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THE METALLICITY OF THE MOST DISTANT QUASARS

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Quasars are among the most luminous objects in the Universe, and therefore they can be detected and investigated in detail even at very high redshifts, up to $z > 6$ (Fan et al. 2001, 2003, 2004). The prominent emission line spectrum of high redshift quasars contains important information on the enrichment history of the gas and, therefore, provide constraints on the star formation history in their host galaxies (Hamann & Ferland 1999). We investigate the metallicity of the Broad Line Region (BLR) in a sample of 27 quasars in the redshift range at $4 < z \leq 6.4$, by using near-IR and optical spectra. We focus on the ratio of the broad emission lines (SiIVλ1398+OIVλ1402)/CIVλ1549, which is a good metallicity tracer of the BLR. Here, we present measurements of the (SiIV+OIV)/CIV ratio with the goal of better investigating the metallicity evolution of quasars in the early Universe.

We observed a sample of 27 high redshift quasars ($4 < z \leq 6.4$) from the SDSS by means of near-IR and optical spectra covering the main UV rest-frame emission lines (e.g. SiIVλ1398+OIVλ1402, CIVλ1549, HeIIλ1640, CIII]λ1909).

Observations were obtained with NICS at the Telescopio Nazionale Galileo (TNG) in Spain and with FORS2 at Very Large Telescope (VLT)-ESO in Chile. observations were permormed in several observing runs from 2002 to 2005. All observations were obtained in low resolution modes (R 500 to R 75), depending on the specific instrumental setup. This low resolution is appropiate for the investigation of the quasar continuum shape, but also for the detection of broad emission lines. The quasar and standard star spectra from both observatories were procesed with standard IRAF routines. For some of the $z < 5$ quasars observed with NICS, for which no FORS2 observations were available, we combine our near-IR spectra with optical data taken from Anderson et al. (2001).

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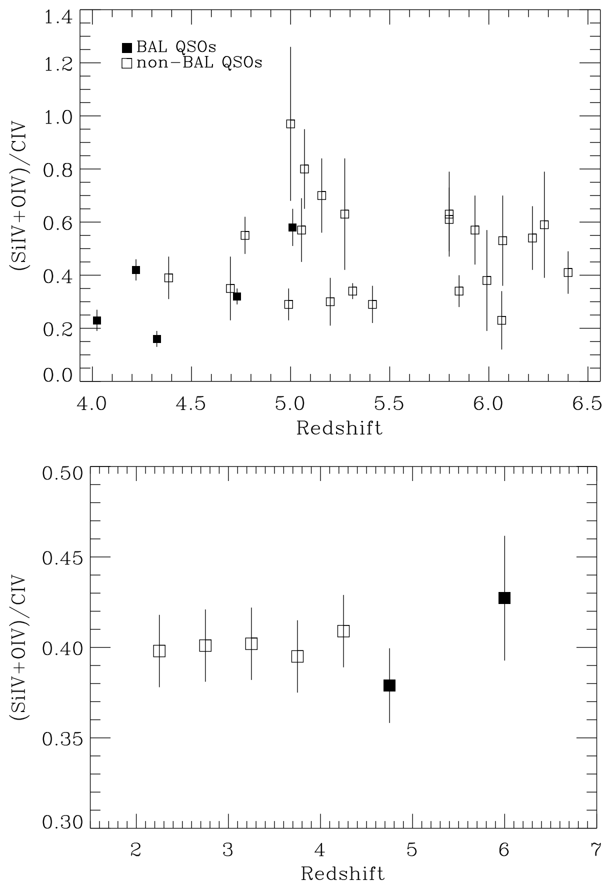

Fig. 1. Top: (SiIV+OIV)/CIV flux ratio as a function of redshift for the quasars in our sample. Bottom: (SiIV+OIV)/CIV ratio inferred from quasar stacked spectra for the high redshift quasars presented here (filled squares) and compared with the results of Nagao et al. (2006) in the luminosity range $-27.5 < M_B < -28.5$.

In order to measure emission line fluxes, the quasar spectra were fitted with a model consisting of a power-law continuum, $F_\nu \propto \nu^\alpha$, and gaussian profiles to model the emission lines. SiIV and OIV are unresolved and are fitted with a single gaussian. Five of our sources are Broad Absorption Line (BAL) quasars, in these cases the measurement of the emission line flux is more complex and uncertain because of the absorption troughs. Absorption troughs are avoided when fitting both the contiuum and the emission lines. Figure 1 (top panel)

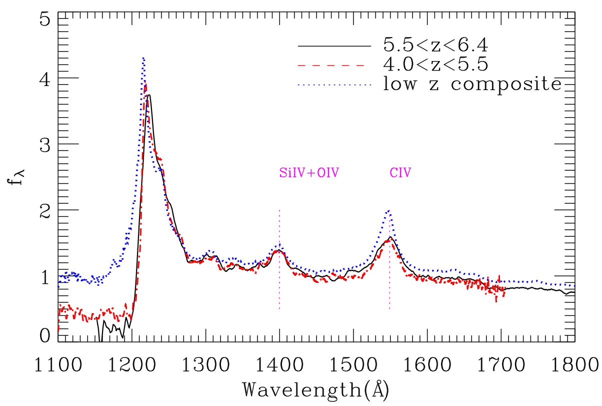

Fig. 2. Stacked spectra of quasars within the reshift bins $4 < z \leq 5.5$ and $5.5 < z \leq 6.4$. Individual spectra were normalized to continuum at 1500Å prior to averaging and avoiding BAL quasars. The solid line and the dashed line are the stacked spectra from our sample. For comparison, we also plot the low redshift quasar spectral composite from Vanden Berk et al. (2001).

shows the distribution of the (SiIV+OIV)/CIV ratio as a function of redshift. No correlation is observed between the emission line ratio (hence metallicity) and redshift. As we want to investigate the evolution of the (SiIV+OIV)/CIV ratio over a wide range in cosmic time, our results can be compared with the line ratios and metallicites inferred at lower redshifts, as obtained by Nagao et al. (2006). Figure 1 (bottom panel) shows the average spectra of $z > 4$ quasars compared with the average spectrum of luminous quasars at $2.5 < z < 4$. which are all very similar. The lack of evolution with redshift can be appreciated in this figure where we show the (SiIV+OIV)/CIV ratio measured in average quasar spectra at different redshifts.

Figure 2 shows the spectra of the quasars in our sample averaged within two redshift bins ($4 < z \leq 5.5$ and $5.5 < z \leq 6.4$), and where the relative intensities of SiIV+OIV and CIV appear almost identical in the two redshift intervals, again highlighting the lack of evolution.

The observed (SiIV+OIV)/CIV imply very high metallicities in the BLR of luminous, high redshift quasars. According to Nagao et al. (2006), the (SiIV+OIV)/CIV$\sim$0.4 observed in the stacked spectrum of the most distant quasars corresponds to a gas metallicity of $\sim 7\ Z_\odot$. Such huge metallicities were also inferred by Nagao et al. (2006) based on a much wider set of lines of lower redshift quasars.

The inferred metallicity of the BLR gas is so high (several times solar) that metals ejection or mixing with lower metallicity in the host galaxy is required to match the metallicities observed in local massive galaxies. On average, the observed metallicity does not change among the quasars in the observed redshift interval ($4 < z \leq 6.4$), nor it changes when compared with quasars at lower redshifts. The apparent lack of metallicity evolution is a likely consequence of both the black hole-galaxy co-evolution (Granato et al. 2004) and of selection effects. The data also suggest a lack of evolution of the carbon abundance, even among $z > 6$ quasars. This result is puzzling, since the minimum enrichment timescale of carbon is about 1 Gyr, i.e. longer than the age of the universe at $z \sim 6$.

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