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Evolution of Ly_α Forest in Redshift Range $0.5 < z < 3.4$

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Abstract. We collect 23 spectral data from literature, which is regarded as a relatively sufficient sample. The evolution index γ was calculated to study the evolution of Ly_α line density of Ly_α forest. This paper discusses the relationship between the evolution with the redshift in different interval threshold of column density. The results are in accordance with the results of previous research.

Key words. Ly_α forest: evoution—Ly_α absorption line—column density—evolution.

1. Introduction

A large number of absorption lines in quasars spectra short-wavelength of the Ly_α emission line is composed of Ly_α absorption lines arising in intergalactic gas clouds along the line-of-sight, in general, which is called Ly_α forest. So far, research has been done for about 30 years on Ly_α forest. In recent years, using earth-based and space telescopes, research has made a great progress. A large number of studies show that line density of Ly_α forest increase as z increases, which is known as evolution of Ly_α forest.

The research of Ly_α forest is very important, as it provides a great deal of early universe information. It also provides information about the formation and evolution of early universe. So far, research is being carried out using low- and medium-resolution spectra, but blending lines in shortward of Ly_α emission lines is very serious. Therefore, it is necessary to research using high-resolution spectra.

In recent years, there are many using high-resolution to do research on the evolution of Ly_α forest. For example, Cristiani and his colleague researched 3 samples of spectra which are R 22000 ($\log N_{\rm HI} > 13.8$), and found that $\gamma = 1.86 \pm 0.21$; Giallongo researched 10 samples of spectra which are R 25000 ($\log N_{\rm HI} > 14.0$), and found that $\gamma = 2.7$. Kim's group researched 5 samples of quasar which was got from HIRES on the Keck telescope and they found that $\gamma = 2.78$. But we researched hence, involving a few quasars, and it is necessary to use a bigger sample.

We collected 23 spectral data from literature, consisting of sufficient samples and studied the line evolution of Ly_α forest using evolution index γ, in order to study the relationship between evolution and redshift, column density.

2. Evolution of Ly_α forest

2.1 *Properties of evolution of Ly_α forest*

Through observed data, the number of Ly_α absorption lines per unit redshift have a relationship with redshift, called 'evolution of Ly_α forest', and can be expressed as

$$\frac{\mathrm{d}n}{\mathrm{d}z} = \left(\frac{\mathrm{d}n}{\mathrm{d}z}\right)_0 (1+z)^\gamma, \qquad (1)$$

where $\frac{\mathrm{d}n}{\mathrm{d}z}$ represents the number of Ly_α absorption lines in the interval width of unit redshift (z); when z is equal to zero, $\left(\frac{\mathrm{d}n}{\mathrm{d}z}\right)$ is represented by $\left(\frac{\mathrm{d}n}{\mathrm{d}z}\right)_0$, and γ is the evolution index.

In general, we are using maximum likelihood estimation to do a statistical research. For $1.7 < z < 4$, the evolution of Ly_α forest is very strong when $\gamma > 1$. For example, Scott did a research with 99 spectra ($1.6 < z < 4$), which were low and medium-resolution, and found that $\gamma = 1.88 \pm 0.22$. The results were in accordance with previous results. For high-resolution spectra which was obtained from VLT/UVES, Kim's group got $\gamma = 2.19 \pm 0.27$. The above two researches have shown that evolution is very strong among $1.7 < z < 4$. In case of $z < 1.7$, HST's data have

Table 1. Parameter of quasars.

QSO	z_{em}	λλ	n	References
PG 1634 + 706	1.34	1865–2790	195	Janknecht *et al.* (2006)
PKS 0232 – 04	1.44	2280–2940	128	Janknecht *et al.* (2006)
PG 1630 + 377	1.48	2279–3009	118	Janknecht *et al.* (2006)
PG 0117 + 213	1.5	2279–3009	160	Janknecht *et al.* (2006)
HE 0515 – 4414	1.719	3090–3260	220	Janknecht *et al.* (2006)
HE 0141 – 3932	1.8	3061–3384	97	Janknecht *et al.* (2006)
HE 2225 – 2258	1.89	3057–3478	130	Janknecht *et al.* (2006)
HS 0747 – 4259	1.9	2140–3484	189	Janknecht *et al.* (2006)
HE 0429 – 4901	1.94	3188–3538	88	Janknecht *et al.* (2006)
Q 1331 + 170	2.08	3246–3525	69	Kulkarni *et al.* (1996)
Q 1101 – 264	2.145	3230–3778	278	Kim *et al.* (2002)
J 2233 – 6066	2.238	3400–3850	226	Kim *et al.* (2001)
HE 1122 – 1648	2.4	3500–4091	424	Carswell *et al.* (2002)
HE 2217 – 2818	2.413	3350–4050	262	Kim *et al.* (2001)
QSO 2206 – 199	2.574	3771–4334	100	Rauch *et al.* (1993)
HE 1347 – 2457	2.617	3760–4335	363	Carswell *et al.* (2002)
HS 1946 + 7658	3.05	4255–4927	122	Kirkman & Tytler (1997)
Q 0636 + 680	3.174	4314–4893	307	Gurvits *et al.* (1994)
PKS 2126 – 158	3.27	3160–3892	188	D'Odorico *et al.* (1998)
Q 0302 – 003	3.281	4808–3598	265	Hu *et al.* (1995)
Q 0956 + 122	3.301	4414–4976	241	Hu *et al.* (1995)
Q 0014 + 813	3.384	4509–5098	263	Carswell *et al.* (1994)
Q 0055 – 269	3.655	4852–5598	535	Kim *et al.* (2002)

Table 2. Fit parameters of the number density distribution for different conditions.

z	$\log N_{\rm HI}$	γ
0.5–1.7	12.80–14.00	0.54±0.17
0.5–1.7	13.60–16.00	3.85±1.06
1.7–3.4	12.80–14.00	2.28±0.14
1.7–3.4	13.60–16.00	2.99±0.57

shown that $\gamma = 0.5$, which has almost no evolution. Janknect's group researched $0.5 < z < 1.9$ and found that $\gamma = 0.78 \pm 0.27$ when $\log N_{\rm HI} = 13.10 - 14.00$, and $\gamma = 1.66 \pm 0.06$ when $\log N_{\rm HI} > 13.64$.

2.2 *Data analysis*

2.2.1 *Sample.* Table 1 gives an overview of quasars, whose quasars are selected to analyse the Ly$_\alpha$ forest. We list their emission redshift z_{zm}, wavelength regions $\lambda\lambda$, number of detected Ly$_\alpha$ absorption lines, and reference literature. We selected quasars with emission redshifts suitable to show the evolution of Ly$_\alpha$ forest at $0.5 < z < 3.4$.

2.2.2 *Data analysis.* In this paper, we divide a sample into four subsamples. We use the column density range $12.80 < \log N_{\rm HI} < 14.00$ for weak lines, and $13.6 < \log N_{\rm HI}$ for strong ones. These intervals are frequently used in the literature (Janknecht *et al*. 2002; Weymann *et al*. 1998; Kim *et al*. 2001; Dobrzycki *et al*. 2002). Finally, we perform statistical calculation using maximum likelihood estimation.

Table 2 summarizes the results for the fit parameters γ and $\left(\frac{{\rm d}n}{{\rm d}z}\right)_0$ for different column density regions and different redshift regions.

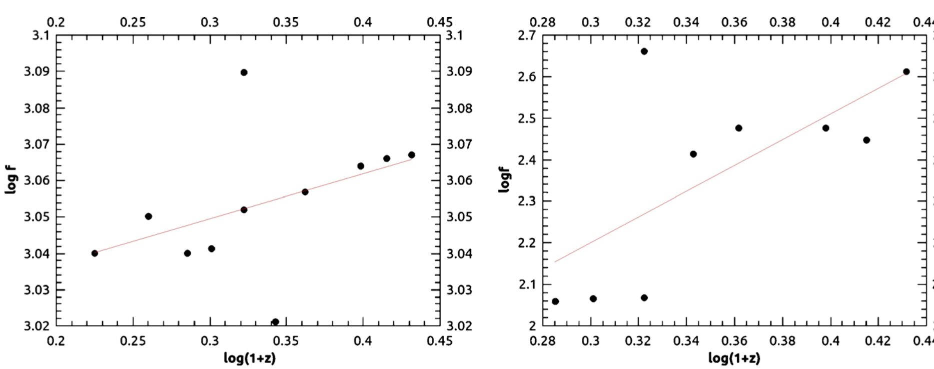

Figure 1. *Left panel*: Study of the number density evolution of the absorbers with $12.80 < \log N_{\rm HI} < 14.00$. The Ly$_\alpha$ lines of this work are binned in $\Delta z = 0.1$ ($0.5 < z < 1.7$) intervals. *Right panel*: Study of the number density evolution of the absorbers with $13.60 < \log N_{\rm HI} < 16.00$. The Ly$_\alpha$ lines of this work are binned in $\Delta z = 0.1$ ($0.5 < z < 1.7$) intervals.

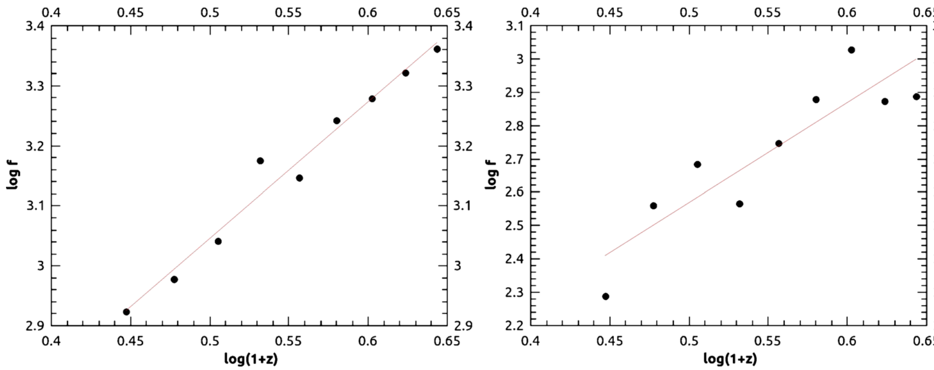

Figure 2. *Left panel*: Study of the number density evolution of the absorbers with $12.80 < \log N_{\mathrm{HI}} < 14.00$. The Ly_α lines of this work are binned in $\Delta z = 0.1\,(1.7 < z < 3.4)$ intervals. *Right panel*: Study of the number density evolution of the absorbers with $13.60 < \log N_{\mathrm{HI}} < 16.00$. The Ly_α lines of this work are binned in $\Delta z = 0.1\,(1.7 < z < 3.4)$ intervals.

2.2.3 *Discussion*

(1) Table 2 represents the statistical results of Ly_α absorption lines in different z intervals and $\log N_{\mathrm{HI}}$ intervals. We found that weak lines in the interval $0.5 < z < 1.7$ show no evolution, while the strong lines in the interval $0.5 < z < 1.7$ show evolution intensely. Both strong or weak lines in the interval $1.7 < z < 3.4$ show evolution intensely. The above results are in agreement with past research.

(2) Keeping in mind the value of γ in different z intervals, we can fit the relation between $\log f$ and $\log(1 + z)$. But from the sample we used in this paper the fitting (Figures 1 and 2) results deviated from the theoretical results. In the future, we will compile a larger sample consisting of higher-resolution spectra to get an accurate evolutionary index.

3. Summary

From the study of spectra of 23 quasars, we found that evolution is obvious after calculating the parameter γ, the result are consistent with the past results. Since, high resolution is difficult to obtain, this paper has certain significance. We hope to master the software of processing Ly_α absorption lines to get a more complete sample.

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