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THE EVOLUTION OF LYMANα FOREST CLOUDS AT $z > 2$

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ABSTRACT

Using the Keck 10 m telescope data with the HIRES spectrograph, we analyzed the evolution of Lymanα forest clouds at $z > 2$ down to the HI column density $10^{12.8}\mathrm{cm}^{-2}$. The number density per unit column density does not change with redshifts at lower HI cloumn density ($N_{\mathrm{HI}} < 10^{14}\mathrm{cm}^{-2}$), while the forest clouds at higher column density disappear rapidly. The cutoff b value, the thermal temperature indicator, increases as redshift decreases. The correlation strength seems to be stronger as redshift decreases.

Key Words : astronomy, astrophysics

I. INTRODUCTION

Lyα forest clouds refer to numerous narrow absorption lines in the spectra of high redshift QSOs, which are produced by intervening neutral hydrogen clouds ($N_{\mathrm{HI}} < 10^{17}\mathrm{cm}^{-2}$) along the lines of sight towards QSOs. Although the true origin of Lyα forest clouds is still uncertain, they are the only normal materials observable up to $z \sim 5$. This advantage provides us to study the structure of materials in the early universe, structure formation, and galaxy formation.

During the past 15 years, Lyα forest clouds were interpreted as pressure-confined intergalactic prestine clouds (Sargent *et al.* 1980) or large haloes or satellites around intervening galaxies. However, recent detections of metal lines in the forest clouds (Cowie *et al.* 1995) indicate that they are closely connected to galaxies. Moreover, recent CDM numerical simulations (Cen *et al.* 1994, Zhang *et al.* 1996) show; 1) The intergalactic medium (IGM) condenses in to a filamentary, clumpy structure producing Lyα absorption lines. 2) Most high N_{HI} clouds ($N_{\mathrm{HI}} > 10^{13}\mathrm{cm}^{-2}$) are produced in the overdensity regions, while low N_{HI} clouds ($N_{\mathrm{HI}} > 10^{11-13}\mathrm{cm}^{-2}$) are produced in the underdensity regions. 3) Most baryons at $z > 2$ are locked in to Lyα forest clouds.

The Keck 10 m telescope enables us to expand the detection limit to 10 times better than pre-Keck era. Using the data taken at the Keck 10 m telescope with the HIRES, we analyzed the properties of lower N_{HI} clouds ($N_{\mathrm{HI}} < 10^{14}\mathrm{cm}^{-2}$) with the different redshifts in order to study the evolution of Lyα clouds at $z > 2$.

II. OBSERVATION AND DATA REDUCTION

A total of 5 QSOs were observed at the Keck 10 m telescope with HIRES ($R = 36,000$) during 1994-1996. Q1623+269 was observed twice at different wavelength coverages. With a total of 6 lines of sight, we sampled three redshifts, $< z >= 2.31$ (Q1623+269, Q1700+643), $< z >= 2.85$ (Q0014+813, Q0302-003), and $< z >= 3.35$ (Q1422+231).

All spectra were fitted by the automatic fitting program and series of simulations with different cutoff b values (see III.) were produced in order to correct incompleteness. All procedures were the same as Hu *et al.* (1995). The range of N_{HI} under this study is $12.8 < Log N_{\mathrm{HI}} < 14.6$ set by blendings and noises.

III. ANALYSIS

(a) Different Density Distribution Function

At lower N_{HI}, $N_{\mathrm{HI}} < 10^{14}\mathrm{cm}^{-2}$, the different density distribution function, f (the number density per unit N_{HI}), is well fitted by a power law, $dN/dN_{\mathrm{HI}} \propto N_{\mathrm{HI}}^{-\beta}$, with $\beta \sim 1.5$ at different redshifts. However, at higher N_{HI}, $N_{\mathrm{HI}} > 10^{14}\mathrm{cm}^{-2}$, the deviation from the power law occurs at different N_{HI} with different redshifts. The deviation N_{HI} gets larger as redshift increses. The uncertain ionization fraction can not account for the disappearance of higher N_{HI} clouds as redshift decreses. The number density per unit redshift of the forest clouds with $N_{\mathrm{HI}} > 10^{13.8}\mathrm{cm}^{-2}$ shows the rapid evolution of higher N_{HI} forest clouds.

(b) Cutoff b Values

The cutoff b values, b_c, (the b value is the thermal temperature indicator) were introduced by Hu *et al.* (1995) to explain the b - N_{HI} diagram. They interpreted the lack of small b value in the forest clouds as existance of uniform temperature in the forest clouds, while larger b values are produced by the blending effect. The simulations show that the b_c value changes with redshifts. At $< z >= 2.31$, the b_c value is 22 km/sec. At $< z >= 2.85$, the b_c value is 20 km/sec. At $< z >= 3.15$, the b_c value decreases to 17 km/sec. Lu (1995) found the b_c value at higher redshift, $< z >= 3.8$, is 15 km/sec. This indicates that the thermal temperature of Lyα forest clouds increases as redshift decreases. Songaila and Cowie (1996) took one possible interpretation of the temperature changes in the forest clouds. The HeII ionization occurring at $z \sim 3.1$ can explain the b_c values at $< z >= 2.85$ and $< z >= 3.15$. However, this does not account for the b_c values at $< z >= 3.8$ and at $< z >= 2.31$.

(c) Correlation Function

At different redshifts, the correlation function seems to get stronger as redshift decreases. However, in the sense of big gap from $< z >= 2.31$ to the highly correlated present day galaxies, the interpretaion of correlation strength is rather ambiguous.

IV. SUMMARY

1. At the HI column density range, $12.8 < LogN_{\rm HI} < 14.6$, the number density per unit $N_{\rm HI}$, f, at the lower $N_{\rm HI}$ clouds ($N_{\rm HI} < 10^{14}{\rm cm}^{-2}$) does not change with redshifts. On the other hand, the higher $N_{\rm HI}$ clouds ($N_{\rm HI} > 10^{14}{\rm cm}^{-2}$) rapidly disappear as redshift decreases. 2. The cutoff b value in the forest clouds increases as redshift decreases. 3. The correlation strength in the forest clouds seems to be stronger as redshift decreases, indicating hierarchical clustering.

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