THE MEAN TRANSMISSION OF THE LYα-FOREST FROM THE SDSS DR10 QUASAR SPECTRA

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INTRODUCTION

Lyα forest in the spectra of high-z quasars traces the underlying matter distribution over a wide range of scales and redshifts. Determination of the intrinsic quasar spectrum is one of the crucial steps in these studies. There are two main classes of methods that are used for this purpose. One class deals with the extrapolation of continuum on wavelengths longer than 1215 Å (like in [1,2]), another class is related to the choice of absorption-free regions within Lyα-forest (manual fitting of the continuum, like in [3,4]). Both of these techniques have several modifications and own pros and cons. Their comparison showed that the value of $\bar{F}(z)$ obtained with the manually determined continuum are systematically higher than those obtained from extrapolated continuum [5] . The difference varies from 5 % at $z = 2$ up to 33 % at $z = 4.5$, respectively (see Fig. 2). Therefore it is very important to use different possible data and develop methods of continuum determination. Through the similarity of quasar spectra their composite spectra can be helpful for solving this problem. A new approach to this problem is proposed.

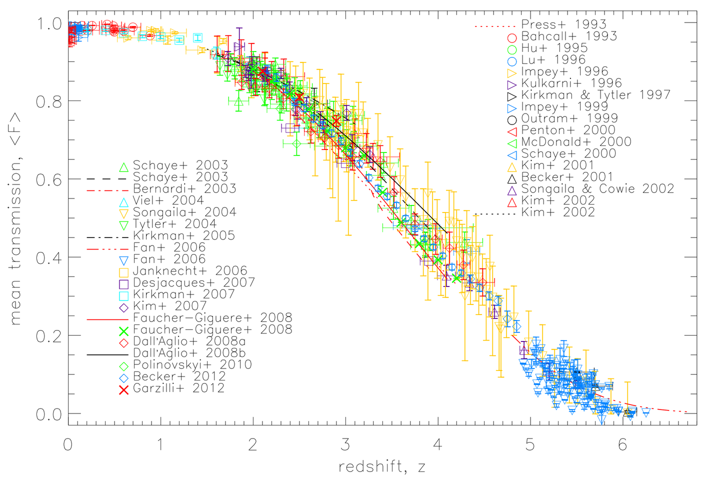

Figure 1: Compilation of the mean transmission data as a function of redshift from literature (see [5]).

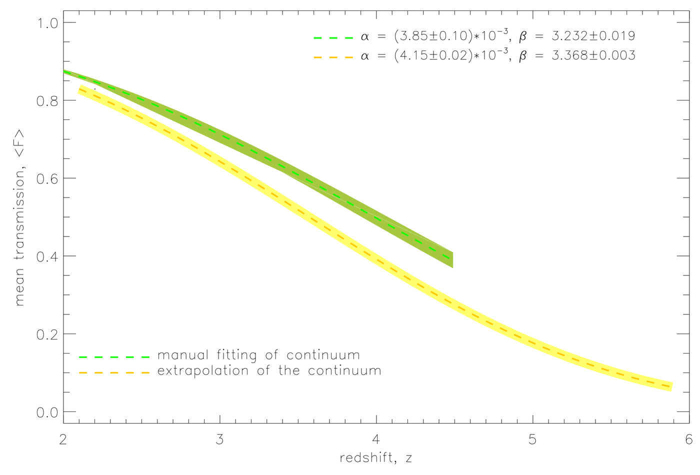

Figure 2: The optimal approximations with 1σ-error ranges for manual method of continuum fitting (green) and for extrapolated continuum (yellow) from [5].

THE SAMPLE

We used the SDSS DR10 quasar catalogue [6] that contains 165 583 objects within the redshift ranges $0.053 < z < 5.855$. Firstly, all objects with $z \geq 2.0$ and $z_{conf} > 0.9$ were selected, since the region Lyα-forest is observed at these redshifts. The resulting preliminary sample contains 125 132 objects. The second step was the visual inspection of the preliminary sample: those objects were not included into the main sample and rejected, are 11 192 quasars with BAL, 6 804 spectra with DLA, 1 248 and 493 spectra with the absorption in Lyα and Lyβ lines, respectively. The "non-quasars" objects, including 191 candidates for blazars and 30 normal or starburst galaxies, as well as 617 quasar spectra with wrong redshift, 417 incomplete spectra and 1 497 spectra with the too low signal-to-noise (S/N) ratio, were also excluded.

After visual examination we obtained a new sample, it contains 102 643 spectra which will be used for study of the matter distribution on the intergalactic scales using Lyα-forest. This sample includes also a subsample of 65 976 spectra for the composite spectra compilation, which will also be used for studying the spectra properties of quasars and relations between them.

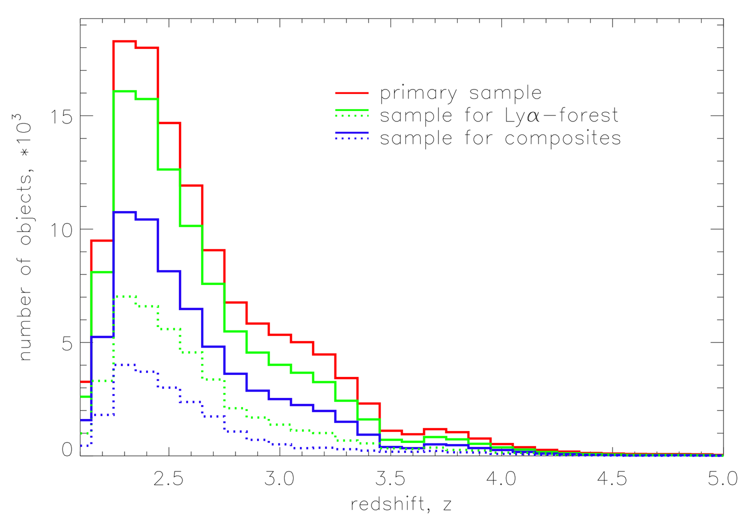

Figure 3: z-distribution before (solid line) and after (dotted line) imposion of the conditions with A.

Additionally, some reductions was applied for both samples: all spectra were smoothed with a simple moving average by three points and each spectrum was normalized to the mean (arithmetic) flux in all pixels within the rest wavelength range $\lambda_{rest} = 1450-1470$ Å . For further study we used only the spectra with RMS of normalisation constant A less than 10%, resulting in the samples of 42 140 spectra (the sample for the Lyα-forest study) and 21 868 spectra (for the composites). The redshift distributions of the preliminary, main and composite samples before and after the imposition of the conditions with a normalisation constant A are shown in Fig. 3. Details of the sample selection in [7].

GENERAL NOTATIONS

The measured flux f_i at observed λ_i^{obs} within the Lyα-forest:

$$\tilde{f}_i(\lambda_i^{obs}) = AC(\lambda_i^{rest})\bar{F}(z_k)(1 + \delta F_i(\lambda_i^{obs})) + n_i,$$

where A is a normalization constant (the mean flux over 1450–1470 Å), C is an intrinsic quasar spectrum ('continuum'), $\bar{F}$ and δ_F are mean transmission and its variation, n_i is the noise. In such consideration the composite spectra within Lyα-forest: $f_j(\lambda_j^{rest}) = C(\lambda_j^{rest})\bar{F}(z_k)$.

COMPOSITE SPECTRA

The true continuum of the quasar spectra redward of 1215.67 Å is considered as $\sim \lambda^{\alpha_\lambda}$; the spectral indices α_λ for individual spectra were calculated using 1278-1286, 1320-1326, 1345-1360 and 1340-1480 Å bands. Also the monochromatic luminosity at 1450 Å (l_{1450}) were determined.

55 composite spectra, compiled from subsamples each of more than 150 spectra with similar α_λ and $\langle\log l_{1450}\rangle$ (with $\Delta\alpha_\lambda = 0.2$ within the range $\alpha_\lambda = -3.3 \ldots -1.3$ and $\Delta\langle\log l_{1450}\rangle = 0.1$ within the range $\langle\log l_{1450}\rangle = 41.7 \ldots 42.3$), were used for continuum determination along with an assumption of the general similarity of quasar spectra and differsity of them in spectral index and luminosity that affect on equivalent width of emission lines and general normalization of spectra [8]. The luminosity, spectral index and redshift distribution of individual spectra is shown in Fig. 4, the same diagrams for already compiled composite spectra is shown in Fig. 5.

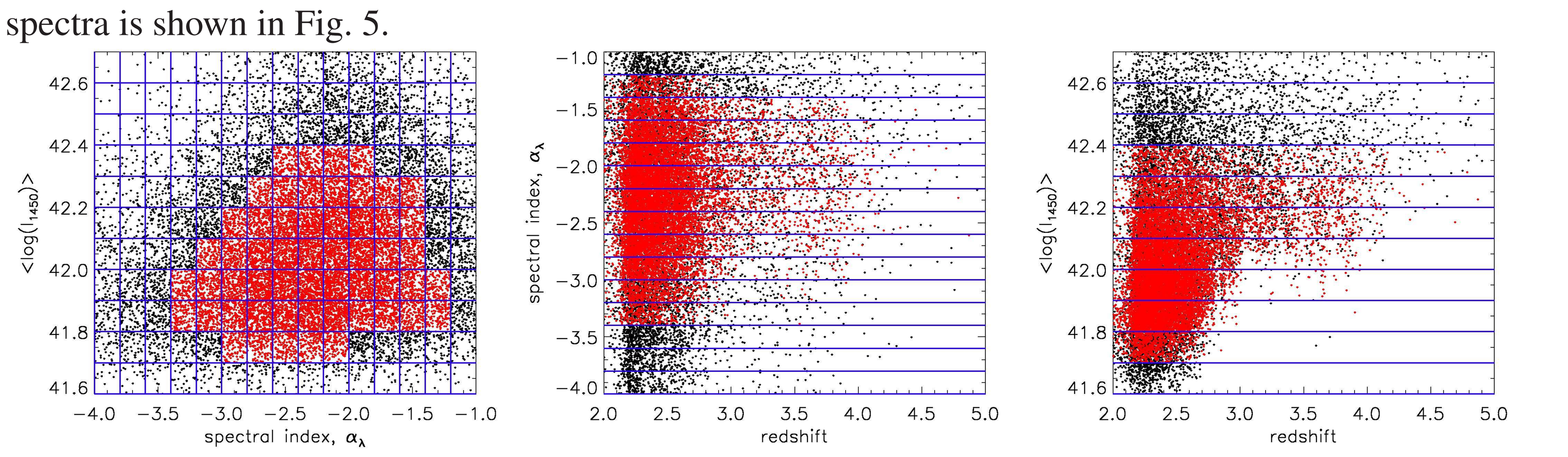

Figure 4: The luminosity, spectral index and redshift distribution of individual quasar spectra. Those spectra were used for compilation of composite spectra are shown by red color. The grid shows how the sample was divided.

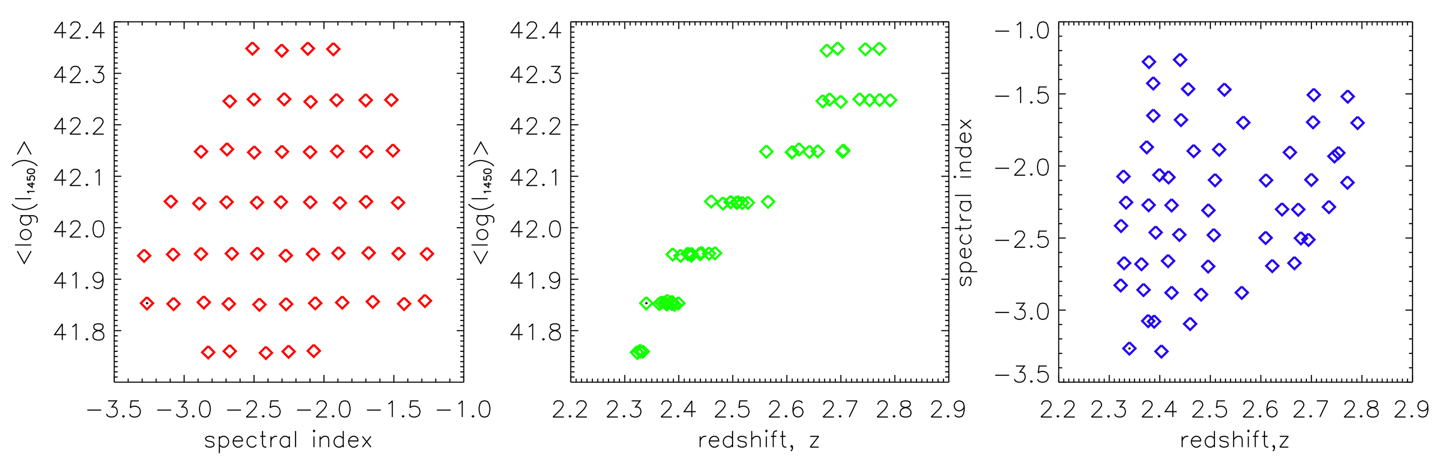

Figure 5: The diagrams of luminosity, spectral index and redshift for compiled composite spectra. The luminosity and redshift are average for subsample and spectral index defined for each composite.

COMPOSITE SPECTRA: EXAMPLES

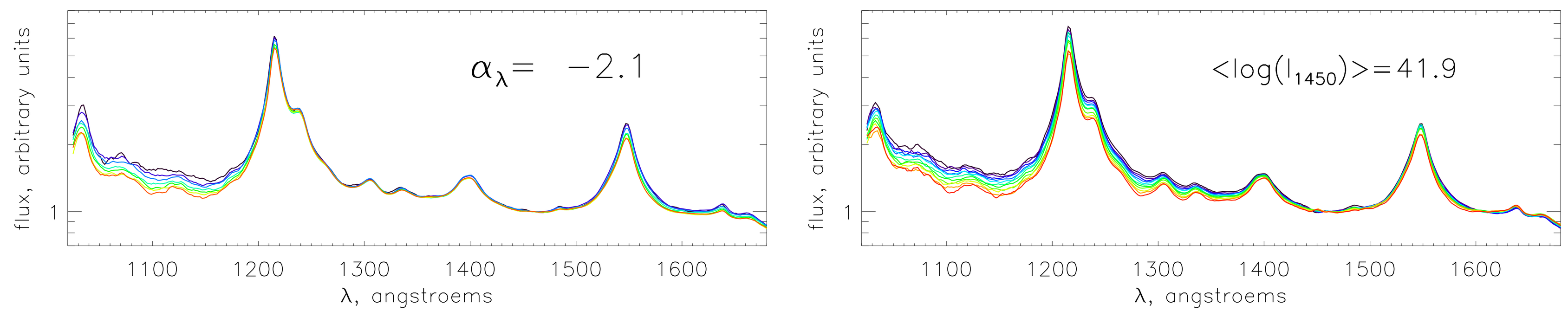

Figure 6: Composite spectra with the same value of $\alpha_\lambda = -2.1$ and $\langle\log l_{1450}\rangle = 41.9$. Colors show a change of the luminosity (left panel) and spectral index (right panel).

CONTINUUM FITTING

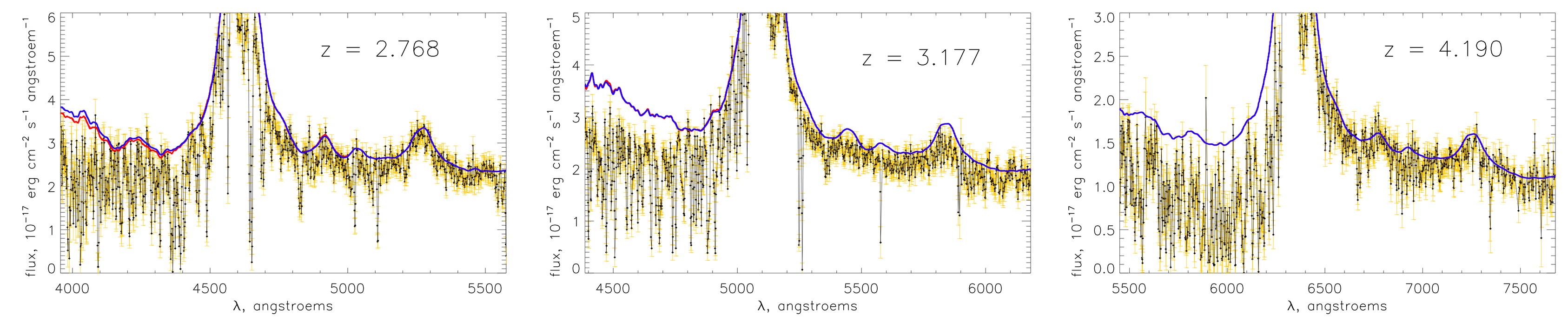

Figure 7: Examples of quasar spectra at redshift z (left to right): 2.768, 3.177, 4.190 with defined continuum before (red line) and after (blue) correction of spectral calibration.

MEAN TRANSMISSION $\bar{F}(z)$

The mean transmission $\bar{F}$ was calculated for $\Delta z = 0.1$ bins after normalization of spectra onto continuum (Fig. 7) and are presented in Fig. 8.

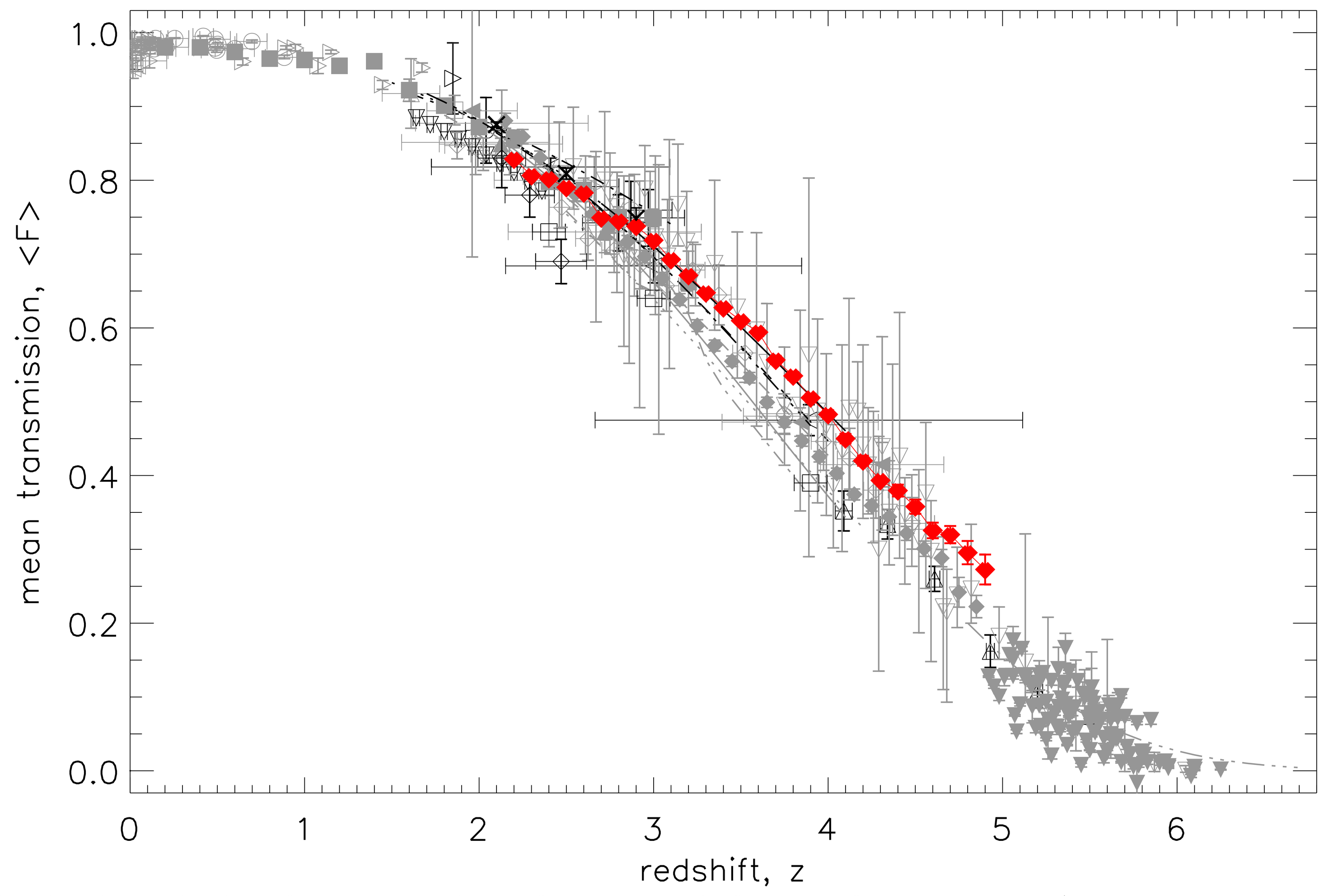

Figure 8: The obtained value of mean transmission for own sample for case of averaging over $\Delta z = 0.1$ steps (red points) in comparison with the results of other authors.

The values of $\bar{F}(z)$ were approximated by $\bar{F} = e^{-\tau_{eff}}$, where $\tau_{eff} = \alpha(1+z)^\beta$, α and β – free parameters. The result of optimal approximation with 1σ error range for own sample and also approximations for manual method of continuum fitting and for extrapolated continuum from [5] are represented in Fig. 9.

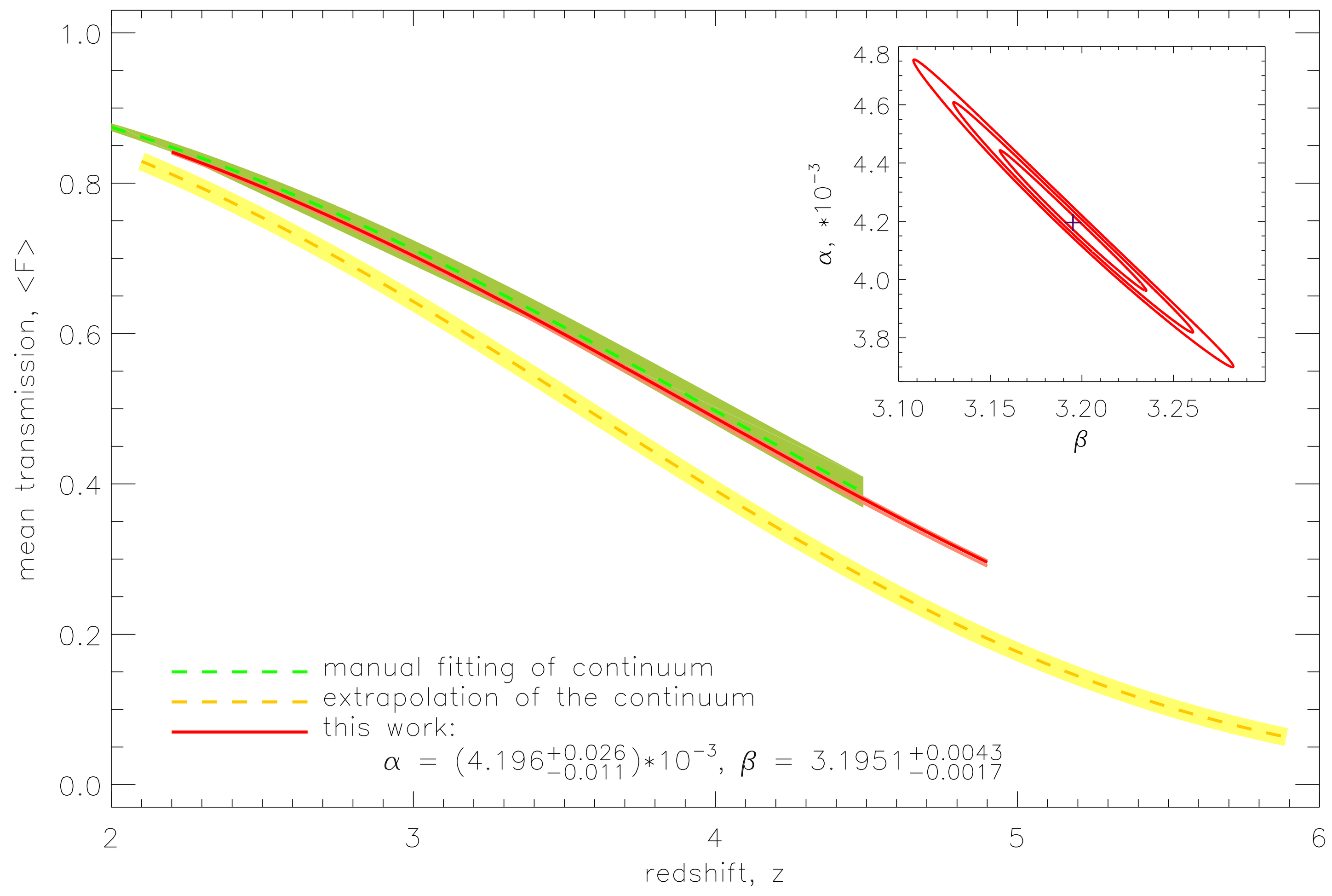

Figure 9: The optimal approximation with 1σ error range and 1,2,3σ-level of maximum likelihood function for own sample (red) in comparison with the approximations for manual method of continuum fitting (green) and for extrapolated continuum (yellow) from [5].

CONCLUSIONS

- We compiled a new sample of quasar spectra from SDSS DR10 for Lyα-forest studying and 55 composite spectra from subsamples with different α_λ and $\log l_{1450}$.
- Using this sample and our own approach for determining continuum level within the Ly-alpha forest region we calculated the values of $\bar{F}(z)$ within $2.2 < z < 4.9$.
- Obtained values of $\bar{F}(z)$ at $z < 4.4$ are in good agreement with the results of other authors, obtained from high-resolution spectra, that means that our automatic method of continuum determination is quite better than the common one.

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REFERENCES

[1] Desjacques V. et al., 2007, MNRAS, 374, 206
[2] Songaila A., 2004, AJ, 127, 2598
[3] Kim T.-S. et al., 2007, MNRAS, 382, 1657
[4] Mcdonald P. et al., 2000, ApJ, 543, 1
[5] Torbaniuk O., 2016, AASP, 6, 34
[6] Pâris I. et al., 2014, A& A, 563, id. A54
[7] Torbaniuk O., 2015, AASP, 5, 84
[8] Torbaniuk O., Ivashchenko G., 2014, in proceeding of WDS, 42