Anisotropic galaxy clustering measurements in BOSS

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MPE

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Theoretical and Observational Progress on LSS - Garching - 20/07/2015

Outline

- The Baryon Oscillation Spectroscopic Survey (BOSS).
- Anisotropic clustering measurements.
- Modelling LSS observations.
- Tests on N-body simulations and mock catalogues.
- Preliminary constraints from BOSS-DR12.
- Summary of BOSS-DR12 analyses and next steps.

Cosmology from LSS observations

- The expansion of the Universe is accelerating.
- Observational effects of cosmic acceleration:

  - Expansion history of the Universe:

$$H(z) \qquad r(z) = \int_0^z \frac{c\,dz'}{H(z')}$$

  - Growth of density fluctuations:

$$\ddot{\delta} + 2H\dot{\delta} = 4\pi G\bar{\rho}\delta$$

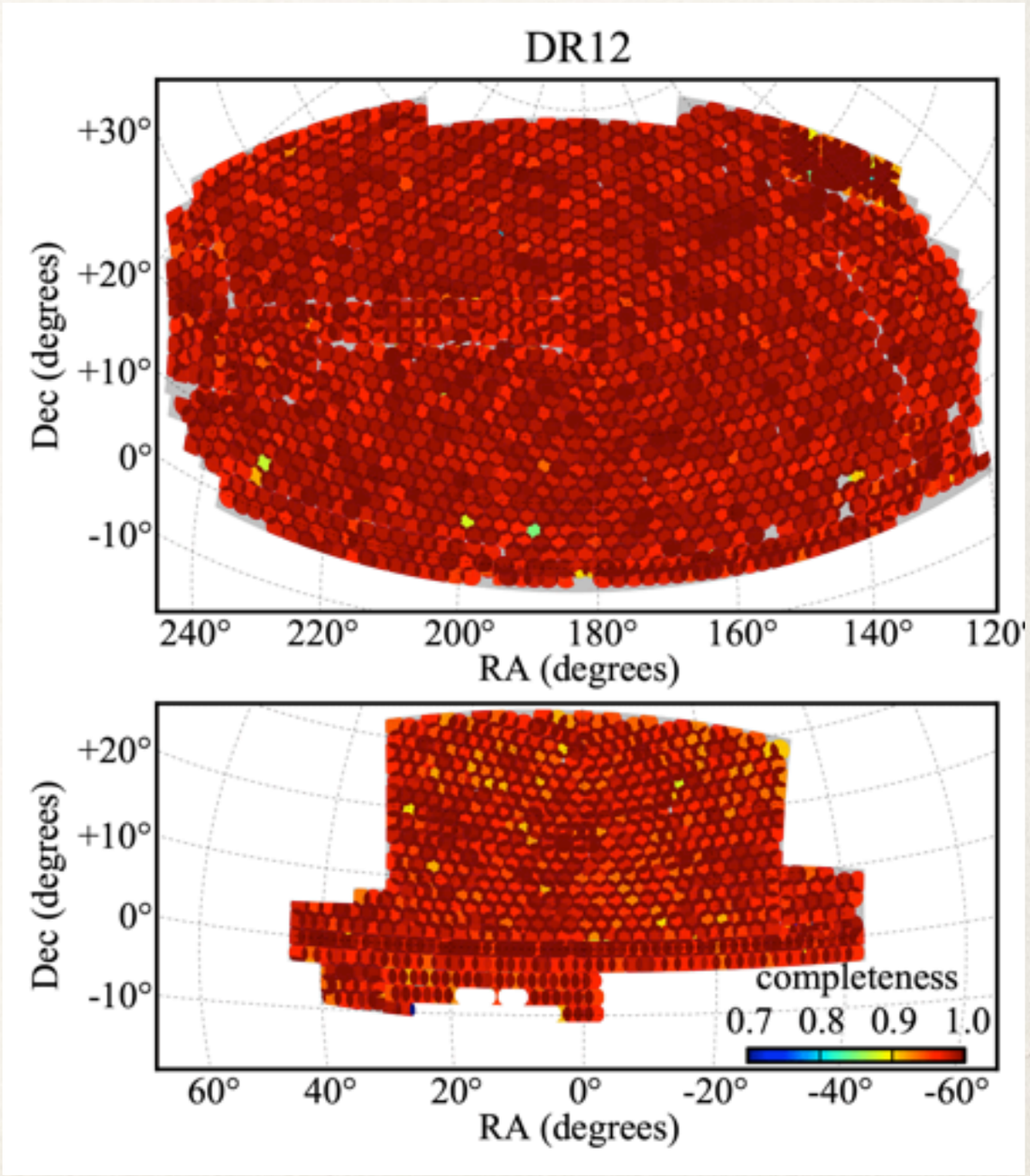
- Both effects can be probed by LSS observations.

BOSS at a glance

- BOSS is a part of SDSS-III
- Designed to tackle DE through BAO measurements
- Time scale: 2009 - 2014
- Total area of 10,000 deg^2.
- Positions for:

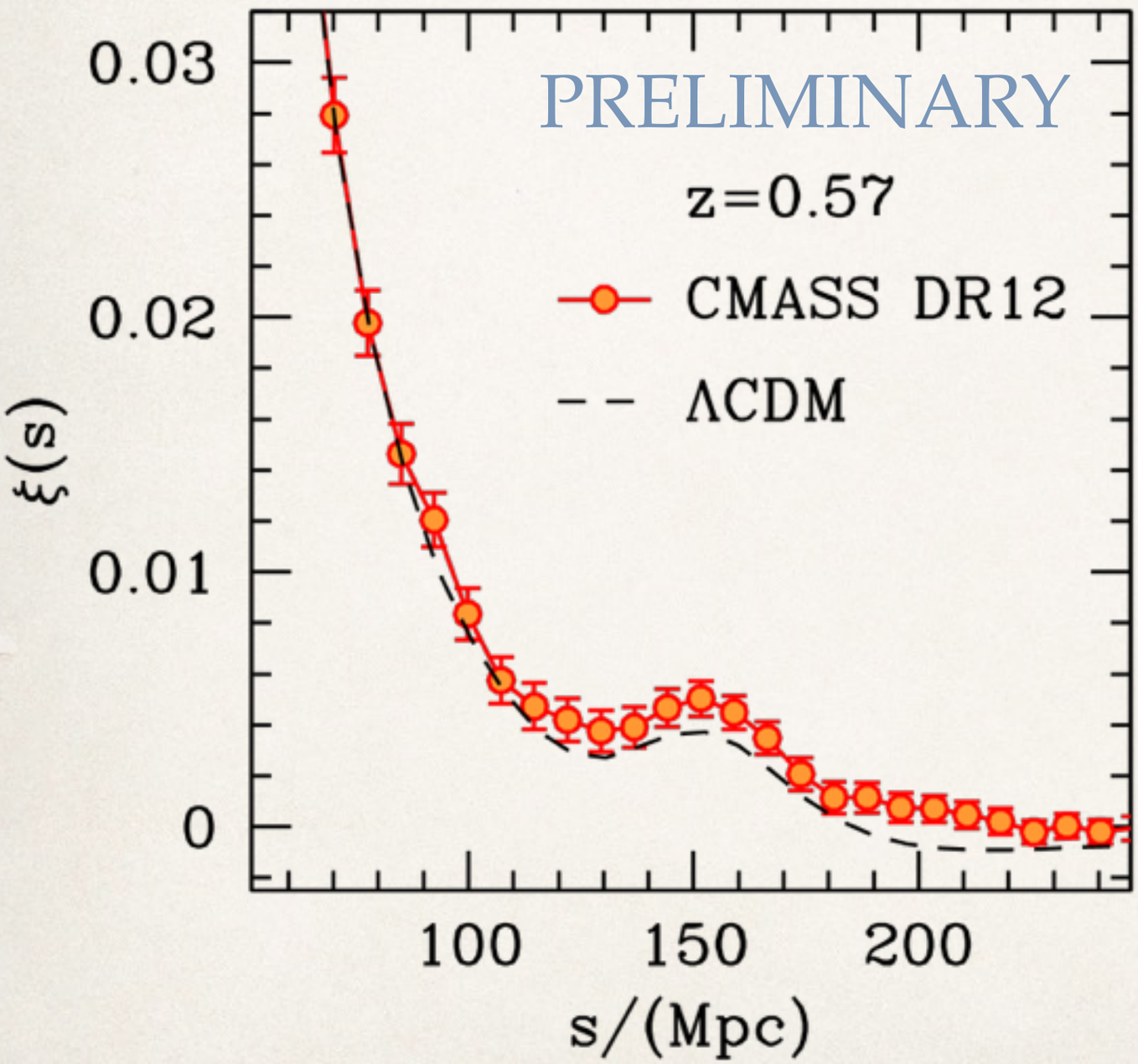
- 1.2x10^6 LGs with $0.1 < z < 0.7$

- 1.6x10^5 QSO with $2.3 < z < 2.8$



Reid et al. (in prep.)

Baryon acoustic oscillations



- CMASS-DR12 monopole correlation function $\xi(s)$.
- Great improvement in statistical errors.
- BAO peak position gives

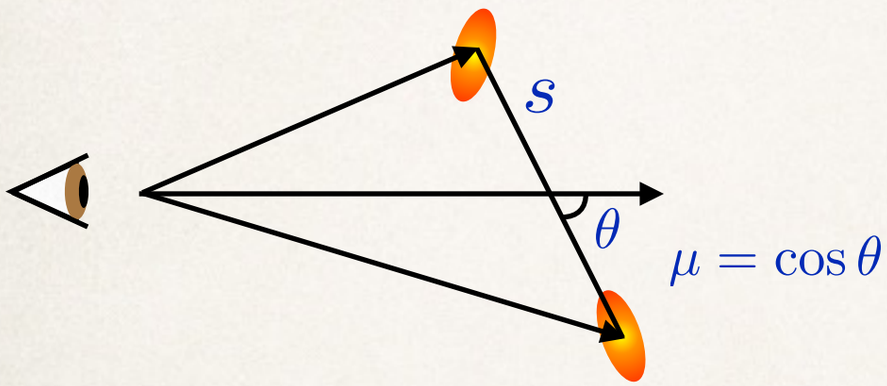
$$y \equiv \frac{D_{\rm V}(z)}{r_{\rm d}}$$

where

$$D_{\rm V}(z) \propto \left(D_{\rm A}(z)^2/H(z)\right)$$

Anisotropic clustering

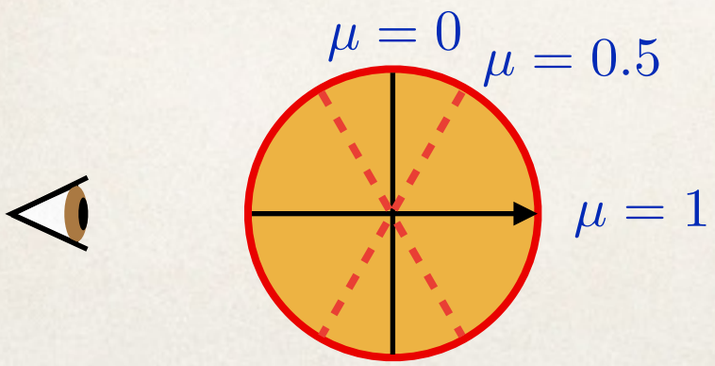
- Anisotropic clustering can be analysed in terms of multipoles of $\xi(\mu, s)$ (Padmanabhan & White 2008).



$$\xi(\mu, s) = \sum_{\text{even } \ell} L_\ell(\mu)\xi_\ell(s)$$

$$\xi_\ell(s) = \frac{(2\ell+1)}{2}\int_{-1}^{1} \xi(\mu, s)\, L_\ell(\mu)\, \mathrm{d}\mu$$

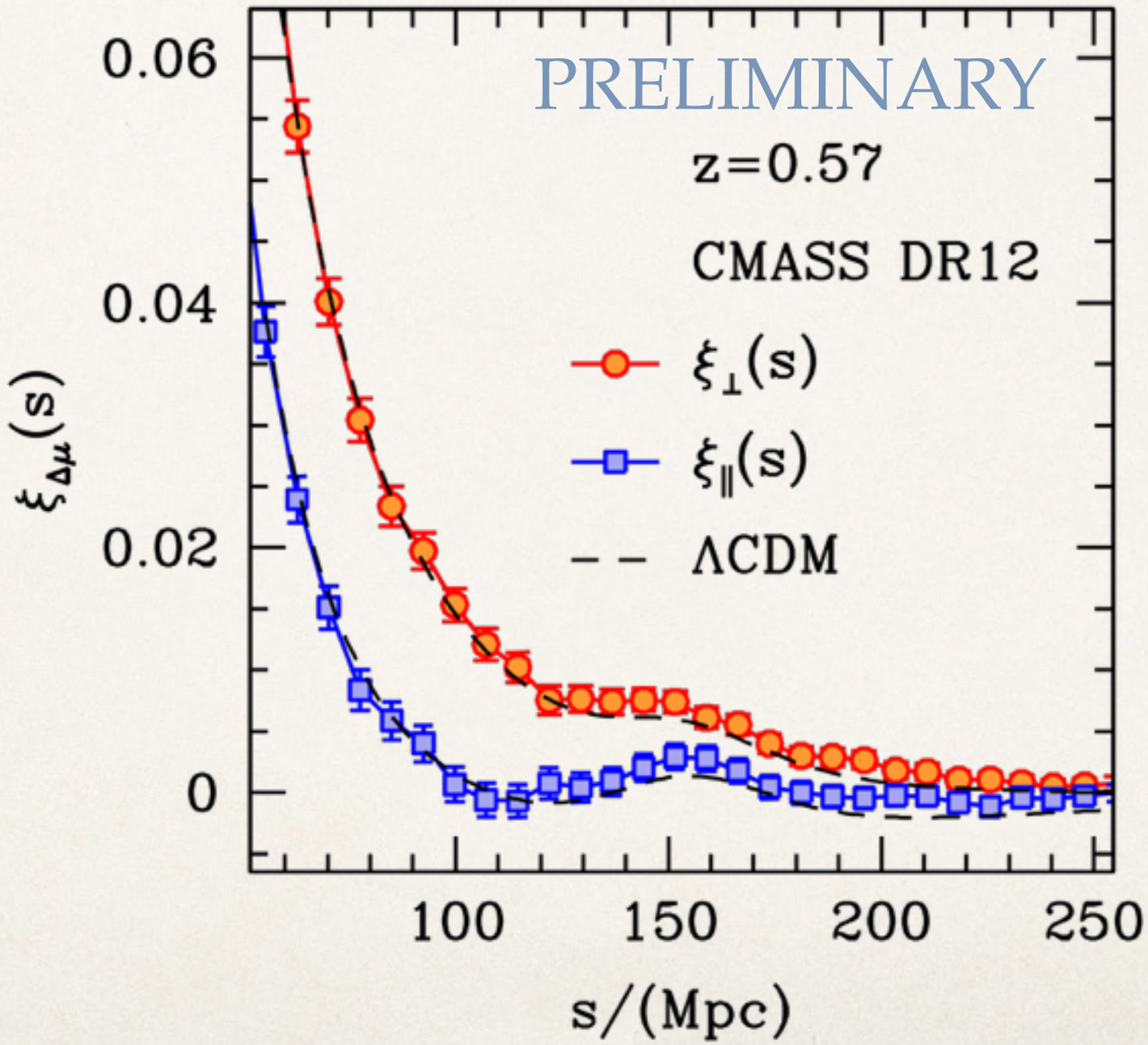
- Alternatively, we can use clustering wedges (Kazin, Sánchez & Blanton 2012)



$$\xi_{\Delta\mu}(s) = \frac{1}{\Delta\mu}\int_{\mu_{\min}}^{\mu_{\max}} \xi(\mu, s)\, \mathrm{d}\mu$$

Clustering wedges

- DR12 CMASS clustering wedges.



Clustering wedges

- Anisotropic BAO measurements constrain

$$y_\perp = D_\mathrm{A}(z_\mathrm{m})/r_\mathrm{d}$$
$$y_\parallel = D_H(z_\mathrm{m})/r_\mathrm{d}$$

where $D_H(z_\mathrm{m}) = c/H(z_\mathrm{m})$

- Full-shape gives additional information on $f\sigma_8(z)$

$$f(z) = \frac{\mathrm{d}\ln D}{\mathrm{d}\ln a}$$

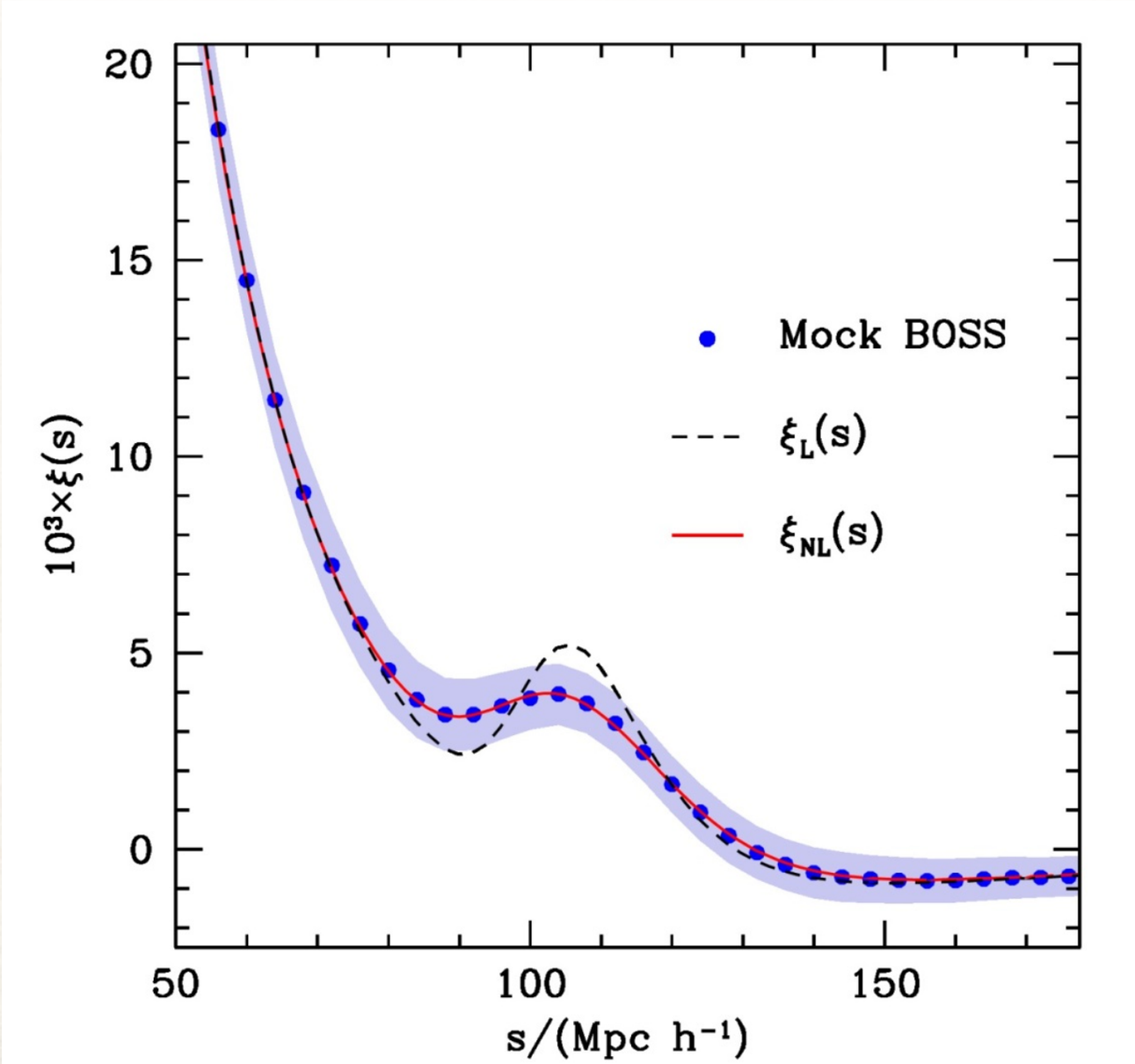
- We need a model of the full shape of $\xi_{\Delta\mu}(s)$.

Modelling LSS observations

- Systematic errors can dominate final error budget.
- Key issue: how does the BAO signal evolves with time?
- In practice, BAOs are not precisely a standard ruler (Crocce & Scoccimarro 2008, Sánchez et al. 2008).
- Our models of $\xi_{\Delta\mu}(s)$ must take into account
  - Non-linear evolution ($\delta \gtrsim 1$)
  - Redshift-space distortions ($z_{\rm obs} = z_{\rm cos} + u_{\parallel}/c$)
  - Galaxy bias (light $\neq$ matter)

Modelling LSS observations

- We used a model based on Renormalised perturbation Theory (Crocce & Scoccimarro, 2006) + bias + RSD



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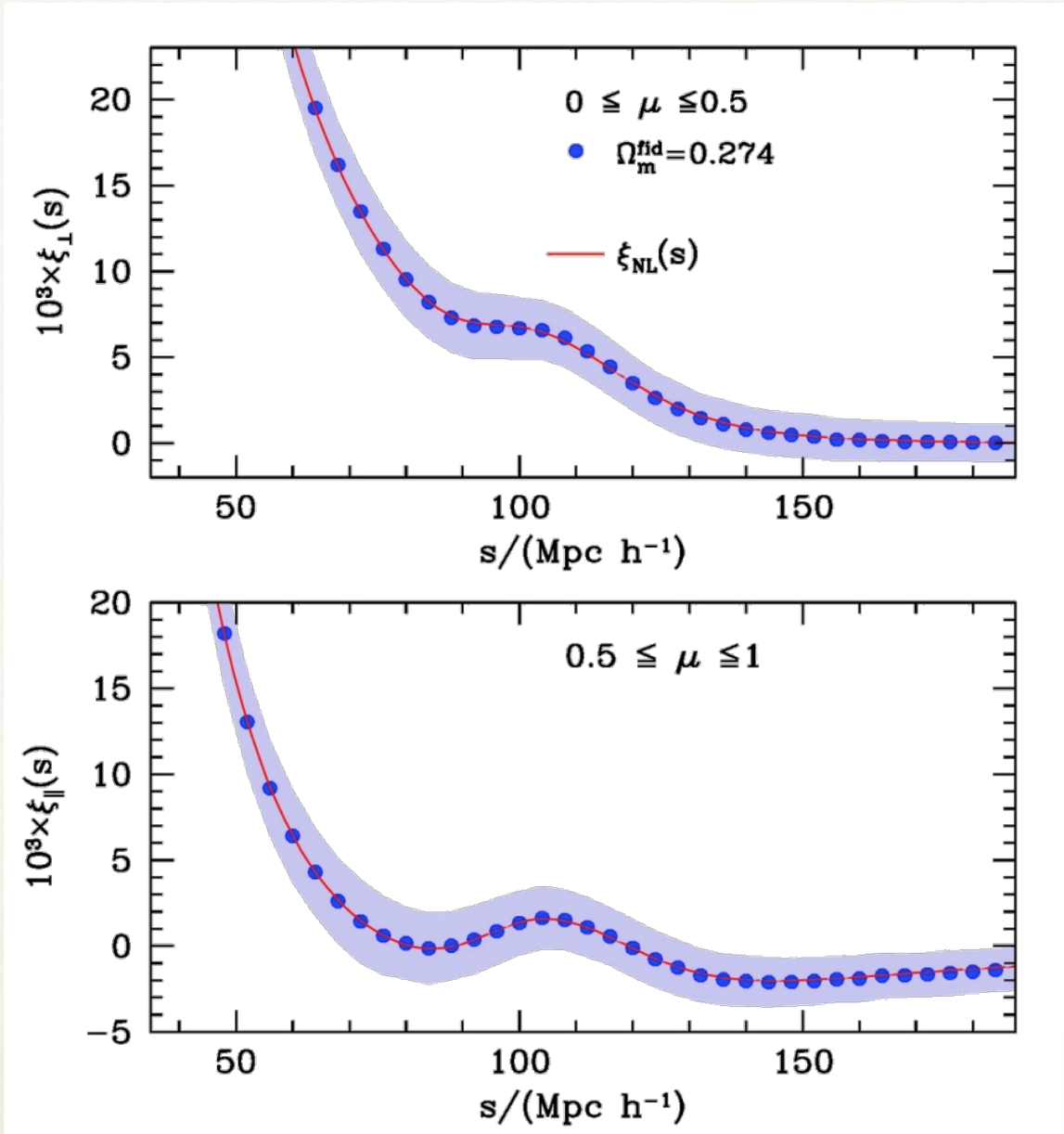
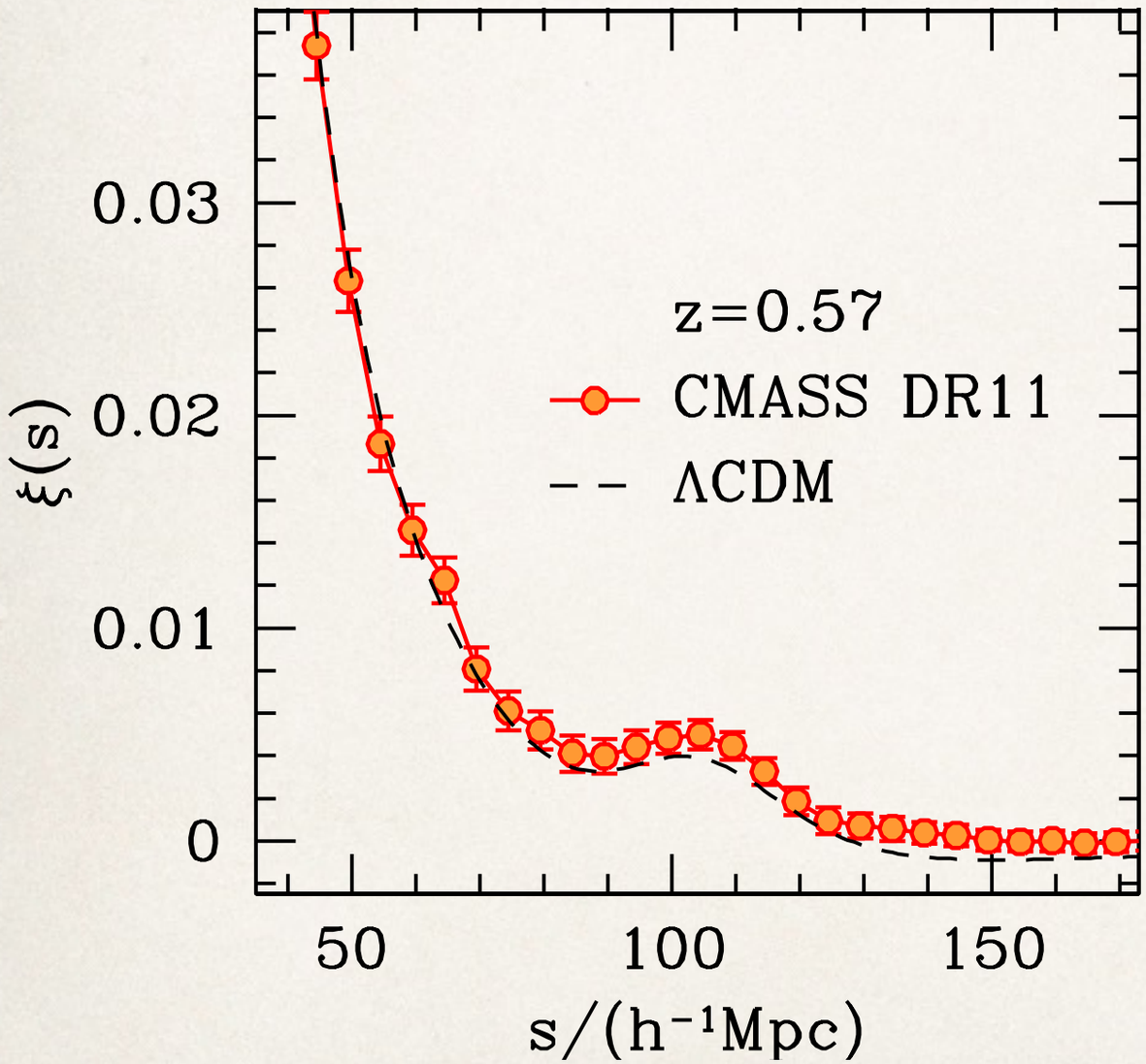
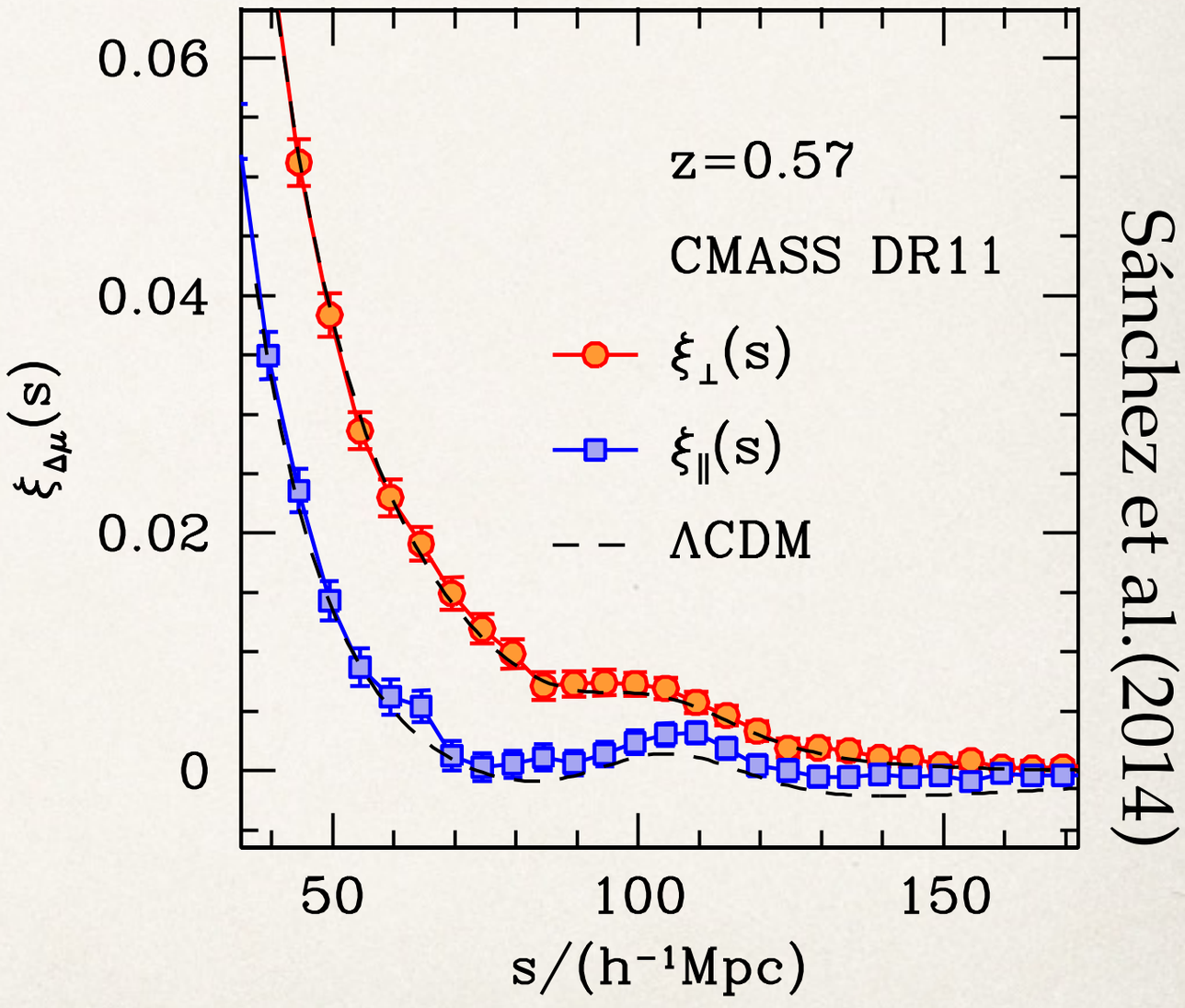


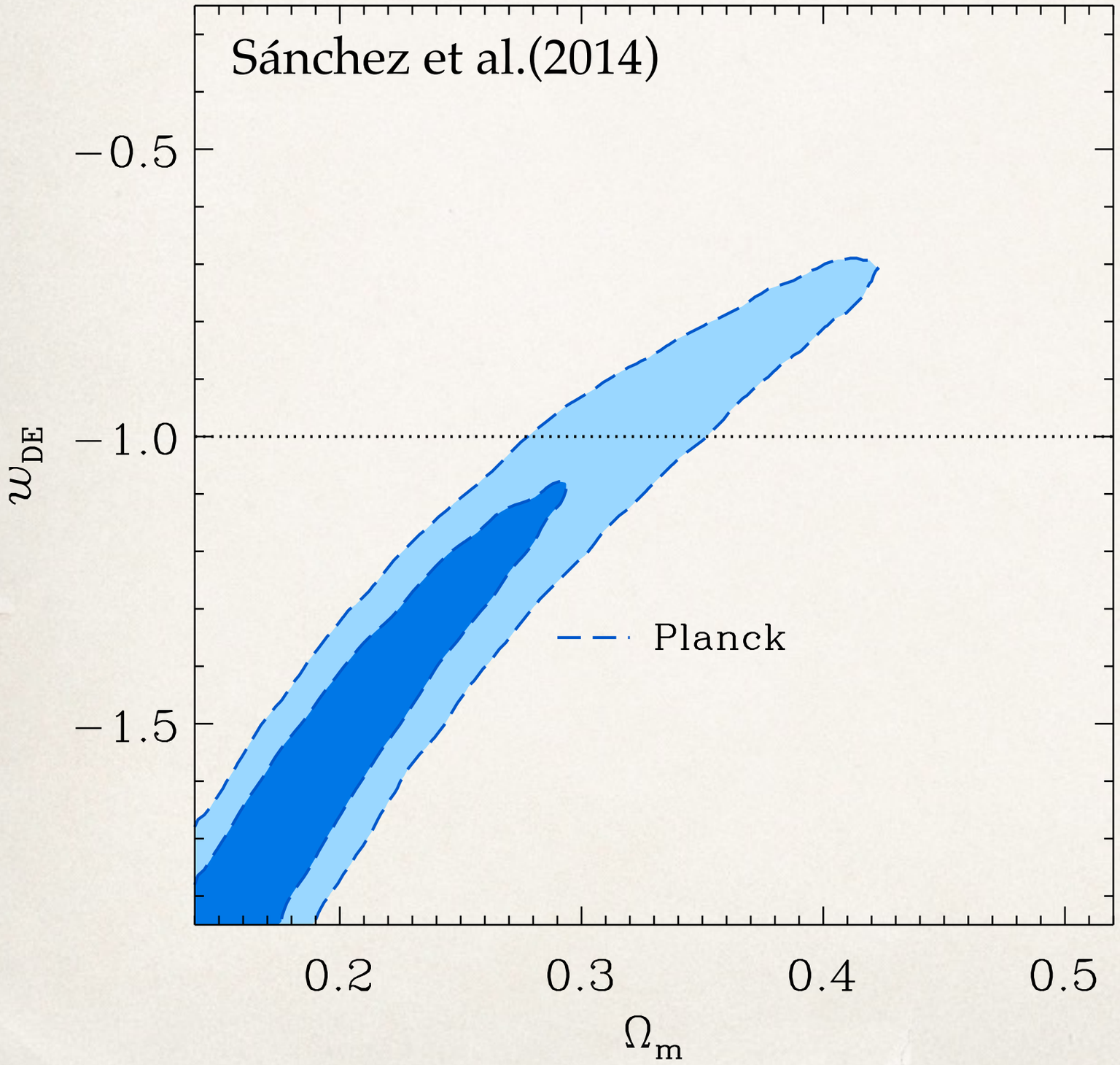
Results from BOSS-DR11

- We applied these models to BOSS-DR11.





The dark energy equation of state



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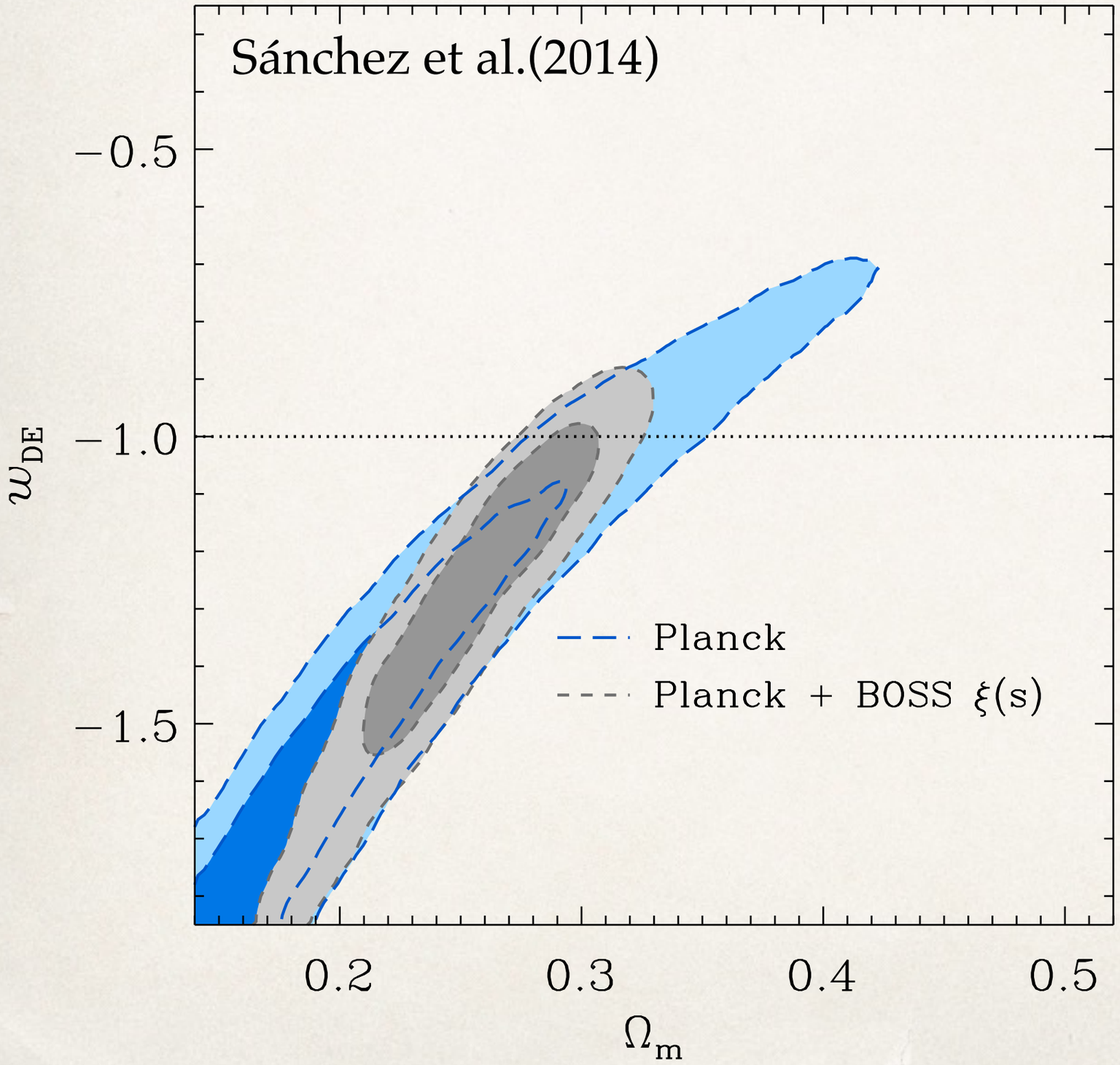

$$\text{Planck} + \text{BOSS}\ \xi(s)$$

$$\Omega_{\rm m} = 0.249^{+0.034}_{-0.026}$$

$$w_{\rm DE} = -1.31^{+0.21}_{-0.16}$$

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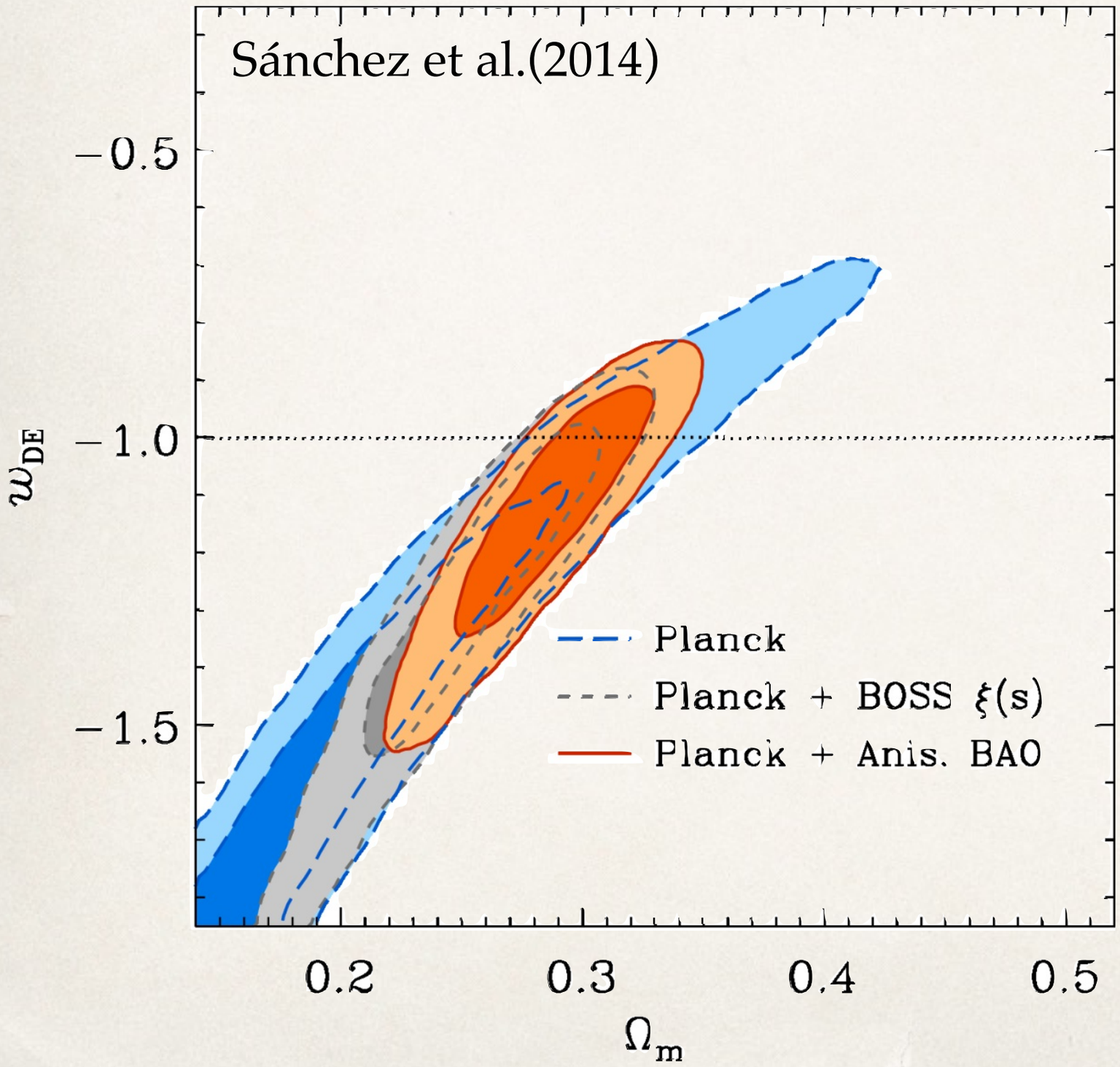

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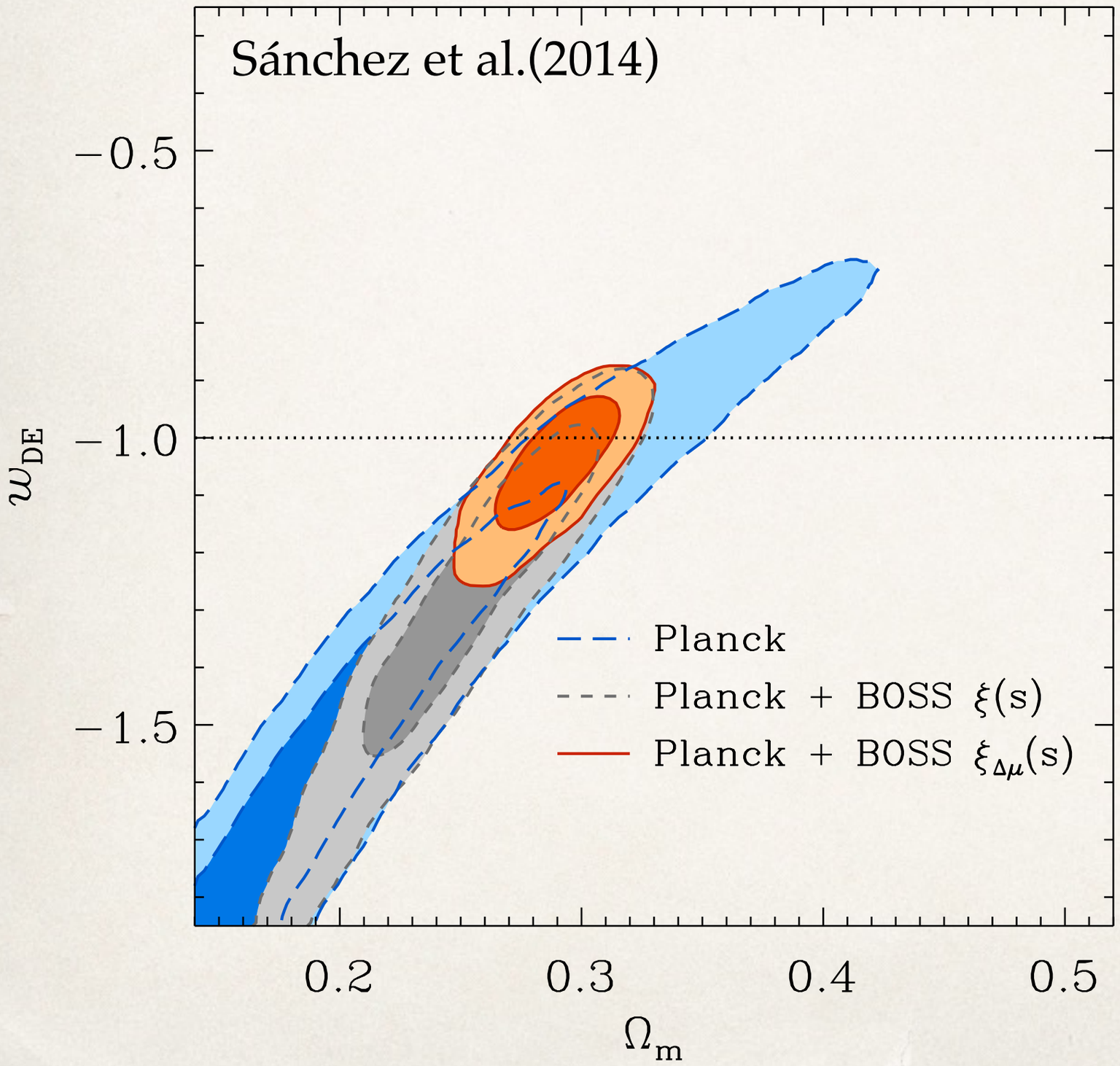

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Planck + BOSS $\xi_{\Delta\mu}(s)$

$$\Omega_{\rm m} = 0.288 \pm 0.016$$

$$w_{\rm DE} = -1.051 \pm 0.076$$

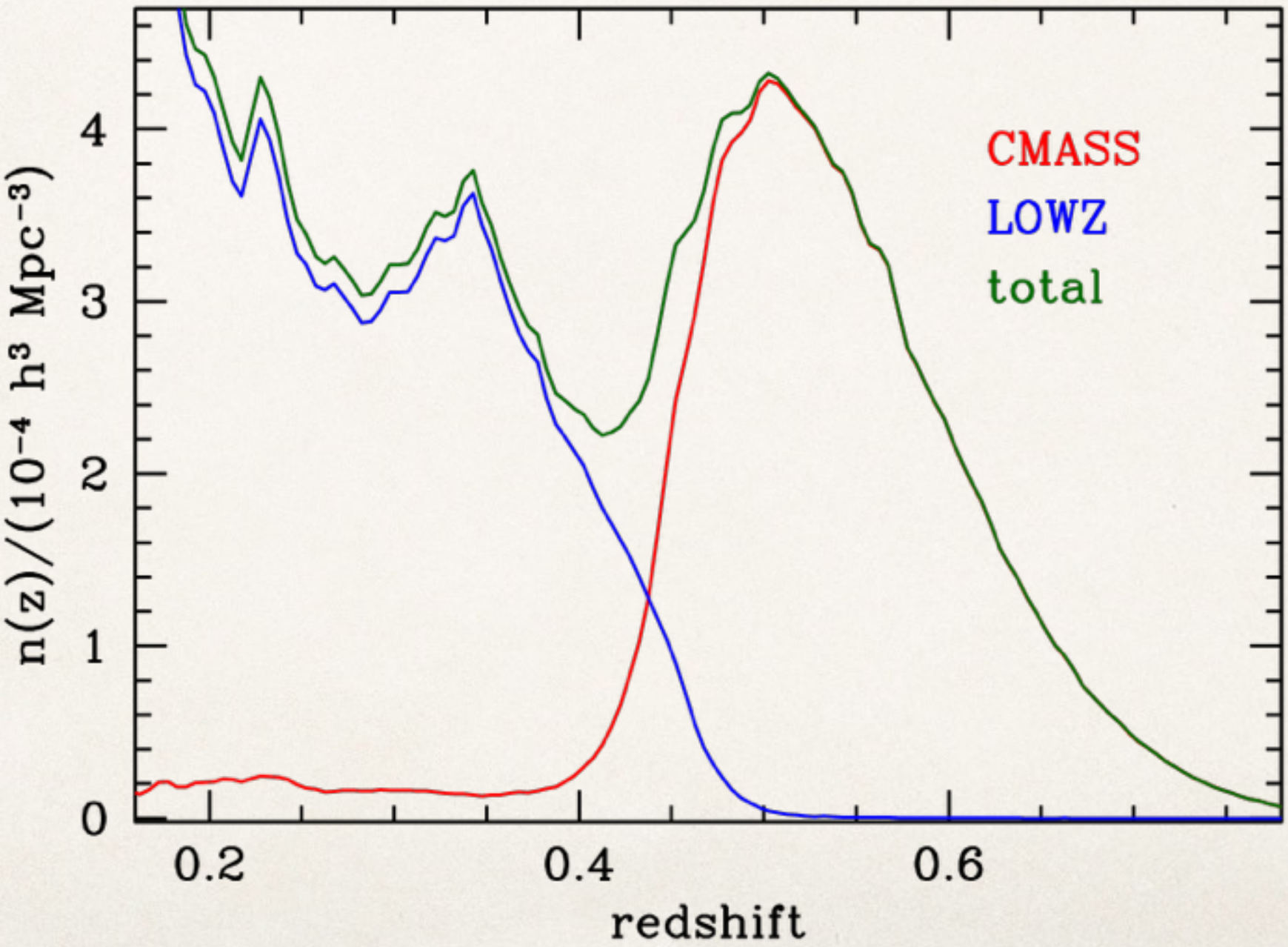
Planck + BOSS BAO

$$\Omega_{\rm m} = 0.301 \pm 0.016$$

$$w_{\rm DE} = -1.06 \pm 0.10$$

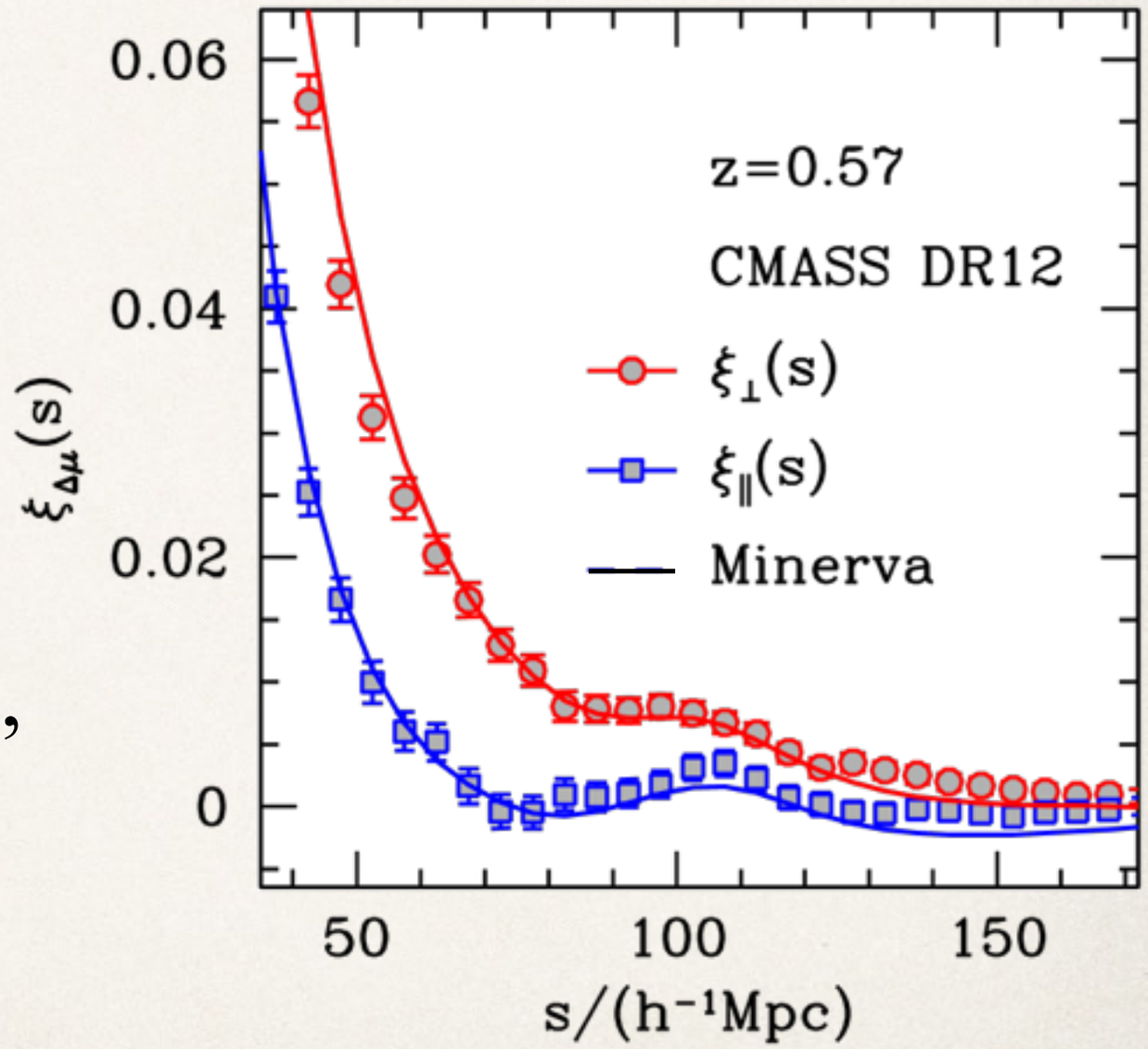
New treatment of the data

- DR12: we use a combined sample of LOWZ+CMASS



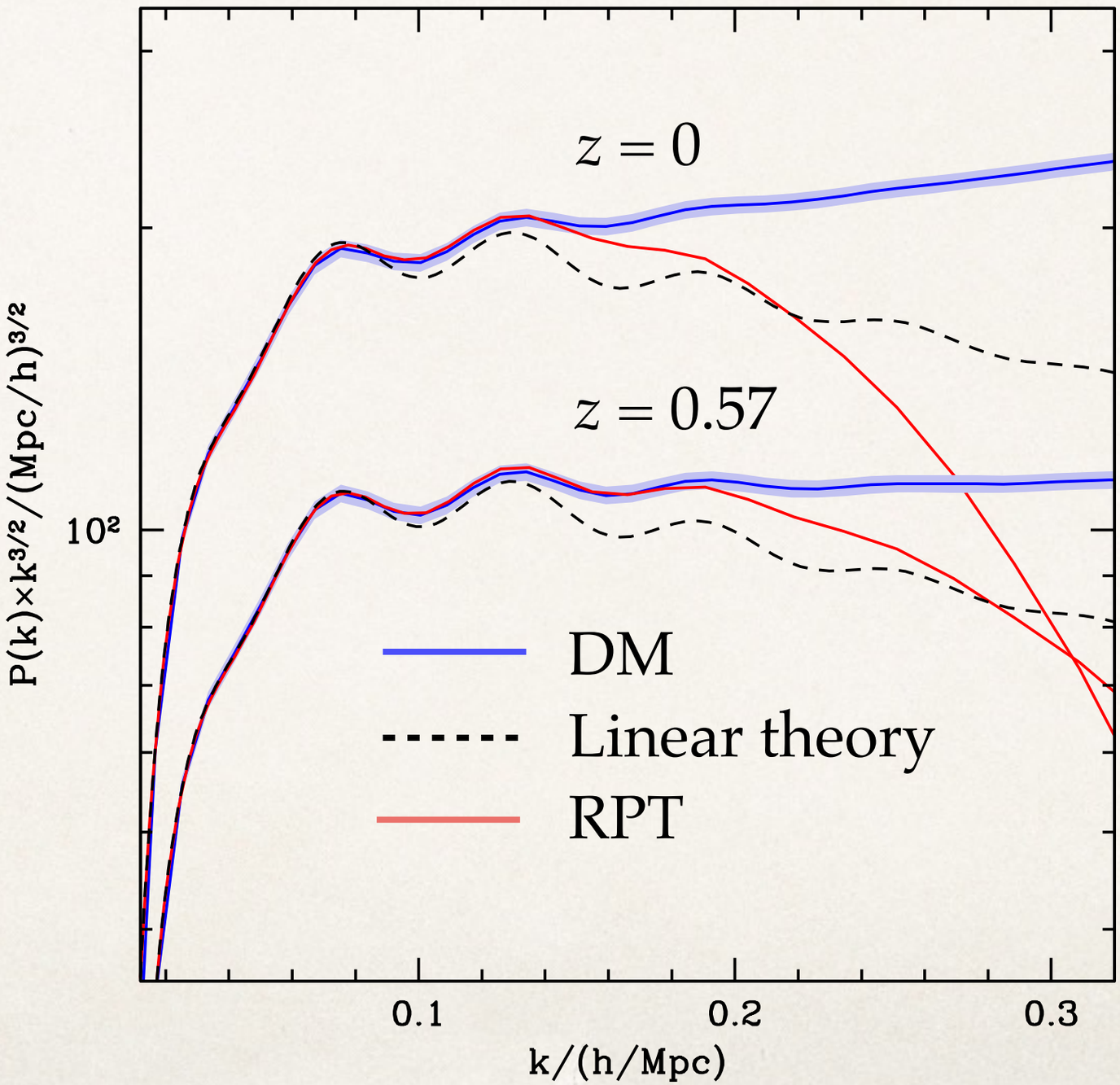
N-body simulations

- MINERVA: a set of 100 DM N-body simulations.
- Cosmology from WMAP +BOSS DR9 ($\Omega_{\rm m} = 0.285$)
- $L_{\rm BOX}$ = 1.5 Gpc/h, $N = 1000^3$
- Snapshots at z = 0, 0.3, 0.57, 1 & 2
- Galaxies with HOD matching CMASS $\xi(s)$



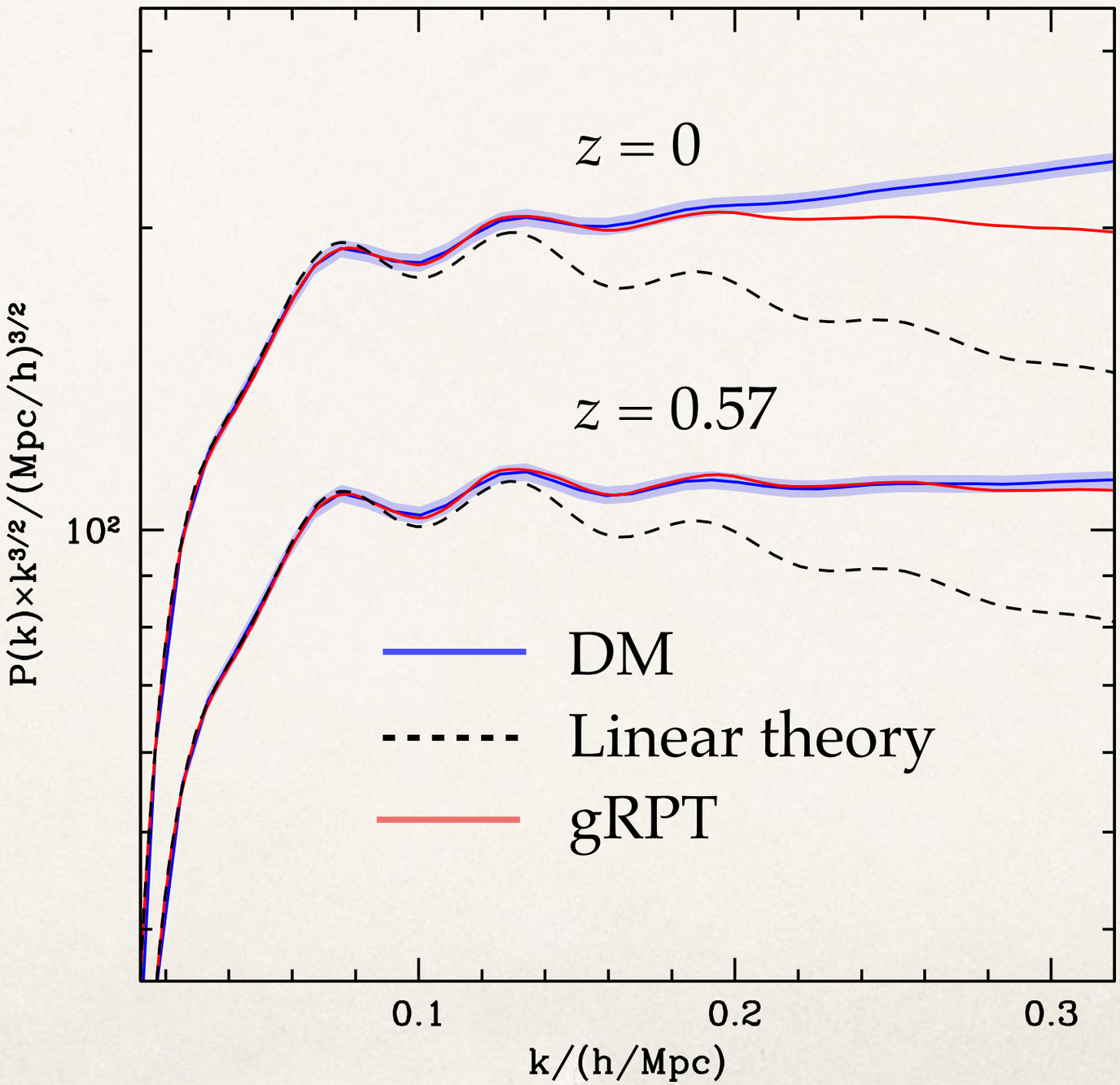
Modelling BAO and RSD

- Previous analyses were based on RPT.



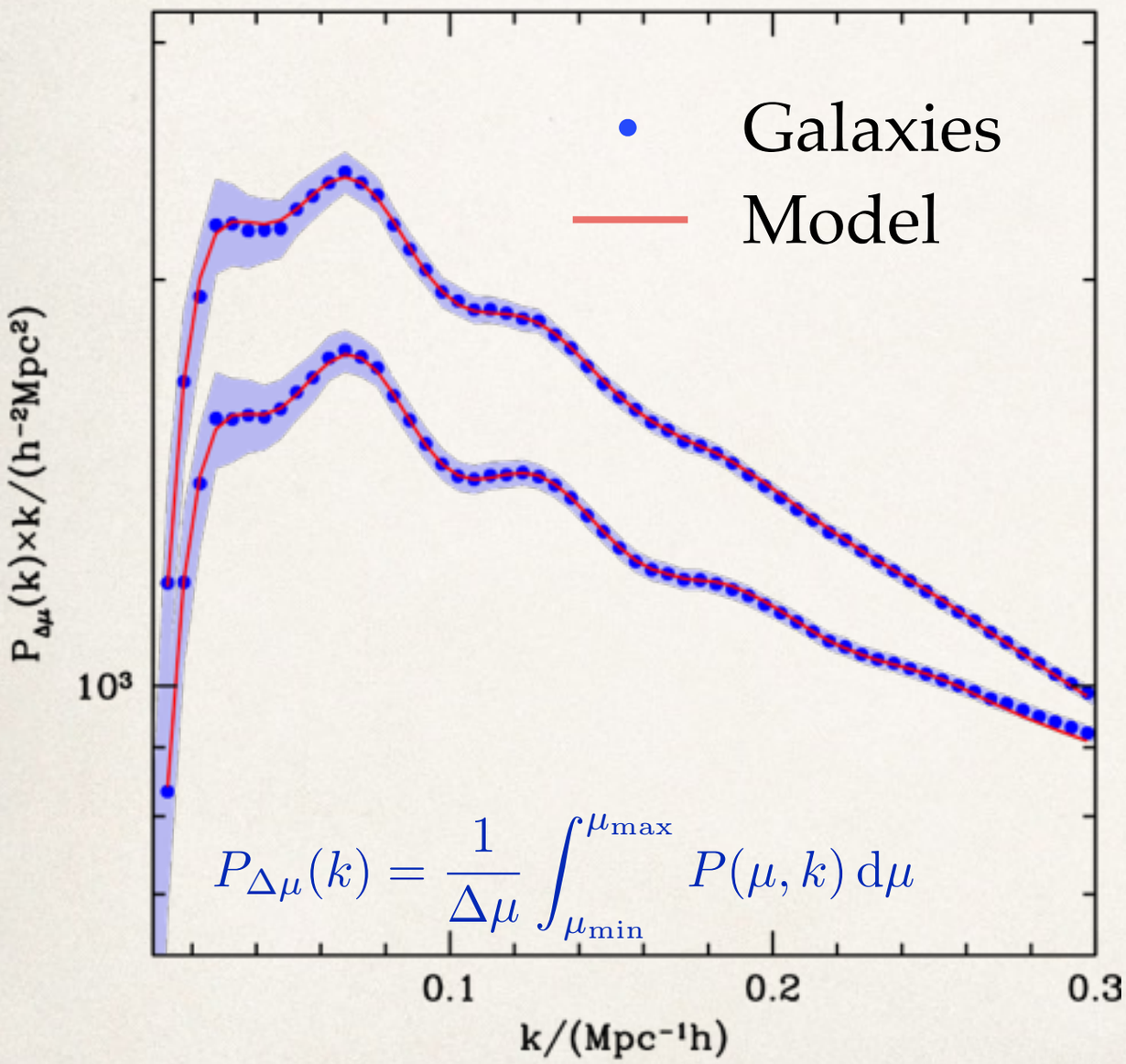
Modelling BAO and RSD

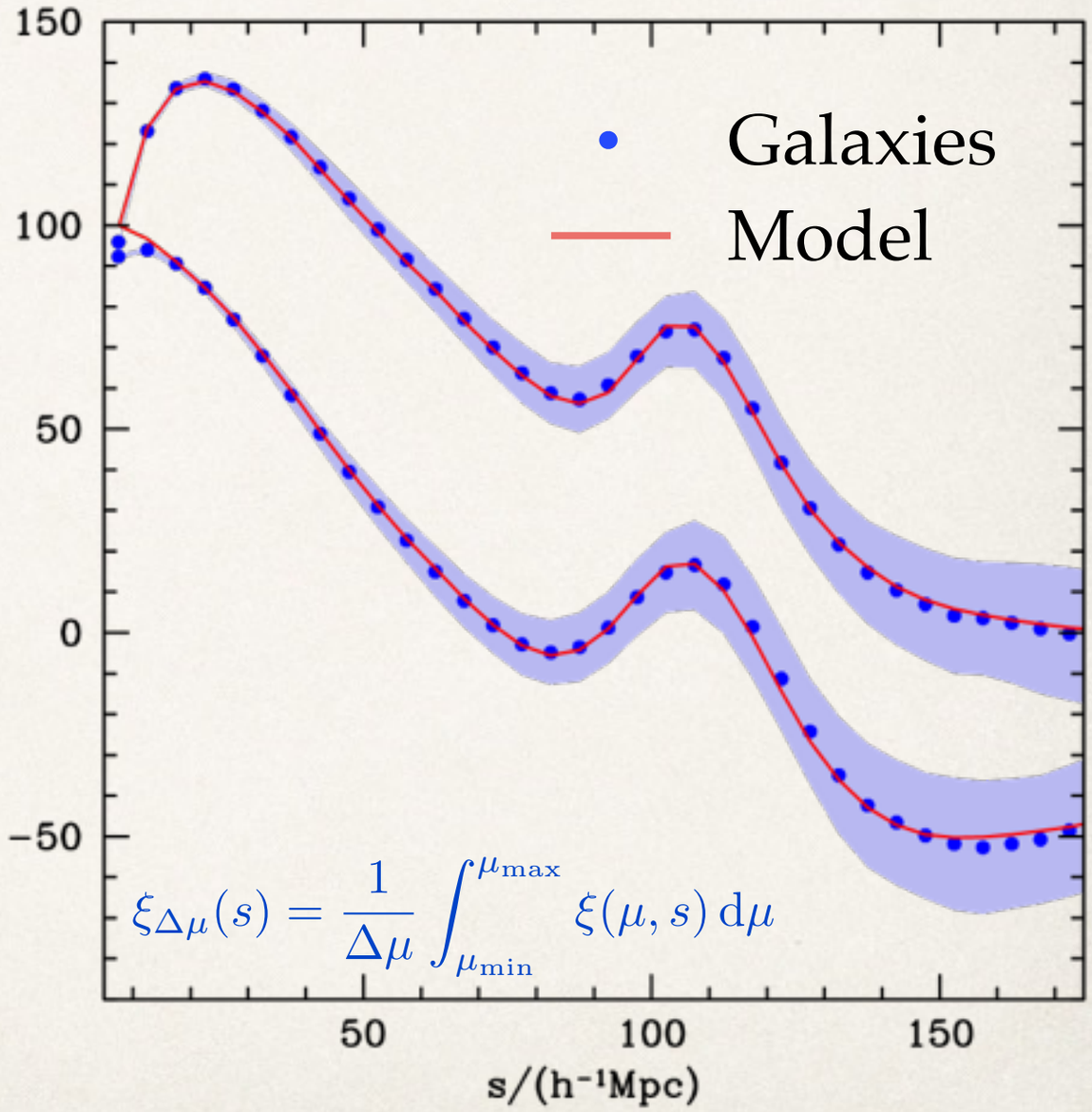
- New recipe based on gRPT: see Roman's talk!



Modelling BAO and RSD

- Excellent agreement with the results from MINERVA.





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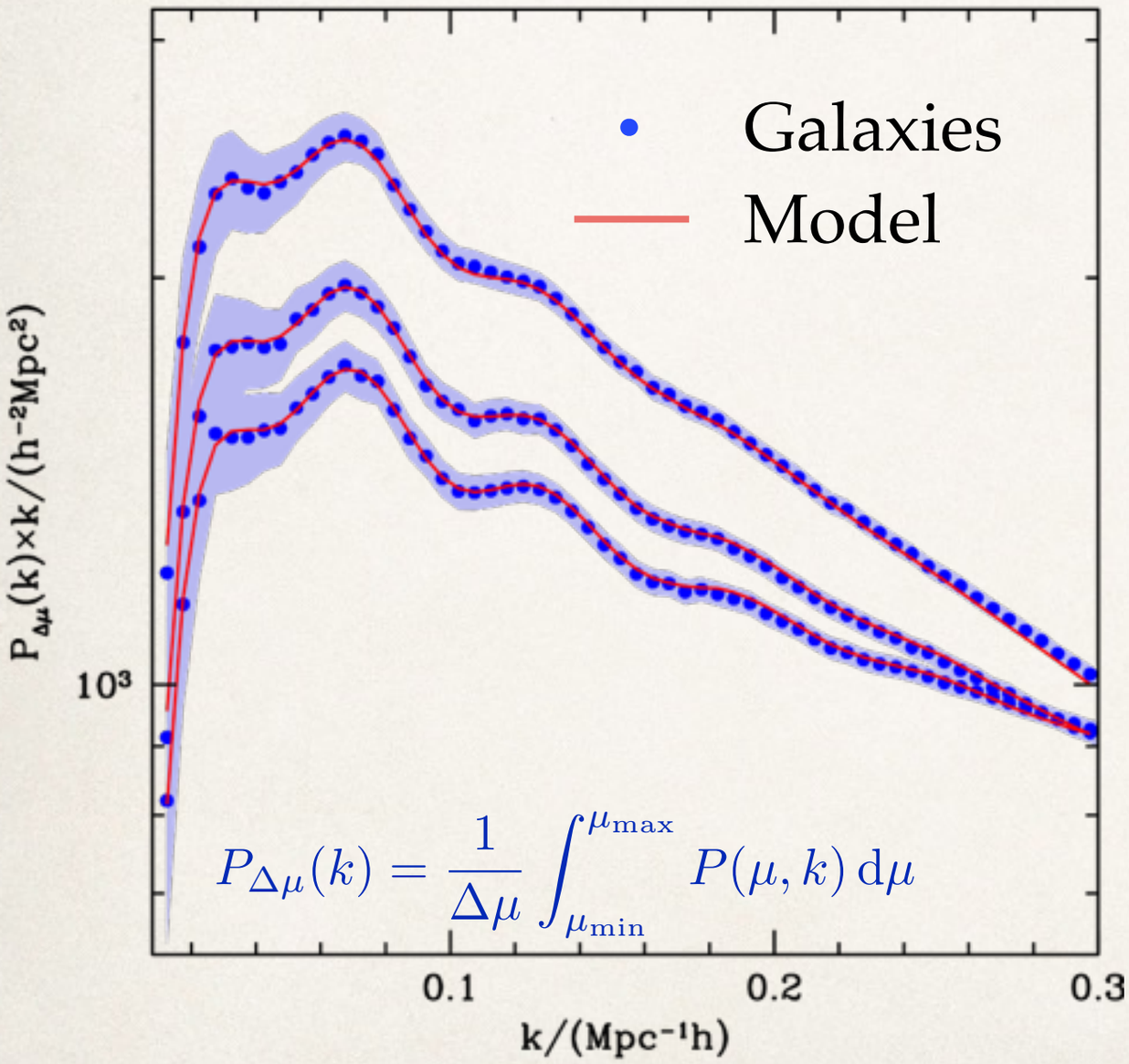
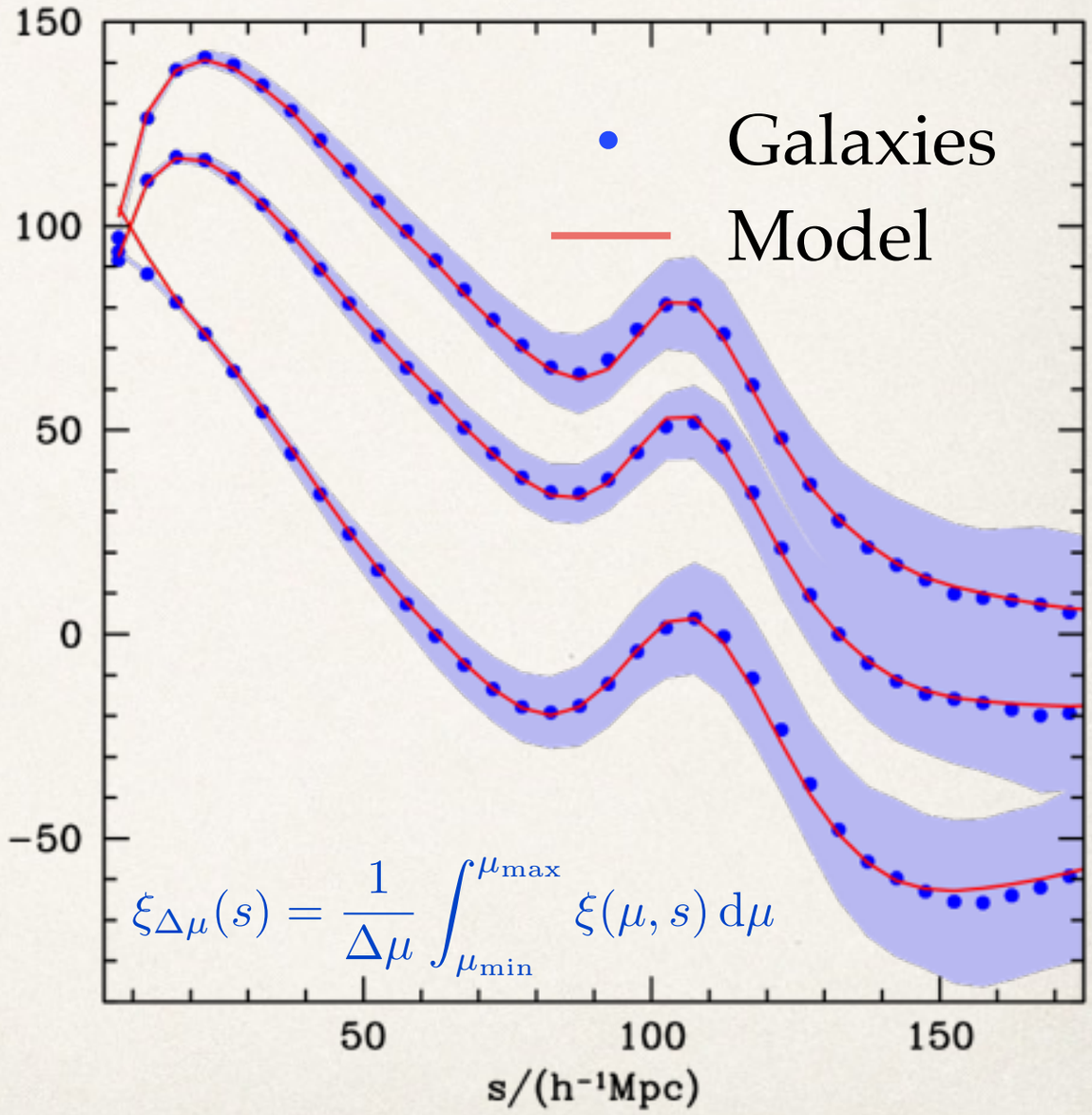
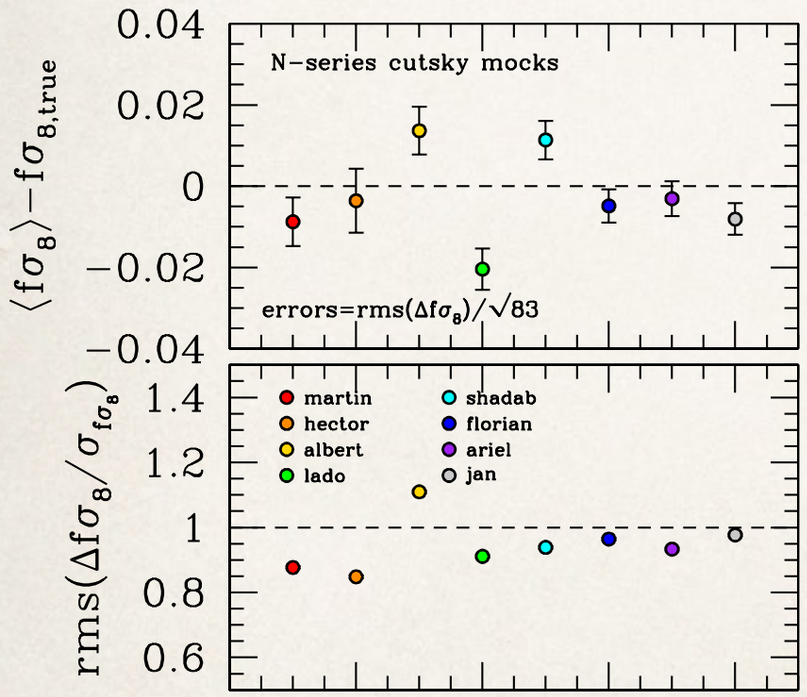
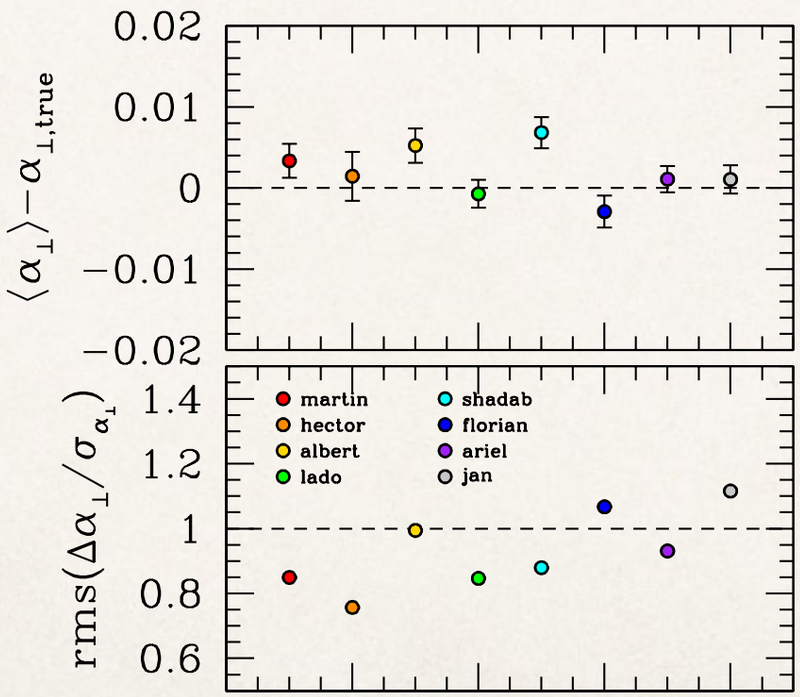


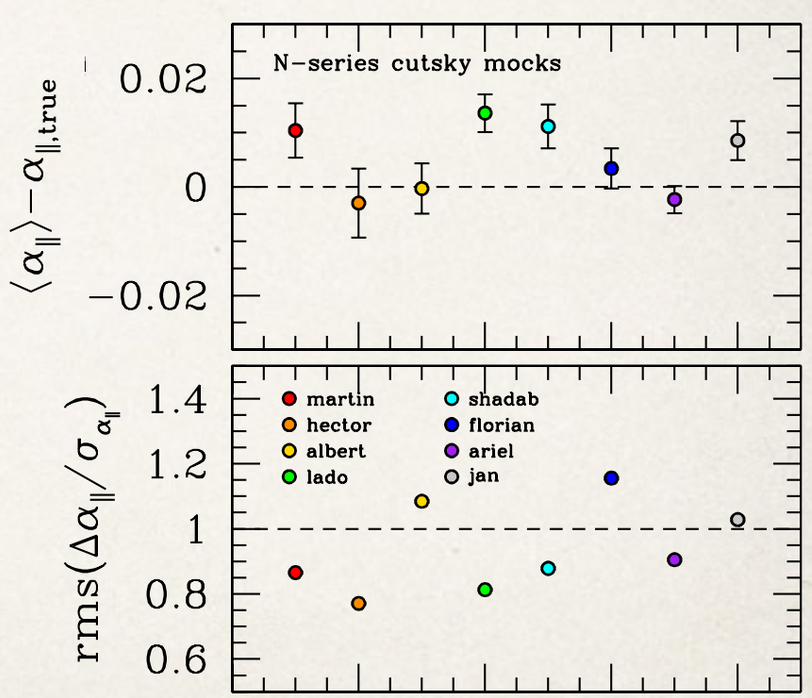


Modelling BAO and RSD

- BOSS internal RSD challenge (Tinker et al. in prep).
- A set of 7 boxes for different cosmologies and HODs.
- A series of 83 CMASS NGC mock catalogs.

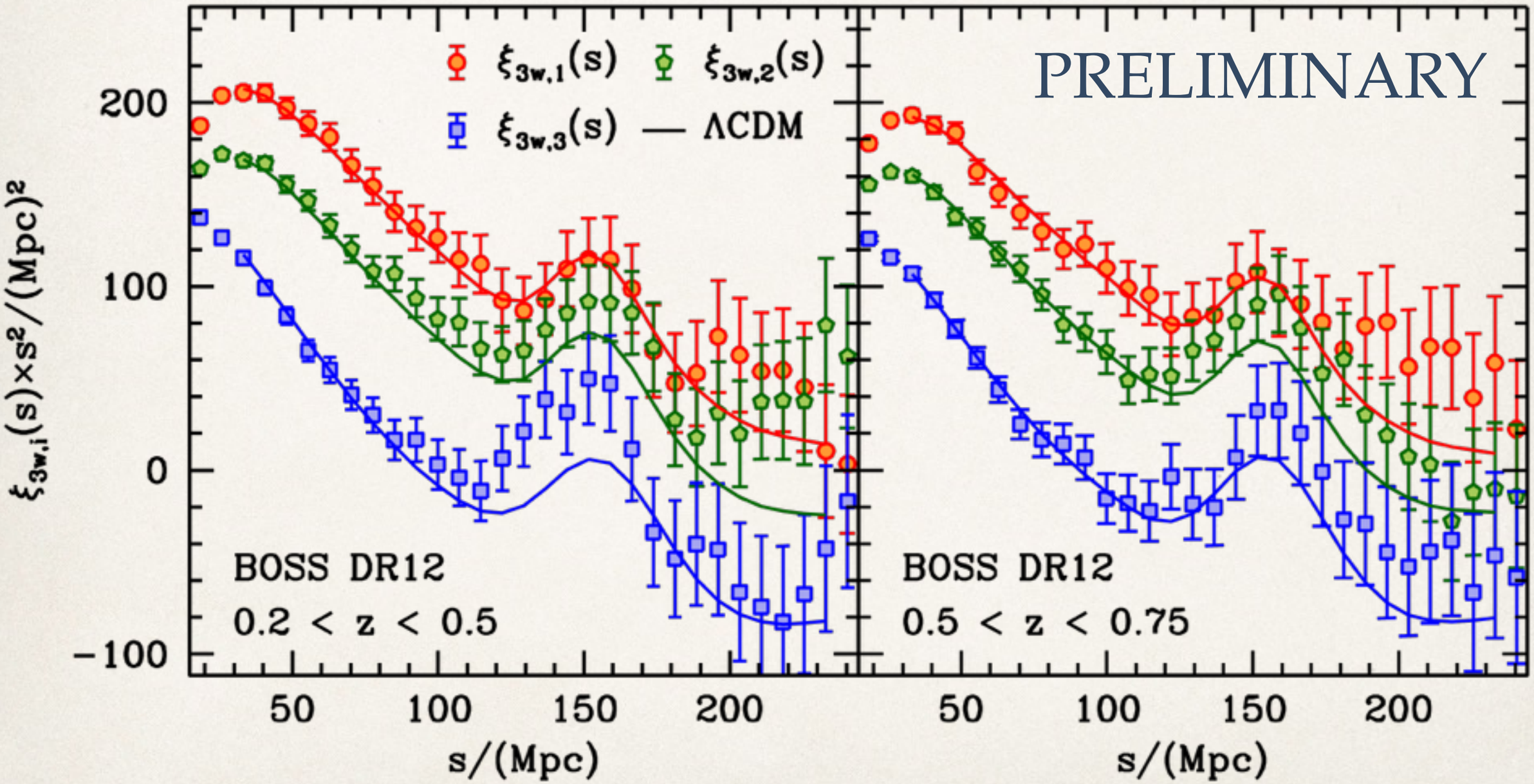






Figures: J. Tinker

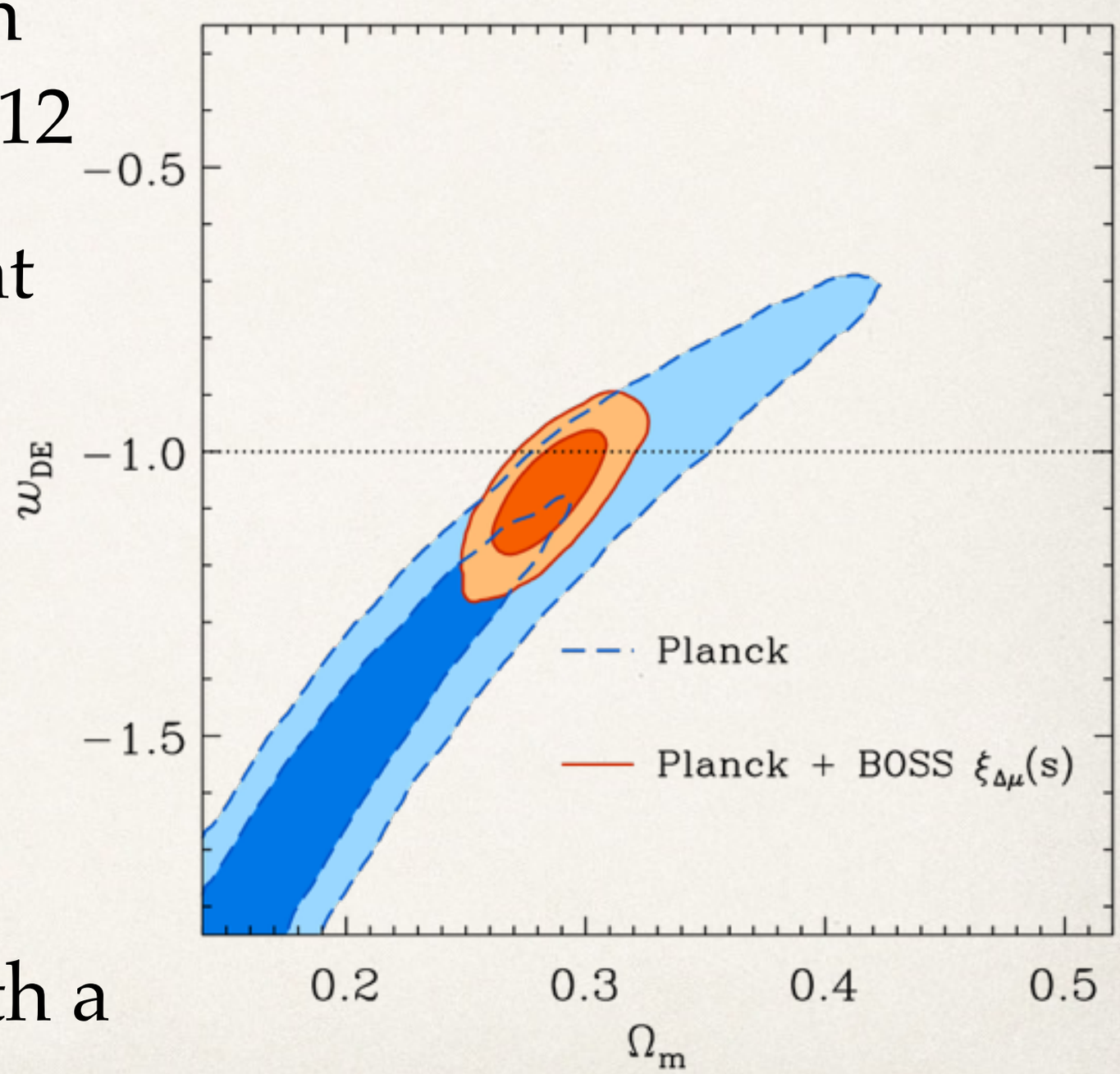
The BOSS-DR12 clustering wedges



Constraints from Planck+BOSS-DR12

- Preliminary results from Planck 2013 + BOSS DR12
- Significant improvement over previous method

Previous analysis:
$w_{\rm DE} = -1.051 \pm 0.076$
New analysis:
$w_{\rm DE} = -{\rm x.xxx} \pm {\rm x.xxx}$



- DE is still consistent with a cosmological constant

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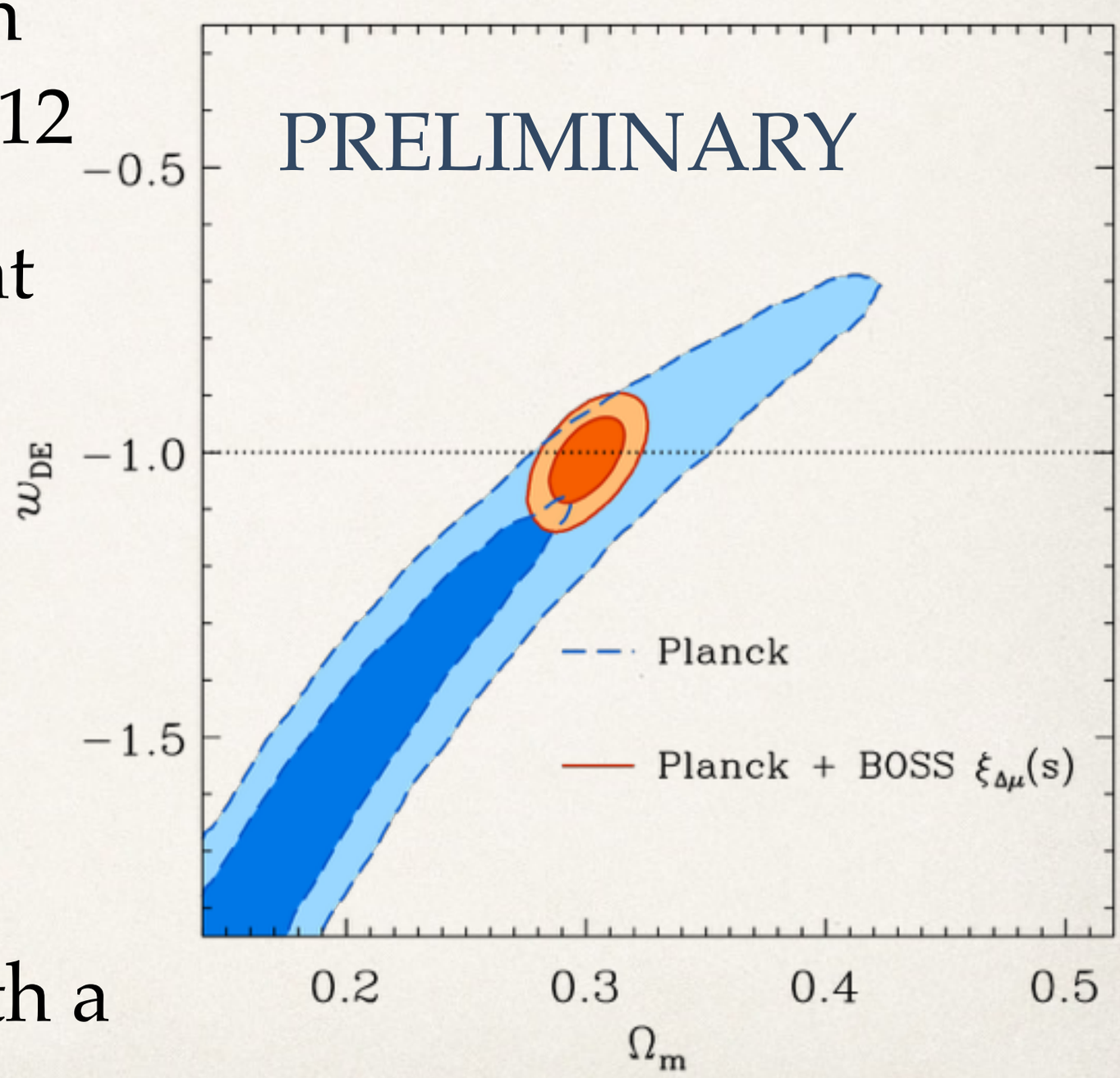

- DE is still consistent with a cosmological constant

BOSS DR12 clustering analyses

- Several companion papers exploring different aspects of galaxy clustering in BOSS DR12.

- A number of these analysis based on the same model:

- Wedges in Fourier space: see Jan Grieb's talk today!

- Clustering tomography with $w(\theta)$: see Salvador Salazar-Albornoz' talk!

- Joint analysis of 2pt and 3pt statistics: see Roman Scoccimarro's talk!

Final remarks and next steps…

- Final BOSS DR12 analyses are almost ready.
- New treatment of the data should improve the constraints with respect to previous DRs.
- New theoretical recipes in agreement with N-body simulations (DM, halos and HOD galaxies).
- Multiple analysis (Fourier- and conf. space, 2pt & 3pt) based on the same underlying model.
- Final papers will be out really soon!