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Emission-Line Properties of $z \geq 4$ QSOs

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Abstract. We report on preliminary results of a program of rest-frame UV spectroscopy of $z \geq 4$ QSOs. Despite their high luminosity and inherent youth, these objects exhibit spectra that are generally very similar to those of AGNs at lower z. We find some evidence that the $z \geq 4$ systems are described by unusually strong O I λ1304 emission, which may be a result of elevated metallicity or unusual prominence of the 'intermediate-line region'. High metallicities are also signaled by strong N V λ1240 emission, consistent with quasar behavior at $z \approx 2$–3.

1. Introduction

Opportunities for the study of AGN properties as a function of redshift and luminosity have expanded significantly in recent years with the increasing number of QSOs discovered at $z \geq 4$. At the time of writing, 69 such objects have been reported. While all of these sources have been observed spectroscopically, the available data often have limited signal-to-noise ratio or are optimized for study of intervening absorption lines; only sparse efforts have been directed at the systematic study of the emission characteristics of these sources.

We have consequently undertaken a program of $z \geq 4$ QSO spectroscopy using the Multiple Mirror Telescope, with data spanning the far-red bandpass corresponding to rest-frame Lyα λ1216 through He II λ1640. The goal of this project is to examine the emission characteristics of these extreme objects in comparison with their lower-redshift and lower-luminosity counterparts. Of particular interest in this regard is the behavior of the N V λ1240 line, which can be used as a diagnostic of metallicity within the broad-line region (BLR). In this contribution, we report preliminary results from spectra of 15 of these objects. These targets were selected from the list of known sources on the basis of their observability.

2. General Results

An average spectrum of 13 $z \geq 4$ QSOs is shown in Fig. 1 (2 sources are excluded due to severe absorption features).

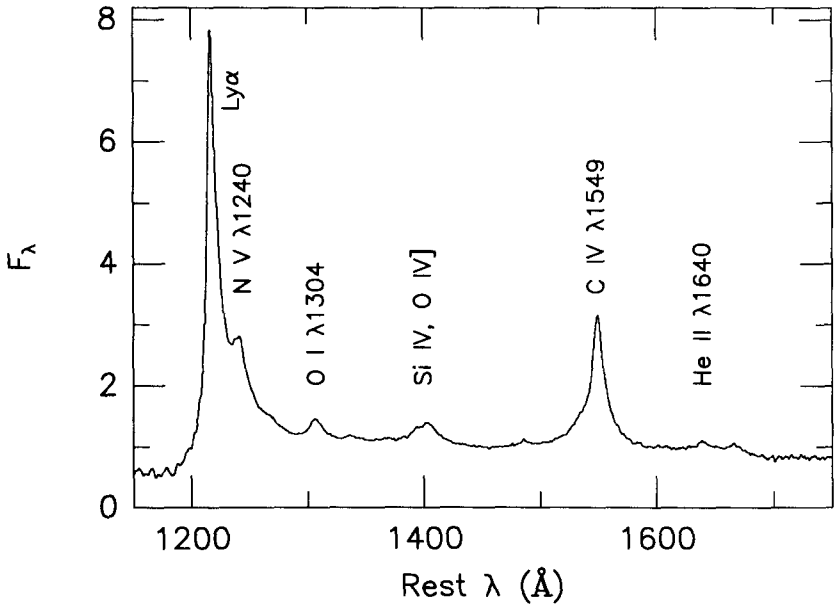

Figure 1. Average spectrum of 13 $z \geq 4$ QSOs observed with the MMT.

The general appearance of this composite is similar to that of average spectra constructed from lower-redshift samples. This similarity is borne out quantitatively by comparison of the luminosity dependence of the C IV λ1549 equivalent width at $z \geq 4$ with the negative correlation found at $z \approx 2$–3 (i.e., the Baldwin effect; Baldwin 1977); see Fig. 2. The level of scatter seen in the $z = 4$ systems is similar to that found at lower redshift (e.g., Osmer et al. 1994).

The $z \geq 4$ spectra exhibit additional systematic behaviors seen in lower-redshift AGNs. Equivalent width and line peak-to-continuum ratio show a negative correlation with line velocity width. Lines of different ionization also exhibit a pattern of characteristic offsets in relative velocity (see also Storrie-Lombardi et al. 1996).

3. O II Emission and the Intermediate-Line Region

One possibly exceptional aspect of Fig. 2 is the strength of emission in O I λ1304. The $z \geq 4$ QSOs show equivalent widths for this line that are often $\sim 50\%$ larger than typical values for lower-redshift systems. This line is believed to be dominated by fluorescence pumped via line coincidence with H I Lyβ. The strength of this feature may stem from high oxygen abundance in the emission plasma, or other factors influencing the fluorescence process.

The $z \geq 4$ QSOs also show some tendency to exhibit narrow lines with large peak-to-continuum ratios, which may signal an unusually prominent role for the so-called 'intermediate-line region' (Francis et al. 1992; Brotherton et al. 1994;

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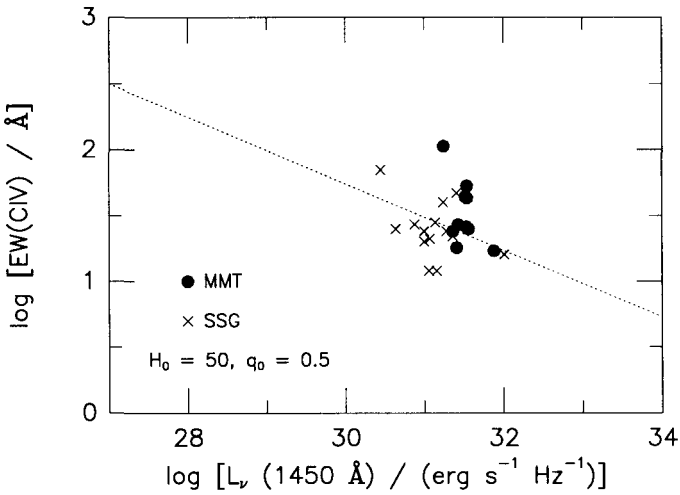

Figure 2. Equivalent width of C IV emission as a function of luminosity measured at rest-frame 1450 Å, for $z \geq 4$ QSOs. Filled points are MMT QSOs with photometry taken from Storrie-Lombardi et al. (1996); crosses represent published measurements from Schneider et al. (1991). The dotted line is the observed correlation found by Osmer et al. (1994) for QSOs at $z < 4$.

Baldwin et al. 1996). This subcomponent of the classical BLR is characterized by narrow line profiles and relatively strong emission in low-ionization species that may include O I.

Additional statistical study as well as consideration of possible selection effects is required before these trends can be deemed systematic attributes of $z \geq 4$ QSOs. The majority of objects we have observed to date were identified on the basis of their broad-band colors, relying in particular on the very red $B - R$ or similar color index that results when Lyα is redshifted into the R bandpass and continuum light in B is then depressed by Lyα forest absorption. The Lyα line can contribute a large fraction of the detected light in the R bandpass, and consequently objects with large Lyα equivalent width will be detected preferentially. The correlation between equivalent width and line profile (§2) could thus lead to a selection bias in favor of objects with narrow, peaky profiles.

4. Metallicity

Hamann & Ferland (1992, 1993) and Ferland et al. (1996) have discussed the use of the N V λ1240 line as a diagnostic of nitrogen abundance and overall metallicity in the emission-line plasma within AGNs. The strength of this feature in luminous QSOs can be understood as the natural consequence of secondary nitrogen production in regions of vigorous star formation, with parameters sim-

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ilar to those obtained in models of elliptical-galaxy and galaxy-bulge formation. The strong N V emission observed in QSOs at $z \approx 2$–3 can be explained if the metallicity in the emitting gas is typically a few times the solar value.

A natural question concerning the $z \geq 4$ QSOs is whether these systems also display metallicity $Z \gtrsim Z_{\odot}$. A systematic difference in these sources would not be surprising, given the short amount of time available for galaxy formation and stellar processing at $z \geq 4$. Preliminary measurements for our MMT sample yield flux ratios of N V/C IV λ1549 and N V/He II λ1640 that are similar to values seen in luminous AGNs at lower z, however, implying that QSOs at even the highest observed redshifts are still characterized by emission plasmas with super-solar metallicity. (For further details, see the contribution in this volume by Hamann et al.).

5. Summary

Despite the high luminosity and young ages of $z \geq 4$ QSOs, these objects present spectra that are generally similar to those of their less exotic counterparts at lower redshift. Our preliminary results suggest that the $z \geq 4$ sources show relatively strong O I λ1304 emission and possibly other peculiarities indicative of unusual conditions in the QSO BLRs, although selection effects may account for a part of this trend. The $z \geq 4$ objects also exhibit strong emission in N V λ1240 that is most readily explained by super-solar metallicities in the emitting matter. Completion of our ongoing spectroscopic survey will provide a strong statistical basis for examining these and other trends in these extreme AGNs.

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