New Results from SDSS-III BOSS: cosmic expansion and growth of structure

Beth Reid
Hubble Fellow
Lawrence Berkeley National Lab

in collaboration with Martin White, Will Percival, Lado Samushia, Baryon Oscillation Spectroscopic Survey [BOSS] collaboration

Outline

- Baryon Oscillation Spectroscopic Survey (BOSS) status
- Measuring geometry and growth with redshift surveys
- BOSS DR9 results and cosmological implications
- DR10/11 coming soon!

SDSS-III Baryon Oscillation Spectroscopic Survey

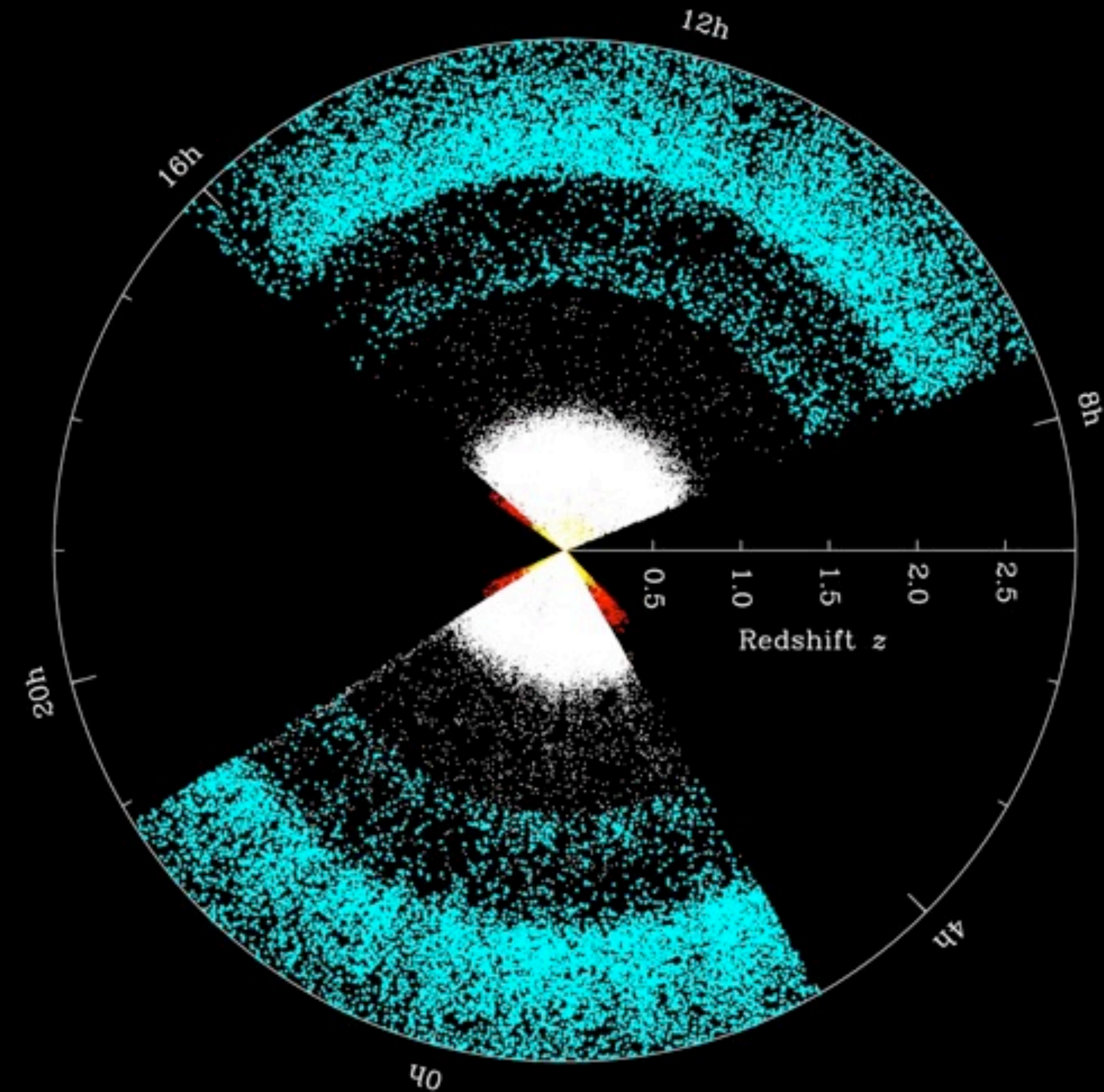
- 10,000 deg^2, 1.35M new redshifts
- %-level distances at $z = 0.35, 0.6, 2.3$

QUASARS

BOSS galaxies

SDSS Main

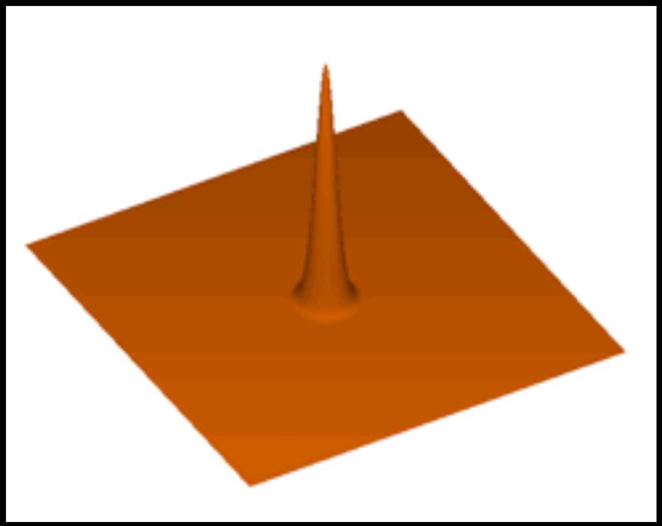
SDSS LRGs



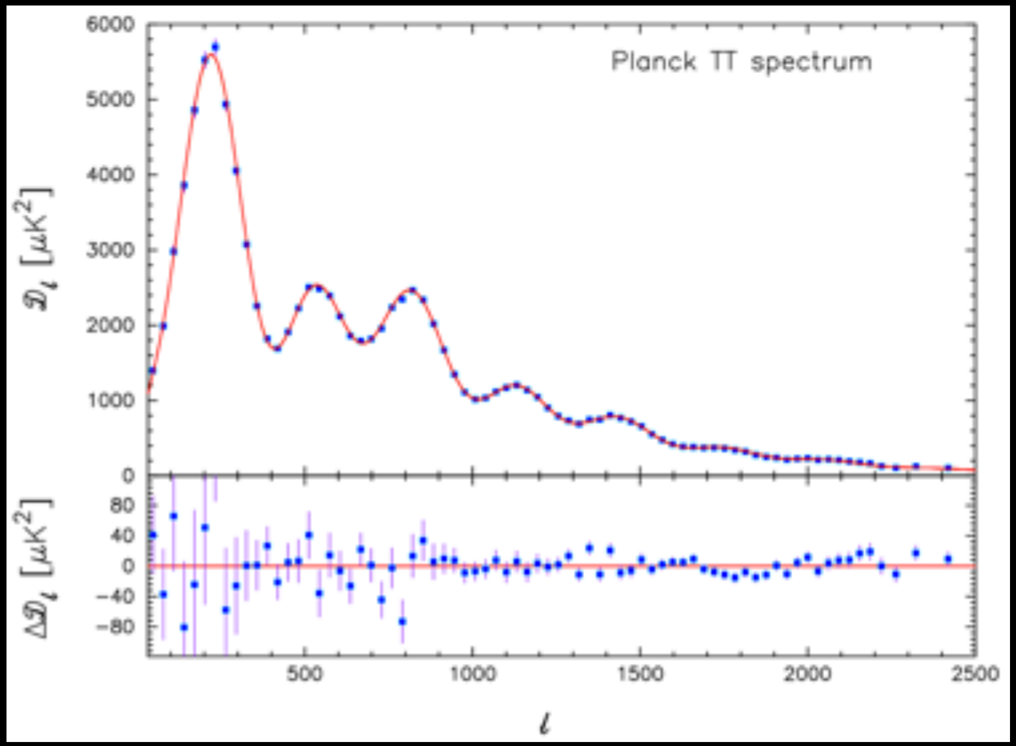
Beth Reid

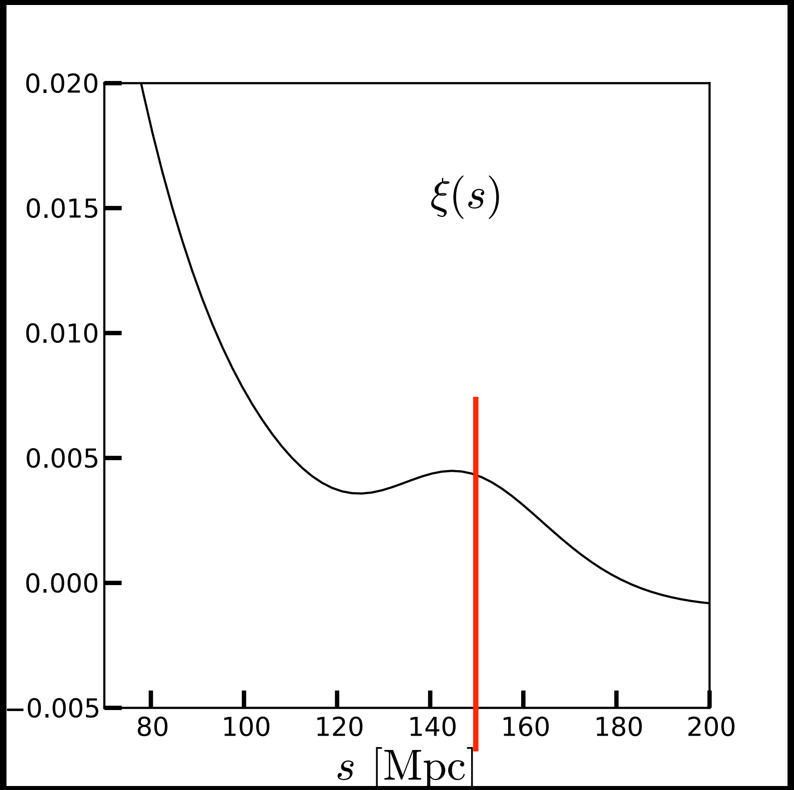
APS DPF 2013

The BAO standard ruler:
[see Mariana Vargas-Magana's talk]



r_s = 151.4 ± 0.66 Mpc
(Planck 2013)

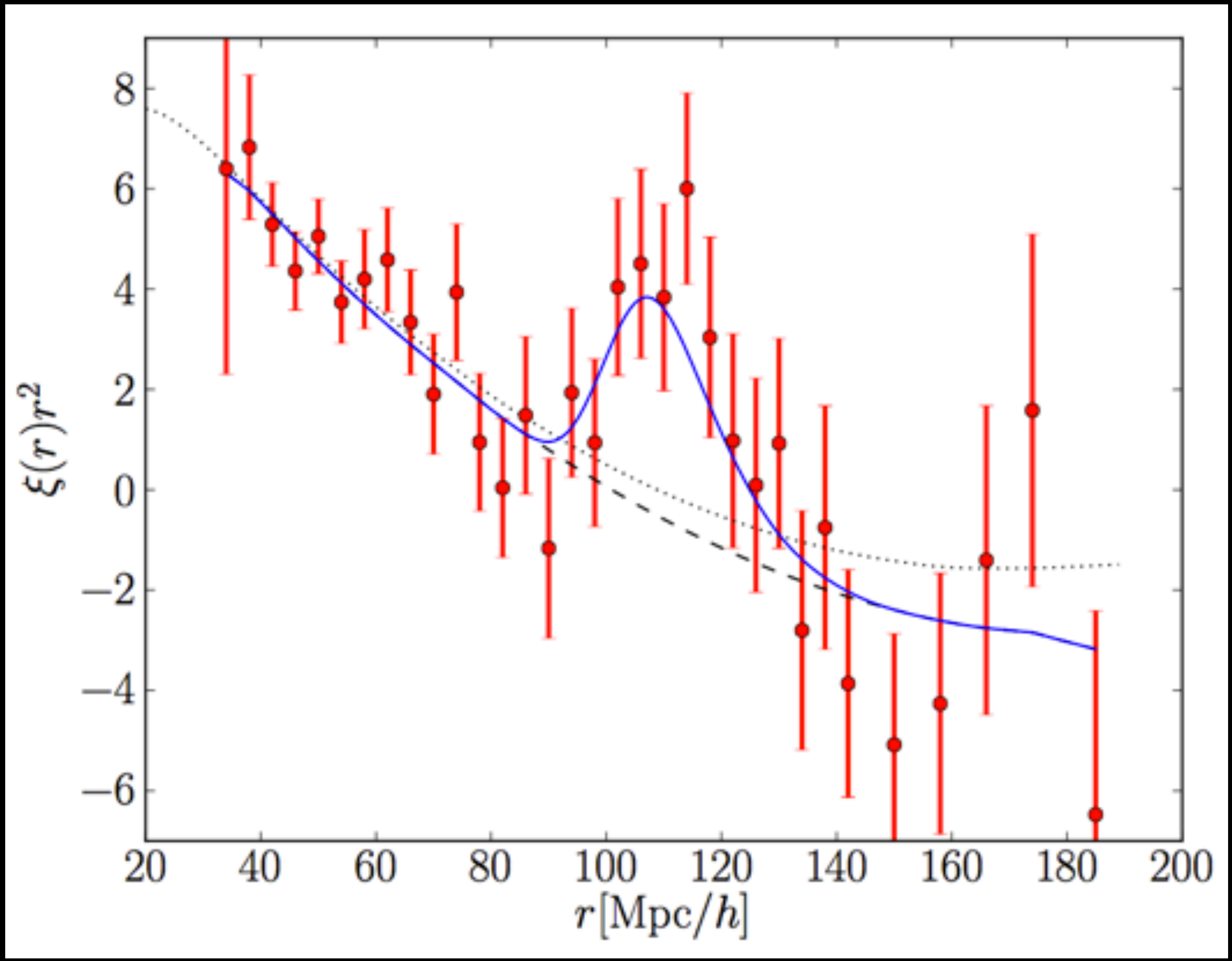




Planck 2013 #16

SDSS-III Baryon Oscillation Spectroscopic Survey Ly-α forest BAO detection

- Busca et al. 2012, Slosar et al. 2013, Kirkby et al. 2013
- H(z=2.3) to <4%!



Slosar et al. 2013

SDSS-III Baryon Oscillation Spectroscopic Survey

- 10,000 deg^2, 1.35M new redshifts

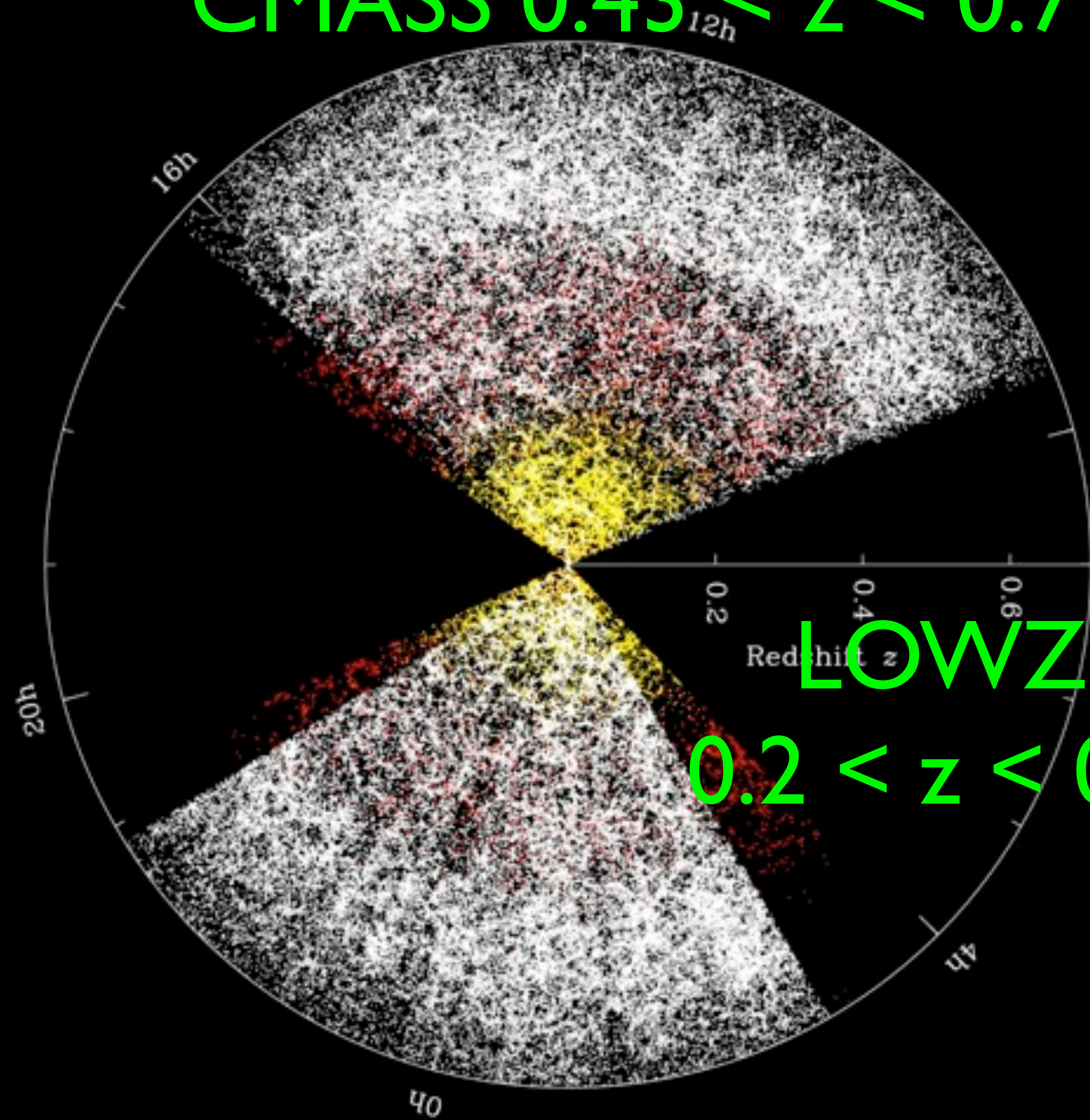
CMASS $0.43 < z < 0.7$

QUASARS

BOSS galaxies

SDSS Main

SDSS LRGs



LOWZ
$0.2 < z < 0.4$

BOSS survey status

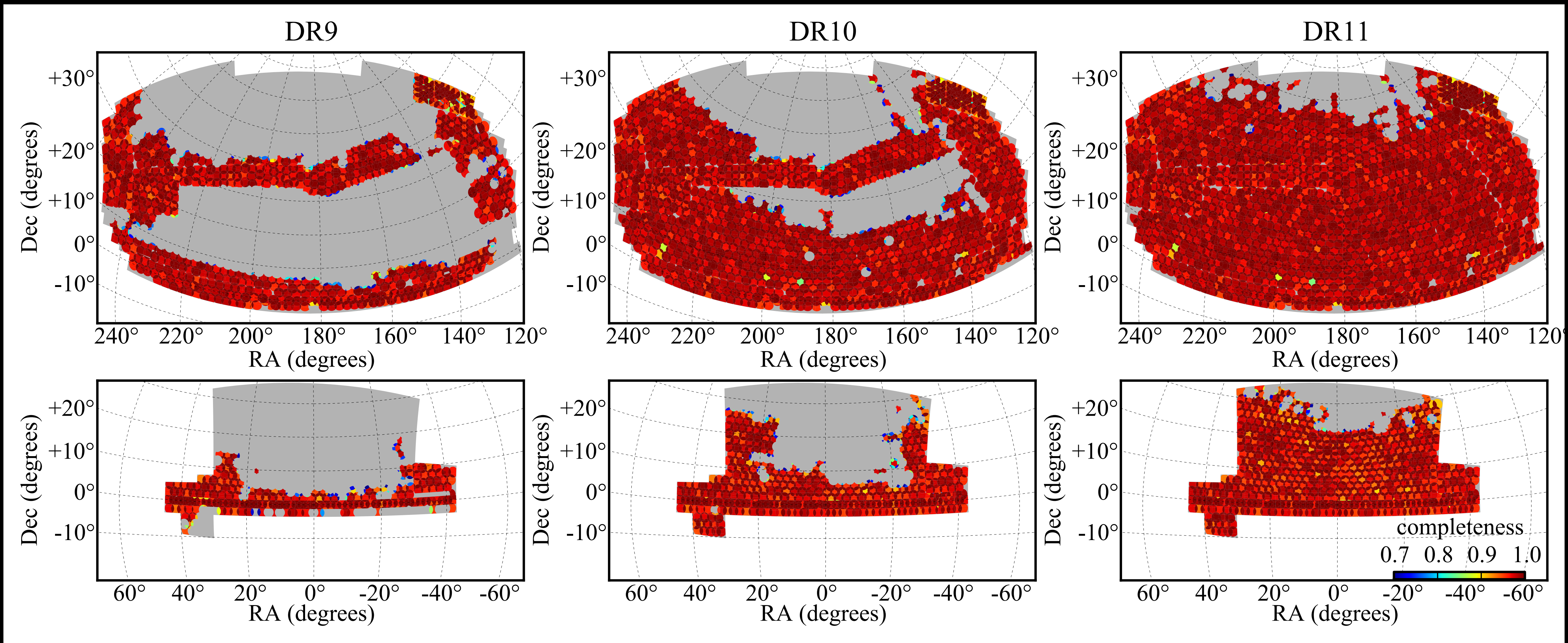


figure credit Molly Swanson

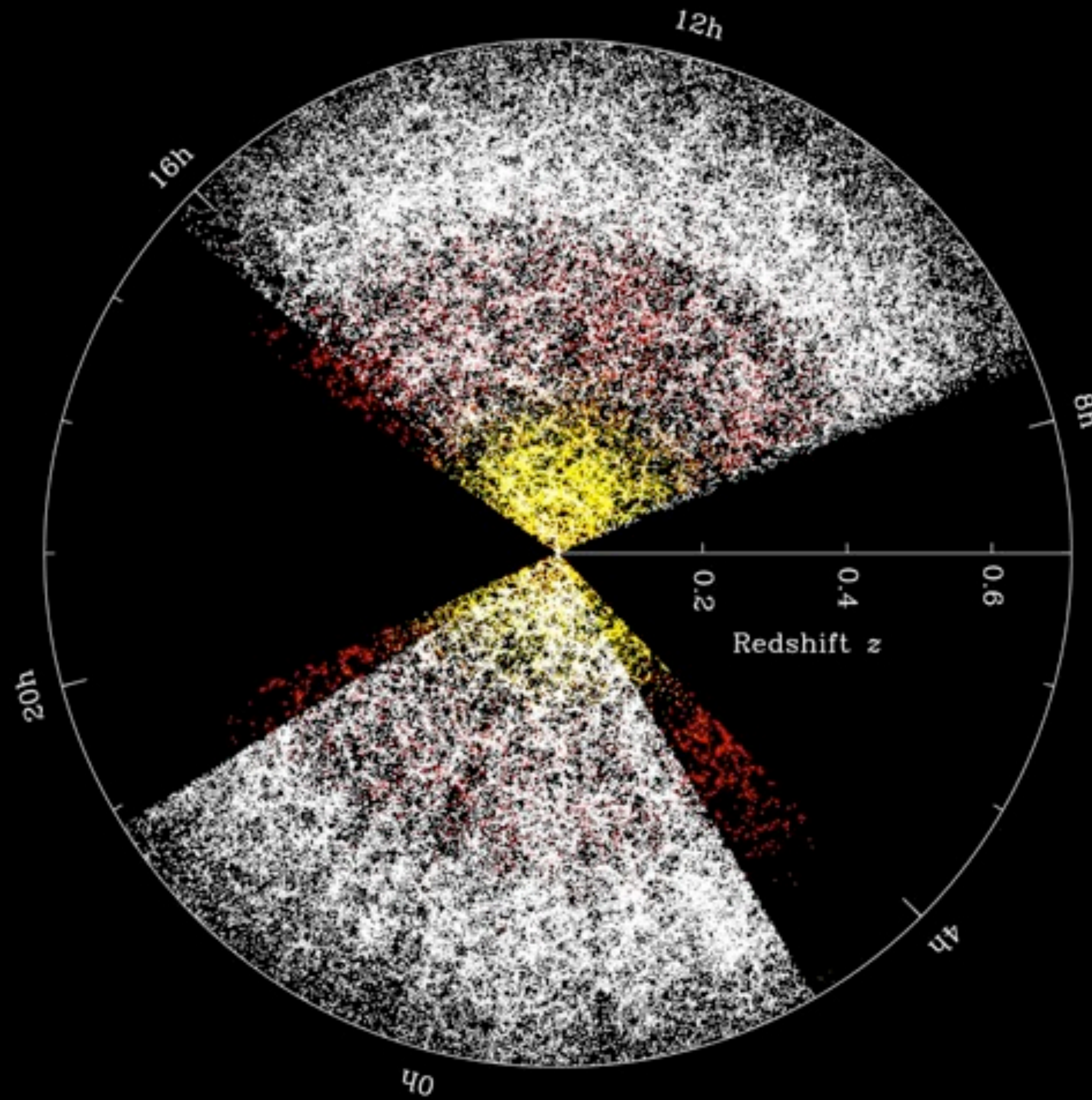
Results presented today
A_{eff}: 3275 deg^2

Public!
data.sdss3.org
6161 deg^2

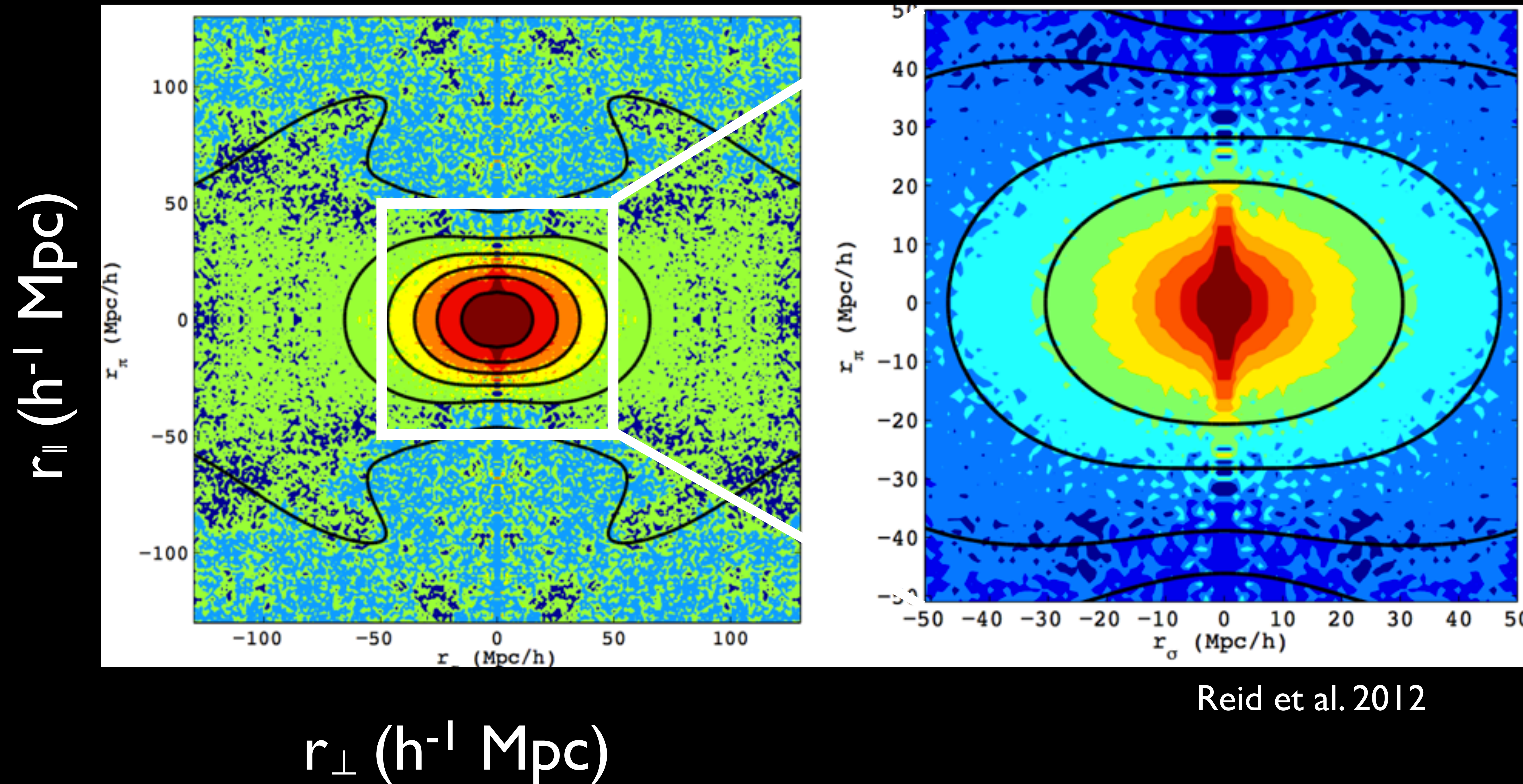
Currently analyzing
8387 deg^2

Motivation

- There is *much* more information in this 3d map than the BAO feature
- Rocky III: RSD is "among the most powerful ways of addressing whether the acceleration is caused by dark energy or modified gravity"



Let's start simple: what can we extract from the full 2d correlation function $\xi(r_\sigma, r_\pi)$?



Reid et al. 2012

Beth Reid

APS DPF 2013

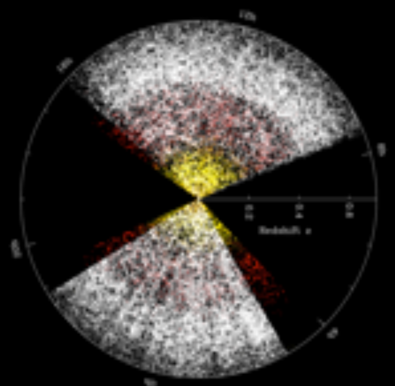
Friday, August 16, 2013

Outline

- Baryon Oscillation Spectroscopic Survey (BOSS) status
- Measuring geometry and growth with redshift surveys
- BOSS DR9 results and cosmological implications
- DR10/11 coming soon!

Geometric constraints from galaxy surveys

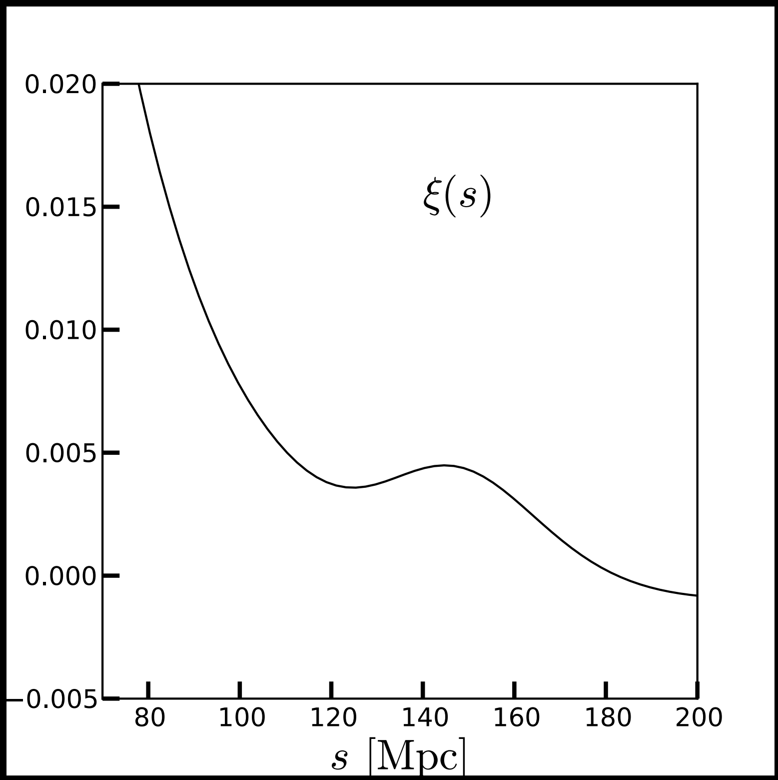
Observer space:
ra, dec, z



depends on H(z)
for z in [0, z_{max}]

↔

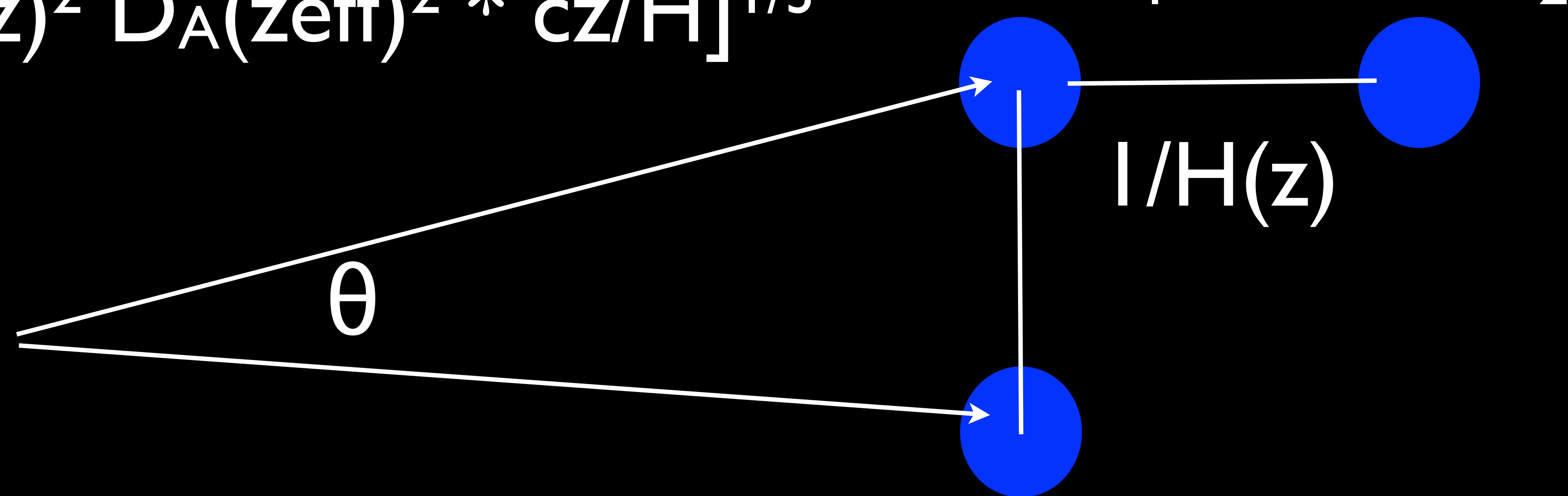
Theory space:
(physical) Mpc



BAO standard ruler

- The BAO feature in the angle-averaged correlation function constrains $\alpha = [D_V(z_{eff})/r_s]/[D_V(z_{eff})/r_s]_{fiducial}$

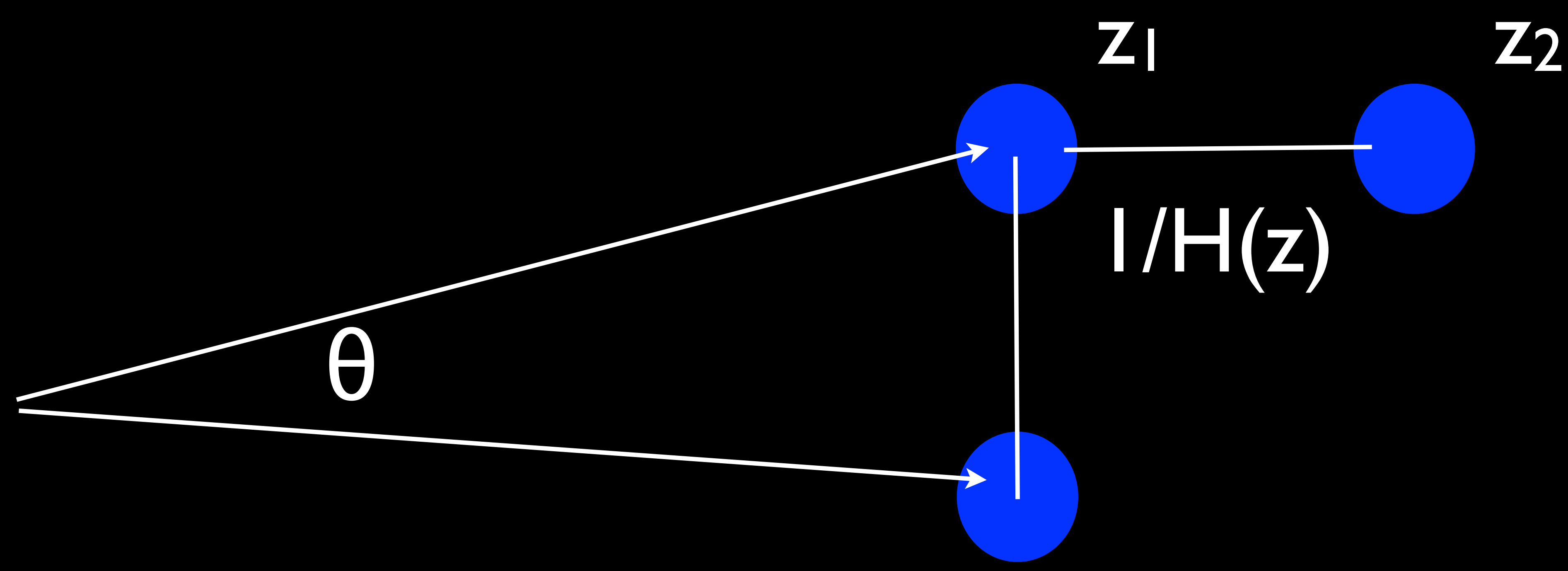
$$D_V \equiv [(1+z)^2 D_A(zeff)^2 * cz/H]^{1/3}$$



comoving angular diameter distance $\equiv (1+z)\, D_A(z)$

Alcock-Paczynski effect

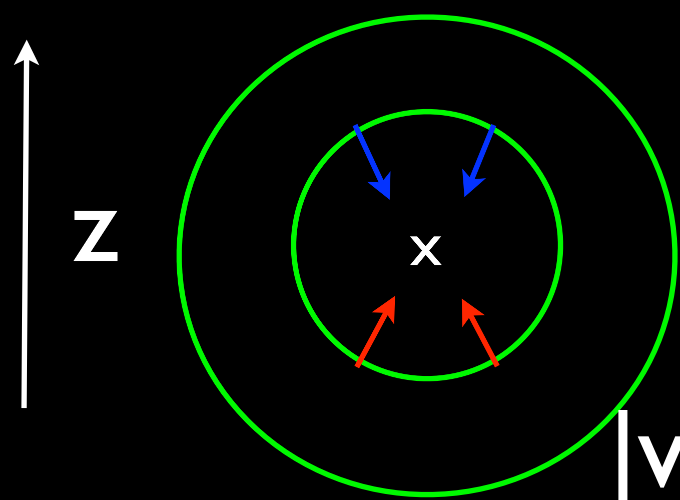
- Even without a standard ruler, comparing clustering along and perpendicular to the LOS allows us to measure D_A * H



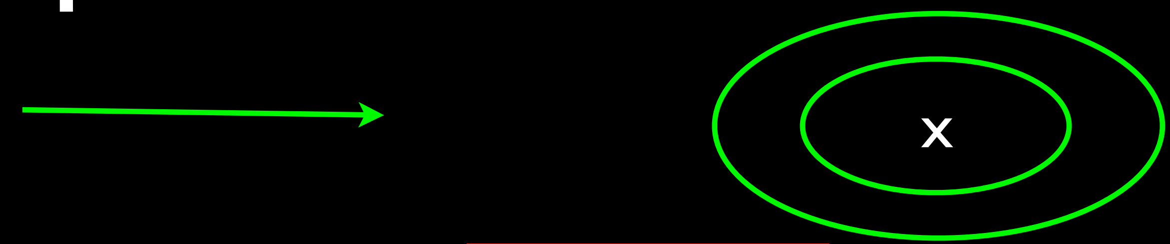
comoving angular diameter distance ≡ (1+z) $D_A(z)$

Redshift Space Distortions (RSD)

real to redshift space separations: $\chi(z) = \chi_{true} + v_p/aH$



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



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

isotropic

squashed along line of sight

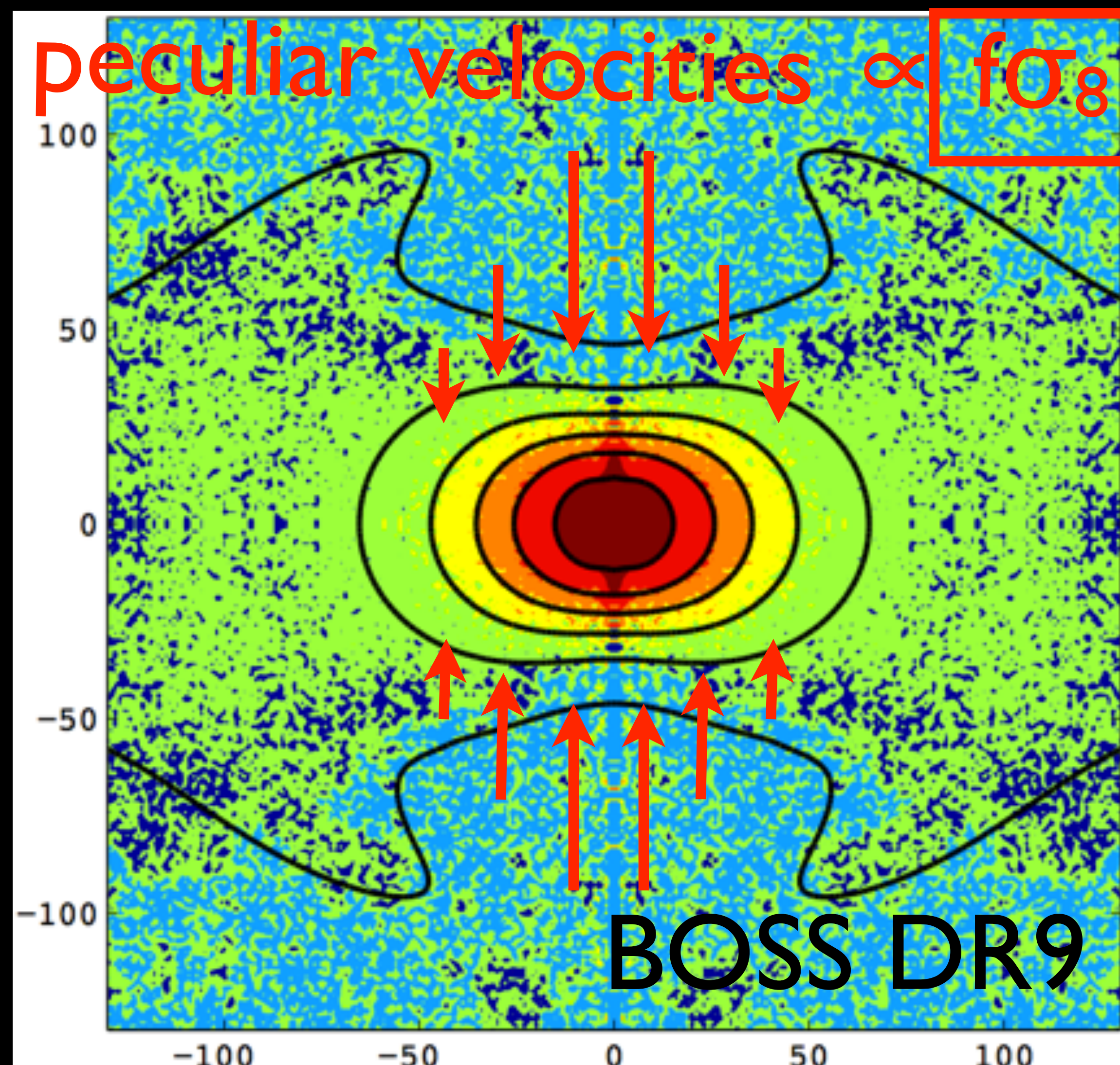
$f = d \ln \sigma_8 / d \ln a \approx \Omega_m^{\gamma}$

Putting it all together

isotropic dilation

$D_V \propto D_A^{2/3} * H^{-1/3}$

$D_A/D_{A,fid}$



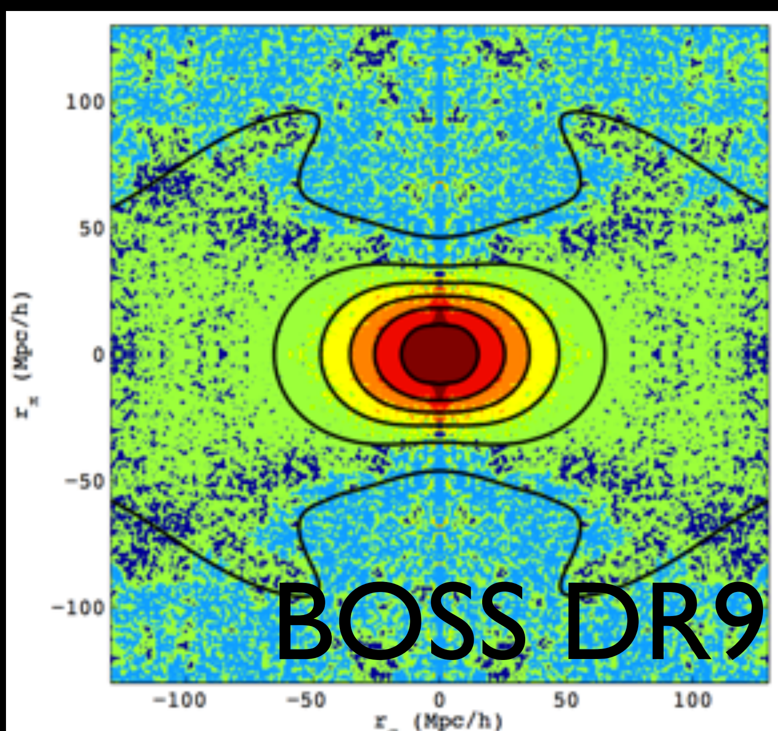
H_{fid}/H

$F_{AP} \propto D_A * H$

$r_\parallel$ (h^{-1} Mpc)

$r_\perp$ (h^{-1} Mpc)

Information compression step 2: Legendre Polynomial moments $\xi_\ell(s)$



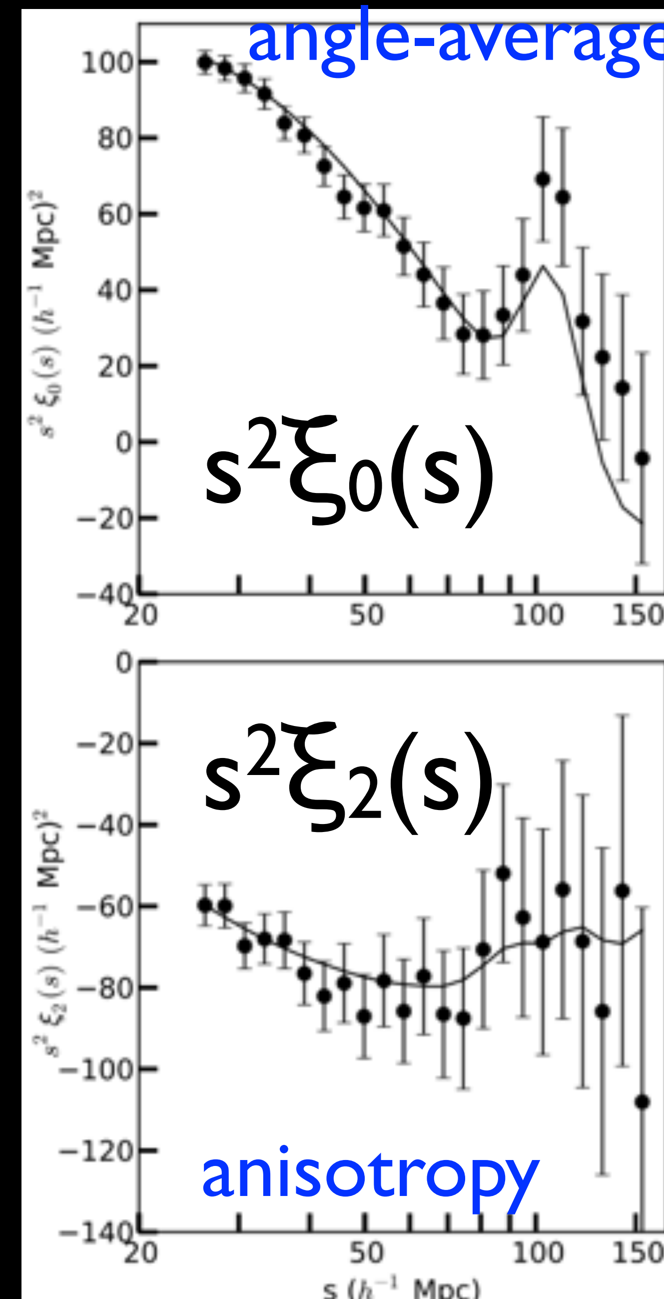
$$\xi(s,\mu_s) = \sum_\ell \xi_\ell(s) L_\ell(\mu_s)$$

$\longrightarrow$

$L_0 = 1$

$L_2 = (3\mu^2 - 1)/2$

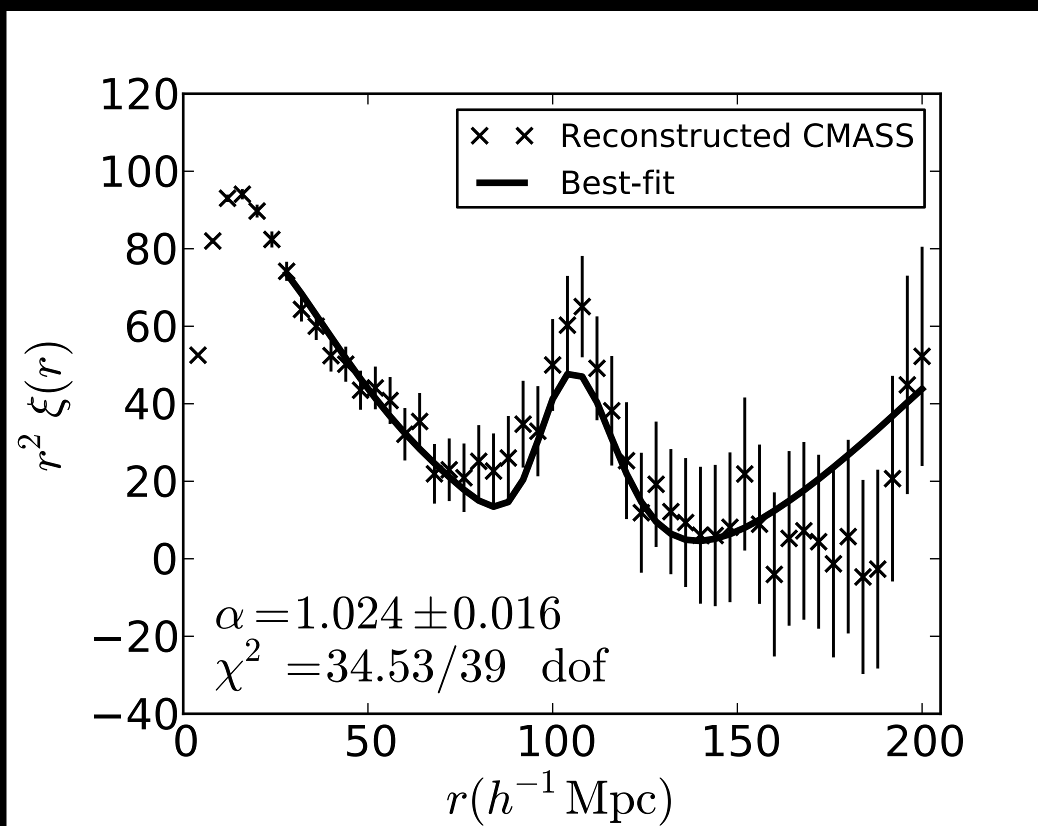
$\mu = r_{LOS}/(r_{LOS}^2 + r_\perp^2)^{1/2}$

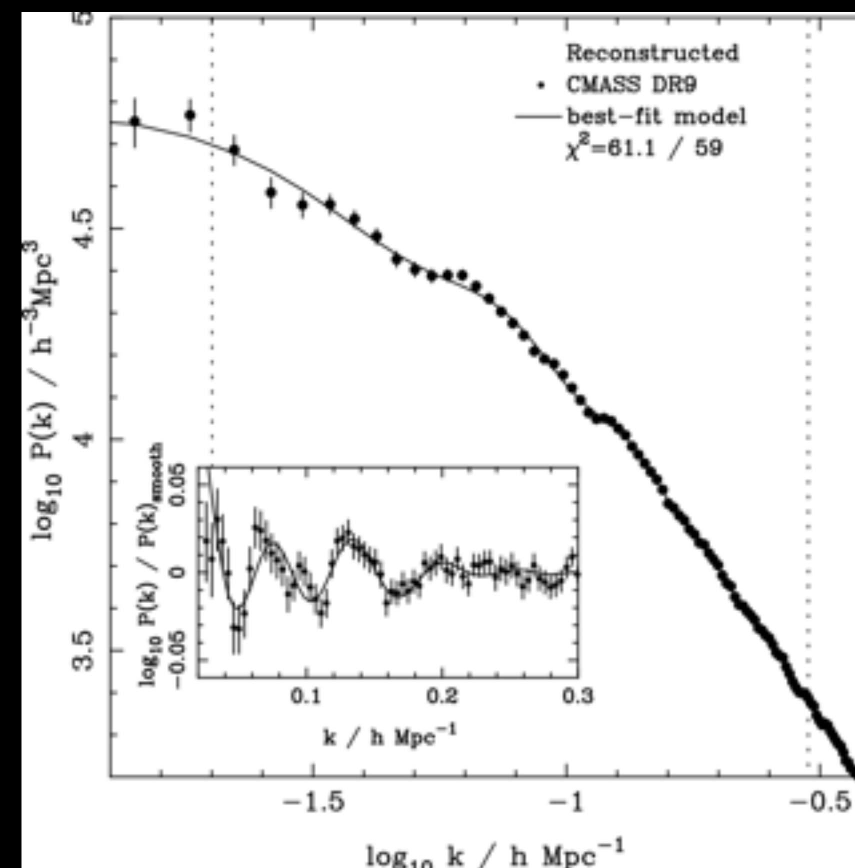


Outline

- Baryon Oscillation Spectroscopic Survey (BOSS) status
- Measuring geometry and growth with redshift surveys
- BOSS DR9 results and cosmological implications
- DR10/11 coming soon!

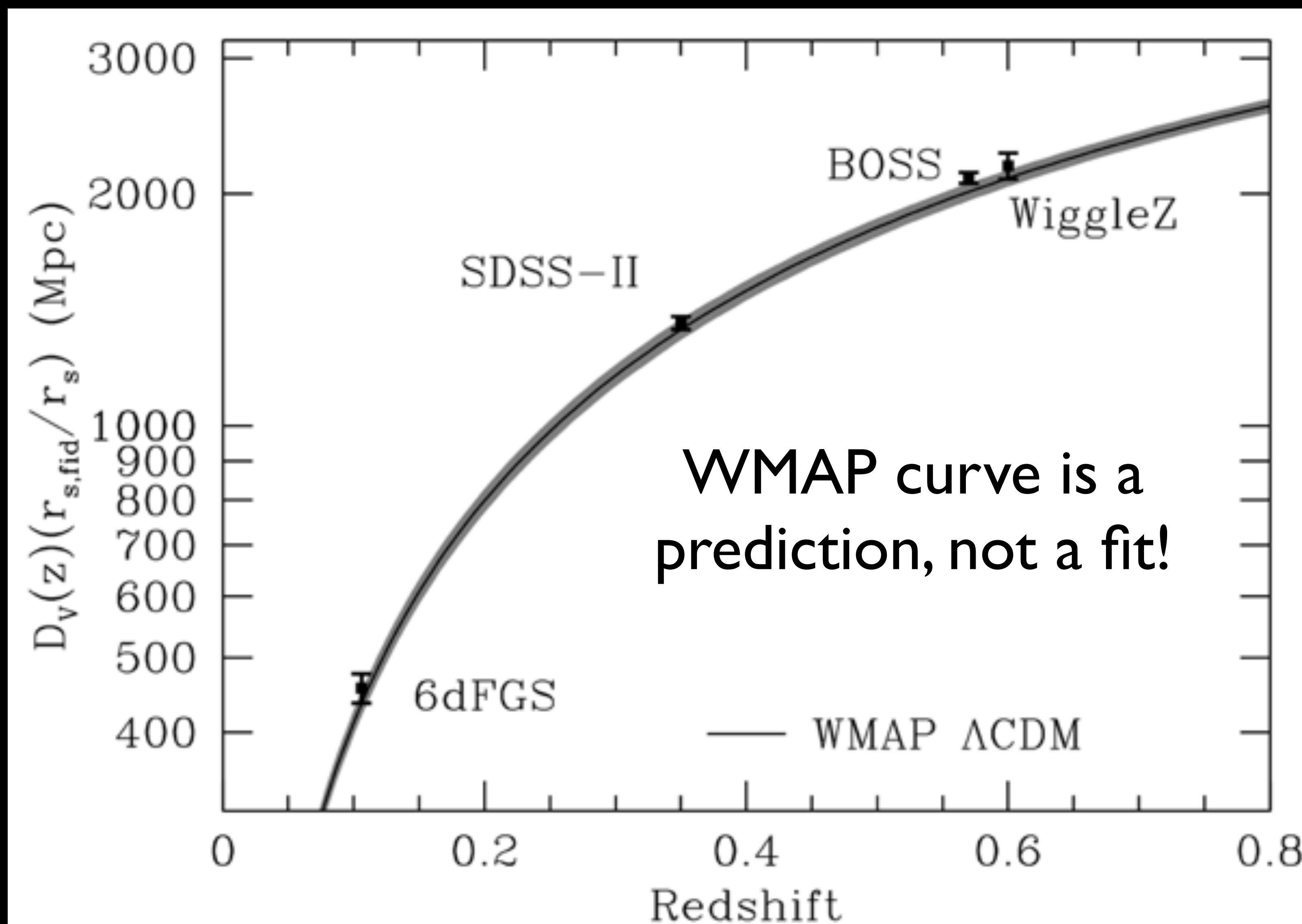
Anderson et al. 2012: fits to α for "reconstructed" ξ(s) and P(k)





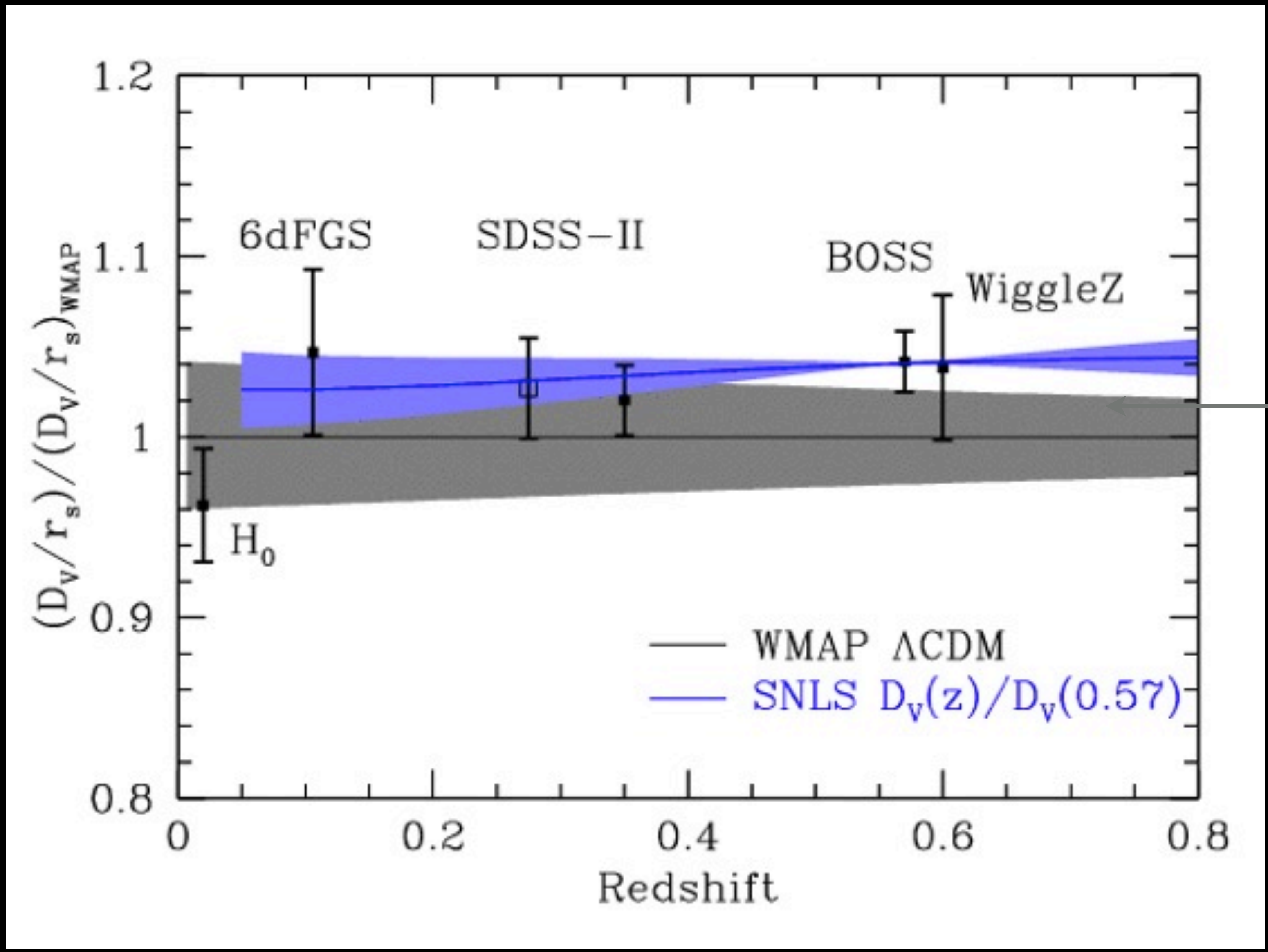
Reid et al.: α = 1.023 ± 0.019

BAO Hubble Diagram



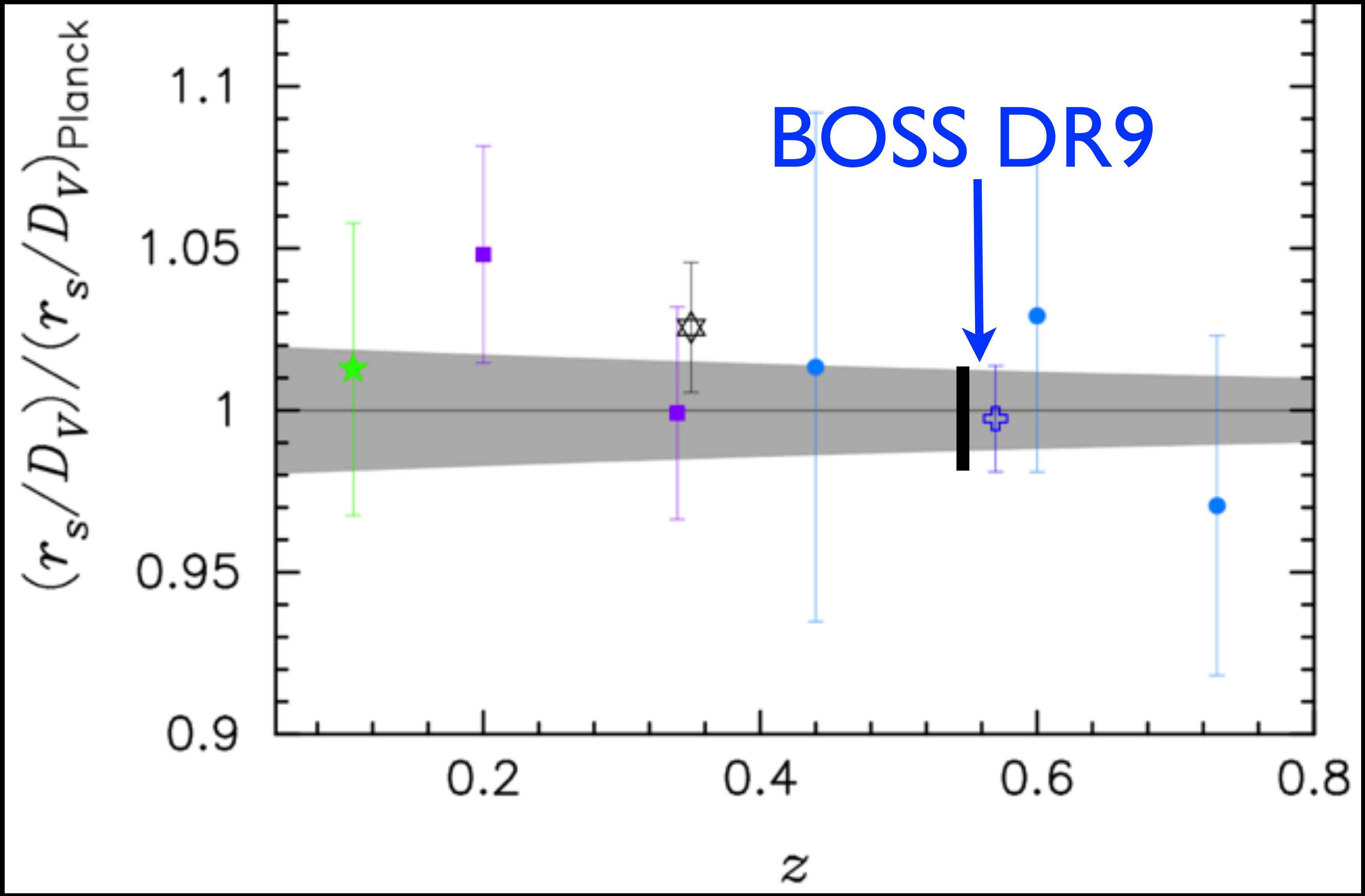
WMAP curve is a prediction, not a fit!

BAO Hubble Diagram: Comparison with CMB, H_0, and SN



+1σ in $\Omega_m h^2$ (WMAP7)

BAO Hubble Diagram: Comparison with Planck

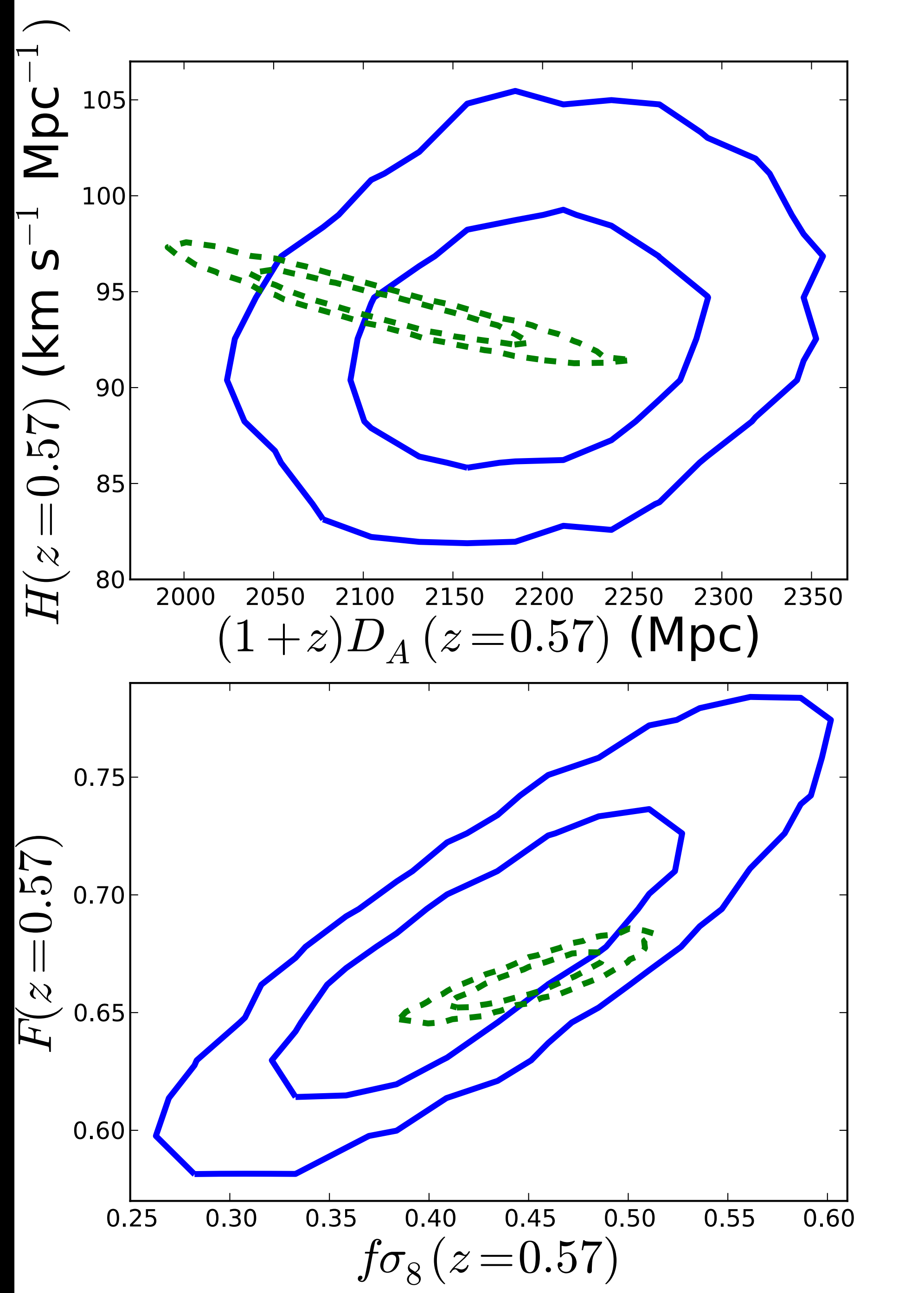


+1σ in $\Omega_m h^2$ (Planck)

DR9 ξ_0 BAO + ξ_2: D_A, H, $f\sigma_8$ at z=0.57

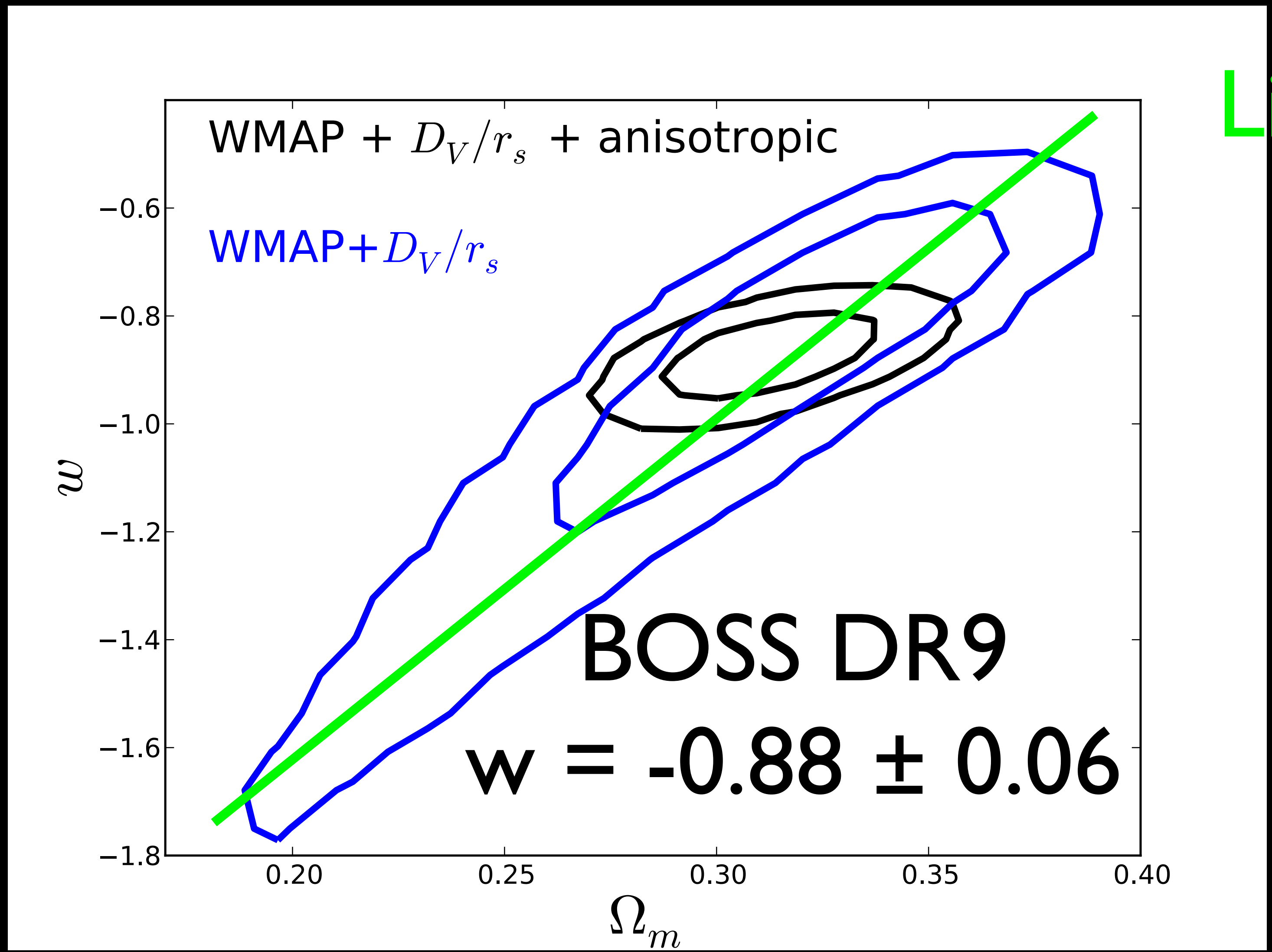
- $f\sigma_8(0.57) = 0.43 \pm 0.069$
- $H(0.57) = 92.4 \pm 4.5$ km s^{-1} Mpc^{-1}
- $D_A(0.57) = 2190 \pm 61$ Mpc

Marginalize over:
-- CMB P(k) shape prior
-- $b\sigma_8$
-- σ^2_{FOG}



DR9 Results

- Modeling ξ(s,μ) buys you a lot of statistical power on dark energy parameters and testing gravity



Line of constant $D_A(z=1091)$

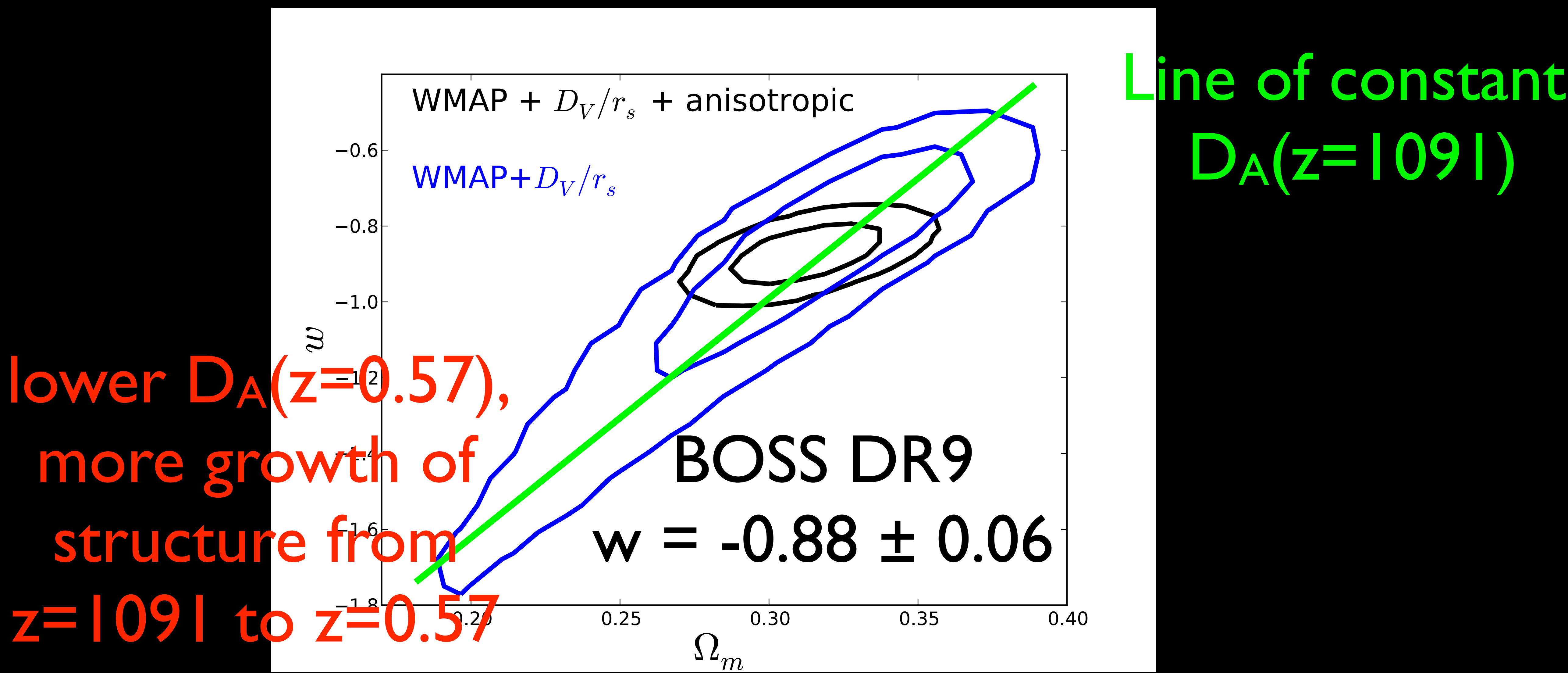
DE more "recent"/ larger H_0

Beth Reid

APS DPF 2013

DR9 Results

- Modeling ξ(s,μ) buys you a lot of statistical power on dark energy parameters and testing gravity



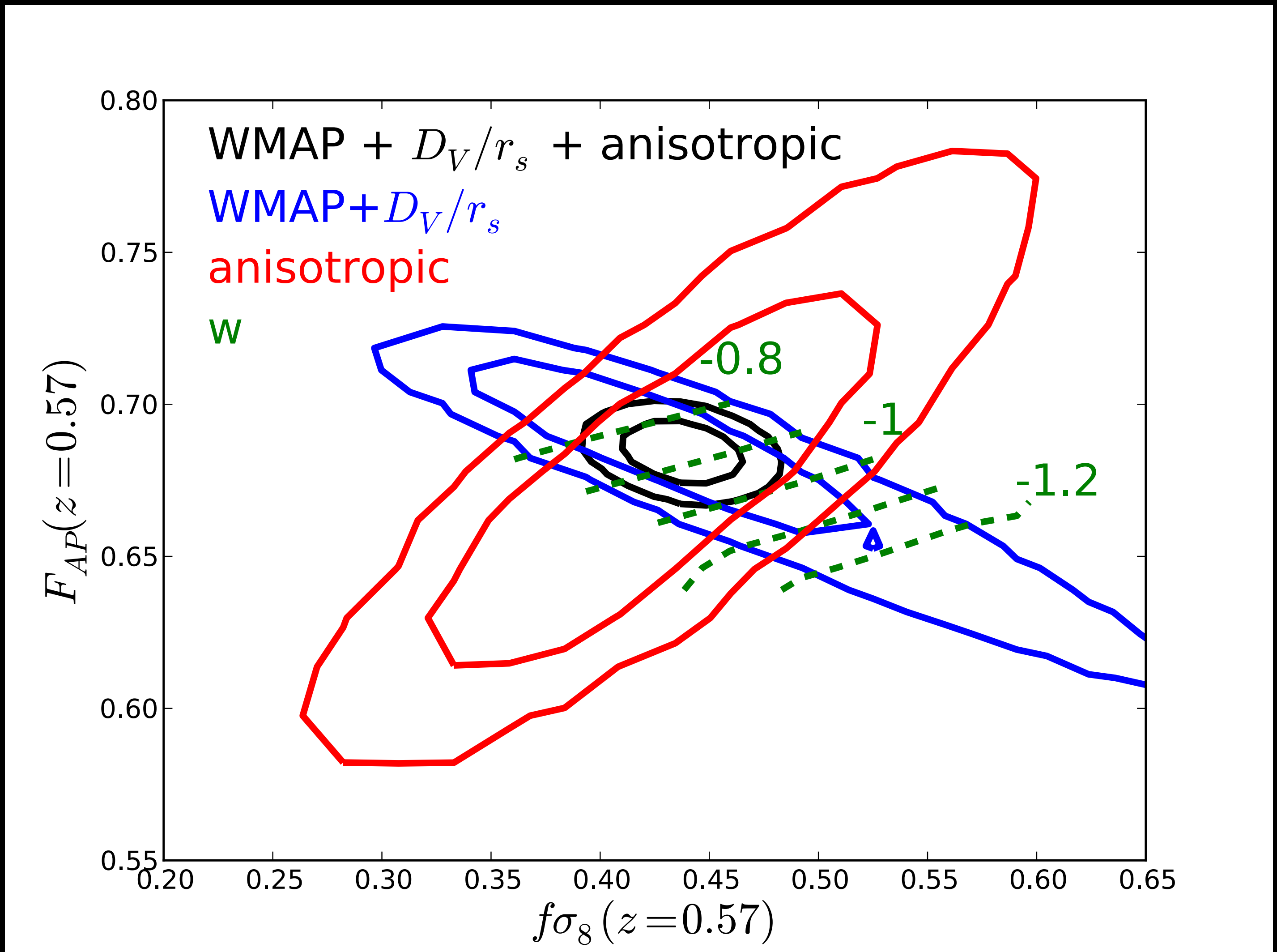
Beth Reid

APS DPF 2013

Friday, August 16, 2013

DR9 Results

- Modeling ξ(s,μ) buys you a lot of statistical power on dark energy parameters and testing gravity

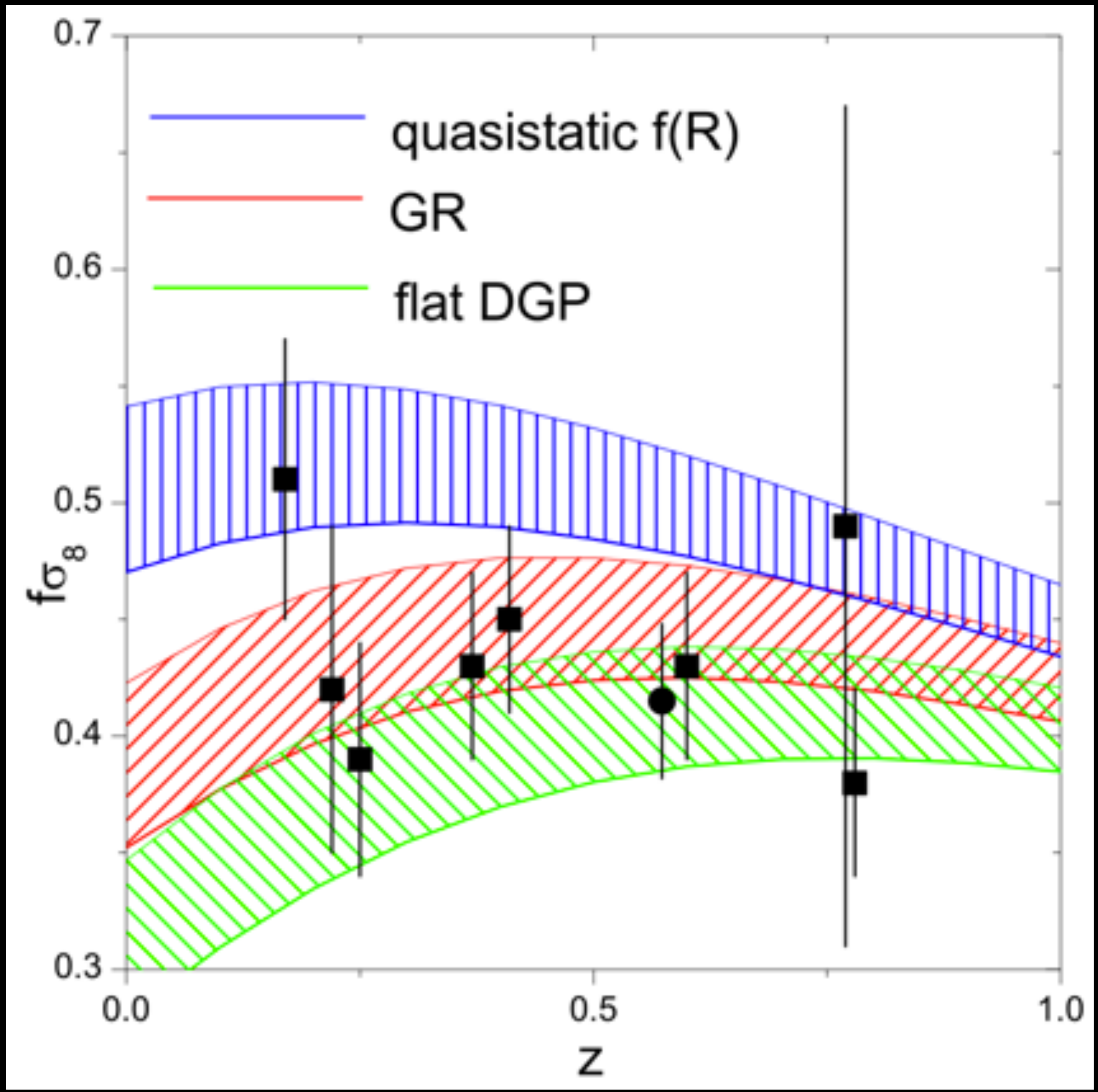


Samushia, BR, et al., 2012

lower $D_A(z=0.57)$, more growth of structure from z=1091 to z=0.57

Dark Energy or modified gravity?

- CMASS geometric constraints tighten ΛCDM $f\sigma_8$ prediction, shift it up
- CMASS $f\sigma_8$ is low by ~ 1.5σ

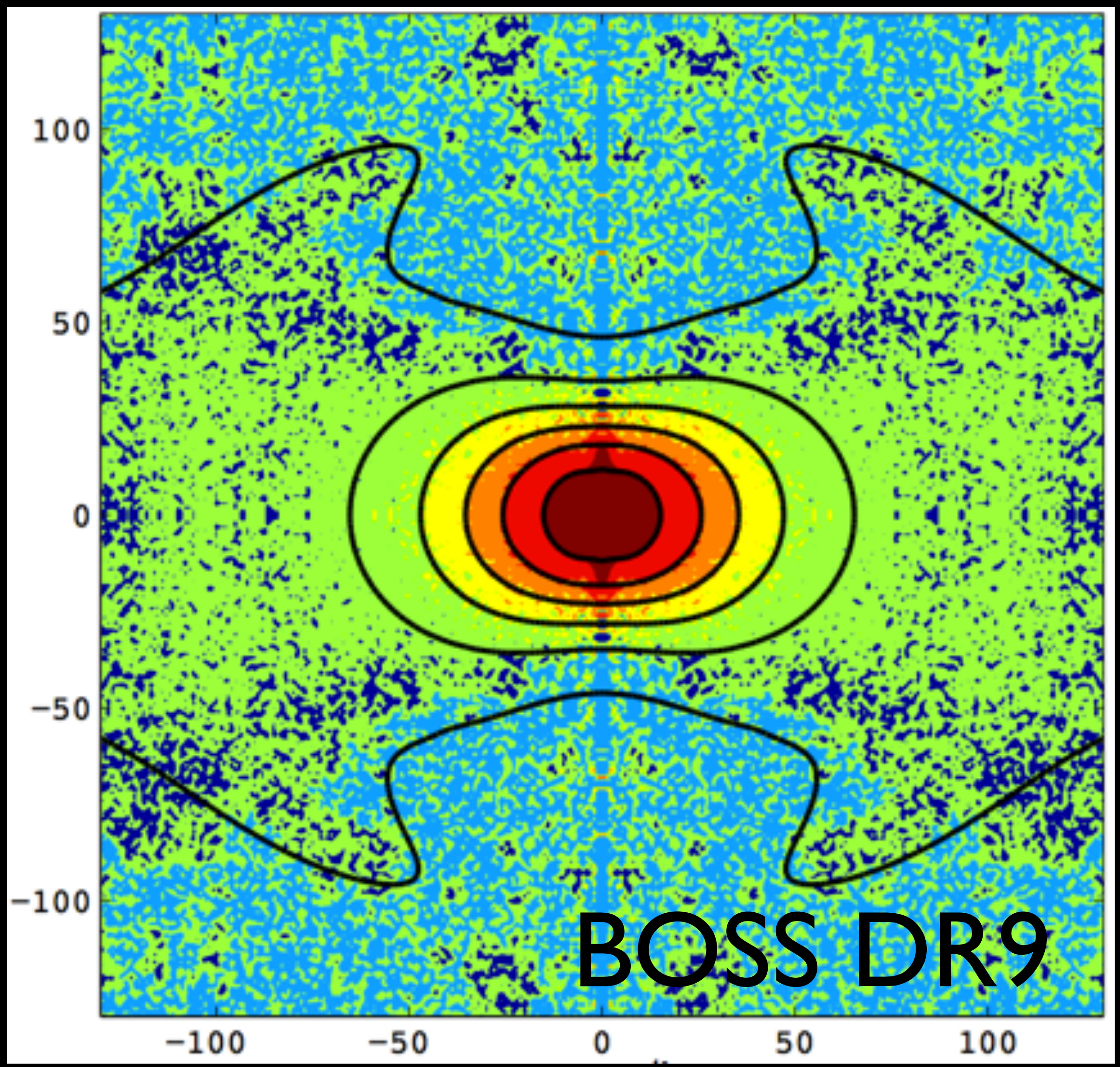


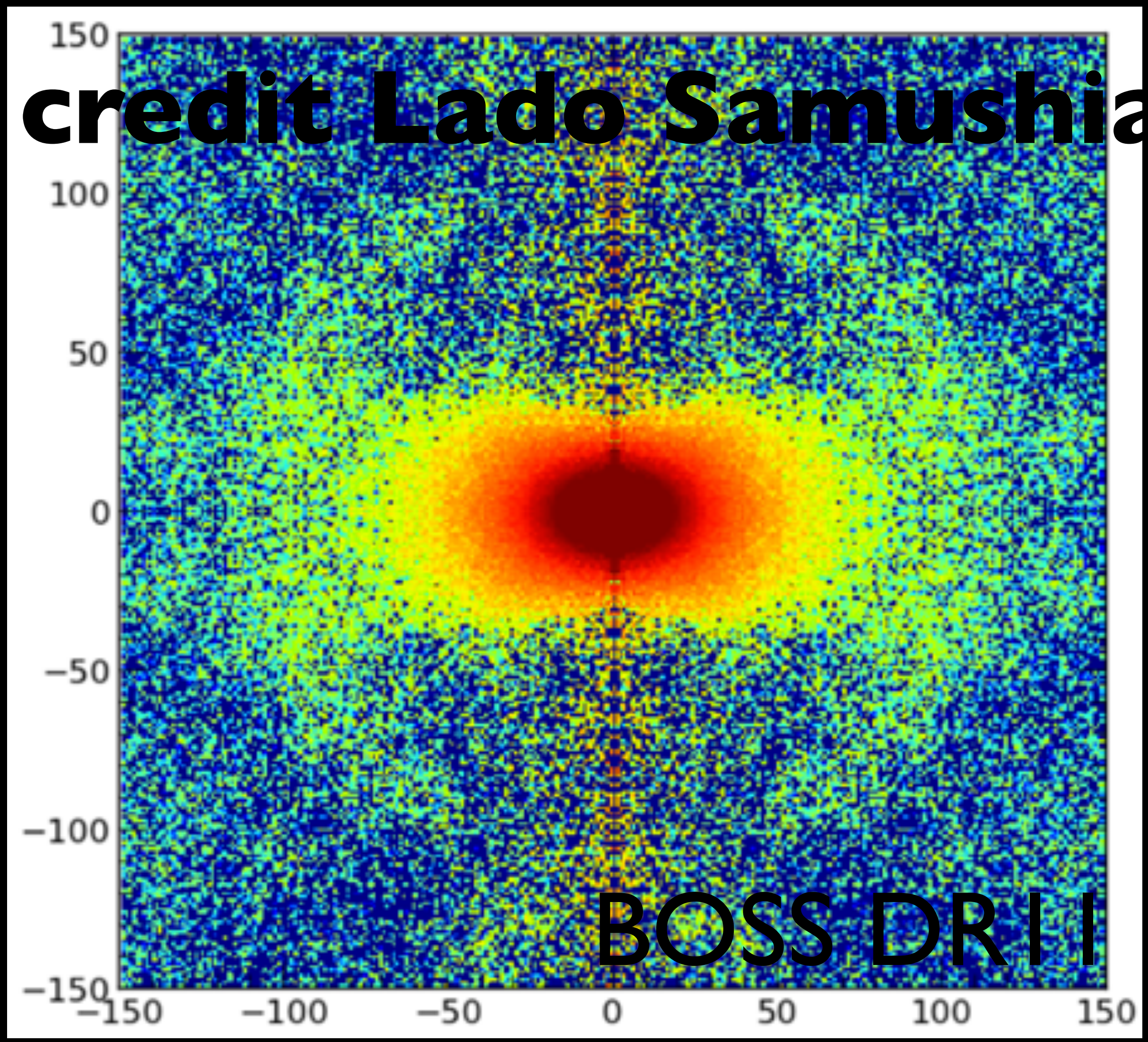
Samushia, BR, et al., 2012

Future prospects

- Including 2d broadband P(k)/ξ(r) increases DETF FOM by factor of ~ 2-4 and allows modified gravity tests using RSD, if we can control the theoretical uncertainties

DR11 coming soon...





EXTRAS

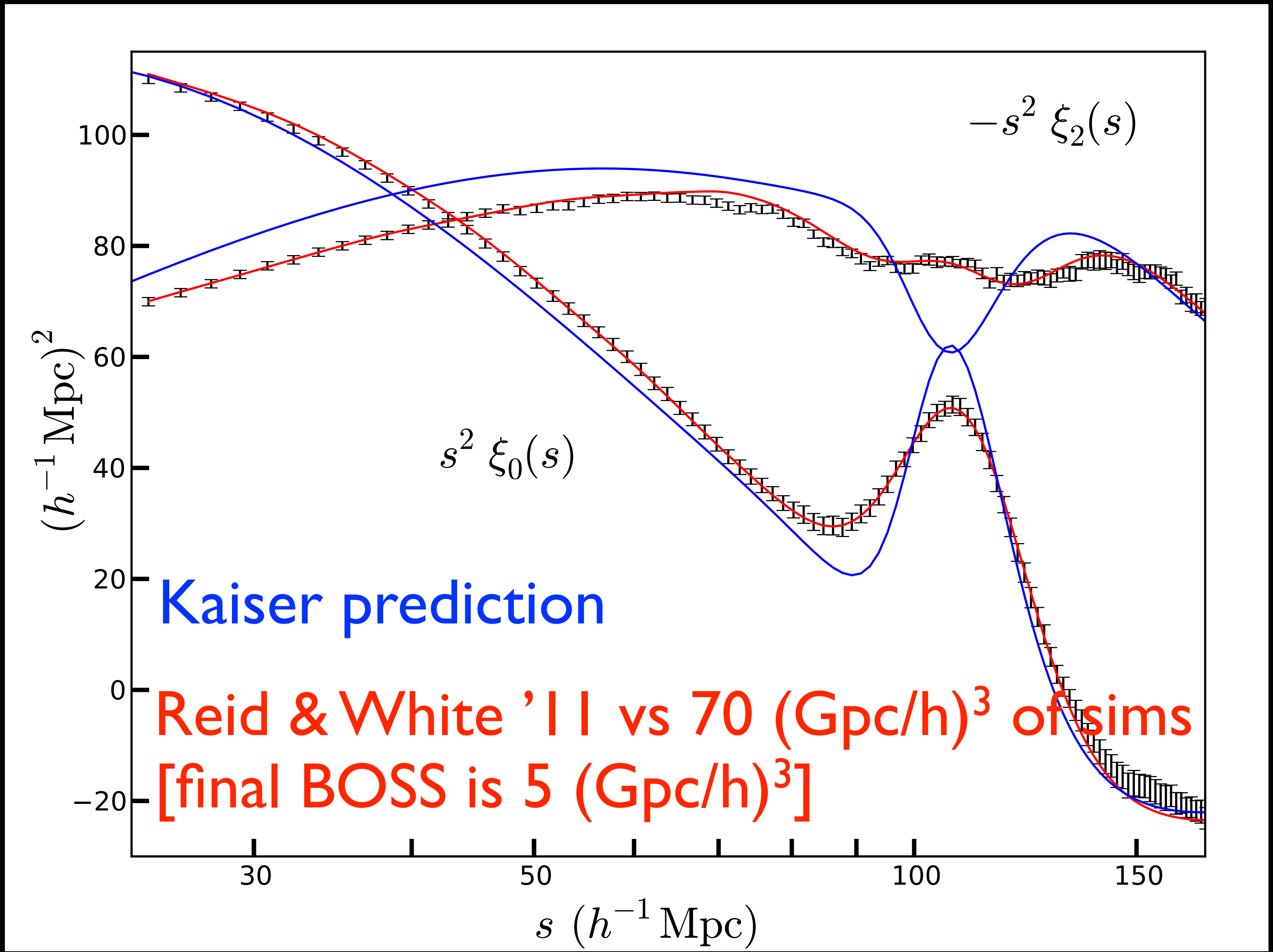
Modeling the full shape of $\xi_{0,2}$ (Reid & White 2011)

- $b\sigma_8$, $f\sigma_8$ determine amplitude of $\xi_{0,2}$

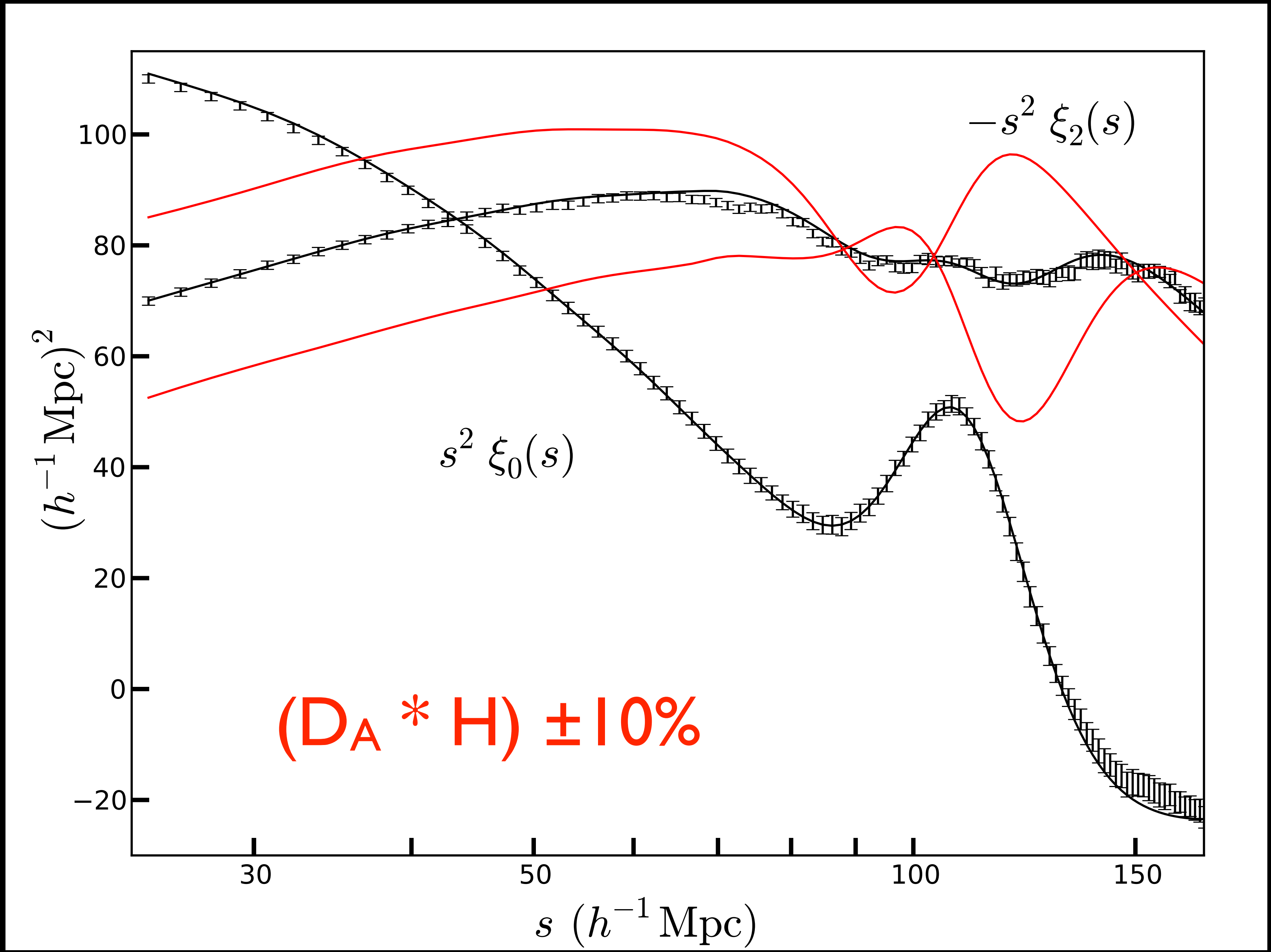
σ_8: amplitude of matter fluctuations

b: unknown conversion factor between galaxy and matter fluctuations

f = d ln σ_8/d ln a; conversion factor between matter and velocity fluctuations



Alcock-Paczynski has different scale-dependence, distinguishable from RSD



D_V stretches s axis ⟷

Beth Reid

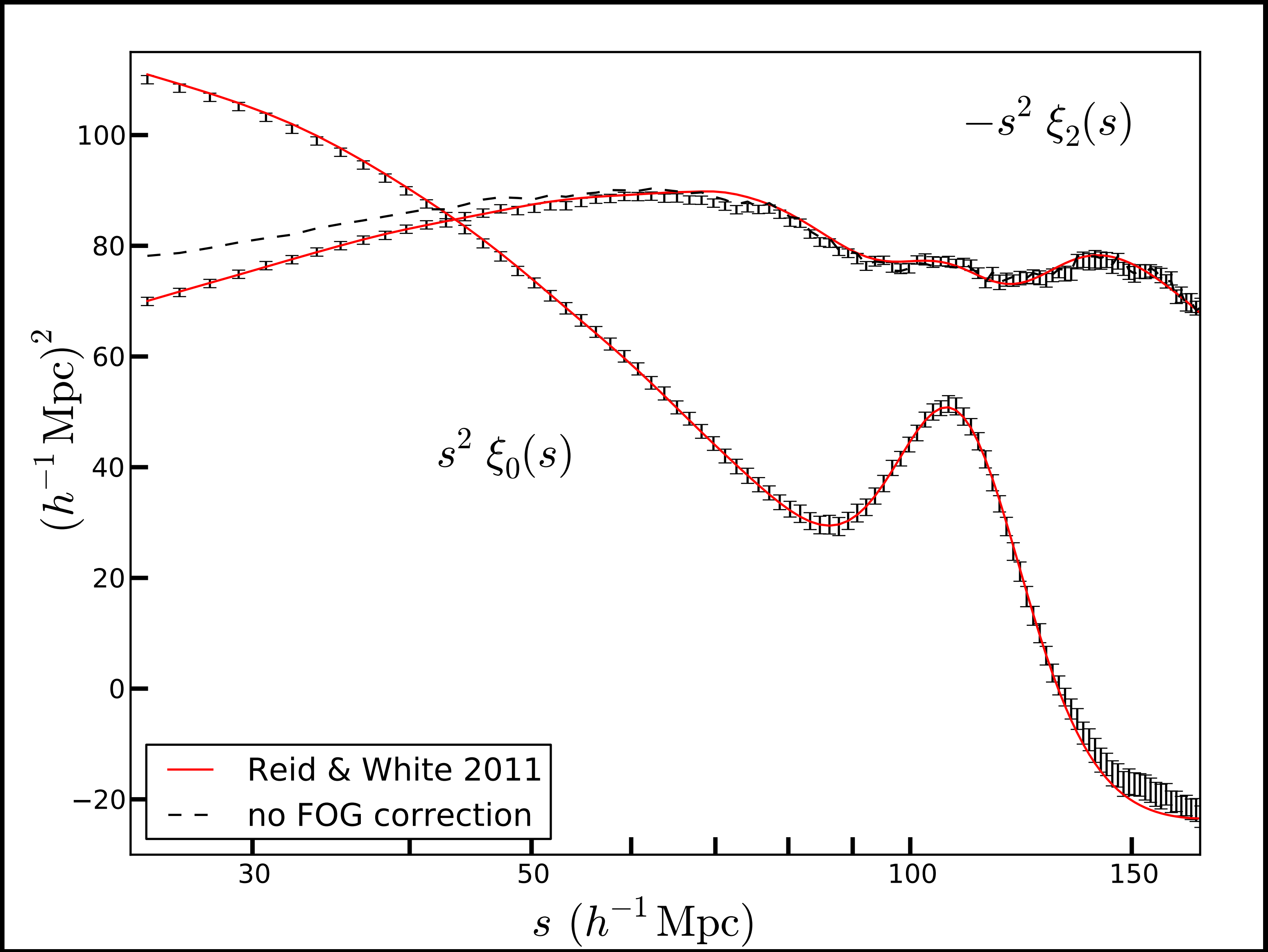
Dark Energy or modified gravity?

- Our strongest evidence for DE is from geometric measures: SNIa, BAO, H_0 + distance to CMB, AP, ... [probes *homogeneous* universe]
- We can distinguish modified gravity from exotic fluid in GR as the reason for cosmic acceleration by the growth of *inhomogeneities*

growth in GR: $$\frac{d^2G}{d\ln a^2} + \left(2 + \frac{d\ln H}{d\ln a}\right)\frac{dG}{d\ln a} = \frac{3}{2}\Omega_{\rm m}(a)G$$

Effect of intrahalo satellite velocities (aka “Fingers of God”)

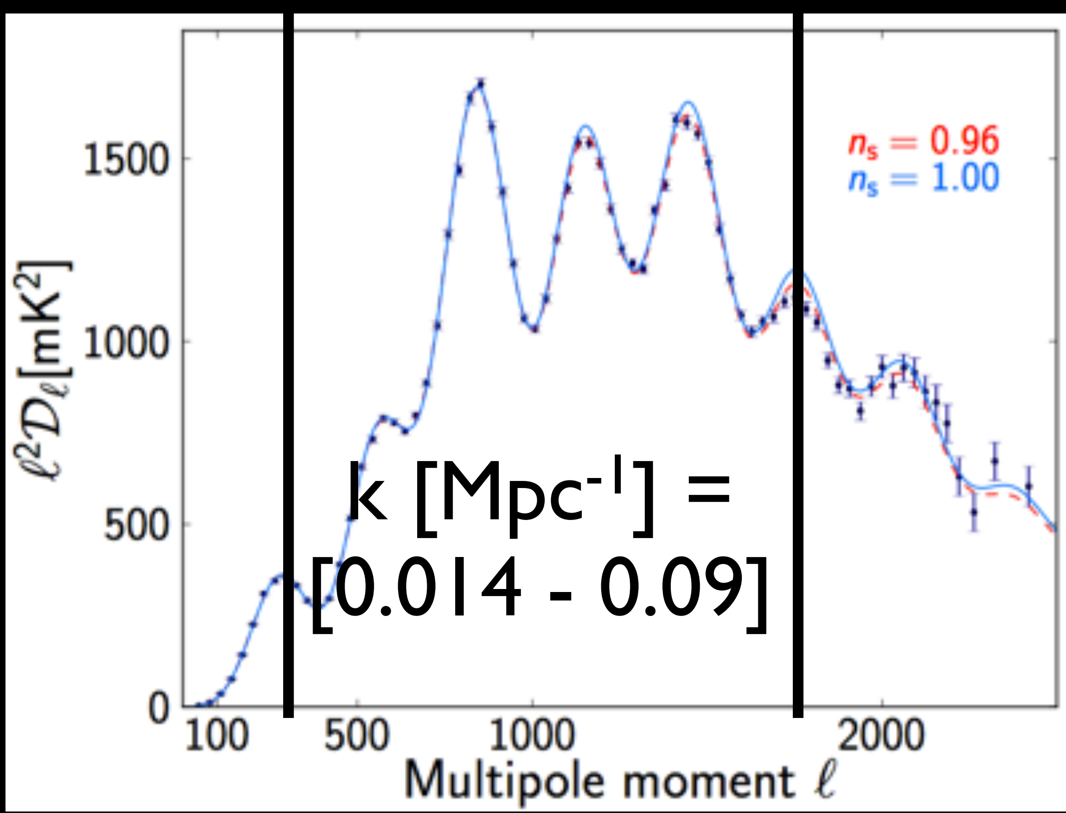
DR9 Battle plan: marginalize over nuisance parameter σ^2_{FOG} with hard prior informed by small-scale galaxy clustering



DRx: derive FOG velocity distribution directly from observed small-scale clustering

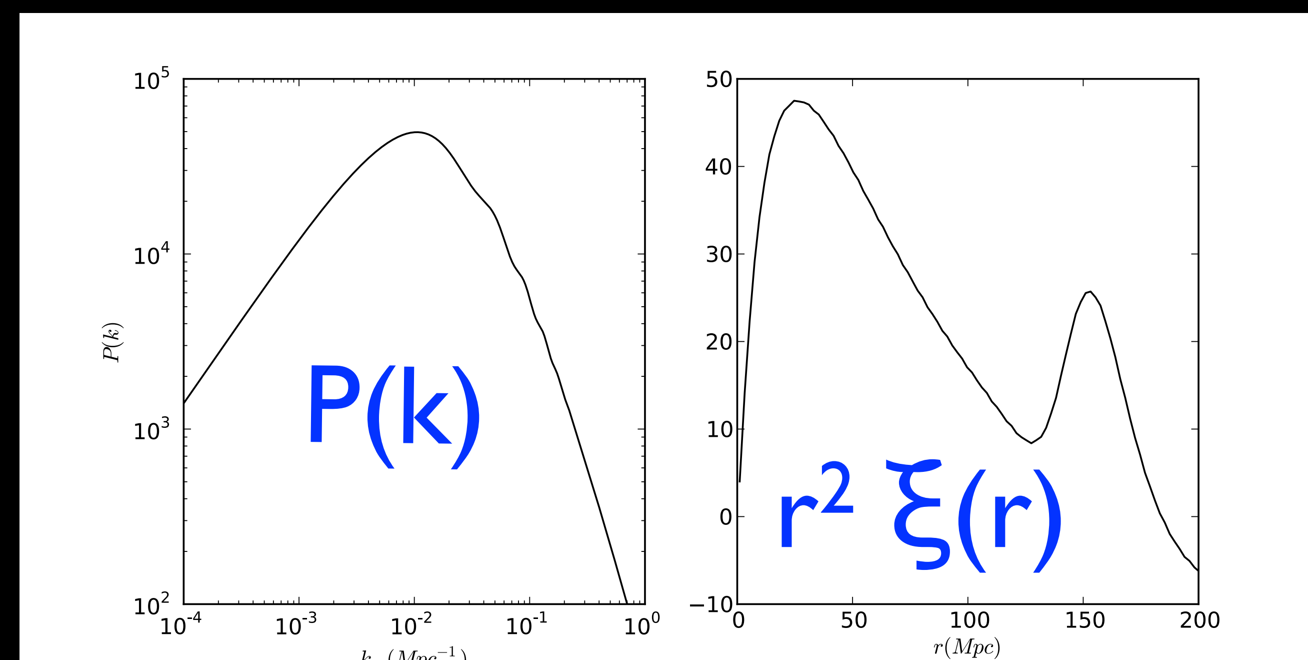
CMB precisely predicts full P(k), not just BAO feature

photon-baryon fluid



Planck 2013 #16

dark matter dominated



Mpc^{-1}

Mpc

r_s =151.4 ± 0.66 Mpc
(Planck 2013)

Beth Reid

APS DPF 2013