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INFRARED SPECTROSCOPY OF HIGH REDSHIFT QSOs

Gary J. Hill[1]
McDonald Observatory, University of Texas at Austin

RESUMEN

Se presenta espectroscopía infrarroja de las líneas de emisión comúnmente observadas de cuatro cuasares de alta luminosidad de z≈2.3. Q0933+733, Q1225+317, Q1246-057 y Q1413+177 fueron observados en la banda de hidrógeno, con una resolución de 1600 km/s, cubriendo la región espectral alrededor de Hβ, incluyendo las líneas [O III] $\lambda\lambda$ 5007, 4959 y los complejos ópticos de Fe II. En comparación a los QSOs de bajo corrimiento al rojo, de menor luminosidad, los QSOs de mayor corrimiento al rojo tienen [O III] débil, anchos equivalentes pequeños de las líneas de Balmer y mucho mayor emisión de Fe II.

ABSTRACT

Infrared spectroscopy of familiar rest-frame optical emission lines in four high luminosity z≈2.3 QSOs is presented. Q0933+733, Q1225+317, Q1246-057, and Q1413+177 were observed in the H-band with a resolution of 1600 km/s, covering the spectral region around Hβ, including the [O III] $\lambda\lambda$ 5007, 4959 lines and optical Fe II complexes. In comparison to low redshift, lower luminosity QSOs, the high redshift QSOs have weak [O III], small Balmer equivalent widths, and much more Fe II emission.

Key words: **INFRARED: GALAXIES — QUASARS: EMISSION LINES**

1. INTRODUCTION

Recent advances in infrared (IR) detector technology now allow spectroscopic observations in the IR of comparable sensitivity to those made in the optical. In particular, it is now possible to observe the familiar rest-frame optical lines in high redshift QSOs, and we present here results from a preliminary investigation involving four z≈2.2 to 2.5 QSOs. These objects have a range of properties: Q1225+317 is radio-loud, Q0933+733 is radio-quiet, Q1246-057 and Q1413+177 are broad-absorption-line quasars, and Q1413+177 is also lensed (see Hewitt & Burbidge 1987 for references). The spectral region around Hβ is very important: the [O III]$\lambda\lambda$ 4959, 5007 lines are the easiest to detect in high redshift objects, there being no forbidden lines in the ultraviolet (UV), and the Balmer lines have been studied much more systematically than any other emission lines in AGN. In order to make direct comparisons between low- and high-luminosity QSOs it is necessary to observe the same emission lines in both low and high-redshift objects, as the high-ionization resonance lines in the rest-UV often have systematically different properties from the low-ionization lines such as Hβ in the rest-optical. The wavelength region around Hβ is ideal for this preliminary investigation as it also contains permitted Fe II emission line complexes which have been studied in detail in low redshift QSOs (e.g., Boroson & Green 1992; BG92). The presence of Fe II and the great variation in the strength of the Fe II emission lines provide a challenge to models in which all the emission lines arise from photoionization, and the behavior of these lines at high luminosity is of great interest.

[1] Visiting astronomer, Kitt Peak National Observatory, which is operated by the Association for Research in Astronomy Inc., under cooperative agreement with the National Science Foundation

2. OBSERVATIONS AND ANALYSIS

The data were obtained using the KPNO Cryogenic Spectrometer (CRSP) at the f/15 focus of the KPNO 2.1-m telescope in March of 1992. A 150 l/mm grating provided a resolution of 1600 km/s in the H-band with a 2.4 arcsec wide slit. Details of the observations may be found in Hill, Thompson & Elston (1993, HTE93) and the reader is also referred to that paper for the reduction procedures.

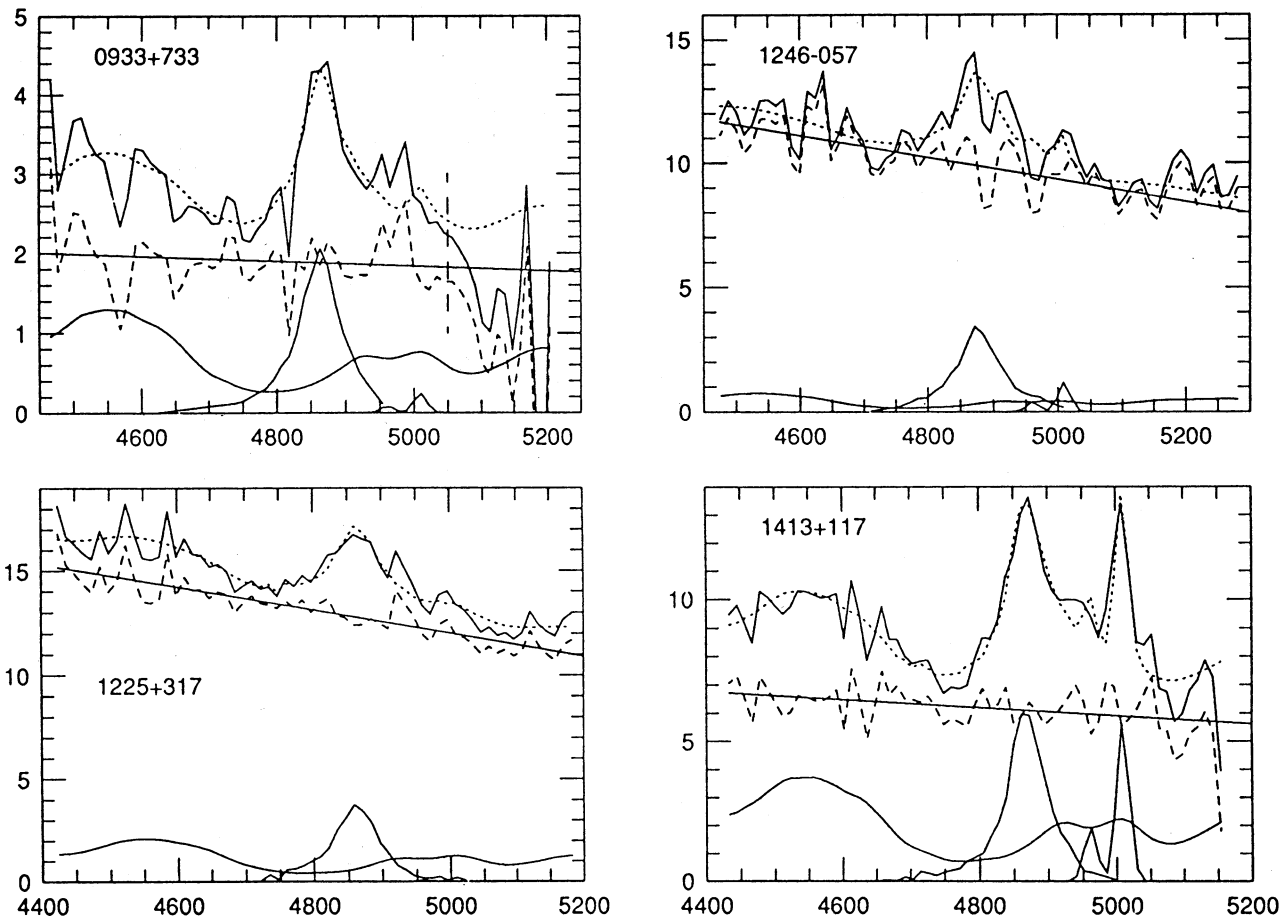

Fig. 1. — Rest-frame spectra of the four QSOs. See text for discussion.

The IR spectra are presented in Figure 1 as flux density in 10^{-16} erg/s/cm^2/Å against rest wavelength (Å). The spectra have been de-redshifted and multiplied by (1 + z) to conserve flux. Visual inspection of the spectra reveals the detection of Hβ in all the objects, and quite strong Fe II emission in Q0933+733, Q1225+317, and Q1413+117. [O III] is only detected in Q1413+117. The emission features were deblended through a least-squares fitting procedure where the Hβ line was taken to be that of Hα (from a separate set of observations, see HTE93), and the Fe II complexes were fit with a scaled spectrum of the Fe II spectrum of I Zw 1 convolved with the Hα line profile. The forbidden [O III] lines were represented by two unresolved Gaussian profiles, and a linear continuum was also included in the fit. The resultant fits are represented by dotted lines in the figure, and the residuals by dashed lines. The various components are shown as solid lines. This fitting procedure is quite similar to that used by BG92 to deblend the Fe II emission in a sample of Bright Quasar Survey (BQS) objects with $z < 0.5$, allowing direct comparison with lower luminosity QSOs. A detailed discussion of these fits can be found in HTE93, and here we restrict ourselves to a qualitative discussion of the various emission components.

3. DISCUSSION

The most striking feature of these spectra is the strength of the Fe II complexes, detected in three of the four QSOs. The signal-to-noise ratio of the 1246-057 spectrum is insufficient to rule out the presence of iron. These observations provide the first detection of the optical Fe II complexes at $z > 1.25$, as the only previously published high-resolution spectrum was of Q1331+170 (Carswell et al. 1992), which shows very strong [O III] emission but no Fe II. In contrast only one of the four QSOs in the present sample has detectable [O III] emission. This tendency towards weak [O III] and strong Fe II is consistent with the general anti-correlation observed by BG92 in their BQS sample. The weakness of [O III] suggests that these lines may not be generally useful in determining the systemic velocity of the QSO host galaxy.

In addition, a comparison with the Fe II/Hβ ratios observed in the BQS sample shows that only four of the 87 low-redshift objects have strengths in excess of the median for the four high redshift QSOs. While this result could be due to the small number statistics, we have also detected strong Fe II emission in two $z \approx 3.3$ QSOs (Elston, Thompson, & Hill 1993), indicating that strong Fe II emission may be a general feature of QSOs of high luminosity (or at high redshift).

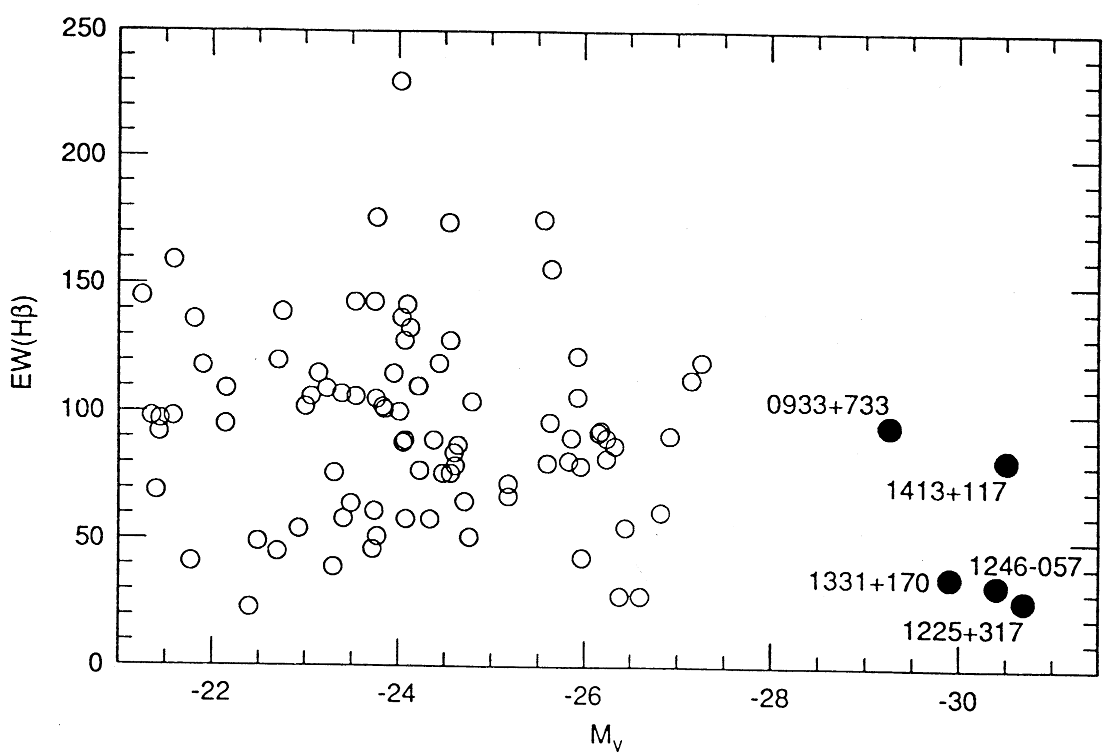

Fig. 2. — Rest-frame EW of Hβ versus absolute V magnitude for BQS (open circles) and the high redshift QSOs.

Figure 2 presents a comparison of the Hβ rest-equivalent widths (EWs) for the BQS sample of BG92 with those measured for these four high redshift QSOs and Q1331+170 (Carswell et al. 1991), which is the only other high redshift QSO with published spectroscopy of the Hβ region of sufficiently high resolution to resolve and deblend the lines. The absolute rest-frame V magnitudes are computed for $H_o = 75\ km/s/Mpc$, and $q_o = 0$. It should be noted that 1413+177 is lensed, so the intrinsic EW and absolute magnitude may be changed by unknown (and potentially different) factors.

A tendency for the high-luminosity objects to have smaller Hβ EWs is evident, as the mean EW of the high redshift QSOs is 2.7σ lower than that of the BQS QSOs. The two broad-absorption-line QSOs appear to have similar properties to the others. The trend is interesting in the context of the Baldwin effect (Baldwin 1977). The much smaller EWs seen in the high redshift QSOs may be due to a selection effect in the sense that they were selected to be bright at both optical and IR wavelengths (for ease of observation), and hence may have atypically strong continua, diluting the Hβ EW. However, this selection effect will only be evident if there is a correlation between the EW and luminosity in the first place. To test for this effect, the distributions of EWs for two subsamples of the BG92 BQS with $0.1 < z < 0.2$ and with $0.2 < z < 0.4$ were considered. Within the lower redshift subsample, the five most luminous objects have the same range and median EW as the subsample as a whole, but in the higher redshift subsample the five most luminous objects have a median EW 2.2σ lower than the median for the rest. Hence, the potential selection effect may be important, and there is probably a *real* inverse correlation between the EW and continuum luminosity. Kinney et al. (1987) discuss correlations between EW of UV lines and luminosity, and their data indicate a more pronounced anti-correlation of Lyα EW with luminosity than is seen here in Hβ. With IR spectra of QSOs over a wider range of luminosity, which can be obtained with present instrumentation on 4-m class telescopes, it will be possible to investigate such potential differences in detail.

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Gary J. Hill: McDonald Observatory, University of Texas at Austin, Administrative & Research Offices, Austin, TX 78712-1083, U.S.A.