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OBSERVATIONS OF Fe II ULTRAVIOLET LINES IN QSOs

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ABSTRACT

Spectrophotometry of 11 intermediate redshift QSOs clearly shows the presence of a very broad emission feature from 2300 to 2600 Å and other broad features at 2748, 2950, and 3200 Å, all of which are interpreted as blended Fe II resonance lines. The strengths of these ultraviolet lines relative to those of the Fe II optical multiplets and other emission lines agree with Netzer's predictions from photoionization models of the broad-line regions of QSOs in which the Fe II is predominantly due to collisional excitation. Some new Mg II absorption line systems are noted in Table 1.

Subject headings: line identifications — quasars — ultraviolet: spectra

I. INTRODUCTION

There has been great emphasis in recent years on the study of Fe II lines in the spectra of QSOs and active galactic nuclei. It is now known that most Seyfert 1 galaxies and some low-redshift QSOs show prominent, broad Fe II emission features in the wavelength range 3000–7000 Å. The observational situation is summarized and discussed by Phillips (1978*a*). The excitation mechanism of the lines has been studied by Wampler and Oke (1967), Bahcall and Kozlovsky (1969), Adams (1975), Oke and Shields (1976), Osterbrock (1977), Boksenberg and Netzer (1977), Phillips (1978*b*), Collin-Souffrin *et al.* (1979*a*, *b*), Netzer (1980), and others. Several ultraviolet Fe II lines between 2300 and 2800 Å are expected but believed to be weak or absent (Phillips 1977, 1978*a*; Oke and Lauer 1979; Kunth and Sargent 1979), which causes some severe difficulties in trying to explain the line excitation.

Most ultraviolet Fe II lines would be difficult to detect on uncalibrated photographic spectrograms, since the features are expected to be very broad or blended with the strong line Mg II λ2798. Previous quantitative (i.e., flux calibrated) QSO spectroscopy concentrated on low-redshift objects (e.g., Baldwin 1975; Phillips 1978*a*) or those of high redshift (e.g., Osmer and Smith 1976, 1977; Baldwin and Netzer 1978); and relatively little has been done to study QSOs with redshifts near 1. We were therefore led to the suspicion that the assumed absence of the ultraviolet Fe II lines may be in part due to selection effects. The present work is a study of QSOs of intermediate redshift made in order to investigate this possibility. We show for the first time that the Fe II ultraviolet lines are prominent in many such objects.

II. THE NEW OBSERVATIONS AND RESULTS

Flux-calibrated spectrophotometry was obtained for the intermediate-redshift QSOs listed in Table 1 and is shown in Figure 1. Some of the objects were observed as part of a program to monitor spectroscopic variability, so they tend to be bright and optically variable and are also strong, compact, variable radio sources. Two objects (0109+200 and 1056+162) are from a program of spectroscopic studies of QSOs identified with radio sources in the deep survey being conducted at the University of Texas Radio Astronomy Observatory (Douglas and Bash 1977), while one or two further QSOs (0957+561 A and B, Walsh, Carswell, and Weymann 1979) from the Jodrell Bank survey at 966 MHz (Porcas *et al.* 1979) were observed as a special study of this close pair (Wills and Wills 1980). We have included *all* our best-quality observations of QSOs in the appropriate redshift range.

The observations were made at McDonald Observatory with a self-scanned Digicon detector and its specially designed spectrograph (Tull, Vogt, and Kelton 1979) at the f/13.5 focus of the 2.1 m Struve telescope, and/or with an intensified dissector scanner[2] (IDS) attached to the UVITS spectrograph at the f/9 focus of the 2.7 m telescope. The useful wavelength range of the IDS data was about 4000–7000 Å and for the Digicon data 3500–6200 Å. In both cases the FWHM resolution was 7–8 Å. One object, 0109+200, was also observed with 4 Å resolution over a wavelength range 3500–5050 Å. The flux scales were calibrated by observations of standard stars (Stone 1977; Oke 1974). The observations were made with a range of entrance aperture sizes, under various seeing conditions, and sometimes through thin cloud. The final scans shown in Figure 1 are usually the result of combining several scans, weighted according to their signal-to-noise ratios and adjusted to match the best-calibrated data. These scans are presented such that the continua near 2400 Å are of equal heights above the zero flux level, i.e., the apparent strengths of the features are a direct indication of their equivalent widths. F_λ is plotted against the rest frame wave-

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[2] A brief description of the spectrograph and detector has been given by Rybski, Mitchell, and Montemayor (1977). The detector is similar to that described by Robinson and Wampler (1972).

TABLE 1

REST FRAME EQUIVALENT WIDTHS AND INTENSITIES RELATIVE TO THAT OF THE MG II λ2798 LINE, FOR SOME FEATURES IN INTERMEDIATE REDSHIFT QSOs

Name	z	C III] λ1909	λ2050	Fe II λλ2300-2600	Fe II λ2748	Mg II λ2798	Fe II λ2950	Fe II λ3200
0109+200	0.746			6		31	4:	
UT				0.2		1.00	0.14:	
0420-01	0.915			25	4:	24	3:	
PKS				1.1	0.2:	1.00	0.13:	
0906+01	1.019	21		20		27		
PKS		1.20		0.9		1.00		
0957+561A	1.408	28	10	17		29		
JB		0.95	0.3	0.5		1.00		
0957+561B	1.408	28	6	30		27		
JB		0.95	0.2	1.0		1.00		
1056+162	1.006	30		46	5:	30		
UT		1.35		1.9	0.2:	1.00		
1828+48	0.692			22		49	3:	
3C 380				0.5		1.00	0.07:	
2145+06	1.000			18	2:	25		
PKS				0.7	0.1:	1.00		
2216-03	0.901			34	4	34	4	10
PKS				1.0	0.1:	1.00	0.13	0.3
2230+11	1.037			28	3:	24	3:	
CTA102				1.2	0.1:	1.00	0.12:	
2251+15	0.859		8	26	3:	29	4	
3C 454.3			0.3	1.0	0.1:	1.00	0.12	

Notes to Table 1:

The upper figure of each pair of entries is the rest frame equivalent width (Å) and the lower figure, the relative intensity. Colons indicate very uncertain values. The symbols next to each name indicate the radio survey whence came the QSO: UT, University of Texas; JB, Jodrell Bank.

0109+200: There is a strong Mg II absorption system at z_a(observed) = 0.5346; $(1+z_e)/(1+z_a) = 1.138$.

0420-01: There is a strong Mg II absorption system at z_a(observed) = 0.6320; $(1+z_e)/(1+z_a) = 1.173$.

0957+561A and B: There is a strong Mg II absorption system at z_a(observed) = 1.3908; $(1+z_e)/(1+z_a) = 1.007$.

2145+06: There is a weak, probably saturated Mg II absorption system at z_a(observed) = 0.7897; $(1+z_e)/(1+z_a) = 1.118$. This system, in which $W_{\lambda,obs} = 1.0$ Å for each Mg II line, is above the detection limit of the Weymann et al. (1979) survey of Mg II absorption, but was not reported by them. Both the C II] λ2326 and He II λ3203 lines, at measured wavelengths of 4653 and 6422 Å, have about 5% the strength of Mg II λ2798.

length, λ_0. In order to improve the signal-to-noise ratio we have formed a composite scan, weighting the individual QSO scans according to their signal-to-noise ratios, but excluding 0109+200 and PKS 2216−03 (for reasons that will become clear below). We have also removed absorption lines before summing the spectra (i.e., the Mg II systems in PKS 0420−01, 0957+561 A and B, and PKS 2145+06). This composite, together with more detail of the scan of PKS 2216−03, is shown in Figure 2. The intensity scale is arbitrary, but the zero intensity level is the same for both scans.

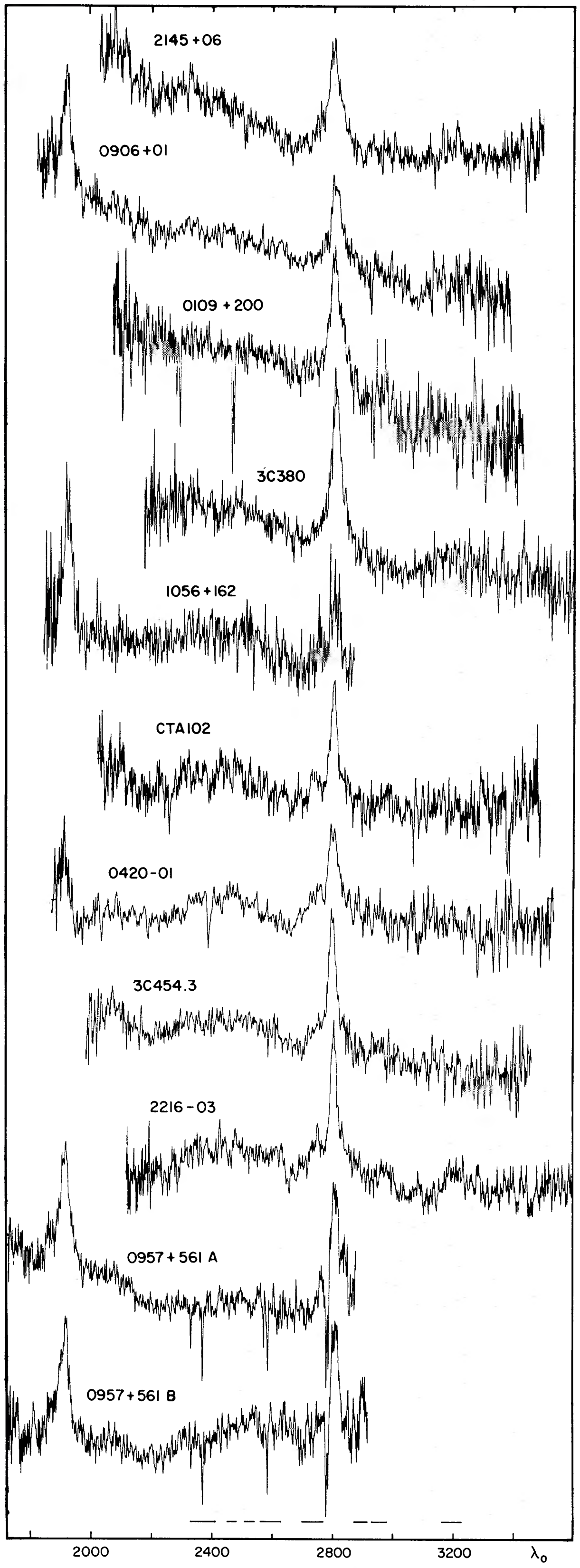

FIG. 1.—Spectral scans for the QSOs, F_λ versus λ_0 (see text).

Clearly there is excess emission present in all these QSOs in the wavelength range 2300–2600 Å. Some of our scans also show features in the blue wing of Mg II λ2798 and near 2950 and 3200 Å. The Fe II ultraviolet and optical multiplet wavelength ranges are shown in Figure 1 and in more detail in Figure 2 and are seen to be in good agreement with the wavelengths of these features. We discuss each of them separately below and argue that they are predominantly due to Fe II multiplet emission. Figure 2 also shows the positions of other lines that have been previously suggested to occur in the near-ultraviolet. Our results are consistent with widths of the individual Fe II ultraviolet lines being the same as those of other broad permitted lines in the spectra, as Phillips (1977, 1978*a*) and Oke and Lauer (1979) have clearly demonstrated for the optical permitted Fe II lines. The Mg II λ2798 line in PKS 2216−03 is the narrowest Mg II line we have observed, and the scans shown in Figures 1 and 2 suggest that the $\lambda\lambda$2300–2600, λ2750, λ2950, and λ3200 features are also the most sharply defined in this object, e.g., the sharp discontinuities near 2600 and 3200 Å and the narrow emission feature in the blue wing of Mg II λ2798. Note there is a hint in Figure 1 that, relative to Mg II, the most prominent of these features are stronger where the optical spectrum (F_ν) is steeper.[3]

We identify the $\lambda\lambda$2300–2600 feature with blended lines of Fe II multiplets UV 1, 2, 3, 33, 34, 35, 36, and 64. Apart from the general wavelength agreement, further support for these identifications is provided by the scan of PKS 2216−03 which shows a sharp rise, leveling off shortward of $\lambda_0 = 2625$ Å. There is a concentration of several strong Fe II lines near this wavelength, especially in multiplet UV 1. Other possible contributors to this feature are as follows—(1) C II] λ2326: we have determined the expected C II] line strengths from model calculations similar to those described by Baldwin and Netzer (1978), for a range of plausible physical conditions. For the densities $N_e > 2.10^9$ cm^{-3} generally accepted to occur in the broad-line emitting region, the C II] line will be suppressed by collisional de-excitation, so its contribution is expected to be small [$<0.25\, I$(Mg II)]. Although this line has been reported many times and is often used to confirm or determine redshifts, it is not seen as a *discrete* line in the QSOs that we have observed, except for PKS 2145+06 (see Fig. 1). (2) Si II] lines: similar photoionization calculations show these lines to be even weaker than C II] and the estimated strength is $\ll 0.5\, I$(Fe II $\lambda\lambda$2300–2600). (3) The λ2175 absorption feature due to interstellar dust: the existence of Galactic-type absorption in some QSOs is quite probable (see, e.g., Baldwin 1977; Baldwin and Netzer 1978; Netzer and Davidson 1979. We have attempted to remove the effects of interstellar-type absorption in the QSO rest frame, using a mean interstellar extinction curve similar to that given by Seaton (1979)

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[3] The steepest spectrum on an F_ν scale appears as the flattest in Figure 1, where an F_λ scale is used.

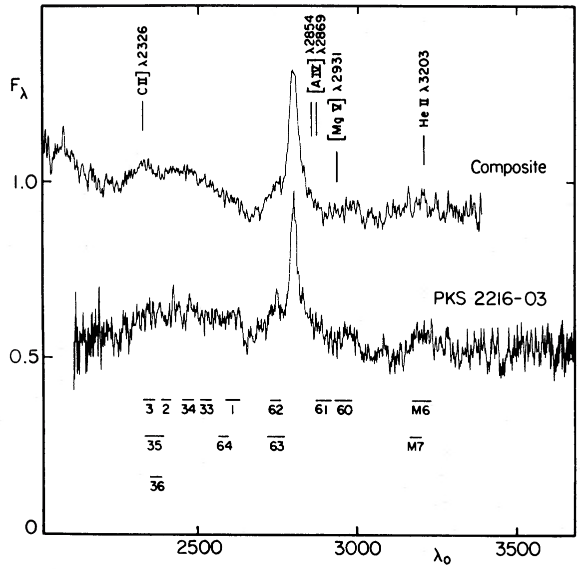

FIG. 2.—The upper scan is a composite formed from scans of all QSOs in Fig. 1, omitting 0109+200, which has weak λλ2300–2600 emission, and PKS 2216−03, which is shown separately in the lower scan, because it has narrow Mg II emission and so may show other features in the spectrum with higher resolution. The horizontal bars indicate the wavelength ranges of Fe II ultraviolet multiplets and the optical multiplets M6 and M7; also shown are the positions of other lines that have been suggested to occur in the near-UV spectra of QSOs. Note that the zero level is the same for both scans.

and varying the strength of the λ2175 feature. If the extinction is similar to that in our own Galaxy or the Magellanic Clouds, the λ2175 feature would be too broad to affect the existence of the features observed but would affect the shape of the continuum and hence the estimated line strengths and equivalent widths. (4) The Lα two photon continuum cannot contribute to the λλ2300–2600 feature, as the peak (in F_ν) occurs near 1621 Å (Spitzer and Greenstein 1951), not 2431 Å as sometimes given.[4]

The rest wavelength of the narrow λ2750 feature in PKS 2216−03 can be measured rather accurately, 2748 ± 2 Å. Multiplets UV 62 and 63 are expected to peak strongly near this wavelength (2749 and 2748 Å, respectively) in both the optically thin and thick cases, which strengthens the identification with Fe II and provides further support for the other Fe II ultraviolet line identifications. There is a suggestion that the 2748 Å feature may be present in other objects, particularly in CTA 102 where the Mg II FWHM is also relatively narrow.[5]

Many observations of the λ2950 feature have been reported by Phillips (1978*a*) and by Grandi and Phillips (1978, 1979). Grandi and Phillips (1978) argued that this line may be Mg II λ2934 that is excited by fluorescence of Mg^+ with Lα and/or N V λ1240. Netzer (1980) has discussed many difficulties with this idea, in addition to the wavelength discrepancy, and has suggested Fe II UV 60 as a more likely identification. The wavelength of the λ2950 feature is also of interest, since Netzer (1980) predicts the wavelength to vary between 2947 and 2957 Å, depending on the optical depth in the lines of the UV 60 multiplet. We measure λ_0 to be 2976 Å and 2947 Å in PKS 2216−03 and 3C 454.3, respectively. Although the wavelength is difficult to measure because of the poor signal-to-noise ratio and possible blending with other lines, it does seem that the feature occurs at a redder wavelength in PKS 2216−03 than in 3C 454.3. Grandi and Phillips (1978) find λ_0 = 2948 Å in 3C 232, and Owen, Wills, and Wills (1980) find λ_0 = 2955 Å in the south-preceding component of 1038+528. It should be possible to test further the hypothesis that the wavelength of this feature differs in different objects, since there are many cases of the λ2950 feature in the literature. We find no evidence for the narrow forbidden lines [A IV] λλ2854, 2869,[6] and [Mg V] λ2931 in the spectra of Figure 1, in our unpublished results, or in other work where scans have been presented in the literature (e.g., Baldwin 1975).

The broad feature near 3200 Å[7] is probably a blend of Fe II optical multiplets 6 and 7 (which are expected to be strong—see Phillips 1977, 1978*b*), He I λ3188 (Baldwin 1975) and/or He II λ3203. Phillips (1978*a*) reports that this feature is not usually detectable, although it is present in a few Seyfert 1 galaxies and low-redshift QSOs (e.g., I Zw 1 and PKS 1510−08). Two other examples, PKS 0736+01 and 3C 345, are illustrated in Netzer *et al.* (1979). The helium line is present in PKS 2145+06 (Fig. 1) at a wavelength of 3210 Å, consistent with its identification as He II but not He I.

Relative line intensities and equivalent widths for the features discussed above, and for Mg II λ2798, are given in Table 1. The notes to the table give further information about the QSOs. Usually, line measurements were made by estimating linear continua through points near 2220, 2670, and 3040 Å. In no object was it possible to use the C III] λ1909 line profile to deblend the Mg II λ2798 and possible UV 60, 61, 62, and 63 features, since either the C III] λ1909 line fell too close to the short-wavelength end of the scan, or Mg II λ2798 was affected by Mg II absorption. Typically,

$$I(\text{Fe II } \lambda\lambda 2300\text{–}2600) \approx I(\text{Mg II } \lambda 2798)\,,$$

and

$$I(\lambda 2748) \approx I(\lambda 2950) \approx 0.1\, I(\text{Mg II } \lambda 2798)\,.$$

Table 2 gives line width measurements for Mg II λ2798 and, where possible, C III] λ1909, as rest frame velocities. Full widths at half of the peak intensity and at zero intensity have been estimated so that comparison may be made with the results given by Grandi and Phillips (1979). The table also gives an indication

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[4] We thank C. M. Gaskell for pointing this out.

[5] Penston (1979) reports blended emission from ultraviolet multiplets 62 and 63 in unpublished spectra of the Seyfert galaxies III Zw 136, Mkn 231, and NGC 1566.

[6] However, a real feature at λ_0 = 2857 Å has definitely been measured in some other QSOs (Hunstead, Murdoch, and Shobbrook 1978).

[7] The λ3200 feature should not be confused with the broad bump at 3000–4000 Å that is present in many QSOs and Seyfert type 1 galaxies.

TABLE 2

RADIO PROPERTIES AND LINE WIDTHS

SOURCE NAME	RADIO[a] STRUCTURE (kpc)	RADIO[b] SPECTRUM	LINE WIDTHS (km s^{-1})			
			Mg II (FWHM)	λ2798 (FW0I)	C III] (FWHM)	λ1909 (FW0I)
0109+200.....	47[c]	*S*	4800	20,000	...	...
0420−01......	< 0.5	*F*	4800	33,800	...	...
0906+01......	< 0.5	*F*	4300	19,300	3400	12,900
0957+561A...	C[d]	*F*	3600:	13,700:	4100	14,100
0957+561B ...	C	...	3500:	14,900:	3800	15,300
1056+162.....	< 100:	...	4500:	20,000:	6700:	20,000:
1828+48......	7	*F*	3700	20,100	...	...
2145+06......	< 0.3	*F*	4100	20,100	...	...
2216−03......	< 0.5	*F*	2700	28,100	...	...
2230+11......	< 0.3	*F*	3200	19.300	...	...
2251+15......	< 0.2	*F*	3200	18,100	...	...

NOTE.—We have not attempted to remove any possible contribution of the Fe II lines to the blue wing of Mg II.

[a] Using $H_0 = 75$ km s^{-1} Mpc^{-1}, $q_0 = 1$ as in Miley and Miller (1979).

[b] *S* is a steep radio spectrum, $\alpha > 0.6$; *F* is a flat radio spectrum, $\alpha < 0.4$.

[c] VLA observations at 6 cm wavelength (F. Owen, private communication) show this to be a triple source with a dominant compact component coincident with the optical QSO.

[d] The structure for these objects is not clear (Pooley *et al.* 1979; Roberts, Greenfield, and Burke 1979) but is probably compact.

of the radio structure (following the system of Miley and Miller 1979) and an indication of high-frequency radio spectral index, α (near 1–10 GHz). The results presented in Tables 1 and 2 are discussed in § III.

III. DISCUSSION

The observations and arguments presented above provide strong evidence for the existence of the Fe II ultraviolet resonance lines. In addition to our new results, there are many published examples of features that we interpret as Fe II ultraviolet emission. Oke, Neugebauer, and Becklin (1970) mention that "an emission line at 2500 Å is clearly present in PKS 0405−12. It also appears somewhat weaker in 3C 334, 3C 345, and 3C 286. Possible identifications are with [Mg VII] or [O II]." The λλ2300–2600 feature is quite clearly present in scans of the optically selected QSOs Q2235−390, Q0118−396, and Q0540−389 (Osmer and Smith 1980) and is also present in Baldwin and Netzer's (1978) scans of Ton 490 and PHL 938—in all cases probably with strengths similar to that of the Mg II λ2798 line, as found in our sample. For at least Ton 490 the blue and red wings of Mg II λ2798 are much broader than those of C IV and C III]. Grandi and Phillips (1979) find that in most cases in a sample of 14 low-redshift QSOs, the profiles of the broad components of Mg II λ2798 and Hβ are observed to be identical, but in five objects they find Mg II to be significantly broader. PKS 1510−08 is one of these five, and it is of note that a scan of this object published by Phillips (1977) seems to show UV 1 and UV 64 near 2600 Å, UV 62 and UV 63 emission near 2748 Å, as well as UV 60 near 2950 Å, and the optical multiplet 6 and 7 emission near 3200 Å. Of particular interest is the QSO 4C 24.23 (1048+240), observed by Baldwin (1977), since it appears to have extremely strong λλ2300–2600 emission. As mentioned earlier, the features near 2950 and 3200 Å are also commonly observed (Phillips 1978; Grandi and Phillips 1978). That all the Fe II ultraviolet lines are a common feature in QSOs is well illustrated in the composite QSO scan shown by Baldwin (1979). In many spectra the Fe II lines have been misidentified because of low resolution, low signal-to-noise ratio, and, in some cases, lack of flux calibration needed to detect very broad features. Examples are the frequent references to C II] λ2326, [A IV] λλ2854, 2869, [Mg V] λ2931, and [Ne V] λ2974 in the literature (Burbidge, Crowne, and Smith 1977). Finally, Jauncey *et al.* (1978) refer to an absorption trough shortward of Mg II in many of their spectra. This feature is observed to be 250 to 500 Å wide and of strength similar to the Mg II emission line. This trough is undoubtedly the absence of emission near 2700 Å (see Figs. 1 and 2).

The total strength of all Fe II ultraviolet lines is comparable to that of Mg II for most of the objects in our sample, but direct comparison with the optical lines is difficult. Only one object, 3C 380, is common to Phillips's (1978*a*) sample and ours, and for this object Phillips measures $I(\lambda 2950)/I(\text{Mg II}) = 0.14$; $I(\text{Fe II }\lambda 4570)/I(\text{Mg II}) \lesssim 0.05$, and $I(\text{Mg II})/I(\text{H}\beta) = 1.76$, which together with our results (Table 1) leads to $I(\text{Fe II }\lambda\lambda 2300\text{–}2600) \gtrsim 10\ I(\text{Fe II }\lambda 4570)$. An indirect statistical approach is to use the Mg II λ2798 or λ2950 features common to both low- and intermediate-redshift samples to tie in the ratio of ultraviolet to optical Fe II lines. Using data from Phillips (1978*a*) and Grandi and Phillips's (1978) Figure 2, we obtain

$$\langle I(\text{Fe II }\lambda 4570)/I(\text{H}\beta)\rangle \approx 0.4$$

and

$$\langle I(\text{Fe II }\lambda 4570)/I(\text{Fe II }\lambda 2950)\rangle \approx 1$$

(the exact values depend on whether one uses the upper limits or puts those ratios to zero and also whether one includes all or just radio compact QSOs). Grandi and Phillips (1979) give

$$\langle I(\text{Mg II})/I(\text{H}\beta)\rangle \approx 1.6\,;$$

we thus derive

$$\langle I(\text{Fe II }\lambda\lambda 2300\text{–}2600)\rangle \approx 4\langle I(\text{Fe II }\lambda 4570)\rangle$$

using Mg II λ2798, and

$$\langle I(\text{Fe II }\lambda\lambda 2300\text{–}2600)\rangle \approx 6\langle I(\text{Fe II }\lambda 4570)\rangle$$

using λ2950. This latter result gives relatively stronger ultraviolet emission, because the λ2950 feature is 50% stronger in Grandi and Phillips's samples [$\langle I(\text{Fe II }\lambda 2950)/I(\text{Mg II})\rangle \approx 0.20$, compared with 0.13 for our sample]—a difference that may not be real because of the subjective nature of determining the strength of this weak, blended feature. Our best estimate for the relation between optical and ultraviolet Fe II line strengths is $I(\text{Fe II ultraviolet}) \approx 2I(\text{Fe II optical})$. This indicates that the number of observed ultraviolet photons is about equal to the number of optical photons. We may have overestimated I(Fe II ultraviolet) if there is a significant contribution from, e.g., C II] λ2326 or if the objects in our sample are also strong optical Fe II QSOs. Reddening corrections (Netzer and Davidson 1979; Netzer 1980) may double this number.

Note that, although we have derived a typical ratio of Fe II ultraviolet to optical line strengths, we do not suggest that this applies to each individual object. Already we know that there is no obvious correlation between I(Fe II λ4570) and I(λ2950) (Fig. 2 of Grandi and Phillips 1978). Observations from the *IUE* (*International Ultraviolet Explorer*) spacecraft have been made for two objects with strong optical Fe II emission, 3C 273 and Mkn 79 (Boggess *et al.* 1979; Penston 1979; Oke and Zimmerman 1979). The Mkn 79 observations set an upper limit consistent with our derived ratio. We believe that the high signal-to-noise ratio observations of 3C 273 reported by Penston may show Fe II λλ2300–2600 emission with the expected strength, if we estimate the continuum in the same way as for the objects in our present sample. Penston believes the feature is not present, probably because he chooses a higher continuum. The apparent conflict may be resolved when flux-calibrated optical and ultraviolet continua are compared in the region of the Mg II λ2798 line.

Comparison with theoretical calculation is complicated and will not be attempted in detail. The assumed weakness of the ultraviolet lines, among other things, led some authors (e.g., Phillips 1978*b*) to prefer fluorescence excitation of Fe II over collisional excitation. Others (e.g., Collin-Souffrin *et al.* 1979*a*, *b*) have been forced to avoid conditions that gave too much ultraviolet Fe II emission. This resulted in part in extreme values of densities and optical depth, which do not seem to be consistent with the strength of other emission lines in the spectrum. Netzer (1980) has argued that collisional excitation of Fe^+ is the only plausible mechanism and that standard QSO-like conditions (i.e., $N_e \approx 3.10^9\ \text{cm}^{-3}$, $U_1 \approx 10^8\ \text{cm s}^{-1}$) lead to strong optical and ultraviolet Fe II lines. Netzer's calculations suggest that the most intense multiplets are UV 2, UV 35, and/or UV 36, UV 33, UV 64, and UV 60. He tabulated the strengths of about half of them, and we assume that those not included by him (UV 35, UV 36, UV 1, UV 62, UV 63, and UV 64) contribute about the same as those included. This gives (Netzer 1980, Table 1) $I(\text{Fe II all ultraviolet}) \approx 0.6I(\text{Mg II }\lambda 2798)$. The uncertainties in the calculations themselves are at least a factor of 2 (both for Fe II and Mg II), and the observed values are therefore within the range of the predicted values.

Setti and Woltjer (1977, hereafter SW) and more recently Miley and Miller (1979, hereafter MM) have suggested that strong Fe II (optical) emission may occur only in QSOs with very compact radio structure. We examine this suggestion further in order to compare the properties of Fe II optical with Fe II ultraviolet emission. Table 3 summarizes information from the literature, relating the degree of compactness of the radio sources to the strength of the optical Fe II multiplets. We have preferred to use high-frequency radio spectral index, rather than direct angular structure, as a measure of the degree of compactness of the radio sources, because this information is more readily available for some of the QSOs. The spectral indices correlate well with the structure criteria of MM, but at the same time are expected to be related even more closely to the optical properties, since a flat radio spectrum is indicative of even more compact structure and thus likely to be more closely associated with the broad-line emitting region. While it is dangerous to draw statistical conclusions from these inhomogeneous data, the results given in Table 3 continue to support the suggestion of SW and MM.

Can we further investigate the possible relation, using the Fe II ultraviolet emission? In our sample of intermediate-redshift objects, all are compact on Miley and Miller's criteria, except for 1056+162 where the structure is uncertain. However, the Fe II λλ2300–2600 emission is weak in 0109+200, which is the only one of our sources that has a steep radio spectrum, suggesting that Miley and Miller's result may also apply to the ultraviolet lines. The broad trough mentioned by Jauncey *et al.* (1978) (see above) is sometimes absent in their observations of radio sources that have flat spectra. Other objects with strong Fe II ultraviolet emission include Ton 490 ($\alpha = 0$), PHL 938 (radio quiet), and some optically selected QSOs observed by Osmer and Smith (1980).

TABLE 3

RADIO STRUCTURE VERSUS Fe II LINE STRENGTH

	Fe II OPTICAL LINE STRENGTH			
RADIO STRUCTURE	Strong	Medium	Weak	None
Compact	5	0	1	9
Extended	0	1	1	21
Radio-quiet	0	3	0	0

In particular, 4C 24.23, apparently with extremely strong UV Fe II emission, has a *steep* radio spectrum ($\alpha = 0.89$) and classic triple radio structure, with 74 kpc separation between the outer components (Pooley and Henbest 1974). There is thus no clear-cut relation at present between Fe II ultraviolet emission and radio structure.

IV. SUMMARY

We have presented evidence, both from our own observations and from the literature, for the existence of strong, broad emission features between 2300 and 2600 Å, and near 2748 and 2950 Å in QSOs, and have argued that these are due to resonance transitions of the Fe II multiplets UV 1–3, 33–36, UV 64 ($\lambda\lambda$2300–2600), UV 62 and 63 (λ2748), and UV 60 and 61 (λ2950). Netzer's (1980) predictions of the strengths of the Fe II lines relative to those of Hβ, Mg II λ2798, and C III] λ1909 agree with our observations within the theoretical and observational uncertainties. Whether strong optical Fe II objects are also strong ultraviolet Fe II objects or not is a most important question at this stage.

We find conflicting evidence concerning a relation between strong Fe II ultraviolet emission and degree of compactness of the associated radio source—a relation that appears to exist for the optical Fe II lines (Setti and Woltjer 1977; Miley and Miller 1979). Further observations with improved signal-to-noise ratio and covering a wide wavelength range (for example, using spacecraft ultraviolet observations) are needed in order to compare the UV and optical Fe II emission in individual objects, to compare the emission-line profiles of the broad "single" lines of Hβ, C IV, and C III] with those of Mg II and the Fe II multiplets, and to measure accurate wavelengths of, for example, the λ2950 feature, which Netzer (1980) predicts may differ from one object to another. According to Netzer the Fe II lines may be more sensitive than other lines to differences in geometry of and physical conditions in the broad-line emitting region. The observations that are presently available are biased toward low redshift and the optically more luminous radio-emitting QSOs. It is therefore important to study a sample of objects that includes a wider range of optical and radio properties.

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