SDSS III

SLOAN DIGITAL SKY SURVEY III

Results from the Baryon Oscillation Spectroscopic Survey (BOSS)

Beth Reid for SDSS-III/BOSS collaboration
Hubble Fellow
Lawrence Berkeley National Lab

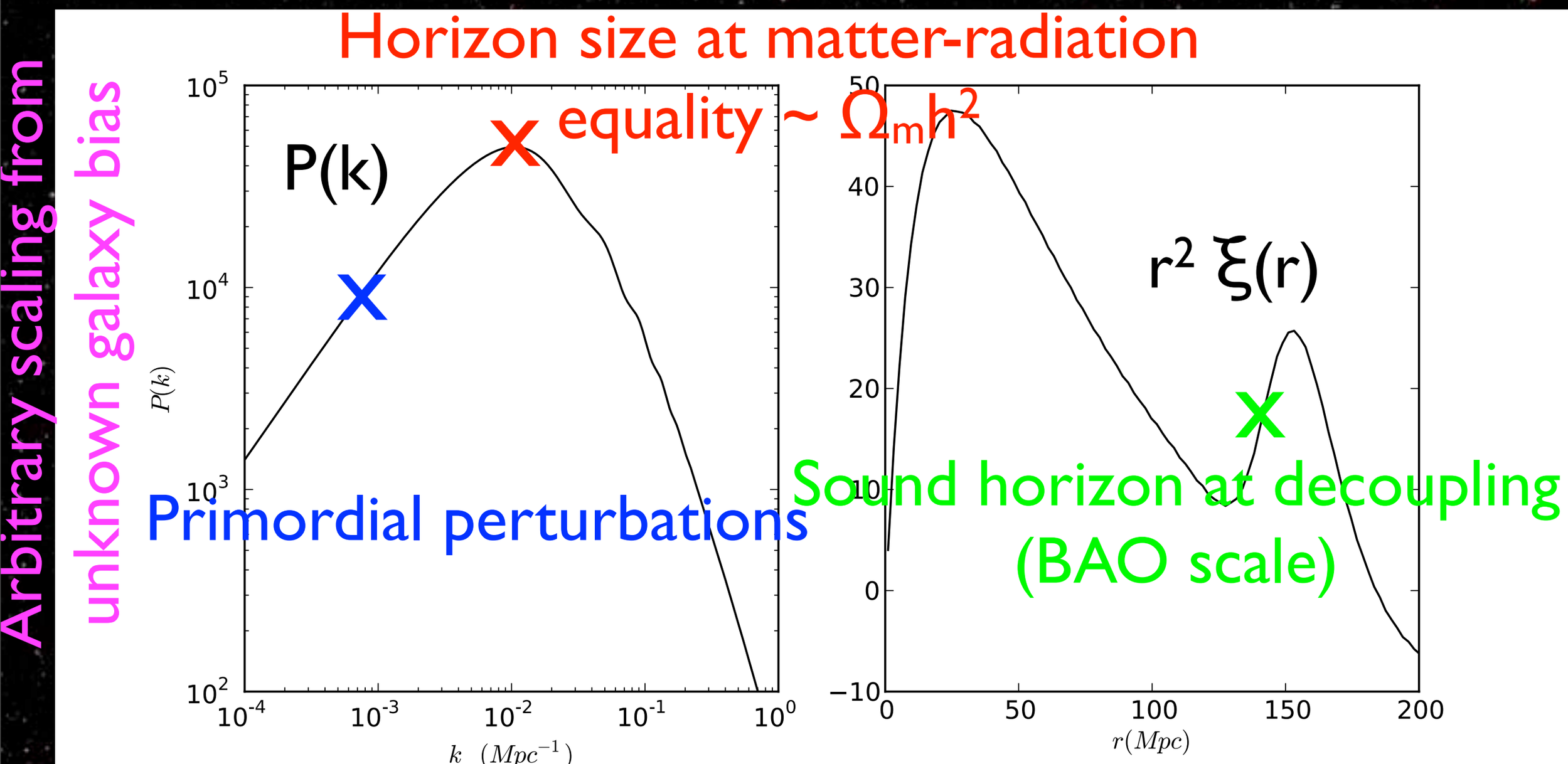
Outline

- No Ly-α forest here, but very exciting!! (Slosar et al., arXiv:1104.5244)
- Quick theory review -- what are we measuring?
- Imaging Survey/Science from 2D maps
- Spectroscopic Survey/Science in 3D maps

Galaxy clustering lightning theory review

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

CMB predicts linear P(k) / ξ(r)

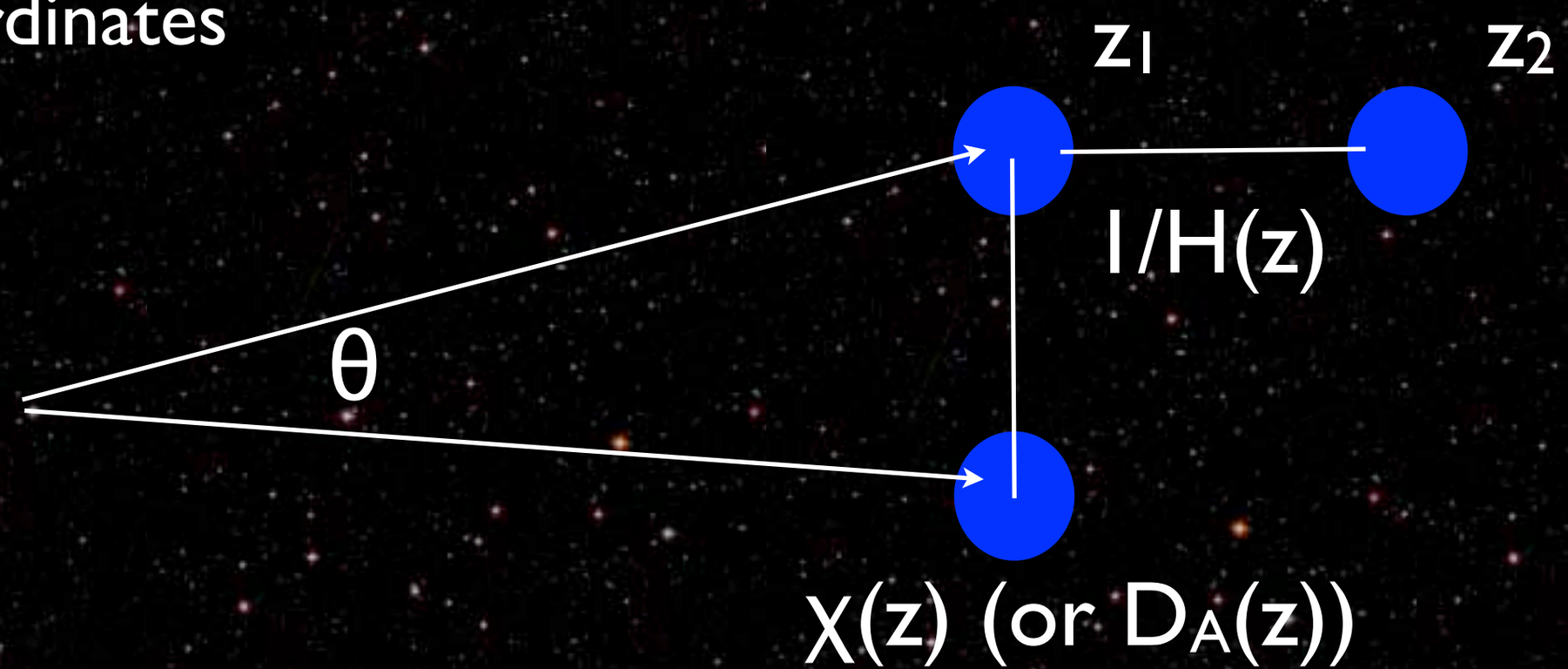


Theory I: gastrophysics

- Non-linear growth
- galaxy biasing
- redshift space distortions
- These can be dealt with, but do your homework!

Theory II: geometry

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

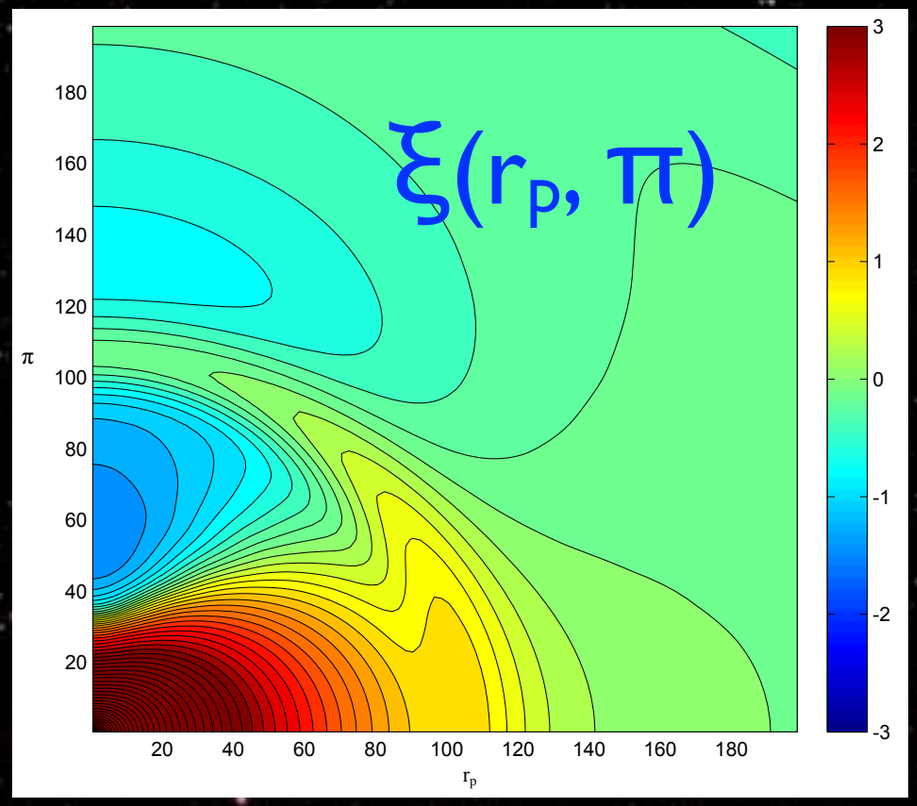


Theory II: Alcock-Paczynski

- $\xi(r_p, \pi)$ appears anisotropic if you assume the wrong cosmogical model (constrain $\eta = D_A * H$)

$$\chi(z) = {}_0\int^z c\, dz'/H(z')$$

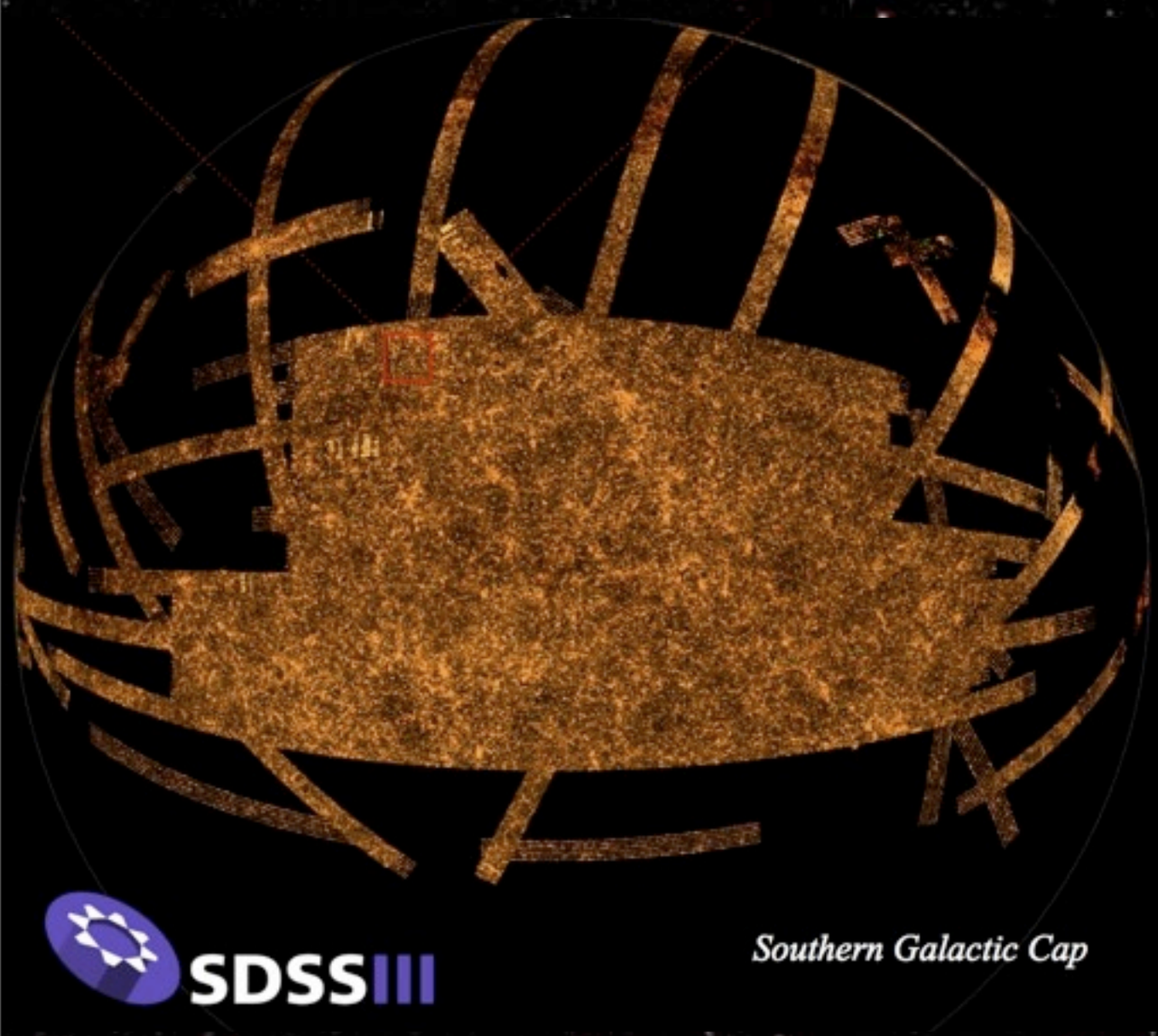
$c\,\Delta z / H(z)$

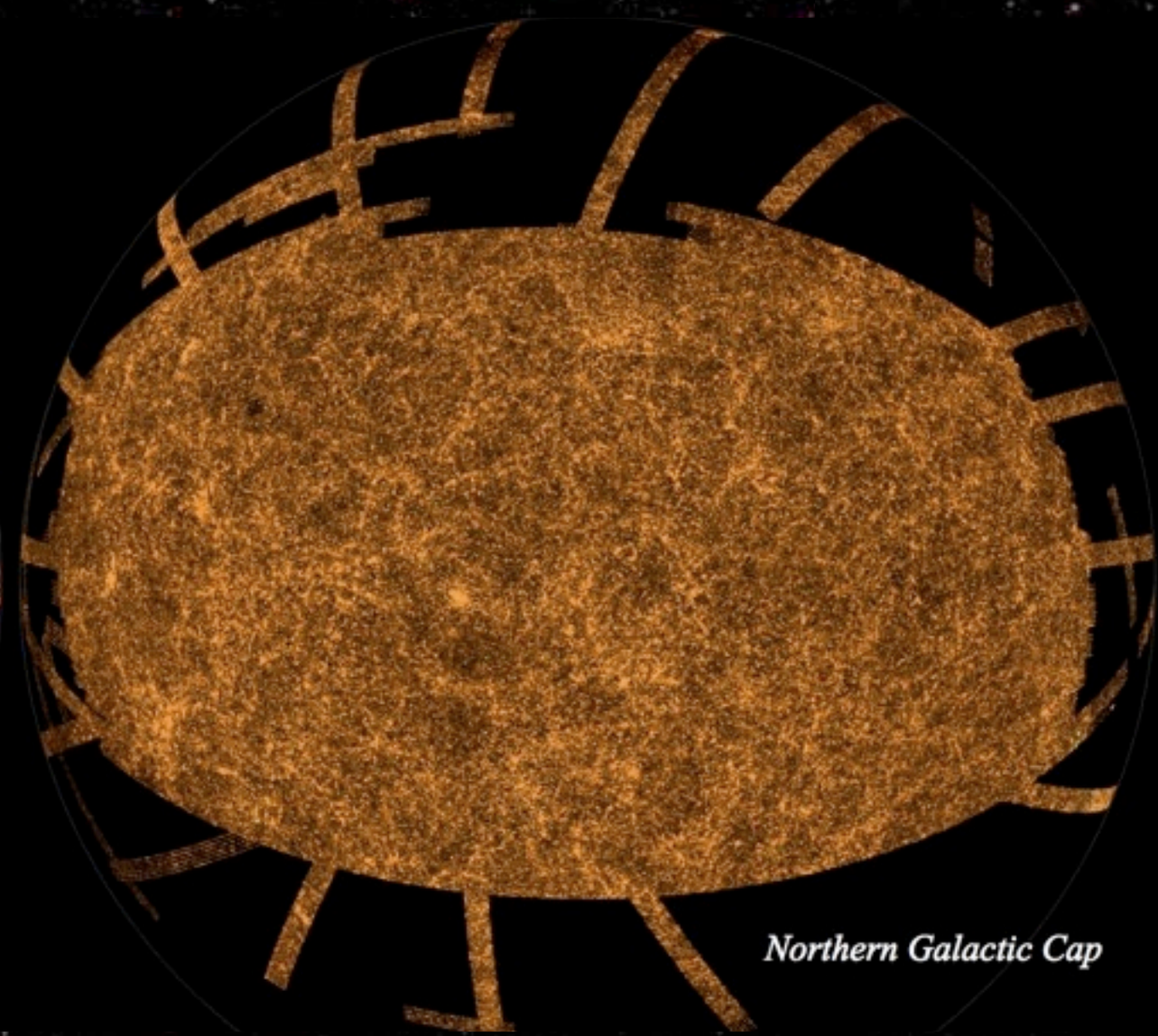


$\chi(z)*\Delta\theta$

Image from Tian et al. arXiv:1011.2481

Imaging survey: making 2d maps



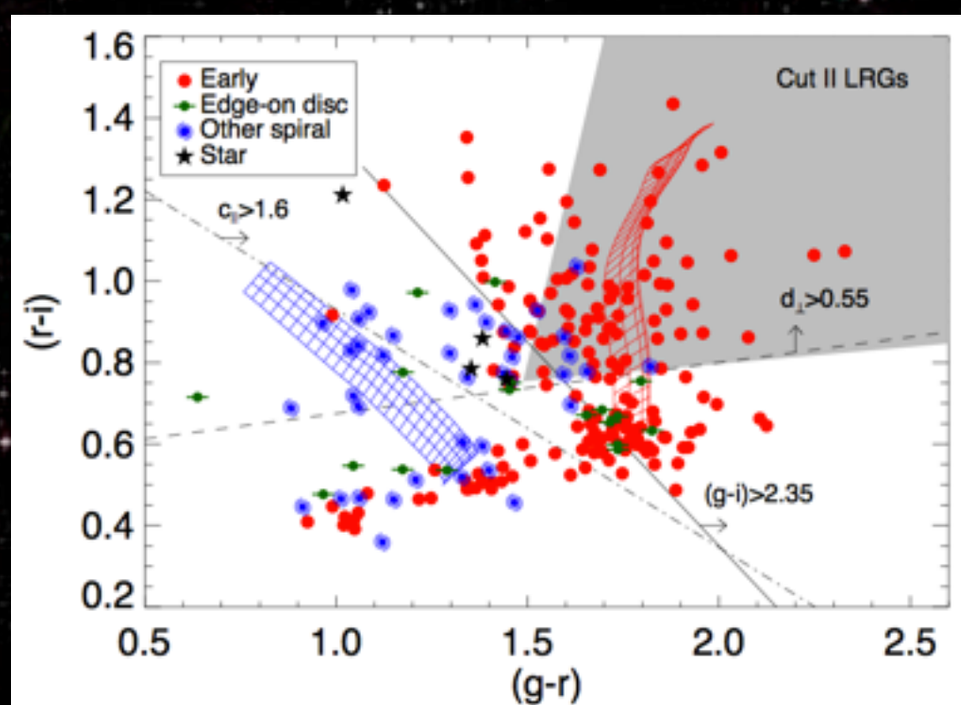


Imaging survey: papers out

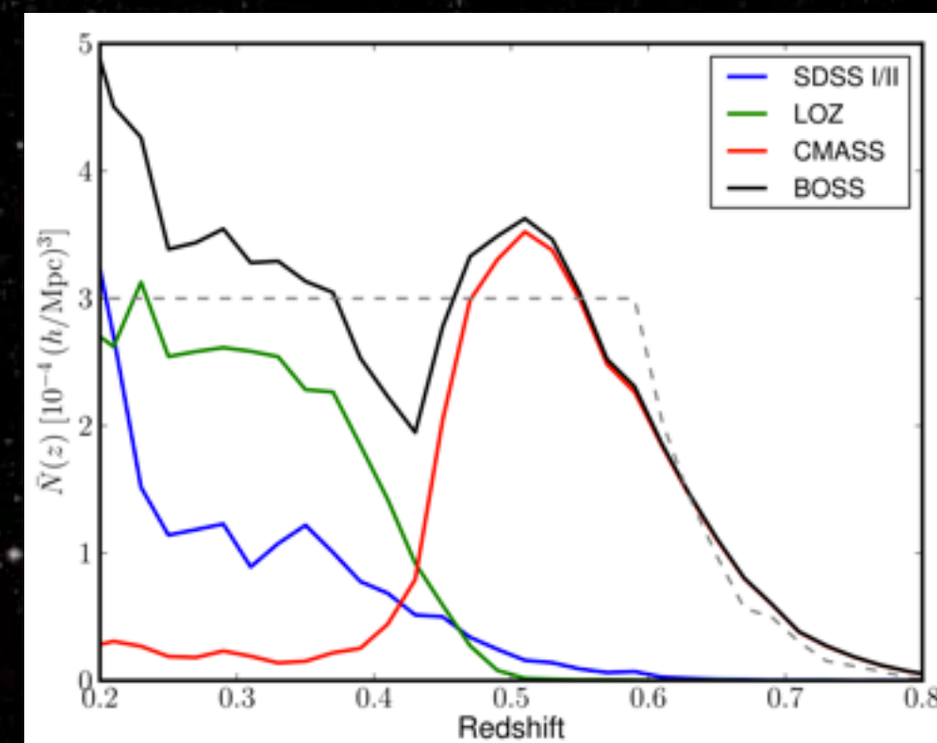
- Ross et al. (arXiv:1105.2320): Ameliorating Systematic Uncertainties in the Angular Clustering of Galaxies: A study using SDSS-III
- Ho et al. (arXiv:1201.2137): Clustering of SDSS-III Photometric Luminous Galaxies: the measurement, systematics, and cosmogical implications
- Seo et al. (arXiv:1201.2172): Acoustic Scale from the Angular Power Spectra of SDSS-III DR8 Photometric Luminous Galaxies
- De Putter et al. (arXiv:1201.1909): New Neutrino Mass Bounds from SDSS-III DR8 Photometric Luminous Galaxies

Imaging survey: target selection

- Color/magnitude cuts select massive "red" galaxies; all results today are "CMASS"

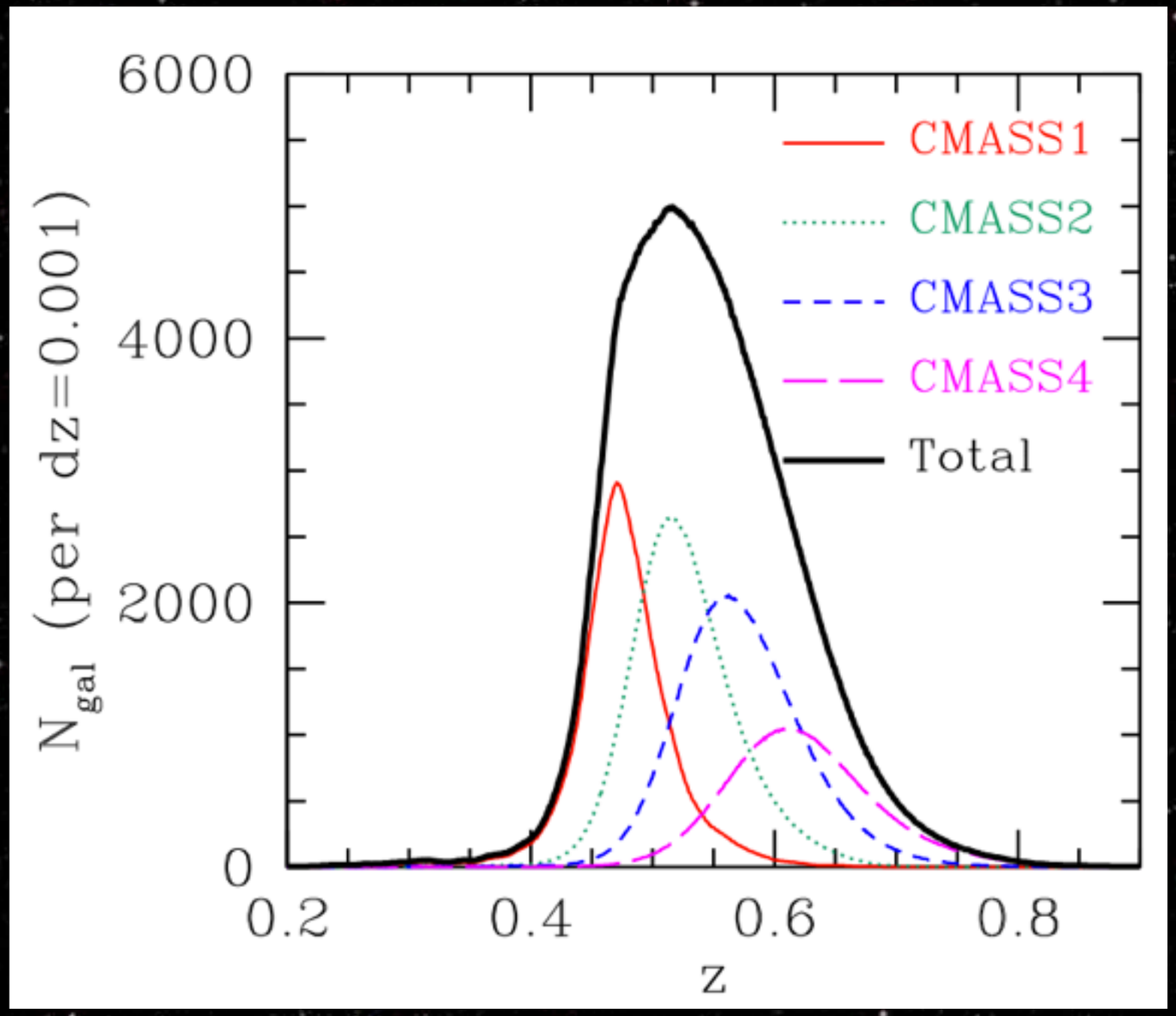


Masters et al. arXiv:1106.3331



Eisenstein et al. arXiv:1101.1529

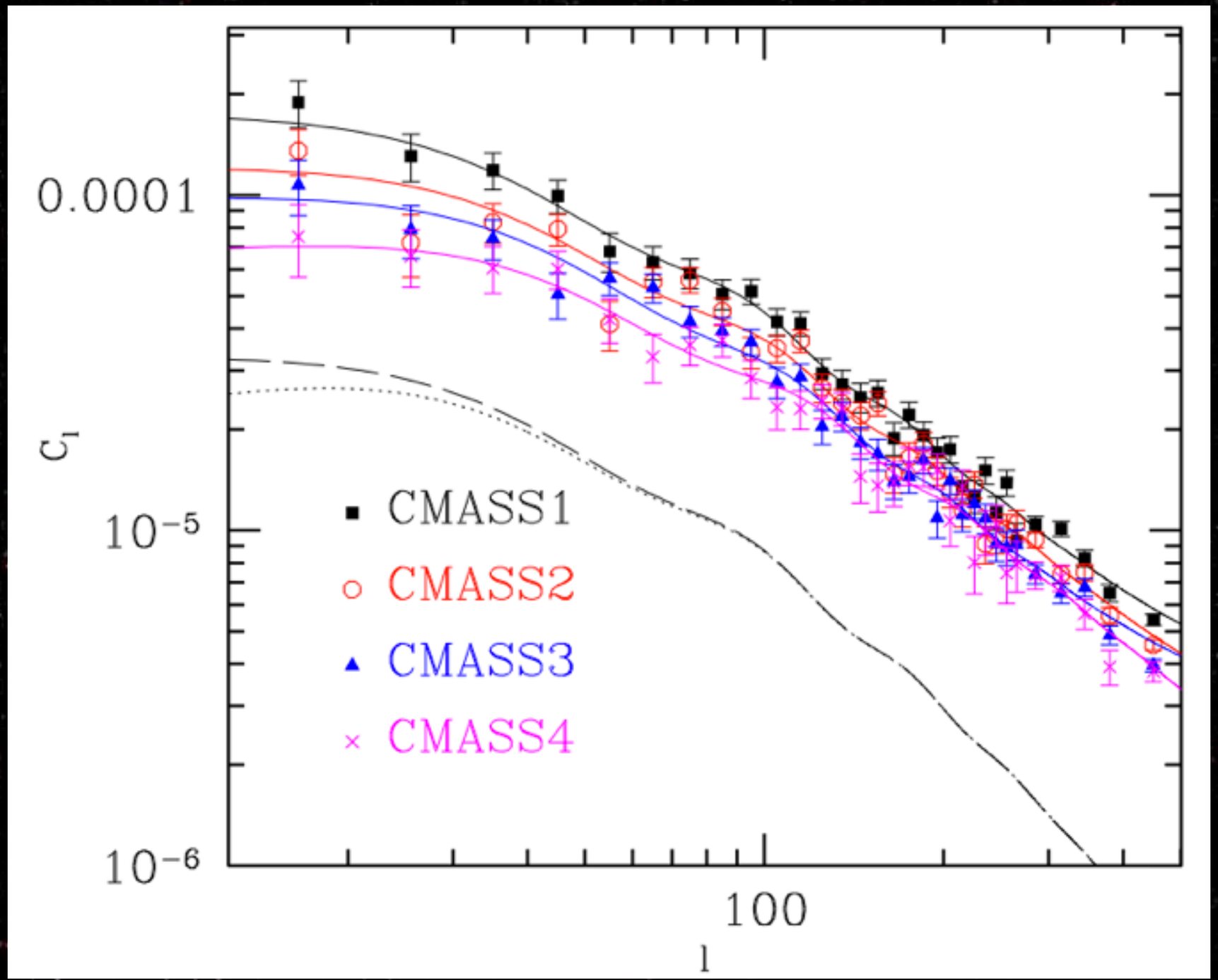
Imaging survey: photo-z slices



Imaging survey: angular clustering

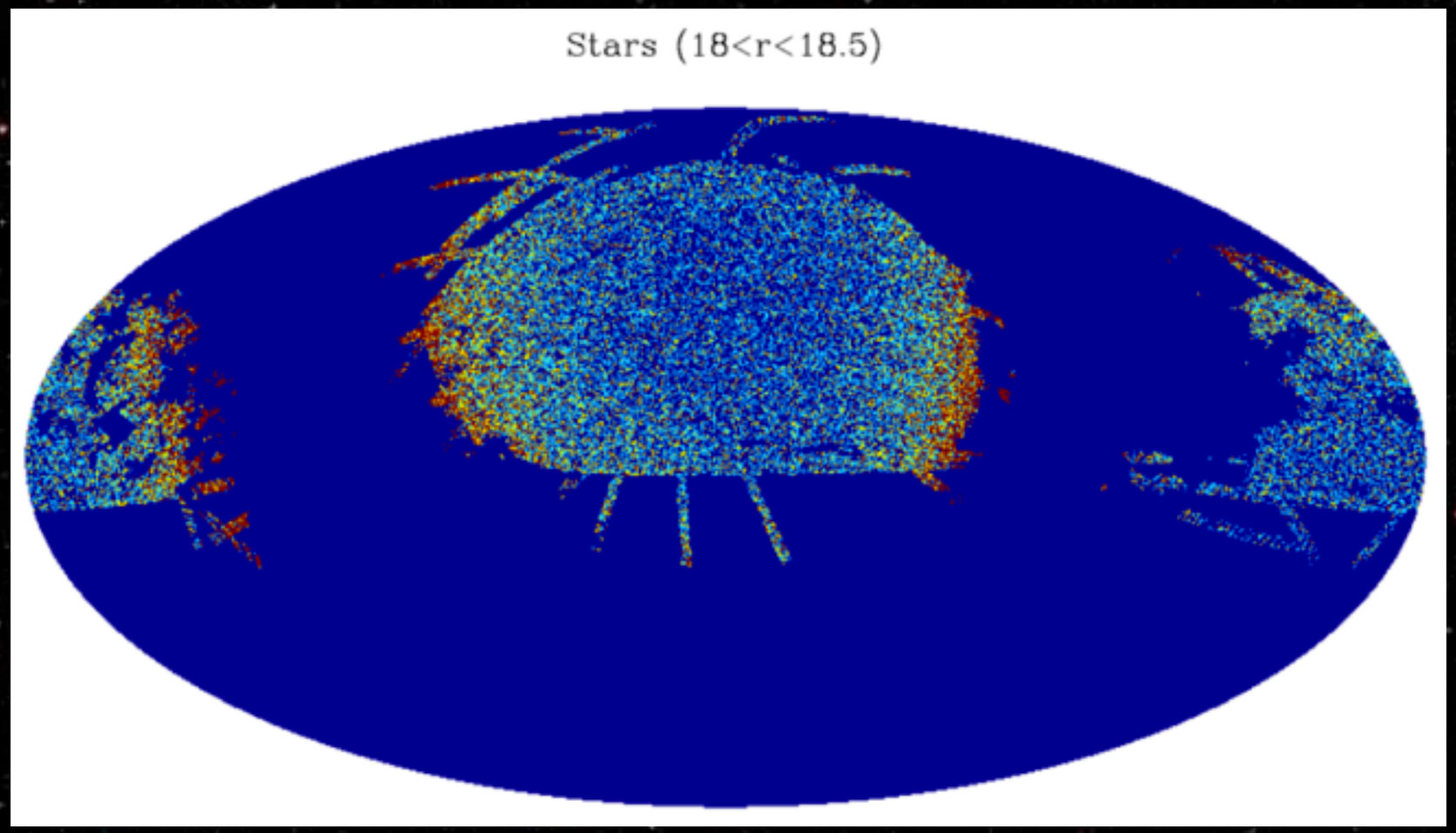
$$C^{gg}(\ell) = \int dz \frac{1}{\chi^2(z)} b^2(z) N^2(z) P(k = \frac{(\ell + 1/2)}{\chi(z)}, z)$$

Imaging survey: angular clustering



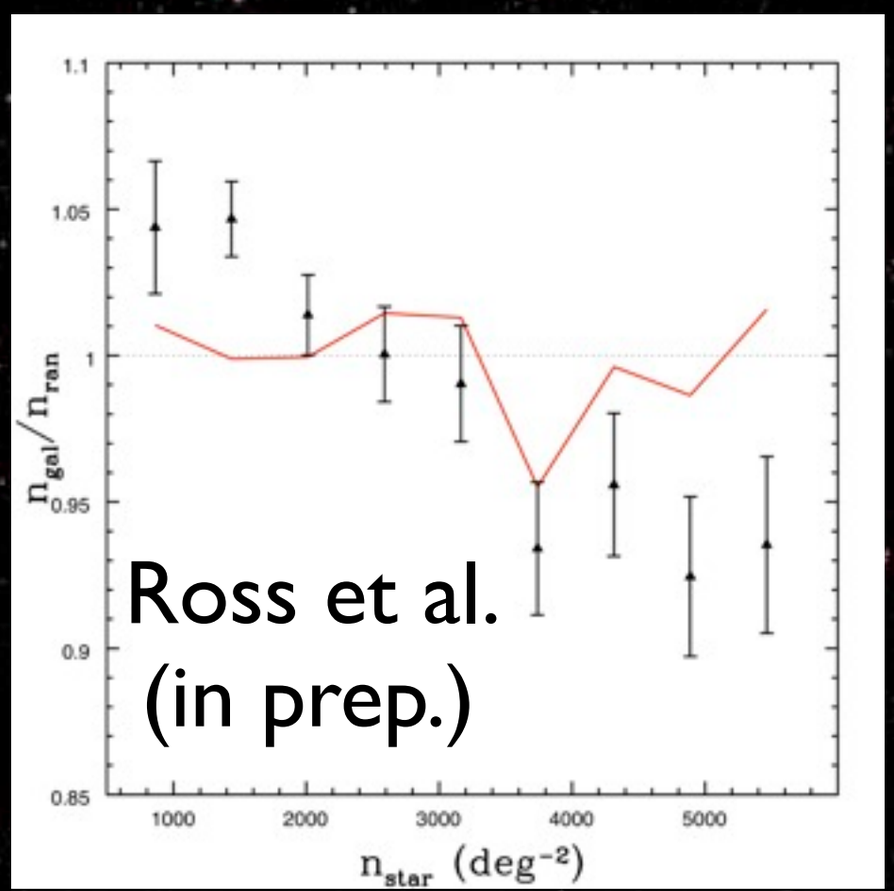
Imaging survey: Results

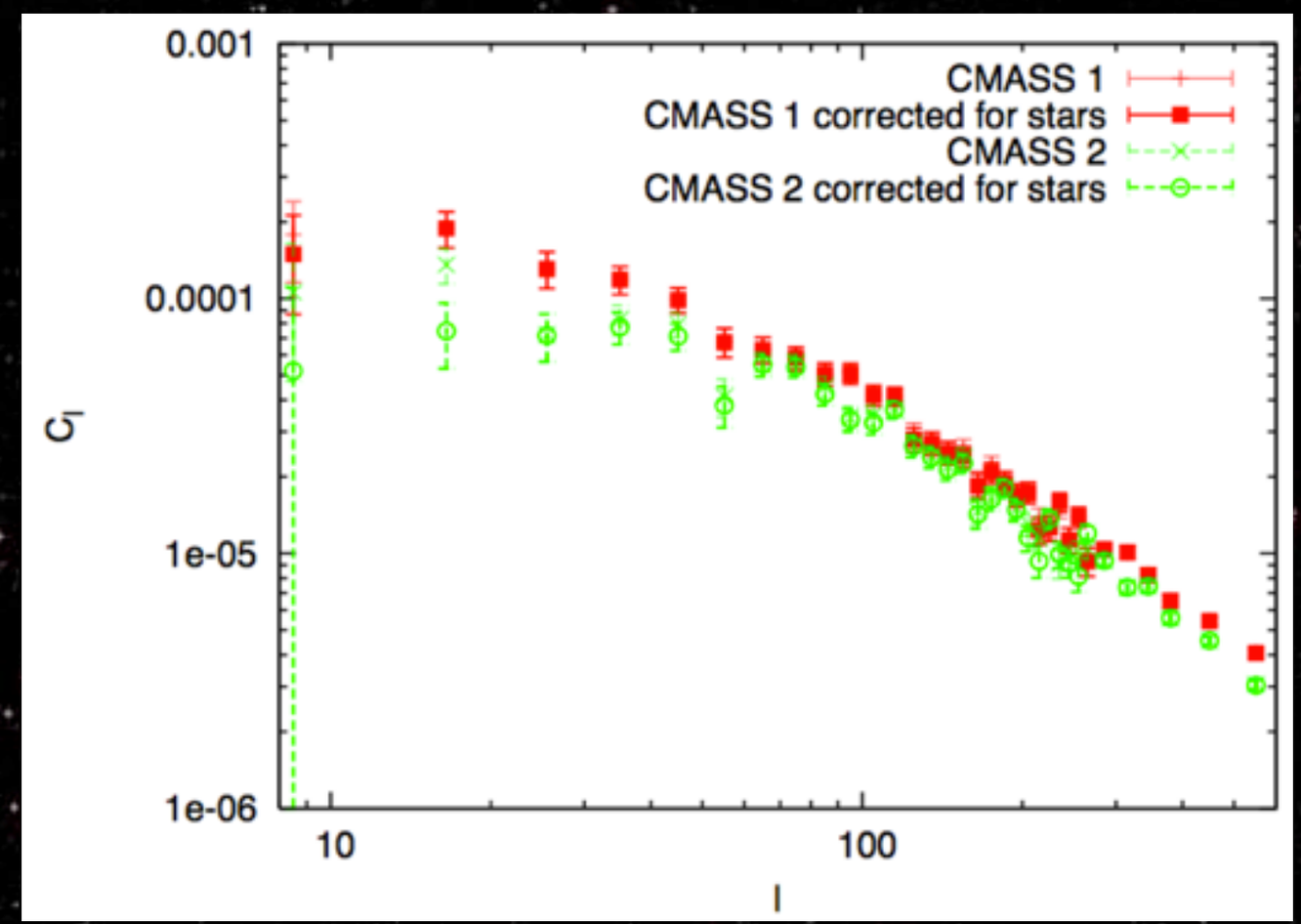
- STARS! Use auto and cross-correlations of data and systematics maps to remove contribution to C_ℓ



Imaging survey: Results

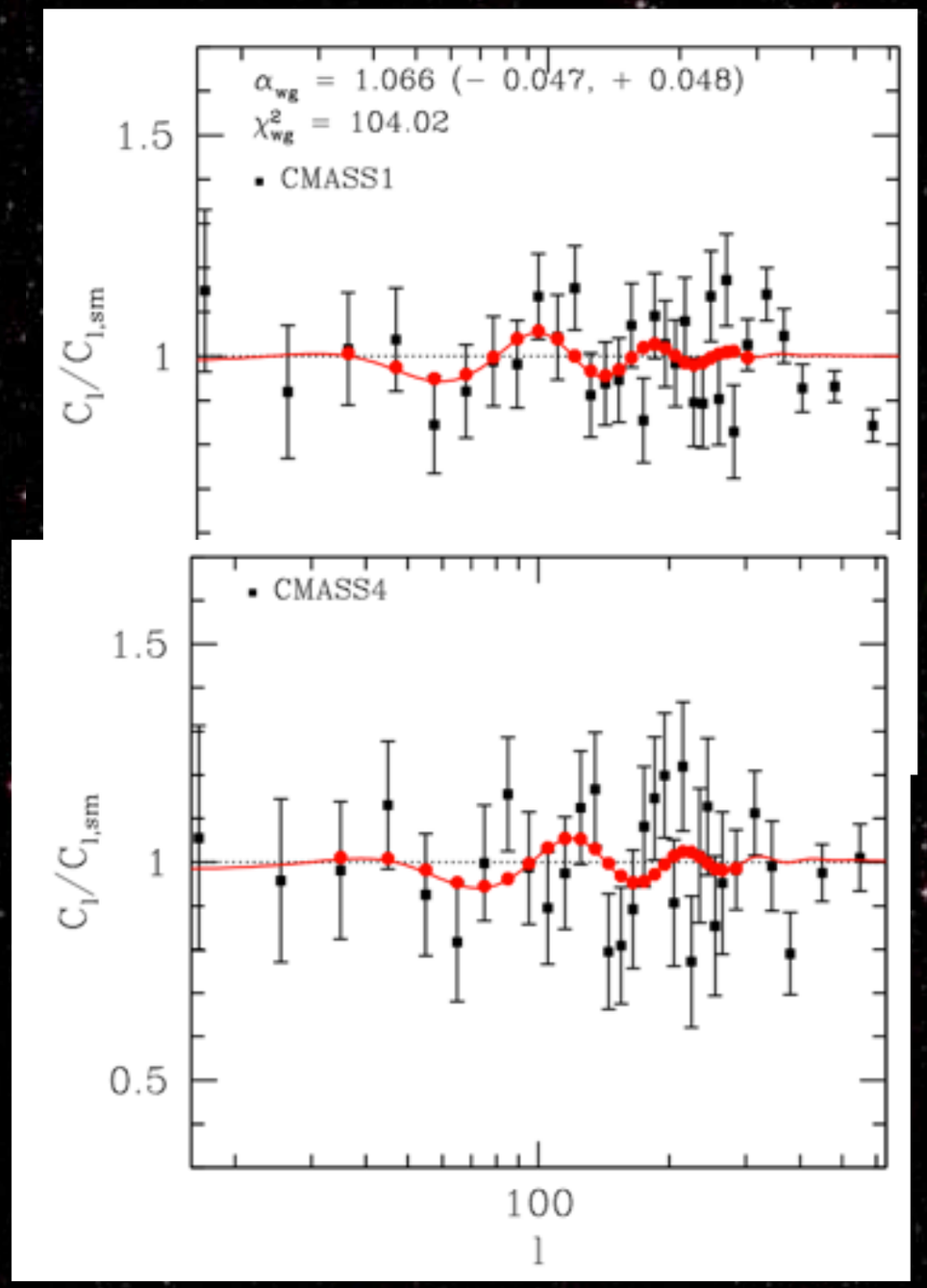
- STARS!





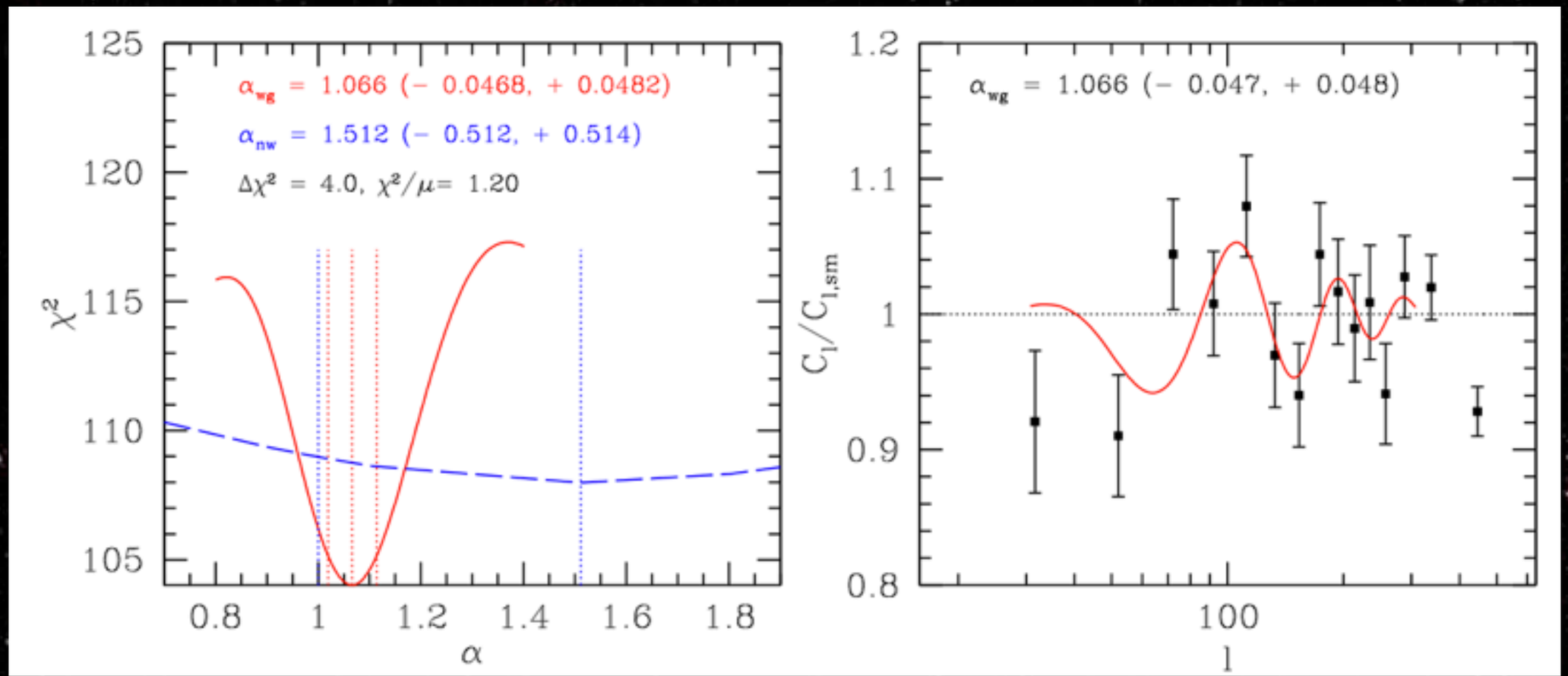
Imaging survey: Results

- BAOs! Need narrow photo-z slices to avoid being washed out by projection
- Method marginalizes over broadband C_ℓ to extract BAO information only



Imaging survey: BAO Results

- $D_A(z=0.54)$ = 2173 ± 100 (comoving) Mpc (4.6%)



Imaging survey: constraints from modeling the full shape of C_ℓ

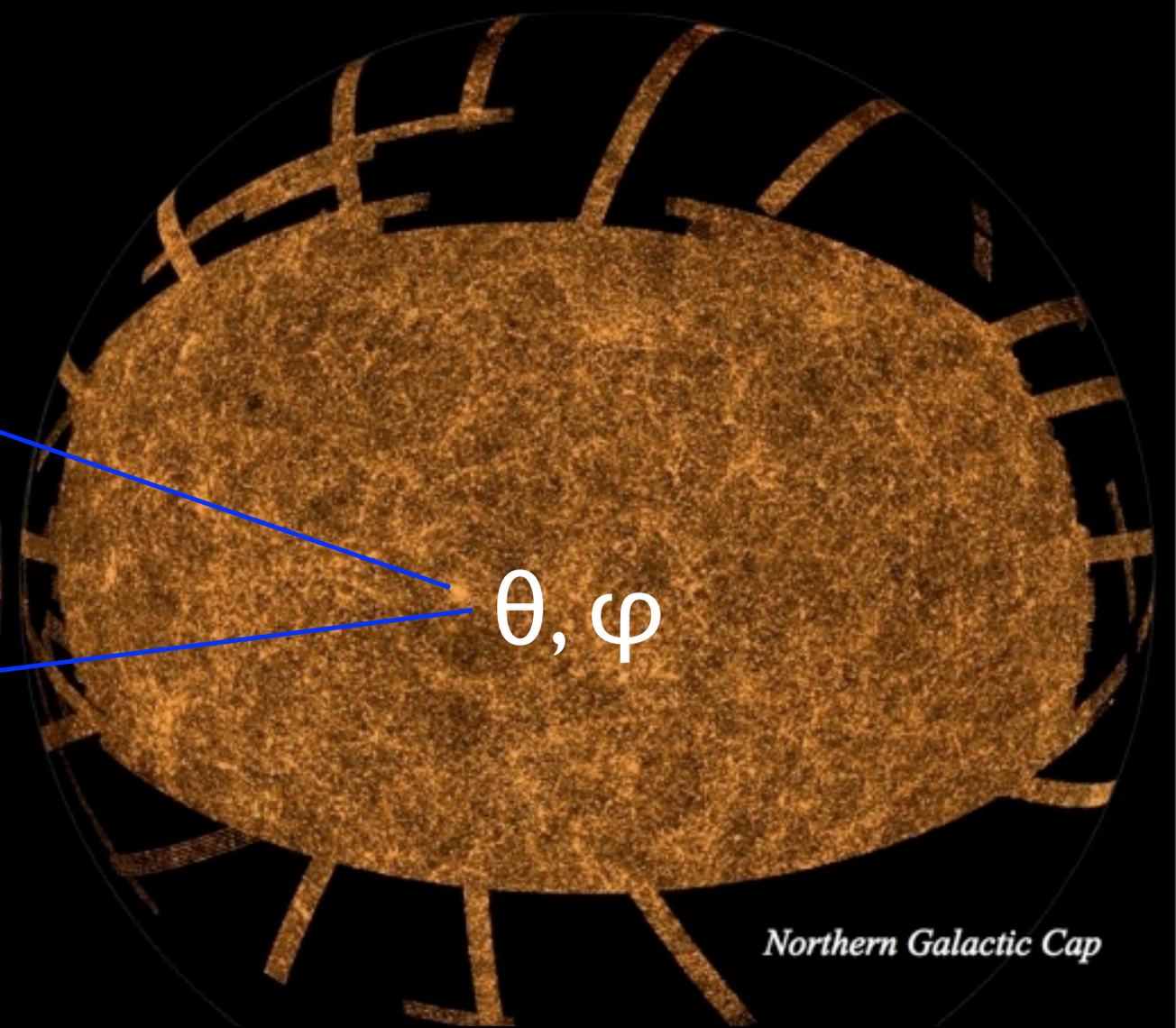
- The model: $$C_g(\ell) = b_g^2 C_(\ell) + N_{\rm shot} + a$$
- + WMAP7 + H0 (73.6 ± 2.4 km/s/Mpc, Riess et al 2011):
  - Ω_k = 0.0035 ± 0.0054; ~ 5% improvements in ΛCDM case
  - $\sum m_\nu$ < 0.36 eV (WMAP7+CMASS+H_0)

Outline

- Quick theory review -- what are we measuring?
- Imaging Survey/Science from 2D maps
- Spectroscopic Survey/Science in 3D maps

Spectroscopic survey

Redshift surveys measure: θ, φ, redshift



SDSSIII

Spectroscopic results: preliminary!

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

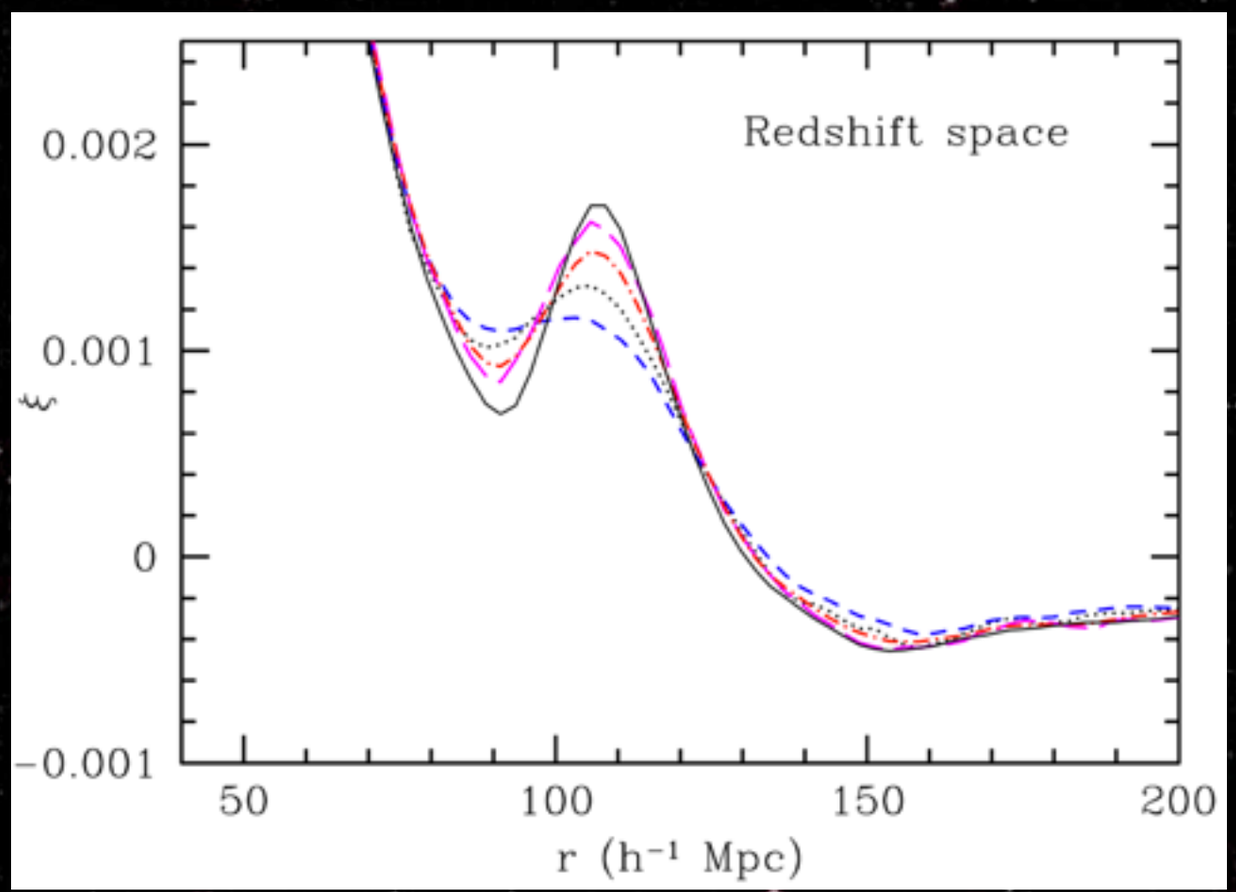
BAO fits in P(k)/ξ(r) consistent

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

Preliminary BAO measurement plot here

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

BAO fits: interpretation

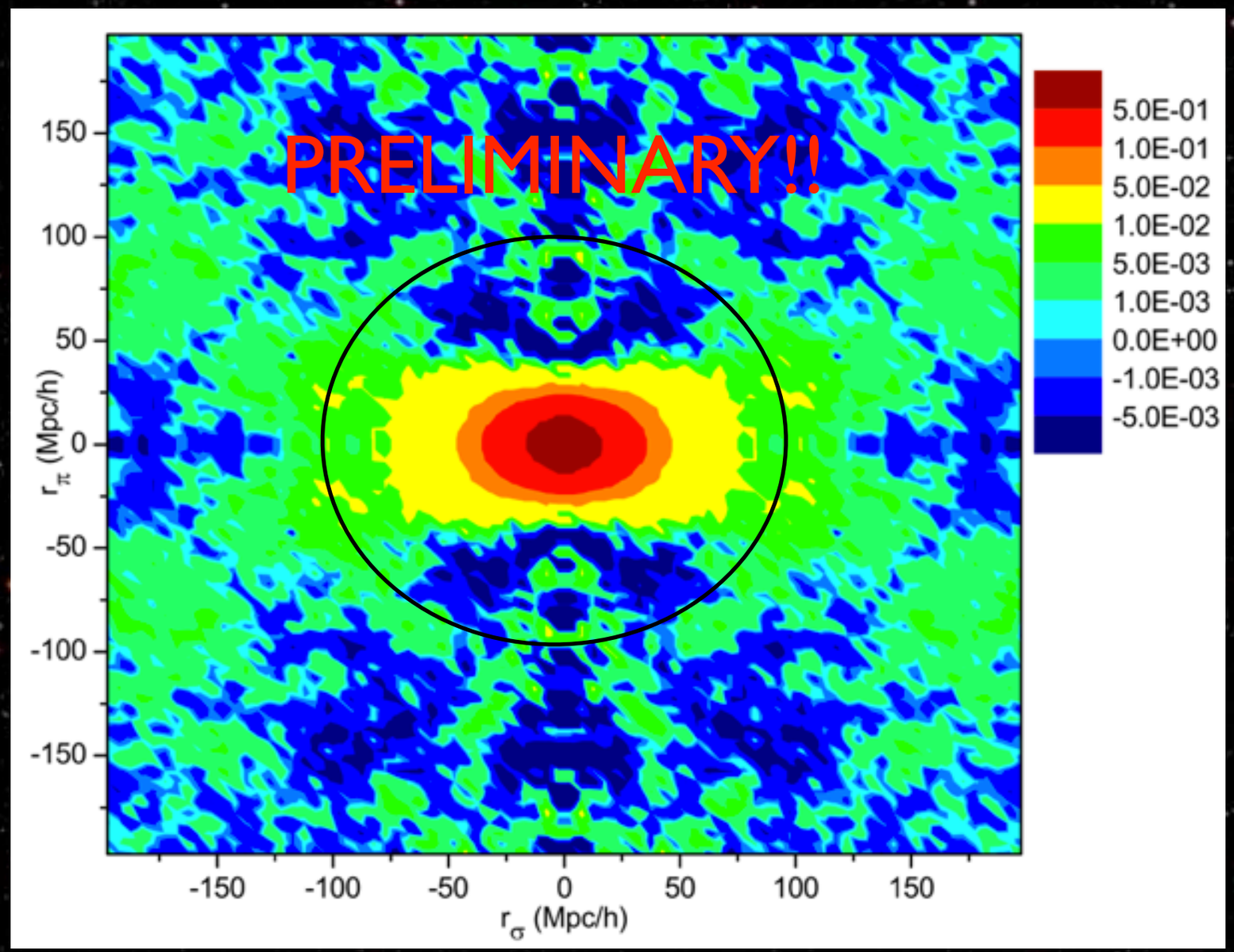


Eisenstein et al. astro-ph/0504362

- Current statistical power comparable to DR7, but at z=0.57
- Watch for reconstruction on DR7 and DR9!

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

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



Big Picture

- Two things make observed ξ anistropic:
  - peculiar velocities
  - Geometry: model to convert $\theta, z \rightarrow x, y, z$ is wrong ("Alcock-Paczynski" effect)

Redshift Space Distortions

θ, φ, redshift

depends on the geometry of the universe

$$\chi(z) = {}_0\int^z c\, dz'/H(z')$$

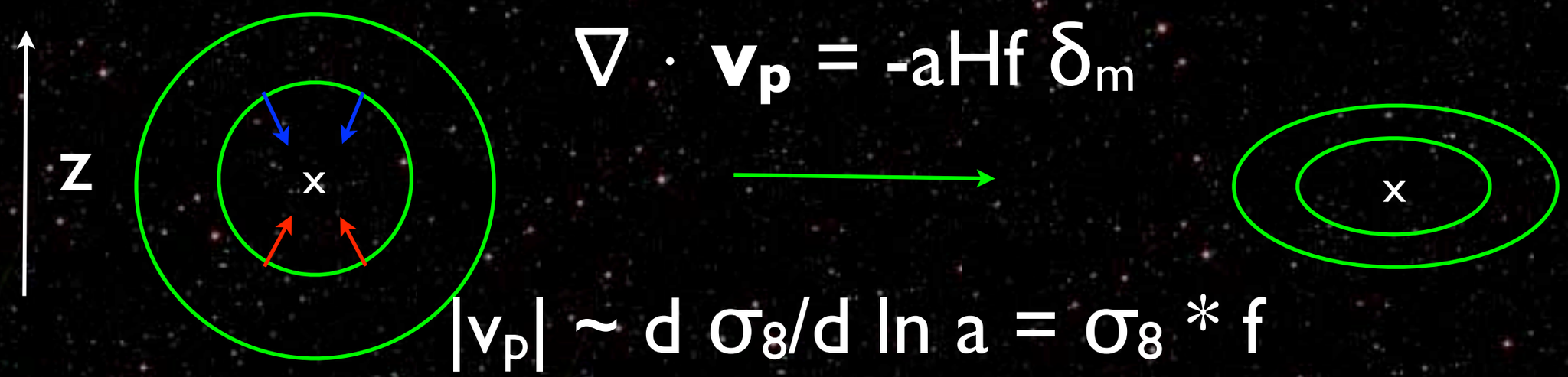
$$\chi(z) = \chi_{true} + v_p/aH(a)$$

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

$$f = d\ln\sigma_8/d\ln a$$

Redshift Space Distortions: Why

- 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

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

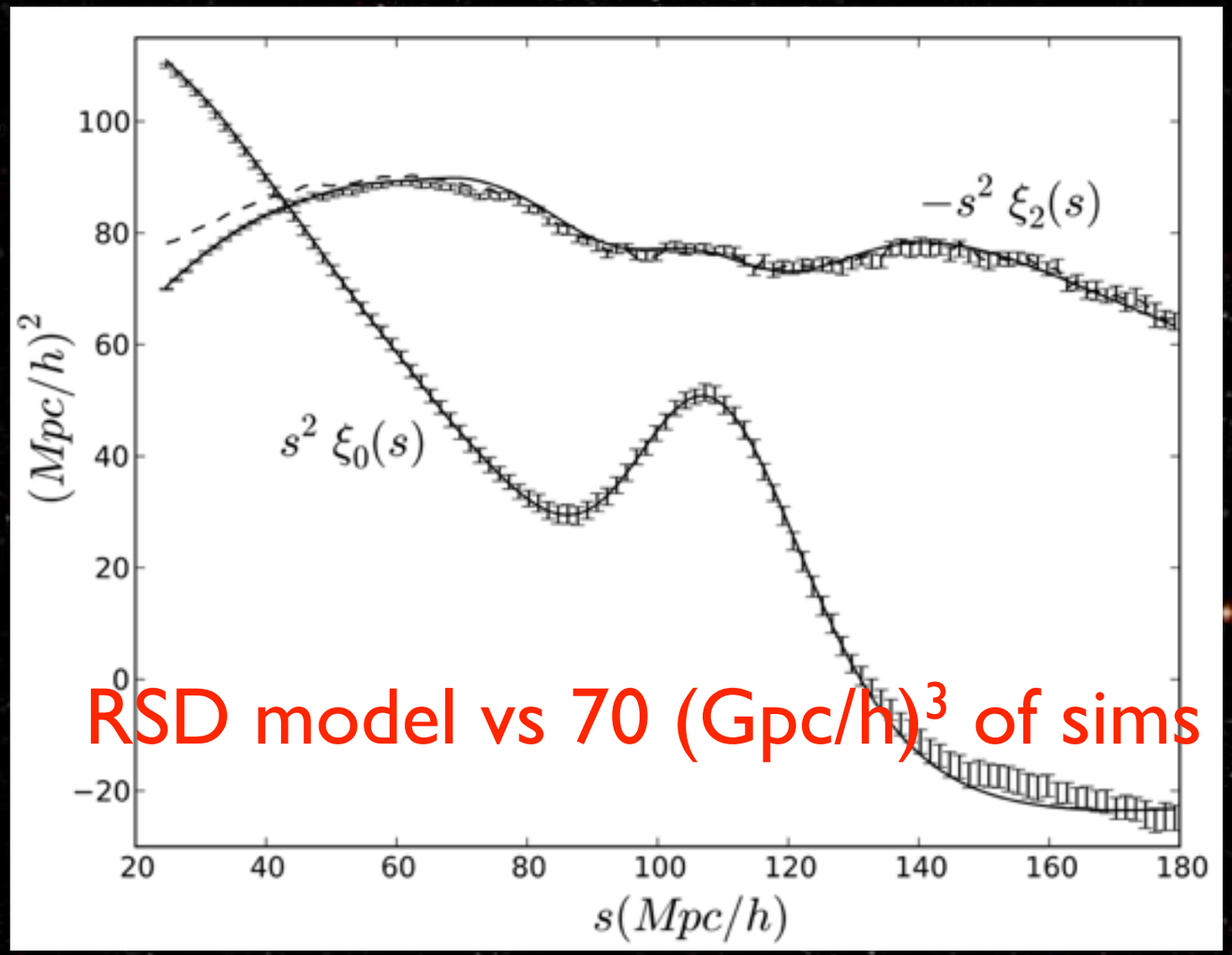
$$\xi(s, \mu_s) = \sum_{\ell} \xi_\ell(s) L_\ell(\mu_s)$$

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

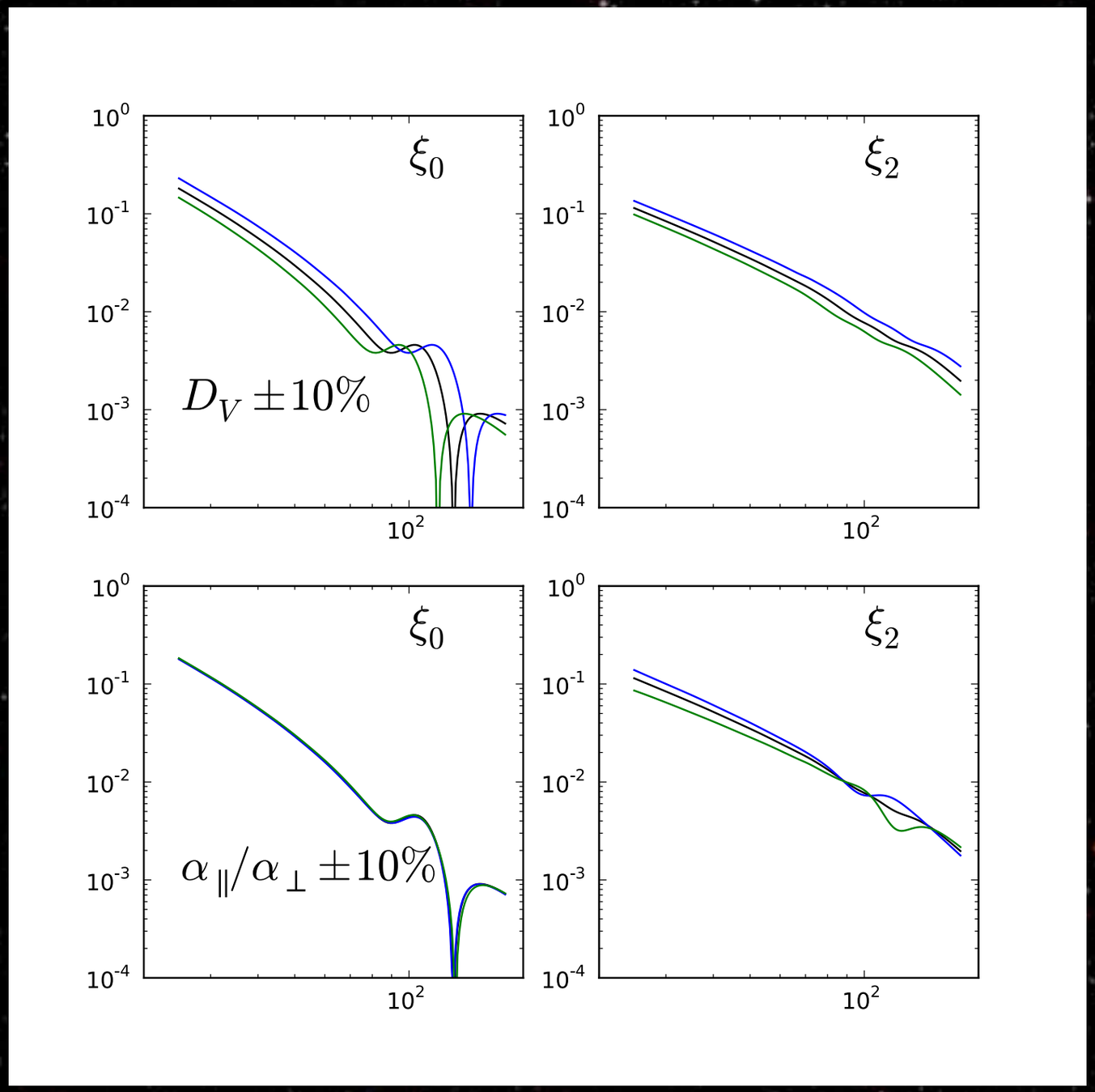


RSD model vs 70 $(Gpc/h)^3$ of sims

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 ($\eta \propto D_A(z_{eff}) * H(z_{eff})$)
  - shape of underlying linear P(k)

Alcock-Paczynski in multipoles



The CMASS measurements

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

Plot of preliminary ξ_0 and ξ_2 measurements

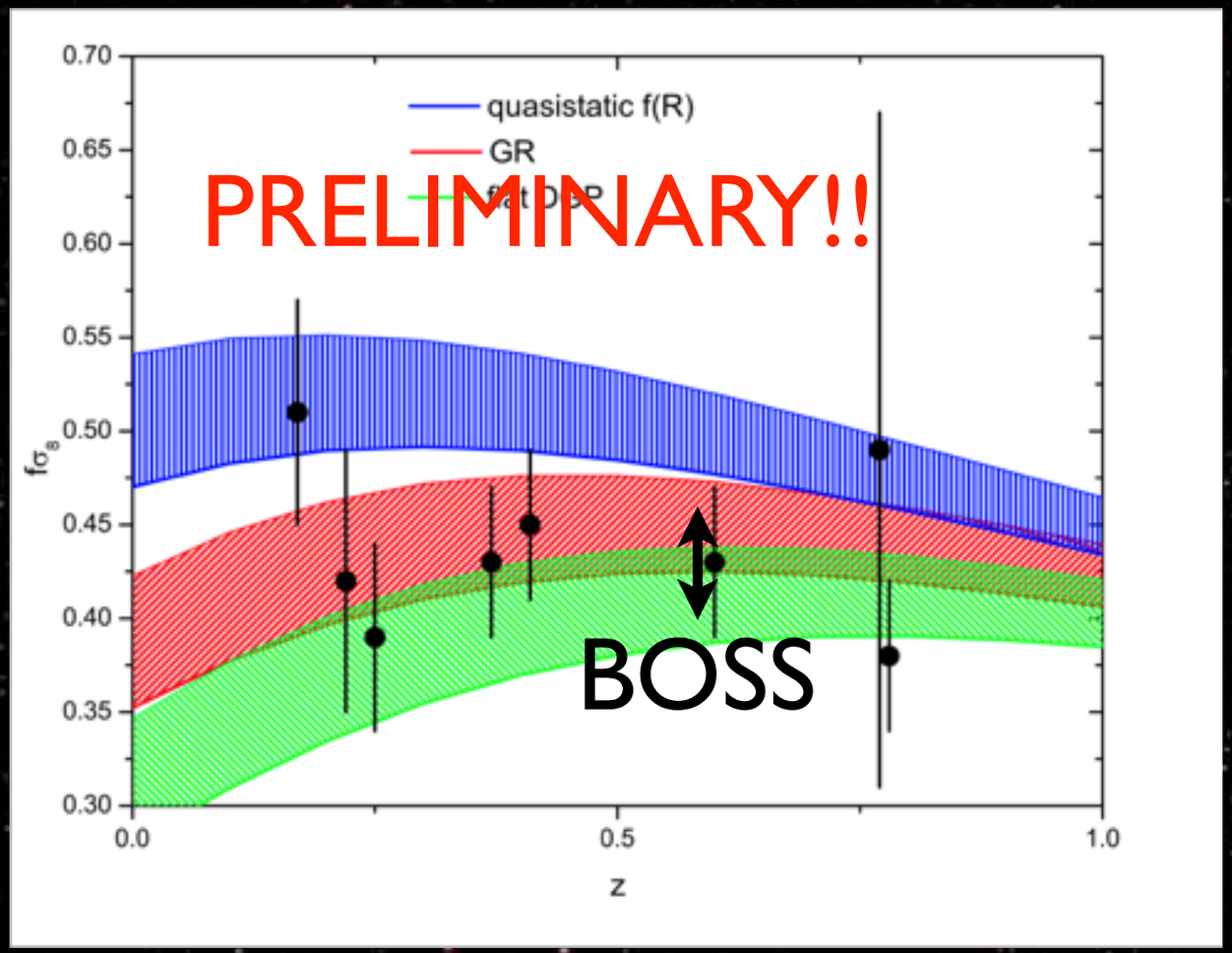
Model Fits

- 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)

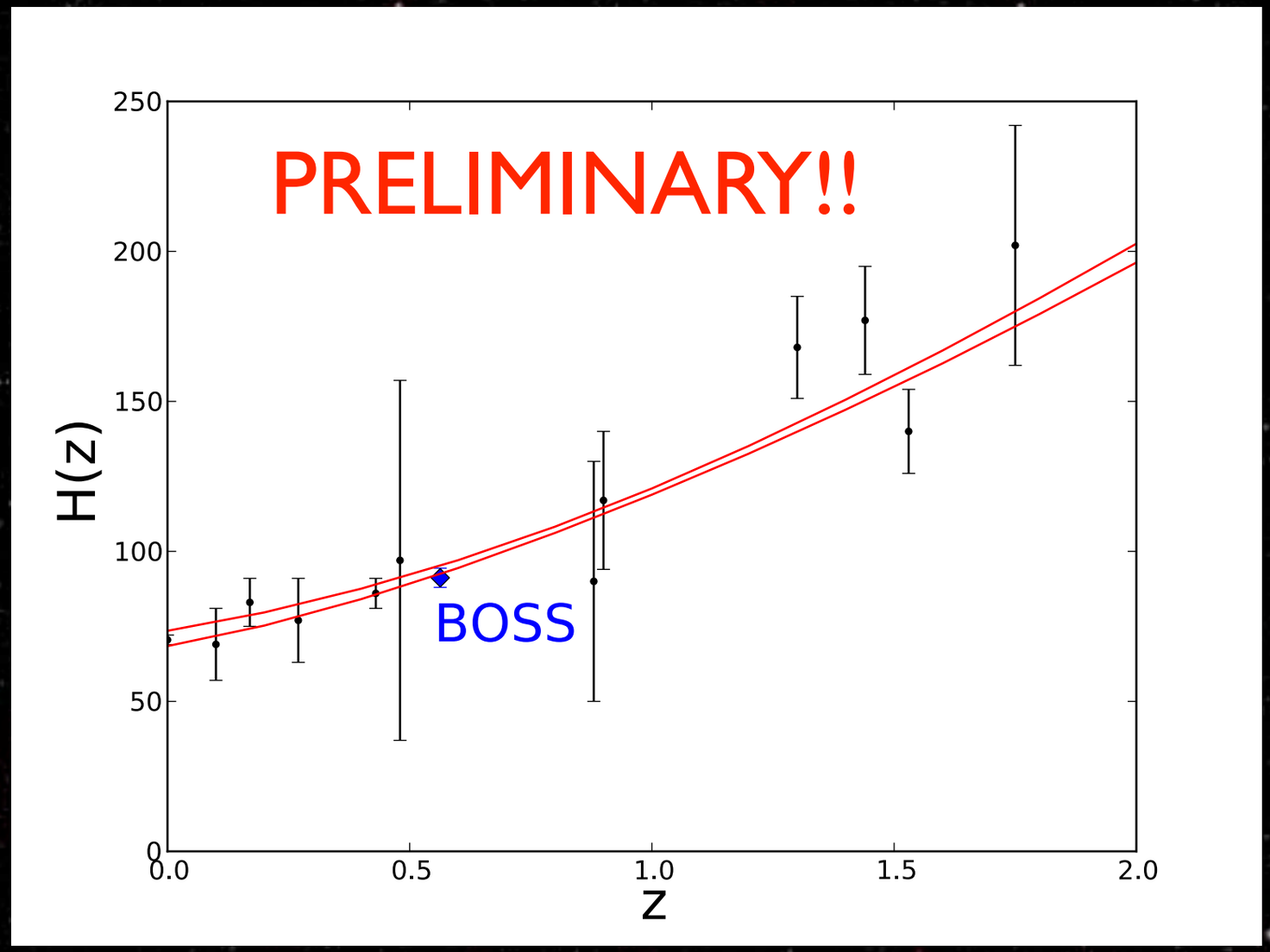
Current status

- $D_V/D_{V,fid}$ = 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 ± 0.03 (3%) [WMAP7 LCDM: 1.00 ± 0.012]
- Fit both: $f\sigma_8$ = xx ± 0.07, η = xx ± 0.07

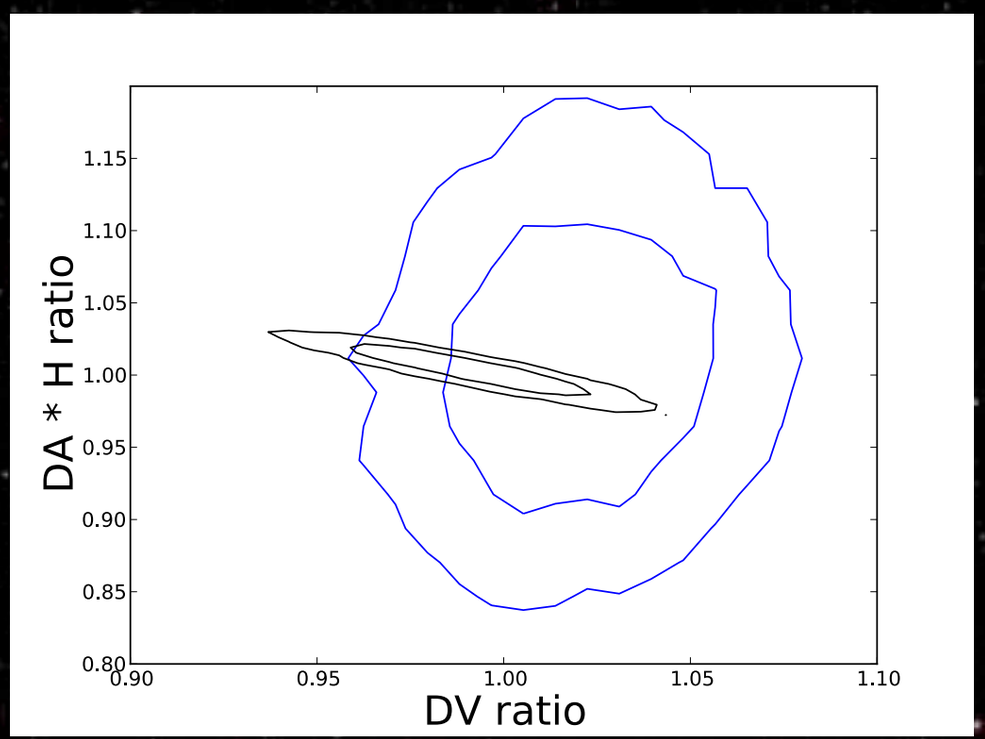
Testing alternative models with amplitude of peculiar velocities

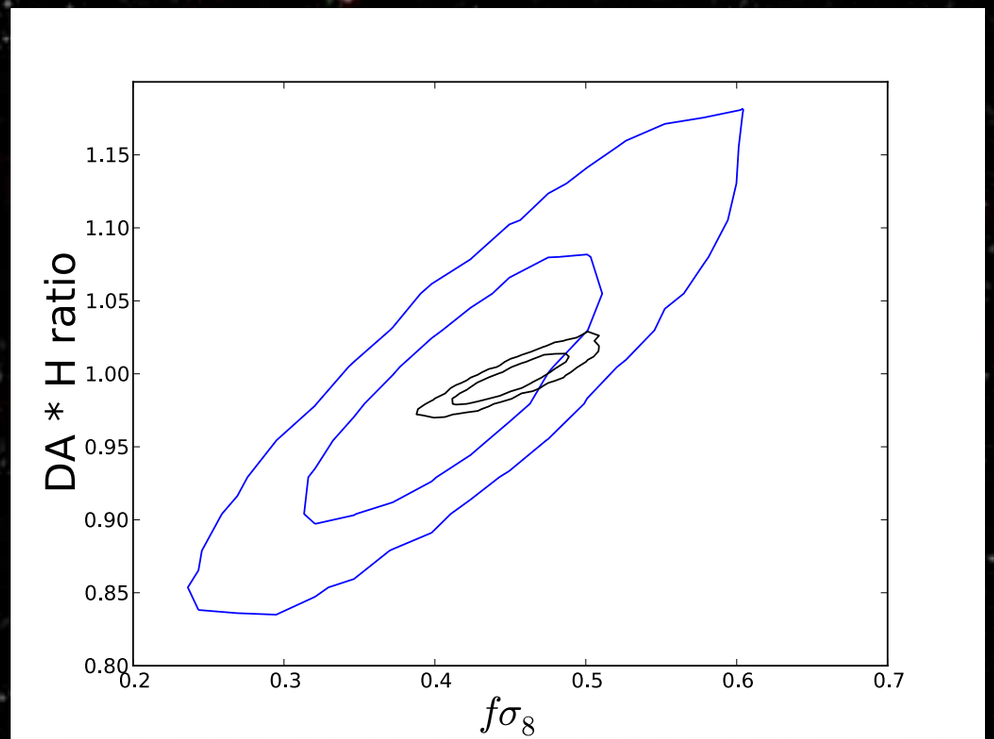


Expansion rate at z=0.57



Simultaneous RSD and AP fits vs WMAP ΛCDM





Summary/Conclusions

- BOSS DR9 -- coming to a laptop near you in July 2012!
- Unprecedented examinations of systematic errors
- High significance detection of BAO at z=0.57
- RSD and AP constraints from 2d clustering