LOW RESOLUTION INFRARED SPECTRA OF QUASARS

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Abstract

Low resolution spectra of a significant sample of quasars show that the Paschen α and Balmer line ratios do not agree with the radiative recombination case B result and vary widely within the quasars sampled. The range in Pα:Hβ ratios is a factor of ~ 6, while the range in Lyα:Hα ratios is a factor of ~ 5. For the Pα:Balmer series, the deviations from case B recombination are not consistent with reddening, but appear, within large dispersions, to be consistent with optical depth effects in the Balmer lines affecting the line ratios. The Lyα:Hα ratio is, however, correlated with the continuum spectral index, and can be explained as due to reddening affecting both the lines and continuum.

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In this paper we summarize recent observational results based on a joint infrared/optical survey of the hydrogen line spectra of a significant number of the brightest low and high redshift quasars (Soifer et al., 1980). This survey includes 12 quasars in the redshift range $0.07 \leq z < 0.30$, where the Paschen α line of hydrogen is redshifted into the 2.2 μm atmospheric window, and seven quasars with $z > 1.5$, where Hα and/or Hβ is redshifted into the 1.65 μm or 2.2 μm atmospheric windows.

For the low redshift quasars, the equivalent width of Pα in the quasar rest frame varies from ~ 200 Å to less than 30 Å. The large variation in Pα flux is reflected in a similar large variation in the ratio Pα/Hβ which is found to vary from less than 0.15 to ~ 0.9. The intensity ratios Pα:Hβ:Hα are found to deviate significantly from the nominal case B recombination theory result; the scatter between quasars is large. Although in the case of the Seyfert 2 galaxy NGC 1068 the case B recombination ratios combined with a normal extinction law can explain the observed line ratios including Lyα (Neugebauer et al., 1980), the observations of quasars do not appear to be consistent

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with this simple result. Rather the results for quasars appear to be more consistent with the deviations from case B predicted due to effects of large optical depth in the Balmer lines (Netzer, 1975; Krolik and McKee, 1978).

In addition, there appears to be no correlation in the low redshift quasars between the line ratio Pα:Hβ and the continuum spectral index measured at these wavelengths. This results seems to rule out external reddening as a dominant factor in determining the line ratios and is consistent with the result found previously by Neugebauer et al. (1979) from considerations of the lack of correlation between Hα:Hβ, and the continuum slope.

Hα and/or Hβ has been observed at infrared wavelengths in a total of seven high redshift quasars by the Caltech group. The range of equivalent width of Hα is ~ 250 Å to ~ 650 Å in the quasar rest frame, with an average of 420 Å; no attempt has been made to remove any contribution from the blended N II lines 6548+6584 (the results of Baldwin (1975) suggest these are a negligible contribution compared to the uncertainties in the measurements). This agrees remarkably well with the range and average equivalent widths (440 Å) found in the low redshift quasars.

The Lyα/Hα line ratio has been calculated for each of these quasars and is found to vary from 1 for Ton 490 to 5 in the case of 1623+26. The average value is Lyα/Hα ~ 2. This result is consistent with the previously reported deviation of the Lyα/Hα ratio by a factor of ~ 10 from that expected for simple quasar models. No account was taken of the contribution of N V to the Ly + N V total flux, but this is expected to be only ~ 20% of the total measured flux (Baldwin, 1977).

The ratio of Lyα:Hα flux may correlate with the continuum spectral index in high redshift quasars. The apparent correlation is in the sense that the decreasing Lyα/Hα ratio implies a more negative spectral index α (where $F_\nu \propto \nu^\alpha$). The low redshift quasars 3C273 and PG 0026+129 appear to obey this same relation. The slope of this correlation agrees remarkably well with the predictions for a simple model of external reddening affecting both the lines and the continuum in the same amount. Explanations of the discordant quasar line ratios as due to this effect have been put forth by Netzer and Davidsen (1979), and Shuder and MacAlpine (1979), but many problems may exist with these models. To name just two obvious ones: (1) Why do the Balmer and Paschen series lines not show any evidence for reddening? and (2) Where is all of the energy coming out? In the case of 3C273 there is no evidence of any excess energy emergant, yet the simple model predicts 3C273 is at least 10 times more luminous than observed. Clearly the apparently conflicting observations indicate that the resolution of this problem is not a simple one.

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DISCUSSION

Tyson: Why couldn't the dust be local to us?

Soifer: The agreement in the Lyα/Hα ratios in low and high redshift quasars means that if due to extinction, the extinction must be either local to the quasars or local to us. To cite a specific example, for the high redshift (z = 2.20) quasar B2 1225+31, Lyα/Hα ~ 1, so that if due to galactic extinction then A (4000 Å) ~ 3 mag. This quasar is very near the north galactic pole, where visual extinctions are likely to be a few tenths of a magnitude at most. Similar arguments can be made based on other high redshift quasars, which leads me to rule out galactic extinction as a possibility.

B.J. Wills: Soifer has suggested that the Netzer and Davidson (1979, M.N.R.A.S., 187, 871) photoionization models, including dust, may be untenable because no excess infrared emission is observed. However, the above authors have suggested that the missing energy may be radiated (perhaps by some electronic transitions on dust grains) as at least part of the 3000 Å "bump." Evidence that this "bump" is associated with emission from a large volume (e.g., the broad line emitting region) comes from spectrum time variability arguments (Netzer et al., 1979, Ap. J. (Letters), in press). If the 3000 Å bump is due to the dust causing the "Lyα/Hβ problem," then it must co-exist with or lie beyond the broad line emitting clouds; this is inconsistent with the QSO model presented by Rees (this symposium), where the "bump" originates between the continuum source and the line-emitting region.

Soifer: The problem with this explanation is the energetics of the sources. The Netzer-Davidson model predicts that quasars are intrinsically a factor of ~ 10 more luminous than their observed ultraviolet luminosities. This energy should be detectable somewhere. It does not emerge in the 3000 Å band, and in the case of 3C 273, at least, there is no observational evidence for this energy emerging at any longer wavelengths.

Smith: I have the (unquantitative) impression that the Lyα/Hα ratio is relatively stable, as if there were some regulation mechanism, while there is a larger dispersion in the Pα/Hα ratio. Do you see this in your data?

Soifer: I have not specifically looked at the Pα/Hα ratio for our sample of low redshift quasars; however the Pα/Hβ ratio varies by a factor of ~ 10. On the other hand, for the high redshift quasars, we find the Lyα/Hα ratio varies by a factor of 5. However, if the QSO 1623+26 is eliminated from our sample, the variation in this ratio is only a factor of ~ 2.

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