Direct cosmological inference from three-dimensional correlations of the Lyman-\(\alpha\) forest

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ABSTRACT

When performing cosmological inference, standard analyses of the Lyman-\(\alpha\) (\textit{Ly}\(\alpha\)) three-dimensional correlation functions only consider the information carried by the distinct peak produced by baryon acoustic oscillations (BAO). In this work, we address whether this compression is sufficient to capture all the relevant cosmological information carried by these functions. We do this by performing a direct fit to the full shape, including all physical scales without compression, of synthetic \textit{Ly}{}\(\alpha\) auto-correlation functions and cross-correlations with quasars at effective redshift \(z_{\text{eff}} = 2.3\), assuming a DESI-like survey, and providing a comparison to the classic method applied to the same dataset. Our approach leads to a 3.5% constraint on the matter density \(\Omega_{M}\), which is about three to four times better than what BAO alone can probe. The growth term \(f\sigma_8(z_{\text{eff}})\) is constrained to the 10% level, and the spectral index \(n_s\) to \(\sim 3 - 4\%\). We demonstrate that the extra information resulting from our ‘direct fit’ approach, except for the \(n_s\) constraint, can be traced back to the Alcock-Paczyński effect and redshift space distortion information.

Key words: cosmological parameters – large-scale structure of universe – methods: data analysis

1 INTRODUCTION

Over the last couple of decades, after the discovery of the accelerated expansion of the Universe (Riess et al. 1998; Perlmutter et al. 1999), cosmology has focused on investigating the properties of dark energy. Among the multiple probes used to place a constraint on the parameters of the current \(\Lambda\)CDM model, there is the baryon acoustic oscillation (BAO) scale on different tracers\(^1\) of the matter density field (Eisenstein et al. 2005; Cole et al. 2005). Measurements of this standard ruler over a range of redshifts place a constraint on the expansion history (Seo & Eisenstein 2003).

Complementary to low-redshift galaxies \((z \leq 1)\), the Lyman-\(\alpha\) (\textit{Ly}{}\(\alpha\)) forest is a tracer of the intergalactic medium (IGM) that probes the cosmic expansion via BAO at higher redshifts, as first proposed by McDonald & Eisenstein (2007). The \textit{Ly}{}\(\alpha\) forest is a sequence of absorption lines in high-redshift quasar (QSO) spectra, caused by the neutral hydrogen distributed along the line of sight, between the quasar and the observer. The first BAO detection from the \textit{Ly}{}\(\alpha\) auto-correlation function and from its cross-correlation with QSOs was in the Baryon Oscillation Spectroscopic Survey (BOSS) DR9 data (Busca et al. 2013; Slosar et al. 2013; Kirkby et al. 2013) and DR11 data (Font-Ribera et al. 2014), respectively.

BAO produce a distinct feature in the correlation functions, which we wish to measure and use to probe cosmology, in a robust and model-independent way. When performing cosmological inference, a standard method, as applied in BOSS and eBOSS (du Mas des Bourboux et al. 2020) analyses of the \textit{Ly}{}\(\alpha\) three-dimensional correlation functions, relies on splitting them into a peak and a smooth component and only considers the information carried by the BAO feature.

Recently, Cuceu et al. (2021) (C21 hereafter) demonstrated that further cosmological information can be obtained from the broadband component using the Alcock-Paczyński (AP) effect (Alcock & Paczynski 1979). When computing the 3D correlation functions from observations, as a standard approach, we change from angular and redshift separations to comoving coordinates, based on the assumption of a fiducial cosmological model. In particular, if the latter differs from the true underlying cosmology, then the AP effect will appear as an apparent anisotropy in the correlation functions. Another source of anisotropy is redshift space distortions (RSD), which are induced by peculiar velocities and hence carry extra information. However, measuring redshift space distortions for the \textit{Ly}{}\(\alpha\) auto-correlation alone is not informative about the growth rate of structure because of its degeneracy with an unknown velocity divergence bias (Seljak 2012). For this reason, C21 jointly employed the \textit{Ly}{}\(\alpha\) auto- and cross-correlation with quasars to explore the potential of measuring the linear growth of structure.

All physical scales of the 3D \textit{Ly}{}\(\alpha\) correlation functions, beyond the BAO peak, carry information about the underlying cosmology.
Throughout this work we will refer to the sum of all of these scales, with no compression, as the full shape of these functions. Both the Ly$\alpha$×Ly$\alpha$ auto- and Ly$\alpha$×QSO cross-correlation functions can be directly used to perform cosmological inference. The work of C21 motivates a further investigation, assessing whether or not the compressed analysis based on BAO, AP and RSD successfully captures all cosmological information from the correlation functions of interest.

The same point is relevant also in the field of galaxy clustering, where the compressed standard approach extracts cosmological information from BAO, AP and RSD (Alam et al. 2017, 2021). Over the past few years, advancements in perturbation theory computations boosted the interest in fitting the observed two-point statistics and directly inferring cosmological parameters without compression (Lewis et al. 2000; Howlett et al. 2012). We construct a likelihood for directly inferring cosmological parameters, without the usual compression due to quasar continuum fitting. The latter filters out information and ‘distorts’ the true correlation function (Bautista et al. 2017; Du Mas des Bourboux et al. 2017). Our synthetic data was generated using the framework of C21, and is given by an uncontaminated model based on the best fit of eBOSS DR16 (see Tab. 1). We did not add noise to the data vector, as we are only interested in forecasting. We used covariance matrices based on DESI mocks similar to those used in Youlès et al. (2022). These mocks were created with the CoLoRe (Ramírez-Pérez et al. 2022) and LyCoLoRe (Farr et al. 2020) packages, covering 14000 sq. degrees with a target density of ~50 QSOs/sq. degree (DESI Collaboration et al. 2016). The covariance was computed using the community package picca (Du Mas des Bourboux et al. 2020). In this analysis, we limit ourselves to linear scales, assuming $r_{\text{min}} = 30h^{-1}\text{Mpc}$, up to $r_{\text{max}} = 180h^{-1}\text{Mpc}$. The effective redshift of the correlation functions is $z_{\text{eff}} = 2.3$.

2.1 Synthetic data vector and covariance
In this work, we focus on idealised 3D Ly$\alpha$ synthetic correlations in flat $\Lambda$CDM, without contaminants. However, we do include the distortion due to quasar continuum fitting. The latter filters out information and ‘distorts’ the true correlation function (Bautista et al. 2017; Du Mas des Bourboux et al. 2017). Our synthetic data was generated using the framework of C21, and is given by an uncontaminated model based on the best fit of eBOSS DR16 (see Tab. 1). We did not add noise to the data vector, as we are only interested in forecasting. We used covariance matrices based on DESI mocks similar to those used in Youlès et al. (2022). These mocks were created with the CoLoRe (Ramírez-Pérez et al. 2022) and LyCoLoRe (Farr et al. 2020) packages, covering 14000 sq. degrees with a target density of ~50 QSOs/sq. degree (DESI Collaboration et al. 2016). The covariance was computed using the community package picca (Du Mas des Bourboux et al. 2020). In this analysis, we limit ourselves to linear scales, assuming $r_{\text{min}} = 30h^{-1}\text{Mpc}$, up to $r_{\text{max}} = 180h^{-1}\text{Mpc}$. The effective redshift of the correlation functions is $z_{\text{eff}} = 2.3$.

2.2 Modelling
To infer cosmology from these synthetic correlations, we first need a theory to model the data given any cosmology $p_C$. The theoretical 3D Ly$\alpha$ correlation functions are computed from the isotropic matter power spectrum $P(k)$ and then compared against data to evaluate the likelihood.

When modelling and fitting Ly$\alpha$ correlations, we must match the coordinate grid for the theoretical correlation $\xi$ with the grid of the data. When measuring the 3D Ly$\alpha$ correlation functions from observations, we change from angular $\Delta\theta$ and redshift $\Delta z$ separations to a set of comoving coordinates $(r_\parallel, r_\perp)$, respectively defined along and across the line of sight. This is motivated by the fact that both the radial comoving distance $D_C(z) = c \int_0^z dz/H(z)$ and the comoving angular diameter distance $D_M(z)$ are redshift dependent, where $c$ is the speed of light and $H(z)$ the Hubble parameter. For this reason, we wish to refer instead to a set of comoving coordinates. Given two locations at redshift $z_i$ and $z_j$ separated by an angle $\Delta\theta$, these are defined as

\[ r_\parallel = |D_{C,\text{fid}}(z_i) - D_{C,\text{fid}}(z_j)| \cos \frac{\Delta\theta}{2}; \]
\[ r_\perp = |D_{M,\text{fid}}(z_i) + D_{M,\text{fid}}(z_j)| \sin \frac{\Delta\theta}{2}, \]

where both $D_C$ and $D_M$ are computed using an assumed fiducial cosmology (fid subscript). In our case, the fiducial cosmology coincides with the cosmological model that was used to generate the data vector. Given that the sampled cosmology that generated the theoretical $\xi$ can be different from the fiducial one, we need to match coordinate grids of data and $\xi$ by rescaling at each sampling step the coordinates of the correlation via

\[ q_\parallel = D_H(z_{\text{eff}})/D_{H,\text{fid}}(z_{\text{eff}}); \]
\[ q_\perp = D_M(z_{\text{eff}})/D_{M,\text{fid}}(z_{\text{eff}}). \]

where $D_H(z) = c/H(z)$, such that $r'_\parallel = q_\parallel r_\parallel$ and $r'_\perp = q_\perp r_\perp$.

In modelling the Ly$\alpha$ correlation functions of interest we follow Eq. (27) of Du Mas des Bourboux et al. (2020), adopting the prescriptions of C21. For any cosmology $p_C$, the power spectra of the tracers are computed from the isotropic linear matter power spectrum $P(k, z)$ as

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2 https://github.com/andreicuceu/vega
Direction, where \(r_d\) is the sound horizon at the drag epoch. In flat \(Λ\)CDM, at low redshifts, the Hubble parameter \(H(z)\) can be expressed as a function of \(\Omega_0\) and \(\Omega_M\), \(\Omega_k\) will ultimately place a constraint on \(\{H_0, \Omega_M, \Omega_k\}\). Additionally, \(r_d\) can be numerically approximated as a function of \(\Omega_b h^2\), \(\Omega_M h^2\) and \(\Omega_B h^2\) (Aubourg et al. 2015), which are the neutrino, matter and baryon densities respectively, evaluated at redshift \(z = 0\) by definition. This further motivates the choice of sampling \(\{H_0, \Omega_M, \Omega_B h^2\}\), where \(\Omega_B h^2\) is constant for a given choice of the neutrino mass. Extra information on \(\Omega_M\) also comes from the AP effect (Alcock & Paczynski 1979)

\[
F_{\text{AP}} = \frac{a}{a_{\parallel}} = \frac{D_M(z_{\text{eff}})D_{\text{H}}^2}{D_M^2(z_{\text{eff}})D_{\text{H}}^2} = \left[\frac{D_M(z_{\text{eff}})H(z_{\text{eff}})}{D_M(z_{\text{eff}})H(z_{\text{eff}})}\right]_{\text{fid}}
\]

which is an apparent anisotropy present if the sampled cosmology differs from the fiducial one. For the same assumptions as before, the AP parameter will only be a function of \(\Omega_M\). As we fit the full shape of the correlation functions directly and the amplitude of primordial fluctuations \(A_s\) and their spectral index \(n_s\) affect the functional form of \(\xi\), we will sample the full set of parameters \(\mathbf{p}_C = \{H_0, \Omega_M, \Omega_B h^2\}\), on the other hand, \(\{h_{1/2}, b_{\text{QSO}}, \beta_{\text{Ly}a}, \sigma_v\}\) are treated as nuisance parameters \(\mathbf{p}_A\) to marginalize over.

For all these parameters we choose uniform priors, which are listed in Tab. 1. As is common, \(A_s\) is sampled in logarithmic space, and we made the choice of doing the same with the two linear biases because they are degenerate with \(A_s\) and span over several orders of magnitude.

In this work, we assume a Gaussian likelihood, which is also computed using \(\text{vega}\). A likelihood evaluation, via \(\text{camb}\), first computes the comoving distances, to calculate \(q_{\parallel}\) and \(q_{\perp}\), and then the isotropic linear matter power spectrum, along with \(r_d\), the growth rate at \(z_{\text{eff}}\) and \(f\sigma_8(z_{\text{eff}})\). Then, \(\text{vega}\) computes the correlation functions, based on the modelling description in Sect. 2.2, and the \(\chi^2\) value.

## 3 RESULTS

In this section we present the forecasts produced using the method outlined in Sect. 2 on 3D \(\text{Ly}_a\) and \(\text{Ly}_b\) simplified synthetic correlation functions. We sample over the cosmological parameters \(\mathbf{p}_C = \{H_0, \Omega_M, \Omega_B h^2, A_s, n_s\}\), marginalizing over the astrophysical model parameters \(\mathbf{p}_A = \{h_{1/2}, b_{\text{QSO}}, \beta_{\text{Ly}a}, \sigma_v\}\). The fiducial values of these parameters, along with the priors, are listed in Tab. 1.

In Fig. 1 we show the results for \(\{H_0, \Omega_M, \Omega_B h^2, A_s, n_s\}\) using the noiseless mock data vector. In the last column of Tab. 1 we list

### Table 1. Full set of sampled parameters, alongside with the fiducial values used to compute the synthetic correlations and the uniform (\(\mathcal{U}\)) priors adopted for the sampling procedure. When sampling in logarithmic space we add a ‘log’ subscript to \(\mathcal{U}\). In the last column, we provide the one-dimensional marginals (68% c.l.) for all the parameters sampled, where for any asymmetric posteriors we report the posterior maximum with lower and upper 68% limits.

| Parameter | Fiducial | Prior | 68% limits |
|-----------|---------|-------|------------|
| \(H_0\) [\(\text{km/(s} \times \text{Mpc)}\)] | 67.31 | \(\mathcal{U}(40, 100)\) | 67.69^{+5.5}_{-3.16} |
| \(\Omega_M\) | 0.3144 | \(\mathcal{U}(0.01, 0.99)\) | 0.318 \pm 0.011 |
| \(\Omega_k h^2\) | 0.0222 | \(\mathcal{U}(0.01, 0.05)\) | 0.0229^{+0.006}{-0.0038} |
| \(A_s\) | 2.196 \cdot 10^{-9} | \(\mathcal{U}_{\log}(0.1, A_s)\) (0.5, 6) | 2.06^{+0.42}_{-0.36} \cdot 10^{-9} |
| \(n_s\) | 0.9655 | \(\mathcal{U}(0.8, 1.2)\) | 0.958^{+0.025}_{-0.035} |
| \(b_{1/2}\) | -0.117 | \(\mathcal{U}_{\log}(-b_{1/2})\) (-2, 0) | -0.111^{+0.011}_{-0.012} |
| \(\beta_{\text{Ly}a}\) | 1.67 | \(\mathcal{U}(0, 5)\) | 1.67 \pm 0.03 |
| \(b_{\text{QSO}}\) | 3.8 | \(\mathcal{U}_{\log}(b_{\text{QSO}})\) (-2, 1.3) | 3.61^{+0.47}_{-0.32} |
| \(\sigma_v\) (Mpc/h) | 6.86 | \(\mathcal{U}(0, 15)\) | 6.74^{+0.64}_{-0.55} |

\[P_{\text{Ly}a}(k, \mu_k, z) = b_{\text{Ly}a}^2 \left(1 + b_{\text{Ly}a} \alpha_k^2 \right) \frac{2}{2} P_{\text{Ly}a}(k, \mu_k) \]  
\[P_{\text{QSO}}(k, \mu_k, z) = b_{\text{QSO}}^2 \left(1 + b_{\text{QSO}} \alpha_k^2 \right) \frac{2}{2} P_{\text{QSO}}(k, \mu_k) \]  

The table above shows the full set of sampled parameters, alongside with the fiducial values used to compute the synthetic correlations and the uniform (\(\mathcal{U}\)) priors adopted for the sampling procedure. When sampling in logarithmic space we add a ‘log’ subscript to \(\mathcal{U}\). In the last column, we provide the one-dimensional marginals (68% c.l.) for all the parameters sampled, where for any asymmetric posteriors we report the posterior maximum with lower and upper 68% limits.
From Fig. 1, it can be seen that we do recover the true values (shown in grey dashed lines) of cosmological parameters $p_C$ well within $1\sigma$ (Tab. 1). The analysis provides a $3.5\%$ constraint on the matter density $\Omega_M$. Clear degeneracies are present between $H_0$ and $\Omega_B h^2$. As previously mentioned, the baryon acoustic oscillation peak measures the product $H_0 r_d$, which can be expressed as a function of $H_0$, $\Omega_B h^2$ and $\Omega_M$. Given that we have a good measurement of $\Omega_M$ from the AP information, the remaining degeneracy is between $H_0$ and $\Omega_B h^2$: if there were no other information on either one of them, these two parameters would be fully degenerate. The fact that both $H_0$ and $\Omega_B h^2$ are strongly correlated with the spectral index $n_s$ could hint that the turnover of the power spectrum is the feature partially breaking the degeneracy. Despite this correlation, we are able to place a constraint on the spectral index, namely $n_s = 0.958^{+0.025}_{-0.035}$.

We obtain a $21\%$ constraint on the amplitude of fluctuations $A_s$, with a corresponding constraint on the amplitude of linear matter fluctuations in spheres of $8 h^{-1}\text{Mpc}$ of $\sigma_8(z_{\text{eff}}) = 0.317 \pm 0.032$. We will further analyze the constraining power of our analysis against the state-of-the-art results later in Sect. 4.1.

In Fig. 2 we show the strong correlation among the linear biases, $b_{\text{Ly}\alpha}$ and $b_{\text{QSO}}$, and $A_s$, which is expected given the functional form of Eqs. (5-6). The $\text{Ly}\alpha$ auto-correlation alone would not be able to place a constraint on $A_s$ since, for $\mu = 0$, we would measure the combination $A_s b_{\text{Ly}\alpha}^2$ only, whereas its anisotropy would provide a
measurement of $\beta_{\text{Ly}a}$. On the other hand, the transverse mode of the cross-power spectrum (Eq. 6), combined with the auto-correlation, measures the combination of $A_s b_{\text{Ly}a}^2$ and $b_{\text{QSO}} b_{\text{Ly}a}$, while through the RSD term we are able to constrain $A_s$ (or $f\sigma_8$ in compressed analyses).

## 4 DISCUSSION

In Sect. 4.1 we provide a direct comparison of the forecasts presented in Sect. 3 and the literature. In particular, we will focus on a comparison with the results on the same synthetic data obtained using the standard BOSS and eBOSS analysis first, as well as the C21 approach. Our goal is to understand whether the compressed analyses successfully capture the cosmological information carried by the 3D Lya correlation functions and discuss which components of the data are the most informative. In Sect. 4.2 we discuss how results change when marginalizing over the growth of structure. This is instructive to further understand from where extra information originates.

### 4.1 Cosmological information

As mentioned above, in flat ΛCDM the BAO scale, along and across the line of sight, identifies a banana-shaped degeneracy in the $[H_{\text{d}f}/c, \Omega_M]$ plane. This justifies that any comparison among methods which have the BAO as a primary feature should necessarily happen in this plane. On the other hand, the Lya-QSO cross-correlation can in principle measure $f\sigma_8(z_{\text{eff}})$ because of the functional form of Eq. (6). However, because of the degeneracy with the linear biases, the combination with the Lya auto-correlation is needed. In what follows we will focus on a comparison based on the derived parameters $P_A = \{H_{\text{d}f}/c, f\sigma_8(z_{\text{eff}})\}$ and $\Omega_M$. In particular, in Fig. 3 we plot the two-dimensional contours of $\{H_{\text{d}f}/c, \Omega_M\}$ and in Fig. 4 the one-dimensional marginal of $f\sigma_8(z_{\text{eff}})$ for the methods we want to compare.

As discussed above, standard BOSS and eBOSS analyses focus on the peak component of the 3D Lya correlation functions only. For this reason, we will refer to this approach as ‘BAO’ for simplicity. We run this analysis using our noiseless mock data, and the most important result is shown in Fig. 3. This approach provides $\Omega_M = 0.32 \pm 0.04$, $H_{\text{d}f}/c = 0.0329 \pm 0.0015$, with a constraining power on $H_{\text{d}f}/c$ of 4.5%, a factor of three worse compared to our direct fit (summarized in Tab. 2).

Such an improvement was already found by C21, who demonstrated that considering the AP effect from the smooth component in addition to the peak provides significantly tighter constraints. We present results using their method with the additional RSD information, and we will refer to it as ‘BAO+AP+RSD’. By running their analysis over our noiseless data, we find that ‘BAO+AP+RSD’ is able to place a constraint on $H_{\text{d}f}/c$ of 1.65%, which is of the same order as for our analysis (Tab. 2).

### 4.2 Direct fit analysis without RSD

In order to further investigate where some of the information in the ‘direct fit’ alone is coming from, we repeat the same analysis, along the same direction as observed by C21. Our method constrains the growth of structure (Eq. 5-6) as well. For this reason, we also compare the RSD information of C21 with ours. The $f\sigma_8(z_{\text{eff}})$ one-dimensional marginals for both methods are plotted in Fig. 4 and the constraining power is given for completion in Tab. 2. Overall, our method provides tighter constraints on $H_{\text{d}f}/c$, $\Omega_M$ and $f\sigma_8(z_{\text{eff}})$, with respect to the ‘BAO+AP+RSD’ analysis, by about 16%, 17% and 18%, respectively.

### Table 2. Constraining power of our method (‘direct fit’) on the listed parameters, against those from the standard analysis (BAO) and the one of C21 (BAO+AP+RSD).

| Parameter      | BAO   | BAO+AP+RSD | direct fit |
|----------------|-------|------------|------------|
| $\Omega_M$     | 12%   | 4%         | 3.5%       |
| $H_{\text{d}f}/c$ | 4.5%  | 1.65%      | 1.43%      |
| $f\sigma_8(z_{\text{eff}})$ | $-12.5\%$ | 10.4%       |           |

## Figure 3. Two-dimensional contour plots of $\{H_{\text{d}f}/c, \Omega_M\}$, comparing our method (‘direct fit’) in blue against standard BOSS and eBOSS analysis (‘BAO’) in orange and C21 (‘BAO+AP+RSD’) in green. On the right, there is a zoom-in to further highlight the differences among the ‘direct fit’ and ‘BAO+AP+RSD’ methods.

## Figure 4. Posterior plot for $f\sigma_8(z_{\text{eff}})$, comparing our method (‘direct fit’) in blue against C21 (‘BAO+AP+RSD’) in green.

\[
P_x(k, \mu_k, z) = b_{\text{Ly}a} \left( 1 + \beta_{\text{Ly}a} \mu_k^2 \right) \\
\times b_{\text{QSO}} \left( 1 + \beta_{\text{QSO}} \mu_k^2 \right) F_{\text{nl,QSO}} P(k, z),
\]
5 CONCLUSIONS

Given that baryon acoustic oscillations (BAO) produce a distinct feature in 3D Ly\(\alpha\) correlation functions, and its properties are well understood, BOSS and eBOSS analyses so far considered only the peak for cosmological inference (‘BAO’ analysis). A previous analysis conducted by Cuceu et al. (2021) (C21 throughout the paper) highlighted the importance of also considering the broadband component, as it significantly contributes to the overall cosmological information via the Alcock-Paczynski (AP) effect (‘BAO+AP’ analysis – ‘BAO+AP+RSD’ if redshift space distortions (RSD) are included). Given these premises, in this paper we addressed the question about whether or not the compressed analyses based on BAO, AP and RSD parameters are able to capture all the cosmological information brought by the Ly\(\alpha\) correlation functions. We performed a full shape analysis without any of the above parameters and instead directly inferred cosmology (‘direct fit’ analysis).

The inference framework we used is \texttt{COHAYA}, for which we implemented an \textit{ad-hoc} gaussian likelihood based on the \texttt{VEGA} package, as extensively described in Sect. 2.

We performed ‘BAO’, ‘BAO+AP+RSD’ and ‘direct fit’ analyses on the same set of synthetic Ly\(\alpha\times\text{Ly} \alpha\) auto- and \text{Ly} \(\alpha\times\text{QSO}\) cross-correlations, which include distortion effects due to continuum fitting, but no other contaminants, and ran the inference over \(p_C = \{H_0, \Omega_M, \Omega_B h^2, A_s, n_s\}\). We also marginalized over the nuisance astrophysical parameters \(p_A = \{b_{\text{Ly} \alpha}, b_{\text{QSO}}, \beta_{\text{Ly} \alpha}, \sigma_v\}\), which are the Ly\(\alpha\) and quasars linear biases, the Ly\(\alpha\) RSD term and the velocity dispersion of quasars respectively.

We were able to measure the matter density parameter \(\Omega_M\) and the...
amplitude of primordial fluctuations $A_s$ with a precision of 3.5% and 21%, respectively, and $f\sigma_8(z_{\text{eff}})$ at 10.4%, which is a noteworthy result given the few measurements of this parameter at $z > 2$. For these parameters we do not obtain a significant improvement in constraining power with respect to the ‘BAO+AP+RSD’ approach. However, we obtain a constraint of the spectral index $n_s$ at the $\sim 3 - 4\%$ level. Similarly to the findings and solutions put forward in Brieden et al. (2021), we could account for this extra information by adding a slope parameter to the compressed analysis.

The robustness of the ‘direct fit’ method against systematics must be tested. In forthcoming work, it would be interesting to investigate whether the compressed analysis is more robust, given it measures specific physical effects that are well understood. A further natural next step should be including contaminants to the analysis. The constraining power in the spectral index that we achieve could be affected in particular by Damped Lyα System (DLA) contamination (McQuinn & White 2011; Font-Ribera et al. 2012) and fluctuations in the UV background (Pontzen & Governato 2014; Gontcho et al. 2014), which would change the correlation function in a way that could mimic $n_s$. Further improvements to the analysis could come from varying $r_{\text{min}}$ and $r_{\text{max}}$, and also checking how effects of continuum distortion consequently behave.

We conclude by recalling that soon DESI will provide even better measurements of Lyα correlations. Therefore this kind of study is key to finding the optimal approach to infer cosmology from the data.

ACKNOWLEDGEMENTS

This work was partially enabled by funding from the UCL Cosmoparticle Initiative. AC acknowledges support from the United States Department of Energy, Office of High Energy Physics under Award Number DE-SC-0011726. AFR acknowledges support by the program Ramon y Cajal (RYC-2018-025210) of the Spanish Ministry of Science and Innovation and from the European Union’s Horizon Europe research and innovation programme (COSMO-LYA, grant agreement 101044612). IFAE is partially funded by the CERCA program of the Generalitat de Catalunya. BJ acknowledges support by STFC Consolidated Grant ST/V000780/1. PL acknowledges support of STFC Consolidated Grants ST/R000476/1 and ST/T000473/1. For the purpose of open access, the authors have applied a creative commons licence to any author-accepted manuscript version arising.

DATA AVAILABILITY

The code is publicly available at https://github.com/frgerardi/LyA_directfit. The data underlying this article will be shared on reasonable request to the corresponding author.

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