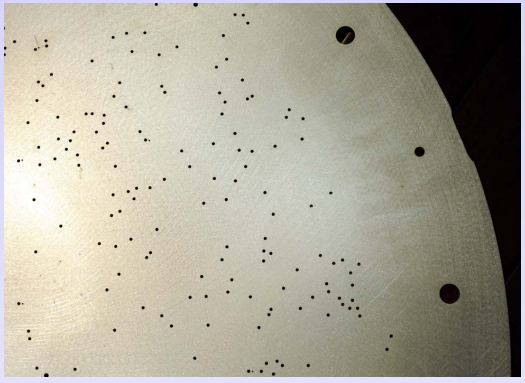
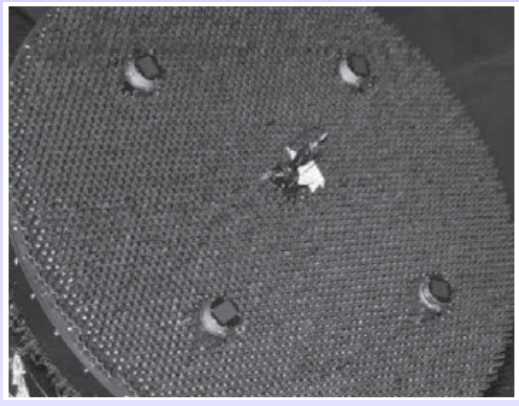
Lyman-α forest in BOSS

Anže Slosar, Brookhaven National Laboratory

Santa Barbara, 4/24/13

Introduction

- Lyman-α forest is a unique field:
  - Got hammered with WMAP1 for running of spectral index
  - Very strong results in 2004 from 3000 SDSS QSOs by McDonald et al, but at a large emotional cost
  - Undergoing a revival now driven by BOSS
- Introduction to Lyman-α forest
- Recent BAO results
- Other interesting up-and-coming results

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Date: 9 Jan 2013 06:08:45 +0800
From: Am. J. Plant Sci. <ajps@elert-scirp.org>
Reply-To: ajps@scirp.org
To: anze@bnl.gov
Subject: Dr.An e Slosar, Special Issue on "The future of Forests" CFP

This message was sent to [anze@bnl.gov].Unsubscribe by clicking here [www.member.scirp.org].

Dear Dr.An e Slosar,

I am writing to let you know about our upcoming Special Issue on "The future of Forests", which will be published in American Journal of Plant Sciences (AJPS, ISSN:2158-2750), an open access journal. The deadline for submission is January 22nd, 2013, and the publication date is March 2013. You can find the Call for Papers for this Special Issue at the following website: www.scirp.org/journal/ajps [www.scirp.org]. The Special Issue is open to both original research articles as well as review articles.

I am contacting you about this Special Issue since I understand that you have published before in this area and I wanted to invite you to submit your manuscripts. American Journal of Plant Sciences (AJPS) is an open access journal, which means that all published articles are made freely available online without a subscription.

Please read over the journal's Authors' Guidelines [www.scirp.org] for more information on the journal's policies and the submission process [papersubmission.scirp.org]. Please include an indication of your intention to publish within the special issue to be entitled "Special Issue- The future of Forests". If you have any questions about this Special Issue, or about the journal, please do not hesitate to contact me.

Best regards,

On behalf of

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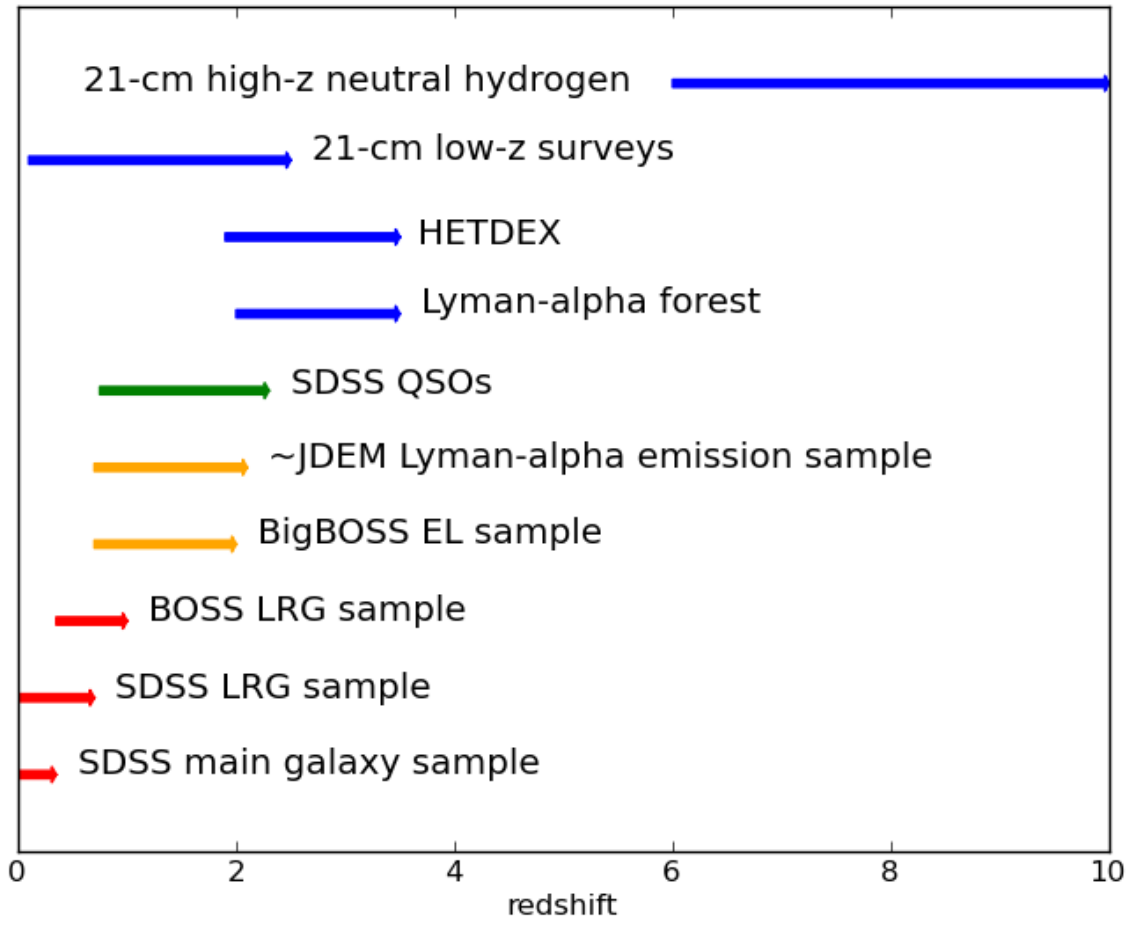
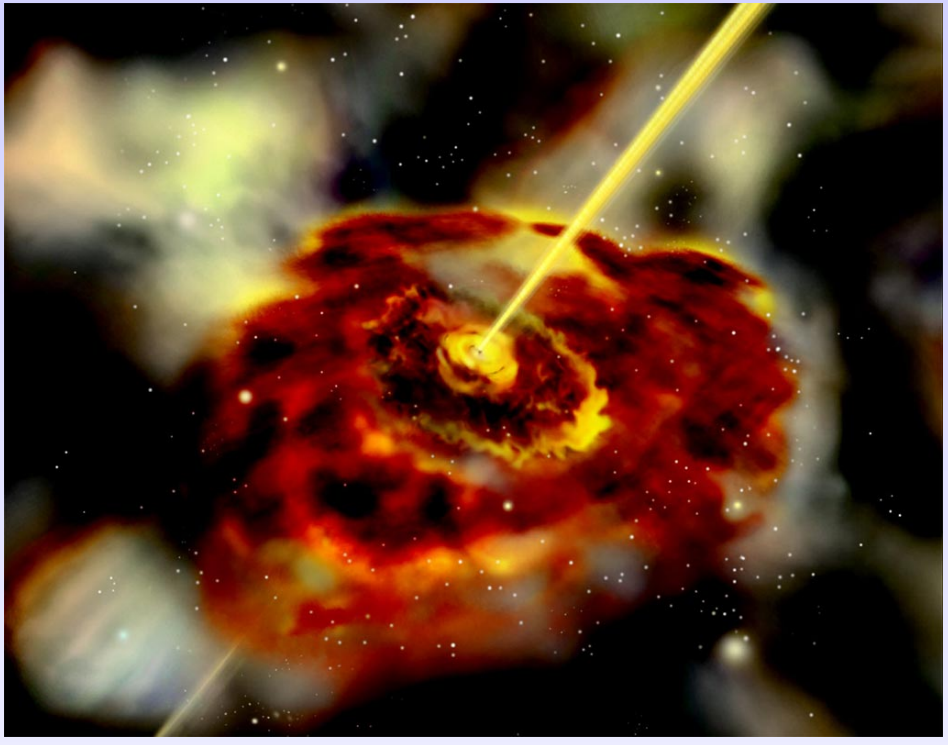
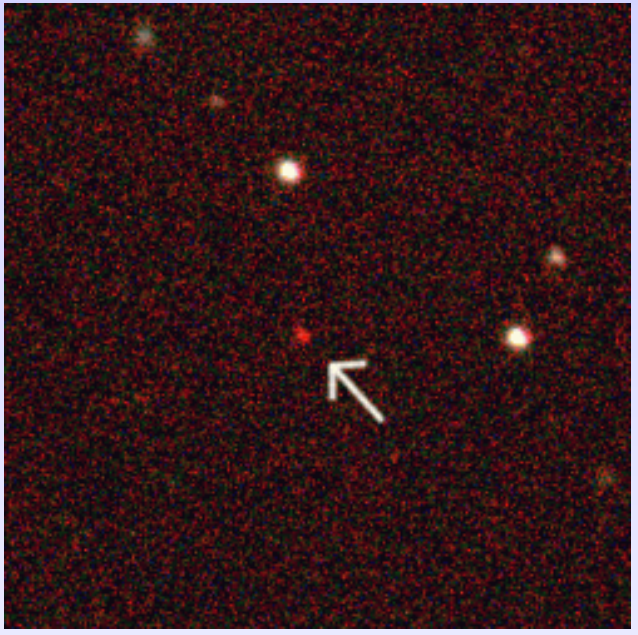
Measuring Density fields



- To do cosmology, one needs a tracer of dark matter
- Lyman-α forest pretty unique in probing redhift 2-3 universe
- Volume probed is very, very large
- Systematics very different to galaxy surveys
- At $z < 2$ limited by forest moving into UV
- At $z > 3.5$ limited by faintness and number-density of quasars

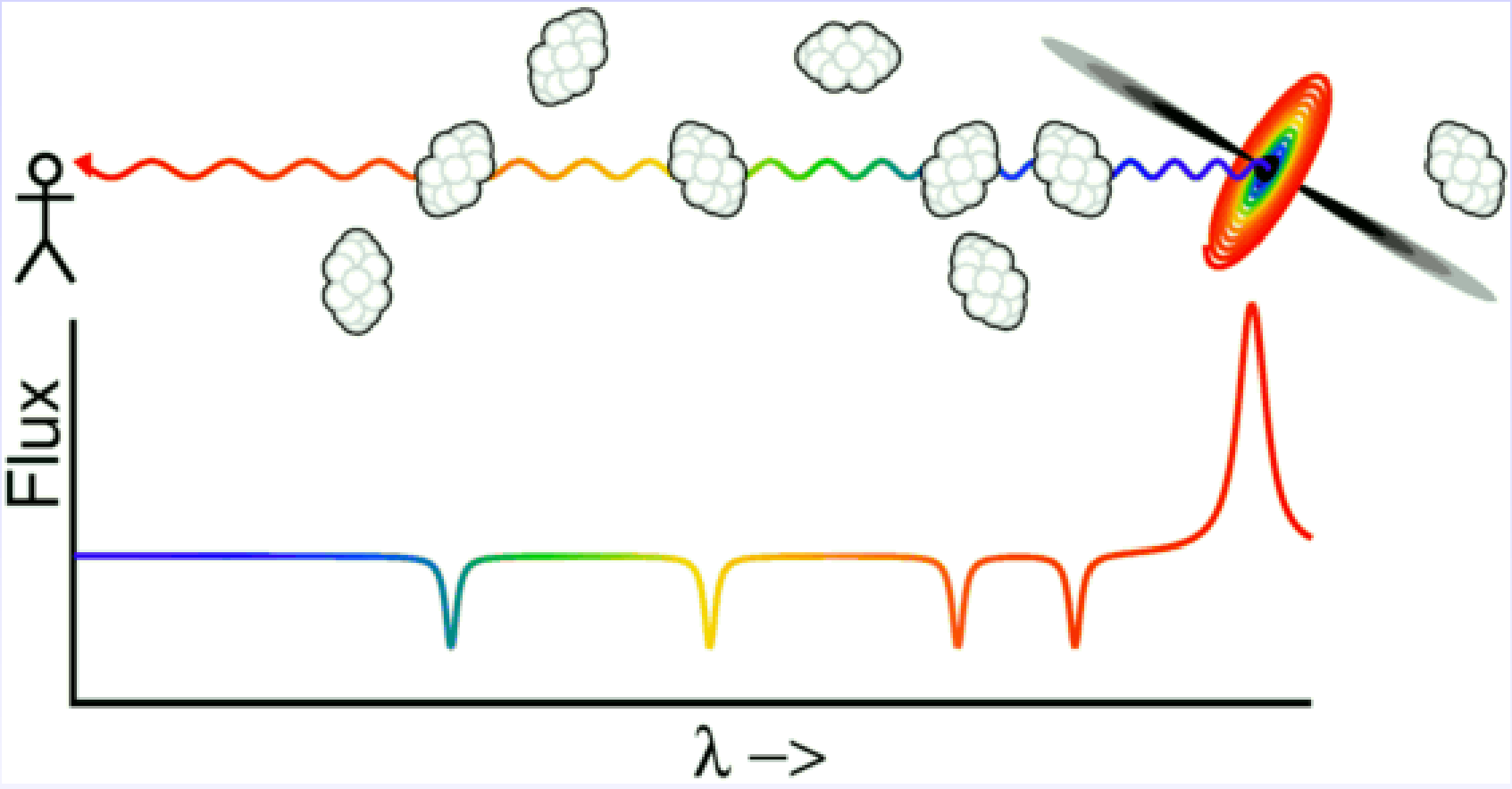
What are quasars





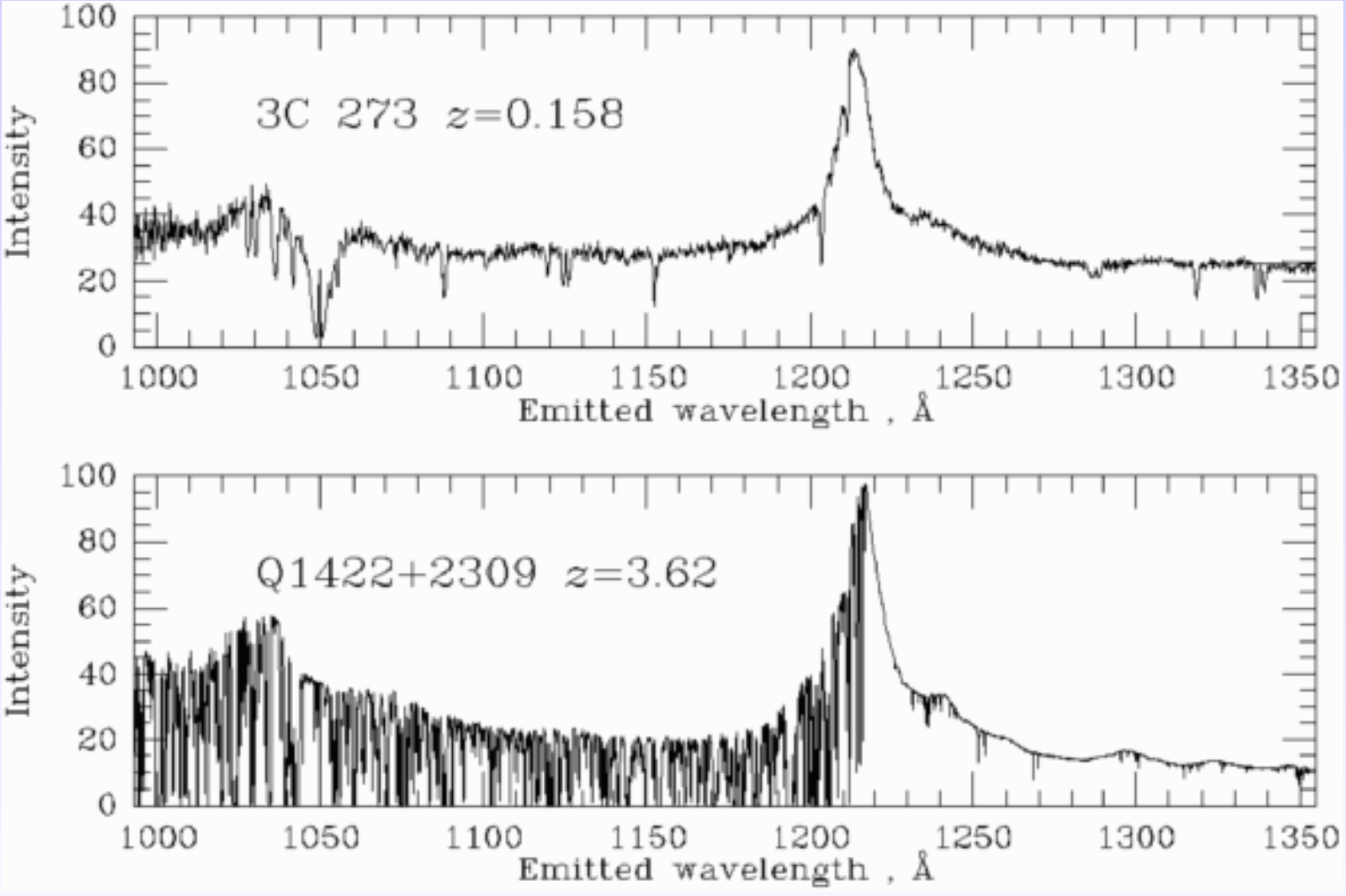
- Brightest things in the Universe
- Powered by energetic active galactic nuclei – can see them *very* far
- Featureless spectrum with a few broad emissions
- Understanding of underlying physics not important for our application.

Lyman-α forest



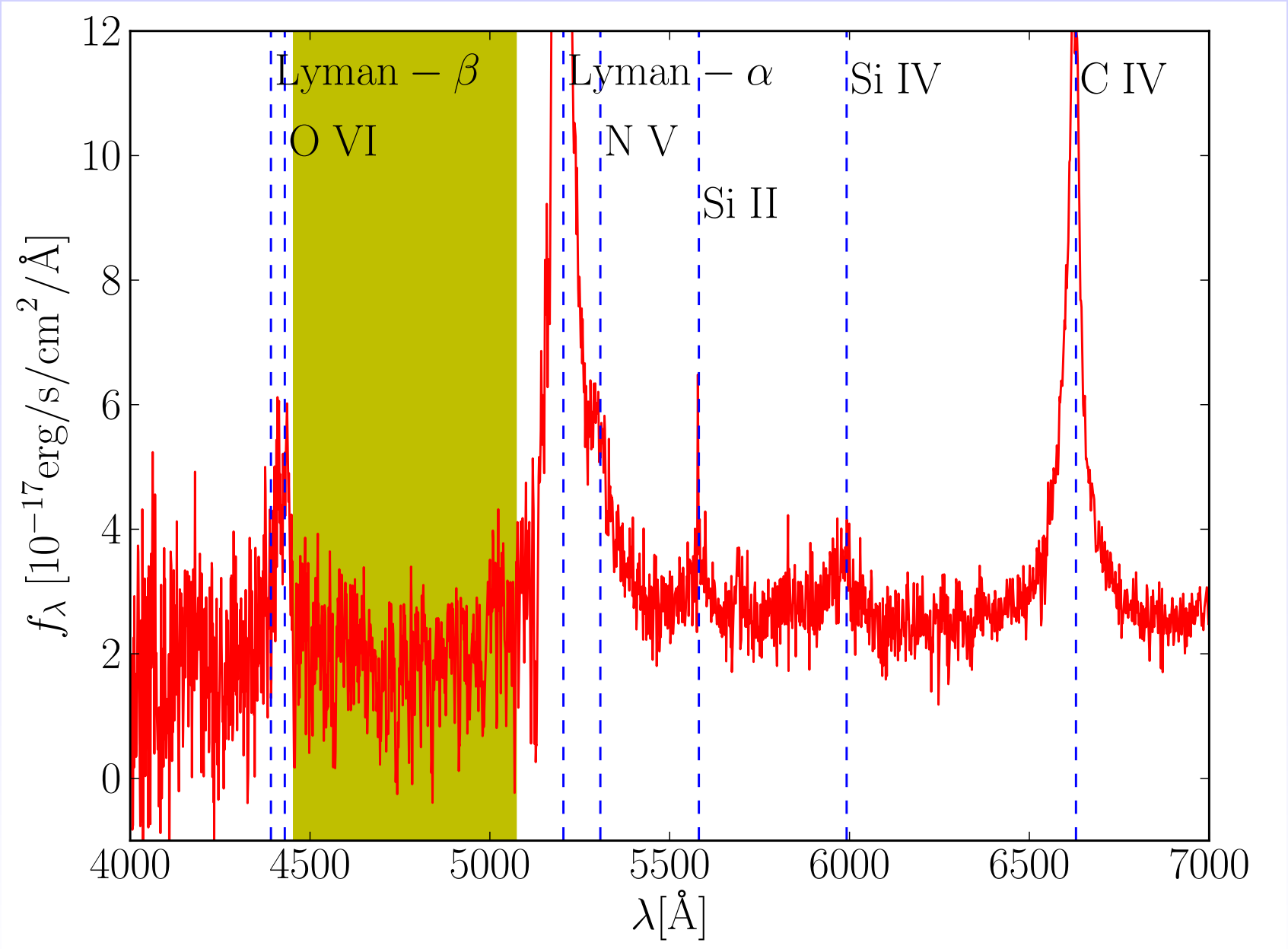
Neutral hydrogen absorbs light from distant quasars blue-ward of Lyman-α emission.

Lyman-α forest



Neutral hydrogen absorbs light from distant quasars blue-ward of Lyman-α emission.

BOSS spectra



From baryons to flux

Absorption done by neutral hydrogen in photo-ionization equilibrium:

$$\Gamma n_{\rm HI} = \alpha(T) n_p n_e \tag{1}$$

$$n_{\rm HI} = \frac{\alpha(T)\rho_b^2}{\Gamma} \ll 1 \tag{2}$$

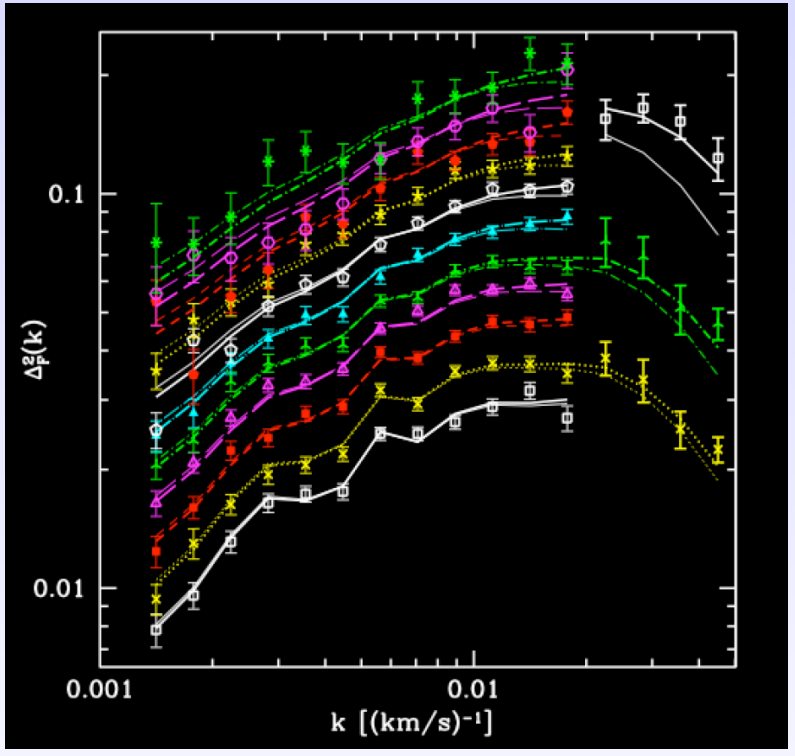
and so the absorbed flux fraction is given by

$$f = \exp(-\tau) \sim \exp\left(-A(1+\delta)^{1.7}\right) \tag{3}$$

What we are observing is a very non-linear transformation of the underlying density field.
On large scales this is simply a biased tracer. On small scales physics can be understood from first principles.

1D vs 3D

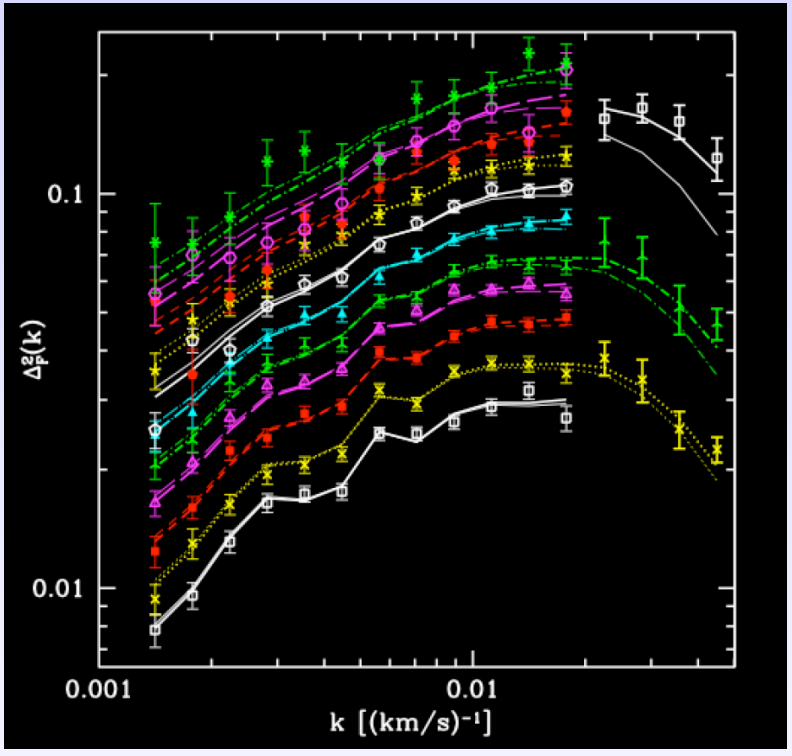
- Lyman-α forest is mapping the Universe through a very weird window function
- Historically: few and far apart high SNR measurements
- Quasars can be assumed independent in that limit: measure the 1D power spectrum of flux fluctuations
- With SDSS12: resolution down, noise up, quasar number up (from few tens to 15,000), but limited to 1D
- With SDSS3: resolution down, noise up, quasar number up (to 160,000): can finally measure correlations in three dimensions.



1D vs 3D

Power spectrum of Lyα measures:

- small scales (1D, $\sim 0.1\ \mathrm{Mpc/h}$): Effects of warm dark matter, sterile neutrinos, etc.
- medium scales (1D, $\sim 1\ \mathrm{Mpc/h}$): Inflation models, masses of light neutrinos, etc.
- large scales (3D, $> 10\ \mathrm{Mpc/h}$): Baryonic acoustic oscillations (dark energy, curvature of the universe), etc.



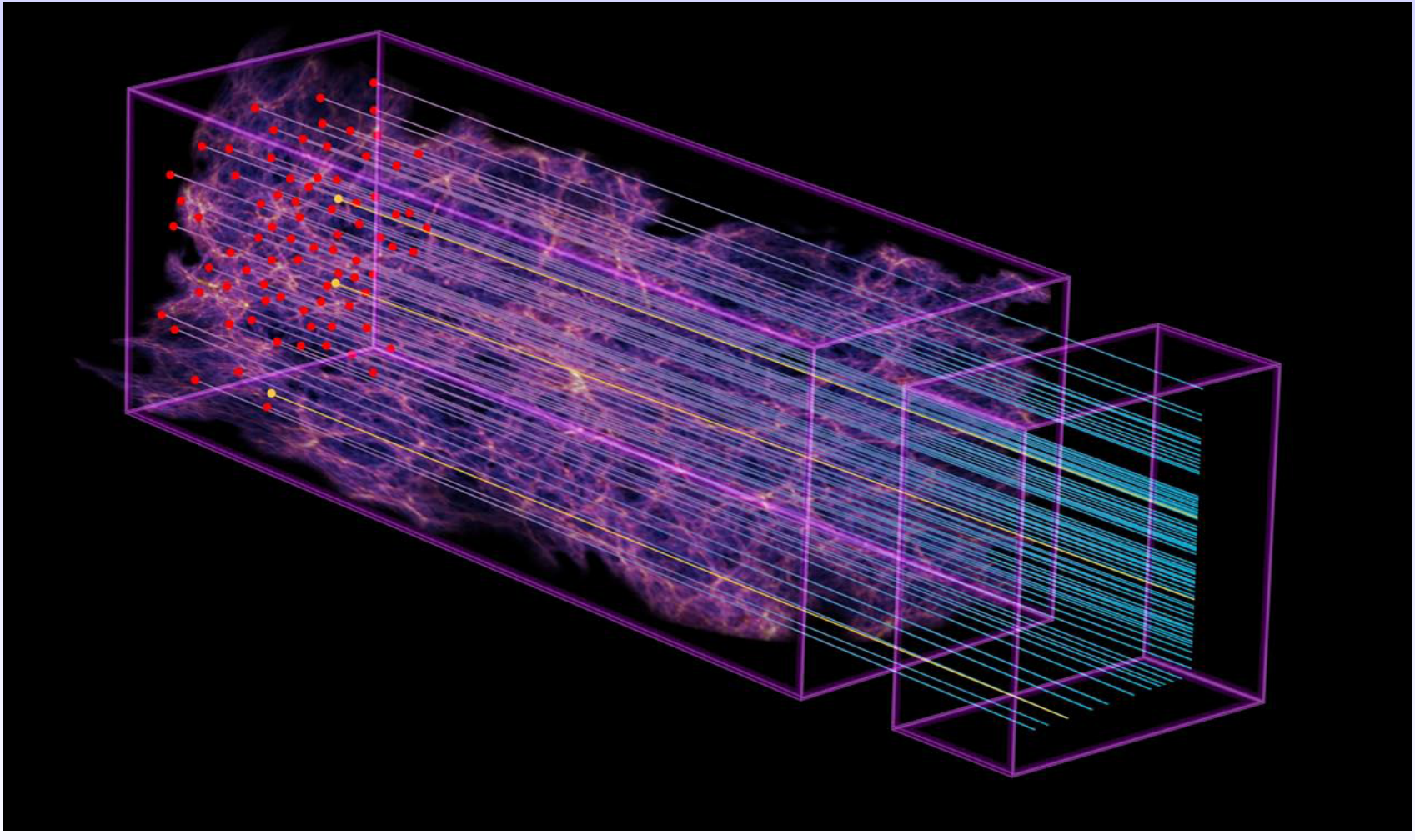
Baryon Oscillation Spectroscopic Survey (BOSS)

- BOSS is one of 4 experiments making up SDSS3.
- Uses 2.5m SDSS telescope
- Large etendue
- A 1000 fiber spectrograph
- Medium resolution: $R \sim 2000$
- Wavelength: 360nm (UV) 1000 nm (IR)

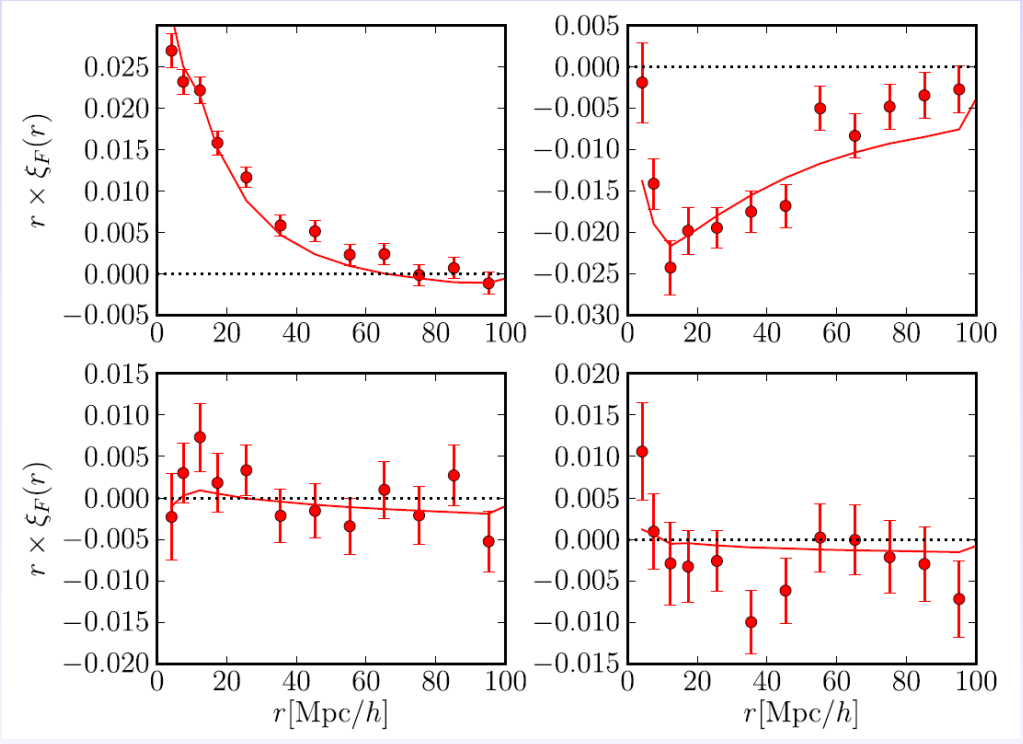
History of BOSS Lyman-α

- Nobody has done 3D Lyman-α to cosmological scales before BOSS
- We published first proof-of-concept paper in 2011
- Two papers with Lyman-α forest BAO appeared recently:
  - Busca et al paper: `arXiv:1211.2616`
  - Slosar et al apper: `arXiv:1301.3459`

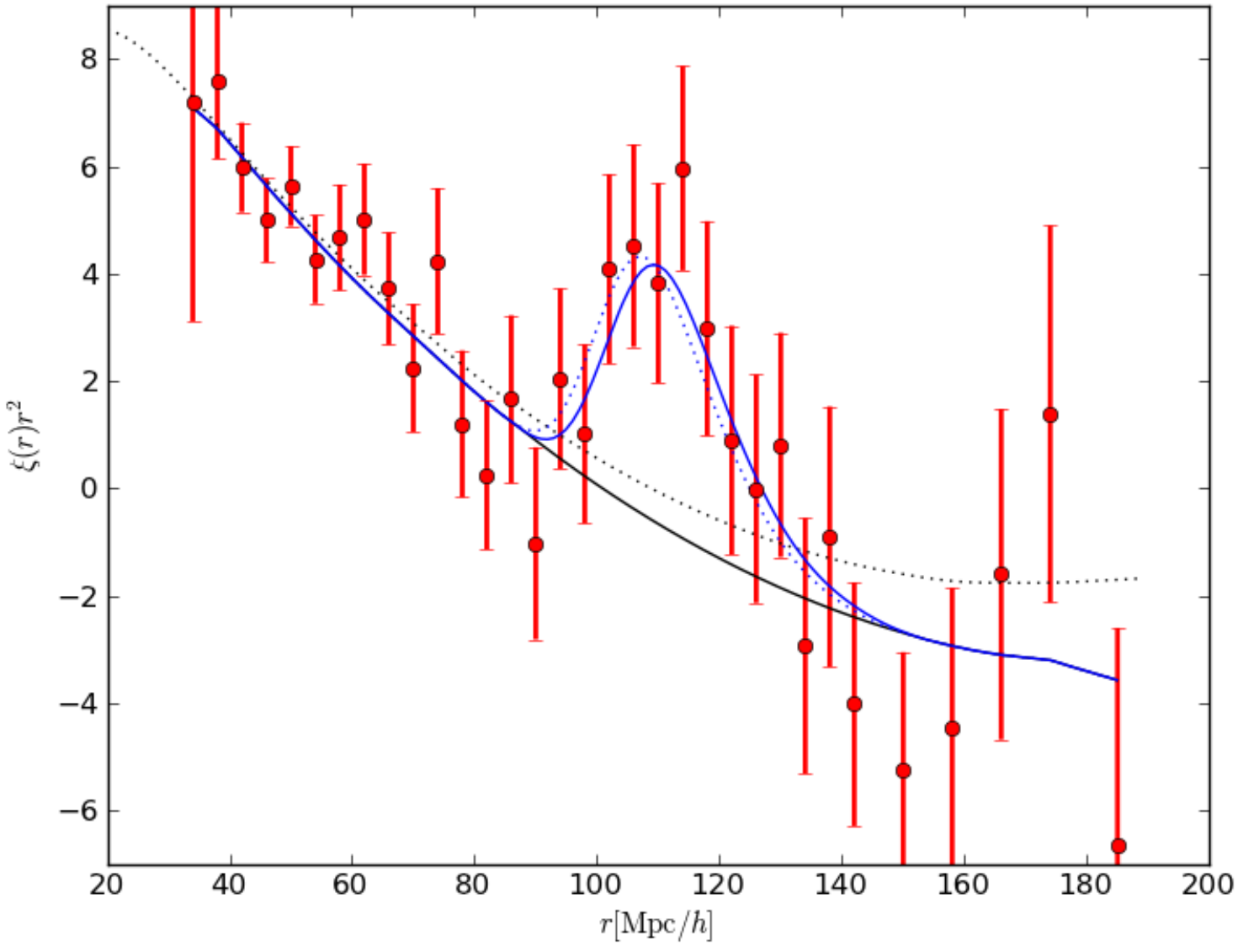
3D sampling of the universe



The 2011 analysis: ξ push



- Clear detection of correlations with no significant contamination
- The measured correlation function is distorted due to continuum fitting
- Analysis is harder than galaxy analysis:
  - Redshift-space distortions always matter
  - Redshift-evolution does matter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20
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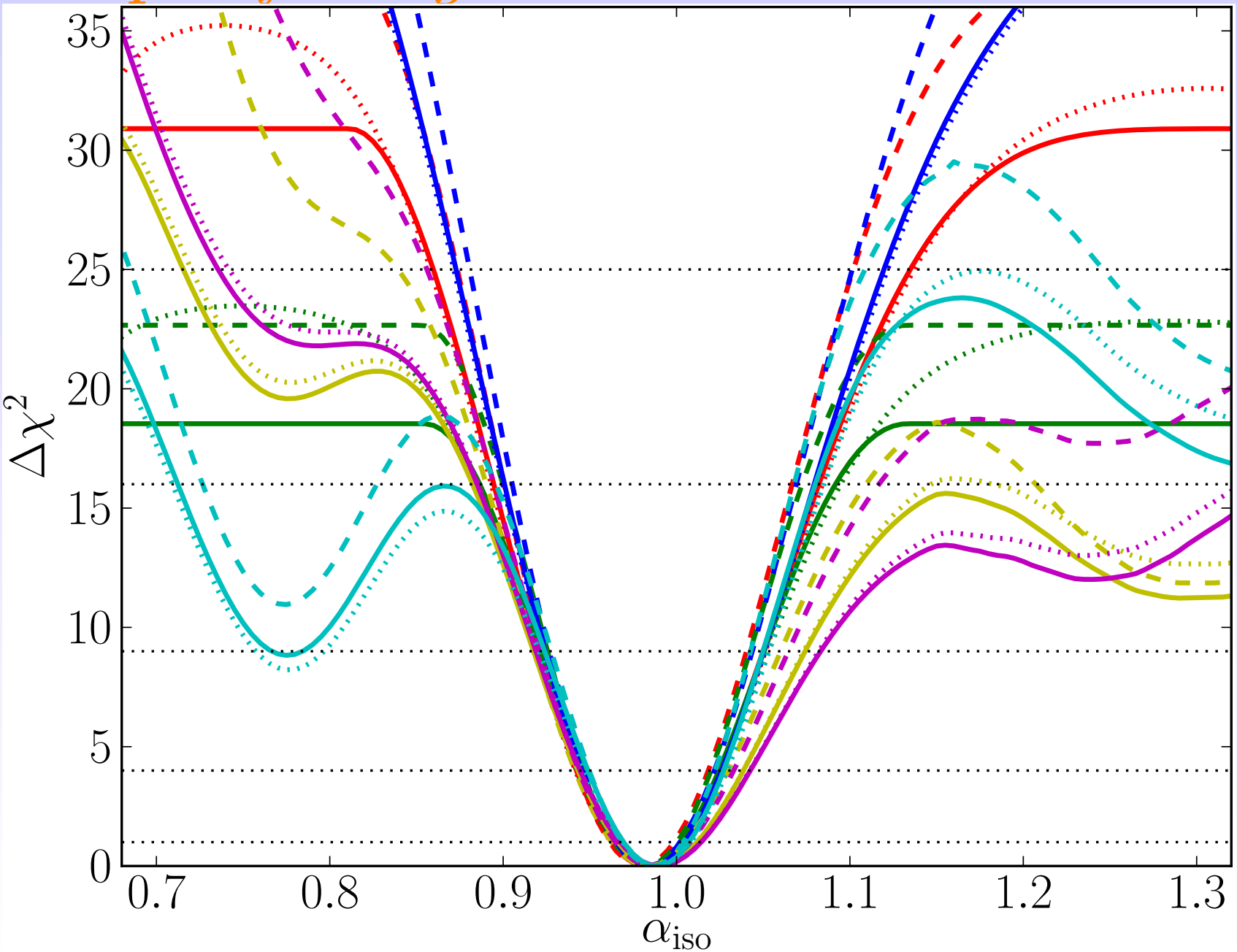
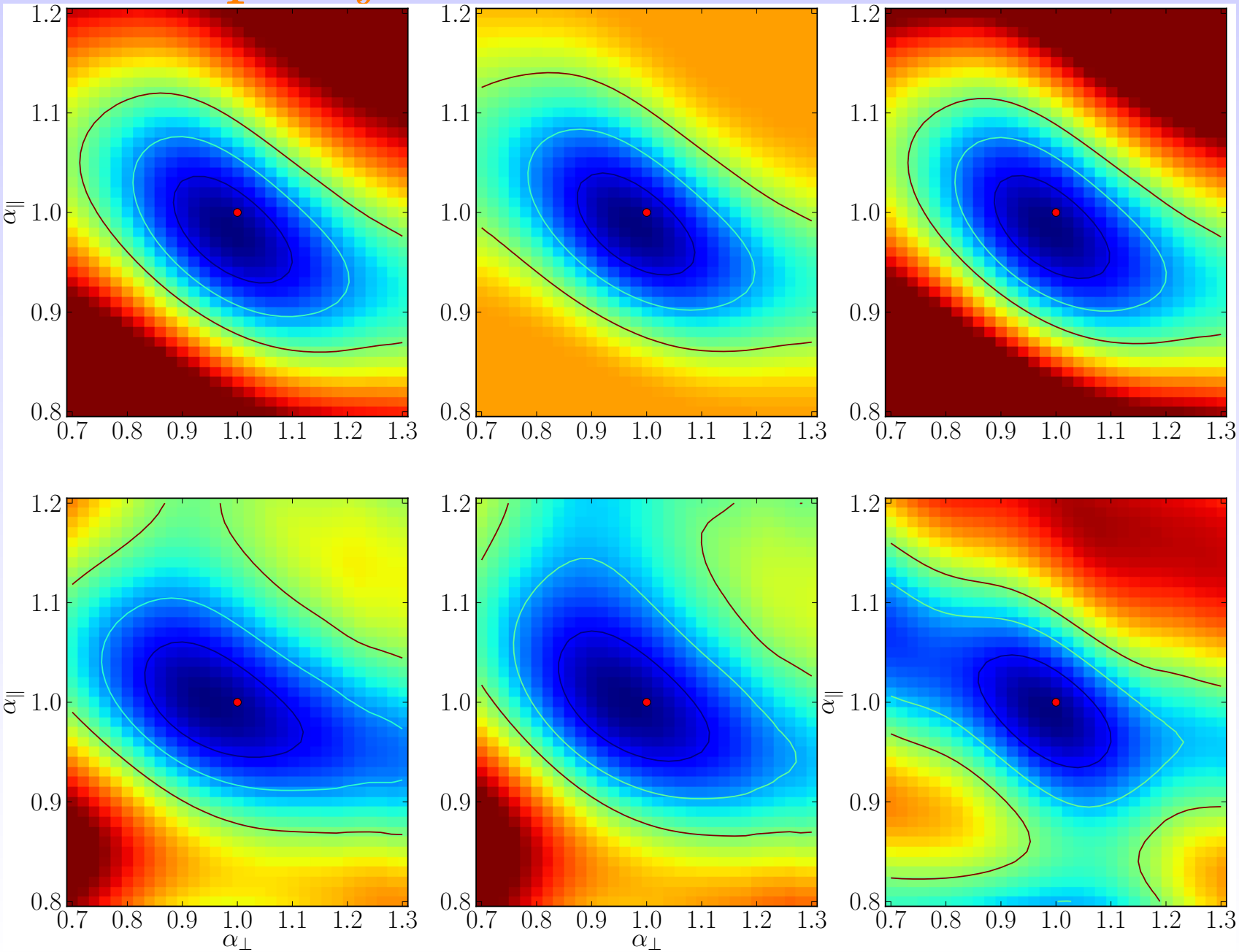
$\xi(r)r^2$
$r[\mathrm{Mpc}/h]$

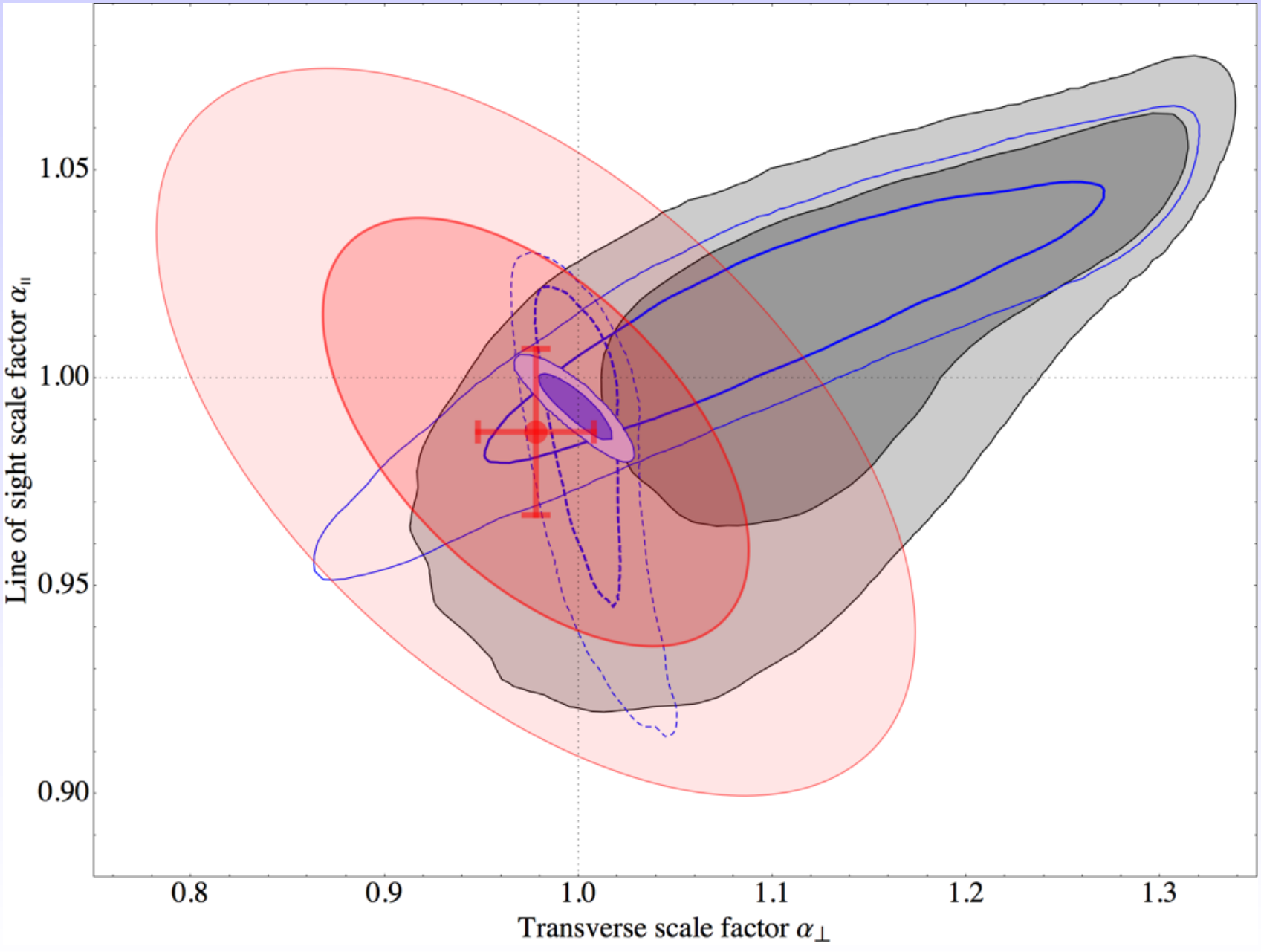
Isotropic fitting: real data



Anisotropic fit with data



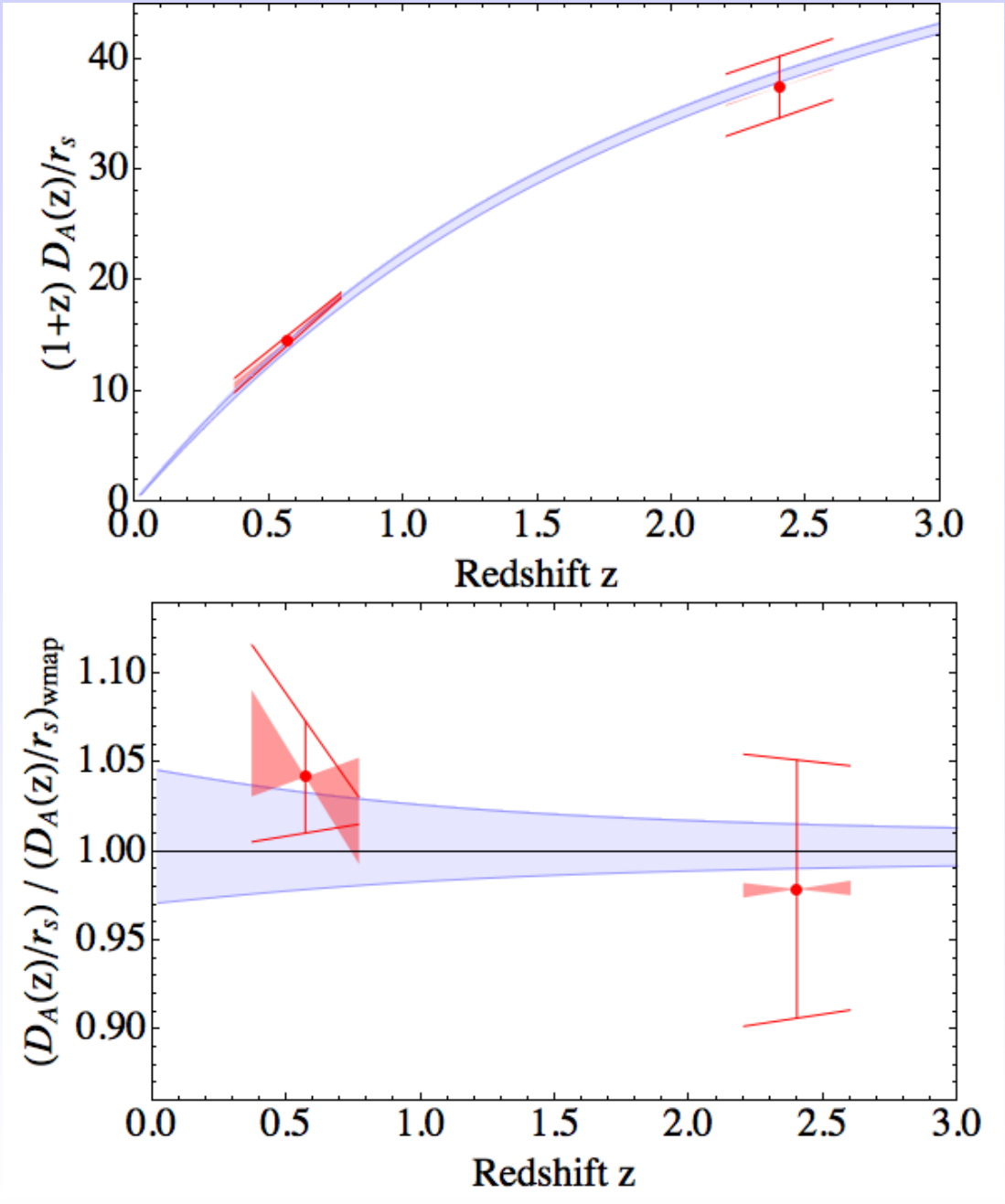
Cosmology fits



Distance plot

A cunning plot:

- Error-bars are distance errors
- bow-ties are Hubble-parameter measurements at central value: i.e. slopes
- Slanting of upper and lower errorbar is the correlations between parallel and perpendicular direction measurement.



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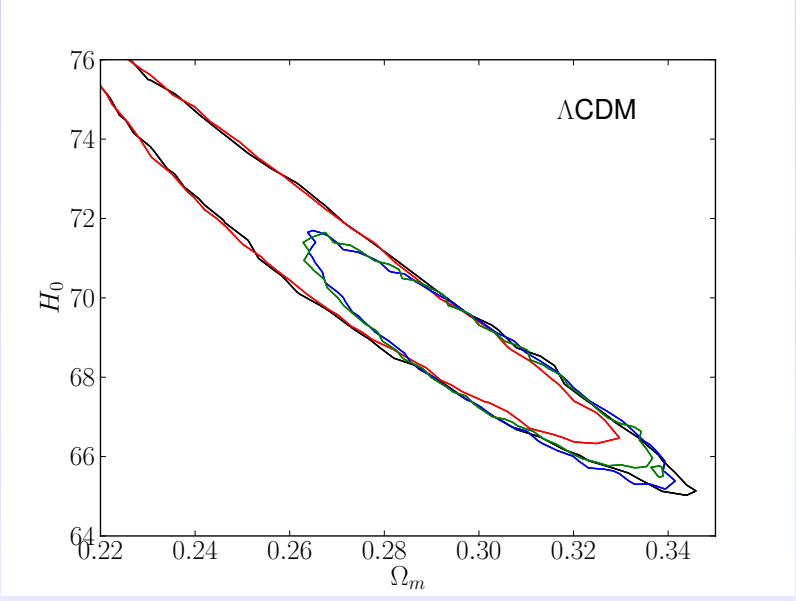

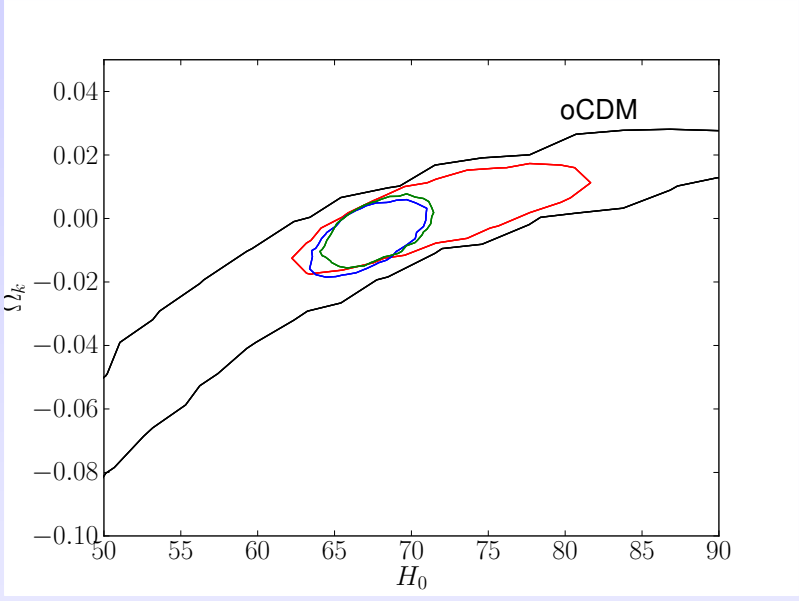

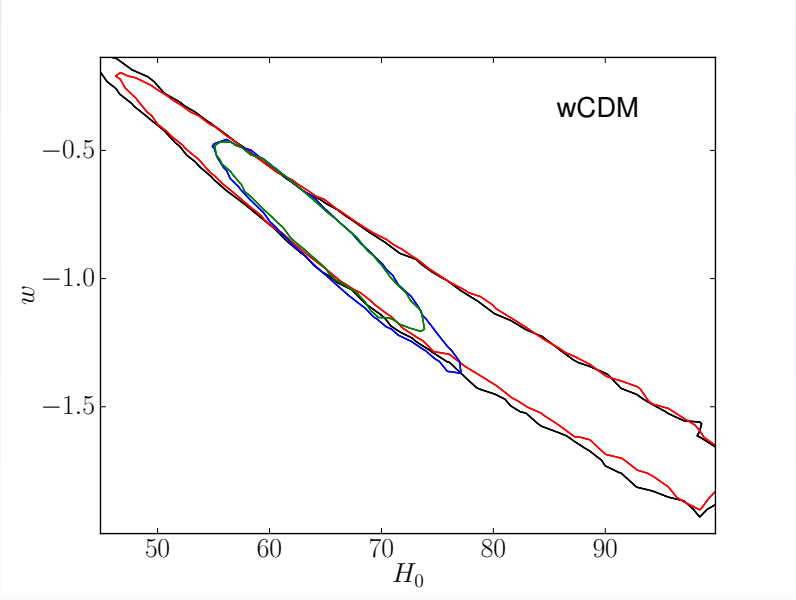

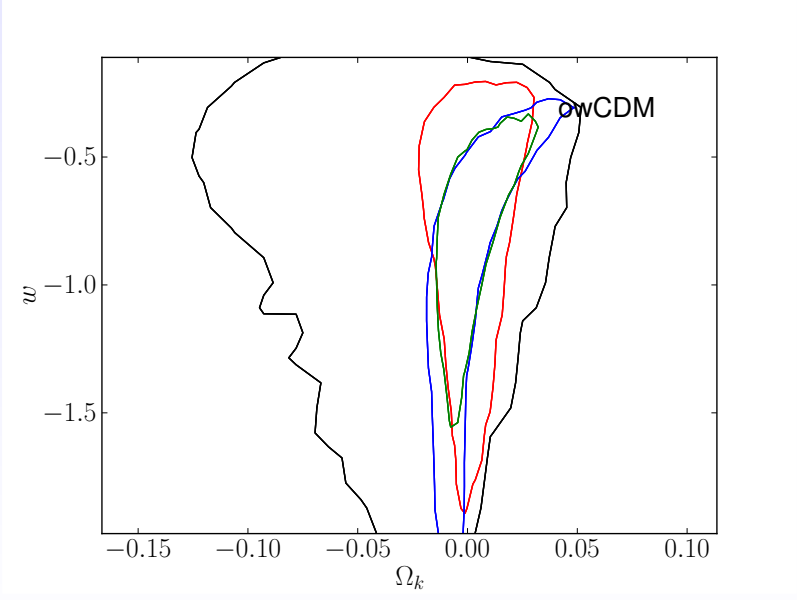

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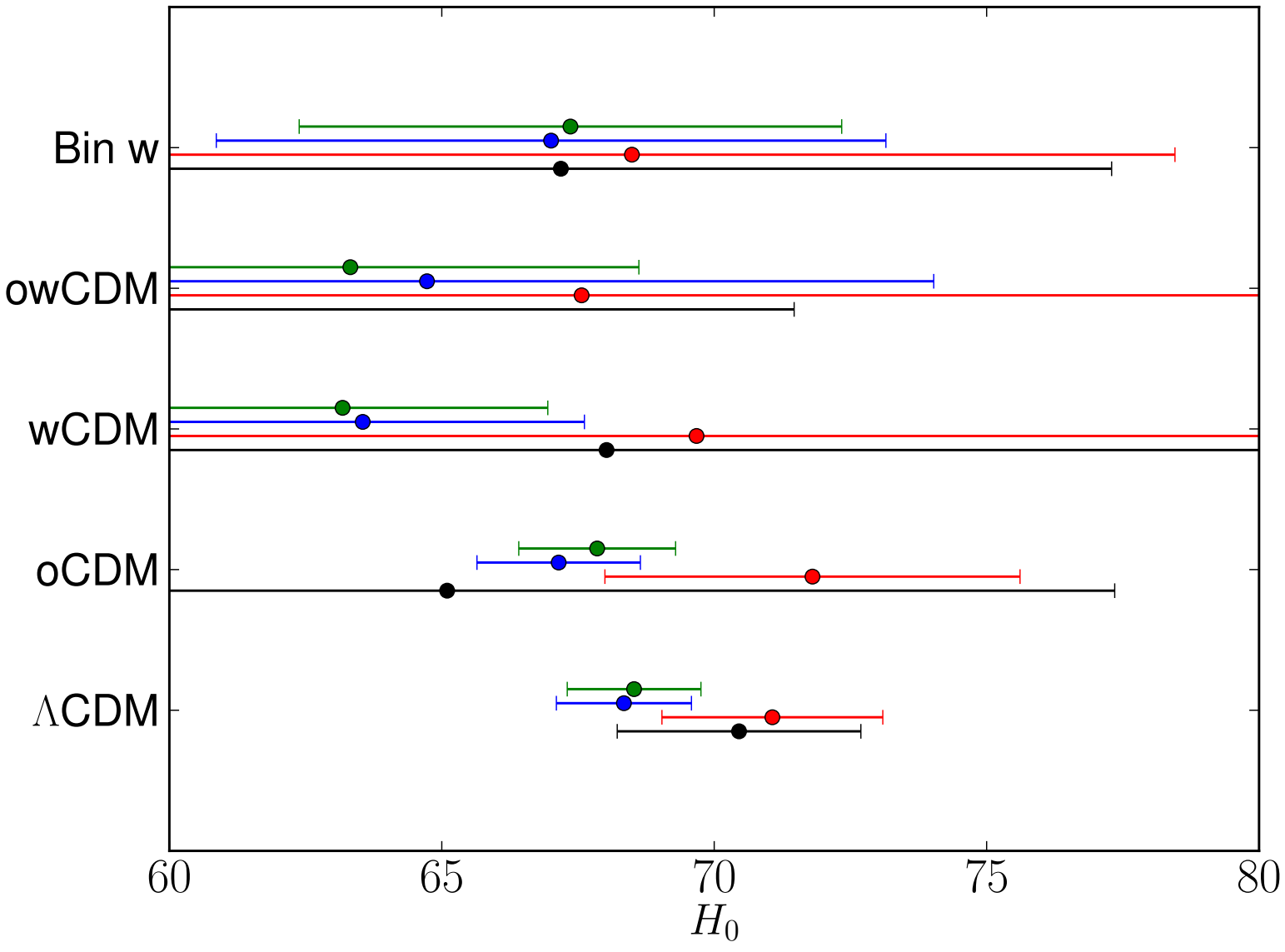
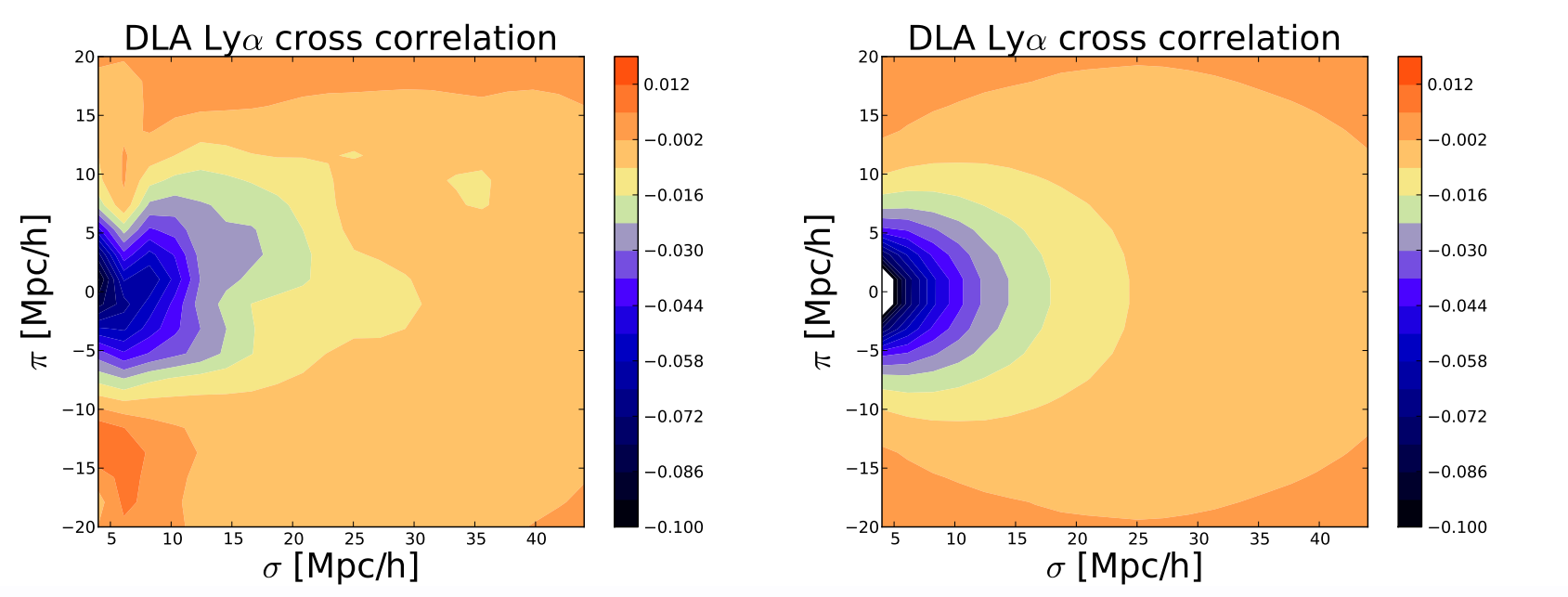


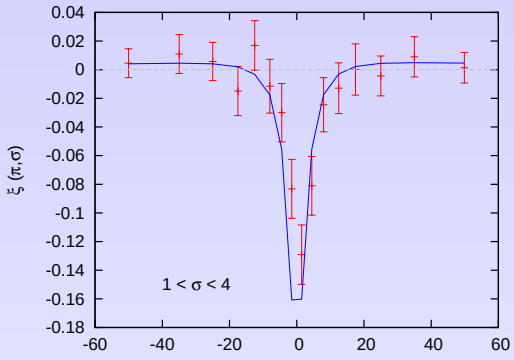
Cross-correlations: DLA-forest

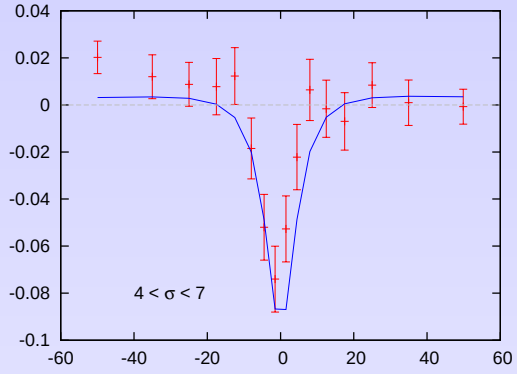
This is in the forest-forest cross-correlation. But we can do other correlations too:

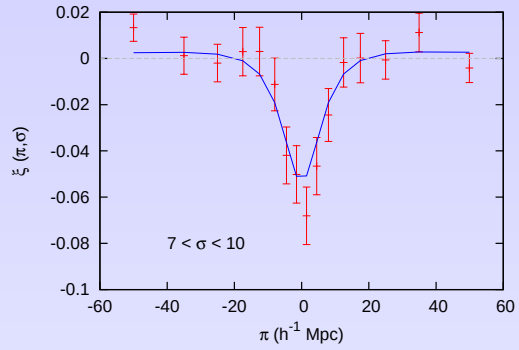
- 7458 DLAs in $2 < z < 3.5$ in DR9
- `arxiv:1209.4596`, Font-Ribera et al.
- $b_D = (2.17 \pm 0.20)\beta_F^{0.22}$, considerably higher than models predict

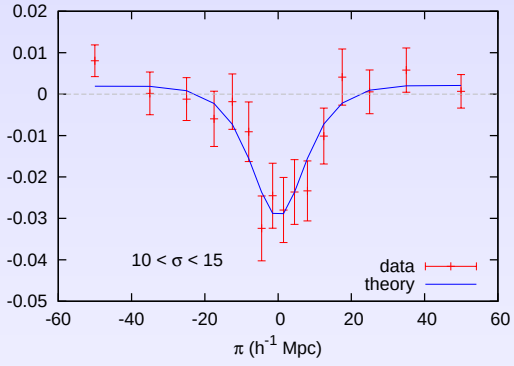


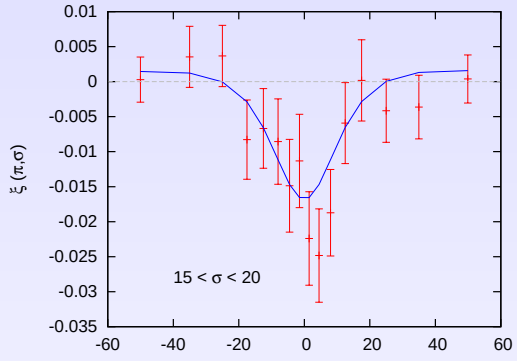
Cross-correlations: DLA-forest

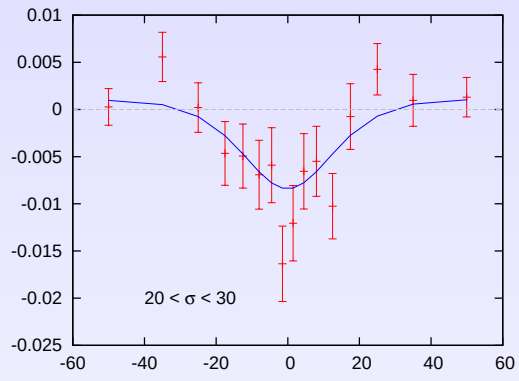


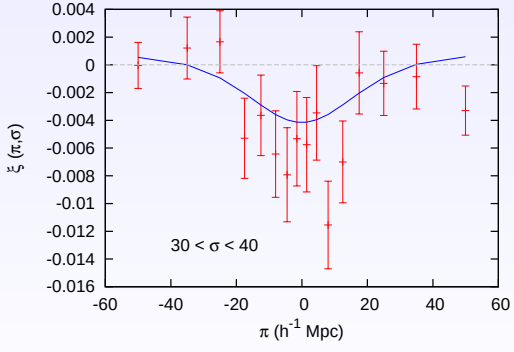


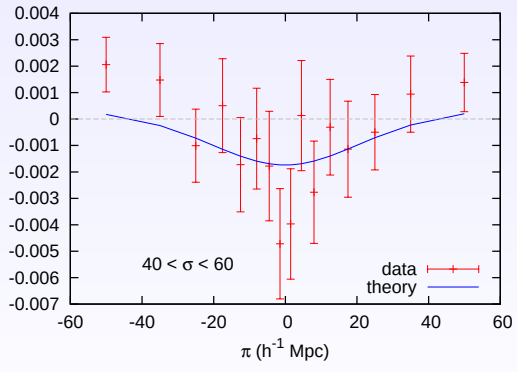








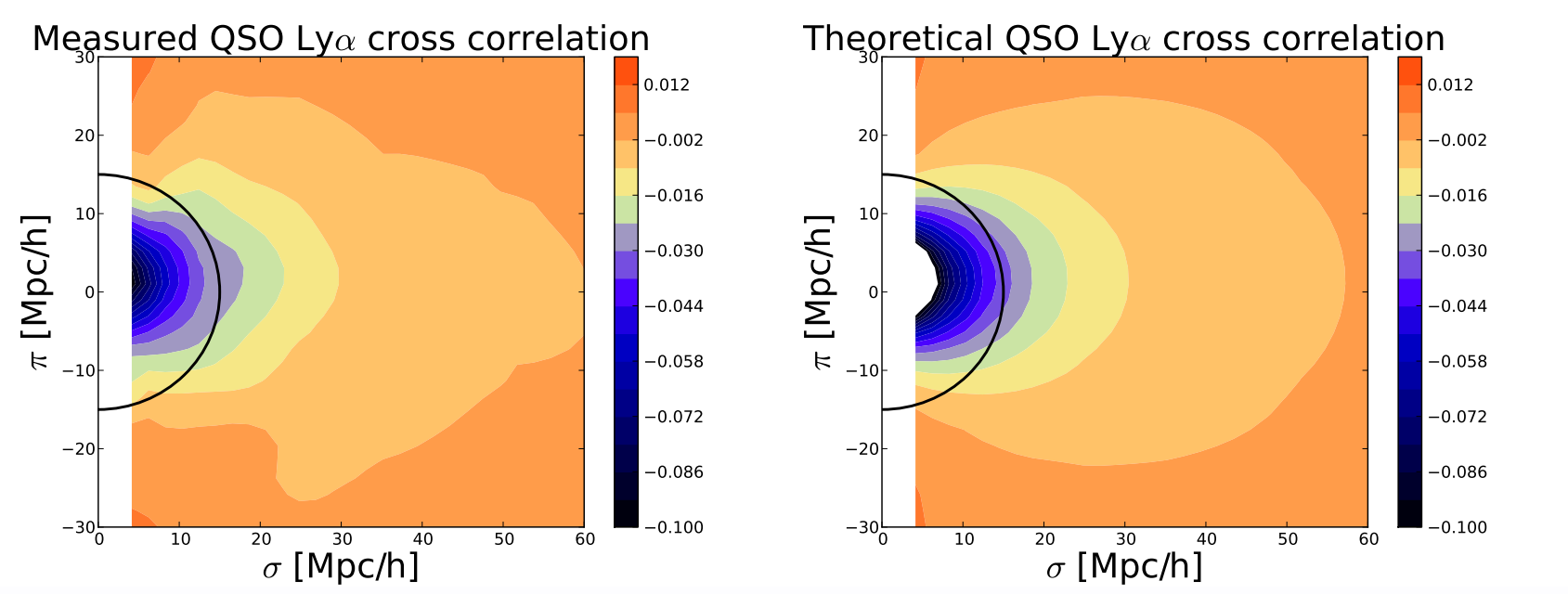




Cross-correlations: QSO-forest

This is in the forest-forest cross-correlation. But we can do other correlations too:

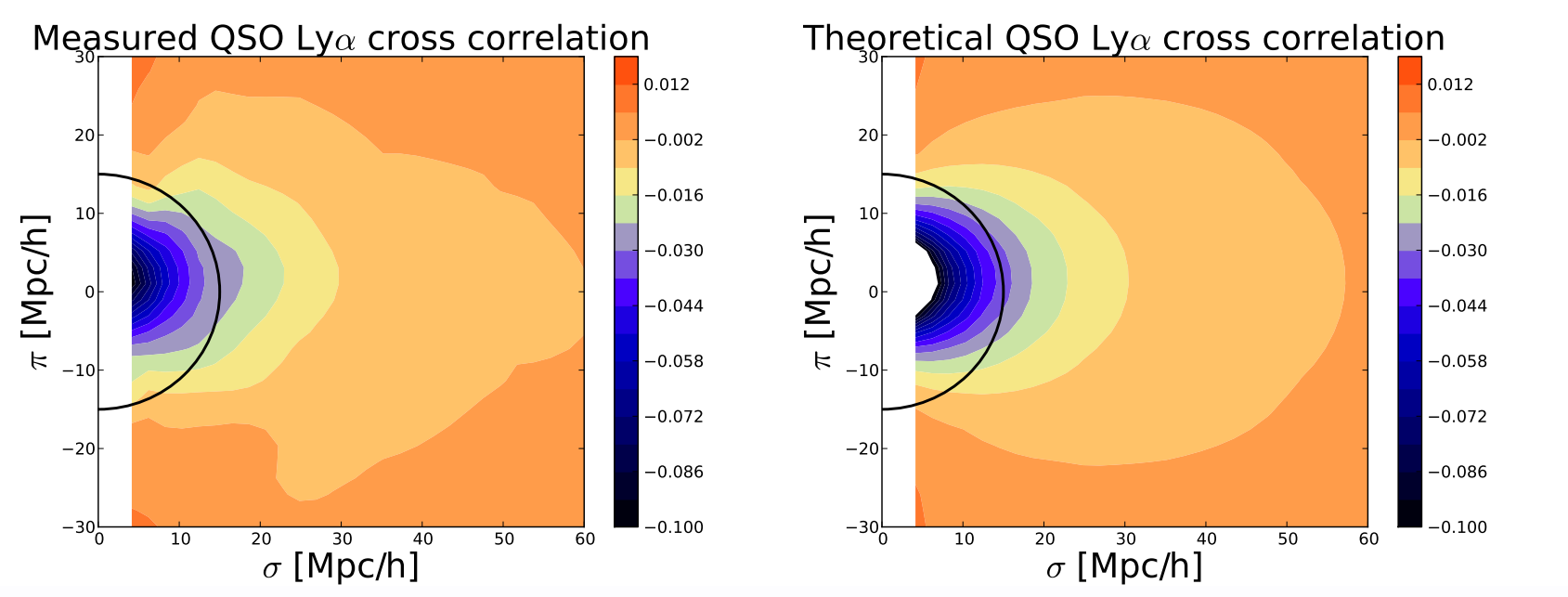
- 60,000 QSOs in $2 < z < 3.5$ in DR9
- Font-Ribera et al., in preparation
- Assuming our bias, they measure $\beta_F = 1.1 \pm 0.15$, $b_q = 3.64^{+0.13}_{-0.15}$



Cross-correlations: QSO-forest

This is in the forest-forest cross-correlation. But we can do other correlations too:

- The simple linear model fails at separations $r < 15\mathrm{Mpc}/h$
- A clear detection $\Delta z = -160 \pm 40$ (non zero even for z_{MgII} at 2σ)
- Should be able to see BAO by end of BOSS !!



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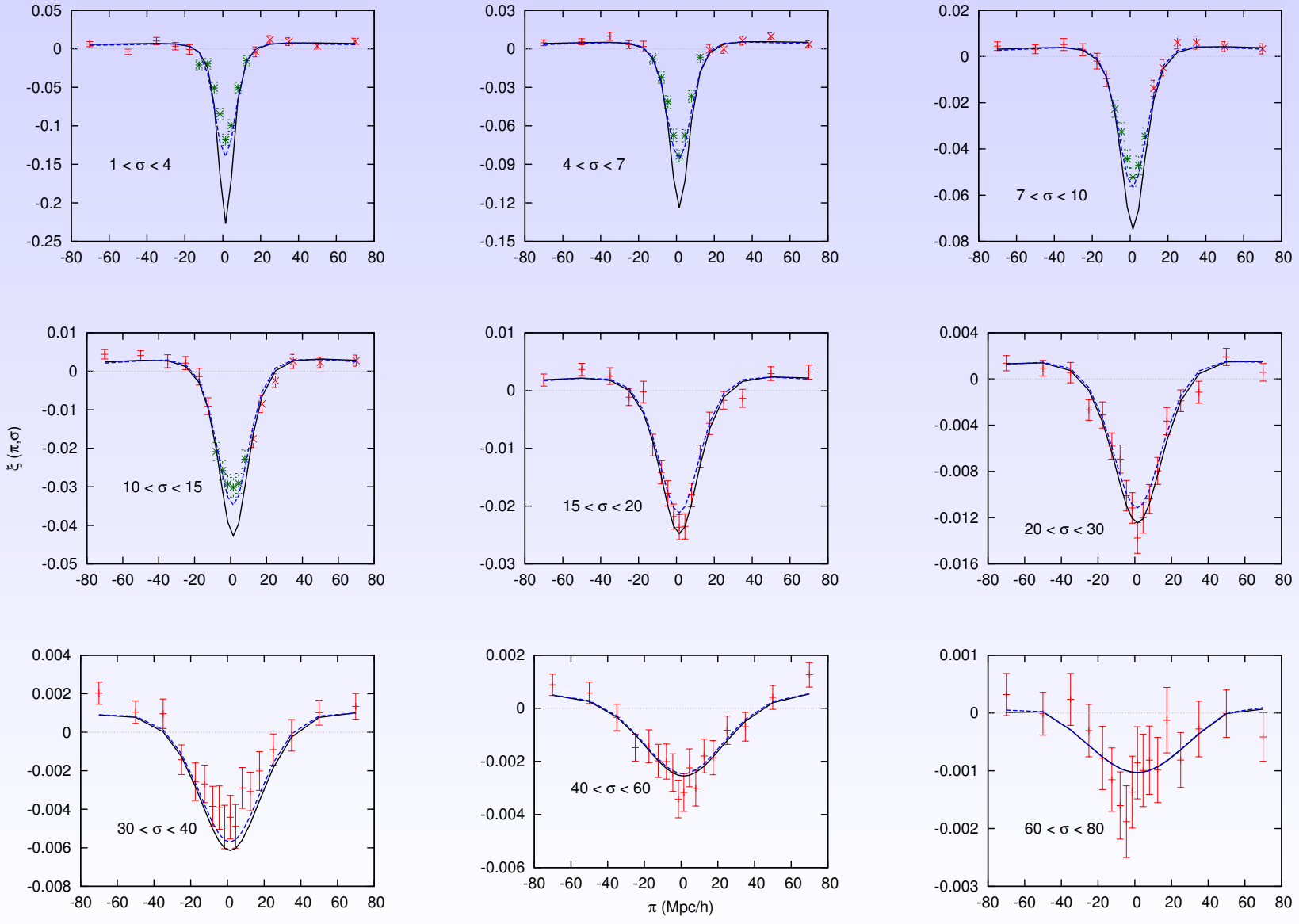
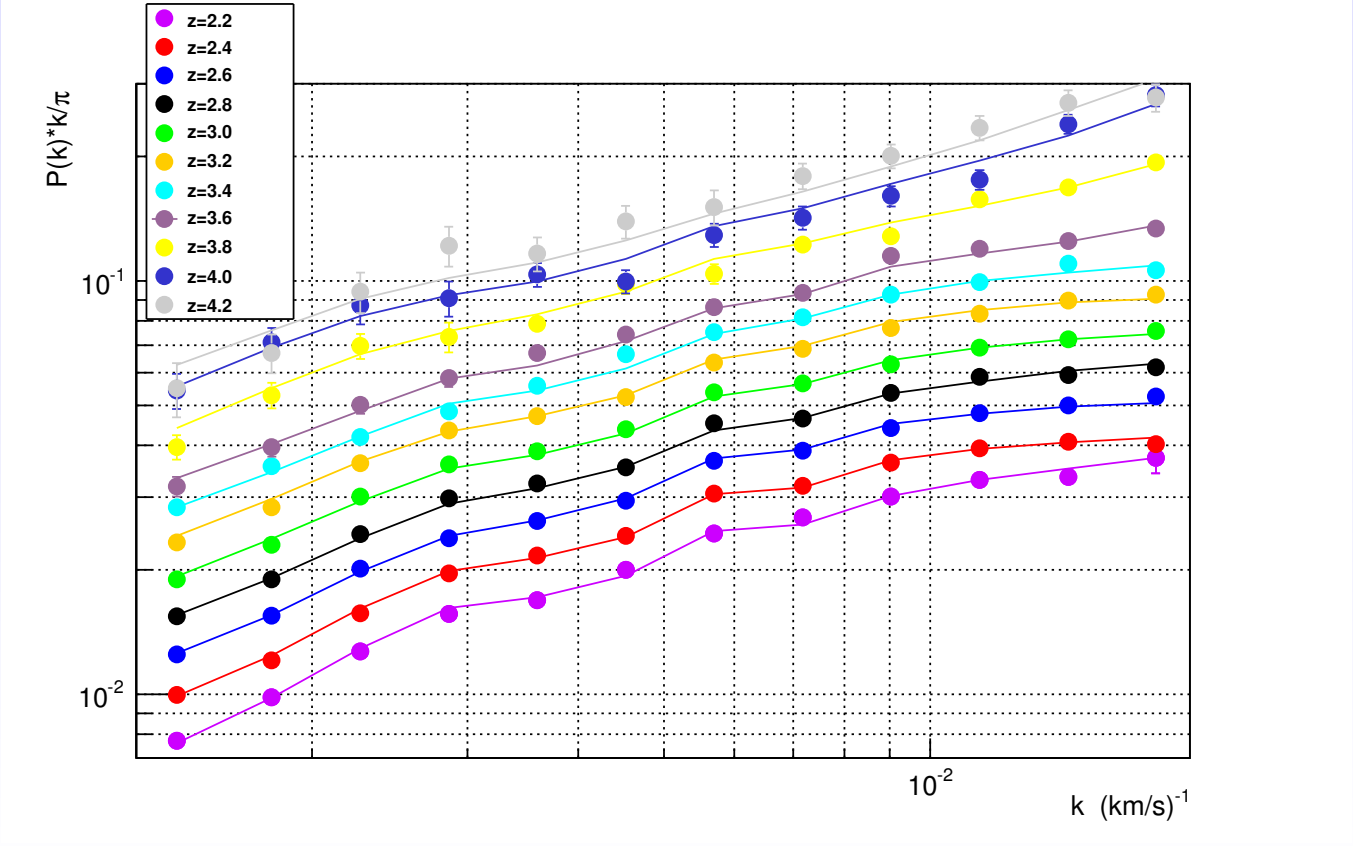


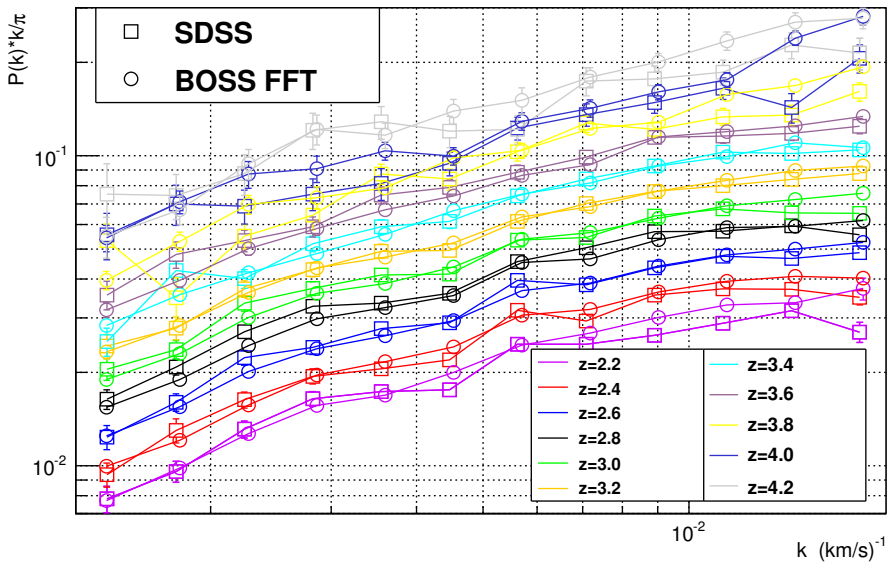
1D power spectrum from BOSS

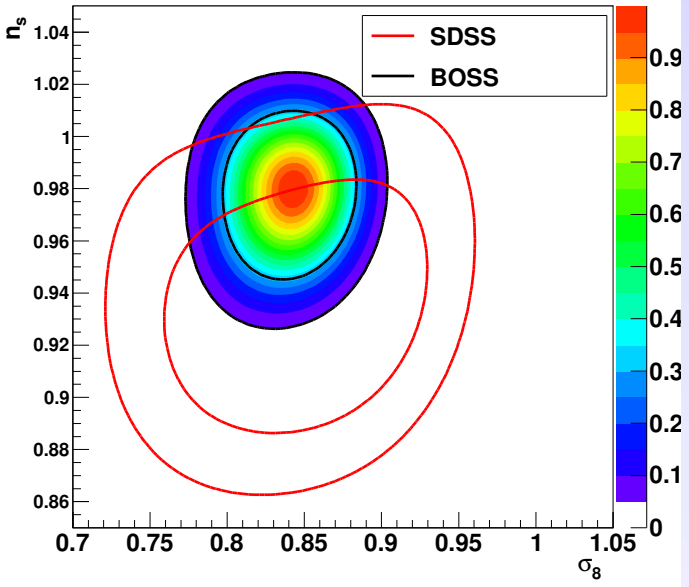
- Work done by Saclay group
- Doing very good, very careful work
- Selected $\sim 14,000$ quasars from $\sim 90,000$
- Using two methods: the FFT and likelihood maximization

PRELIMINARY



1D power spectrum from BOSS





PRELIMINARY

Lyman-β forest

Why do we want to add Lyβ:

- The absorption cross section for Lyβ is smaller: $\sigma_\beta = \sigma_\alpha/5.27$
- Lyβ forest measurements would be more sensitive to higher density and temperature where Lyα is saturated
- Increasing the effective path length in Lyα forest by nearly 20%

Transmitted flux:

$$F = \exp\left[-\tau\right] = \bar{F}\left(1+\delta_F\right) = \bar{F}_\alpha \bar{F}_\beta \left(1+\delta_\alpha\right)\left(1+\delta_\beta\right)$$

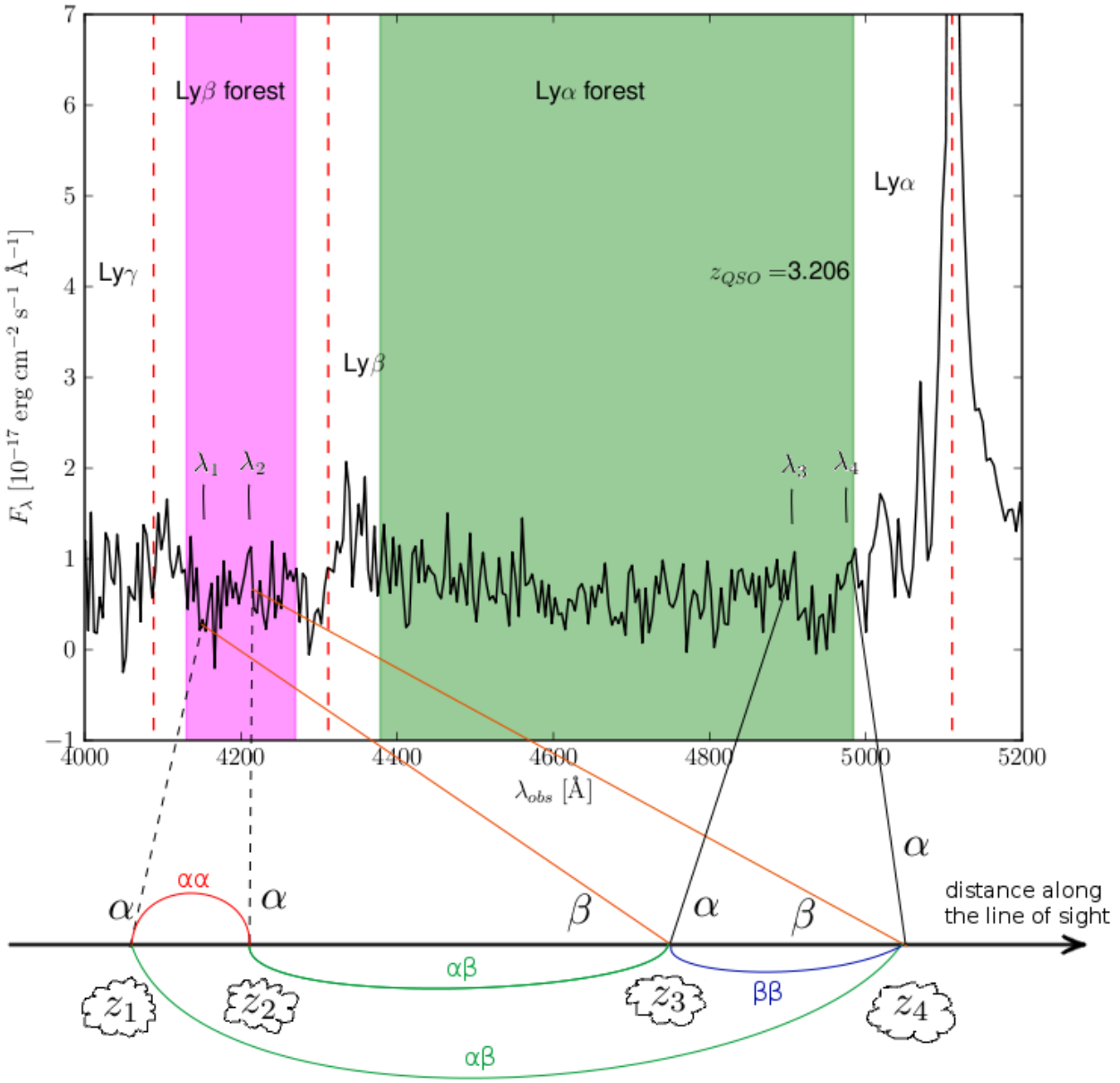
In the linear approximation

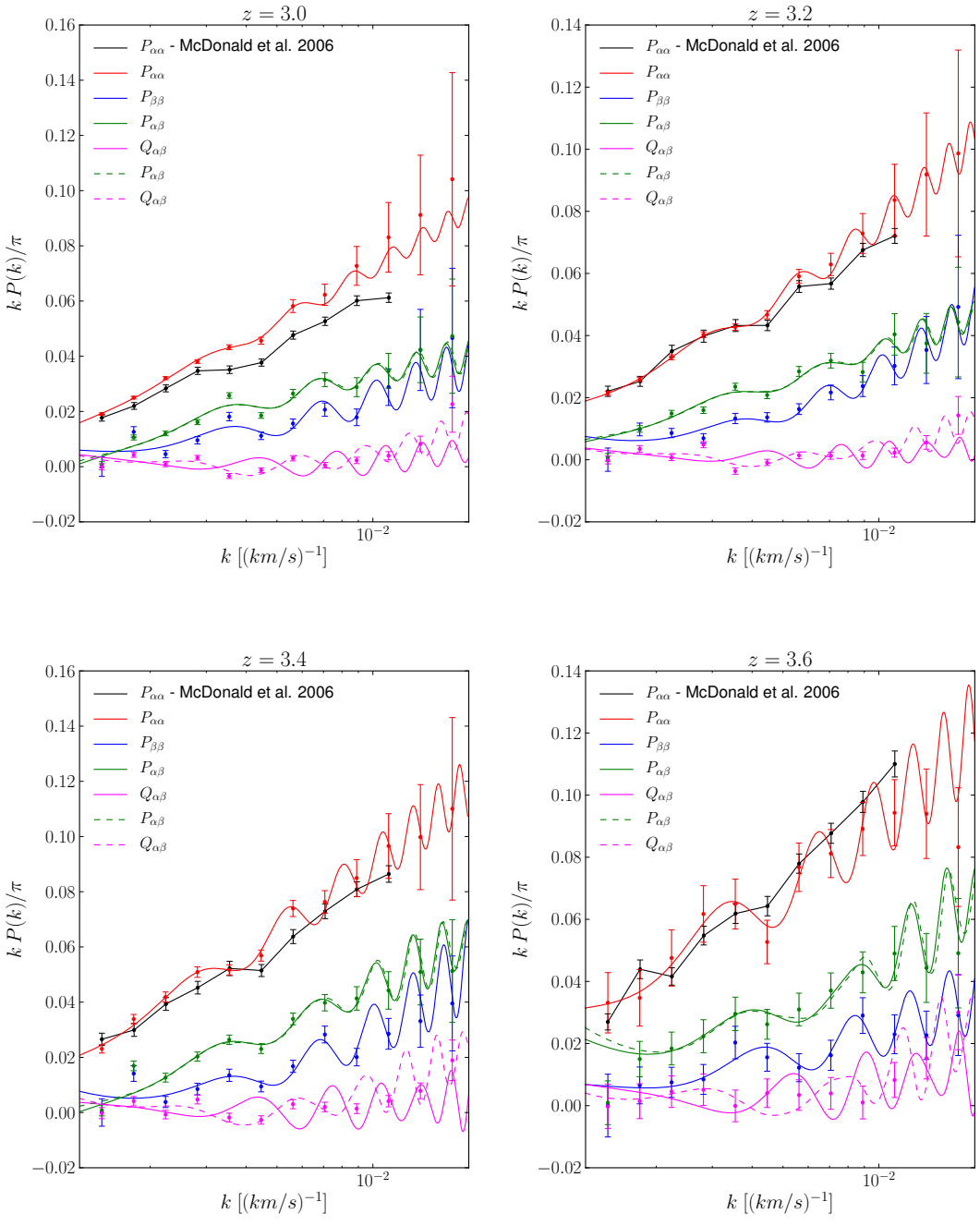
$$\delta_F = \delta_\alpha + \delta_\beta + \delta_\alpha\delta_\beta$$

The cross correlation of two evolving fields yields both real and imaginary parts to the cross power spectrum $P^{tot}_{\alpha\beta} = P_{\alpha\beta} + iQ_{\alpha\beta}$

$$\xi_{\alpha\beta}(x,z) = \frac{1}{\pi}\int_0^\infty \left[P_{\alpha\beta}(k,z)\cos\left(kx\right) - Q_{\alpha\beta}(k,z)\sin\left(kx\right)\right]\, dk$$

Lyman-β forest





Similar to Si3 in Lyman-α , we see O5 in Lyman-β forest

Beyond BAO with MS-DESI

- A lot lies beyond BAO
- 1D power spectrum, but also Lyman-β, bispectra, etc.
- Can do neutrinos:
  - 1-σ errors on $\sum m_\nu$: 0.042eV (Planck+H_0+BBLyα), 0.016 (+BB ELGs), c.f. **guaranteed minimum** $\sum m_\nu$ 0.05
  - 1-σ errors on N_ν: 0.063 (Planck+H_0+BBLyα), 0.049 (+BB ELGs)
- Can do running of spectral index:
  - 1-σ errors on α: 0.0023 (Planck+H_0+BBLyα+ELGs) (0.0056 ELGs alone)
  - Approaching $\sim (n_s - 1)^2 \sim 0.002$

Conclusions

- BOSS Lyman-α forest analysis progressing well
- FPG made great progress in measuring 1D power spectrum, we want to do something similar in 3D
- Much remains to be done regarding simulations
- Many other measurements possible: cross-correlations, 1D power spectra, Lyman-β forest, higher order correlations,...
- BigBOSS will allow more of the same at unprecedented precision
- Neutrino masses and running of spectral index particularly interesting