Measuring the BAO scale with the Lyα and Lyβ regions: last results from eBOSS

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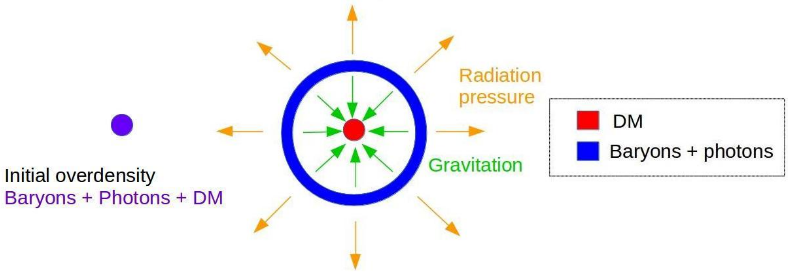
Outlines

- What are the Baryonic Acoustic Oscillations (BAO) and how they can be used to measure the expansion ?
- The eBOSS experiment
- Measuring the BAO with the quasar Lyα forests : last results from eBOSS

What are the Baryonic Acoustic Oscillations (BAO) ?



- The **competition between gravitation and radiation pressure** creates the baryonic acoustic oscillations in the primordial plasma, that propagates in the expanding Universe.
- At **recombination**, these oscillations **freeze**.
- Since recombination, the BAO scale has **evolved only with the expansion** of the Universe.

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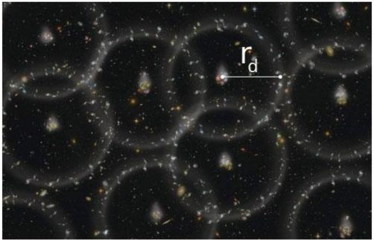
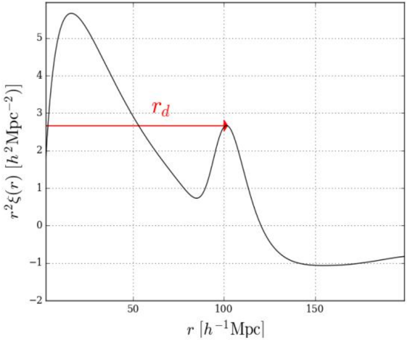
How can we measure the expansion rate with the BAO ?





- The BAO feature is still **imprinted in the matter distribution in the Universe**.
- The BAO peak is measurable as a **small excess in the matter 2-point correlation function at 100 h^{-1}Mpc**.
- We need to probe **large volume** with **sufficient density tracers** to detect it.

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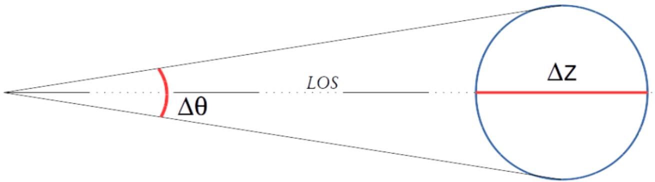
How can we measure the expansion rate with the BAO ?



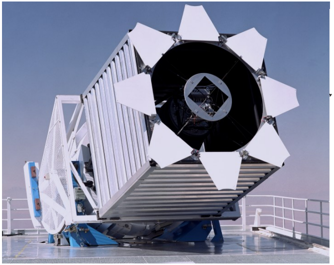
$$\left.\begin{array}{l}\Delta z \longrightarrow D_H(z^{\text{meas}}) = r_d \Delta z = \frac{c}{H(z^{\text{meas}})} \\ \Delta\theta \longrightarrow D_M(z^{\text{meas}}) = r_d \Delta\theta = \int_0^{z^{\text{meas}}} \frac{cdz}{H(z)}\end{array}\right\} \longrightarrow (\Omega_M, \Omega_\Lambda)$$

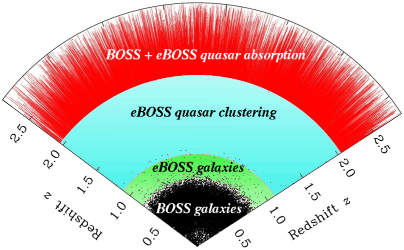
At recombination, the BAO scale was :

$$r_d = \int_{z_{\text{dec}}}^{\infty} \frac{c_s dz}{H(z)}. \qquad (1)$$

The extended Baryonic Oscillation Spectroscopic Survey (Jul 2014 - Feb 2019)

- 2.5m telescope at APO, USA
- 1000 fibers per 7-square-degree plate
- Wavelength: 360-1000 nm, resolution $R \sim 2000$
- 475,000 **LRG + ELG** over 6,000 square degrees, $0.6 < z < 1.1$
- 500,000 **quasars** over 6,000 square degrees, $0.8 < z < 3.5$
- 1-2% distance measurements between $0.6 < z < 2.5$





The Lyα absorption as mass tracers

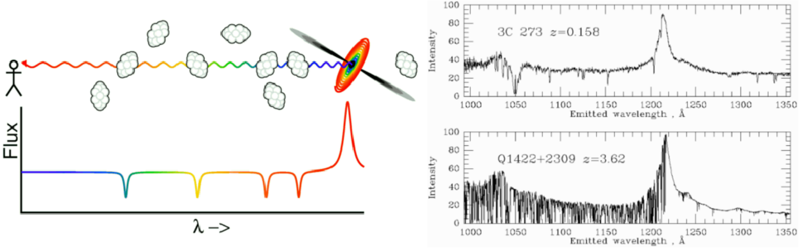


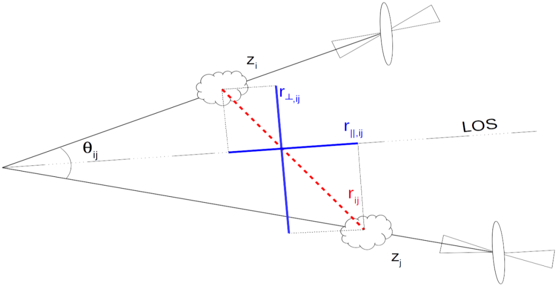
Figure: http://www.astro.ucla.edu/wright/Lyman-alpha-forest.html

- The matter is traced by the **absorption seen in quasar spectra**.
- **Continuous** tracer.
- If $\lambda_{Ly\alpha}$ is absorbed at z, it appears on the spectrum at :

$$\lambda_{\text{obs}} = (1 + z)\lambda_{Ly\alpha}$$

Measuring the BAO peak with Lyα forests (de Sainte Agathe et al. (2019)[1], submitted)

$\Longrightarrow$ We **extract the Lyα absorption fields** from the spectra then we compute their **2-point correlation function**:



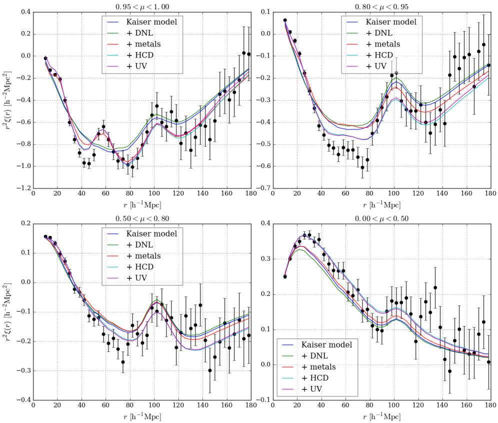
$$\xi(r_\parallel, r_\perp, \alpha_\parallel, \alpha_\perp) = \xi^{\rm smooth}(r_\parallel, r_\perp) + \xi^{\rm BAO}(\alpha_\parallel r_\parallel, \alpha_\perp r_\perp)$$

$$\boxed{\alpha_\parallel = \frac{D_H(\bar{z})/r_d}{[D_H(\bar{z})/r_d]_{\rm fid}} \qquad \alpha_\perp = \frac{D_M(\bar{z})/r_d}{[D_M(\bar{z})/r_d]_{\rm fid}}}$$

[1] https://arxiv.org/abs/1904.03400

Measuring the BAO peak with Lyα forests (de Sainte Agathe et al. (2019)[2], submitted)

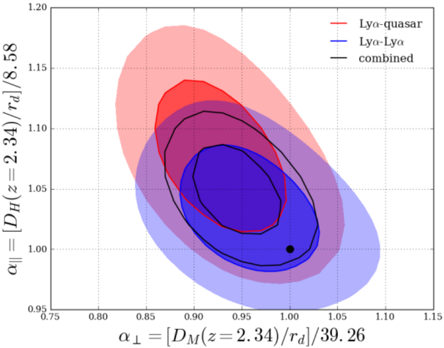
$\longrightarrow$ We have tried several physical and non-physical models for $\xi^{\rm smooth}$ in order to check the **stability** of the $(\alpha_{\parallel}, \alpha_{\perp})$.



[2] https://arxiv.org/abs/1904.03400

Measuring the BAO peak with Lyα forests (de Sainte Agathe et al. (2019)[3], submitted)

QSO$\times$Lyα : Blomqvist et al. (2019), submited

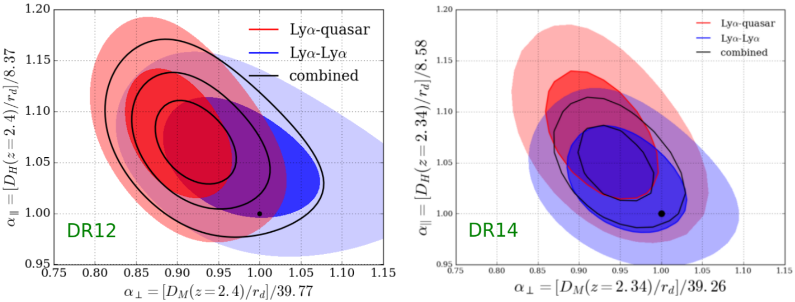


- **Auto** : 1σ from Planck Collaboration (2015).
- **Combined** : 1.7σ from Planck Collaboration (2015).

[3] https://arxiv.org/abs/1904.03400

Measuring the BAO peak with Lyα forests (de Sainte Agathe et al. (2019)[4], submitted)

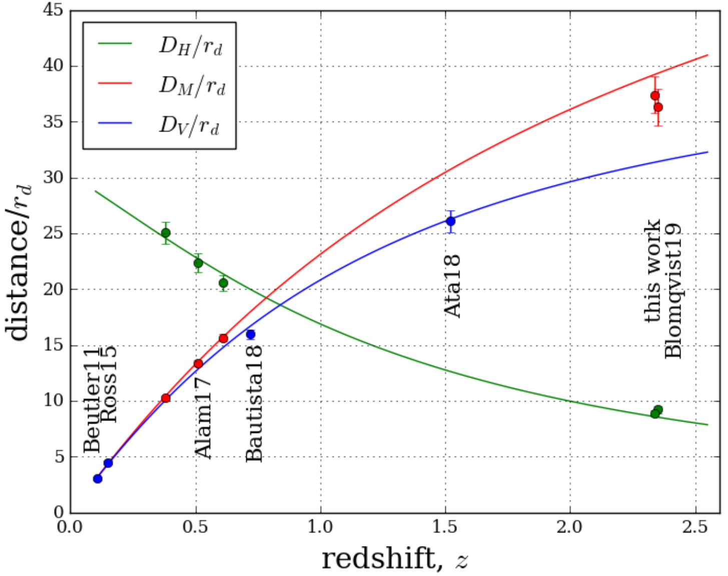
Auto : we have increased by 25% the precision over the measurement of $\alpha_\perp$ compared to Bautista et al. (2017).



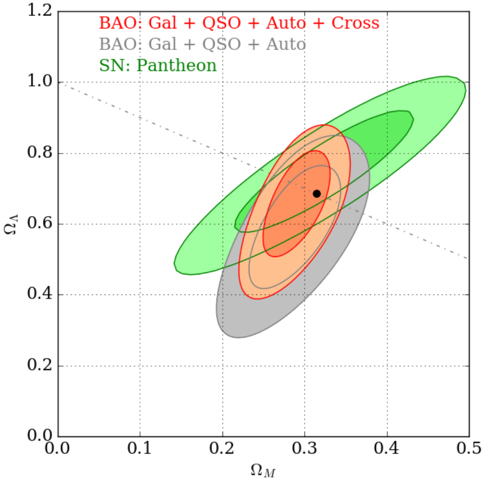
Comparaison to du Mas des Bourboux et al. (2017)

[4] https://arxiv.org/abs/1904.03400

Cosmological constraints with BAO



Cosmological constraints with BAO



$\Omega_M = 0.293 \pm 0.027$ $\qquad$ $\Omega_\Lambda = 0.675 \pm 0.099$

Conclusion

- We have used the $\sim$ **200,000 eBOSS Lyα forests** and added the **Lyβ region** for the first time.
- D_H/r_d is measured with a $\sim 3.3\%$ precision at $z = 2.34$ and D_M/r_d, with a $\sim 4.4\%$ precision .
- The combination of BAO measurements is in **good agreement with the CMB-inspired flat ΛCDM model**. By themselves, the BAO data provide a good confirmation of this model.

What's next ?

- Feb 2020: **last eBOSS results**.
- **DESI** experiment: less than 1% uncertainty at $z \simeq 2.5$.

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