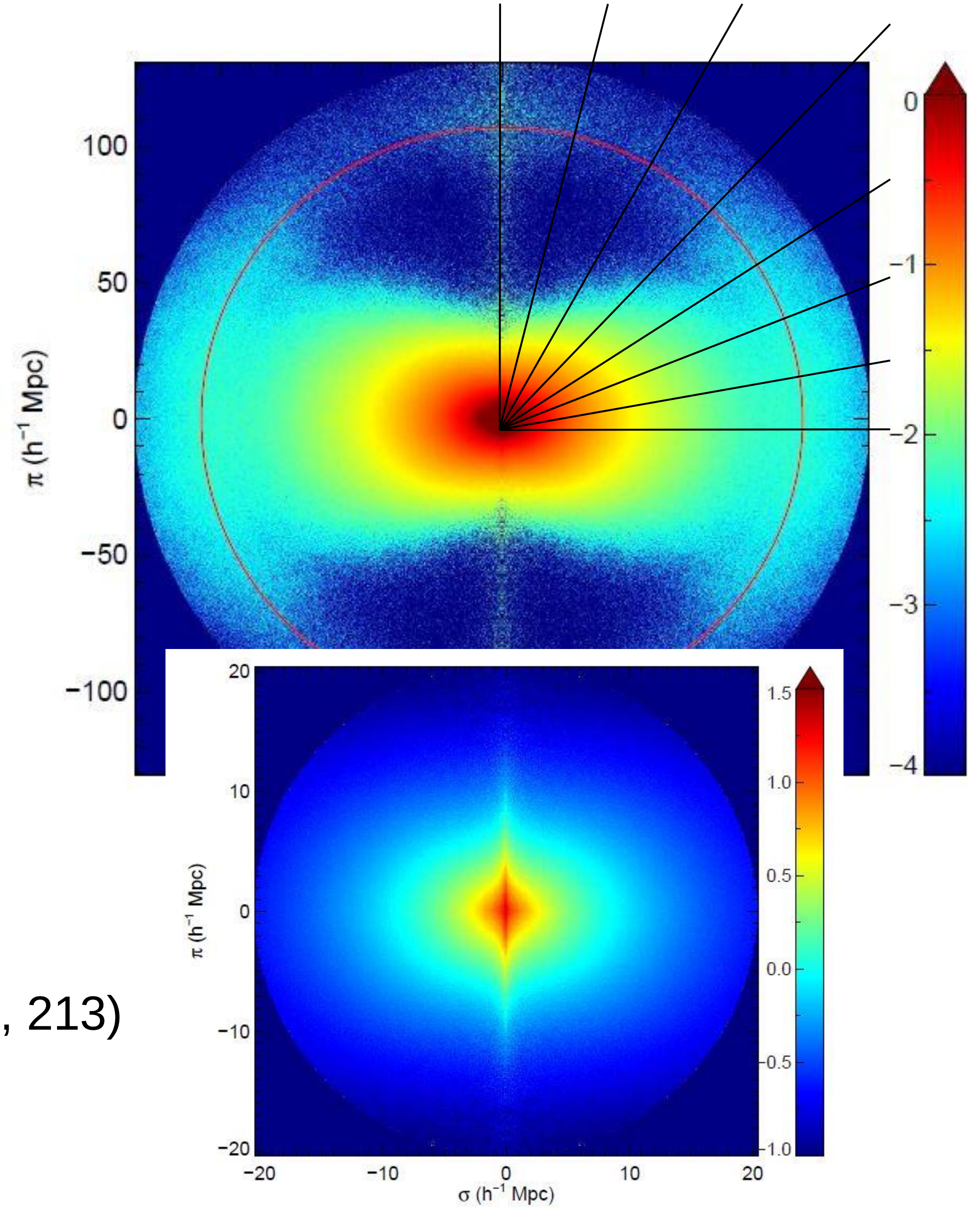




Redshift-space distortion effects
on 2-point correlation function along (π) & across (σ) LOS

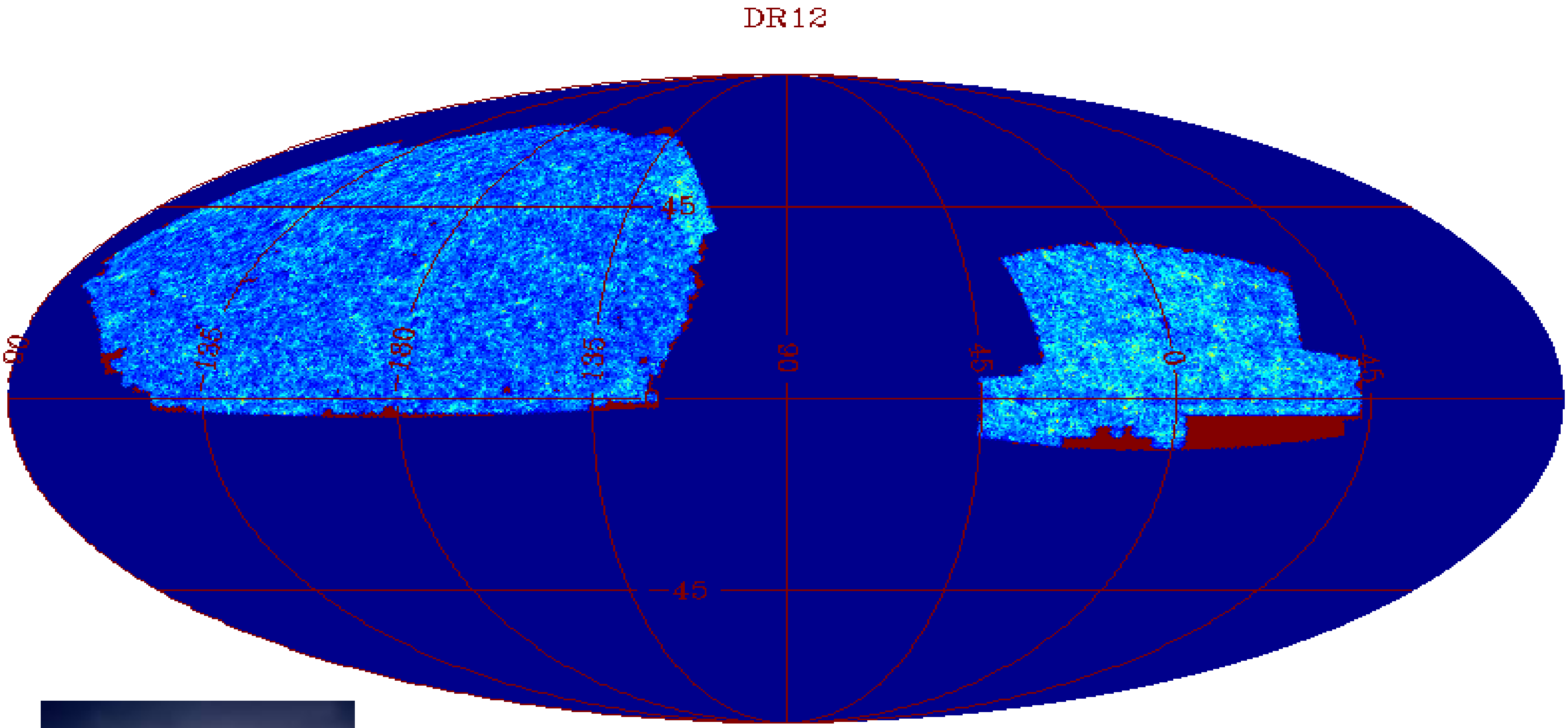


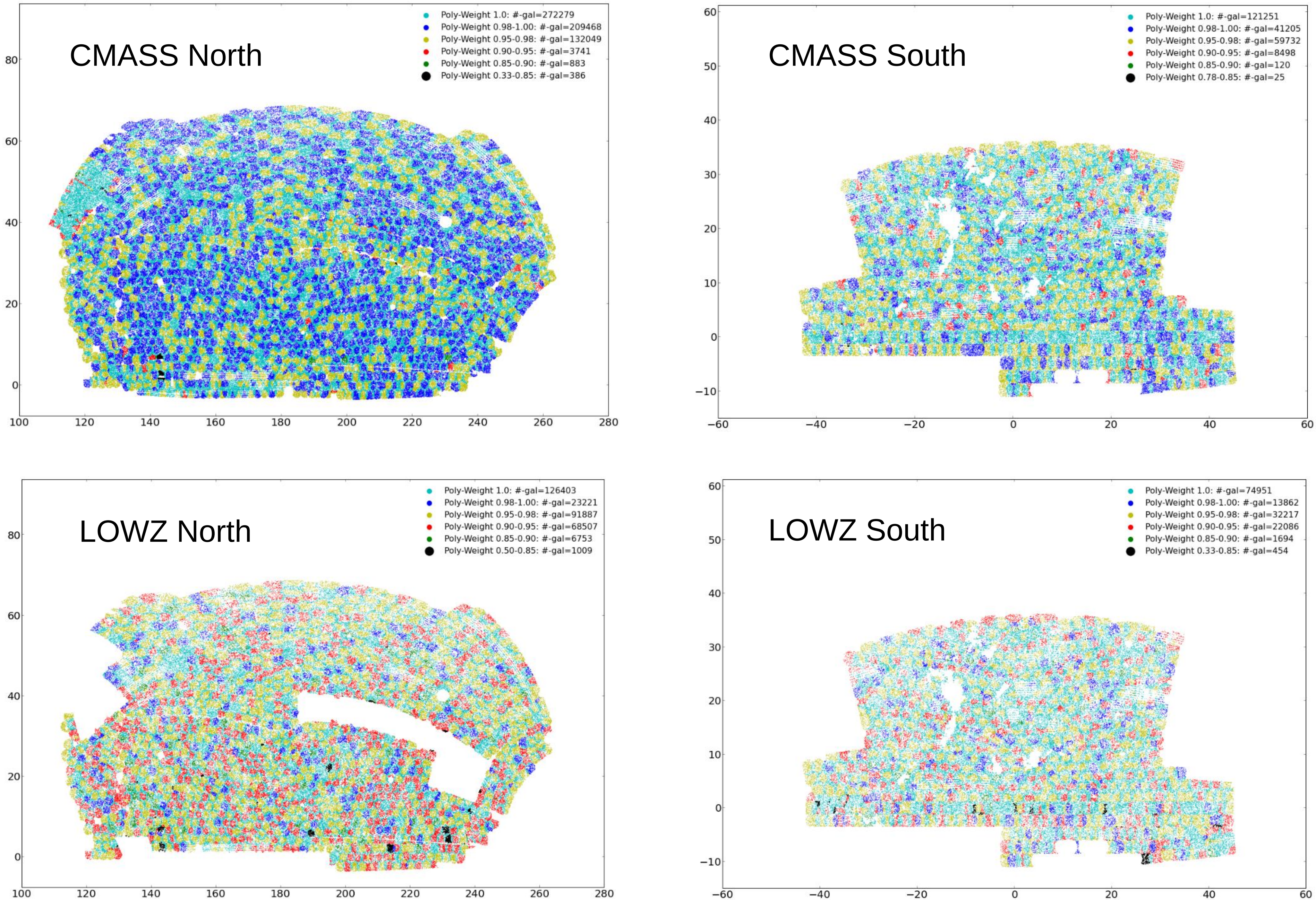
(a) real space



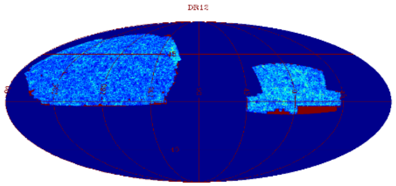
Horizon-Run 4 (Kim et al. 2015, JKAS, 48, 213)
CF of PSB dark matter halos

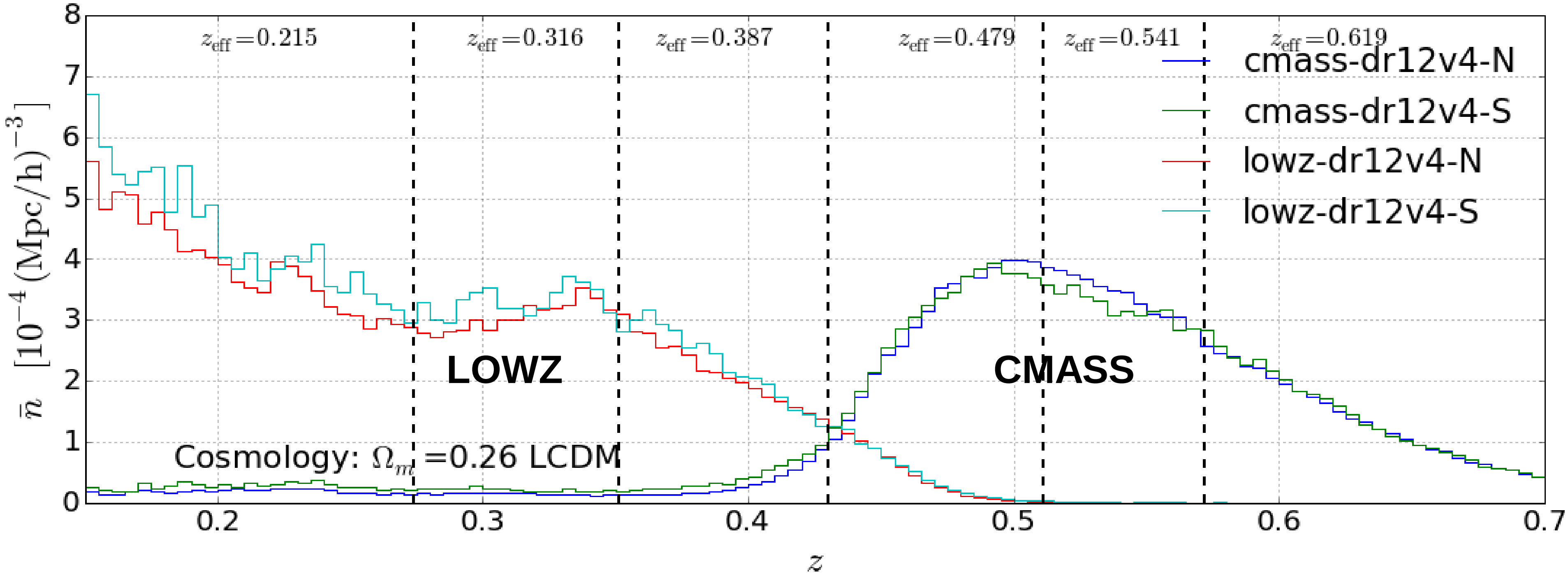
Application to BOSS DR12 Samples




CMASS North
Poly-Weight 1.0: #-gal=272279
Poly-Weight 0.98-1.00: #-gal=209468
Poly-Weight 0.95-0.98: #-gal=132049
Poly-Weight 0.90-0.95: #-gal=3741
Poly-Weight 0.85-0.90: #-gal=883
Poly-Weight 0.33-0.85: #-gal=386
CMASS South
Poly-Weight 1.0: #-gal=121251
Poly-Weight 0.98-1.00: #-gal=41205
Poly-Weight 0.95-0.98: #-gal=59732
Poly-Weight 0.90-0.95: #-gal=8498
Poly-Weight 0.85-0.90: #-gal=120
Poly-Weight 0.78-0.85: #-gal=25
LOWZ North
Poly-Weight 1.0: #-gal=126403
Poly-Weight 0.98-1.00: #-gal=23221
Poly-Weight 0.95-0.98: #-gal=91887
Poly-Weight 0.90-0.95: #-gal=68507
Poly-Weight 0.85-0.90: #-gal=6753
Poly-Weight 0.50-0.85: #-gal=1009
LOWZ South
Poly-Weight 1.0: #-gal=74951
Poly-Weight 0.98-1.00: #-gal=13862
Poly-Weight 0.95-0.98: #-gal=32217
Poly-Weight 0.90-0.95: #-gal=22086
Poly-Weight 0.85-0.90: #-gal=1694
Poly-Weight 0.33-0.85: #-gal=454

Methodology





0. Split each of CMASS & LOWZ samples into 3 redshift bins

1. Adopt a r(z) relation by choosing a cosmology

2. Measure ξ(s, μ) in each z-bin;

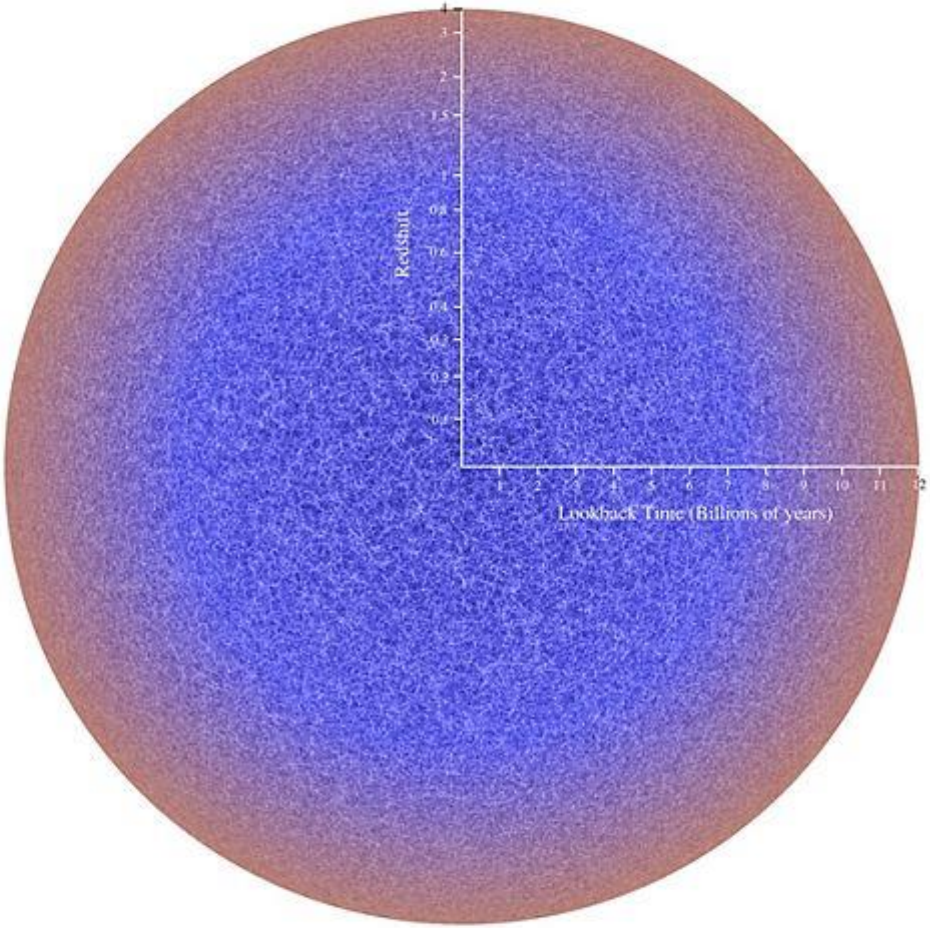
3. Quantify the redshift evolution of ξ(s, μ) by a chisq value

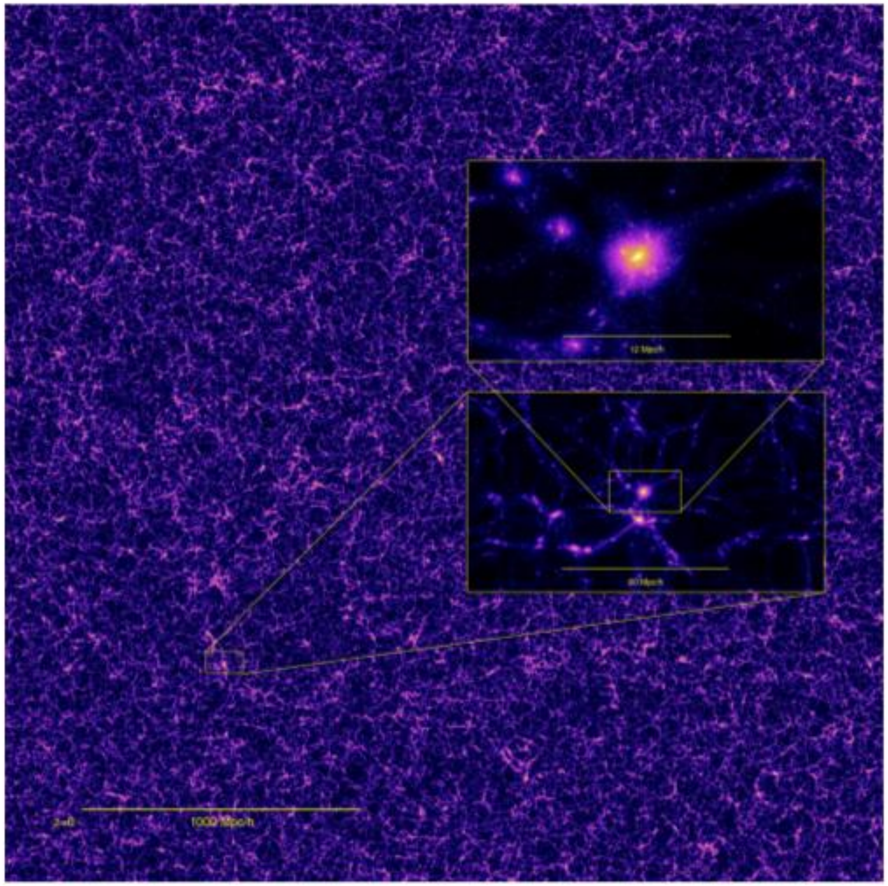
(Wrong Cos. → Large redshift evolution → Large chisq → Disfavored)

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

Systematic Correction (intrinsic redshift evolution): HR4 mock galaxy samples

Covariance Matrix: HR3 PSB subhalo samples





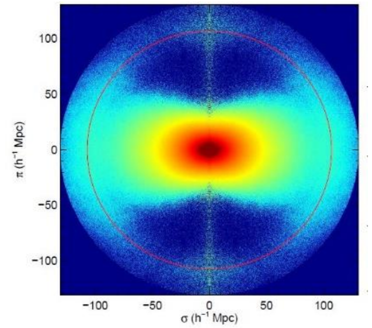
Horizon Run 3 (Kim et al. 2012)
V=(10.815 h^{-1} Gpc)^3 , 7120^3 particles
WMAP5 Cosmology

PSB halos in 27 whole-sky lightcones

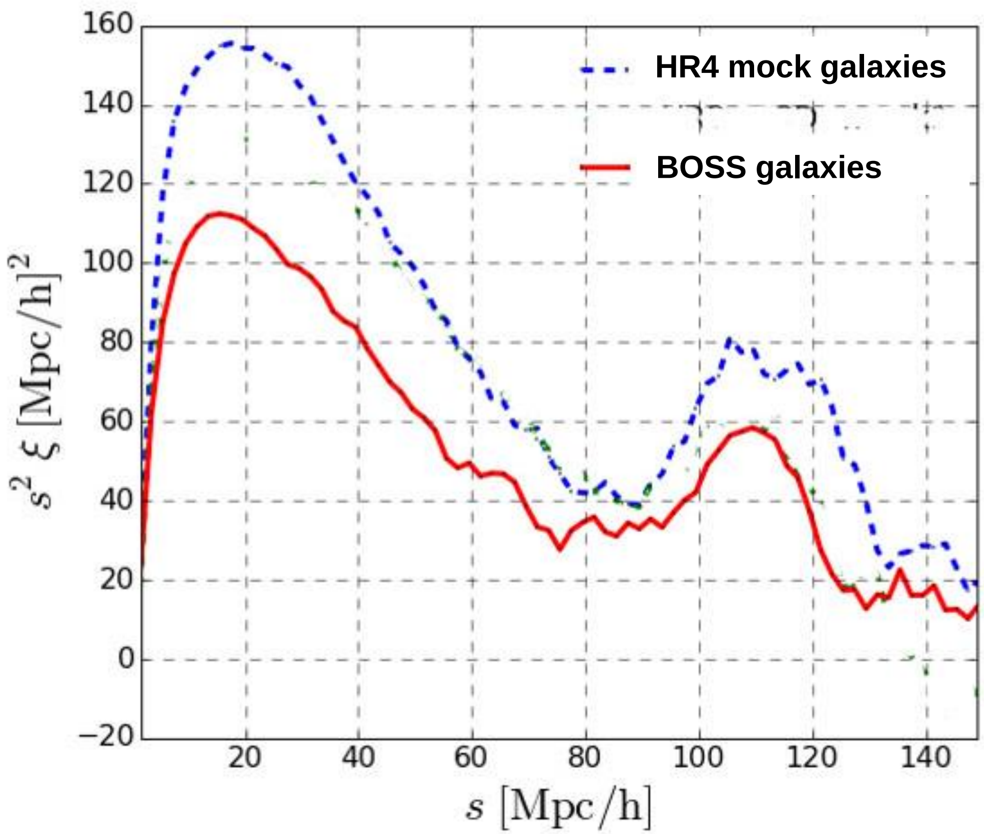
Horizon Run 4 (Kim et al. 2015)
V= (3.15h^{-1} Gpc)^3 , 6300^3 particles
WMAP5 Cosmology

Mock ‘galaxies’ in 1 whole-sky lightcone
(Hong et al. 2015)

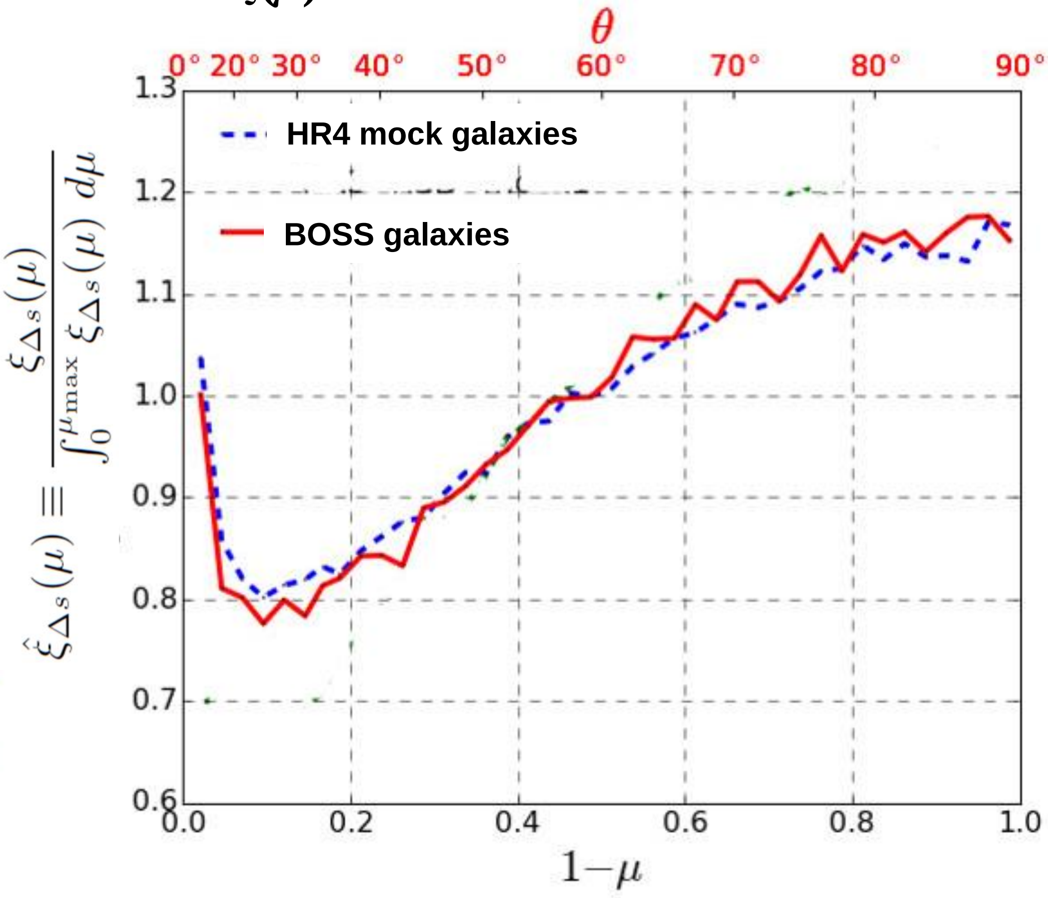
2pCF from SDSS BOSS data
and simulated mock samples



ξ(s)



$\xi(\mu)$



Constraints on cosmological parameters

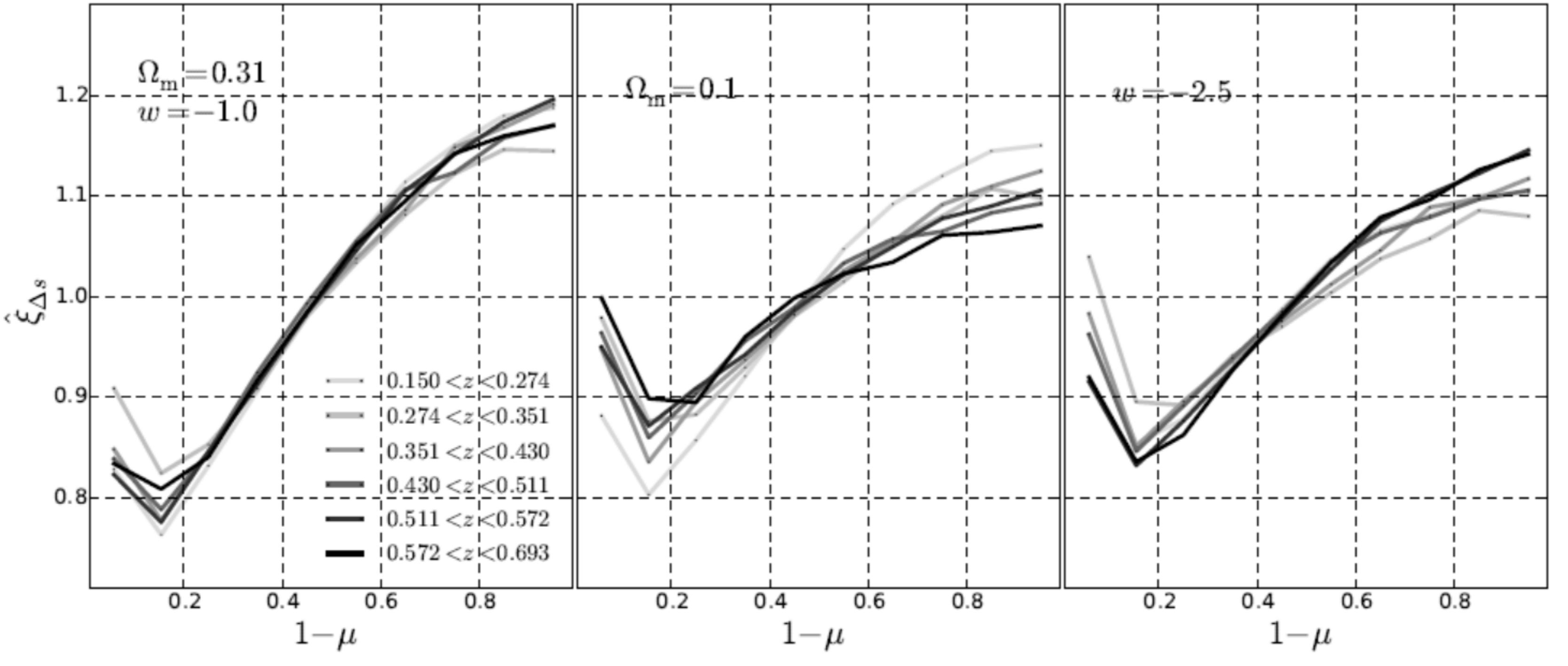
Chisq = Σ $\delta\xi$ *** Cov**$^{-1}$ ***** $\delta\xi$: summation over redshift bins and direction bins

$\delta\xi$ = *ξ(first z-bin) – ξ(other z-bins)* : a measure of redshift evolution

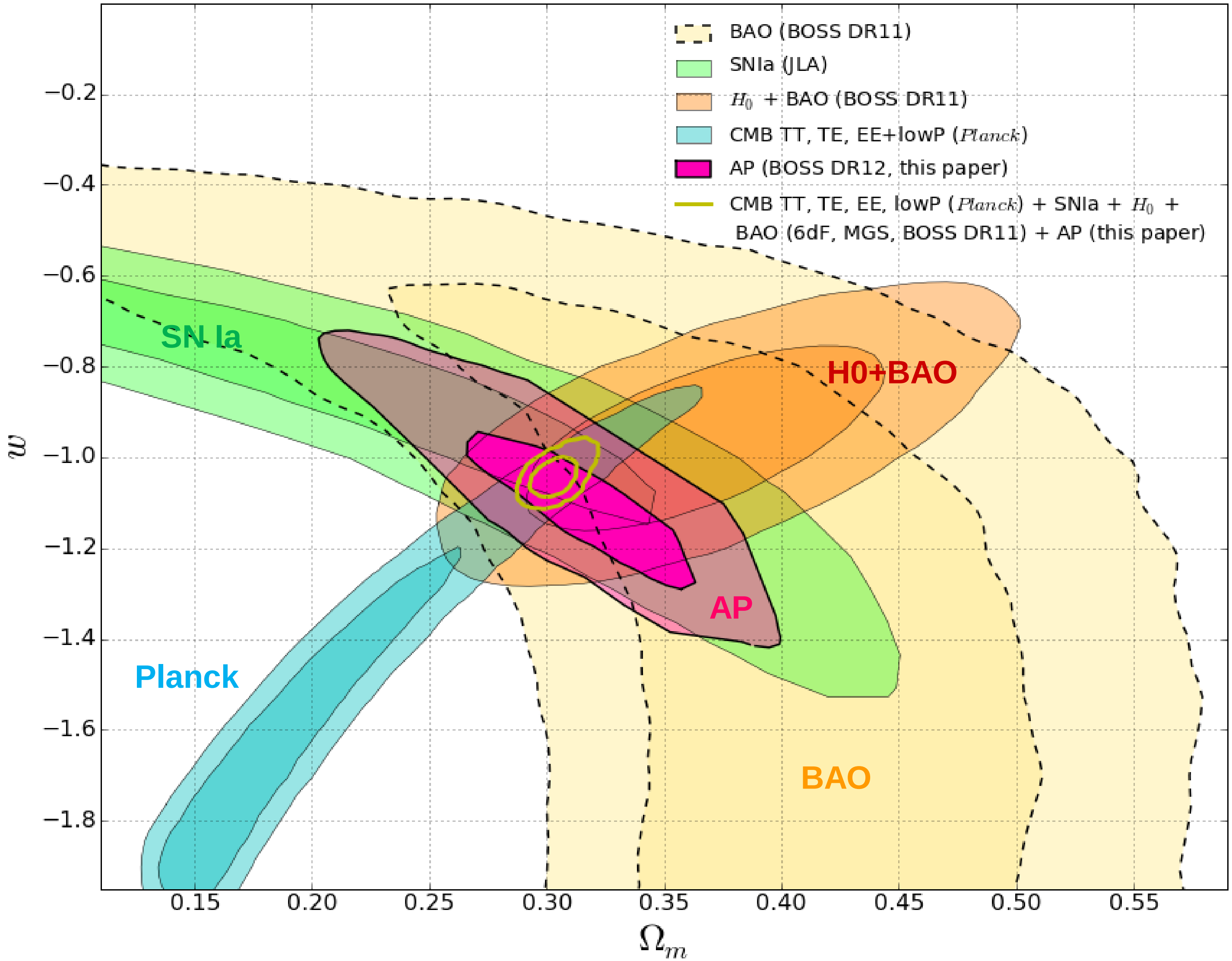
Systematics: $\delta\xi \rightarrow \delta\xi$ *– (sys. est. from HR4)*

Covariance between different bins: HR3 mock surveys

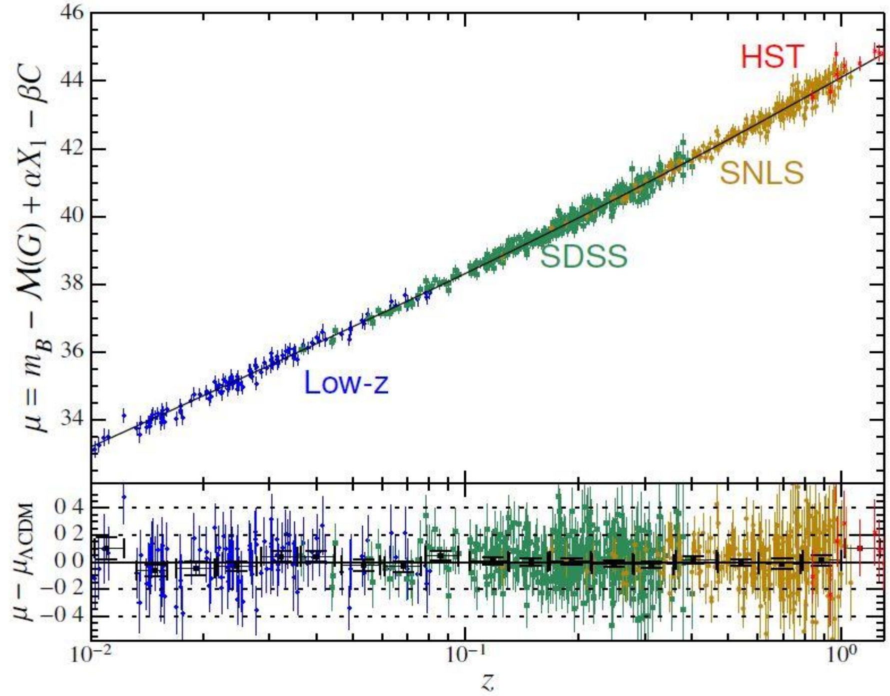
Likelihood = Exp(**-Chisq** / 2.0)

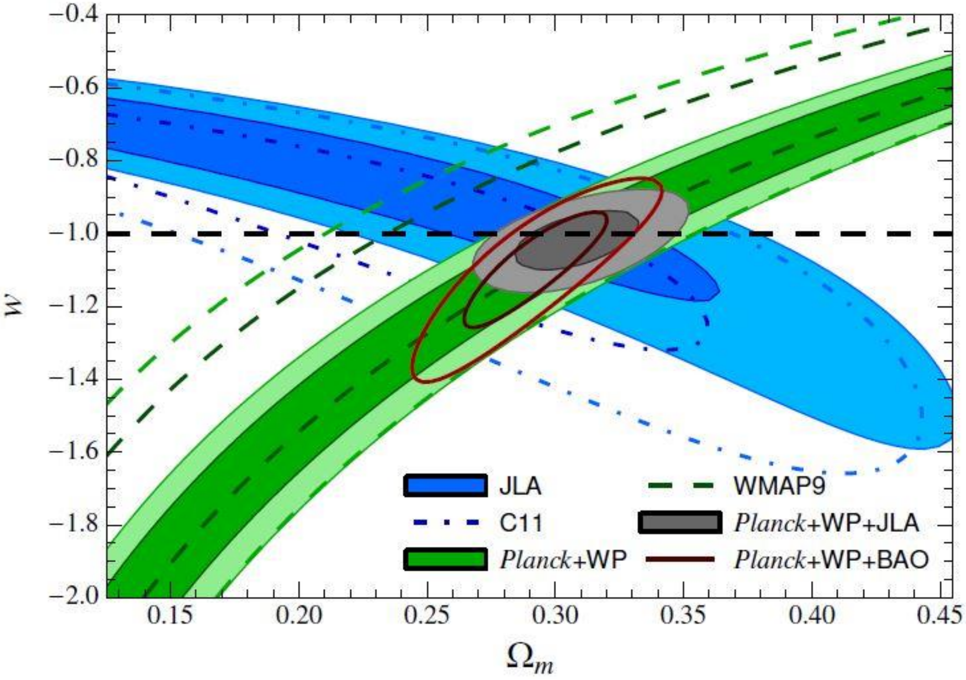


Constraints on cosmological parameters



JLA SN Ia (Betoule+ 2014); BOSS DR11 BAO (Anderson+ 2013); HST H0 (Efstathiou+(2014)
Planck CMB (Ade+ 2015): BOSS DR12 AP (this work)





Betoule et al. 2014

Joint analysis of the combined SN samples

Summary

We propose to use the redshift dependence of galaxy clustering anisotropy to constrain a(t) or r(z), which constrains $D_A*H(z)$ or Ω_m and dark energy eq. of state.

The method requires very small corrections for the RSD effects.

The constraints on Ω_m-w by the AP test are as strong as other methods (because of high statistics). Complementarity!

(AP → $D_A*H(z)$; SN Ia → $D_L(z)$; BAO → $D_A(z)/r_S$ & $H(z)/r_S$)

$\Omega_m = 0.314 \pm 0.038, \quad w = -1.09 \pm 0.14$ ← AP alone

$\Omega_m = 0.304 \pm 0.007, \; w = -1.04 \pm 0.03$ ← combined with other methods

The method applies not just to 2pCF, but can be used in combination with any clustering statistics (ex. the genus statistic Park & Kim 2010; density gradient vector Li et al. 2014; higher order moments).