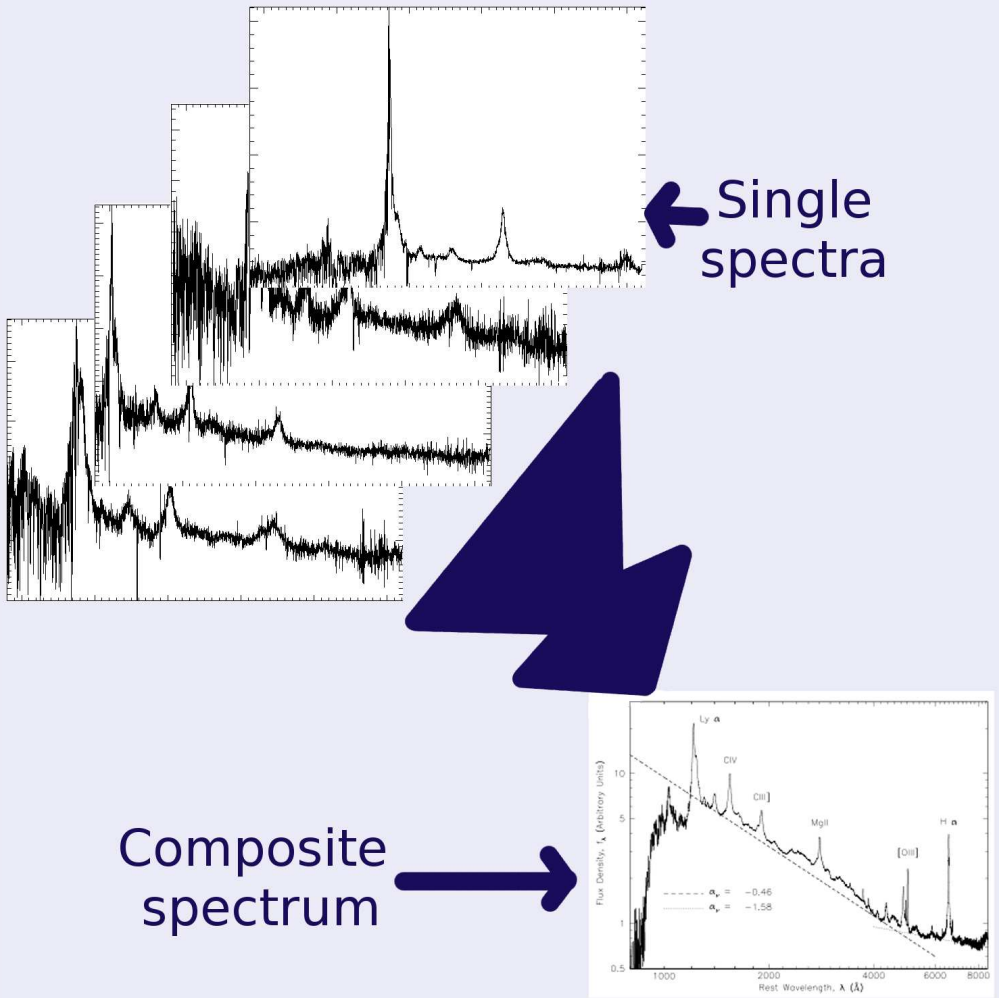
Properties of intrinsic quasar spectra within the HI Lyα forest region

Ganna Ivashchenko[1], O. Sergijenko[2], O. Torbaniuk[3]

[1]Astronomical Observatory of the Taras Shevchenko National University, Kyiv, Ukraine
[2]Astronomical Observatory of the Ivan Franko National University, Lviv, Ukraine
[3]Faculty of Physics of the Taras Shevchenko National University, Kyiv, Ukraine

What is a composite spectrum?

= a mean arithm./geometr. spectrum



How it is made?

- de-redshifting of spectra
- normalization
- stacking and averaging

+ advantages

very high S/N ratio

⇓

allowes to reveal tiny details hiden in low S/N ratio spectra

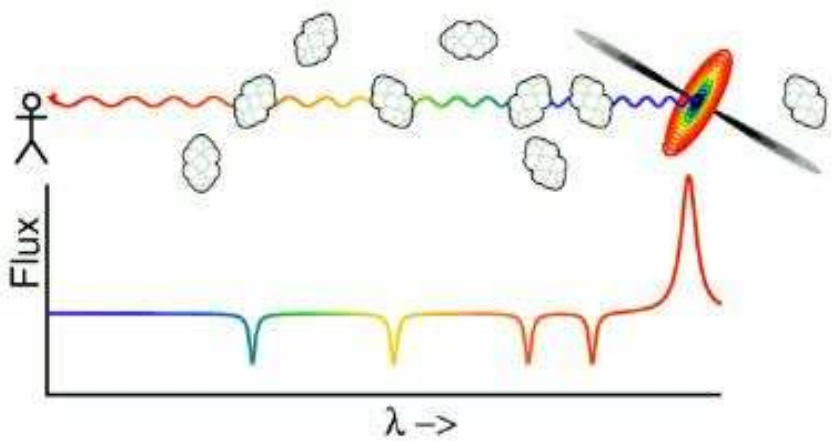
but...

make sence for objects with similar spectra, e.g. quasars

For what purpose do we need composite spectra?

- templates for redshift determination in large surveys;
- precise color diagrams for photometric selection of quasar candidates;
- study of quasar physics (general spectral properties of quasars as a class of objects);
- determination of "initial" quasar spectrum prior to absorption by HI in IGM for Lyα-forest study

HI Lyα-forest: a simple picture

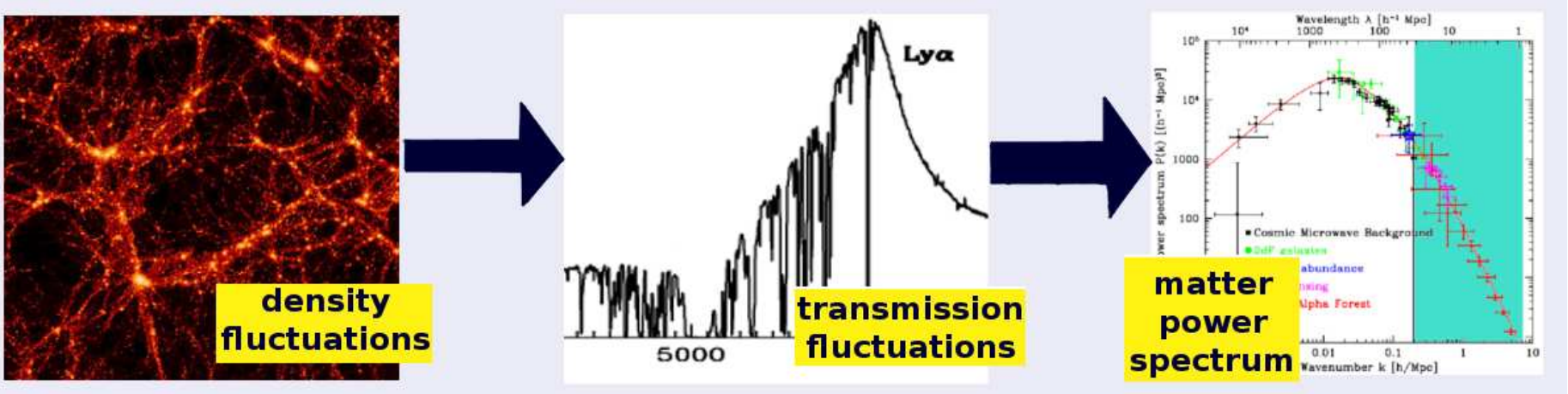


$$\lambda_{abs}^{Ly\alpha} = 1215.67(1 + z_{\text{“cloud”}}) \text{ [Å]}$$

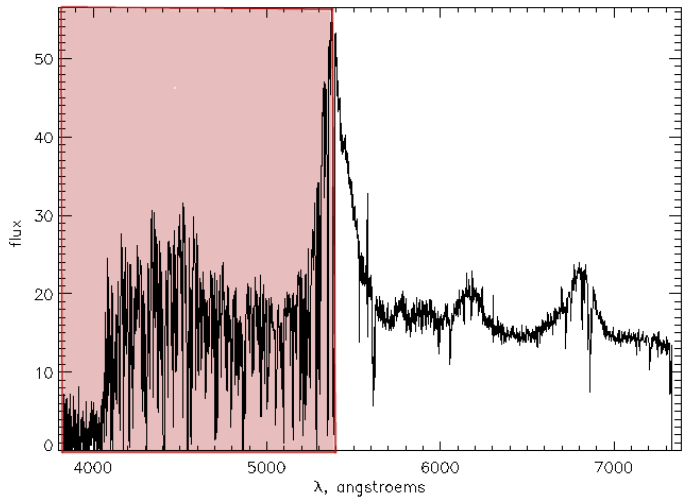
$$\Downarrow$$

forest of absorption lines with

$$\lambda \leq 1215.67(1 + z_{\text{qso}})$$



What does a measured spectrum mean?



$$\text{flux}(\lambda_{obs}) = \text{initial spectrum} \times (\bar{F} + \delta F_i) + \text{noise}$$

$\bar{F} = \bar{F}(z)$ can be determined with high precision only with large samples

$\Downarrow$

SDSS (low S/N)

$\Downarrow$

need composite spectra

$$\langle \text{flux}(\lambda_{obs})_i \rangle = \langle \text{spectrum}(\lambda_{rest}) \rangle \times \left(\bar{F} + \langle \delta F_i \rangle\right) + \langle \text{noise} \rangle$$

$\Downarrow$

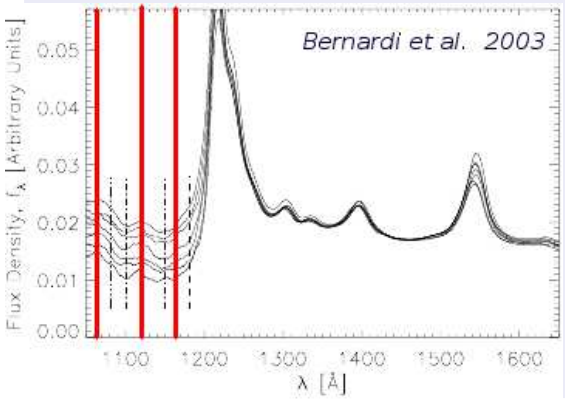
$$\langle \text{flux}(\lambda_{obs})_i \rangle = \langle \text{spectrum}(\lambda_{rest}) \rangle \times \bar{F}$$

$\Downarrow$

precise spectrum $\Longrightarrow$ precision in $\bar{F}$ $\Longrightarrow$ precision in δF $\Longrightarrow$ precision in $P(k)$

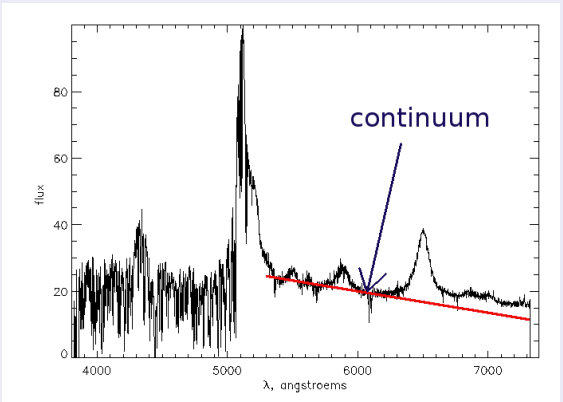
The problem with composite spectra of quasars

The problem...

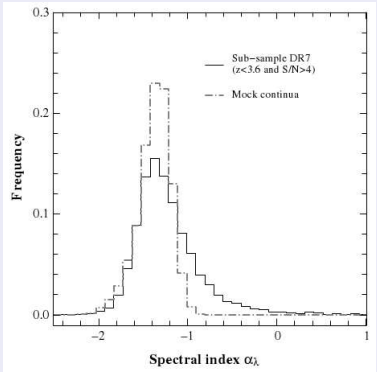


all studies of quasar composite spectra and on their usage in Lyα studies reveal only 2-3 lines between Lyα and Lyβ with uncertain λ_0, which vary from author to author

... and its reason and solution



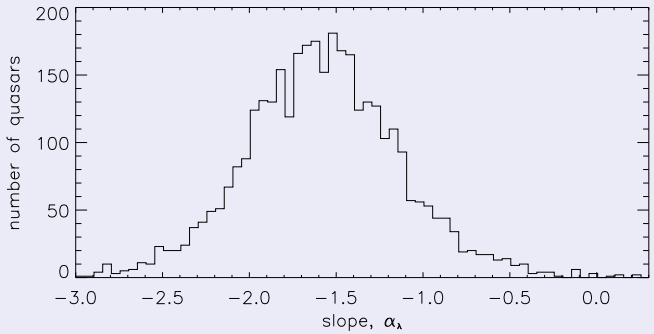
the spectra are similar, but:
different slopes of continuum!
$\Longrightarrow$
what if we combine
spectra with similar α?



The data and binning

The sample

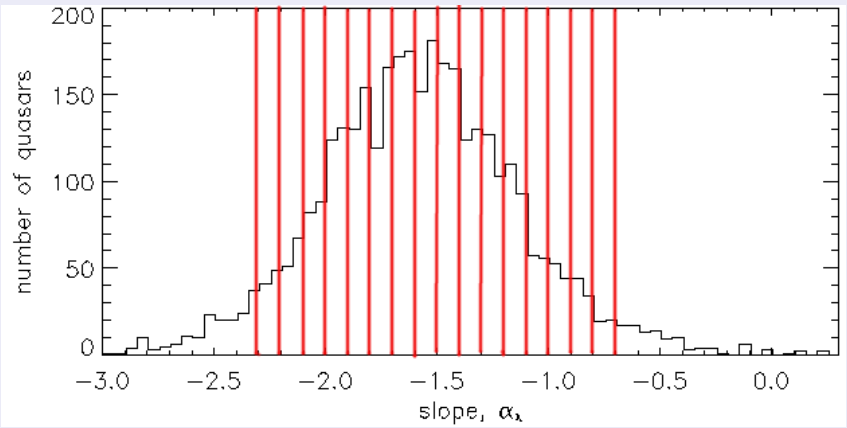
- from SDSS DR7 (*Abazadjian+09*)
- $2.3 < z < 4.4$ & $z_{conf} > 0.9$
- by-eye examination (no BALs & DLAs)
- new z from *Hewett & Wild, 2002*
- $\Rightarrow$ 3493 quasar spectra



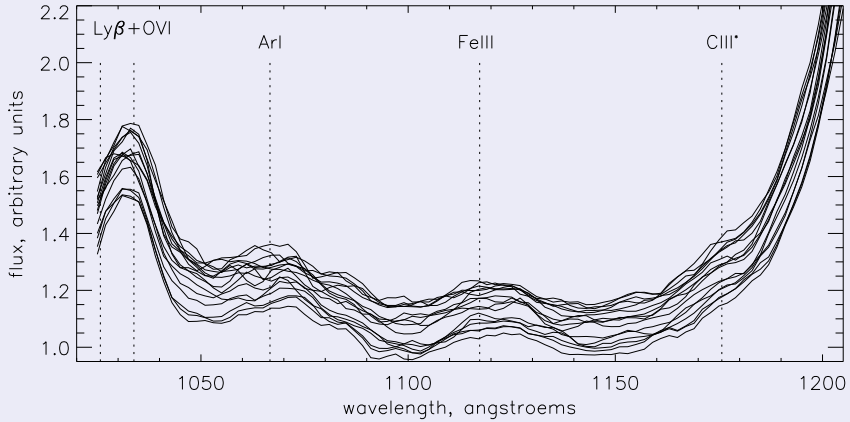
α_λ distribution

α_λ-binning

16 subsamles each of 200 spectra with α_λ close to $-0.7 - k \cdot 0.1$, $k = 0..15$



The subsamples



The composite spectra

The technique: step by step

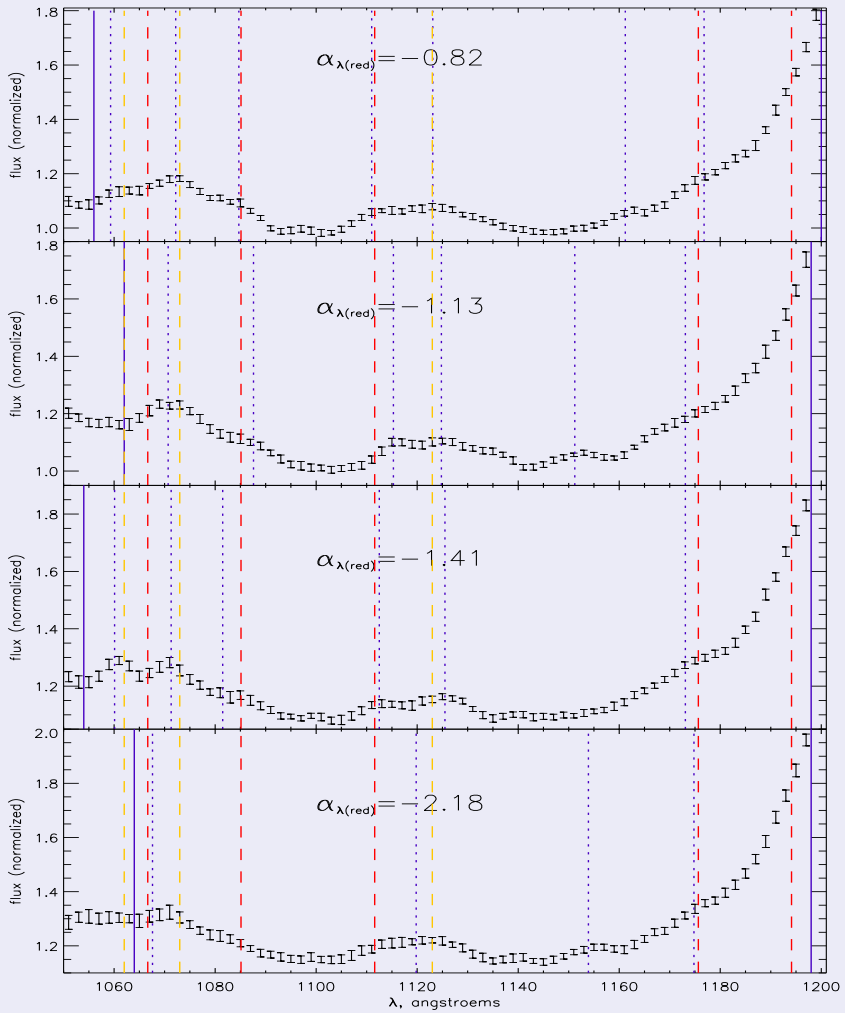
- consider each of 3 spectra features as a multiplet (not a single line!)
- forget about "power low" continuum in forest region
- λ_0's $\Leftarrow$ fitting each multiplet with `IDL lmfit` subroutine, assuming

$$\text{flux} = b_1 + \sum_{i=1}^{N} a_i \exp\left[-\frac{(\lambda - \lambda_0^j)^2}{2w_i^2}\right] \quad (N = 1..4)$$

- line parameters $\Leftarrow$ fitting the same multiplets with MCMC method with the `CosmoMC` package with the same model with fixed central linewidth

Identifications of lines and their λ_0's

"Our" and "known" lines



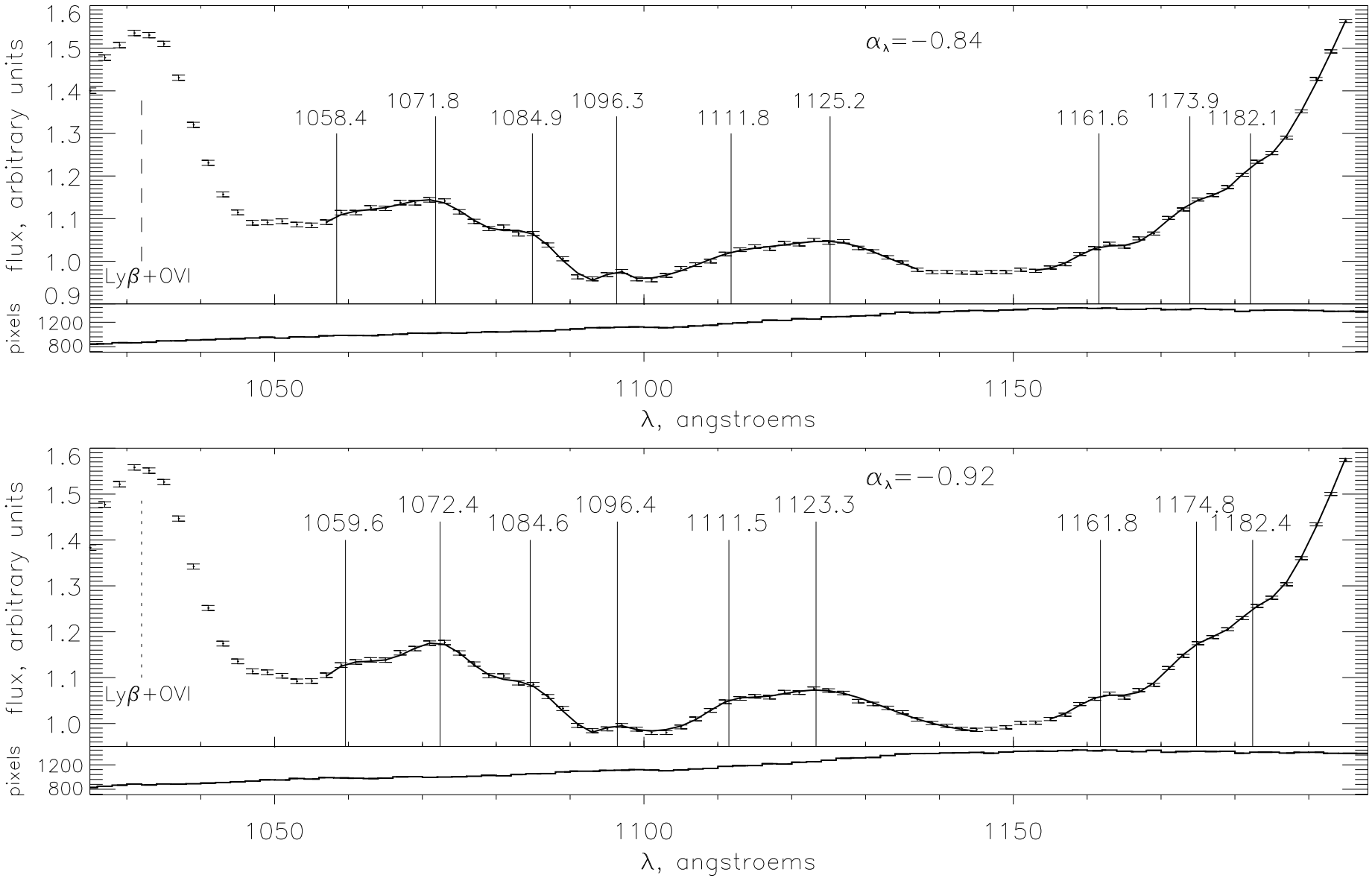
The "known" lines:

- S IV+ArI+S IV+NII(+HeII) (1062/1066.66/1073/1085.12/?)
- Si III*+Fe III (1111.59/1123)
- C III*+Si II+Lyα (1175.67/1194.12/1215.67)

Possible reasons of discrepancies:

- intrinsic line shifts
- unknown lines
- systematic errors

Couple of resulting composite spectra ...



The lines found in spectra... ...

Table: Emission lines found in spectra. Lines in backets are dublets in case of triplets. Arrows stand for failed fit.

	1	2	3	4	5	6	7
	?	?+ArI+?	NII+?	?+?	FeIII-multiplet	?	?+CIII*+?
1	$\longrightarrow$	1058.4+[1071.8]	1084.9	1096.3	1111.8+1125.2		1161.6+1173.9+1182.1
2	$\longrightarrow$	1059.6+[1072.4]	1084.6	1096.4	1111.5+1123.3	tent.	1061.8+1174.8+1182.4
3	$\longrightarrow$	1059.5+[1073.9]	1086.1	1096.9	1118.3+1125.7+1134.4	tent.	1061.4+[1176.5]
4	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$	tent.	1117.0+1126.2+1136.5	$\longleftarrow$	$\longleftarrow$
5	$\longrightarrow$	tent.+ [1070.7]	1087.6		1115.2+1124.4+1136.2	1052.3	1171.8
6	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$	1100.9	1116.9+1125.0+1132.4	tent.	tent.+[1174.2]
7	$\longrightarrow$	1061.6+[1071.1]	1079.3+1091.0		1108.4+1116.6+1127.0+1143.9		tent.+[1171.9]
8	$\longrightarrow$	1060.3+[1071.3]	1080.8	1098.5	1111.5+1125.4+1141.0	tent.	1172.4
9	$\longrightarrow$	tent.+[1070.2]	1086.0	$\longleftrightarrow$	$\longleftrightarrow$	tent.	$\longleftarrow$
10	$\longrightarrow$	1056.3+[1071.7]	1086.8	1099.6	1117.3+1127.4+1141.7	tent.	1063.7+[1174.2]
11	$\longrightarrow$	1058.1+[1070.4]	1079.9		1106.7+1115.7+ 1125.6	tent.	[1068.5]+1178.5
12	$\longrightarrow$	[1063.0]+1074.1	1084.0		1115.5+1123.8+1129.0		tent.+1172.9+1178.5
13	$\longrightarrow$	[1063.8]+1072.6	1082.0+1087.5	1103.3	1111.9+1124.3+1135.9	1053.9	1164.1+[1175.6]
14	$\longrightarrow$	$\longrightarrow$	$\longrightarrow$	1101.6	1116.2+1126.2+1135.5	tent.	1172.0
15	1055.8	[1066.6]+1072.5	1083.2	tent	1108.3+1117.3+1125.5+tent.	$\longleftarrow$	$\longleftarrow$
16	1052.4	1060.6+[1071.4]	1083.1	tent.	1111.3+1123.7+1140.1	1155.8	1165.7+[1174.2]

Conclusions:

- A new method for the composite quasar spectra generation is proposed, which allowes to increase a signal-to-noise ratio of the spectra;
- Up to 15 lines were found within $1050 < \lambda < 1200$ Å; most of them were previously found only in high-resolution ground-based spectra of single quasars, or in AGN UV composite spectra from HST and FUSE;
- Obtained results could be used for more precise measurements of two-point statistics of the Lyα-forest region.