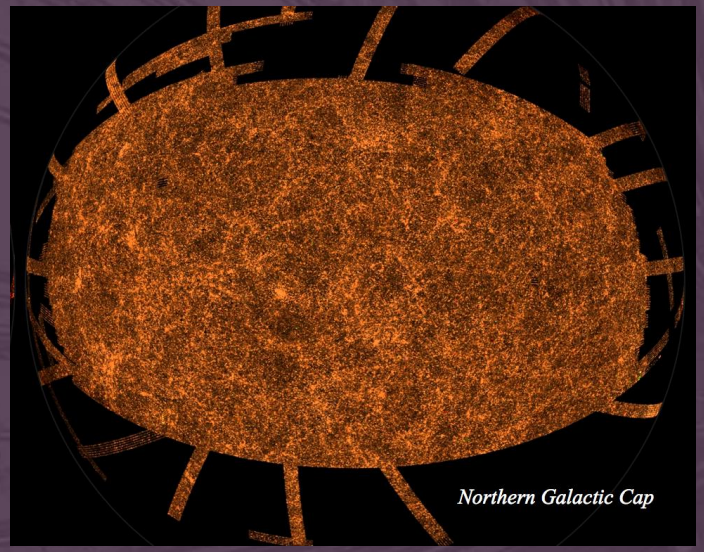
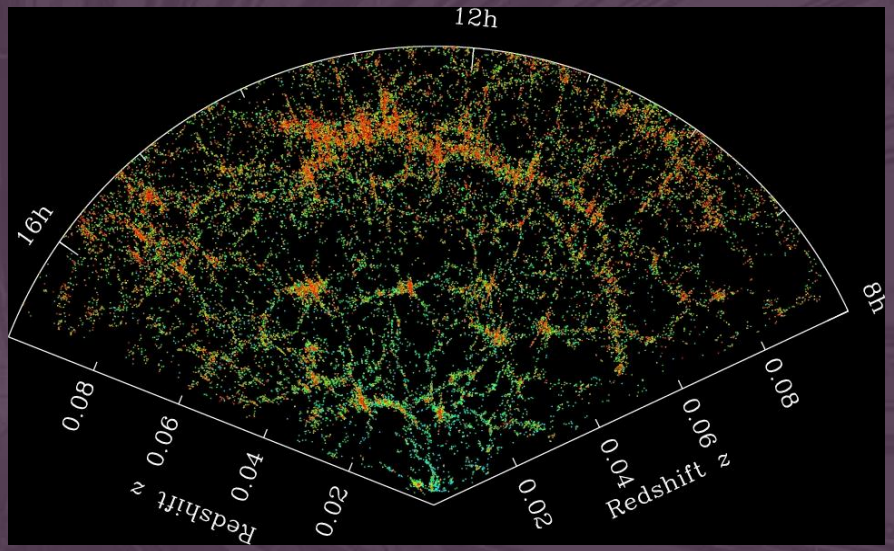
Why Joint Imaging and Spectroscopic Surveys are Good

David Weinberg, Ohio State University





Based largely on the

Report of the DES-BigBOSS Joint Working Group (4/20/12)

Available now at http://www.astronomy.ohio-state.edu/~dhw/jwg.pdf

Jim Annis, Gary Bernstein, Pat McDonald, Jeff Newman, Nikhil Padmanabhan, Will Percival, David Weinberg

Why Joint Imaging and Spectroscopic Surveys are Good

Joint surveys enable broader science and higher quality science.

Both deep multi-band imaging and extensive spectroscopic follow-up are needed for the cutting-edge studies of

- galaxies and galaxy evolution
- quasars and quasar evolution
- stellar populations and Galactic structure

For dark energy studies, joint surveys allow you to

- understand the tracers you are observing
- investigate intrinsic alignments
- calibrate photo-z's via cross-correlation w/ redshift survey
- exploit opportunities in cross-correlation of WL and 3-d galaxy P(k) [redshift-space distortions in particular]

Observational Probes of Cosmic Acceleration*

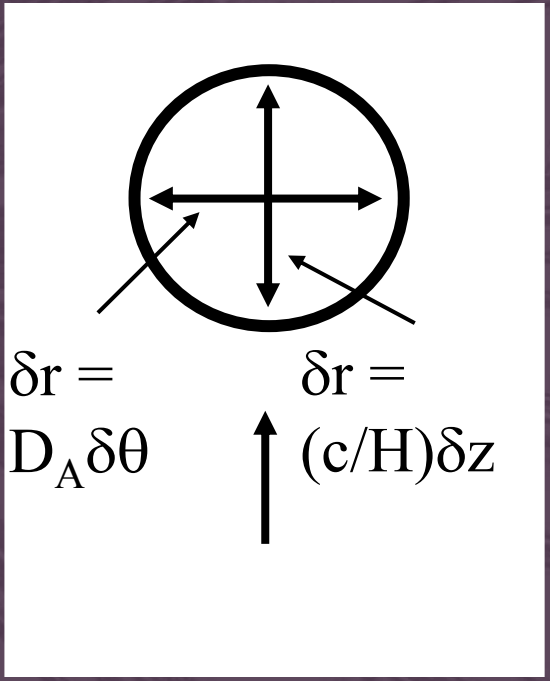
David H. Weinberg[a,b], Michael J. Mortonson[b], Daniel J. Eisenstein[c,d], Christopher Hirata[e], Adam G. Riess[f], Eduardo Rozo[g]

arXiv:1201.2434, for Physics Reports

1. Introduction
2. Observables, Parameterizations, and Methods
3. Type Ia Supernovae
4. Baryon Acoustic Oscillations
5. Weak Lensing
6. Clusters of Galaxies
7. Alternative Methods (includes RSD and AP)
8. A Balanced Program on Cosmic Acceleration
9. Conclusions

Four main ways a DESpec-like redshift survey can constrain cosmic acceleration:

BAO: Constrains $D_A(z)$ and $H(z)$. Robust – likely to be limited by statistics rather than systematics.



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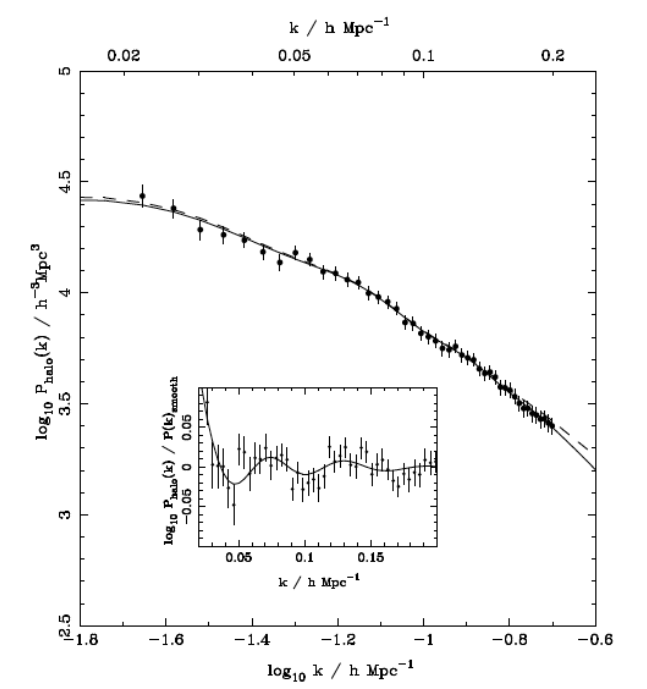

Reid et al. 2010, SDSS DR7

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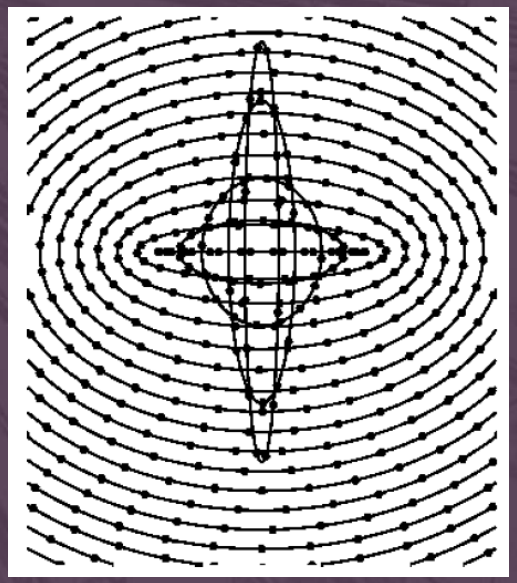

Kaiser 1987, Hamilton 1998

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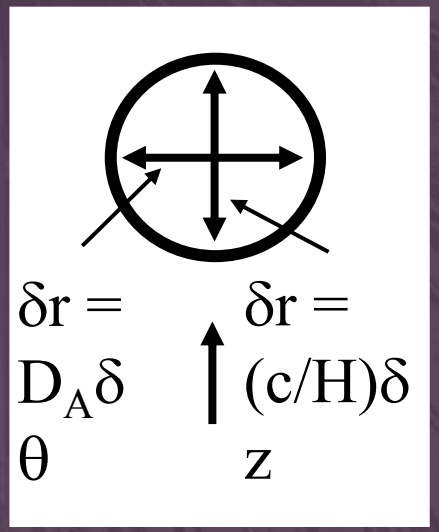
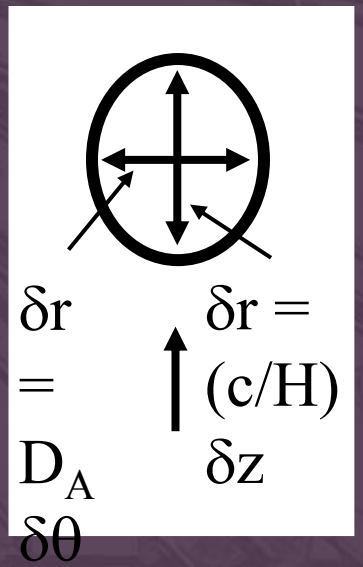
Alcock-Paczynksi (AP) test:





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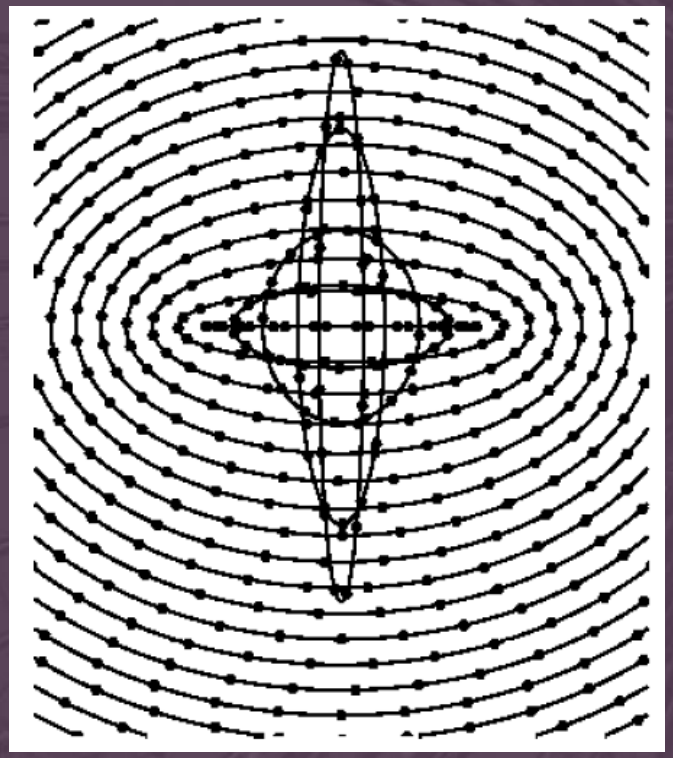
AP test: Demanding statistical isotropy of structure constrains $H(z)D_A(z)$. Potentially large gains if measured at smaller scale than BAO. Can transfer BAO/SN measures of $D_A(z)$ to H(z), improving dark energy sensitivity.
RSD (the peculiar velocity part) is a systematic for AP.

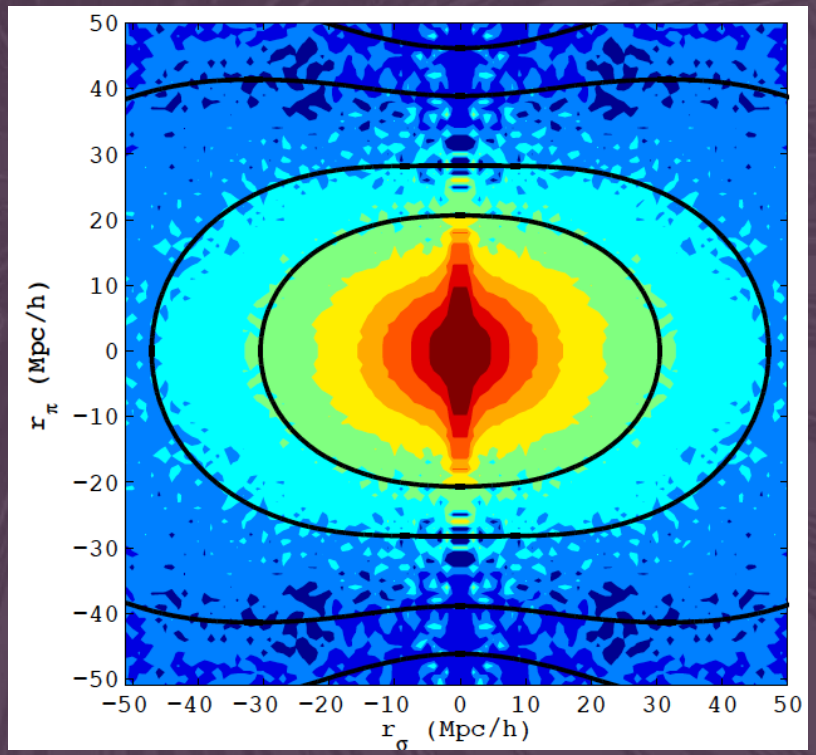
Peculiar Velocity Distortions

Coherent peculiar velocities compress large scale overdensities along the line of sight.

Incoherent velocity dispersions in collapsed structures stretch them along the line of sight, producing “fingers of God.”



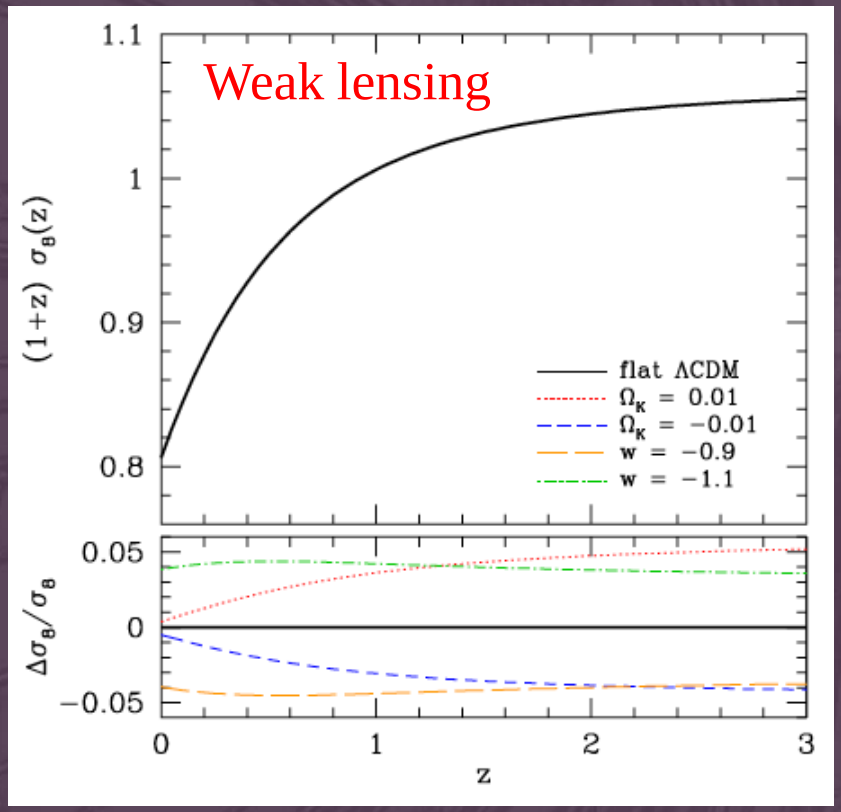
Hamilton 1998 (Kaiser 1987)



Reid et al. 2012, BOSS

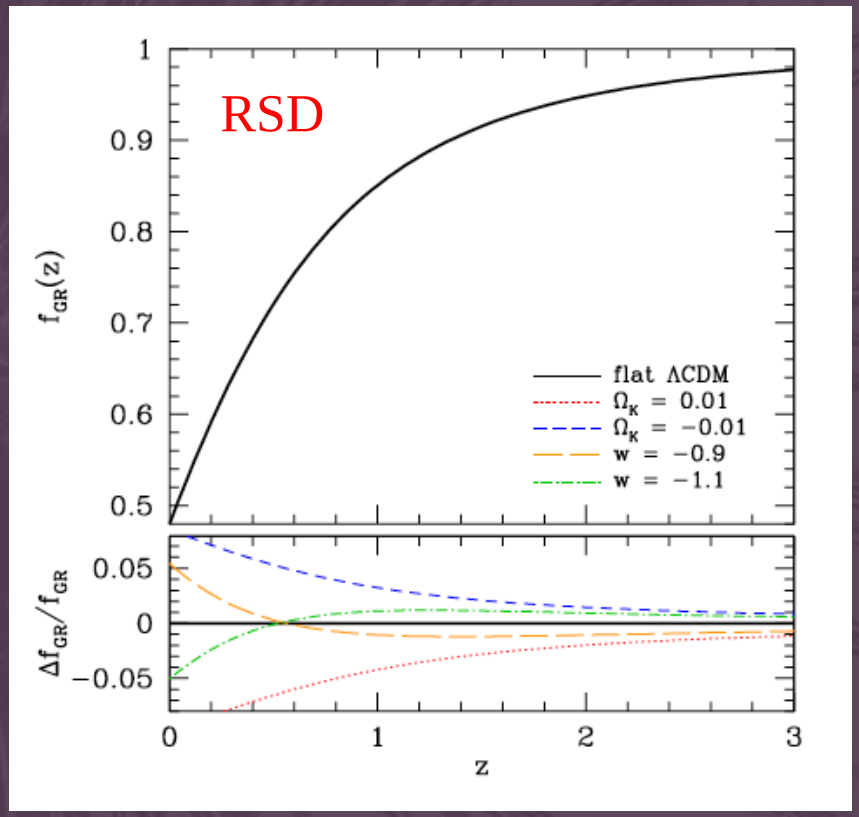
In General Relativity, large scale fluctuations grow in proportion to linear growth factor G(z), with logarithmic growth rate

$d\ln G/d\ln a = f(z) \approx [\Omega_m(z)]^\gamma$



Matter fluctuation amplitude

$\sigma\ (R = 8h^{-1}\ \mathrm{Mpc}) = \sigma_8$



Logarithmic growth rate

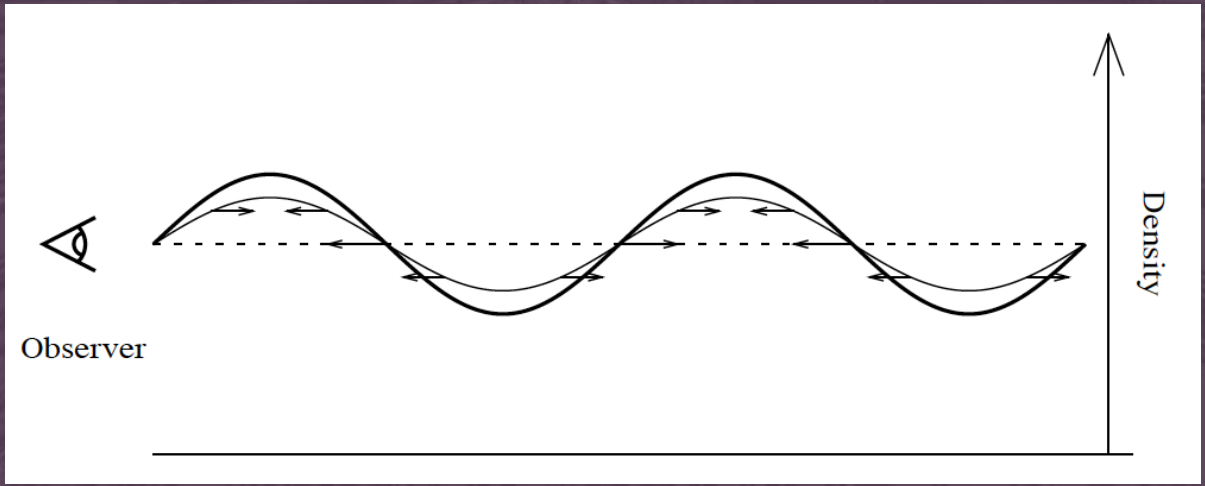
Linear perturbation theory (Kaiser 1987) for single Fourier mode:

$$\Delta_{g,s} = [b_g + f(z)\mu^2]\,\Delta_{m,r} \quad ; \quad \mu = \cos \mathbf{k} \bullet \mathbf{l}$$

making the power spectrum

$$P_{g,s}(k,\mu) = [b_g + f(z)\mu^2]^2\, P_m(k) \times \exp(-k^2\mu^2\sigma_v^2)$$

where small scale random velocities are incoherent, dispersion σ_v.



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- Use μ-dependence of $P_{g,s}(k,\mu)$ to back out $\sigma_8(z)f(z)$.
- Small scale velocities treated via "nuisance parameters."

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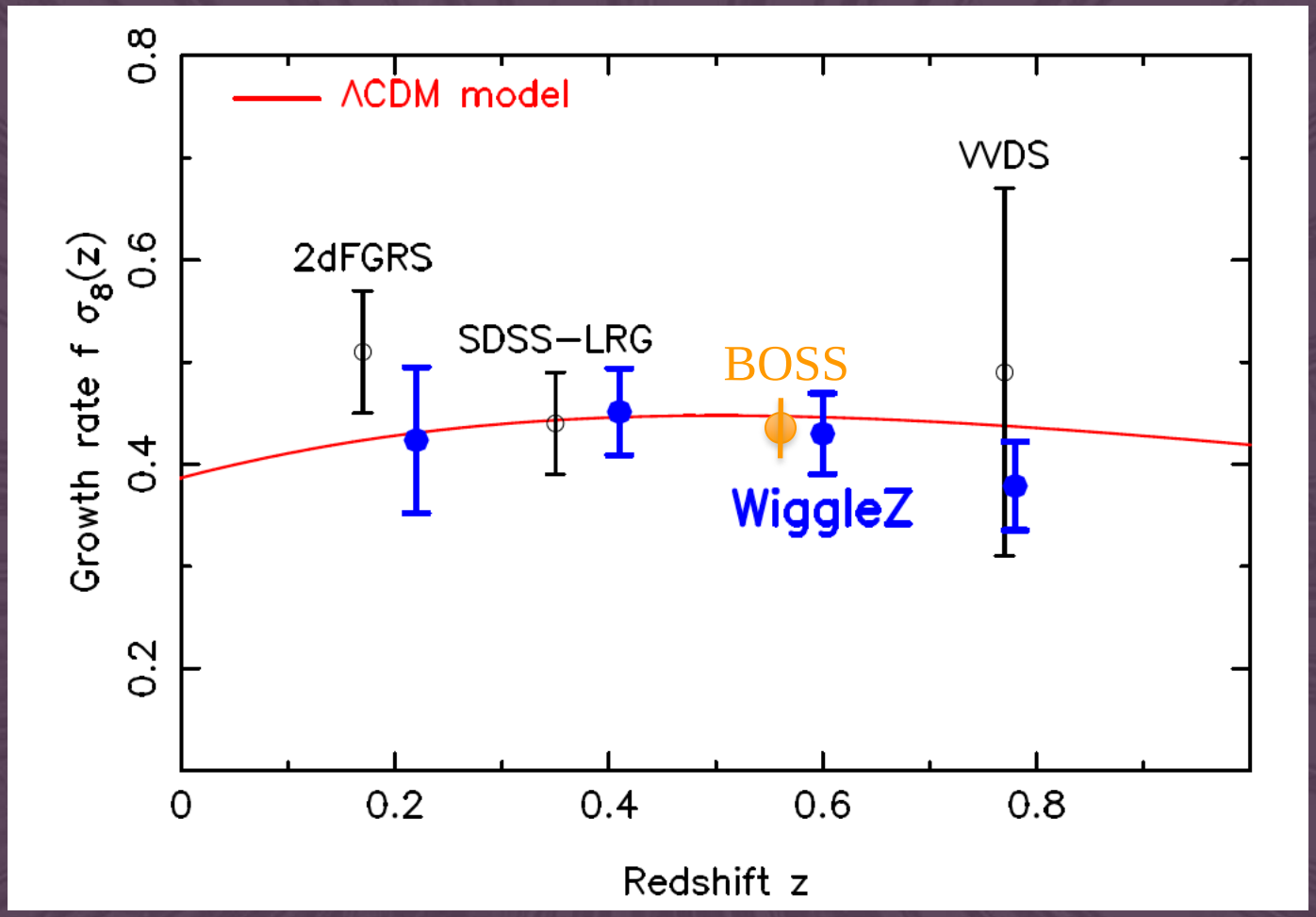
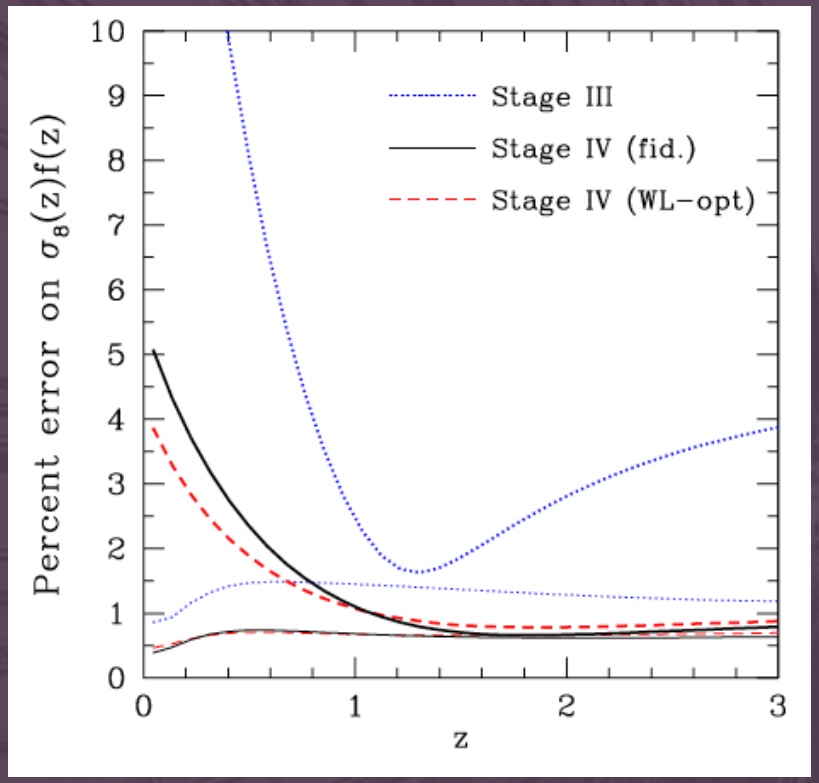
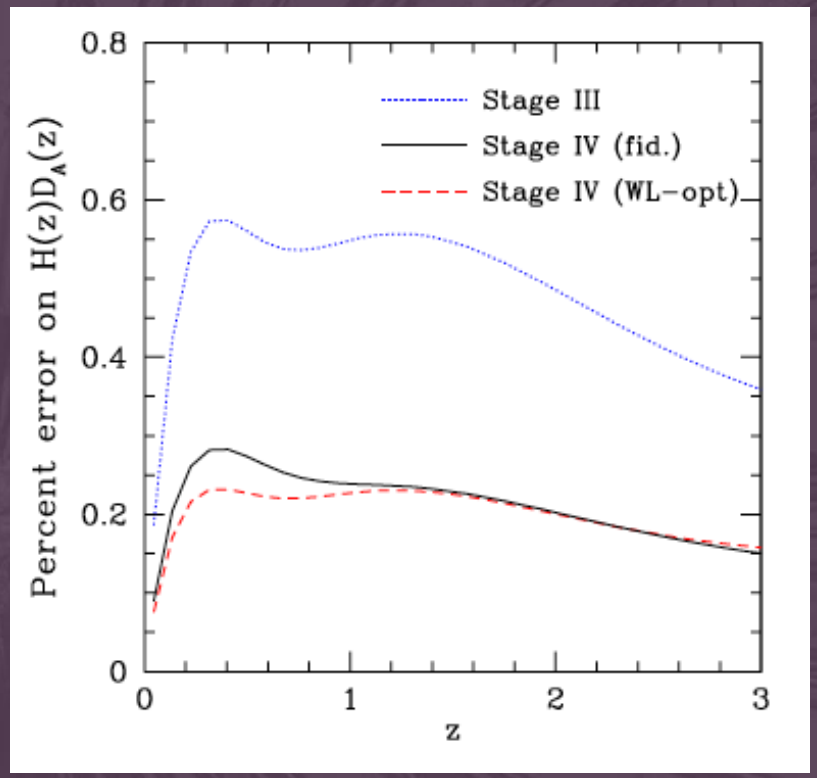
- Use μ-dependence of $P_{g,s}(k,\mu)$ to back out $\sigma_8(z)f(z)$.
- Small scale velocities treated via "nuisance parameters."
- Cross-correlation of tracer populations of different b_g yields additional, mode-by-mode leverage (McDonald & Seljak 2008).
- Recent papers (Bernstein & Cai 2011; Gaztanaga et al 2011; Cai & Bernstein 2012) suggest that overlapping WL and spectroscopic surveys can yield significantly better constraints than non-overlapping surveys.
- In essence, WL by redshift survey galaxies calibrates absolute scale of b_g. Expected gain is quite dependent on details of surveys.



Blake et al. 2011, plus Reid et al. 2012 (BOSS)

From Weinberg, Mortonson, Eisenstein, Hirata, Riess, & Rozo 2012





Blue curves show the forecast precision of the predicted values of the RSD (left) and AP (right) observables from a Stage III CMB+SN+BAO+WL program, assuming w_0-w_a dark energy. In left panel, lower curve assumes GR, upper curve does not.

Forecasting "full P(k)" performance

- Dark energy forecasts for redshift surveys often have "BAO only" and "full P(k)", where most of the information in the latter comes from RSD and AP.
- The main systematic is ability to model effects of non-linear evolution and galaxy bias at the required level of accuracy.
- This is usually characterized by k_{max}, the wavenumber up to which P(k) can be used for cosmological information. Non-linear effects are at the few percent level at $k \approx 0.1$ h/Mpc.
- Constraining power grows rapidly with k_{max} (since $N_{modes} \sim k^3_{max}$)
- Effective value of k_{max} is *survey dependent* ; for a bigger survey, statistical errors are smaller, so demands on accuracy are higher.
- Modeling ability currently demonstrated at the few-percent level. To exploit DESpec survey, would want to get well below 1% accuracy to achieve precision of $k_{max} \approx 0.1$-0.2 h/Mpc.

Remaining plots are from the BigBOSS-DES JWG report.

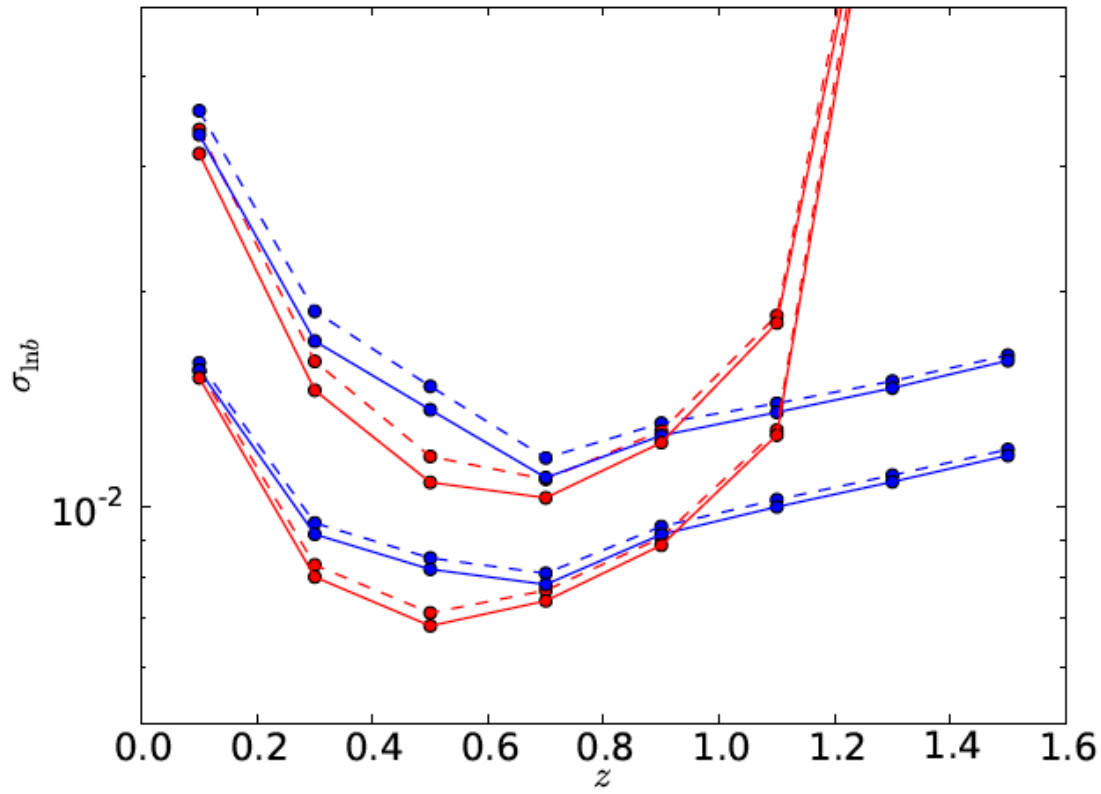
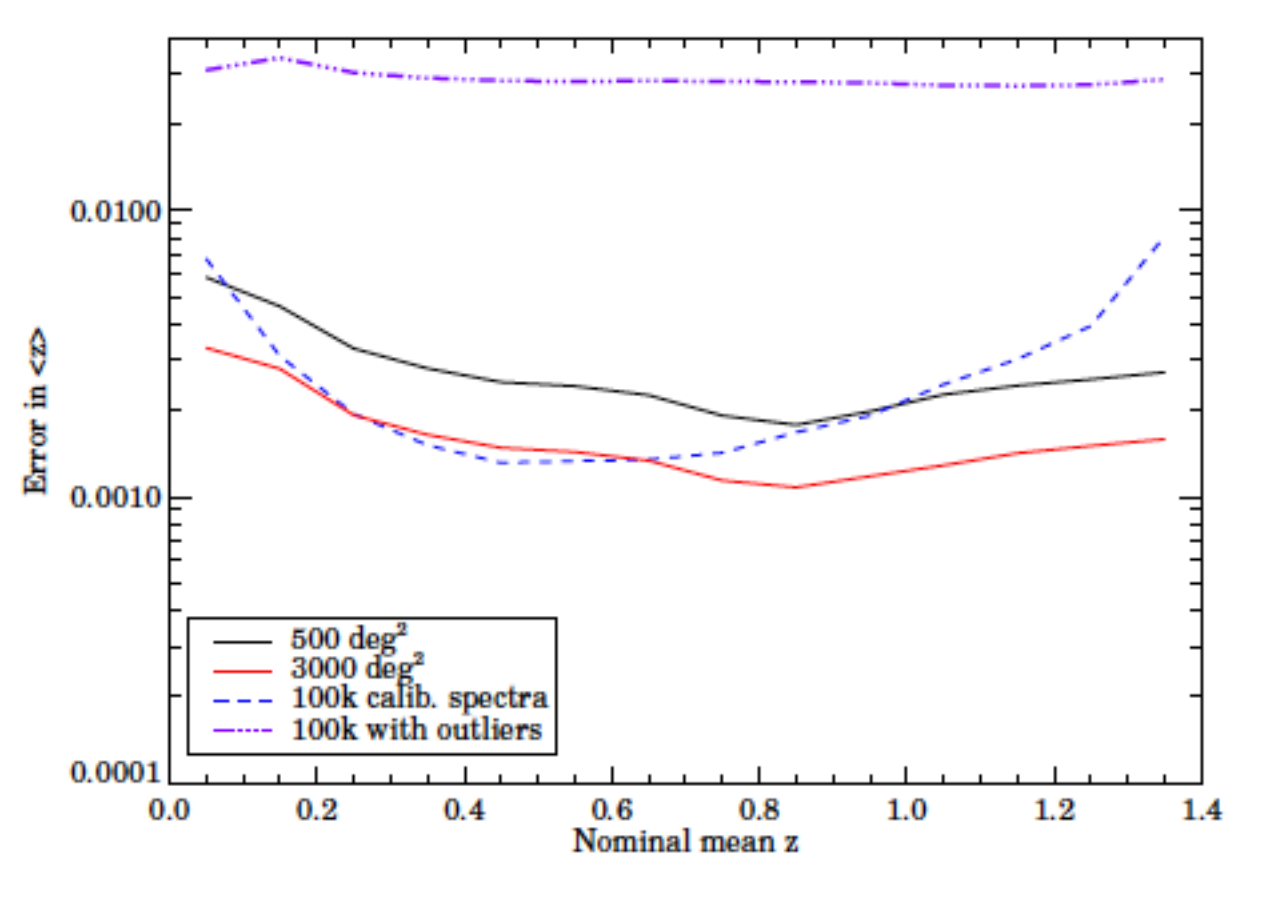
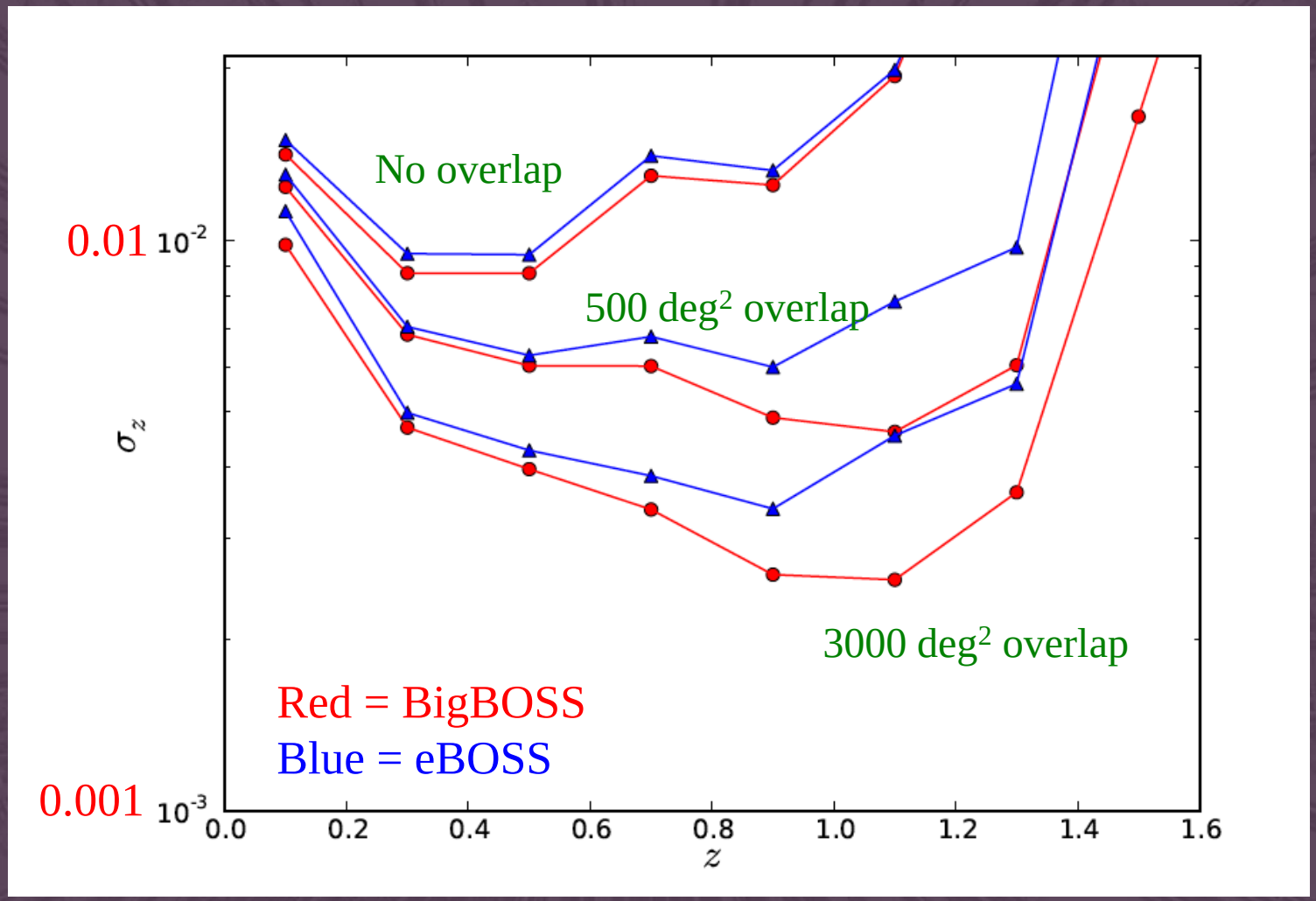


Fig. 1.— Fractional errors on BigBOSS galaxy bias parameters. Red is LRG, blue is ELG. Solid is with 3000 sq. deg. overlap, dashed is 0 overlap. This is with no systematic errors for photometric redshifts. Upper is $k < 0.05\,h\,\mathrm{Mpc}^{-1}$, lower is $k < 0.1\,h\,\mathrm{Mpc}^{-1}$ (for redshift space power).

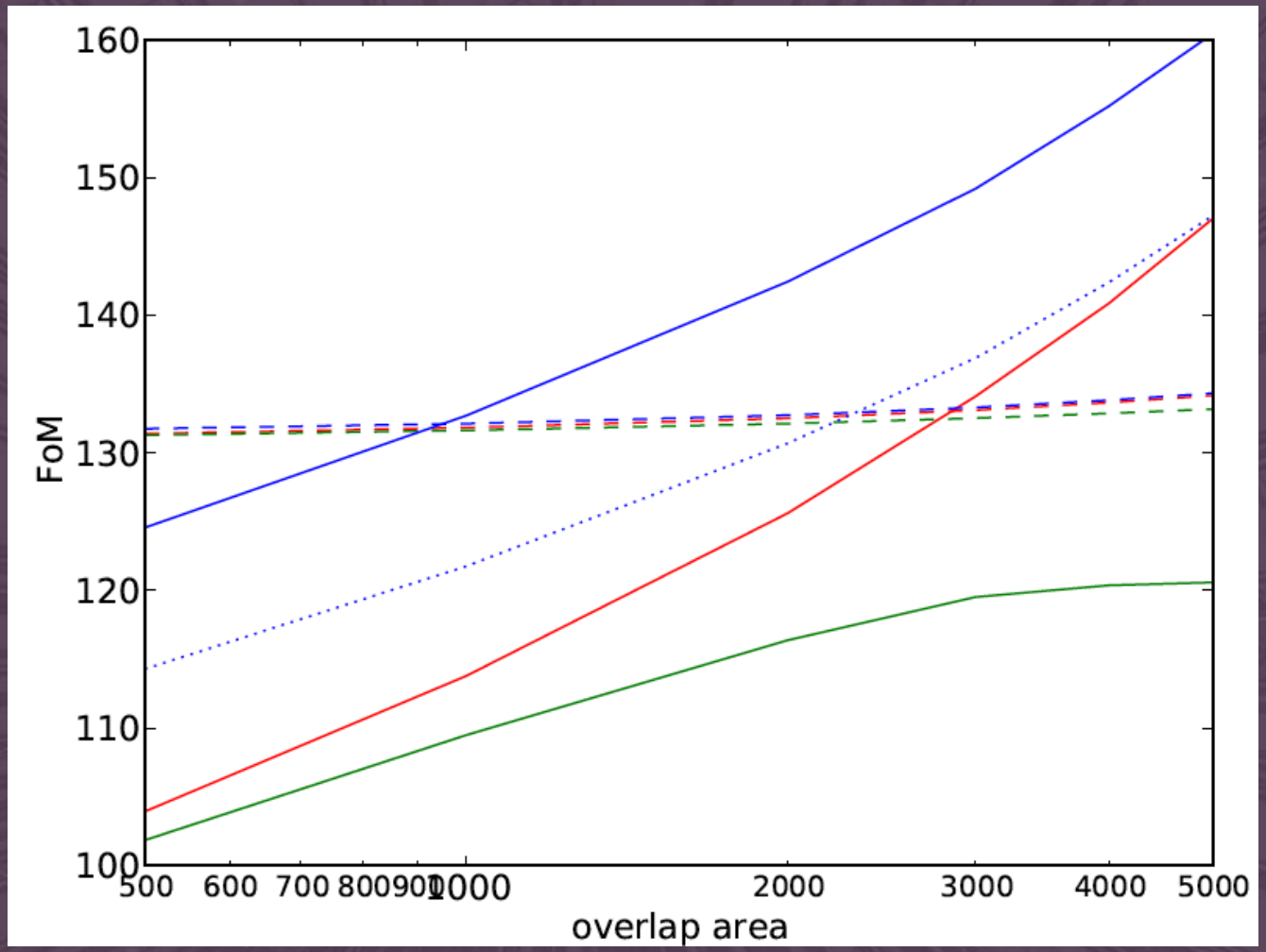
BigBOSS RSD on its own provides good internal calibration of galaxy bias factors.
WL cross-calibration only marginally improves the growth constraints from RSD.



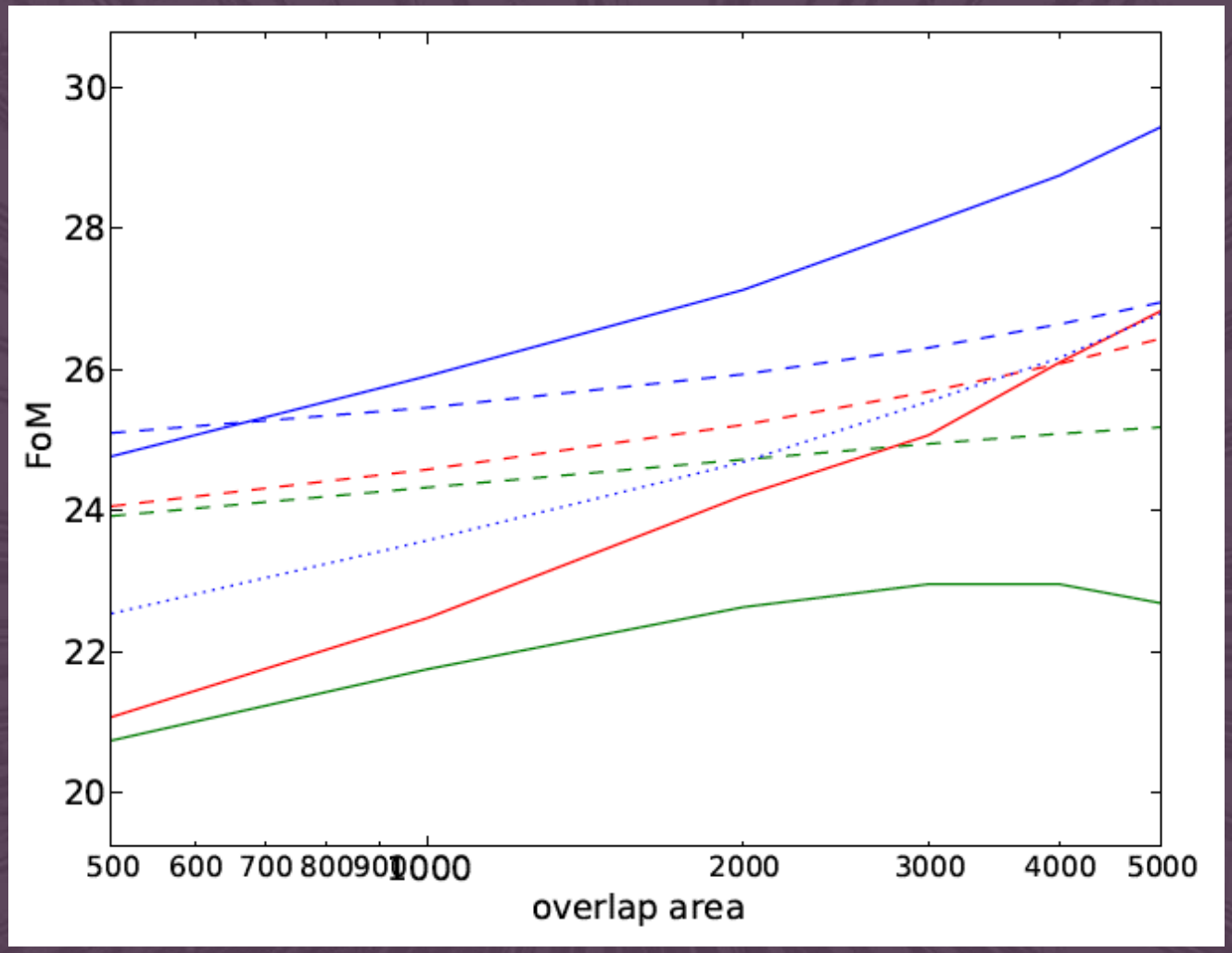
Cross-correlation can yield much better photo-z calibration than even a 100%-complete 10^5-galaxy spectroscopic sample with 5% outlier fraction.



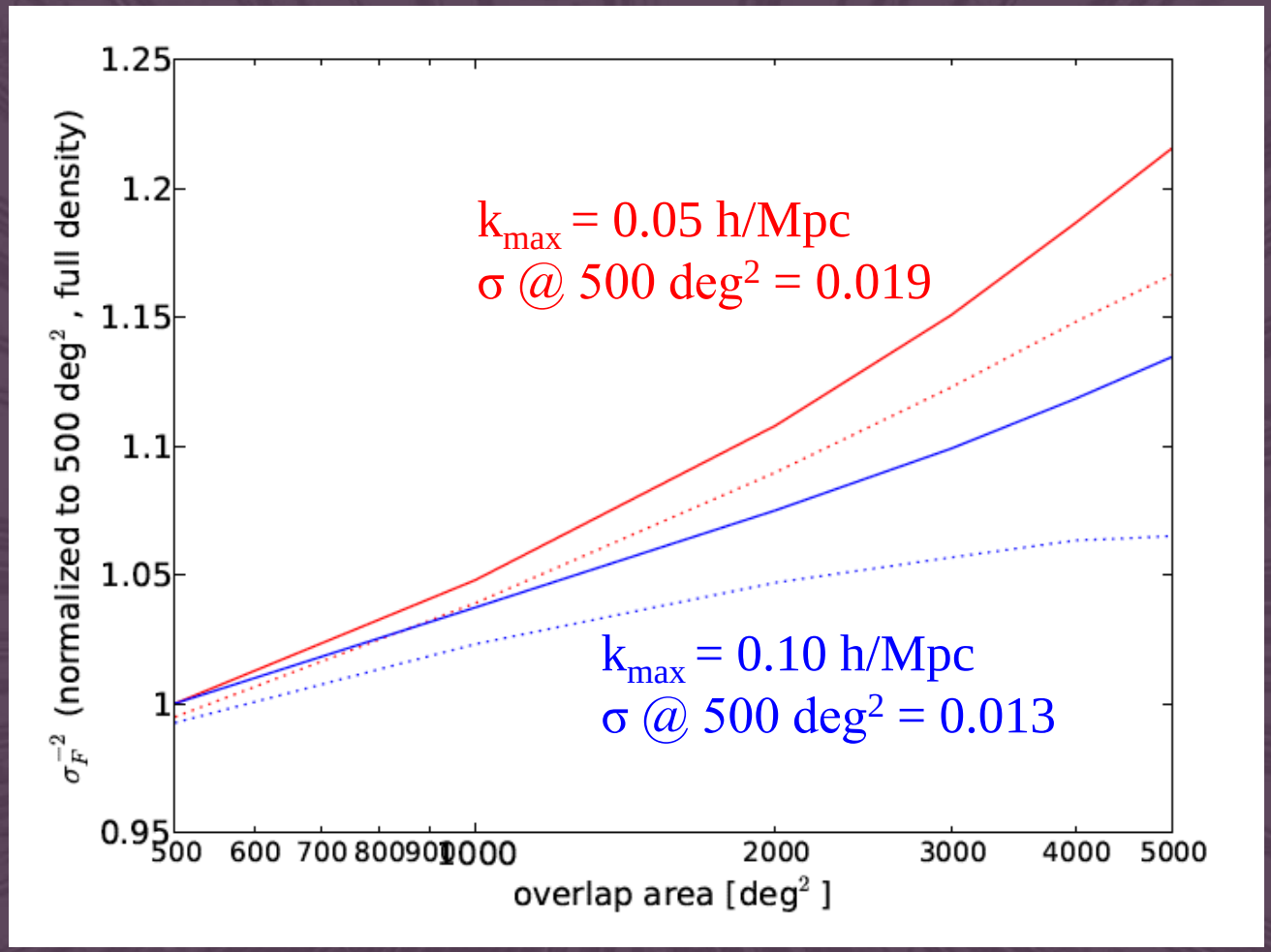
Marginalized errors on photo-z offsets from large scale (l < 2000, roughly k < 0.15 h/Mpc) cross-correlation w/ BigBOSS or eBOSS galaxy redshift survey.



Red curve: Modified gravity FoM = 0.4 $(\sigma_\gamma\ \sigma_{\ln G9})^{-1}$ from DES WL (no RSD), with photo-z calibration from BigBOSS x-corr, as a function of overlap area.



Equivalent plot for eBOSS replacing BigBOSS.



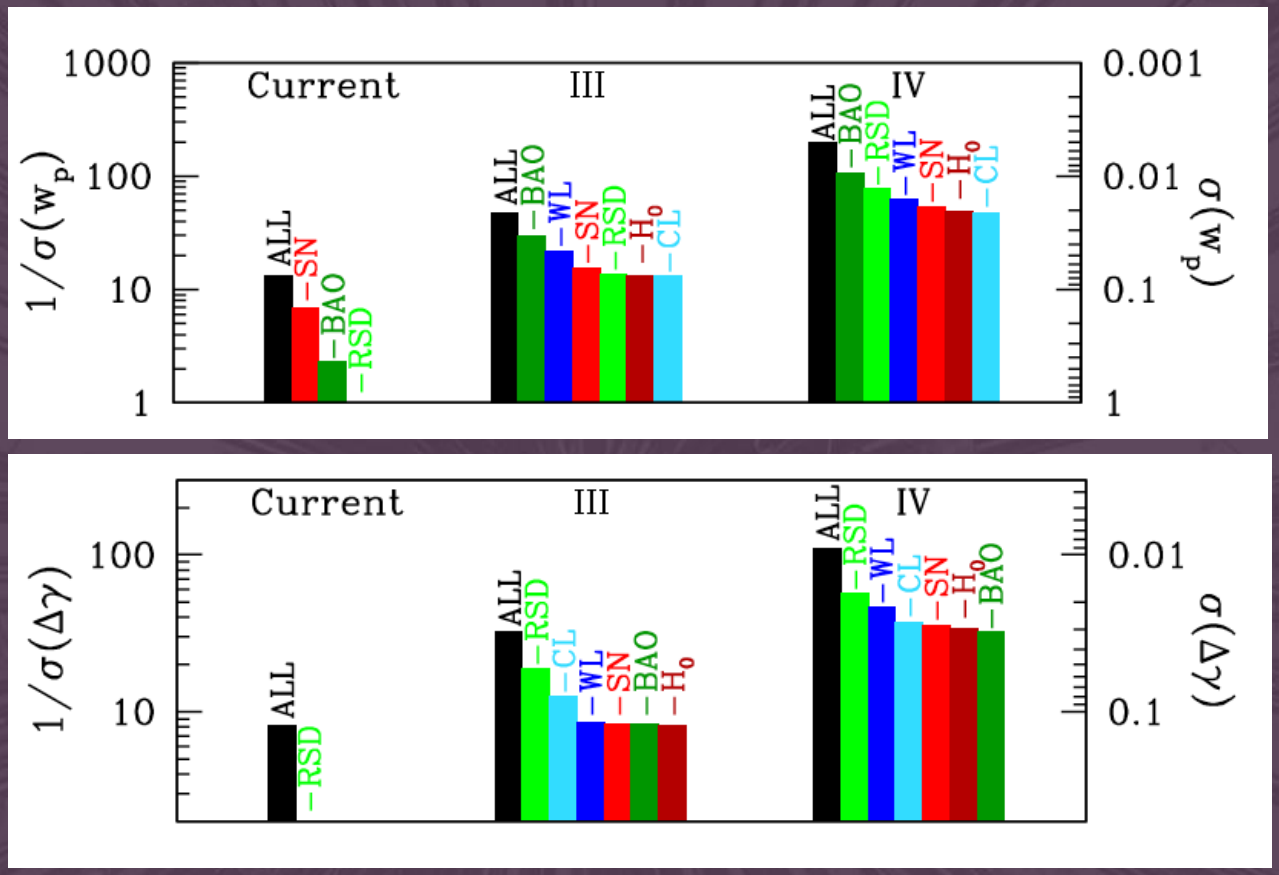
Error (inverse variance) on a multiplicative offset between potentials determining WL and RSD. Important test of modified gravity scenarios.

Some Concluding Remarks

- Joint imaging/spectroscopic surveys allow broader science and higher quality science.
- For BAO, because of low systematics, the natural goal is to map the entire high-latitude volume out to $z \approx 3$. Experiments in the same redshift range but different sky areas are NOT redundant.
- For DES WL, cross-correlation may be the best way to calibrate photo-z's at level demanded by statistical precision of data.
- RSD and AP can dramatically improve DE constraints if they can be exploited to $k_{max} \approx 0.1$-0.2 h/Mpc (sub-percent accuracy).
- RSD at this level can probably overwhelm DES WL constraints on γ. WL more competitive for amplitude offset (G_9).
- Consistency between RSD and WL growth measures is itself an important modified gravity test.
- Methods for extracting cosmological information will probably improve a lot by the time a DESpec survey is underway.

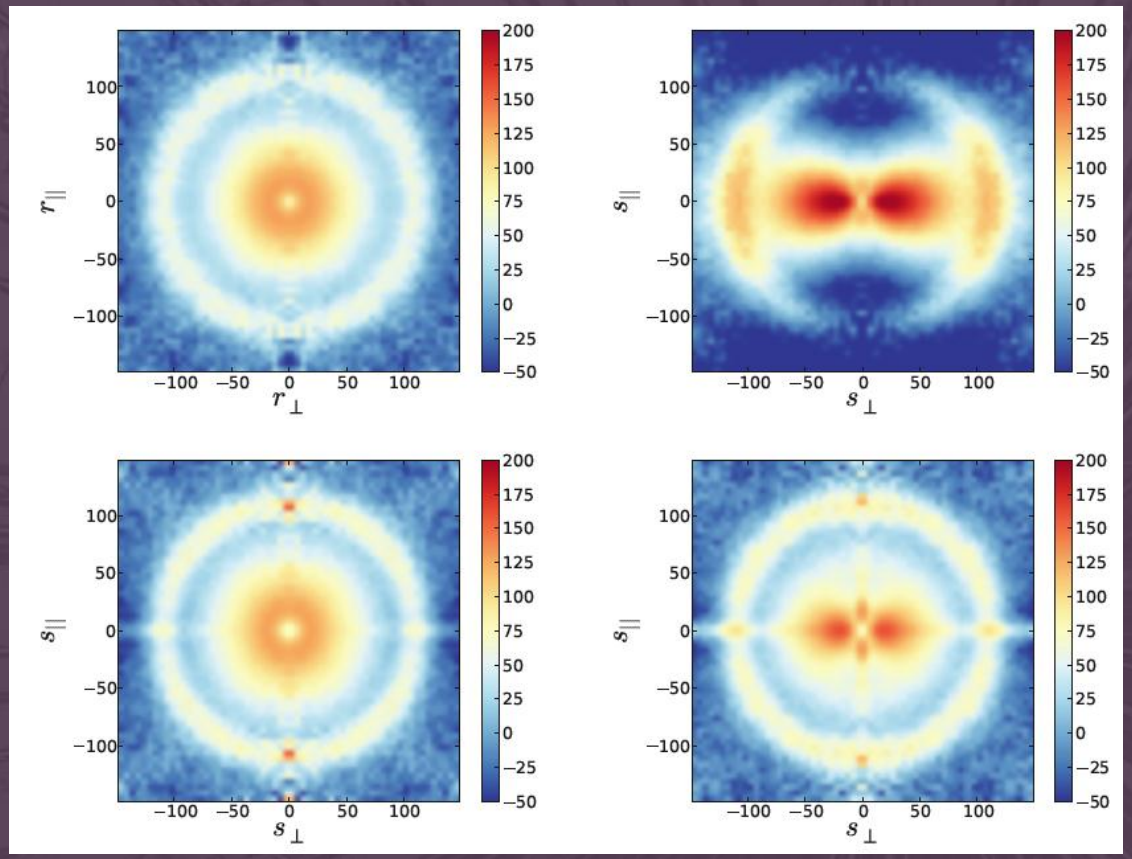
Backup Slides

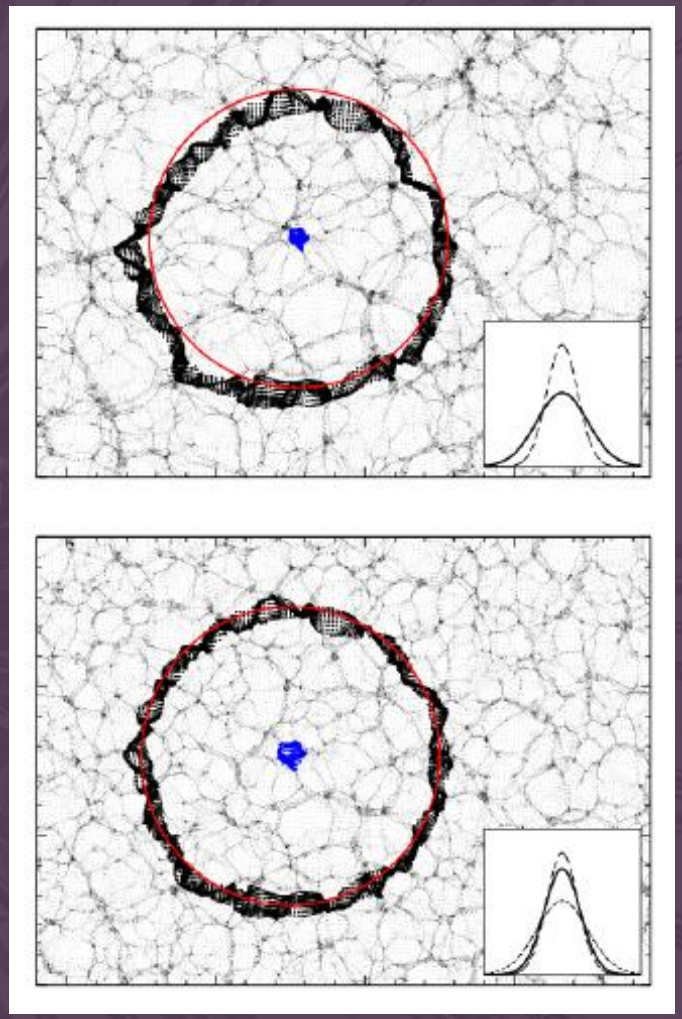
Forecast errors from a notional 6-probe program (+ CMB)



Acceleration review, fig. by M. Mortonson

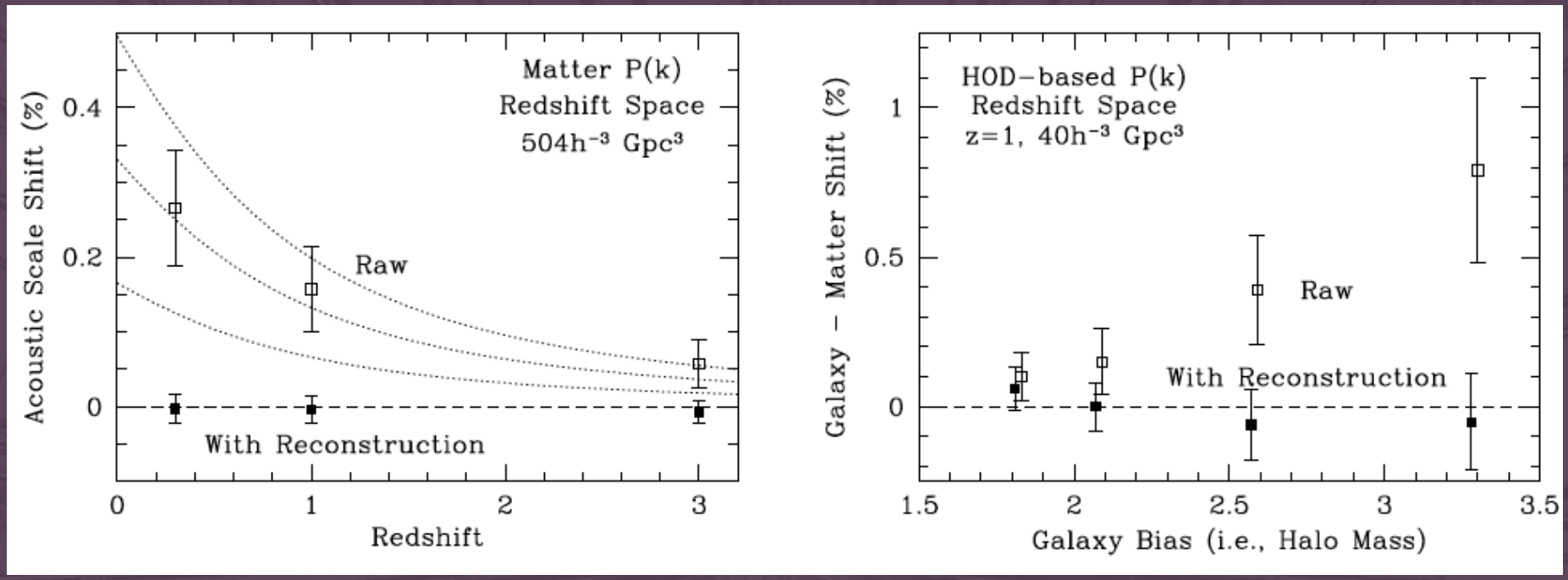
Probes dropped in order of leverage. Note *potentially* powerful contribution from redshift-space distortions (RSD).





BAO reconstruction sharpens acoustic peak and removes non-linear shift by “running gravity backwards” to (approximately) recover linear density field.

Figs from Padmanabhan et al. 2012.

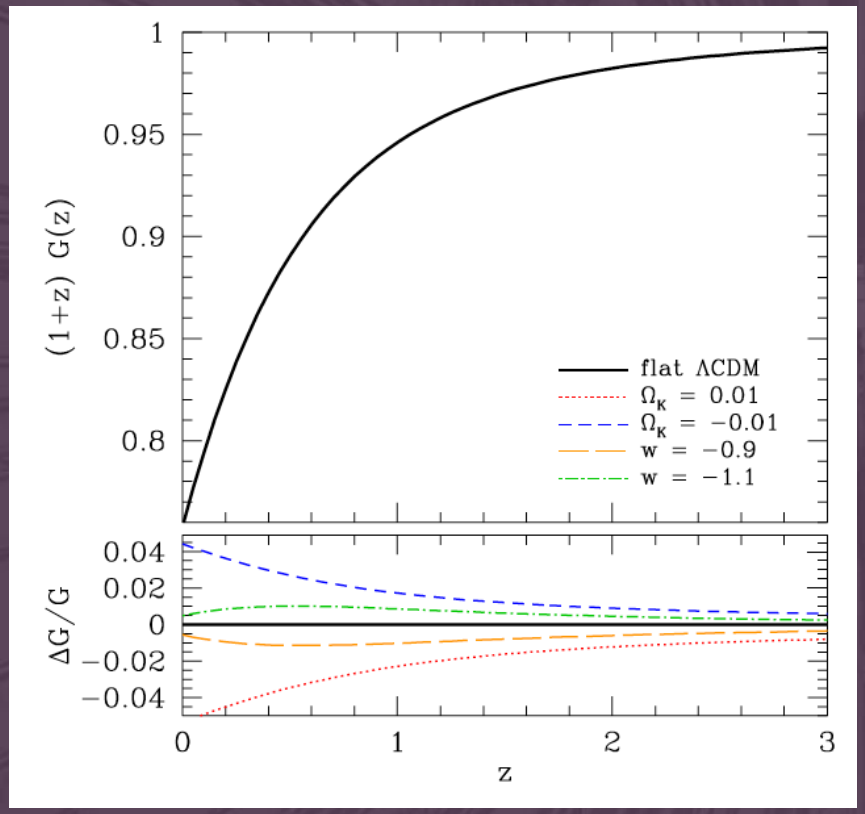


BAO robustness: Current simulations imply 0.1 – 0.3% shifts of acoustic scale from non-linear evolution, somewhat larger for highly biased tracers. Reconstruction removes shift at level of 0.1% or better.

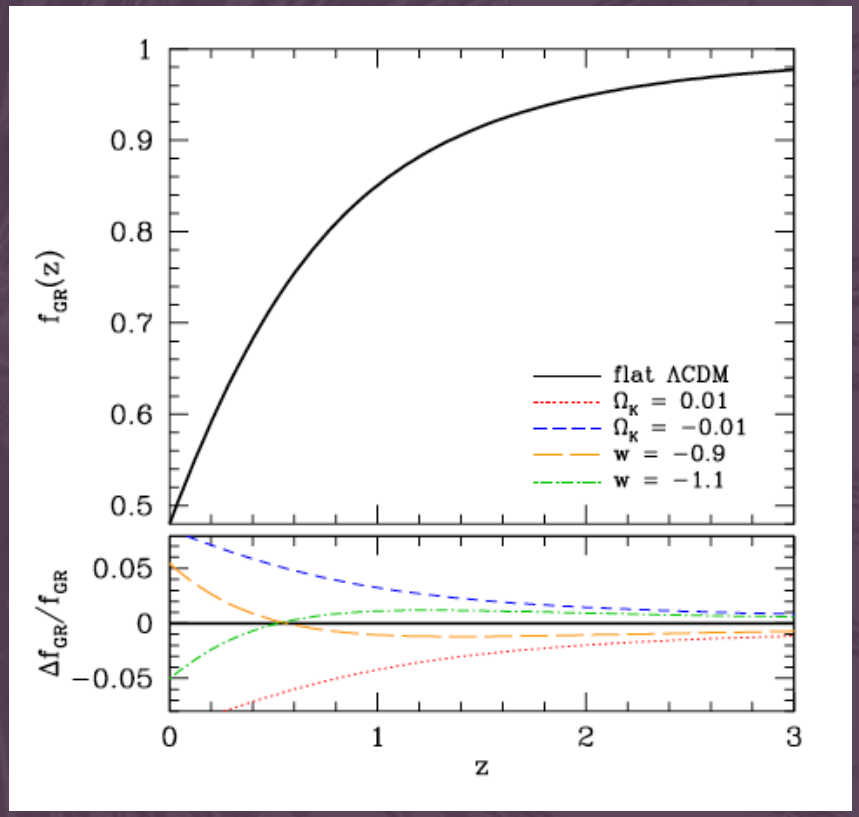
Figs originally from Seo et al. (2010) and Mehta et al. (2011).

In General Relativity, large scale fluctuations grow in proportion to linear growth factor G(z).

Logarithmic growth rate $d\ln G/d\ln a = f(z) \approx [\Omega_m(z)]^\gamma$



Linear growth factor



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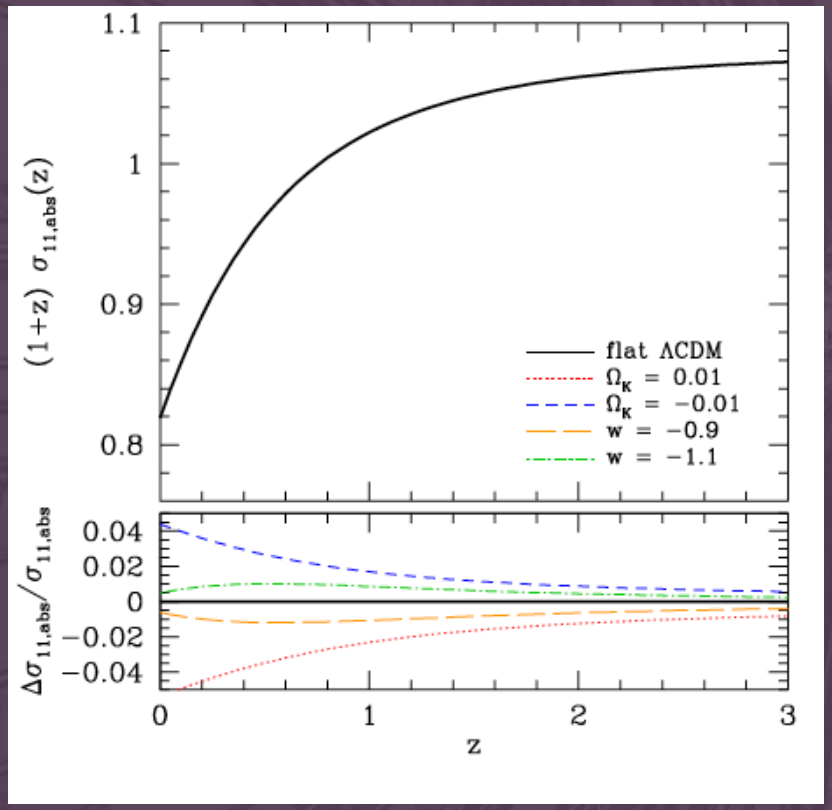
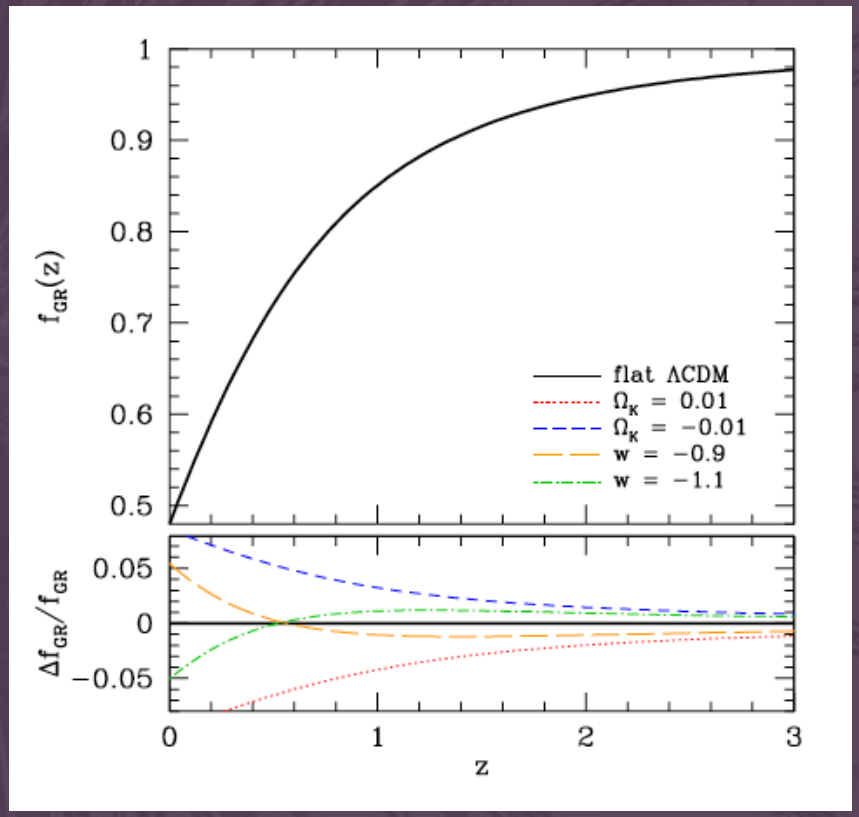


Matter fluctuation amplitude

σ (R = 11 Mpc) = $\sigma_{11,abs}$



Logarithmic growth rate

Table 1: Effect of overlapping BB/DES-like redshift and imaging surveys, compared to no overlap. The BigBOSS area is always 14000 sq. deg., and the full broadband power spectrum is used to the given $k_{\max}$ (measured in $h\,\mathrm{Mpc}^{-1}$). Full standard BAO information is always used. The calculation is done in redshift slices with $\Delta z = 0.2$. Note that our calculation of the DETF FoM $[\sigma(w_p)\sigma(w_a)]^{-1}$ is after marginalizing over γ and G_9; i.e., we do not assume GR when computing this FoM.

case	DES area	overlap area	$k_{\max}$	σ_γ	$\sigma_{\ln G_9}$	DE FoM (w/γ)
	0	0	0.1	0.0247	0.0288	174
1	5000	0	0.1	0.0215	0.0174	220
2	5000	3000	0.1	0.0214	0.0171	222
3	5700	0	0.1	0.0213	0.0169	222
	0	0	0.05	0.0472	0.0375	129
4	5000	0	0.05	0.0377	0.0206	146
5	5000	3000	0.05	0.0369	0.0204	147
6	6100	0	0.05	0.0369	0.0199	147
	0	0	0	∞	∞	122
7	5000	0	0	0.0828	0.0314	133
8	5000	3000	0	0.0793	0.0300	134
9	5700	0	0	0.0780	0.0297	134

Table 2: Effect of overlapping BB/DES-like redshift and imaging surveys, compared to no overlap. From BigBOSS we use only the angular clustering, e.g., to calibrate DES photo-zs, and BAO, with no broad-band radial power. Redshift bins are $\Delta z = 0.2$. provided by internal DES galaxy density cross-correlations. Line 2a shows that the effective calibration of DES photo-z systematics corresponds to $\sigma_z/(1+z) \simeq 0.0028$. Note that we allow for a systematic change in the width of the distribution as well as the mean, with prior on the rms z width equal to twice the prior on the mean z (motivated by the purple lines in Fig. 3). Line 10a uses the FoMSWG Stage III WL Fisher matrix for DES – we see that our calculation, which does not include shear calibration error, among other things, is relatively optimistic. Lines 13-15, with perfect priors on photo-z offsets, are the same as lines 7-9 of Table 1.

case	DES area	overlap area	prior $\sigma_{\bar{z}}/(1+z)$	σ_γ	$\sigma_{\ln G_9}$	DE FoM (w/γ)
1	5000	0	∞	0.127	0.0460	131
2	5000	3000	∞	0.0885	0.0337	133
2a	5000	0	0.0028	0.0873	0.0331	133
3	12300	0	∞	0.0884	0.0327	137
4	5000	0	0.02	0.115	0.0421	132
5	5000	3000	0.02	0.0879	0.0334	133
6	10300	0	0.02	0.0879	0.0328	136
7	5000	0	0.01	0.103	0.0385	132
8	5000	3000	0.01	0.0869	0.0330	133
9	8200	0	0.01	0.0869	0.0327	135
10	5000	0	0.005	0.0928	0.0350	133
10a	5000*	0	0.005*	0.146	0.0492	126
11	5000	3000	0.005	0.0849	0.0322	133
12	6400	0	0.005	0.0844	0.0321	134
13	5000	0	0	0.0828	0.0314	133
14	5000	3000	0	0.0793	0.0300	134
15	5700	0	0	0.0780	0.0297	134