SDSS III

SLOAN DIGITAL SKY SURVEY III

Anisotropic clustering in the Baryon Oscillation Spectroscopic Survey

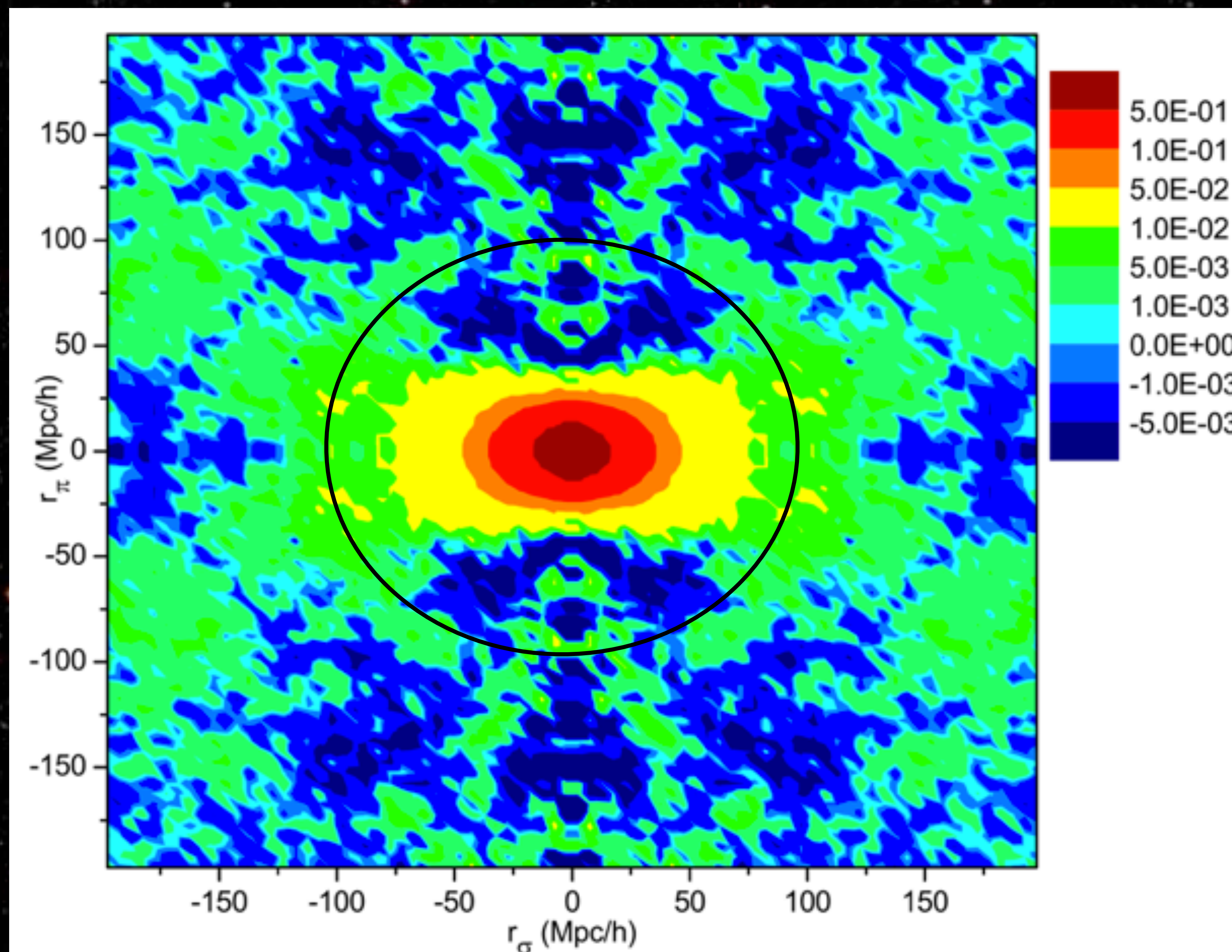
Beth Reid
Hubble Fellow
Lawrence Berkeley National Lab

in collaboration with Martin White, Will Percival, Lado Samushia, BOSS galaxy clustering working group

Motivation for studying Redshift Space Distortions

- Growth function G(a): $\delta(\mathbf{k}, a) = aG(a)\delta_i(\mathbf{k})$
- In General Relativity G(a) is determined once H(a) is specified/measured; generically this relation is different in modified gravity models

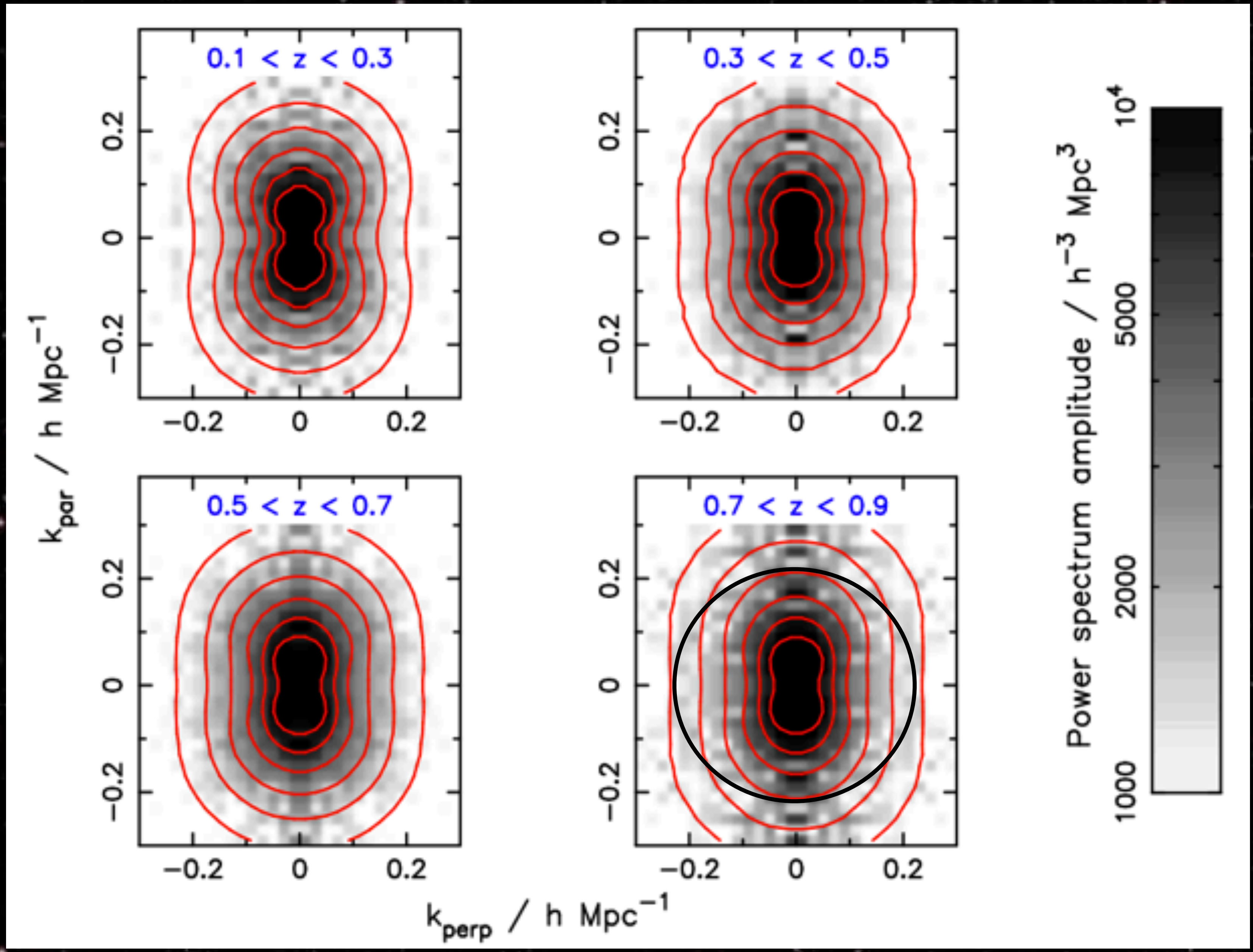
BOSS Anistropic Clustering: $\xi(r_\sigma, r_\pi)$



Reid et al., Samushia et al. (in prep)

WiggleZ Anistropic Clustering: $P(k_\perp, k_\parallel)$

Blake et al., arXiv:1104.2948



Outline

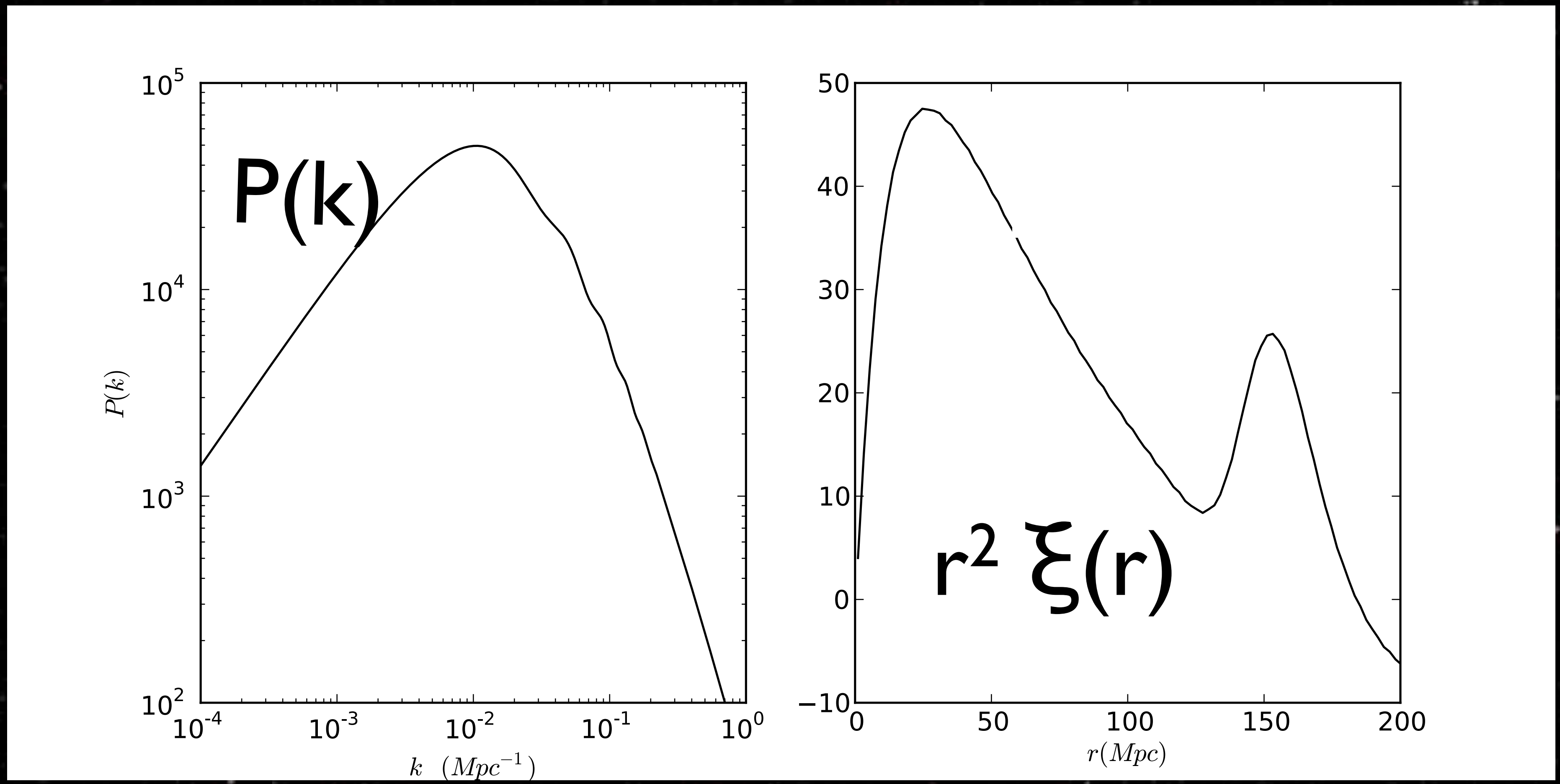
- Our basic model for galaxy clustering
- Anisotropic galaxy clustering
  - Alcock-Paczynski effect
  - Redshift space distortions
- First results from BOSS
- Error budget and future prospects

Galaxy clustering lightning theory review

- Theory I: underlying matter power spectrum (determined at z >~ z_{CMB}, neglecting ν)
- Theory II: Expansion history $H(0 < z < z_{GAL})$

Matter Power Spectrum

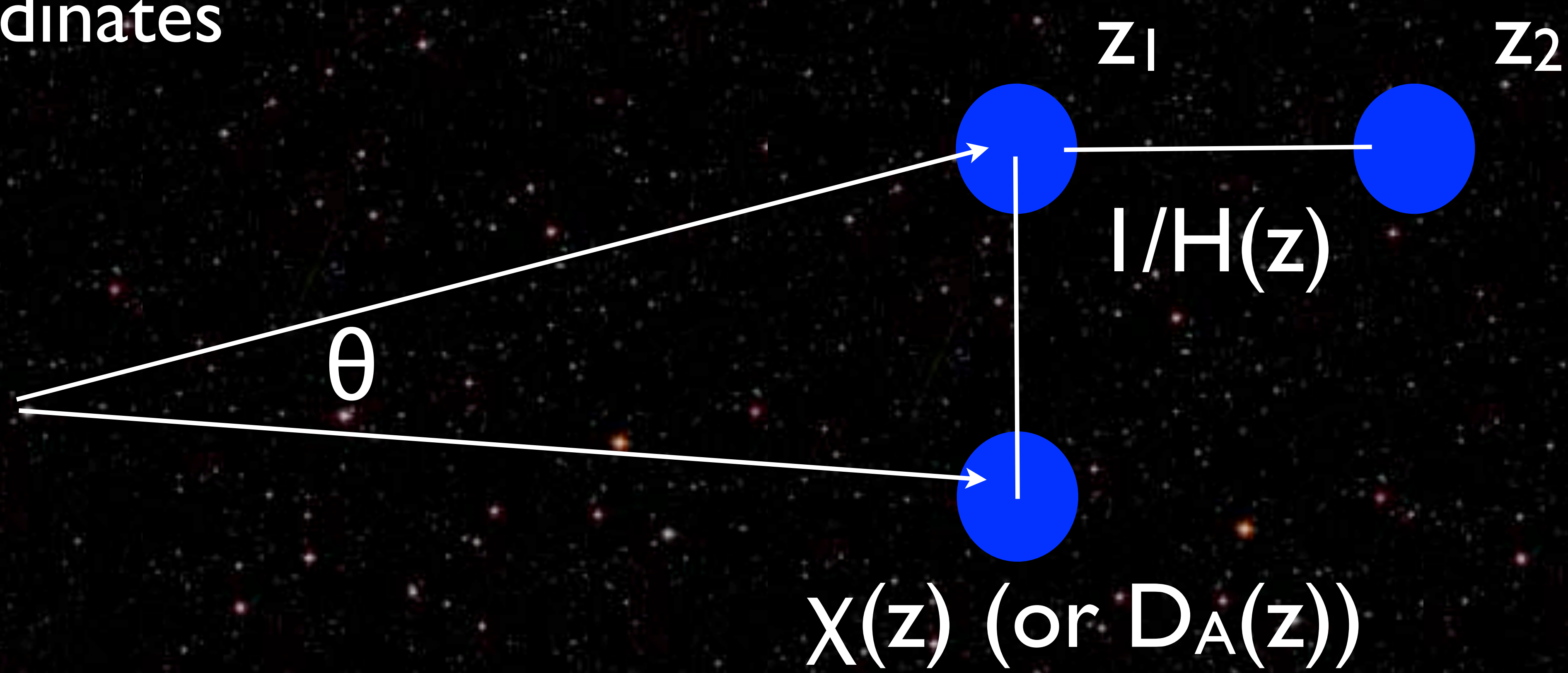
- Entire P(k) (not just BAO) acts as standard ruler determined by CMB
- We marginalize over the (negligible) uncertainty



Mpc^{-1} Mpc

Theory II: geometry

- We measure θ, φ, and z for each galaxy, and use a cosmological model to convert to comoving coordinates



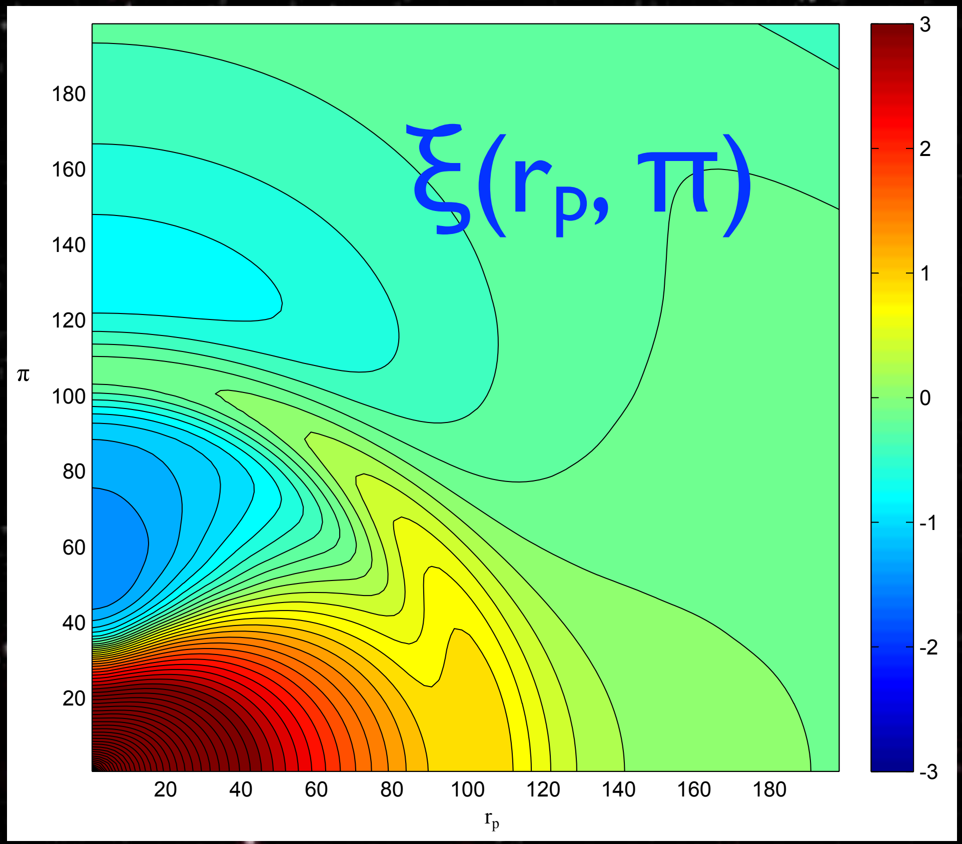
Theory II: Alcock-Paczynski

- $\xi(r_p, \pi)$ appears anisotropic if you assume the wrong cosmological model (constrain $\eta_{AP} = D_A * H$)

$\chi(z) = \int_0^z c\, dz'/H(z')$

BAO in $\xi_0(s)$ determines "geometric mean" $D_V \propto (D_A^2 H^{-1})^{1/3}$

$c\, \Delta z / H(z)$



$\chi(z) * \Delta\theta$

Image from Tian et al. arXiv:1011.2481

Redshift Space Distortions

θ, φ, redshift

↓

depends on the geometry of the universe

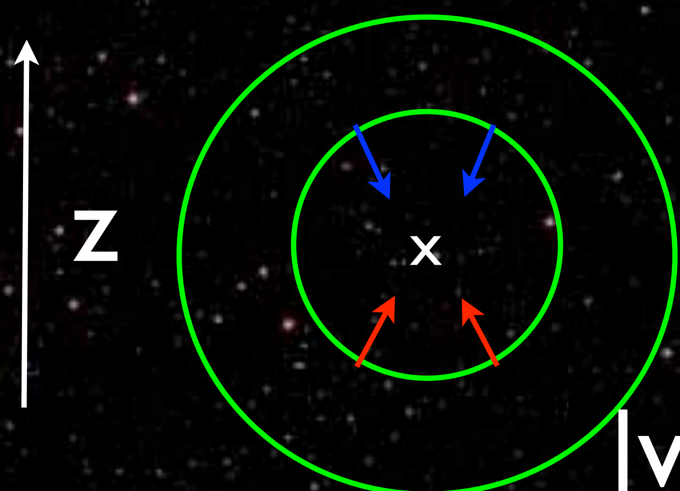
$\chi(z) = \int_0^z c\, dz'/H(z')$

$\chi(z) = \chi_{true} + v_p/aH(a)$

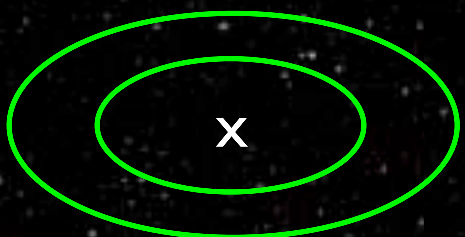
comoving coordinates: x, y, z

Redshift Space Distortions (RSD)

real to redshift space separations



$$\nabla \cdot \mathbf{v_p} = -aHf\,\delta_m$$



$$|v_p| \sim d\,\sigma_8/d\ln a = \sigma_8 * f$$

isotropic

squashed along line of sight

$$f = d\ln \sigma_8 / d\ln a \approx \Omega_m^{\gamma}$$

RSD: linear theory (Kaiser 1987)

$$\delta_g^s(k) = (b + f\mu_k^2)\delta_m^r(k)$$

$$\mu_k^2 = k_z^2/k^2$$

Legendre Polynomial moments: P(k)

General Expansion

$$P(k,\mu_k) = \sum_{\ell} P_\ell(k) L_\ell(\mu_k)$$

Linear theory prediction

$$\begin{pmatrix} P_0(k) \\ P_2(k) \\ P_4(k) \end{pmatrix} = P^r_m(k) \begin{pmatrix} b^2 + \frac{2}{3} bf + \frac{1}{5} f^2 \\ \frac{4}{3} bf + \frac{4}{7} f^2 \\ \frac{8}{35} f^2 \end{pmatrix}$$

Legendre Polynomial moments: ξ(r)

General Expansion

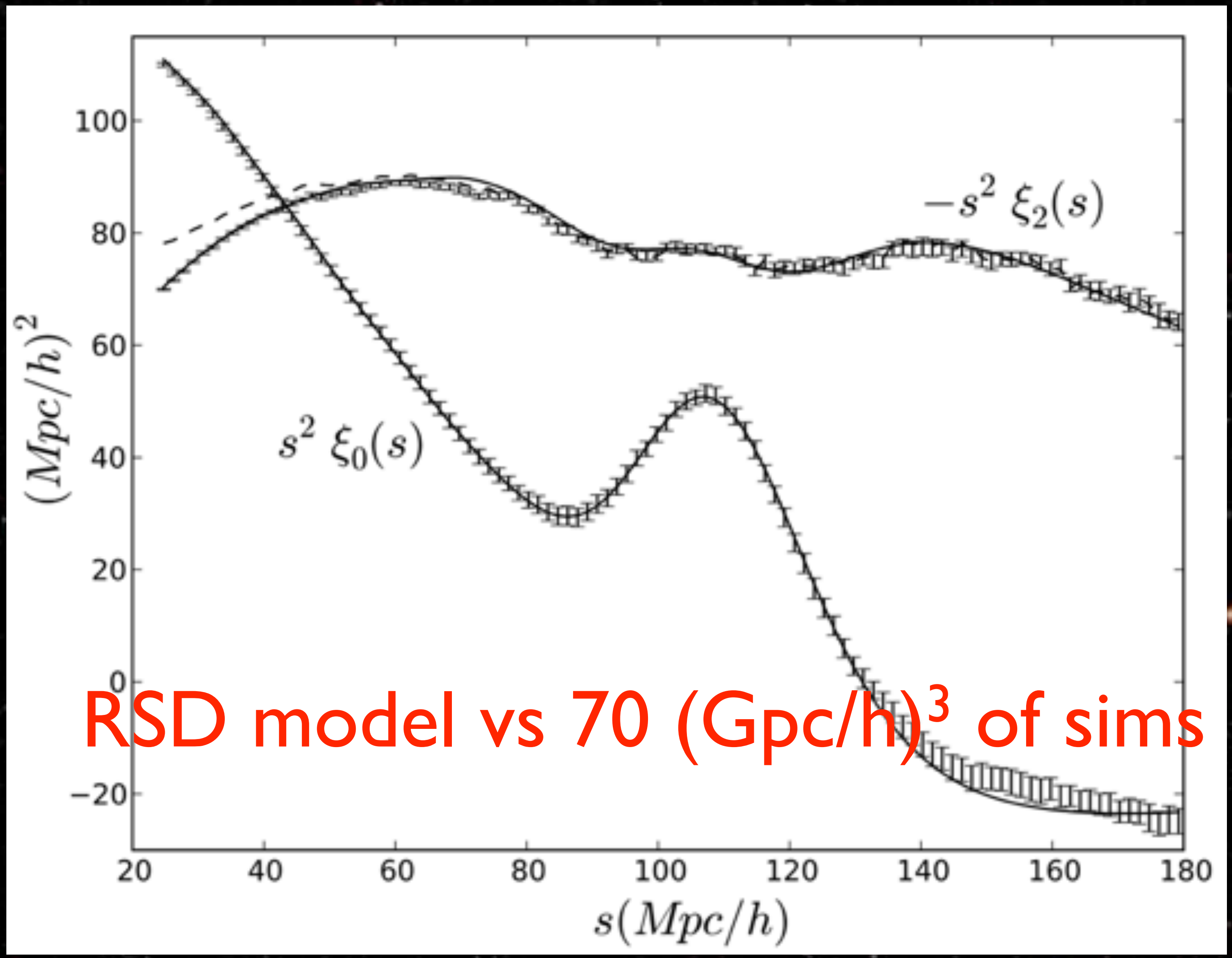
$$\xi(s, \mu_s) = \sum_{\ell} \xi_\ell(s) L_\ell(\mu_s)$$

Relation to $P_\ell(k)$

$$\xi_\ell(s) = i^\ell \int \frac{k^2\, dk}{2\pi^2} P_\ell(k) j_\ell(ks)$$

Modeling RSD: Reid and White 2011 (arXiv: 1105.4165)

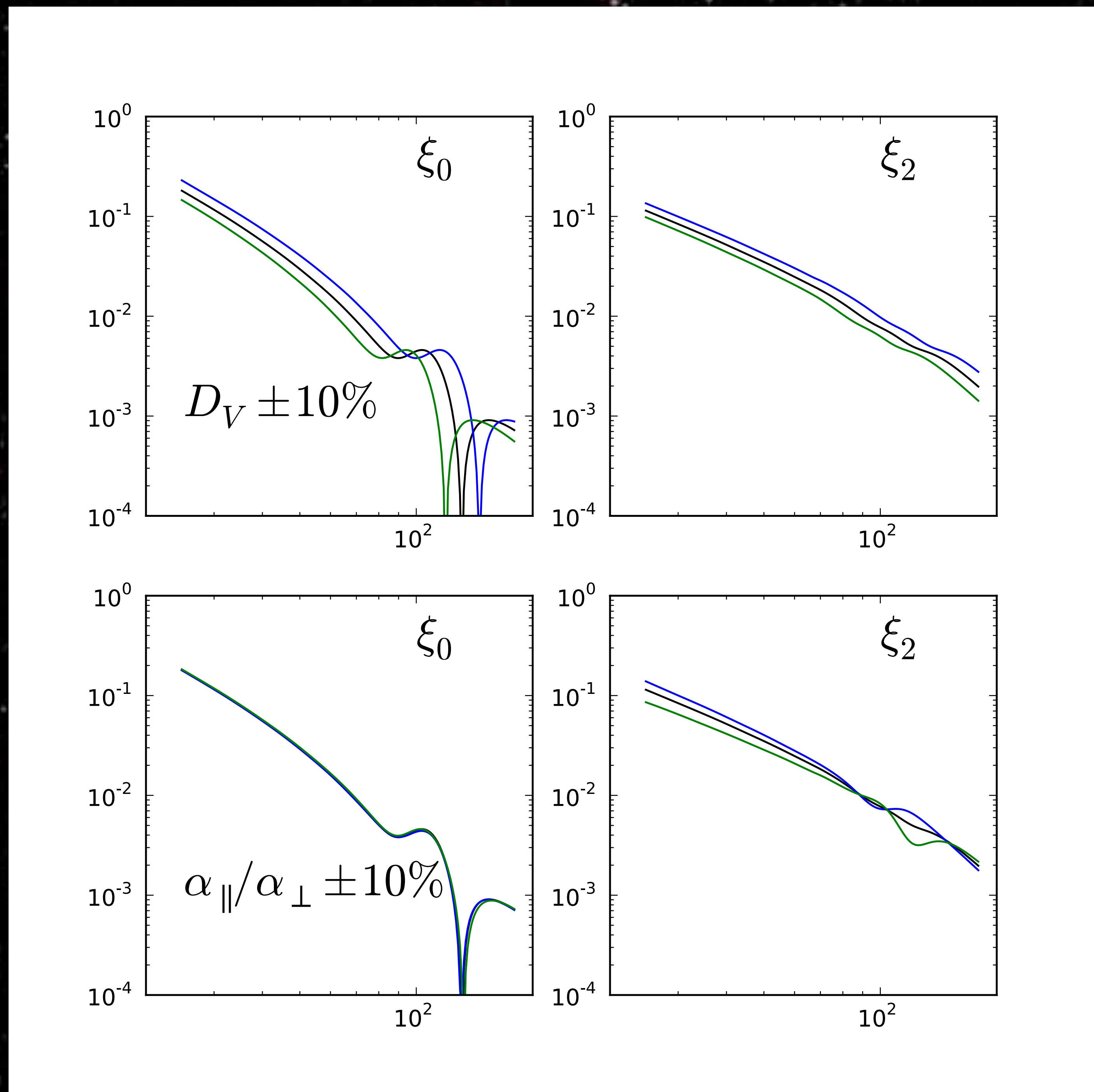
- ξ_0, ξ_2 sufficient to constrain $b\sigma_8$, $f\sigma_8$; MOST of 2d clustering information retained



Fitting to 2d clustering

- Use full model of $\xi_{0,2}(s \geq 25\ h^{-1}\ \mathrm{Mpc})$ to constrain:
  - growth of structure ($f\sigma_8$)
  - $D_V \propto (D_A^2/H)^{1/3}$
  - Alcock-Paczynski ($\eta_{AP} \propto D_A(z_{eff}) * H(z_{eff})$)
  - marginalizing over shape of underlying linear $P(k)$, $b\sigma_8$, σ^2_{FOG}

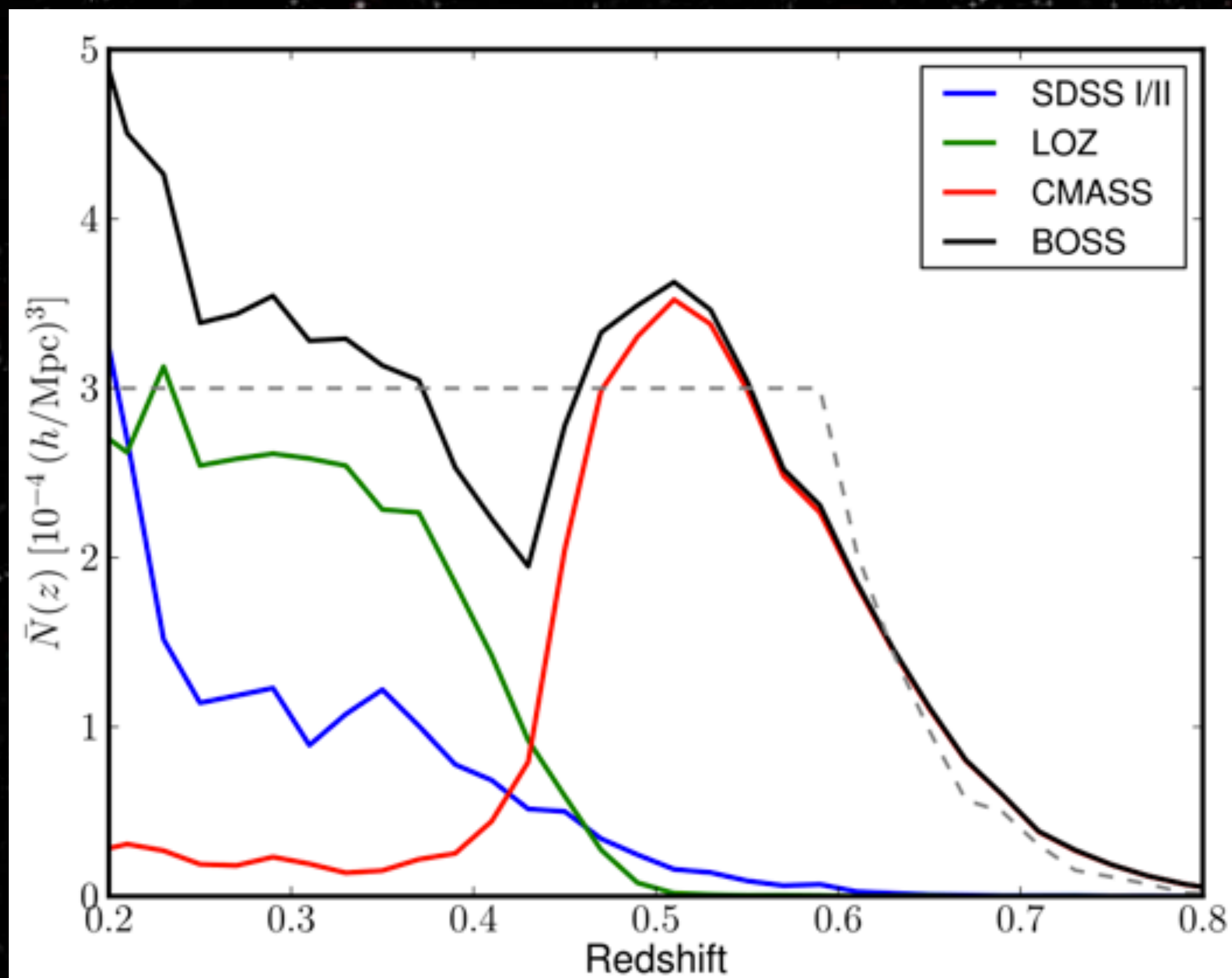
Alcock-Paczynski in multipoles



DR9 spectroscopic results: preliminary!

- DR9 data final (public July 2012), clustering/covariances ~final, cosmological constraints preliminary
- Current uncertainties reported, not central values

BOSS "CMASS" (z_{eff} = 0.57) galaxy sample in perspective



Eisenstein et al. arXiv:1101.1529

BAO fits in P(k)/ξ(r) consistent

X. Xu et al. (in prep; DR7)
BOSS Galaxy Clustering (in prep.)

BAO fit plot was here

- 2-3% uncertainty on BAO position in angle-averaged P(k)/ξ(r)
- Constrains $D_V \propto (D_A^2/H)^{1/3}$

The CMASS measurements

- 26 log bins in s for ξ_0 and ξ_2 = 52 DOF

Measurement of ξ_0/ξ_2 was here

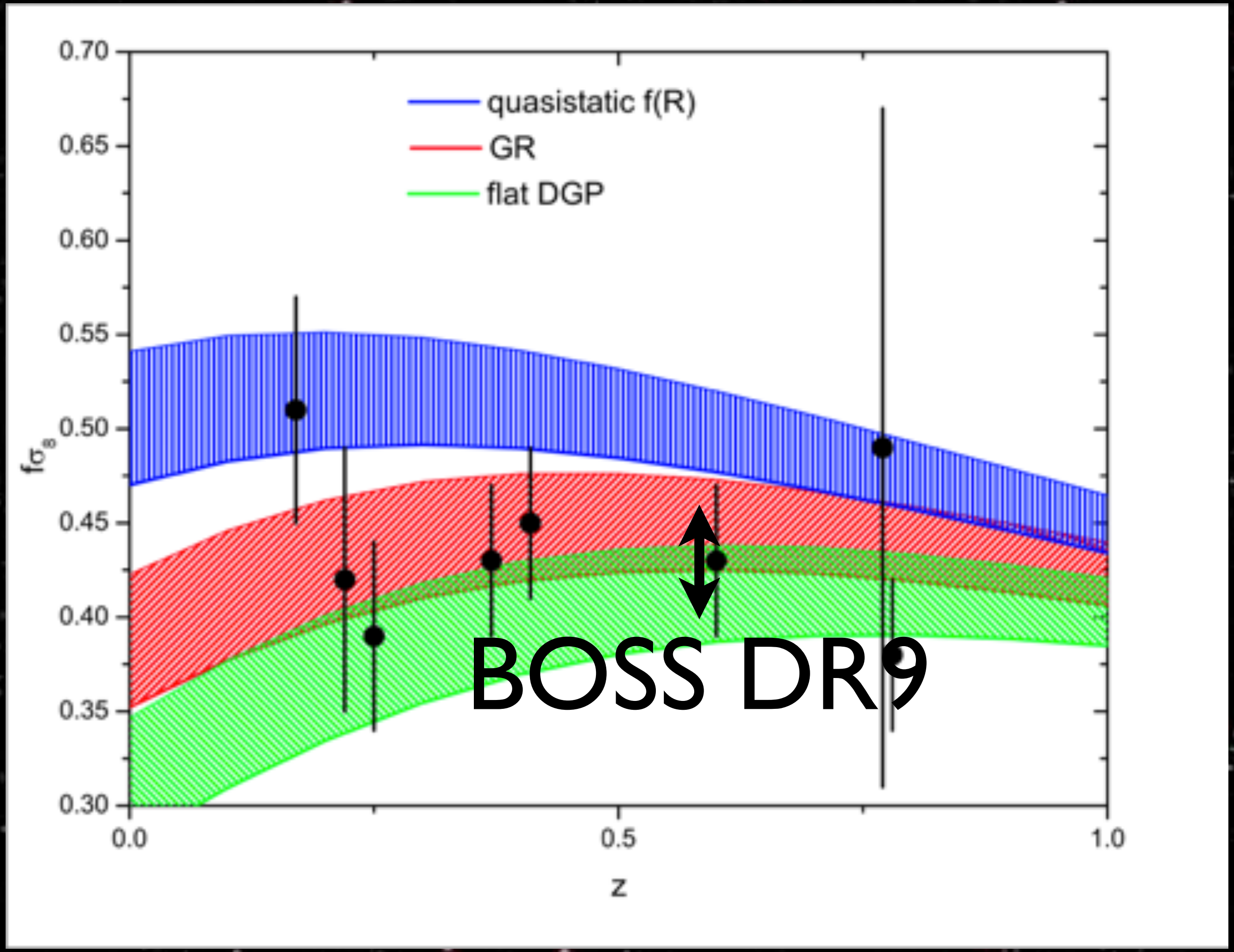
Model Fits

- We test the LCDM hypothesis in 4 models, always marginalizing over P(k) shape and σ^2_{FOG}:
  - LCDM ($b\sigma_8$)
  - LCDM + $f\sigma_8$: ($b\sigma_8$, $f\sigma_8$)
  - LCDM + geometry: ($b\sigma_8$, D_V, D_A*H)
  - LCDM++: ($b\sigma_8$, $f\sigma_8$, D_V, D_A*H)

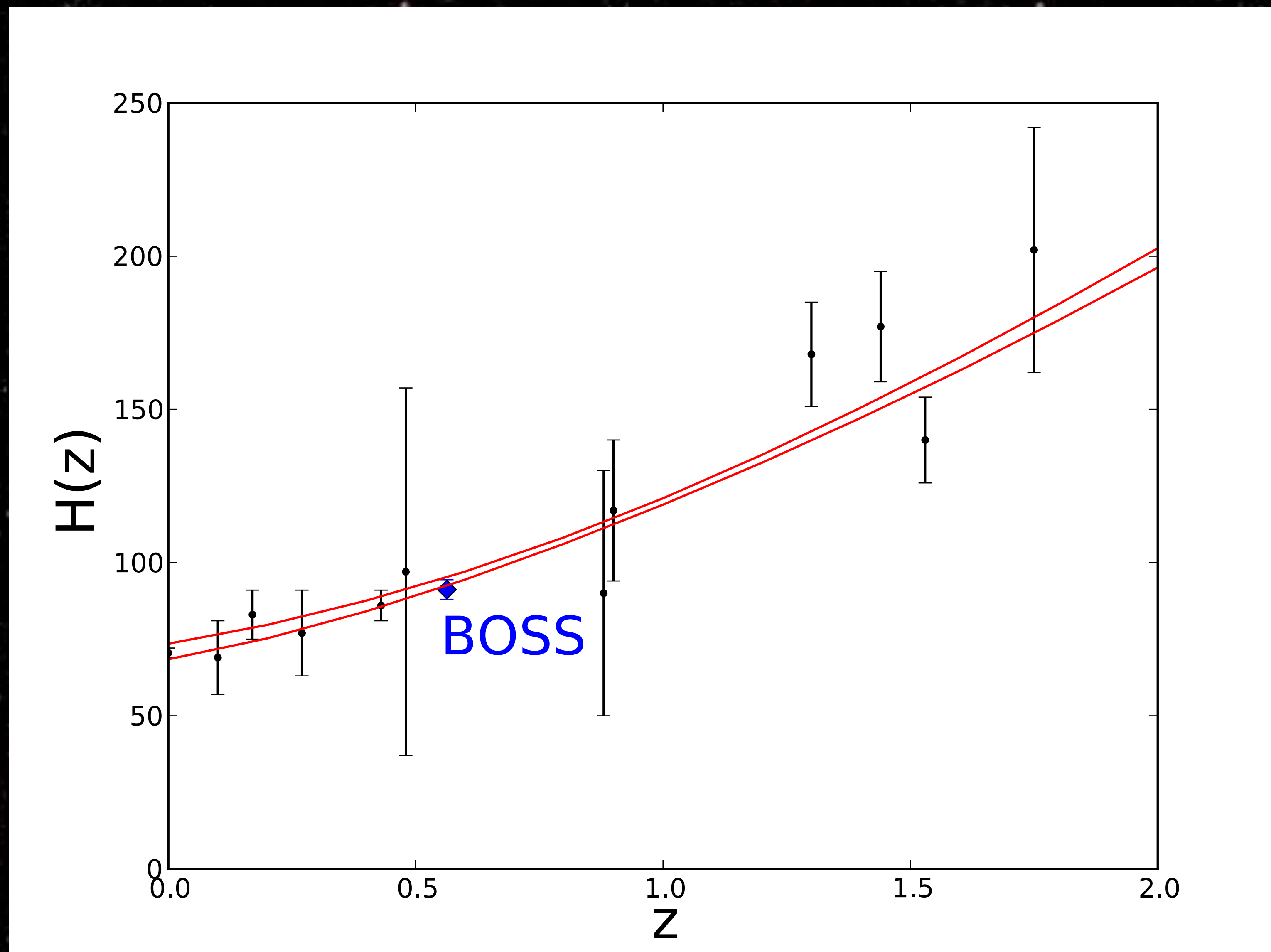
Current status

- $D_V/D_{V,fid}$ = x ± 0.019 (i.e., minimal information gain on D_V compared to BAO only!)
- Geometry LCDM: $f\sigma_8$ = xx ± 0.03 (7%) [WMAP7 LCDM: 0.45 ± 0.025]
- $f\sigma_8$ LCDM: η = xx ± 0.04 (4%) [WMAP7 LCDM: 1.00 ± 0.012]
- Fit both: $f\sigma_8$ = xx ± 0.07, η = xx ± 0.07

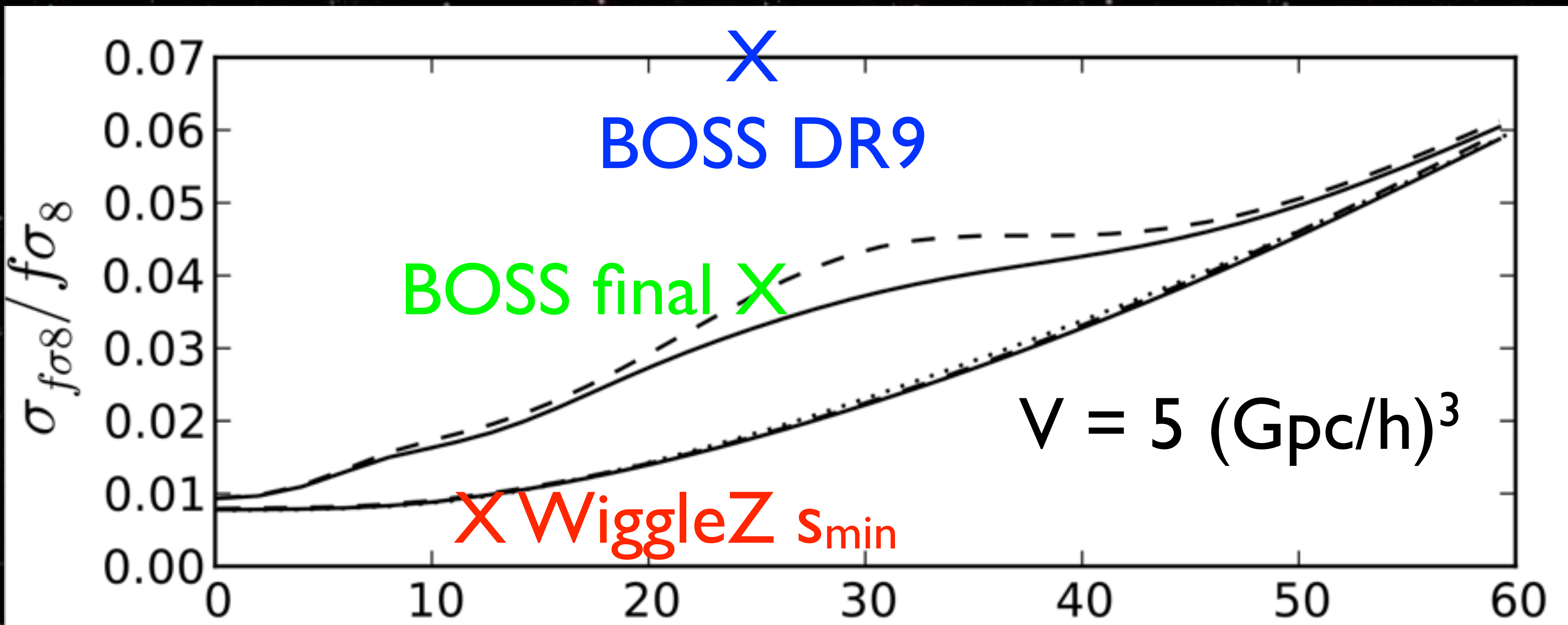
Testing alternative models with amplitude of peculiar velocities



Expansion rate at z=0.57

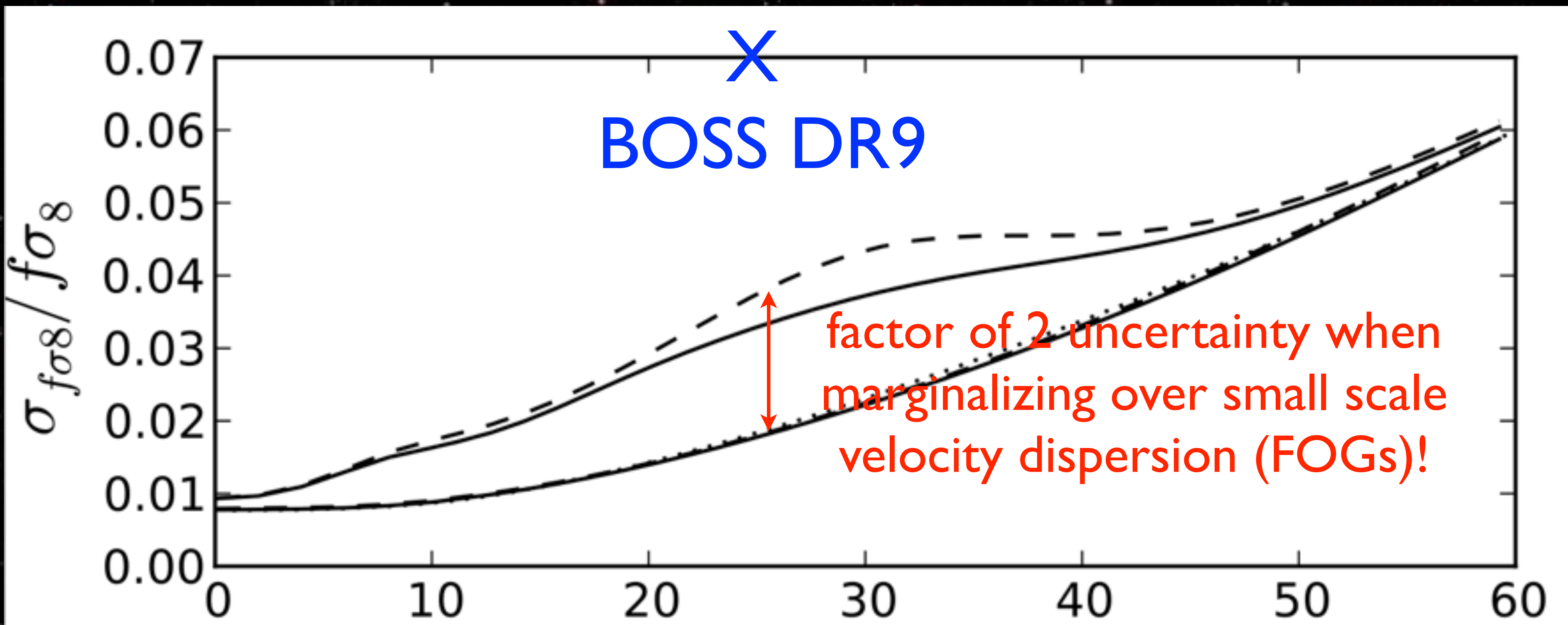


Error Budget/Future Prospects



s_{min} (Mpc/h)

Error Budget/Future Prospects



s_{min} (Mpc/h)

Summary/Conclusions

- DR9 CMASS results:
  - high significance detection of BAO in $\xi_0(r)$, $P_0(k)$ (~2% constraint on $D_V \propto D_A^2/H$)
  - 7% (4%) measurement of $f\sigma_8$ (D_A * H) at z=0.57
- Two “easy” ways to improve our precision:
  - use information on small scales to constrain σ^2_{FOG}.
  - Push modeling of halo clustering to smaller scales