Redshift Space Distortions in Photometric Galaxy Surveys

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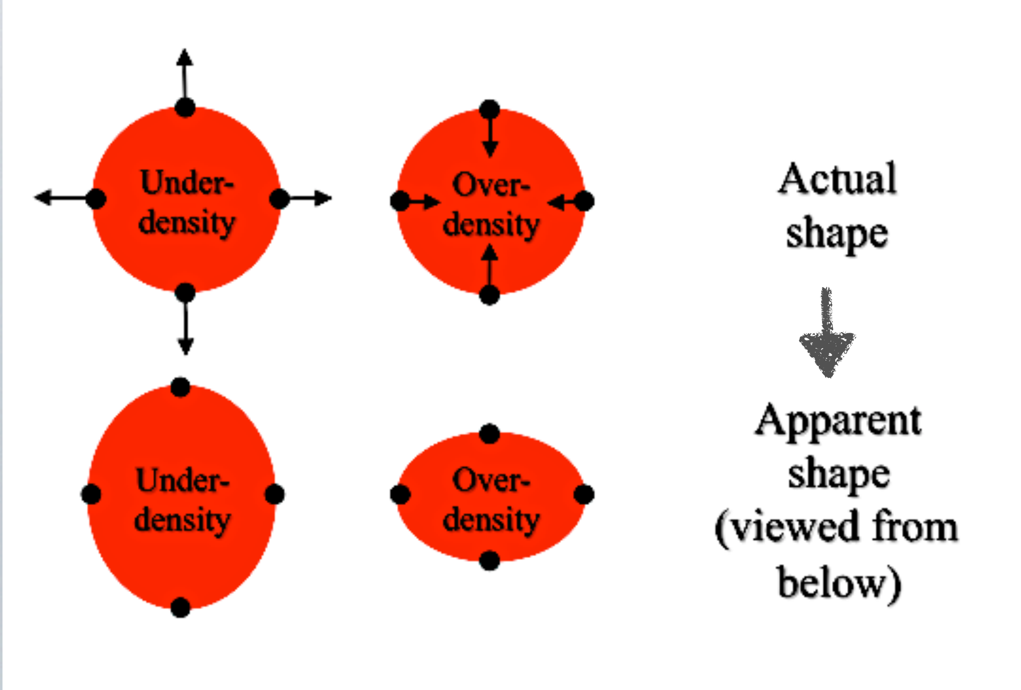
"cosmic acceleration" tests in LSS : Red-shift Space Distortions

Galaxy red-shifts are due not only to expansion but also to peculiar velocities. Hence derived "red-shift space" (s) positions are different from "true" (r) ones.



$$\delta^s_{gal}(k,\mu) = \underbrace{b\,\delta_{mass}(k)}_{\delta^r_{gal}} + \mu^2 \underbrace{\theta_{mass}(k)}_{\theta_{gal}}$$

$$\theta = -\nabla \cdot \mathbf{v}/\mathcal{H}$$

$$\frac{\partial \delta}{\partial \tau} + \nabla \cdot \mathbf{v} = 0$$

$$\theta_{mass} = f(z)\delta_{mass}$$

$$\delta^s(k,\mu) = (b + \mu^2 f)\delta_{mass}$$

$$D(z) = \delta(z)/\delta(z=0)$$

$$f(z) = \frac{\partial \ln D(z)}{\partial \ln a}$$

Anisotropic pattern

Red-shift Space Distortions

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

By measuring the (anisotropic) distribution of galaxy pairs in red-shift space we can constrain the growth of structure

We measure the normalization of the galaxy over-density field ($b\sigma_8$) and the galaxy velocity field ($f\sigma_8$)

Cabre & Gaztañaga (2009)

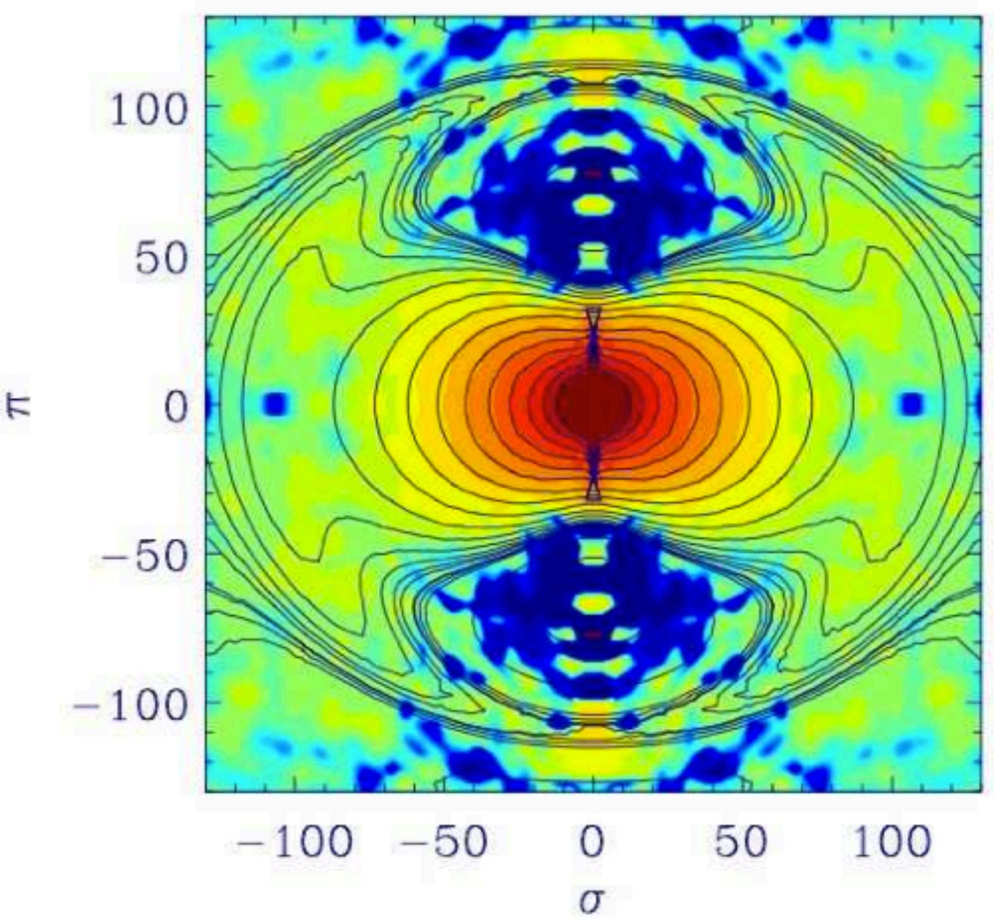


Figure 10. Best fit (solid lines) to the 2-point anisotropic redshift correlation function $\xi(\sigma, \pi)$ for LRG galaxies (colors).

RSD is a test of Growth History : how does structure form and grow within the background evolution (Modified Grav. vs DE models)

Photo-Z surveys

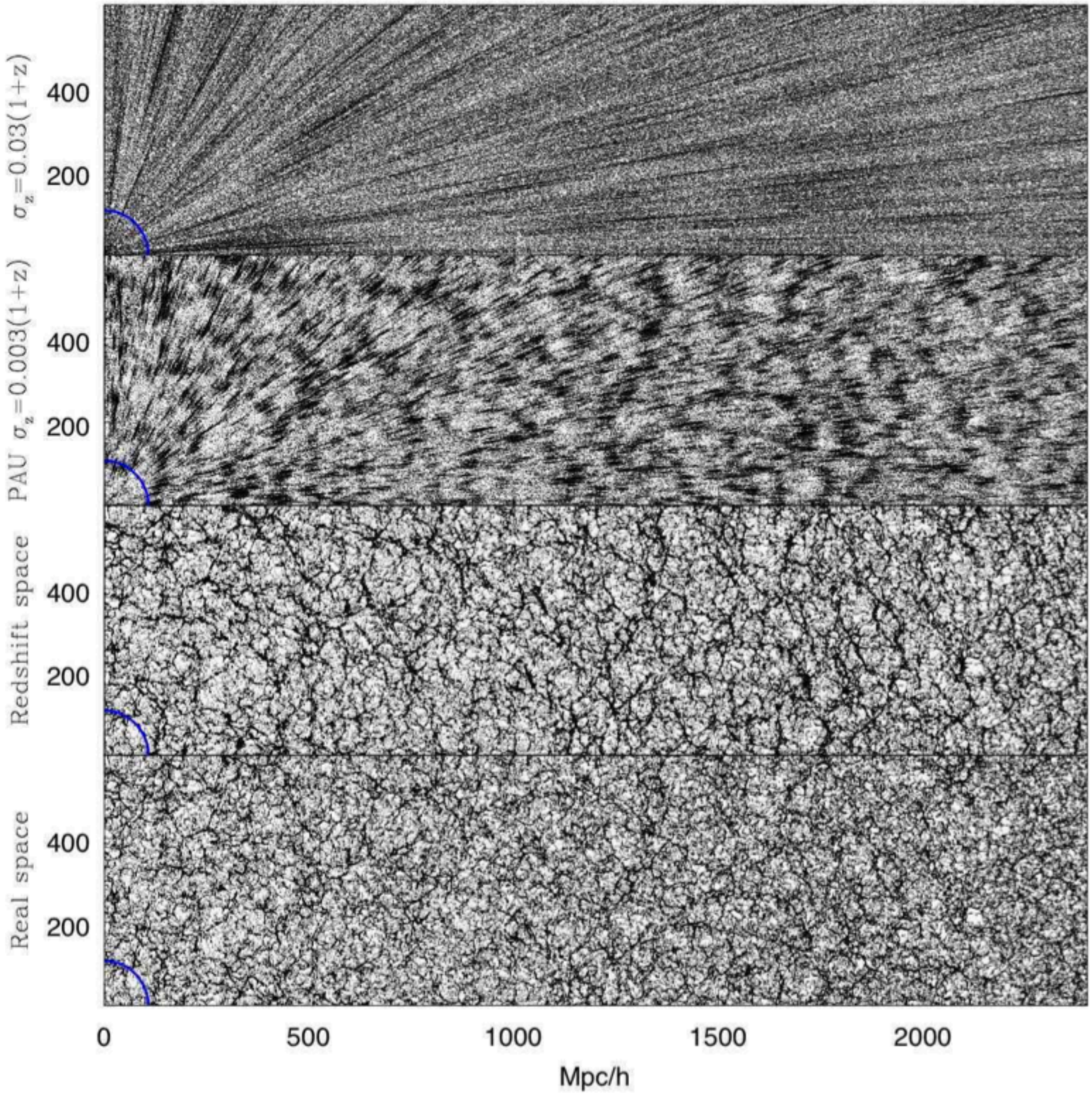
DARK ENERGY SURVEY

Pan-STARRS

More in the future :

Euclid-imaging

LSST



Will probe z>1 in near future. But radial positions of the galaxies will be know with large uncertainties (~ 100 Mpc/h), erasing the 3D-clustering information

Modeling the angular correlation :

$$w(\theta) = \int dz_1 \Phi(z_1) \int dz_2 \Phi(z_2)\, \xi(r_{12}(\theta), \bar{z})$$

$$r_{12}(\theta) = \{r(z_1)^2 + r(z_2)^2 - 2r(z_1)r(z_2)cos(\theta)\}^{1/2}$$

Assuming linearly biased tracers and growth with respect to the mean red-shift of the bin

$$\Phi(z) = D(z, \bar{z})\, \phi(z)$$

Nonlinear Gravity and evolution

$$\begin{aligned} \xi(r,z) &= D(z)\,[\xi_{\mathrm{Lin},0}(r) \otimes \mathrm{e}^{-(r/D(z)s_{bao})^2}]\,(r) \\ &+ A_{mc}\, D^4(z)\, \xi^{(1)}_{\mathrm{Lin},0}(r)\, \xi'_{\mathrm{Lin},0}(r) \end{aligned}$$

Use theoretical estimates for s_{bao} and A_{mc} or a fit in a single redshift b/c they scale with the growth

Red-shift Distortions :

$$\xi(r_1, r_2) = \xi(\sigma, \pi)$$

$$\xi(\sigma,\pi) = \xi_0(r_{12})P_0(\mu) + \xi_2(r_{12})P_2(\mu) + \xi_4(r_{12})P_4(\mu)$$

$$\pi = r_2 - r_1 \quad \text{and} \quad \mu = \pi/r_{12}$$

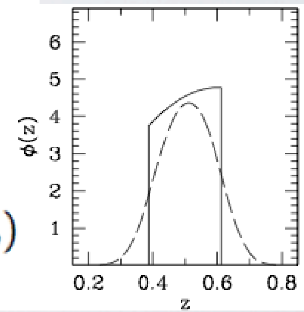
Where ξ_0, ξ_2, ξ_4 are multi-poles of ξ that depend on bias and growth rate

$$f \equiv \frac{d\ln D(a)}{d\ln a}$$

Photo-z :

$$\phi(z) = \frac{dN_g}{dz} W(z).$$

$$\phi(z) = \frac{dN_g}{dz} \int dz_p P(z|z_p) W(z_p)$$



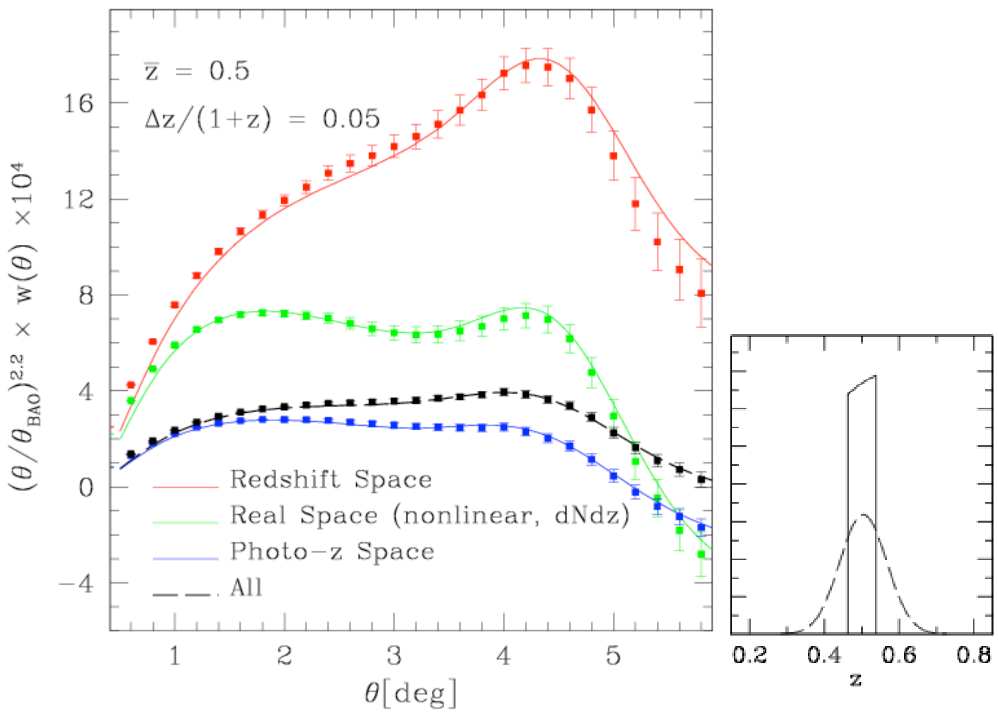
(distribution of galaxies in true red-shifts)

Angular Correlation Function : Theory vs. Mocks

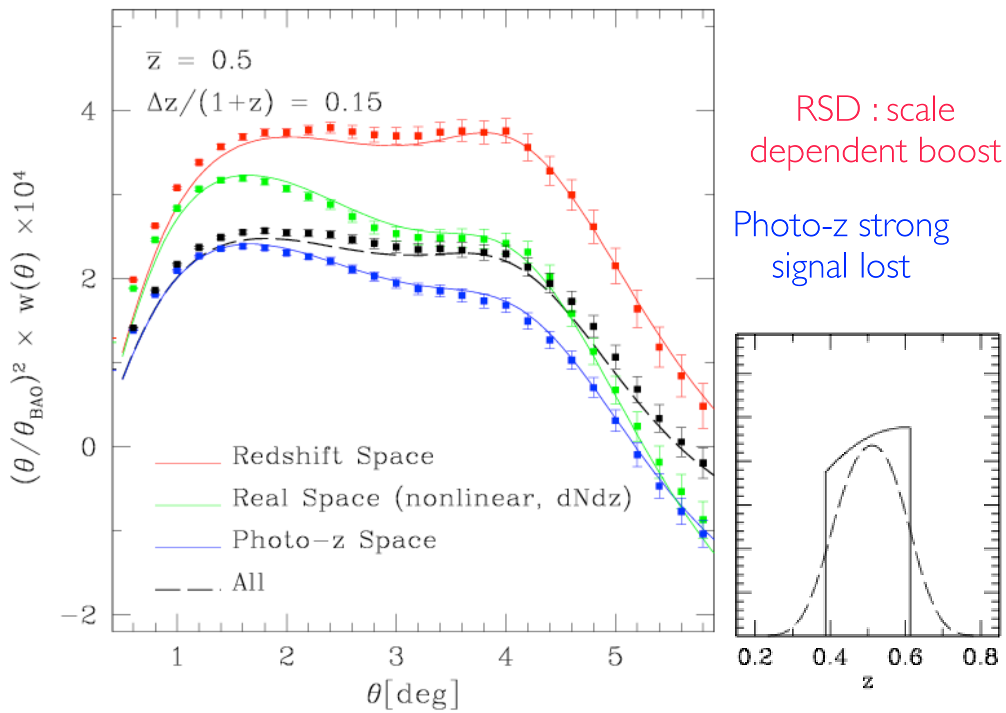
Red-shift Space Distortions and Photo-z effects

$$\sigma_z = 0.06 \qquad \beta = f/b = 0.7047$$

Narrow bin (width ~ 178 Mpc/h ~ photo-z)



Wide bin (width ~ 500 Mpc/h ~ 4 photo-z)

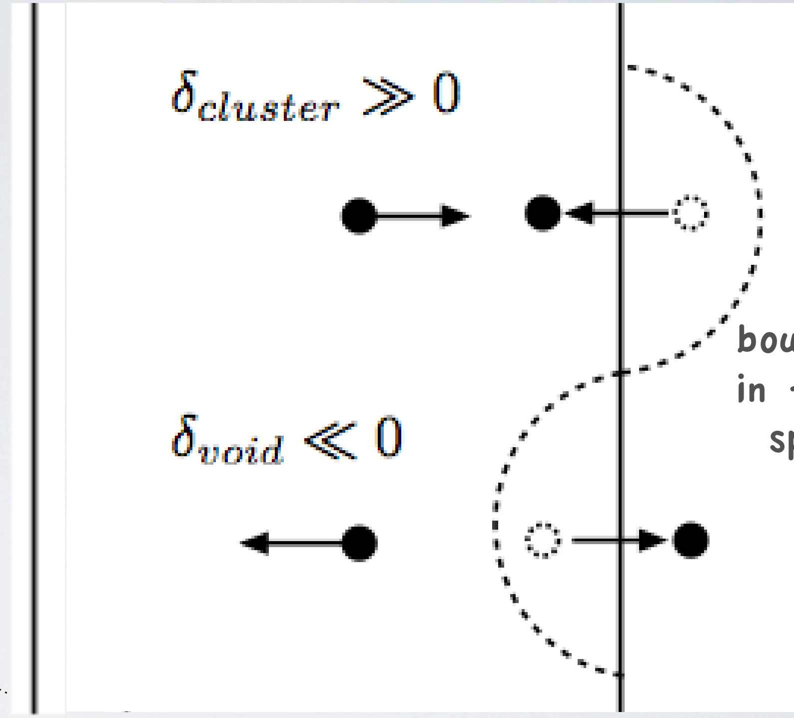


RSD : scale dependent boost

Photo-z strong signal lost

- The effect of RSD is very important even for bins as broad as 500 Mpc/h (where it "counter-acts" the photo-z smearing)
- The theoretical modeling works nicely in all cases

Why ?



Red-shift distortions move particles in and out of the red-shift bin coherently with density perturbations at the edge.

This makes over-densities larger and under-density emptier, increasing the amplitude of fluctuations.

Instead photo-z does this but fully randomly, smoothing out fluctuations

From **M. Crocce** et al arXiv 1004.4640 & Nock et al arXiv 1003.0896

Measuring growth of structure

$$f \equiv \frac{d \ln D(a)}{d \ln a}$$

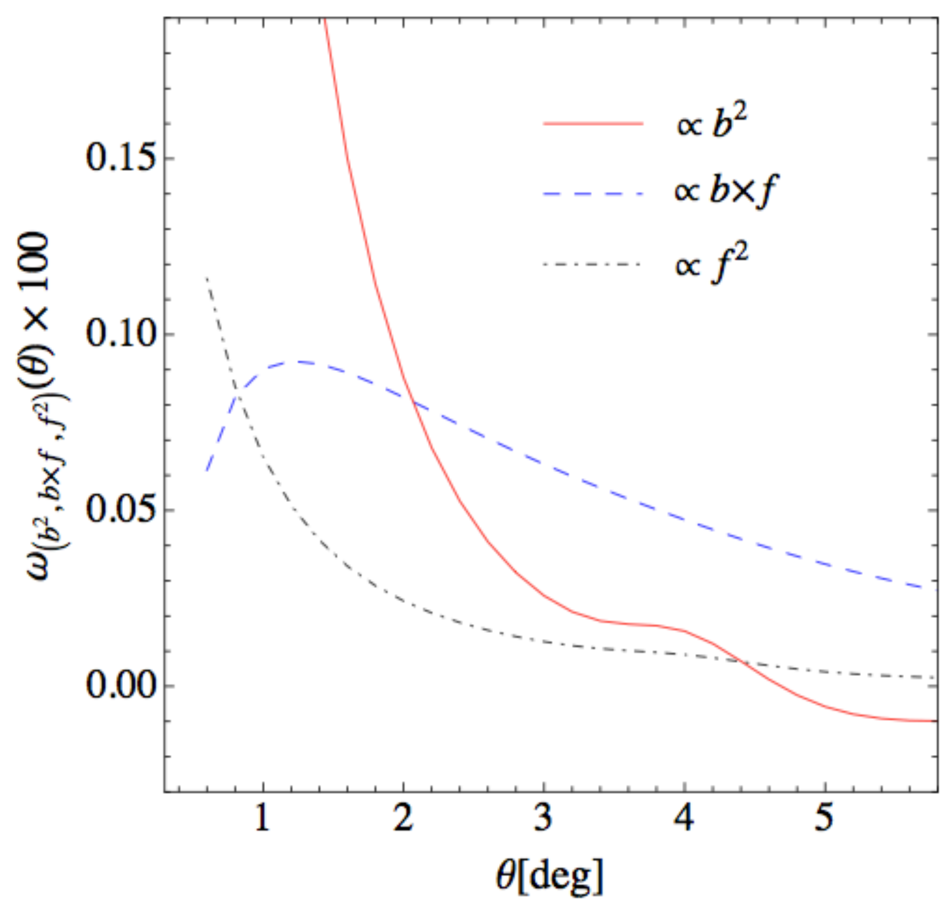
$$\xi^s(s,\mu) = \xi_0(s)P_0(\mu) + \xi_2(s)P_2(\mu) + \xi_4(s)P_4(\mu)$$

$$\xi_0(r) = (b^2 + 2bf/3 + f^2/5)\,[\xi(r)]$$
$$\xi_2(r) = (4bf/3 + 4f^2/7)\,[\xi(r) - \xi'(r)]$$
$$\xi_4(r) = (8f^2/35)\,[\xi(r) + 5/2\,\xi'(r) - 7/2\,\xi''(r)]$$

$$w(\theta) = p_0(b,f)w_0(\theta) + p_2(b,f)w_2(\theta) + + p_4(b,f)w_4(\theta)$$

Collect terms in b^2, f^2 and bf

(degenerate with σ_8 (z))



Modeling the error and covariance :

$$w(\theta) = \sum_{\ell \geq 0} \left(\frac{2\ell+1}{4\pi} \right) P_\ell(cos\theta)\, C_\ell \qquad \langle a_{\ell m} a_{\ell' m'} \rangle \equiv \delta_{\ell\ell'} \delta_{mm'} C_\ell$$

$$\mathrm{Cov}_{\theta\theta'} = \sum_{\ell,\ell' \geq 0} \left(\frac{2l+1}{4\pi} \right)^2 P_\ell(\cos\theta) P_{\ell'}(\cos\theta')\, \mathrm{Cov}_{\ell\ell'}$$

Assume that Cov ~ 1 / f_{sky} and use that in *"full sky"* $\mathrm{Var}(C_\ell) = 2\,C_\ell^2/(2\ell+1)$.

$$\mathrm{Cov}_{\theta\theta'} = \frac{2}{f_{sky}} \sum_{\ell \geq 0} \frac{2\ell+1}{(4\pi)^2} P_\ell(\cos\theta) P_\ell(\cos\theta')\, (C_\ell + 1/\bar{n})^2$$

$$C_{\ell,\mathrm{Exact}} = \frac{1}{2\pi^2} \int 4\pi k^2 dk P(k) \Psi_\ell^2(k) \qquad \Psi_\ell(k) = \int dz \phi(z) D(z) j_\ell(kr(z))$$

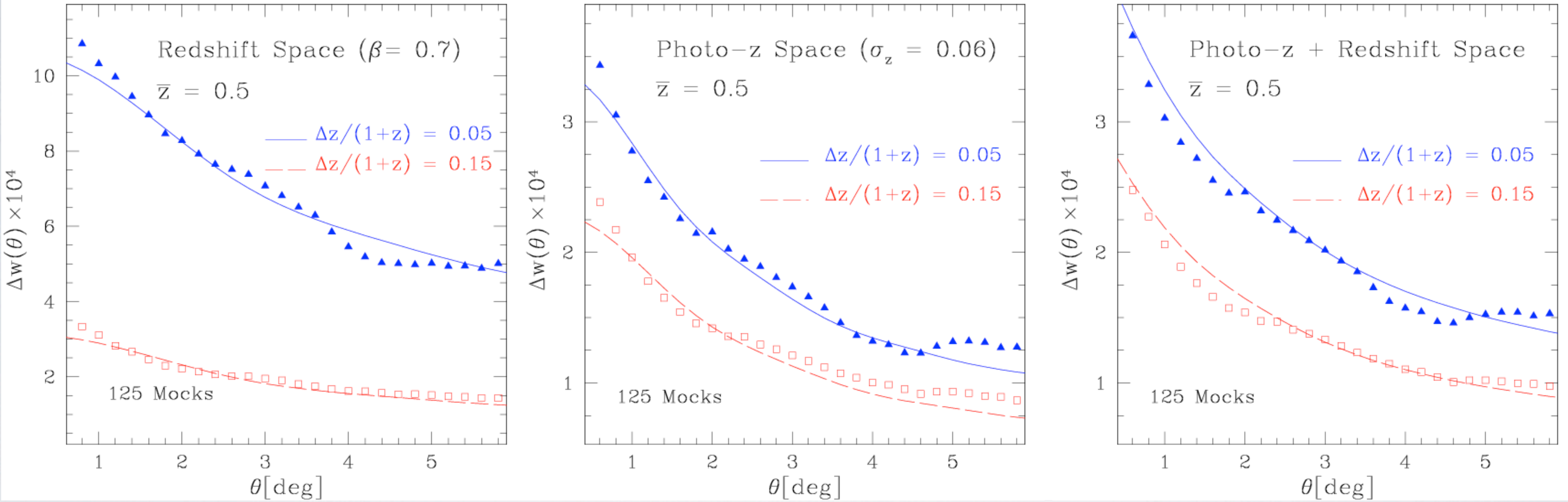
And a similar expression for red-shift space

involving also $j_{\ell-2}(kr)$ $j_{\ell+2}(kr)$

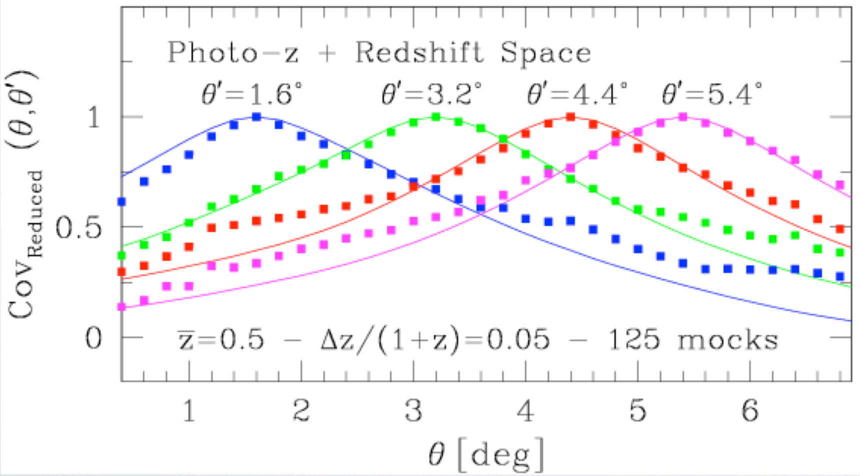
Errors : Theory vs. Mocks

Red-shift and/or Photo-z space

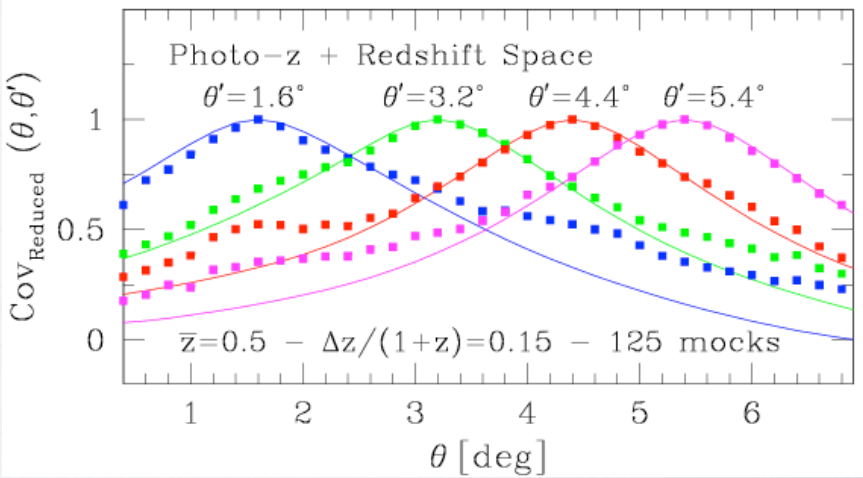
From **M. Crocce** et al arXiv 1004.4640



Redshift + Photo-z Space



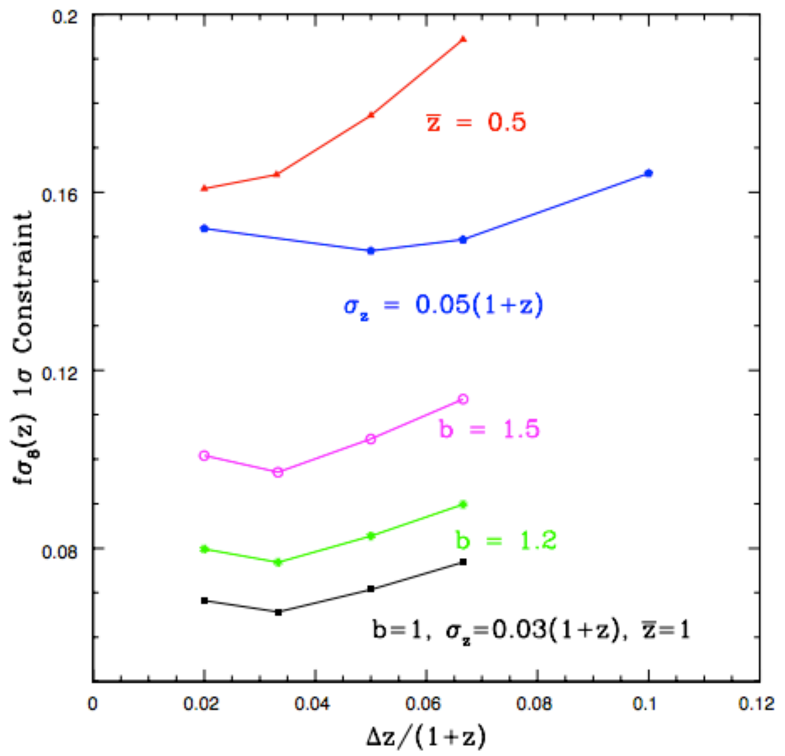
Redshift + Photo-z Space



Forecast - RSD in a DES like survey

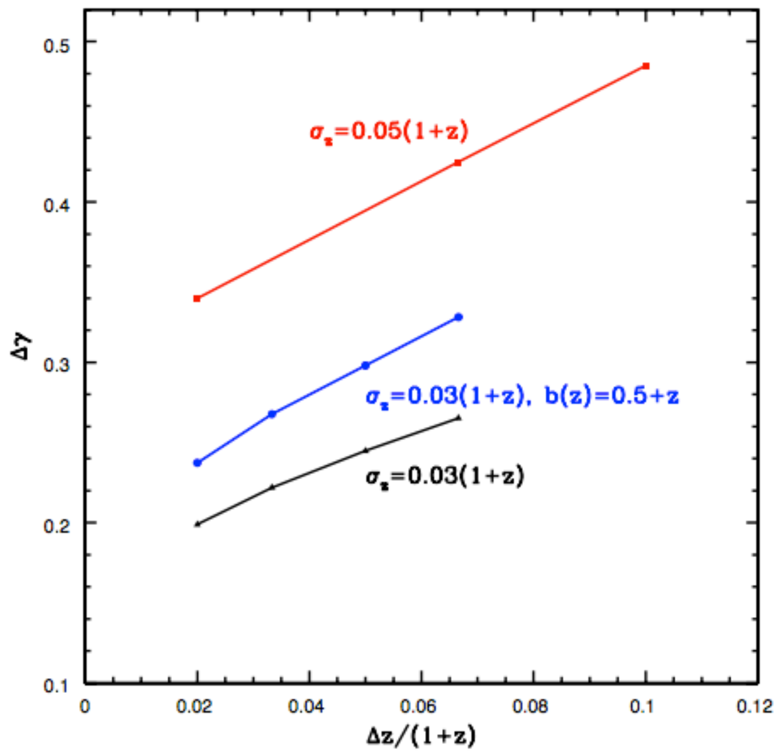
$$f \equiv \frac{d \ln D(a)}{d \ln a}$$

where $f = \Omega_m(z)^\gamma$.



Constrains on growth rate at a single redshift bin

$$f(z)\sigma_8(z) \sim (20 \times b)\%$$



Constrains on growth rate index from the combination of all bins in 0.4 < z < 1.4

$$\gamma = 0.557^{+0.25}_{-0.22}.$$

From A. Ross, W. Percival, **M. Crocce**, A. Cabre and E. Gaztagaña, 2011, arXiv: 1102.0968

Angular clustering in the Sloan Digital Sky Survey II

Imaging catalog of the (final) data release (DR7)

From M. Crocce, E. Gaztagaña, A. Cabre, A. Carnero and E. Sanchez, 2011, arXiv: 1104.5236
(see also Carnero et al 2011, arXiv 1104.5426)

• Use luminous red galaxies (LRG) sample in the imaging catalog of the final Data Release (DR7) of SDSS II

$$(r-i) > \frac{(g-r)}{4} + 0.36, \qquad 17 < petror < 21,$$

$$(g-r) > -0.72\,(r-i) + 1.7, \qquad 0 < \sigma_{petror} < 0.5,$$

• Angular clustering analysis at the *largest angular scales and 0.45 < z < 0.6, including a detailed study* of systematic effects

• Probe to what extent red-shift space distortions and BAO can be extracted from a photometric sample

• Do we match expectations? Are we dominated by systematic effects ? Is the clustering signal compatible with LCDM or anomalous?

$$0 < r - i < 2,$$

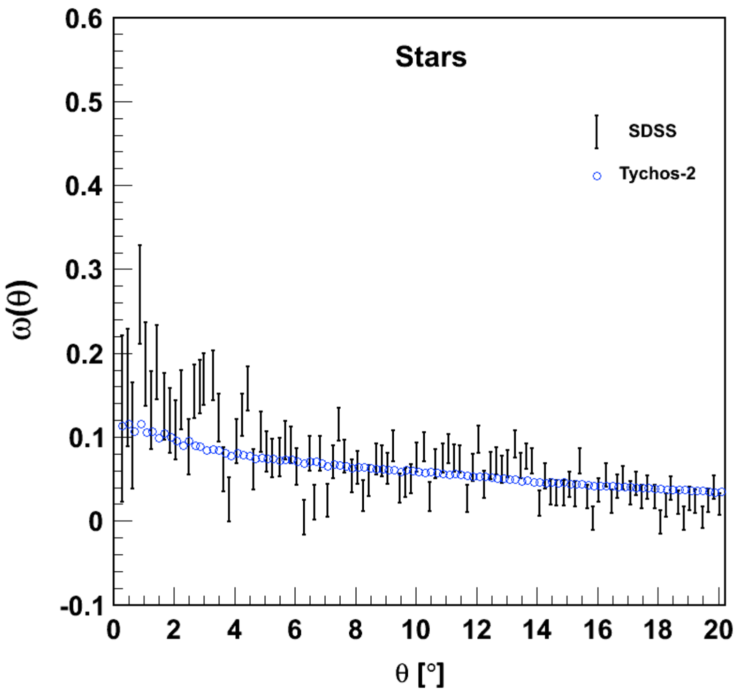
$$0 < g - r < 3,$$

$$22 < mag_{50} < 24.5,$$

• Residual Star Contamination

• From the corresponding SDSS DR7 spectroscopic sub-sample we identify ~ 4% residual star contamination

• Using those objects identified as stars in the SDSS spec sub-sample as well as the Tychos2 star catalog we measure the angular correlation of stars,



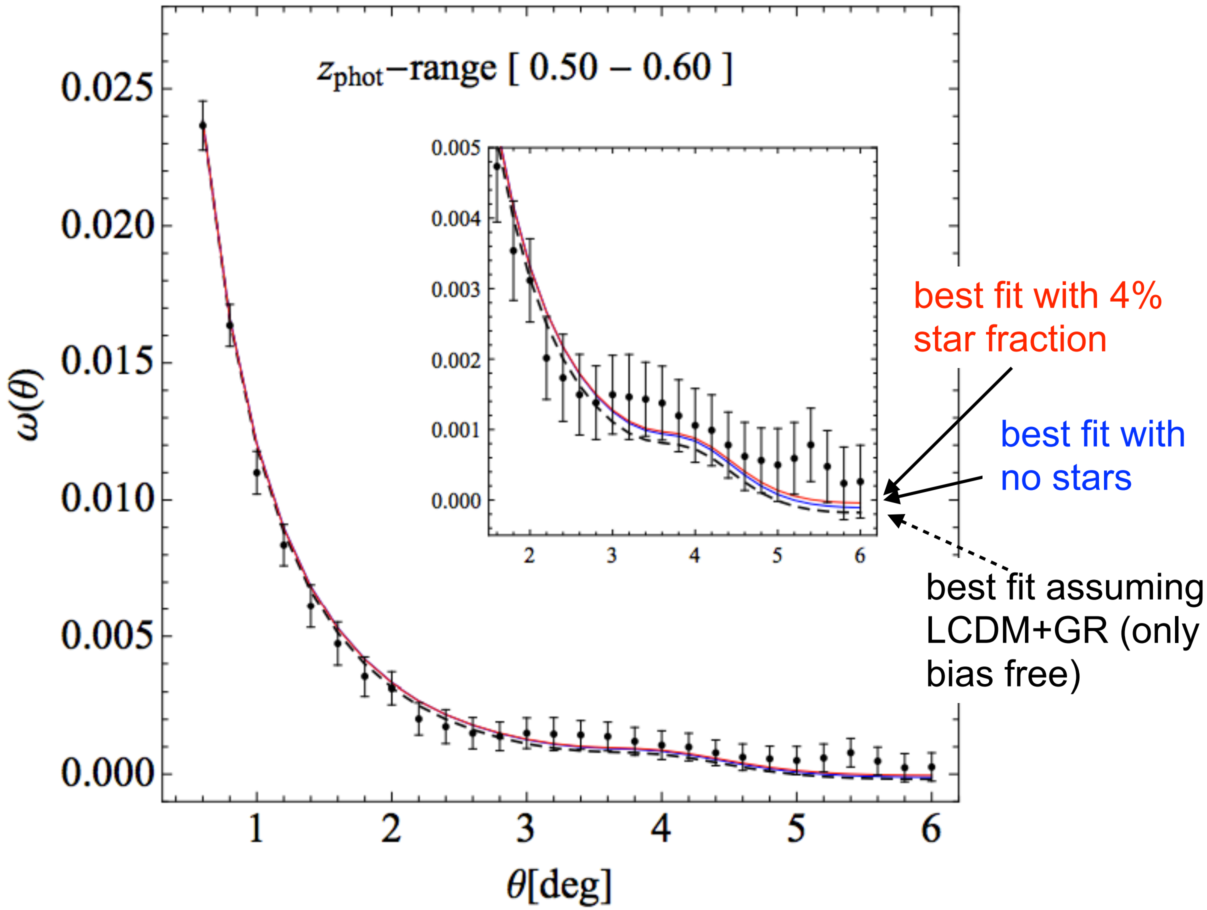
Both estimates coincide and are well fit by,

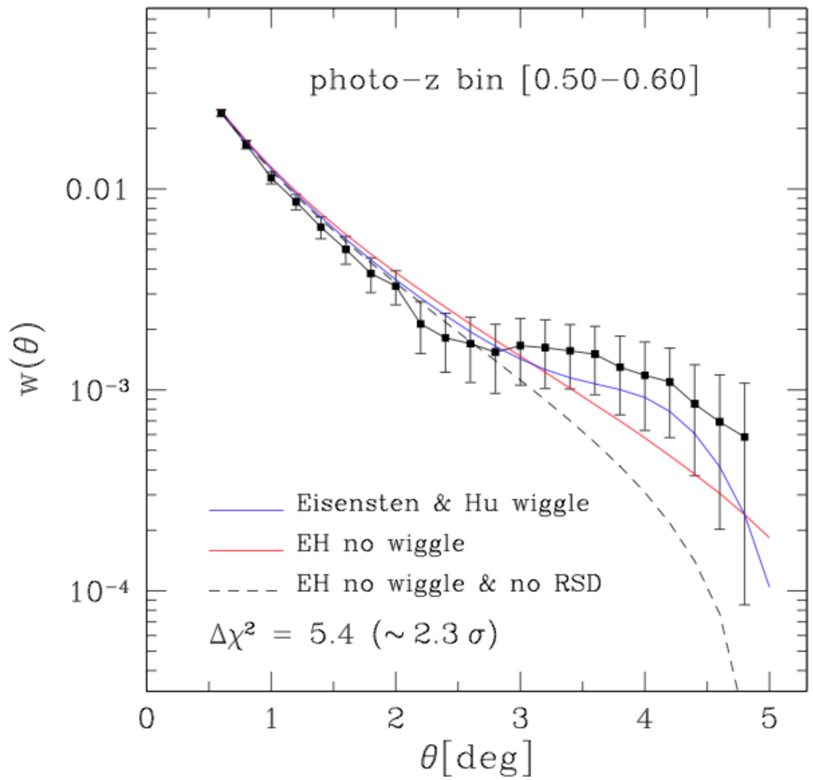
$$w_{stars,fit}(\theta) = 0.0904 - 0.00313\,\theta.$$

$$w_{obs,model}(\theta, z) = (1 - f_{stars})^2 w_{gal,model}(\theta, z) + f_{stars}^2 w_{stars,fit}(\theta)$$

• **Data vs. Model : Fitting for growth and bias**

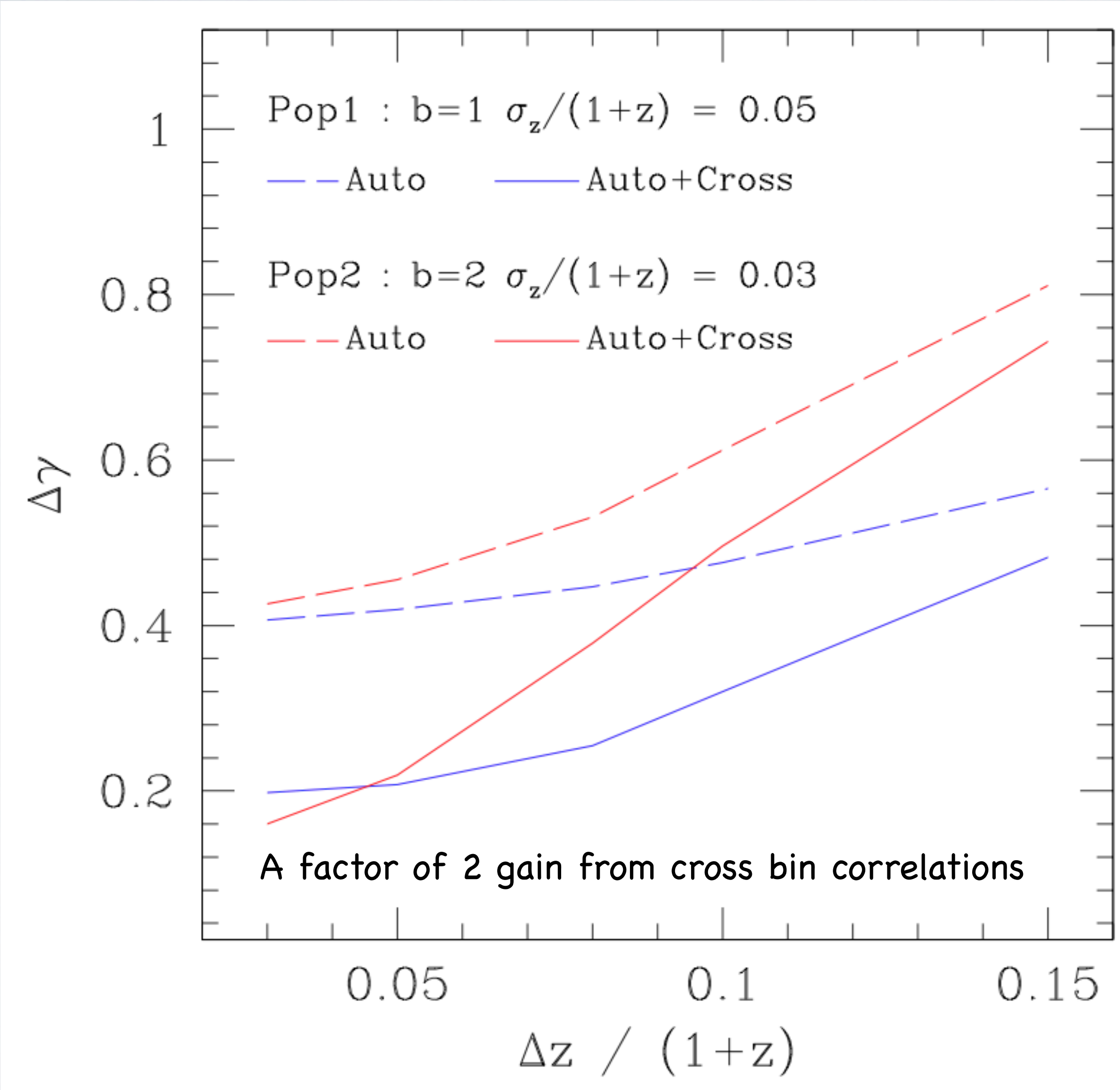
redshift bin	$b(z)\sigma_8(z)$	$f(z)\sigma_8(z)$
0.50 – 0.60	1.12 ± 0.02	0.53 ± 0.42



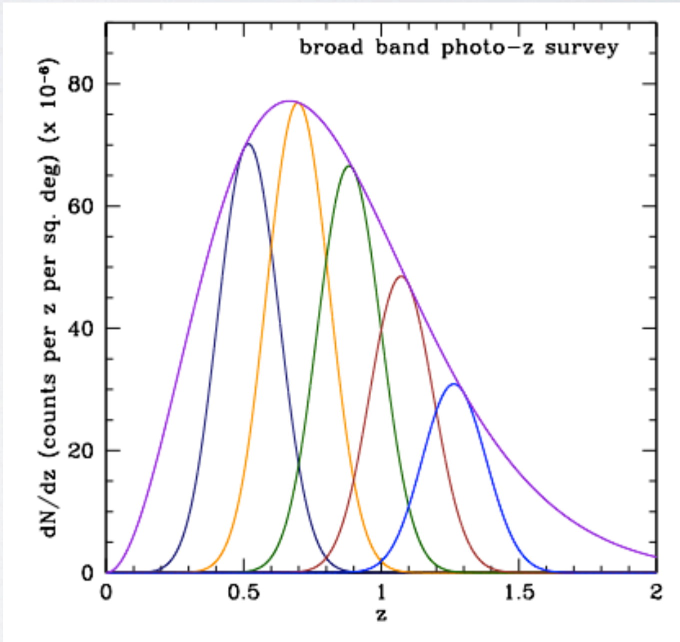


RSD also impacts the detectability of BAO

The gain from including cross-correlation of z-bins



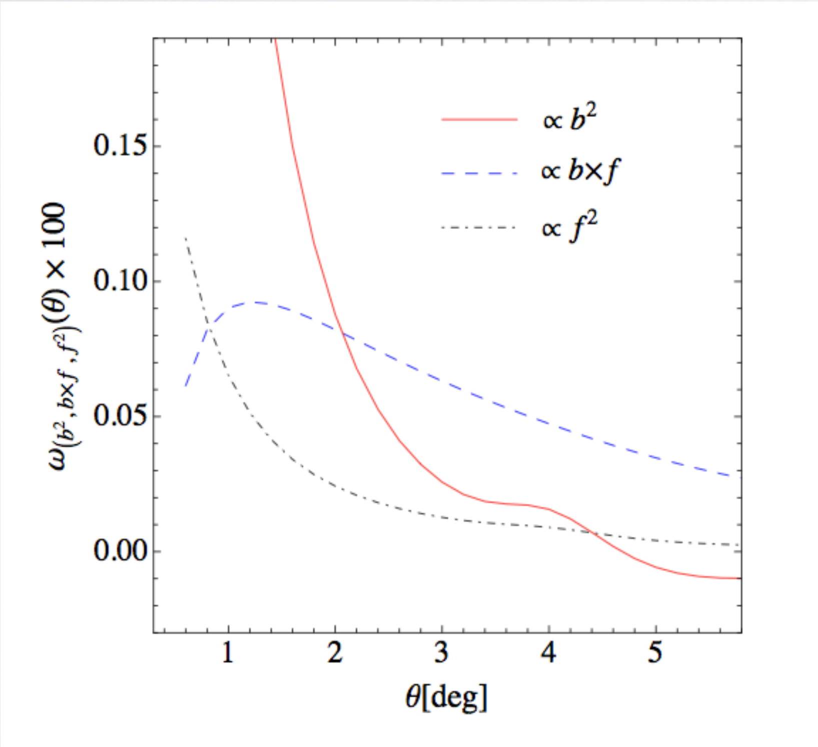
Number of bins N_z	$\Delta z/(1+z)$
4	0.15
6	0.1
8	0.08
12	0.05
19	0.03



From J. Asorey, **M. Crocce**, E. Gaztagaña, 2013, arXiv: 1305.0934

How to measure RSD without sample variance

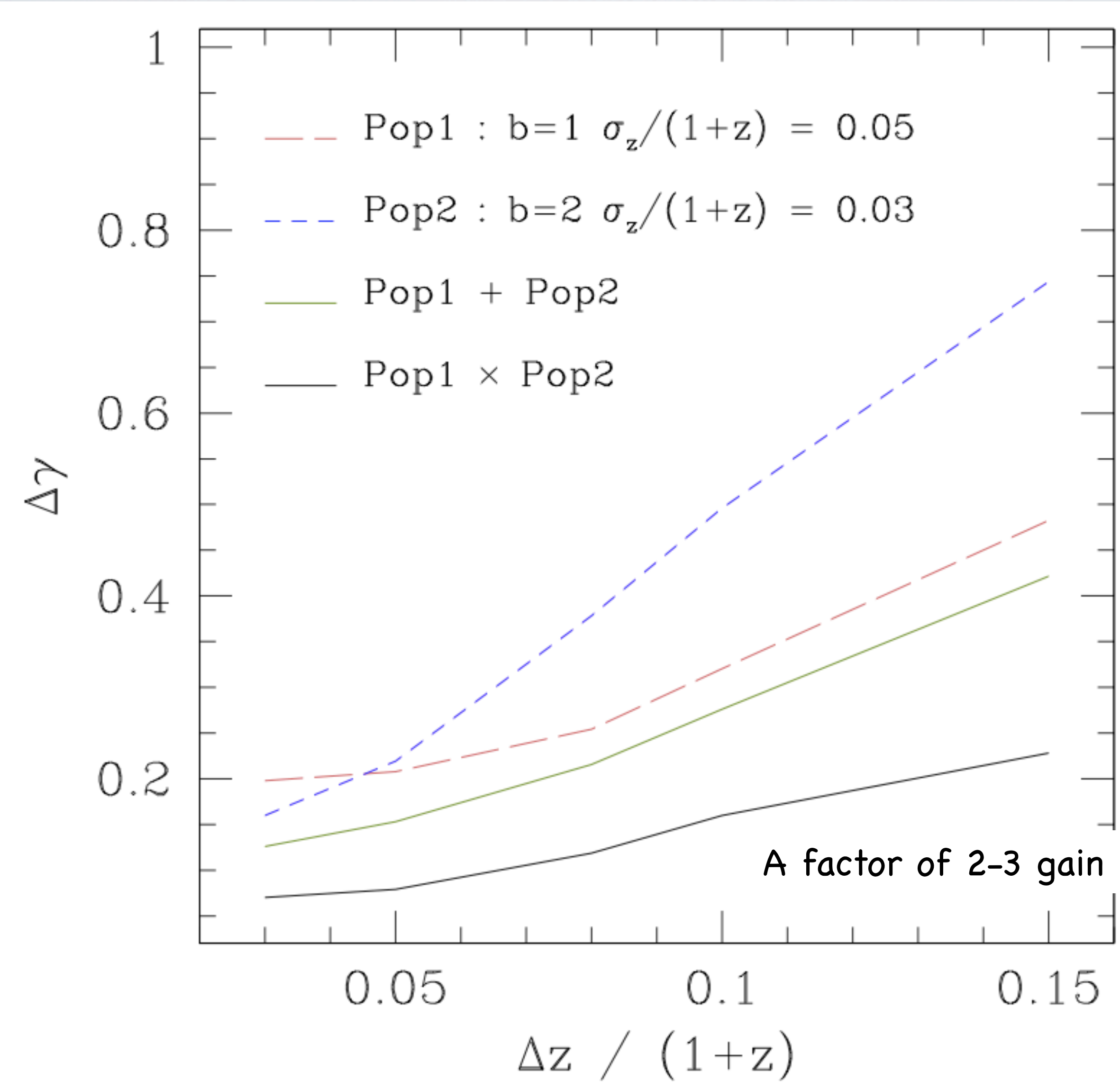
In McDonald and Seljak 2009 is it proposed to use two tracers of the same (DM) density field to over-sample cosmic variance. They focused on the ratio of transverse to radial modes and showed that large gains can be obtained in the low-shot noise limit (and large bias difference)



For each tracer the shape of the monopole will set the bias and the quadrupole (prop to f) will be constrained from the joint correlation.

The gain from combining different populations

(and all their x-correlations)

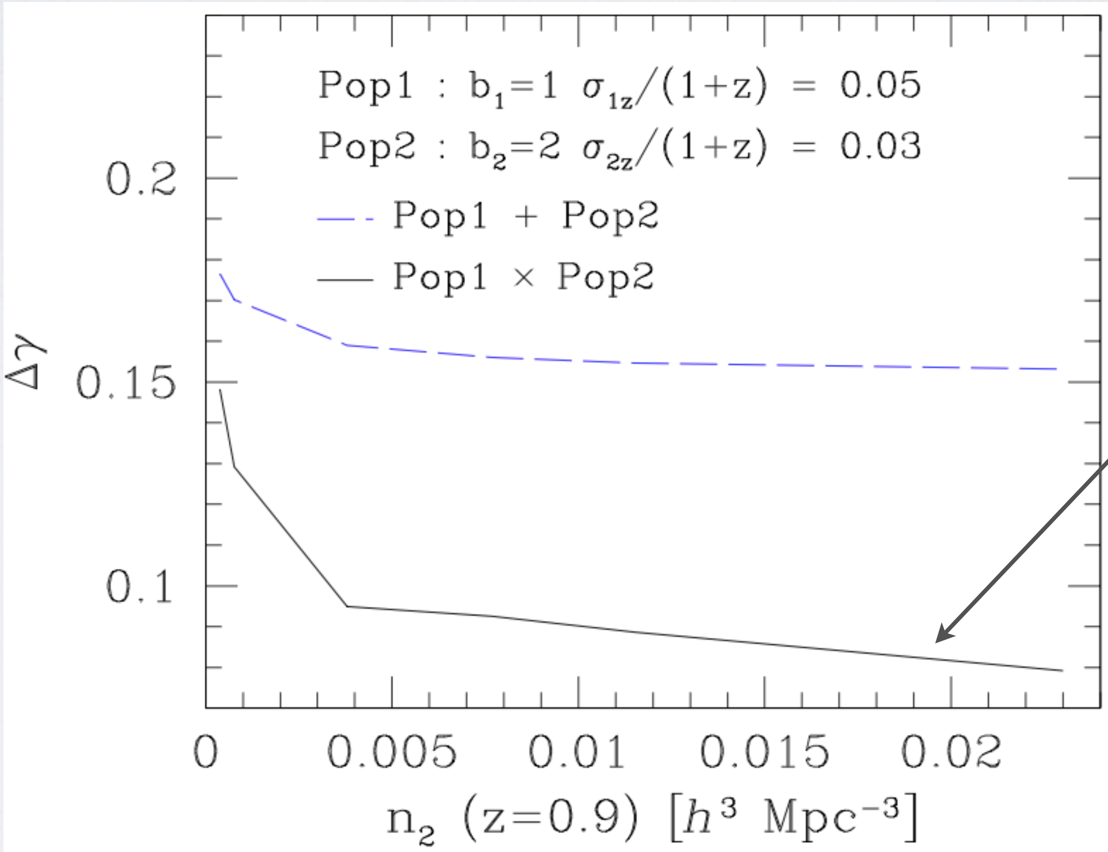


A factor of 2-3 gain from two populations

From J. Asorey, **M. Crocce**, E. Gaztagaña, 2013, arXiv: 1305.0934

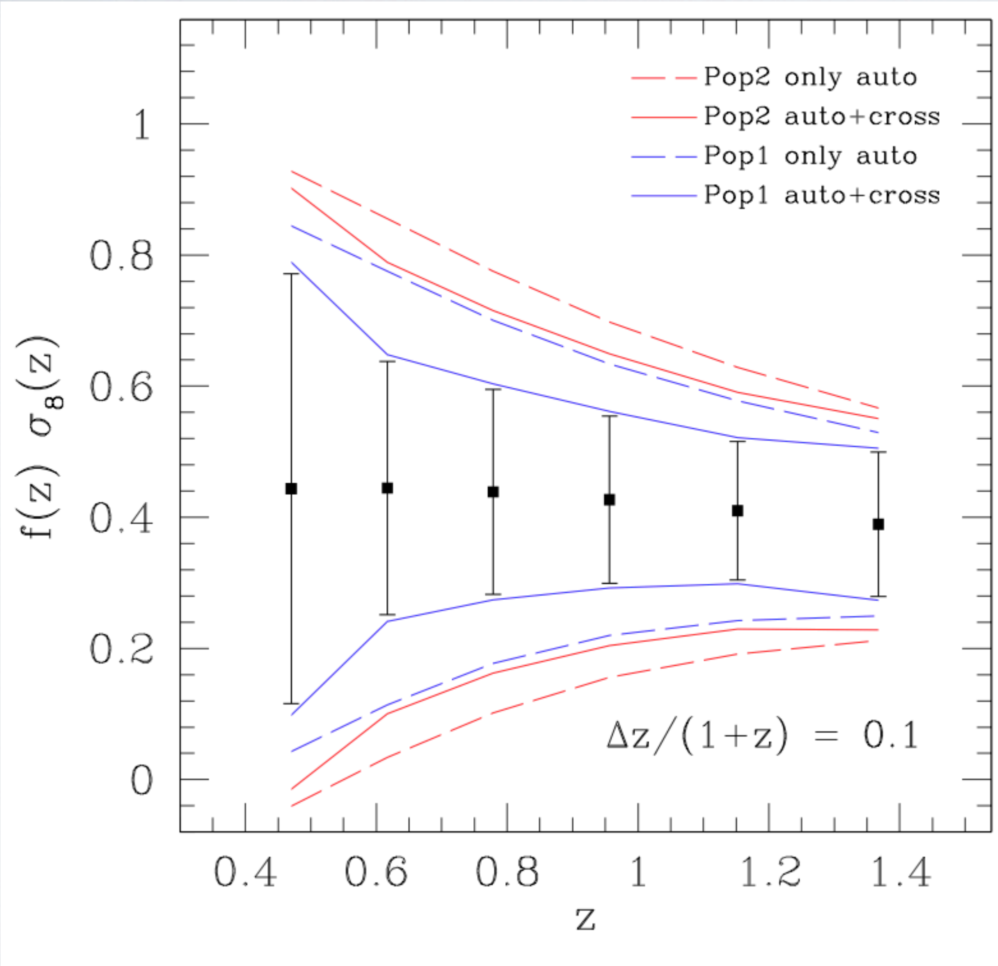
Dependence with the shot noise

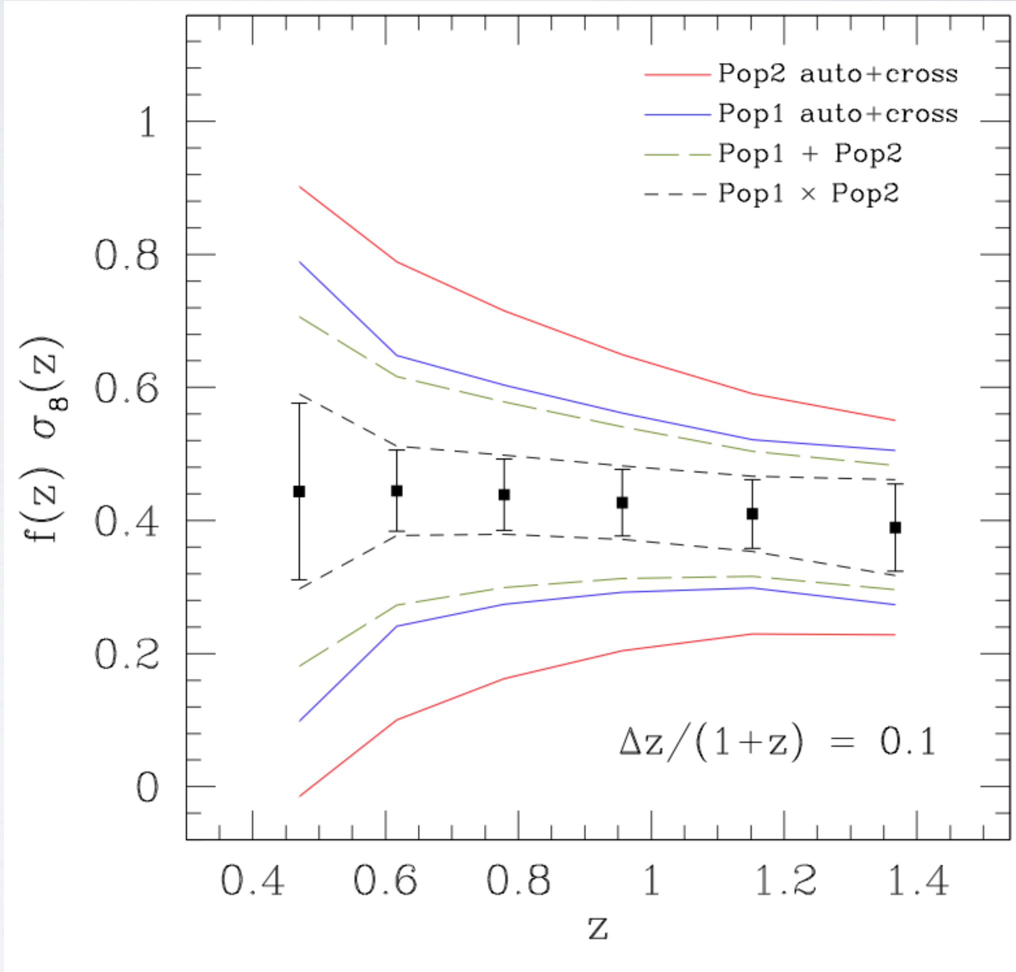
The shot-noise limits the applicability of this idea in redshift surveys. The positive side of a photometric surveys is the high density sampling (and that there is not pre-selection)



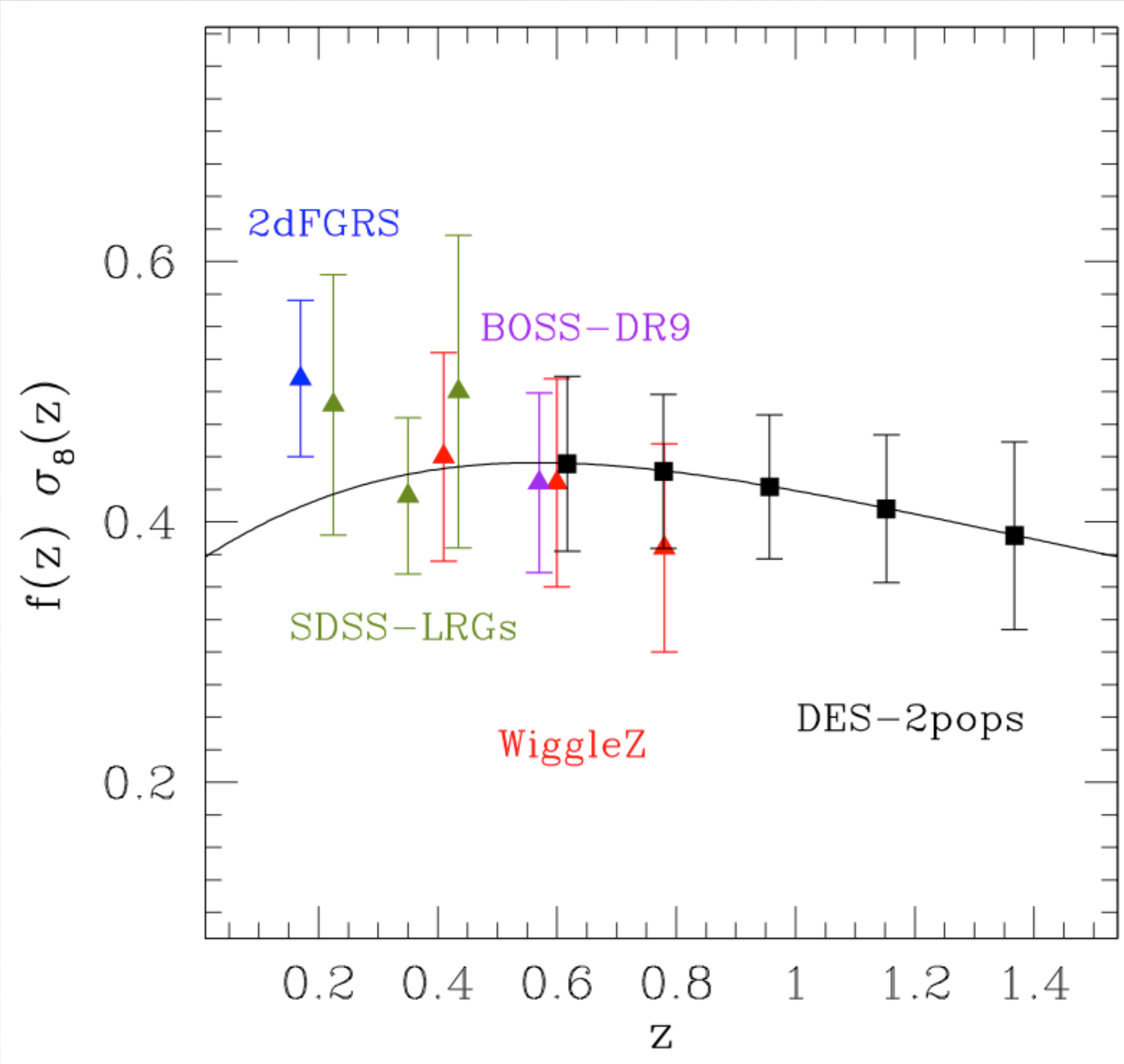
Our fiducial value so far
n = was 0.018 (h/Mpc)3

Impact on determining the evolution of the linear growth rate of structure



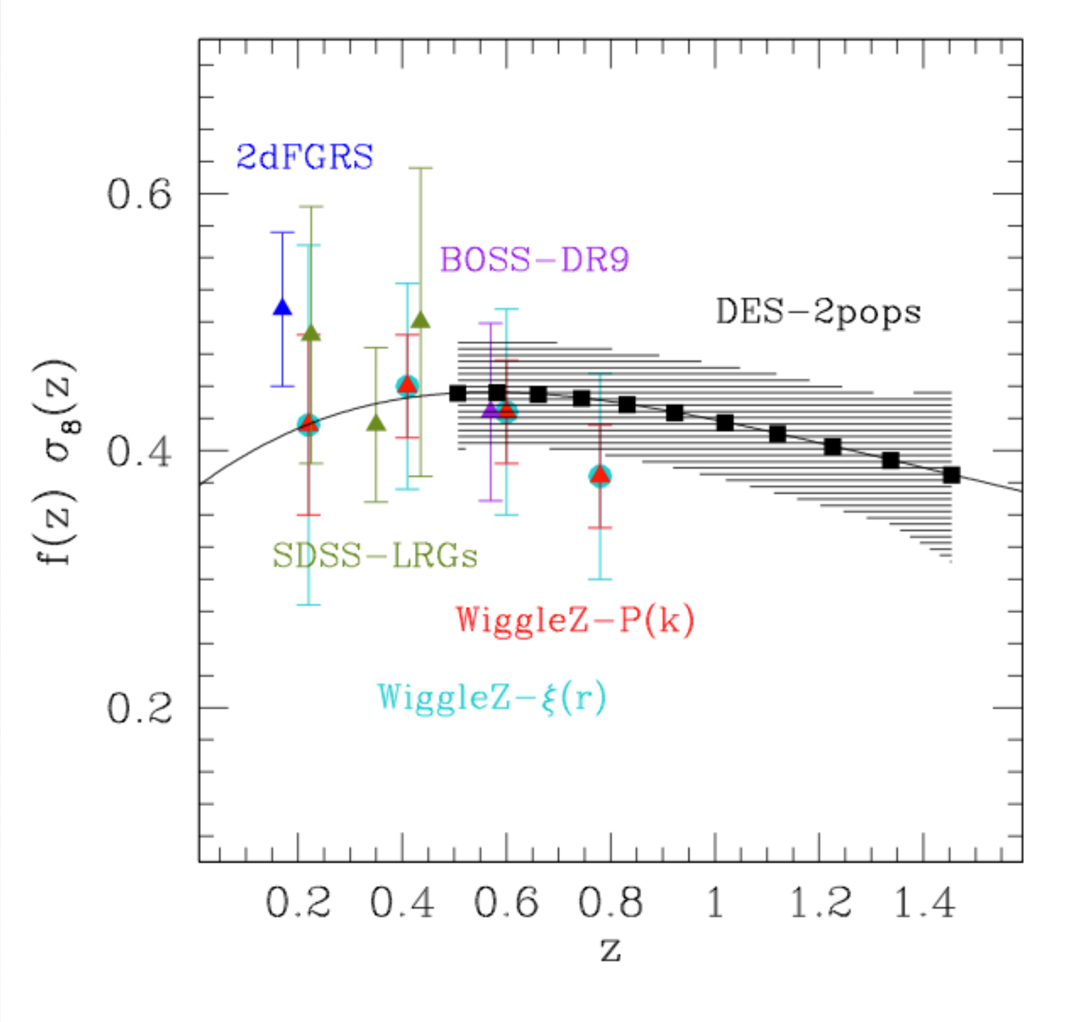


Complementarity with low-z spectroscopic surveys



2dFGRS Percival et al 2004
SDSS-LRGs Tegmark 06 and Cabré & Gaztañaga 2009
BOSS-DR9 Reid et al 2012
WiggleZ Contreras et al. 2013

Complementarity with low-z spectroscopic surveys



2dFGRS Percival et al 2004
SDSS-LRGs Tegmark 06 and Cabré & Gaztañaga 2009
BOSS-DR9 Reid et al 2012
WiggleZ-Pk Blake et al 2011
WiggleZ-xi Contreras et al. 2013

Conclusions

- Accurate and well tested model for the angular correlation function and its full covariance matrix. Publicly available ensembles of mock catalogs for photometric surveys

- Nonlinear gravity and bias seems minor issues on large angles. Red-shift distortions is very important even for wide bins, can compete with photo-z smearing.

- A single sample in a single bin at z ~ 1 in a DES-like survey should measure $f(z)\sigma_8(z)$ to $\sim (20 \times b)\%$, and combining bins in 0.5 < z < 1.4 yields $\gamma = 0.557^{+0.25}_{-0.22}$. (DES alone)

- LRG clustering in the imaging catalog of DR7 in good agreement with LCDM : Red-shift distortions is measured matching expectations (need good control of star-gal separation).

- An optimal scenario: For single populations we find gains by a factor of ~2 in by including all cross-correlations between redshift bins. A further factor of 2-3 is achieved by combining populations (and their cross-correlations) with different bias

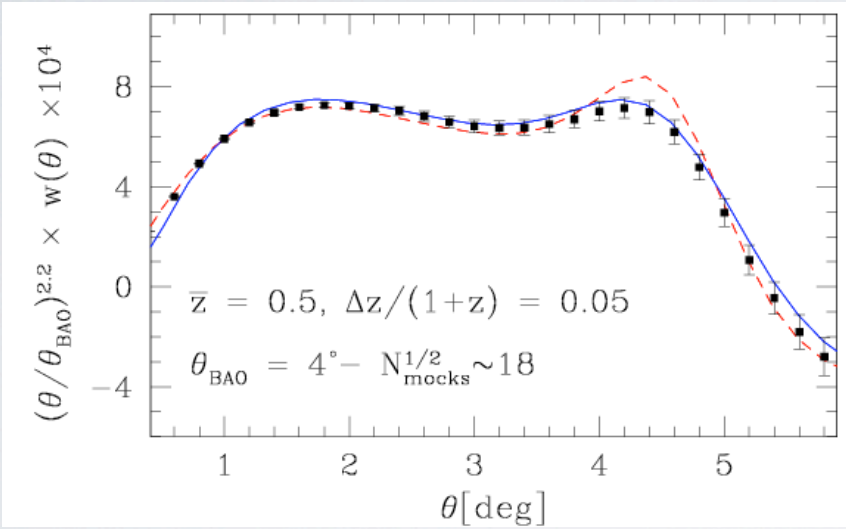
- In all a combination of bins in 0.5 < z < 1.4 should constrain γ at the 5-10% level. The evolution of the growth rate also shows similar gains, leading to 10-15 % level constrains in $f(z)\sigma_8(z)$ in several bins beyond z ~ 0.6.

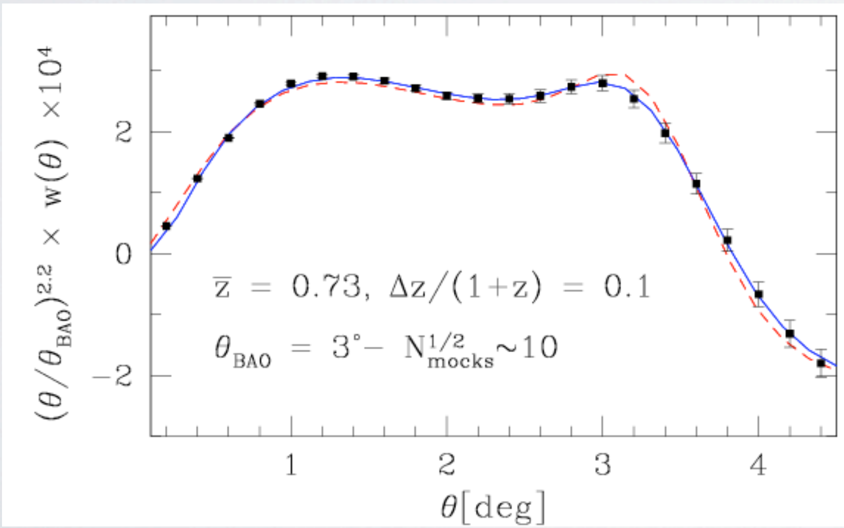
- Future should look for the complementariness of photometric and spectroscopic data.

Angular Correlation Function : Theory vs. Mock

Real space

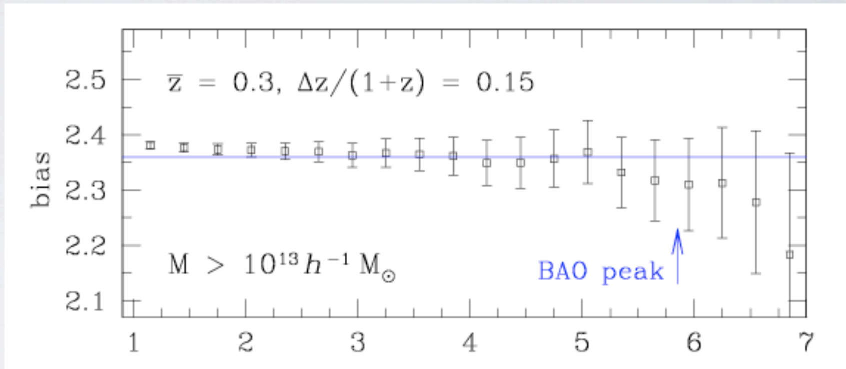
Nonlinear gravity and evolution

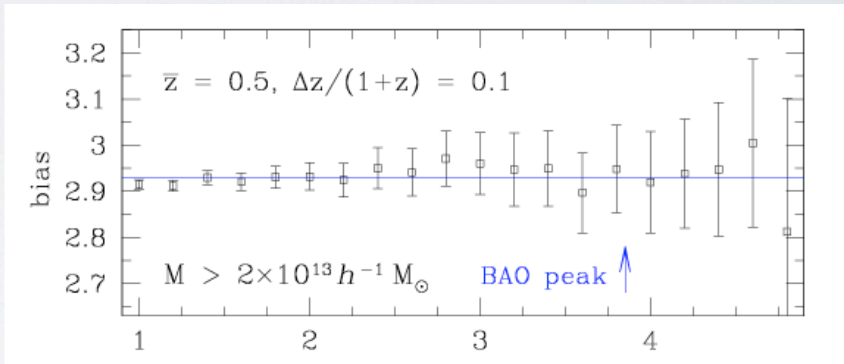




Halo Bias

Roughly galactic halo mass scale





Cluster mass scale