



Meeting on  
Fundamental  
Cosmology



Fuerteventura, 5-6 June 2014

# Latest results from BOSS

Antonio J. Cuesta (on behalf of the BOSS collaboration)  
Institut de Ciències del Cosmos  
Universitat de Barcelona





# Outline

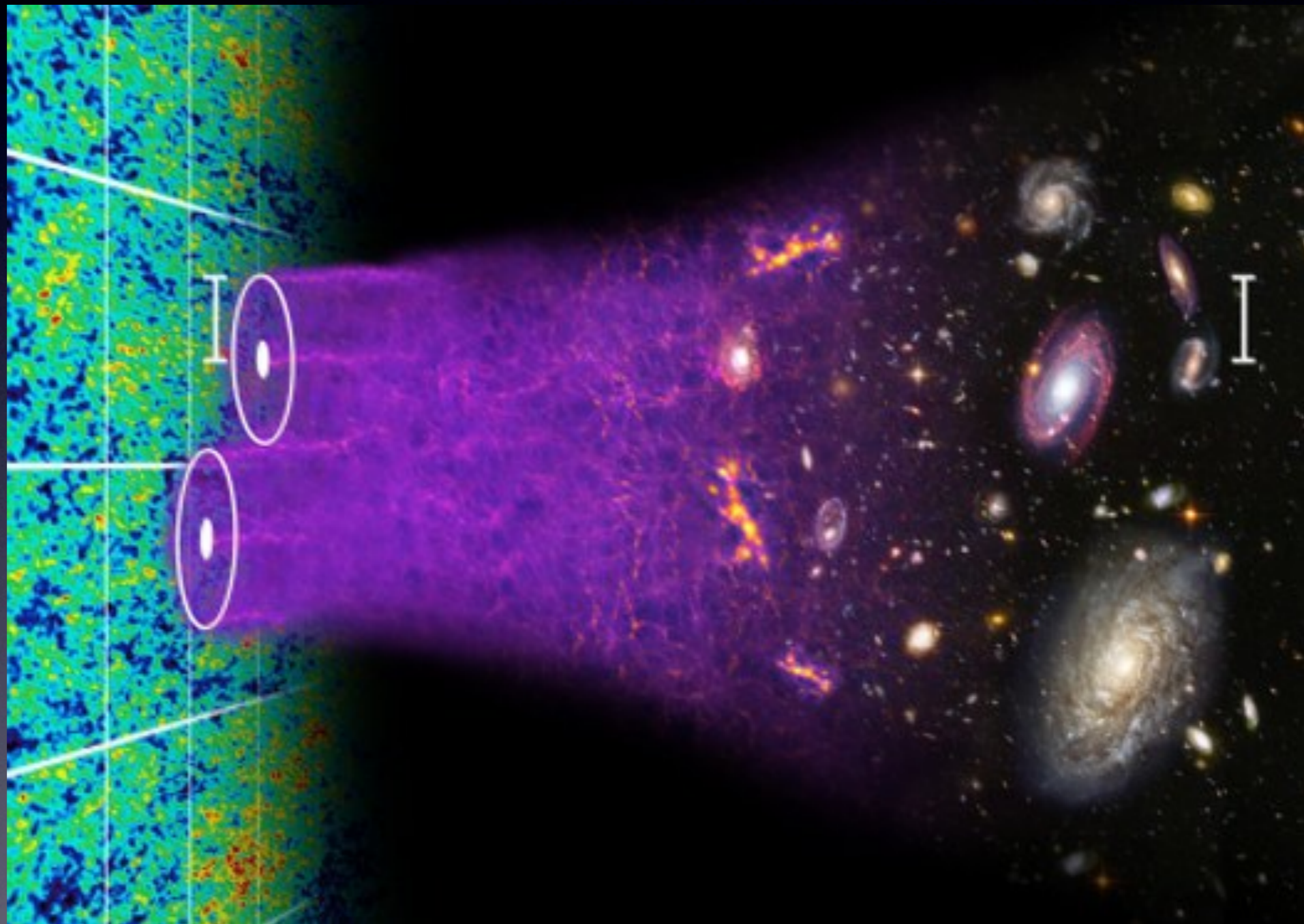
- Current State of BOSS: Data Release 11
- Baryon acoustic oscillation measurements:
  - Galaxies at low redshift (LOWZ)
  - Galaxies at high redshift (CMASS)
  - Lyman-alpha forest auto-correlation (LyA)
  - Lyman-alpha forest - quasar cross correlation (LyA-QSO)
- Beyond BAO:
  - Growth of structure and tests of General Relativity
  - Neutrino masses from galaxy clustering+CMB+lensing
- Preparing for Data Release 12 (Final)



Current state of BOSS

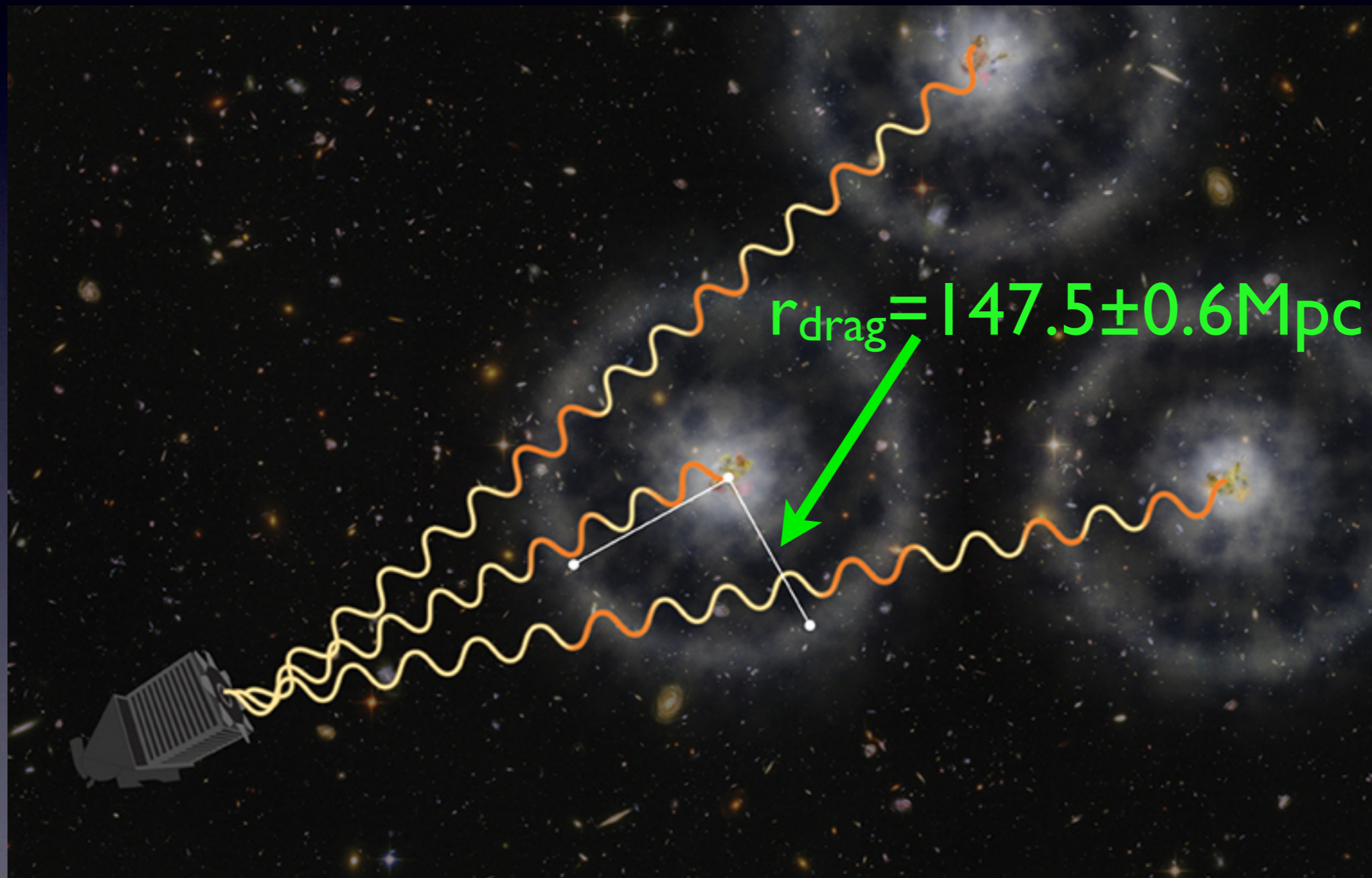


# BOSS: Baryon Oscillation Spectroscopic Survey



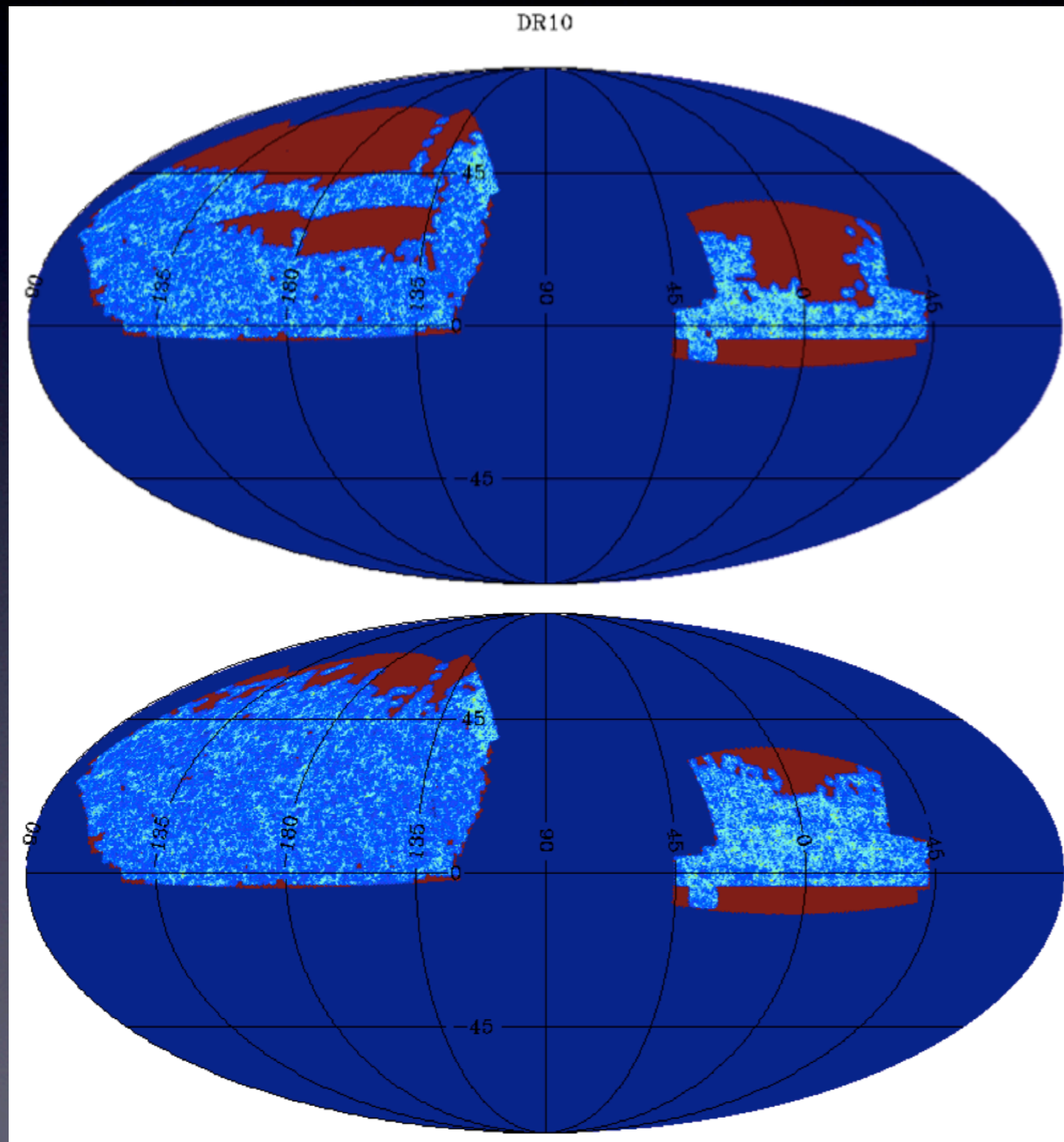


# Measuring distances with BAO





# DR10 and DR11



DR10 (public)  
6,373 sq.deg.  
928,000 galaxies  
182,000 quasars

DR11 (not public)  
8,976 sq.deg.  
1,157,000 galaxies  
239,000 quasars



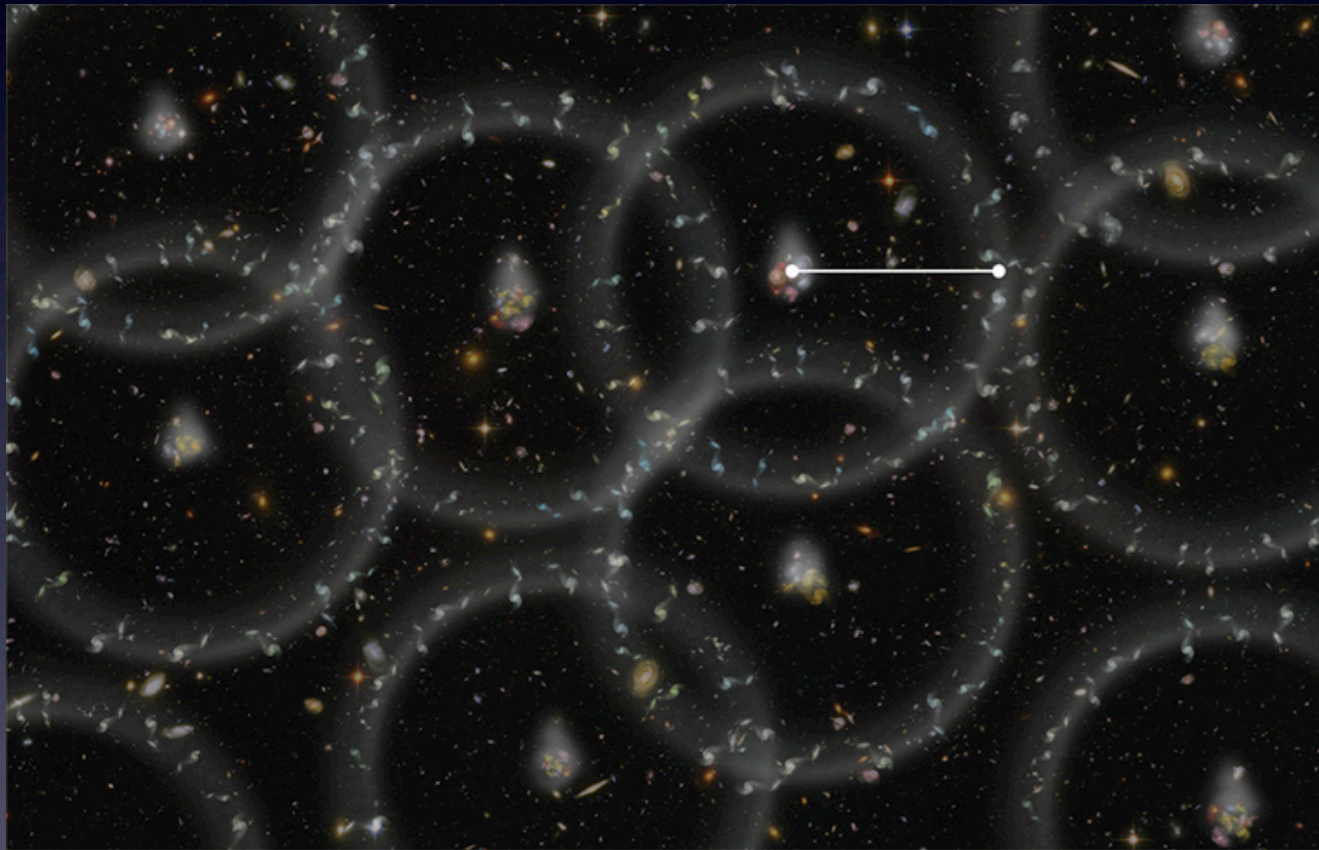
# Galaxy and Ly $\alpha$ F BAO



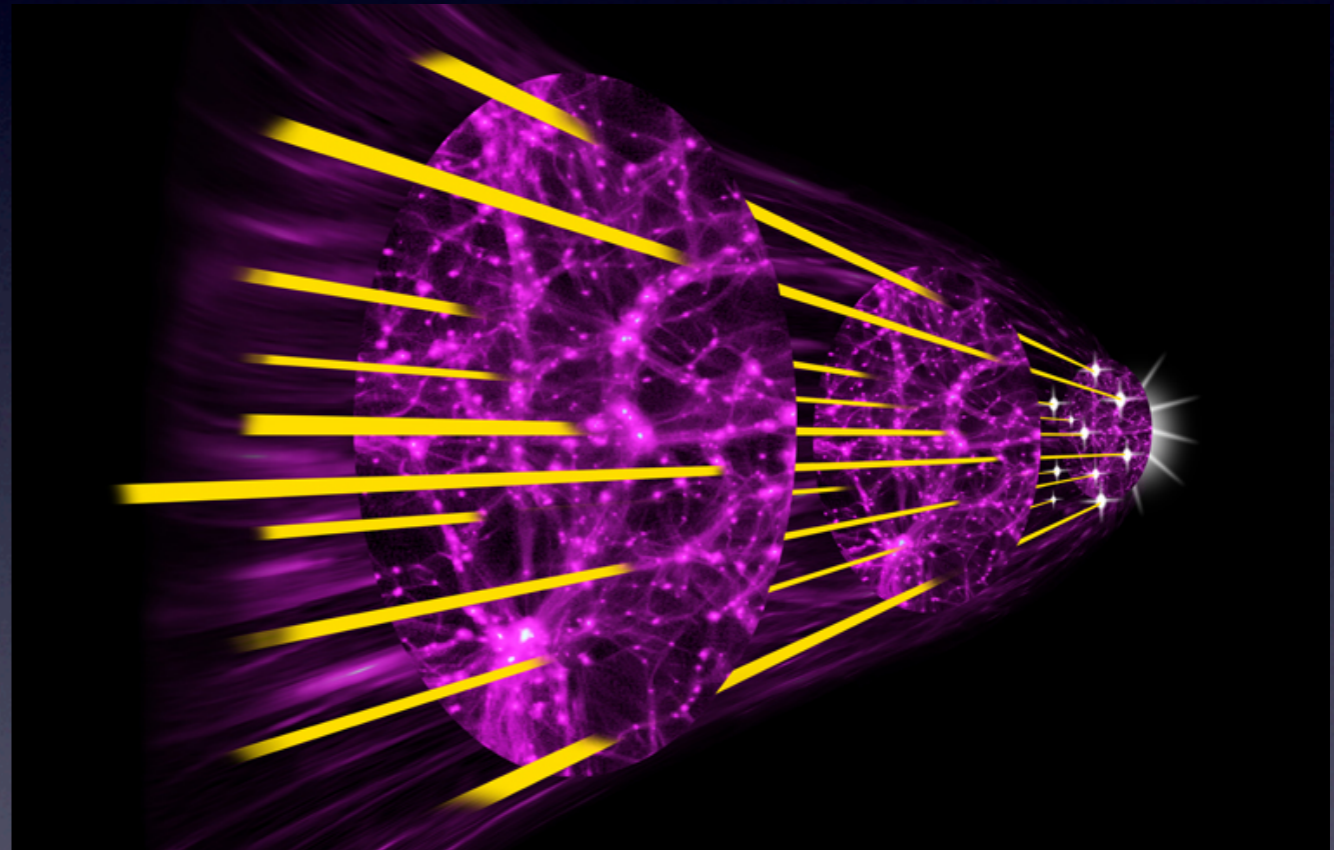
# BAO measurements

## Galaxy BAO

## Lyman-alpha forest BAO

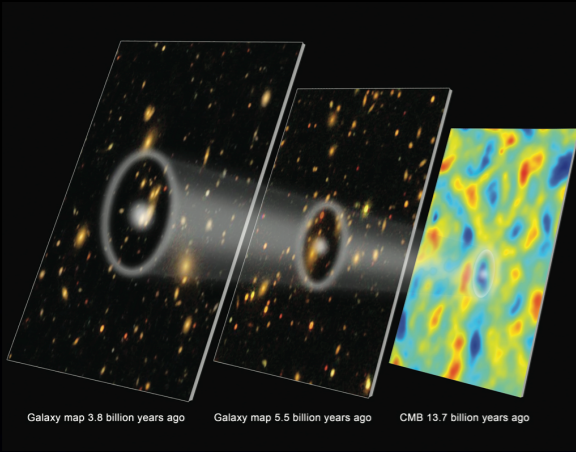


BAO from the clustering of galaxy pairs

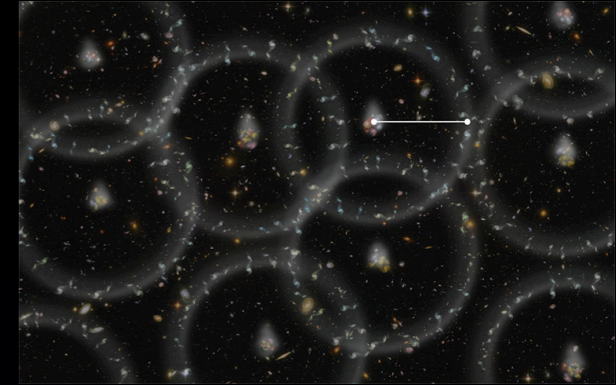


BAO from clustering of absorption features pairs

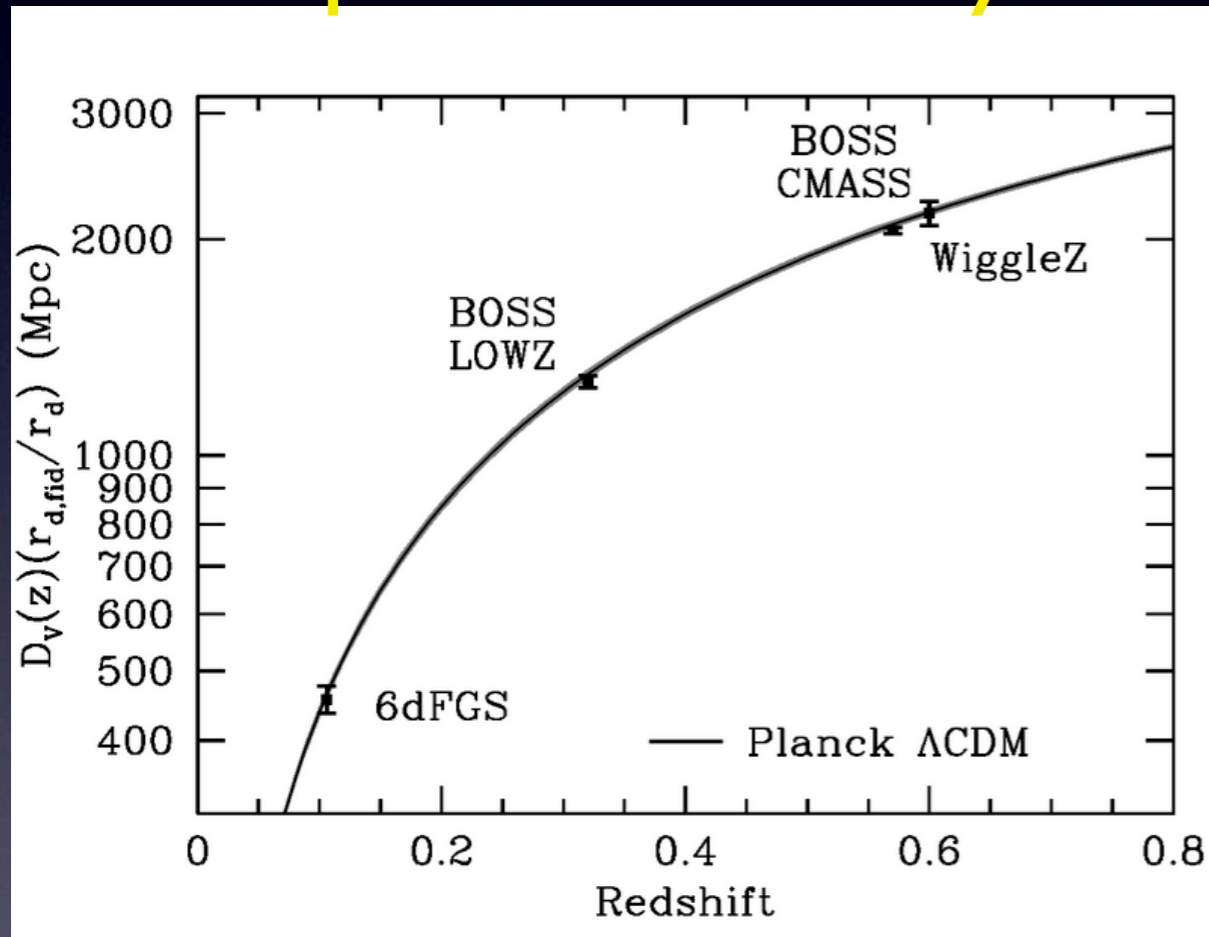




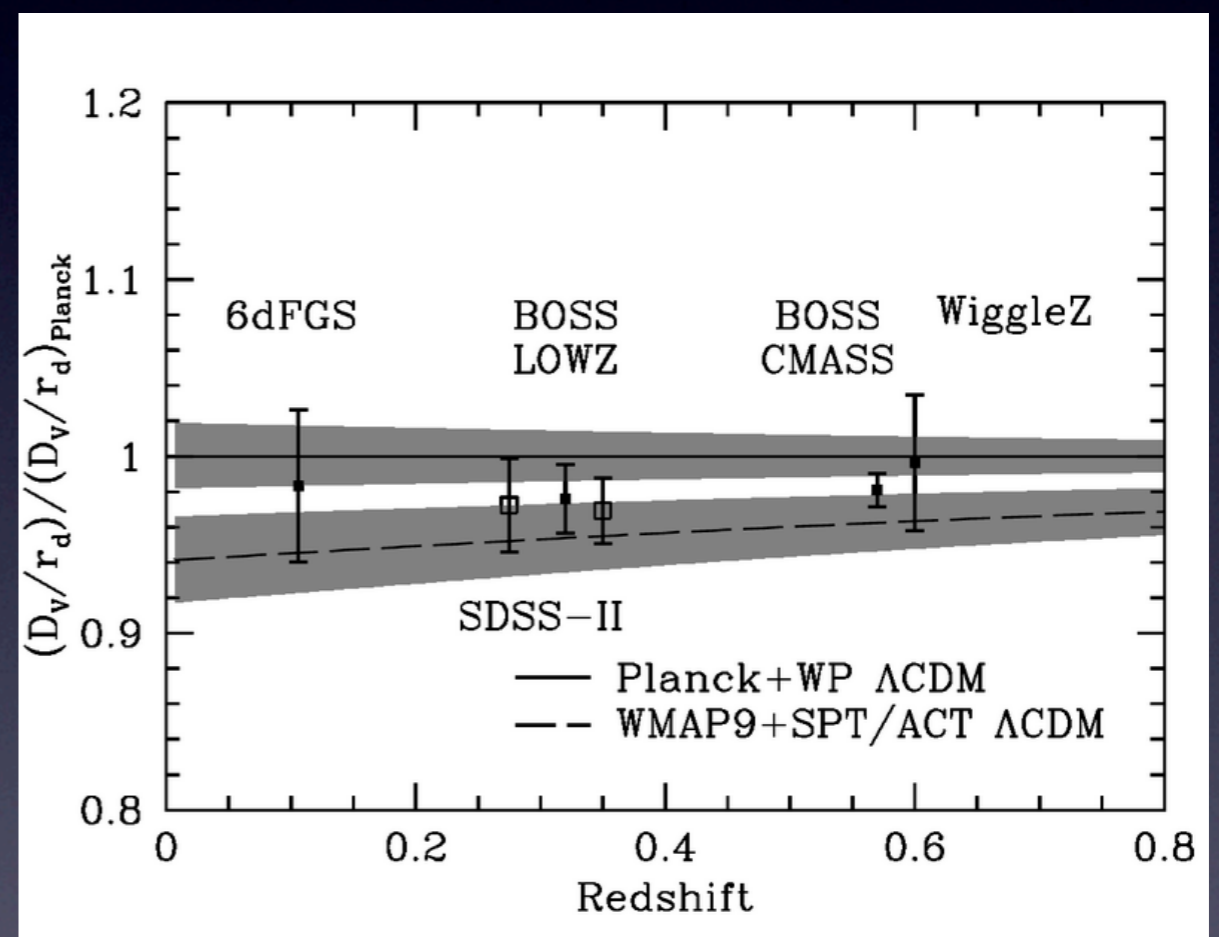
# Galaxy BAO



## Expansion history



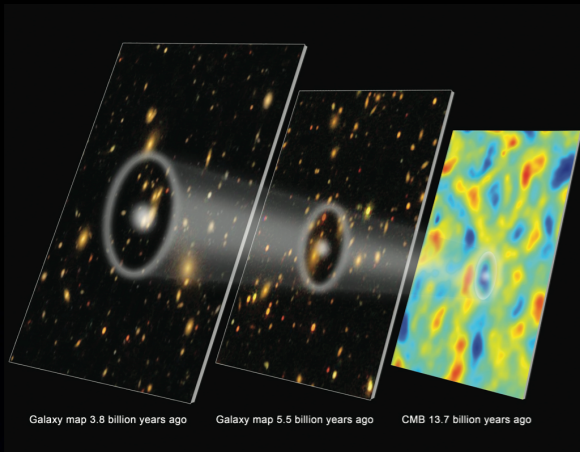
## Normalized to Planck



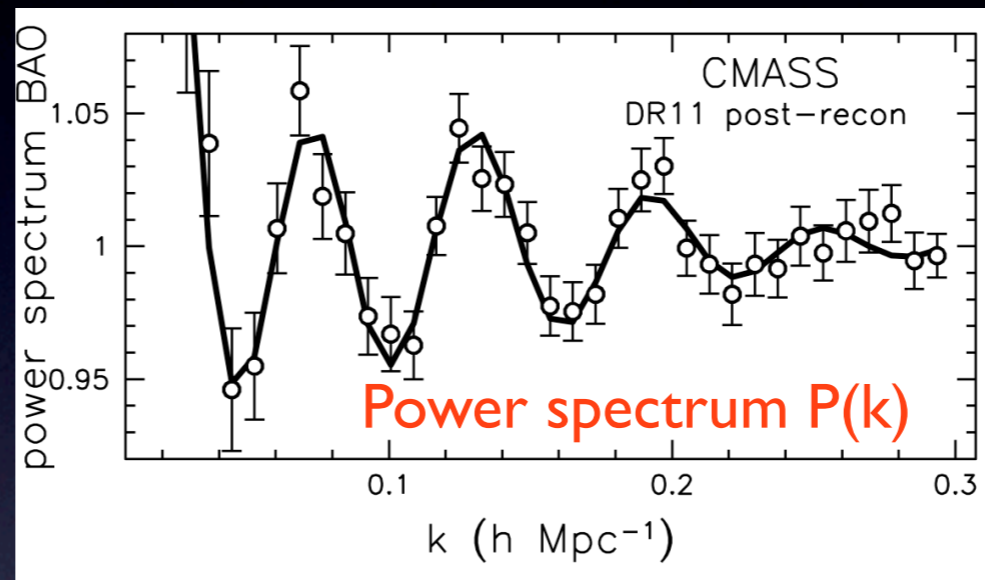
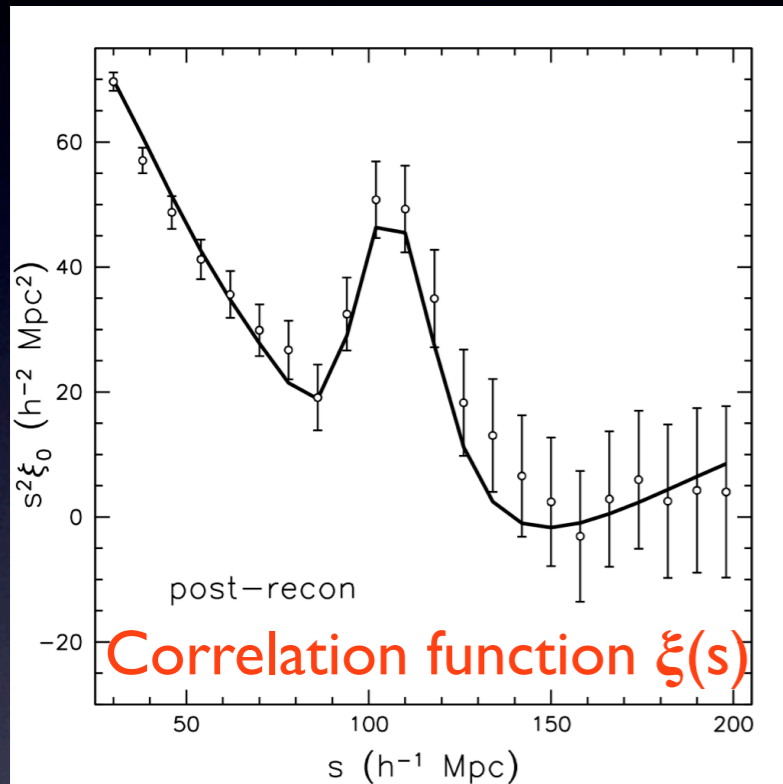
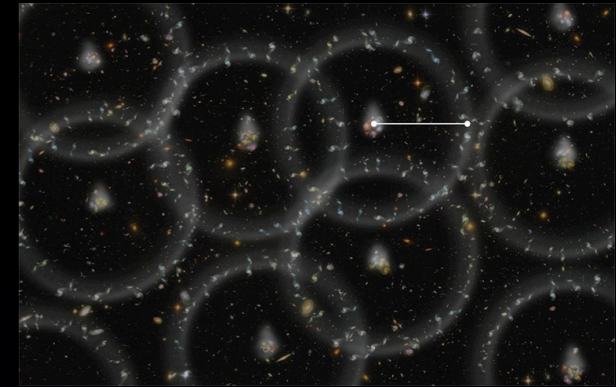
Anderson et al. 2014

BAO measures the **ratio**  $D(z)/r_d$   
 but the values quoted here will assume  **$r_d$  from Planck**





# CMASS BAO



Anderson et al. 2014

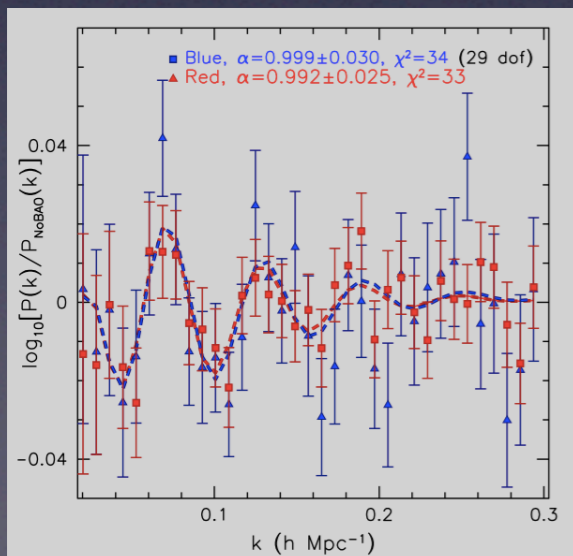
690,000 galaxies between  $0.43 < z < 0.70$   
covering a total of  $10 \text{Gpc}^3$

BAO detected at 8sigma in  $\xi(s)$  and  $P(k)$

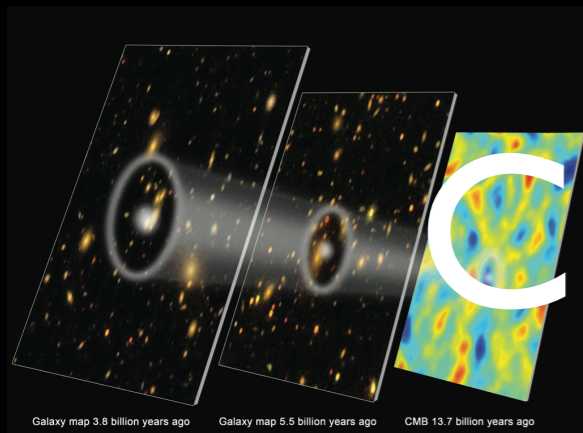
**$D_V(z=0.57) = 2056 \pm 20 \text{Mpc}$  (1% error)**

Results do not depend on galaxy color!

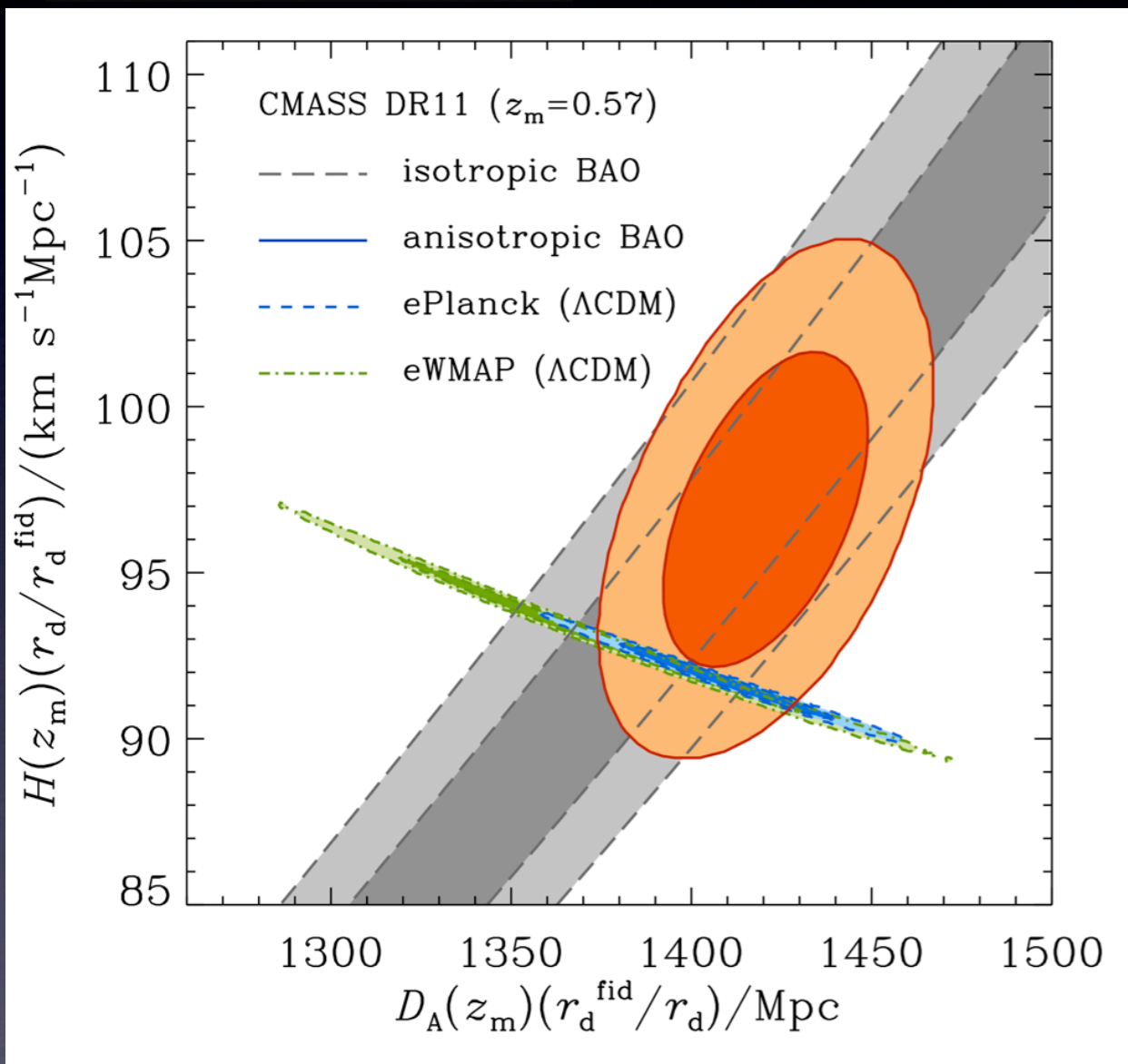
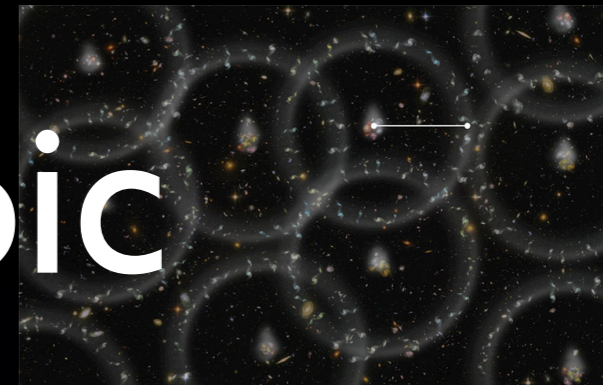
Ross et al. 2014







# CMASS anisotropic



Anderson et al. 2014

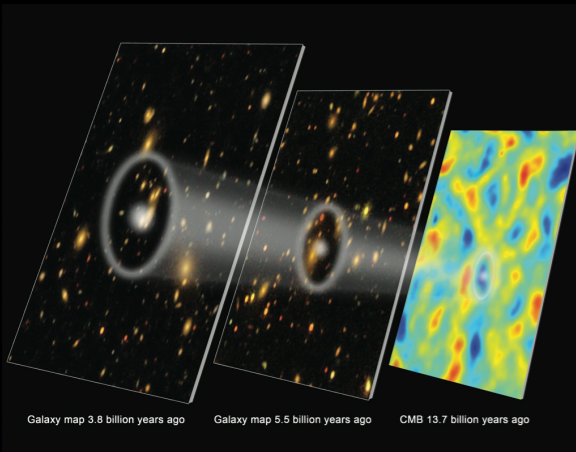
Combining the monopole and the quadrupole of  $\xi(s)$  we can measure the angular dependence of clustering (with respect to the line of sight)

With this we can constrain the angular diameter distance  $D_A(z)$  and the Hubble parameter  $H(z)$

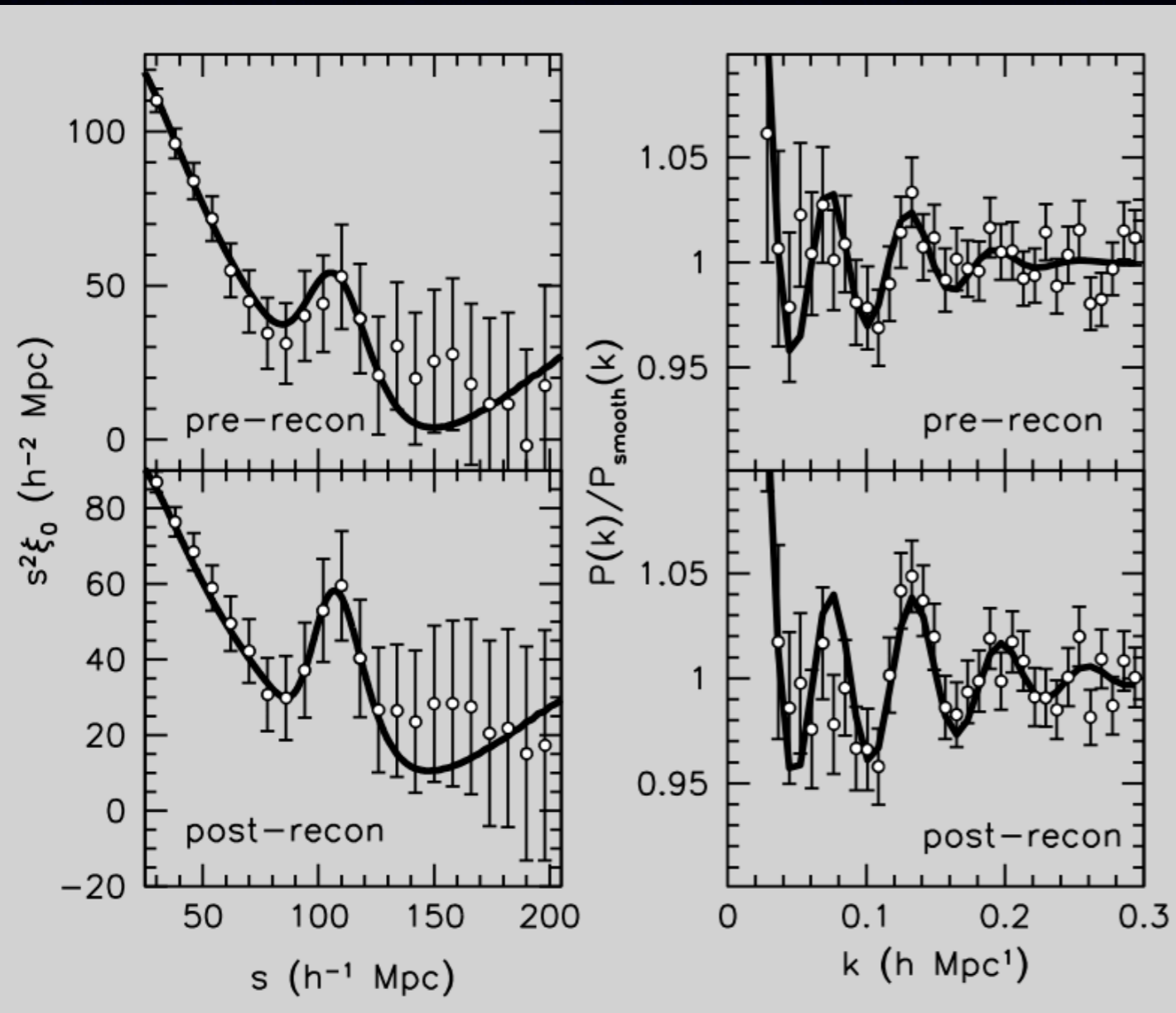
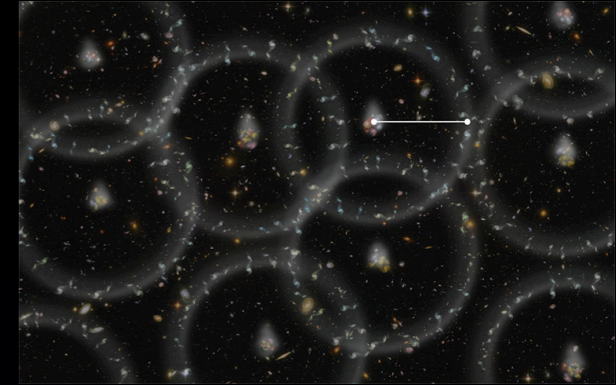
$$D_A(z=0.57) = 1421 \pm 20 \text{ Mpc}$$

$$H(z=0.57) = 96.8 \pm 3.4 \text{ km/s/Mpc}$$





# LOWZ BAO



314,000 galaxies between  $0.15 < z < 0.43$  covering  $3 \text{Gpc}^3$

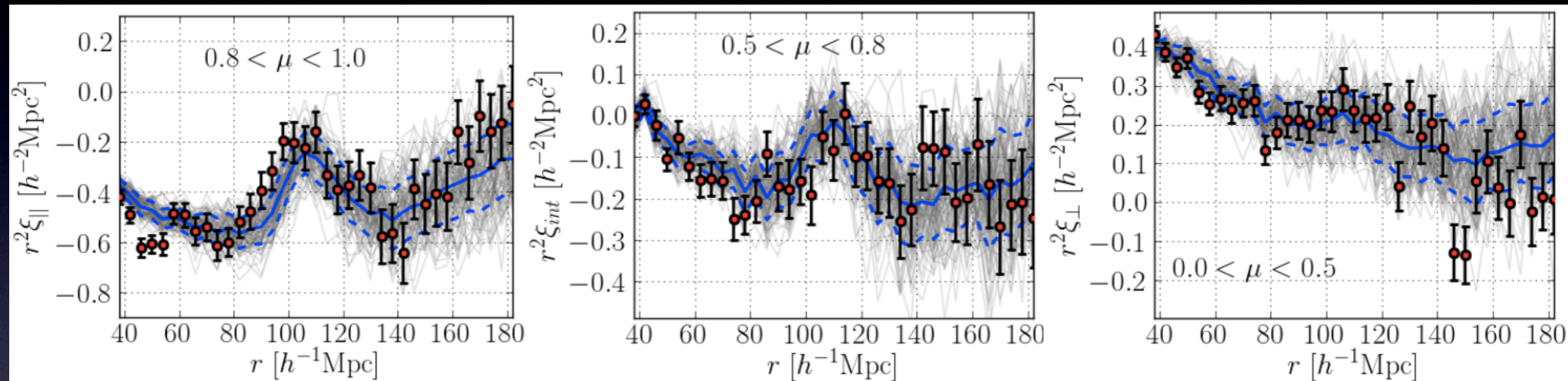
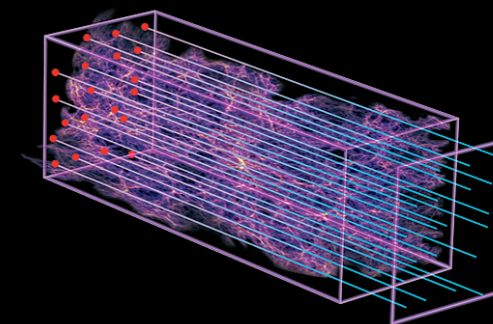
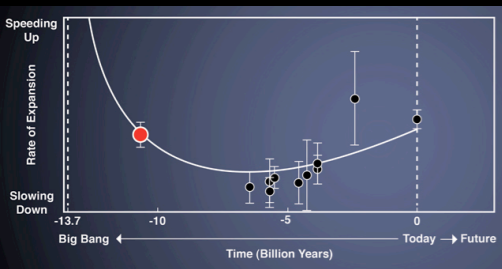
$D_V(z=0.32) = 1264 \pm 25 \text{Mpc}$   
(a 2% measurement)

which is already as good as the SDSS-II LRG result

Tojeiro et al. 2014



# LyaF-LyaF auto-correlation



137,500 quasars between  $2.1 < z < 3.5$

Delubac et al. 2014

Volume sampled  $50 h^{-3} \text{Gpc}^3$

$D_A(z=2.34) = 1662 \pm 96 \text{Mpc}$

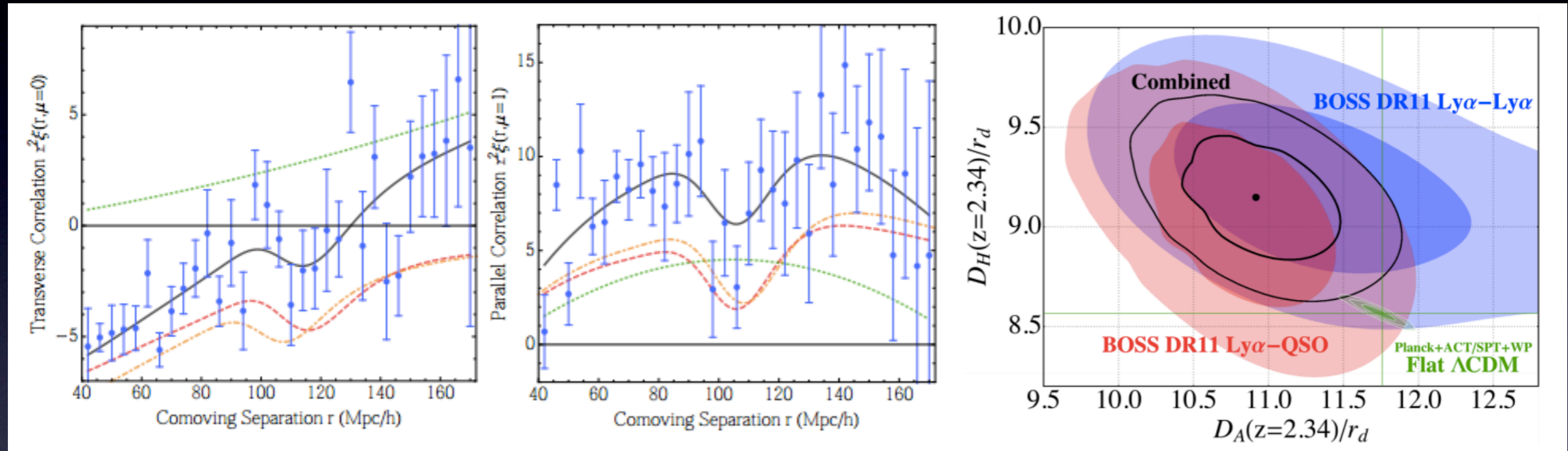
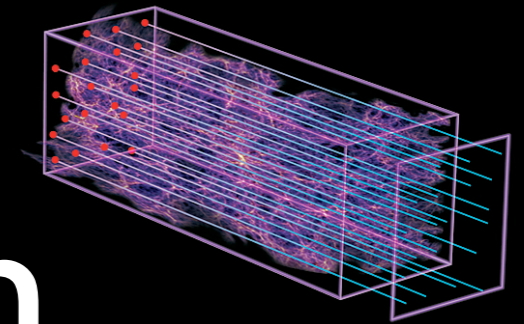
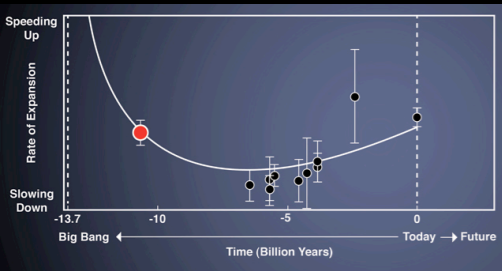
$H(z=2.34) = 222 \pm 7 \text{km/s/Mpc}$

(combined this is a 2% distance measurement)

Most of the signal comes from the line of sight



# Quasar-Ly $\alpha$ cross-correlation



164,000 quasars between  $2.0 < z < 3.5$   
 (of which 131,000 are in the Ly $\alpha$  sample)

Font-Ribera et al. 2014

$$D_A(z=2.34) = 1590 \pm 60 \text{ Mpc}$$

$$H(z=2.34) = 226 \pm 8 \text{ km/s/Mpc}$$

(the error bar in  $D_A$  is 40% smaller than auto)

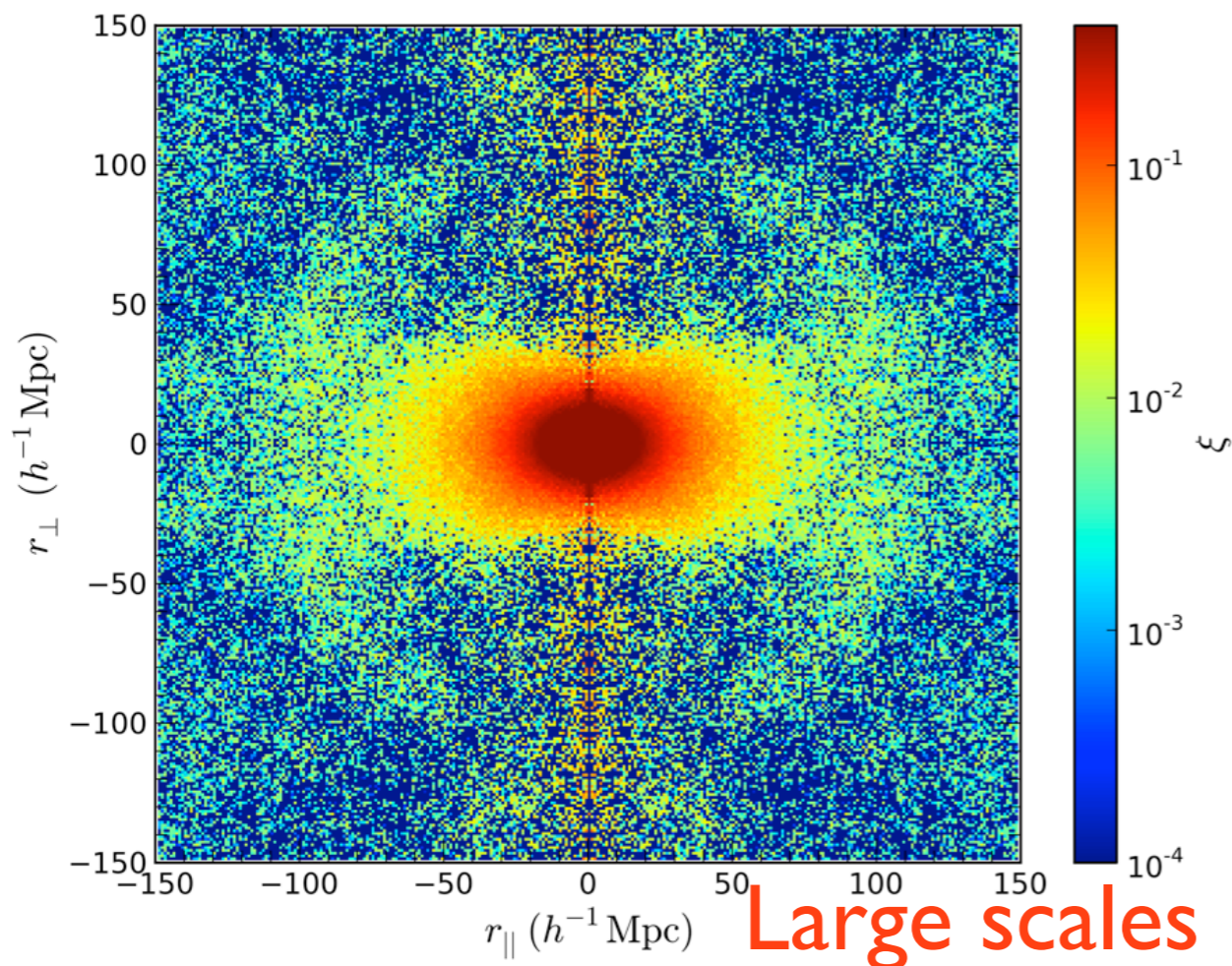


# Beyond BAO



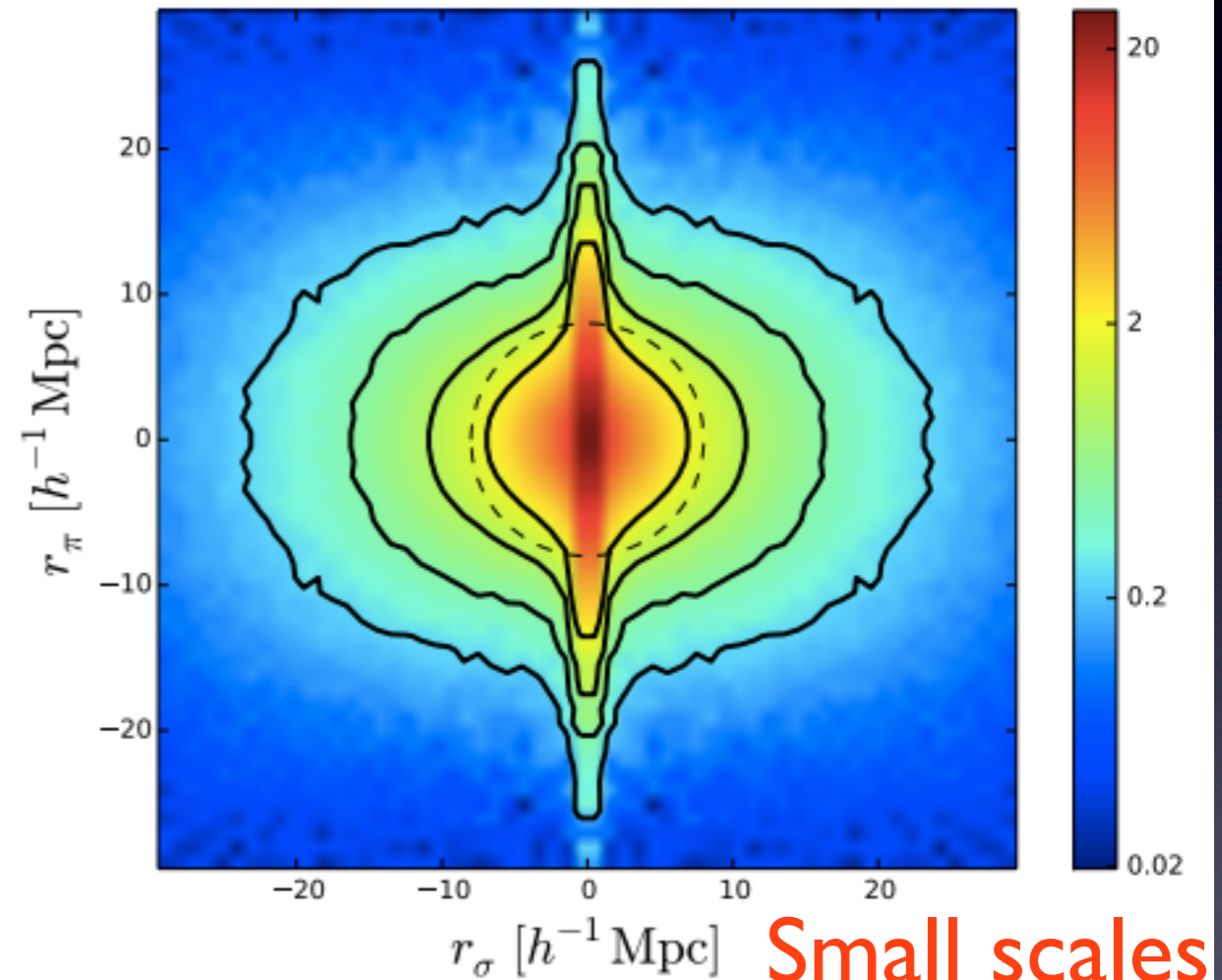
# Redshift-space distortions

## Measurements of Growth of Structure



Samushia et al. 2014

$$24h^{-1}\text{Mpc} < s < 152h^{-1}\text{Mpc}$$
$$f\sigma_8(z=0.57) = 0.447 \pm 0.028$$



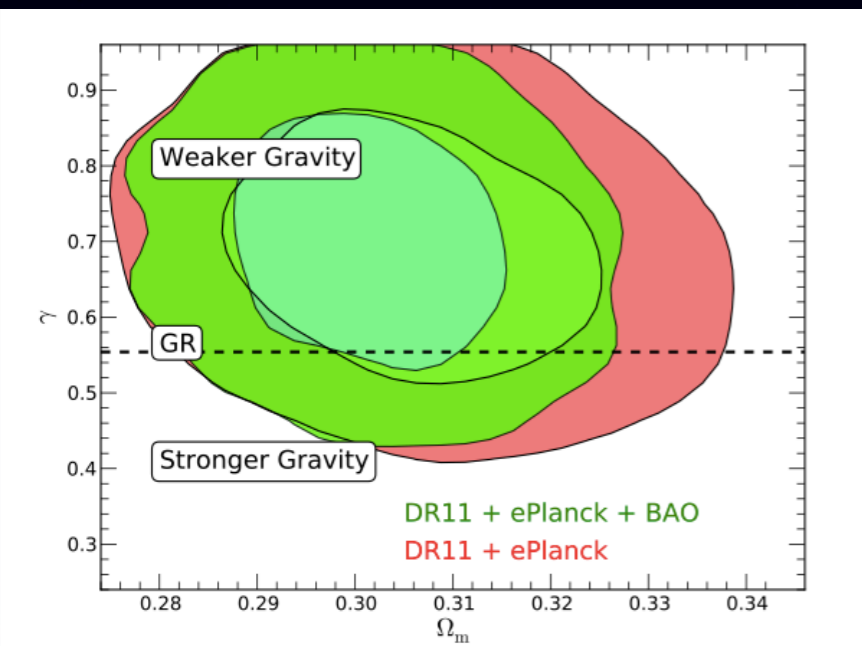
Reid et al. 2014

$$0.8h^{-1}\text{Mpc} < s < 32h^{-1}\text{Mpc}$$
$$f\sigma_8(z=0.57) = 0.450 \pm 0.011$$

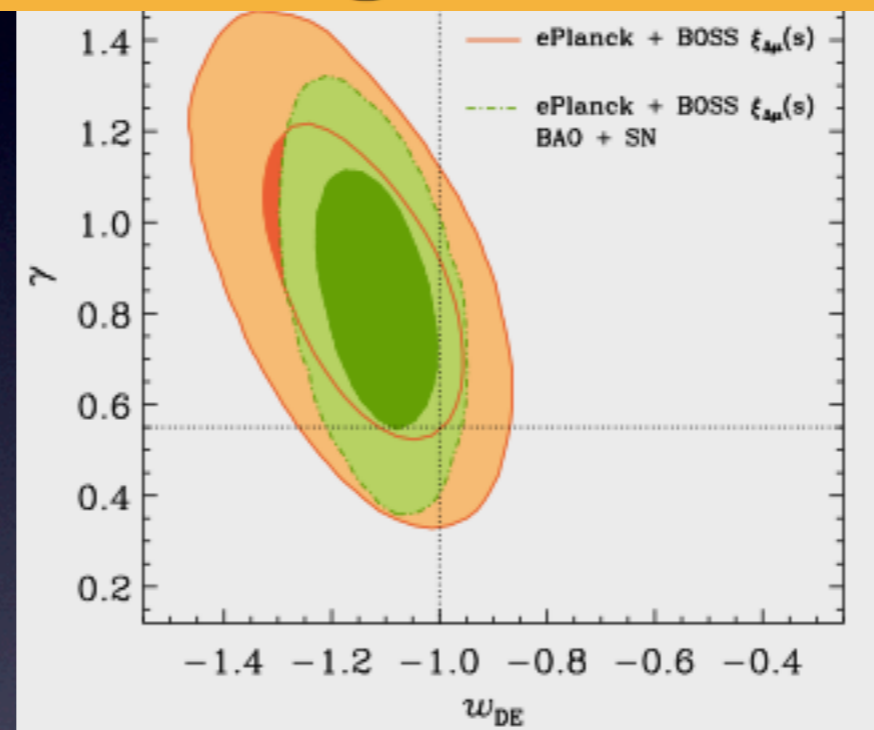


# Testing Gravity

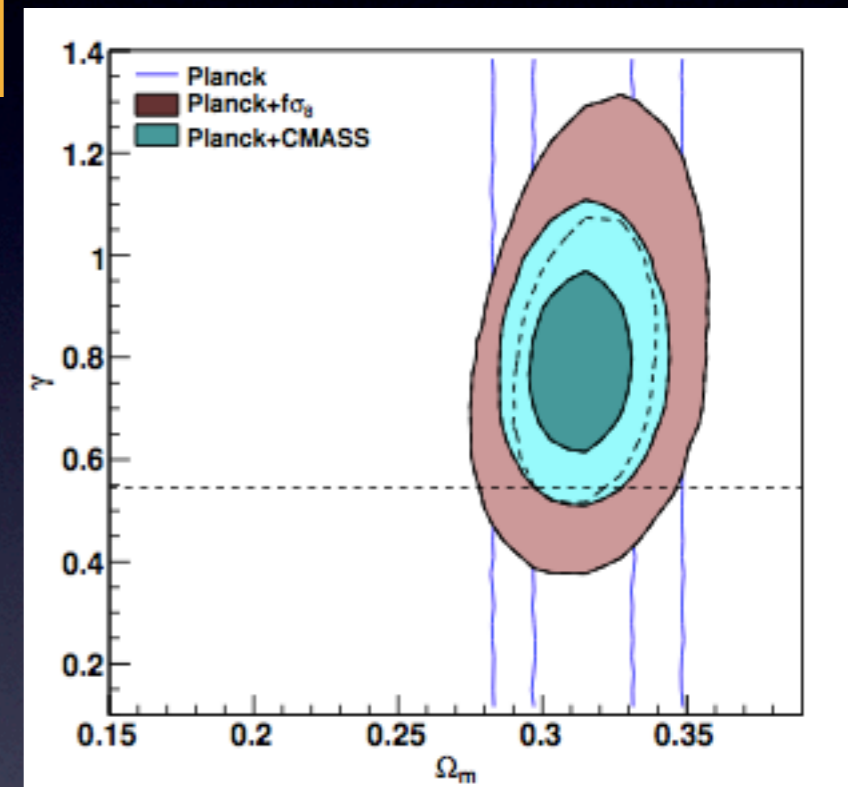
$$f = \frac{d \log D}{d \log a} \approx \Omega_m(z)^\gamma$$



Samushia et al. 2014



Sanchez et al. 2014

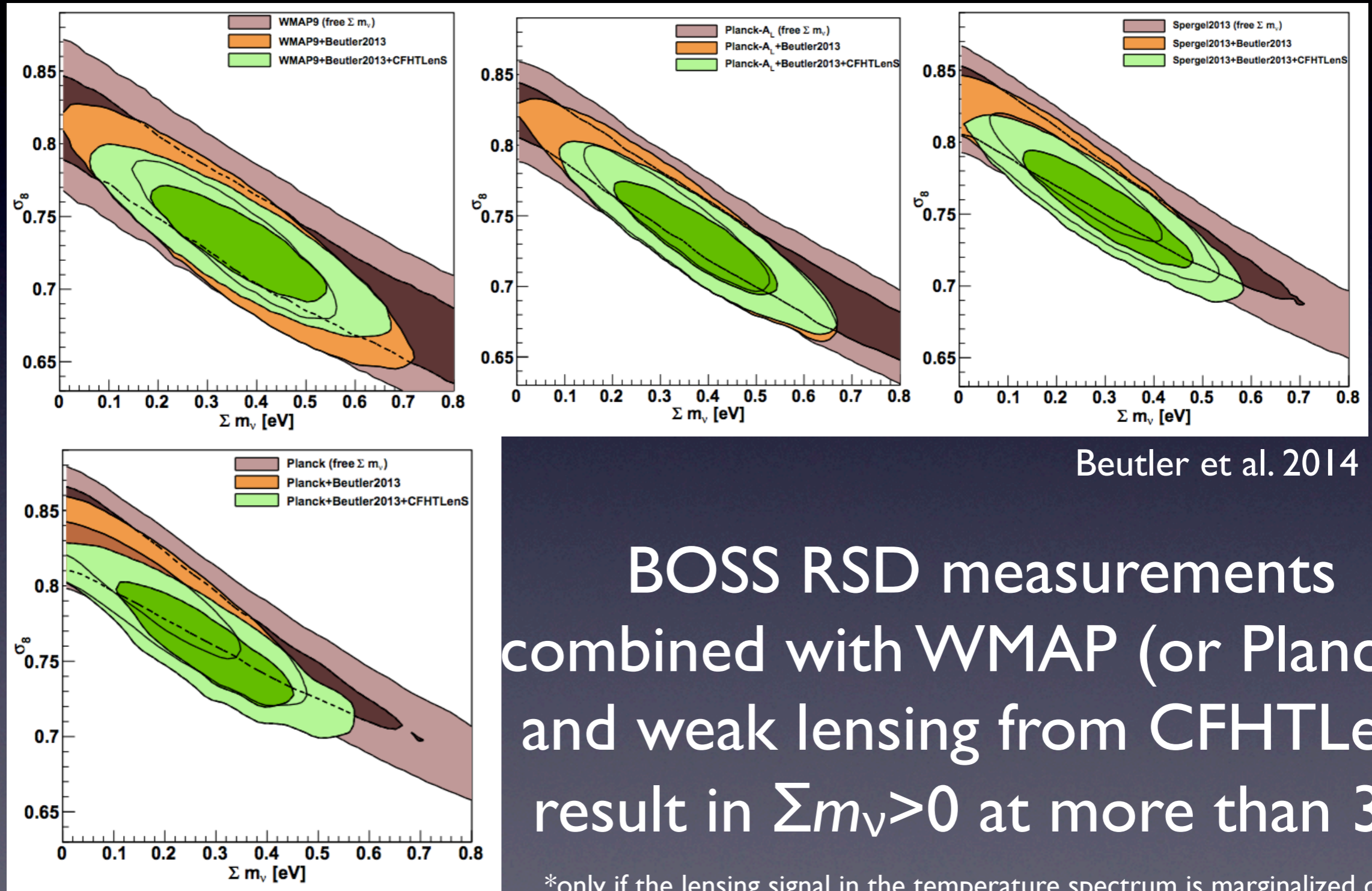


Beutler et al. 2014

All CMASS-DR11 measurements of growth of structure result in weaker gravity (GR still within 2sigma)



# Neutrino masses



Beutler et al. 2014

BOSS RSD measurements combined with WMAP (or Planck\*) and weak lensing from CFHTLenS result in  $\Sigma m_\nu > 0$  at more than  $3\sigma$

\*only if the lensing signal in the temperature spectrum is marginalized over!



The (near) future:  
final data release



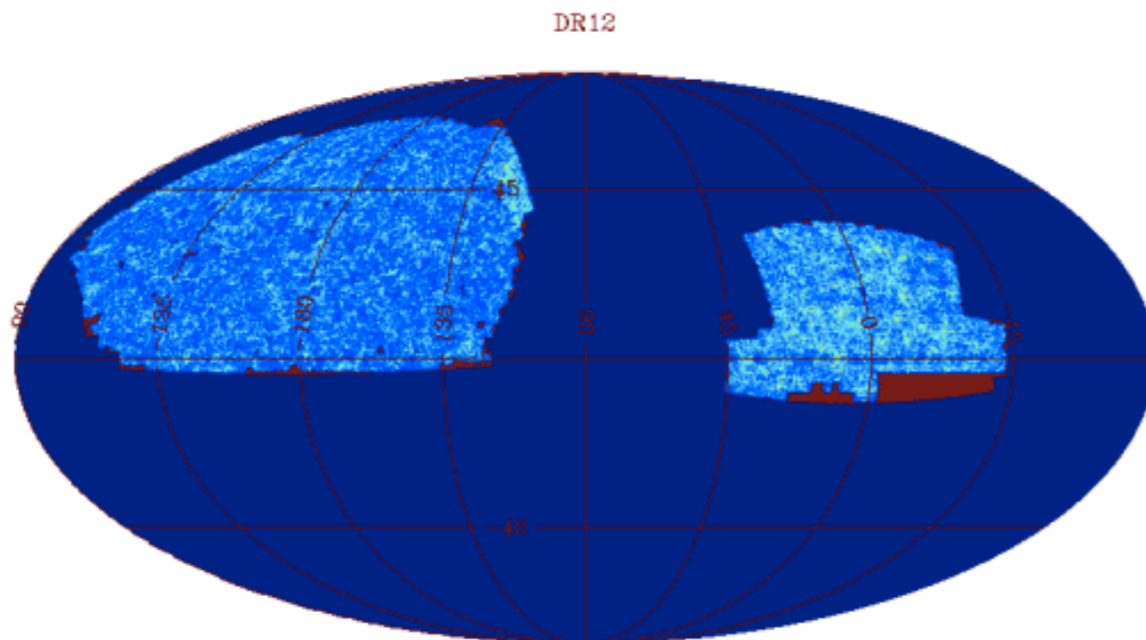
# Getting ready for DR12

## BOSS Completes its Main Survey of Distant Galaxies and Quasars!

The SDSS-III Baryon Oscillation Spectroscopic Survey (BOSS) has completed its main survey of galaxies and quasars. With 1.35 million luminous red galaxies and 230,000 quasars across 10,200 square degrees of the sky, BOSS has exceeded the number of objects and sky area goals from the original SDSS-III proposal.

11  
04  
2014

Reaching this milestone involved the hard work and efforts of many people. In particular, the mountain and observing staff at Apache Point Observatory have been worked hard and efficiently to observe 2,300 plates with the new BOSS spectrograph in 4.5 years of dark time.



Data collection is **DONE**

1.35M galaxies

230k quasars

10,200 sq.deg.

Analysis is in progress...

Public release by Dec 31

<http://blog.sdss3.org>



# Conclusions

- BOSS has measured redshifts of more than 1 million galaxies ( $0.15 < z < 0.70$ ) and 160,000 quasars ( $2.0 < z < 3.5$ ) over 8500 sq.deg in the sky
- It has measured the BAO feature with high significance in galaxies, and for the first time in the Lyman-alpha forest, as well as in its cross-correlation with quasars.
- It has measured distances to redshifts  $z=0.32$  (2%),  $0.57$  (1%) and  $2.34$  (2%)
- In addition to improve curvature and dark energy constraints, it also has helped constrain neutrino masses, structure growth, etc.
- Final data release: December 31 2014.



A large satellite dish antenna is mounted on a complex metal structure, likely a telescope mount, on a rooftop or elevated platform. The scene is captured at sunset, with a bright orange and yellow glow on the horizon and a deep blue sky above. The antenna's surface is dark, and a circular opening is visible in the center. The structure is supported by a blue base. In the foreground, a metal walkway with a railing is visible, and a small black cart with a white box is on the left. The overall atmosphere is serene and technical.

Thanks for your attention