Studies of QSO Absorption Line Systems with Near-Infrared High Resolution Spectroscopy

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Abstract

There are strong needs for high sensitive near-infrared (NIR) high-resolution spectrograph for a variety of science. High-resolution spectroscopy of high-redshift QSOs will be one of the key science which reveals the chemical enrichment history of the high-z universe. Although existing NIR spectrographs at 8m-class telescopes started to see the high-z metal absorption systems for brighter QSOs, next generation spectrograph with more sensitivity and higher resolution is definitely necessary for extensive study of QSO absorption systems at z=3-5. ELT with high-resolution NIR spectrograph will accelerate this scientific area by revealing the chemical enrichment history at very early phase of galaxy formation at z=6-7. Here we summarize the current status, the next step with new instruments, and the future prospects of this field to enforce the strong needs of such spectroscopic capability for ELTs.

1 Introduction

QSO absorption lines are powerful tool to study nucleosynthesis and chemical enrichment in the earlier epochs of the universe, spanning redshifts from 2<z<5.

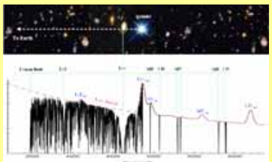

Figure 1 . QSO absorption spectra
On the long journey from its source to our telescopes on Earth , the light from a background QSO intercepts galaxies and intergalactic matter which happen to lie along the line of sight. (Pettini astroph/030327v1)

Measurement of metallicities of the z>3 absorbers offers an excellent method to directly study the chemical evolution concerning galaxy formation. Pettini et al. (1997) have measured metallicities in many DLAs using ZnII, which is a good tracer of the gas-phase metallicity since zinc is thought not to be significantly depleted onto the dust grains. Because chromium is heavily depleted, the column density ratio of **ZnII** and **CrII** is the indicator of dust depletion. Because the same relationship applies to sodium and calcium, the ratio of **NaI** and **CaII** also serves as a good indicator. While the iron is mainly produced by type Ia supernovae, magnesium is produced mostly by type II supernovae. **Mg**/**Fe** is the indicator of the chemical enrichment history of ISM by type Ia supernovae. Because manganese is mostly produced by type Ia supernovae compared to iron, **Mn**/**Fe** essentially acts as Mg/Fe. Because the absorption lines are weak and narrow, high resolution spectroscopy is necessary. So far, QSO absorption lines are extensively studied in optical with high resolution spectrographs such as Keck HIRES and VLT UVES. However, major and important QSO metal absorption lines at high redshift shift into near-infrared as Figure 2 showed.

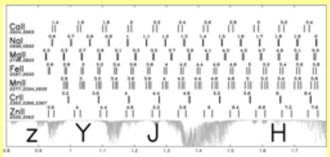

Figure 2. Wavelength shift of high-z metal absorption lines
The tick marks with numbers show the location of redshifted lines. The bottom plot with thin line shows the simulated telluric transmission curve at Mauna kea by HITRAN software (thanks to Mr.Ichizawa at Genesia Corporation)

The advent of high sensitive and high resolution spectroscopy in the near-infrared with the 8m-class telescopes has recently enabled the observation of such high-z QSO metal absorption lines.

2 Current Status with Existing NIR Echelle Spectrographs

High sensitive spectrographs such as Keck NIRSPEC (McLean et al. 2000) or Subaru IRCS (Kobayashi et al. 2000) have the capability of obtaining high S/N spectra of brighter QSOs down to **J=17mag**. Figure 3 shows an example with Subaru IRCS. Although new state-of-the-art facility instrument such as VLT CRIRES (Käufl et al. 2004) is coming on-line, alternative next generation instrument is necessary for sensitive observations of fainter QSOs.

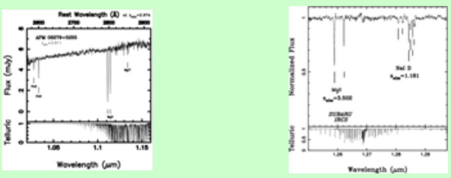

Figure 3. Near-infrared 1.02-1.16 μm (left-side) and 1.18-1.35 μm (right-side) spectra of QSO APM08279+5255 .
Left: Mg II 2796, 2803, Fe II 2600, Fe II 2587, and probable Mg I 2852 absorption lines from z=2.974 DLA are detected. Right: Na ID 5891,5897 absorption lines form z=1.181 DLAs and Mg II 2796,2803 absorption lines from z=3.502 Lyman-limit system are detected.

3 Next Generation NIR Echelle Spectrographs

Our new spectrograph:WINERED

For advancing the study of QSO absorption line systems with NIR spectroscopy, we are developing a new type of high-resolution (R_{max}= 100,000) NIR spectrograph "WINERED", which is specifically customized for short near-infrared bands at 0.9-1.4um (see the detail of the instrument in the poster paper by Yasui et al.). This wavelength range is very essential for QSO metal absorption line studies because major metal absorption lines at high-z nicely fit into this wavelength range (see Figure 2). The major features of this instrument are summarized as follows.

Specifications of WINERED
- Wavelength range: 0.9-1.4 μm (z,Y,J band)
- R=100,000 max (ΔV=3km/s)
- High throughtput (〜0.4)
- No cryogenic optics
- ZnSe immersion grating (n=2.4)

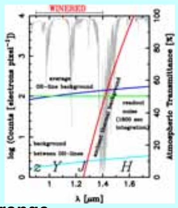

Figure 5. Background count in the target wavelength range
Observations in 0.9-1.4um is essentially readout-noise-limited and ambient thermal background is negligible.

Because of the high spectral resolution, we will be able to observe in between OH lines where the sky background is extremely low as Figure 5 shows. Because the observation is going to be essentially readout-noise-limited, we would expect high quality spectra as have been obtained in optical wavelength range.

Science with WINERED

The estimated sensitivities are shown in the following tables. This new instrument is expected to push the sensitivity limit down to **J=19mag**, which enables routine observation of z=4-5 QSOs. These number are for integration time of 8 hours (=30min×16) and S/N〜100.

R	100,000	50,000	25,000
Jmag	16.3	18.2	19.3

Between OH emission

R	100,000	50,000	25,000
Jmag	16.1	17.9	18.8

With average OH emission

The major purpose of this instrument is the study of ZnII absorption line at high-z (z > 3.5). It is possible to detect ZnII absorption lines of [Fe/H]〜-3 DLAs with log N(HI) 〜21 cm^{-2} with S/N〜100. WINERED would push the redshift limit of the zinc metallicity study up to z=5.

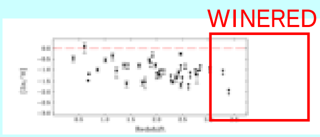

Figure 6. Target redshift of WINERED
WINERED would be able to push the redshift limit of the zinc abundance study up to z=5 (see also Figure 2).

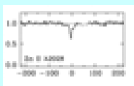

Figure 7. Example of Zn II absorption line
[Fe/H] 〜-1.2 system at z=1.01 (From Pettini et al. 2000)

5 Future Prospect with ELT

R	100,000
Jmag	20.6

If a WINERED-type instrument is installed on ELT with AO, it is possible to observe extremely fainter QSOs (**J > 20mag**), providing the first census of metallicities at z=6-7. Also, the number of observable QSOs will significantly increase and even lower-metallicity clouds can be detected. With NIR high resolution spectrograph on ELT, we would be able to get the final picture of the chemical evolution of intergalactic medium from z=7 to 0.