The Astrophysical Journal, 227:L1–L3, 1979 January 1

THE HYDROGEN LINES IN THE HIGH-LUMINOSITY QUASAR B2 1225+31

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Received 1978 August 1; accepted 1978 August 31

ABSTRACT

The emission lines Hα, Hβ + [O III], and Lα have been observed in the high-redshift quasar 1225+31. The ratios of line intensities in 1225+31 are found to be Lα/H$\alpha \sim 0.8$, Hα/(Hβ + [O III]) ~ 4, and $4 <$ Hα/H$\beta < 10$. The observed value of Lα/Hα agrees well with the ratio derived by Baldwin on the basis of a composite quasar spectrum, and with direct determination of this ratio in 3C 273 and PKS 0237−23. The ratio Hα/Hβ is in the range of values found for a sample of low-redshift quasars by Baldwin. The low value for the Lα/Hα ratio cannot be reasonably explained by foreground extinction between the Sun and 1225+31.

Subject headings: line formation — quasars

I. INTRODUCTION

In the last year observations of quasars have shown that the hydrogen line spectrum differs drastically from that expected from the simplest models of the line-emitting regions. Evidence that low Lα/Hα ratios are common in quasars was presented by Baldwin (1977*a*), who showed that the ratio Lα/H$\alpha \sim 1$ for a composite quasar spectrum. Direct observations of the strength of Lα in 3C 273 (Davidsen, Hartig, and Fastie 1977), coupled with observations of its optical spectrum, have shown that the ratio of intensities of Lα/Hα in 3C 273 is $\sim$1. Hyland, Becklin, and Neugebauer (1978) observed the redshifted Hα line in the high-redshift quasar PKS 0237−23 and found that Lα/H$\alpha \sim 2$ for this quasar. These observations disagree with the simple theories of quasar line-emitting regions (e.g., Davidson 1972; Scargle, Caroff, and Tarter 1974) that predict Lα/H$\alpha \sim$ 10–20.

Because of the importance of these results for understanding the physical conditions in quasar line-emitting regions, we have begun a program of measuring the available infrared and optical lines in a large sample of both low- and high-redshift quasars. In this *Letter* observations of the Balmer and Lyman lines in the very luminous, high-redshift ($z \sim 2.2$) quasar B2 1225+31 (Ulrich 1976) are given.

Optical spectroscopy of 1225+31 has been reported by Ulrich (1976), Baldwin (1977*a*, *b*), and Wilkerson *et al.* (1978). These observations show a rich absorption-line spectrum, while the emission lines are quite broad and relatively weak in relation to the continuum.

II. OBSERVATIONS

The infrared observations of 1225+31 were obtained on 1978 March 24 UT by using the 5 m Hale Telescope at Palomar Mountain in conjunction with a liquid-nitrogen–cooled, circular variable filter wheel spectrometer with a spectral resolution of $\Delta\lambda/\lambda \approx 0.05$. Observations of both H$\alpha$ and Hβ were made at approximately half-resolution element intervals in the lines; observations in the adjacent continua were made at a lower sampling frequency. The data were corrected for instrumental response and atmospheric extinction by observing the nearby B9.5 star α^2 Canum Venatoricum both before and after the observations of 1225+31; the energy distribution of α^2 CVn over the wavelengths observed was assumed to follow a Rayleigh-Jeans spectrum. The data plotted in Figure 1 are averages of two scans of 1225+31. Also plotted is broad-band photometry at 1.25 μm ($\Delta\lambda$ = 0.24 μm), 1.65 μm ($\Delta\lambda$ = 0.30 μm), and 2.20 μm ($\Delta\lambda$ = 0.41 μm) of 1225+31 obtained at the same time as the spectrum. Both Hα and Hβ + [O III] are clearly visible in the spectrum.

The optical observations of 1225+31 were obtained with the multichannel spectrometer on the 5 m Hale Telescope on 1978 February 2 UT. The bandpass was 40 Å for wavelengths below 5760 Å and 80 Å above that wavelength. The fluxes are based on the absolute calibration of α Lyrae by Oke and Schild (1970) except that all points below 3700 Å are decreased by 6% to conform to more recent calibrations (Hayes and Latham 1975). The results are shown in Figure 1. The gap at log ν = 14.52 is caused by a bad channel in the spectrometer. Emission lines of Lα + N V 1240, λ1550 of C IV, and λ1909 of C III] are present; λ2800 of Mg II occurs at the edge of the gap at log ν = 14.52.

The strong absorption-line spectrum of 1225+31 (Ulrich 1976; Wilkerson *et al.* 1978) accounts for the ragged character of the observations above log ν = 14.9. The observed points have been deblanketed by using the absorption-line data of Wilkerson *et al.*, and the resulting "continuum" fluxes are indicated in Figure 1. The true continuum may be even higher than shown, since many weak unmeasured and blended lines may exist.

III. DISCUSSION

The redshifts derived from the C III] and C IV lines are 2.21 ± 0.02 and 2.17 ± 0.02, respectively. Because Lα may be made asymmetrical by blended absorption lines, we adopt z = 2.19 ± 0.02. This estimate lies within the range of determinations by Ulrich (1976) (z = 2.2), Baldwin (1977*b*) (z = 2.23), and Wilkerson *et al.* (1978) ($2.12 < z < 2.23$).

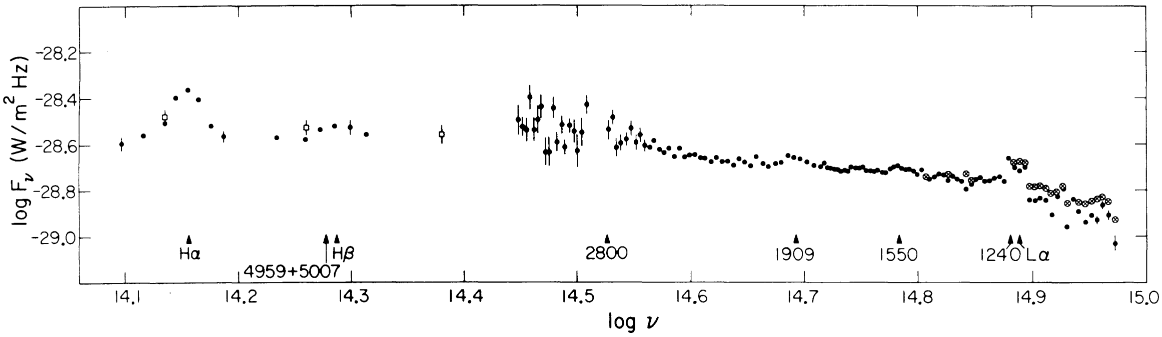

FIG. 1.—The spectrum of 1225+31 from 0.32 to 2.4 μm. *Filled circles*, observed spectrophotometric fluxes. *Open squares*, broad-band photometric observations at 1.25, 1.65, and 2.20 μm. *Circled crosses*, continuum fluxes corrected for blanketing by absorption lines (Wilkerson *et al.* 1978) within the individual bandpasses. Standard deviations are shown if they exceed 3% of the measured flux. The uncertainties in the broad-band infrared photometry include possible absolute calibration uncertainties. The triangles marking the identified lines are based on a redshift of $z = 2.19$.

TABLE 1

LINE PARAMETERS IN 1225+31

Line	z	Equivalent Width (Observed) [Å]	j(Observed) [10^{-16} W m^{-2}]
Hα	2.20±0.03	912	1.7±0.2
Hβ+[O III]	...	141	0.4±0.1
C III]	2.21±0.02	38	0.6±0.2
C IV	2.17±0.02	18	0.4±0.2
N V	...	7	0.2±0.1
Lα	...	40	1.3±0.2

The equivalent width and intensity of Lα have been determined on the basis of the deblanketed observations. The observed equivalent width of Lα + N V 1240 is 44 Å. If it is assumed that λ1240 of N V contributes 60% of the radiation in the measured point at log $\nu = 14.879$, then Lα has an equivalent width of 37 Å and N V an equivalent width of 7 Å. Alternatively, if it is assumed that the redshift of Lα is $z = 2.19$ and that Lα is asymmetrical because of absorption to the short-wavelength side of the line center, then measuring only the red half of the lines, less N V, and multiplying by 2 leads to an equivalent width of 43 Å. We adopt 40 ± 5 Å as the equivalent width of Lα. The equivalent widths of C IV and C III] are 18 and 38 Å, respectively. The observed equivalent widths of 44, 18, and 38 Å from Lα + N V 1240, C IV, and C III] can be compared with 44, 22, and 50 Å, respectively, measured by Wilkerson *et al.* (1978). The equivalent widths, converted to line intensities, are given in Table 1. Estimates of the uncertainties are also indicated.

For Hα the continuum was established by using the spectrophotometric observations both longward and shortward of Hα and the 1.25 μm broad-band datum as continuum points. The redshift derived for Hα is $z = 2.20 \pm 0.03$, and is thus consistent with those derived from the optical lines. A comparison of the width of Hα with that of unresolved lines observed with this instrument suggests that the line is partially resolved at the instrumental resolution of $\Delta\lambda/\lambda \sim 0.05$. This is consistent with the breadths of the lines observed at optical wavelengths. No correction was made to the Hα flux for possible contributions by λλ6548, 6584 of [N II]. In low-redshift quasars studied by Baldwin (1975), this flux is never more than 15% of the Hα flux and is often undetectable.

The continuum established to derive the Hα flux was also used to derive the Hβ + [O III] flux. The major uncertainty in determining the flux in Hβ + [O III] is the determination of the continuum level; because of the low contrast of Hβ + [O III] to the continuum, an error of 4% in establishing the continuum introduces a 30% change in the derived Hβ + [O III] flux. This uncertainty is reflected in the uncertainty associated with the measured flux (Table 1).

Since Hβ and [O III] 4959+5007 are unresolvable with the filter wheel spectrometer, the best measure of the relative contributions of these lines is the centroid wavelength of the combined lines; this wavelength is estimated to be 1.56 ± 0.02 μm. If z(Hβ) = z([O III]) = 2.19, and if the observed centroid wavelength is determined by the relative contributions of Hβ and [O III], the ratio Hβ/(Hβ + [O III]) = 0.7 ± 0.3, so the contribution of Hβ is a minimum of 40% of the total flux in the line. Since the ratio of [O III]/Hβ in a sample of low-redshift quasars (Baldwin 1975) is observed to range from 0 to greater than 1.5, this result is not surprising if the low- and high-redshift quasars are similar.

On the basis of the data of Table 1, the ratio of intensities of Lα/Hα 0.8 ± 0.2 and Hα/(Hβ + [O III]) = 4 ± 1. Based on the limit of the contribution from the [O III] lines, the ratio Hα/Hβ is ~6, with an allowed range of $4 < \mathrm{H}\alpha/\mathrm{H}\beta < 10$. The smaller value of $\mathrm{H}\alpha/\mathrm{H}\beta$ corresponds to assuming that all the flux observed in the 1.56 μm line is in fact Hβ, while the larger value is derived from the assumption $I(\mathrm{H}\beta) = \frac{2}{3} I([\mathrm{O\ III}])$. The ratio of $\mathrm{H}\alpha/\mathrm{H}\beta$ found in 1225+31 is thus well within the range found by Baldwin (1975) for a sample of low-redshift quasars. Furthermore, it is seen that 1225+31 has line ratios similar to those found by Baldwin (1977*a*) on the basis of a composite quasar spectrum derived from low- and high-redshift quasars. This argues against any spectroscopic distinctions between low- and high-redshift quasars.

The observation of Hβ + [O III] in 1225+31 allows additional constraints to be put on models that explain the $\mathrm{L}\alpha/\mathrm{H}\alpha$ and $\mathrm{H}\alpha/\mathrm{H}\beta$ ratios. If the true emitted line ratios are due to radiative recombinations, then the observed ratios determine the reddening between Hα, Hβ, and Lα. If the intrinsic line ratios are $\mathrm{H}\alpha/\mathrm{H}\beta \sim 2.9$ (e.g., Osterbrock 1974) and $\mathrm{L}\alpha/\mathrm{H}\alpha \sim 8$ (Miller 1974) then the observed line ratios require $0.3 < E(\mathrm{H}\beta - \mathrm{H}\alpha) < 1.3$ mag, and $2.3 < E(\mathrm{L}\alpha - \mathrm{H}\alpha) < 2.8$ mag. The high galactic latitude of 1225+31 precludes a significant contribution to this reddening from extinction in the Galaxy.

From these results, $1.8 < E(\mathrm{L}\alpha - \mathrm{H}\alpha)/E(\mathrm{H}\beta - \mathrm{H}\alpha) < 9.3$. The galactic reddening curve of Code *et al.* (1976) gives $E(\mathrm{L}\alpha - \mathrm{H}\alpha)/E(\mathrm{H}\beta - \mathrm{H}\alpha) \sim 5.8$, consistent with the range derived above. Therefore it is potentially possible to explain the observed line ratios in 1225+31 as due to galactic-like foreground reddening associated with the quasar. This simple explanation presents several conflicts with other observations. One problem is that there is no evidence for an absorption band at 2175 Å in the rest frame of 1225+31 corresponding to the strong UV extinction band seen in the Galaxy at that wavelength. Baldwin (1977*a*) could find no evidence in 1225+31 for any such absorption, and from the data of Figure 1, a conservative limit of 0.10 mag can be put on the extinction in such a band. With the reddening curve of Code *et al.*, this implies an upper limit $E(\mathrm{L}\alpha - \mathrm{H}\alpha) \lesssim 0.25$ mag, a factor of 10 lower than the reddening required to explain the line ratio. A further implication of this amount of reddening is that the emitted continuum would be altered to roughly a $f_\nu \propto \nu^{+1}$ slope between Hα and Lα, and the luminosity of 1225+31 over the wavelengths observed would be increased by over a factor of 10. These inferences are clearly not valid if the reddening applies to the emission lines and not to the continuum.

Another possibility for explaining the $\mathrm{L}\alpha/\mathrm{H}\alpha$ line ratio, discussed, *inter alia*, by Hyland *et al.*, is dust absorption in the line-emitting regions. In this model the increased path length of the resonantly scattered Lα photons provides sufficient optical depth for effective absorption by a relatively small amount of dust. The required amount of dust would not be observable in the other properties, such as 2175 Å absorption, that argue against direct foreground extinction. This model can account for the $\mathrm{L}\alpha/\mathrm{H}\alpha$ ratios, but does not account for the large Balmer decrements that are found to be common in quasars. Because the optical depths in the Balmer lines are (presumably) much less than in Lα, there is much less dust optical depth in these lines, and the smaller reddening will not produce the required Balmer decrements. London (1978) has discussed the origin of the $\mathrm{L}\alpha/\mathrm{H}\alpha$ ratio in quasars and concludes that dust-absorption models can fit the observed line ratios better than collisional excitation models. However, he notes that there are serious problems with dust-absorption models, and it cannot be concluded that such models provide a reasonable explanation of the observations.

Krolik and McKee (1978) have proposed a model where the Balmer decrement and small $\mathrm{L}\alpha/\mathrm{H}\alpha$ ratio in 3C 273 is caused by a combination of large electron density and large optical depth in Lα. The predicted line ratios in this model are extremely sensitive to both the density and the optical depth, and the apparently small variation of $\mathrm{L}\alpha/\mathrm{H}\alpha$ among the quasars thus argues against such a model where the line ratios are such a sensitive function of parameters that could reasonably be expected to vary widely among quasars. Indeed, this same argument can be used against models with dust extinction providing the cause of the observed line ratios, because it would seem that such an effect would depend critically on the dust content associated with an individual quasar.

The apparently common values of the hydrogen line ratios in quasars seem to require the explanation of these ratios be quite insensitive to the parameters that would be expected to vary widely among quasars. Until such explanations are developed, the origins of the hydrogen line ratios in quasars cannot be considered to be understood.

We thank Steve Beckwith and Gary Tuton for assistance with the infrared observations. This research was supported by NASA grants NGL 05-002-207 and NGL 05-002-134, and NSF grant AST77-20516.

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