SOME IMPLICATIONS OF ULTRAVIOLET OBSERVATIONS OF QUASARS AND ACTIVE GALAXIES

Arthur F. Davidsen*
Department of Physics, The Johns Hopkins University,
Baltimore, Maryland 21218, U.S.A.

ABSTRACT

The problem of the order of magnitude discrepancy in the expected and observed ratios of the Lyman and Balmer lines in quasars and active galaxies is reviewed. Whereas early photoionization models for the emission line regions predicted F(Lα)/F(Hβ) $\gtrsim$ 40, the observations give values for this ratio in the range 3-8. Attempts at explaining the observations have involved dust, both external and internal to the emission line regions, and improved treatments of the collisional processes and radiative transfer effects in dense ($N_e \sim 10^{10}$ cm^{-3}), optically thick clouds. None of the effects considered is, by itself, able to explain all the observations, and a combination of several of them is probably required.

The most significant result which has so far come from ultraviolet observations of quasars and active nuclei is the realization that the intensity ratios of ultraviolet and optical lines are not at all what was expected a few years ago. In attempting to construct photoionization models for quasar emission line regions, most authors (e.g. Davidson 1972, MacAlpine 1972) assumed F(Lα)/F(Hβ) = 40, based on ordinary radiative recombination theory with a small additional contribution of collisionally excited Lα. However, a compilation of photographic data on equivalent widths by Chan and Burbidge (1975) suggested F(Lα)/F(Hβ) $\sim$ 18, while spectrophotometric data by Baldwin (1977) yielded F(Lα)/F(Hβ) $\sim$ 3 for a composite of 26 QSO's of various redshifts. Reddening by dust was an obvious candidate to explain the order of magnitude discrepancy in the predicted and observed Lα/Hβ ratio, but Baldwin argued that the absence or weakness of the 2175 Å feature in several quasars indicated the continua were not generally reddened. Steep Balmer decrements in quasars and Seyfert nuclei had also often been ascribed to reddening, but observations of the Pα/Hβ ratio in 3C 273 by Grasdalen (1976) apparently ruled out reddening of the emission line region for at least that one object.

*Alfred P. Sloan Foundation Research Fellow.

G.O. Abell and P. J. E. Peebles (eds.), Objects of High Redshift, 235–245.

Baldwin (1977) also pointed out that it was not at all clear that a depressed Lα flux was responsible for the discrepant Lα/Hβ ratio. Indeed, the general absence of Lyman continuum absorption in high redshift quasars was taken to indicate that the optically thick emission line clouds surrounding the central continuum source covered only a small fraction of the sky, of order 10 per cent, and the typical Lα equivalent widths observed were consistent with this only if Lα had not been substantially reduced by dust or any other means. Baldwin was lead to suggest that perhaps the Balmer lines have instead been substantially enhanced by collisions or radiative transfer effects. Alternatively it was possible that the composite QSO spectrum was meaningless because high and low redshift QSOs were intrinsically different. Baldwin concluded by recommending that simultaneous uv and optical observations of Lyman and Balmer lines in quasars and Seyfert galaxies should be made.

Preparations for such observations with a rocket-borne telescope had been underway in our group since Spring of 1976, and in April 1977 the Faint Object Telescope (FOT) obtained the first far-ultraviolet spectrum of the quasar 3C 273 (Davidsen, Hartig and Fastie 1977). The order of magnitude low Lα/Hβ ratio was independently discovered in this observation and also inferred at about the same time by Wu (1977), from broad band uv observations of 3C 273 with the ANS satellite. The ANS observations did not extend to wavelengths as short as Lα, but yielded an estimate of the C IV flux, from which F(Lα) could be inferred. Wu (1977) interpreted the ANS results in terms of reddening of the lines and continuum in 3C 273.

The absolute fluxes reported by Davidsen, Hartig, and Fastie (1977) have been revised, due mainly to the discovery of a previously unknown telemetry system deadtime correction during preparations for a second launch of the FOT (Hartig 1978). The corrected observed Lα flux is $F(L\alpha) = 12.3(\pm 2.0) \times 10^{-12}$ erg cm^{-2} s^{-1}. The Lα flux in 3C 273 has also been measured with IUE, (Boksenberg *et al.* 1978, Boggess *et al.* 1979) with the result that $F(L\alpha) = 11.5 \times 10^{-12}$ erg cm^{-2} s^{-1} in the observed frame (Boggess *et al.*). Thus there is excellent agreement between the IUE and FOT observations of Lα in 3C 273. Using the recent optical spectrophotometry reported by Boggess *et al.*, which gives $F(H\beta) = 2.1 \times 10^{-12}$ erg cm^{-2} s^{-1} in the observed frame, we have $F(L\alpha)/F(H\beta) = 5.7$, uncertain by perhaps ±25 per cent. Note that differences among various measures of the Hβ flux are as large as those for Lα.

The continuum flux reported for 3C 273 by Davidsen, Hartig and Fastie (1977) must also be revised, for the same reason mentioned above, with the result that $F_\nu(\lambda_{obs} = 1400\ \text{Å}) = 1.2(\pm 0.2) \times 10^{-25}$ erg cm^{-2} s^{-1} Hz^{-1}. This is also in excellent agreement with the results of Boggess *et al.* (1979) using IUE. Extrapolating to the Lyman limit as $\nu^{-\alpha}$, with $\alpha = 0.43$ (Boggess *et al.*) and converting to the emitted frame ($H_o = 50$ km s^{-1}, $q_o = 1$), we find $L_\nu = 1.0 \times 10^{31}$ erg s^{-1}Hz^{-1} for the luminosity at 1 Rydberg. This result includes no correction for any possible reddening of the continuum. Boggess *et al*. detected no 2175 Å feature, either in the rest frame of 3C 273 or of our Galaxy, with a limit $E_{B-V} \lesssim 0.06$ for the extinction curve of Code *et al*. (1976). The corresponding upper limit on the factor by which F(Lα)/F(Hβ) could be reduced (assuming the same reddening limit applies to lines as well as continuum) is 1.4. Taken together with the Pα observations (Grasdalen 1976, Puetter *et al*. 1978) it is clear that reddening by intervening dust cannot explain the uv/optical line ratios in 3C 273 unless the properties of the dust are quite different from that in our Galaxy.

Shortly after the first Lyman α observations of quasars in the ultraviolet were made, infrared astronomers were able to measure redshifted Hα in the spectra of high redshift objects, where Lα was observed in the optical. Ratios F(Lα)/F(Hα) = 1.7 ± 0.6 for PKS 0237-23 (Hyland, Becklin and Neugebauer 1978), ∿0.8 for B2 1225 + 317 (Soifer *et al*. 1979) and ∿0.34 for the same object (Puetter, Smith and Willner 1979) were found. Using typical Balmer decrements for quasars, the corresponding values of F(Lα)/F(Hβ) are ∿3-8, consistent with that observed for 3C 273.

Subsequently the ultraviolet spectra of a large number of galaxies and quasars have been observed with IUE. Objects for which uv fluxes have appeared in the literature are listed in Table 1, where I have given, in addition to the Lα/Hβ ratio, the ratios He II(1640)/He II (4686) and C IV(1550)/Hβ. Many additional objects will be added from continuing observations with IUE (see the papers by M. Penston and R. Green in

TABLE 1. UV/optical Line Ratios in Quasars and Active Galaxies

Object	Lα/Hβ	He II(1640)/He II(4686)	C IV/Hβ
3C 273	5.7	--	2.0
PG 0026+129	6	--	--
NGC 4151	2.7-4.4	1.3-2.0	2-4
NGC 1068	--	3-4	4.1
3C 120	4.8	2.3	9.7
Mrk 79	2.2	24[1]	2.1
3C 390.3			
broad lines	3.1	--	1.9
narrow lines	35	$\lesssim$10	14
Composite QSO[2]	2.8	1.5	1.2

notes: [1]Only a weak narrow He II λ4686 feature was found by Oke and Lauer (1979), but the spectrum in this region is affected by strong Fe II blends.

[2]Compiled by Shuder and MacAlpine (1979).

this Symposium). With one exception (the narrow line component in 3C 390.3 [Ferland *et al.* 1979], discussed below) the observations all indicate that the Lα/Hβ intensity ratio is about an order of magnitude smaller than expected from simple models for the emission line regions in quasars and active nuclei.

Efforts to understand the small uv to optical line intensity ratios may be divided into two general classes: (1) those which have considered various collisional and radiative transfer effects in a purely gaseous emission line cloud, and (2) those which have considered the possible effects of dust on the line ratios. The latter class may be further divided into those where the dust is (a) internal, affecting the ionization structure and thermal balance of the cloud as well as attenuating resonance lines which are multiply scattered before escaping, and (b) external, reducing the observed intensity of all uv lines and continuum relative to the optical by an extinction law more or less similar to that produced by dust in our own Galaxy.

The earliest extensive discussion of the Lα/Hβ problem is by Krolik and McKee (1978), who considered models with $N_e \gtrsim 10^{10}$ cm^{-3} and found that collisional de-excitation of n = 2, together with large optical depths, could potentially explain the Lα/Hβ ratio, the steep Balmer decrement, and the Pα/Hβ ratio in 3C 273. A limitation of the calculation, however, was that it was essentially a homogeneous model, employing a mean escape probability calculation for the line strengths. Subsequently Ferland and Netzer (1979) employed Monte Carlo calculations, which take into account the optical depth where each photon is created, and found that for $N_e \lesssim 10^{10}$ cm^{-3} the overall destruction of Lα is not substantial. They showed that much of the Lα is produced by recombinations at relatively small optical depth where it can escape easily. Only the collisionally excited Lα, created deeper in the cloud, was effectively destroyed. Since observations of C III] λ1909 in quasars indicate that $N_e \lesssim 10^{10}$ cm^{-3}, Ferland and Netzer concluded that collisional and radiative transfer effects in a purely gaseous nebula cannot reduce the Lα/Hβ intensity ratio substantially below its recombination value of ∿35. Instead they suggest that dust must be invoked to explain the low observed ratio. London (1979) also suggested that dust was the most promising mechanism for reducing F(Lα)/F(Hβ).

The effect of internal dust, mixed with the emission line gas in quasars, has been considered in some detail by Baldwin and Netzer (1978), Ferland and Netzer (1979), and Shuder and MacAlpine (1979). Internal dust can, of course, be very effective at destroying resonantly trapped Lα (and to a lesser extent C IV λ1550), but if one tries to reduce F(Lα)/F(Hβ) to the observed value in this way, other line ratios present problems. For example, He II λ1640 becomes too strong relative to Lα. Baldwin and Netzer (1978) cite the observed He II λ1640/Lα ratio, which is about a factor 2 larger than expected in many quasars, as evidence that a small amount of internal dust is attenuating Lα. However, Ferland and Netzer and Shuder and MacAlpine demonstrate that the amount of internal dust permitted by this and other line ratios is

https://doi.org/10.1017/S0074180900068613 Published online by Cambridge University Press

too small (perhaps 10 per cent of the galactic dust-to-gas ratio) to explain the observed Lα/Hβ ratio. They suggest that, in addition to internal dust, there must be external dust, either surrounding the quasar or somewhere along the line of sight.

The case for extinction in quasars and Seyfert nuclei by external dust has been made by Netzer and Davidson (1979). They suggest that the ratio of the He II recombination lines λλ1640, 4686 provides a good measure of reddening. Since the theoretical ratio, F(1640)/F(4686) = 6.6 for $n_e = 10^4$ cm^{-3}, $T_e = 10^4$°K (Brocklehurst 1971), is not very sensitive to density or temperature, and because neither line involves the ground level so that the lines should be optically thin, this ratio should not be affected much by internal destruction mechanisms. Since the observed ratio in several cases (see Table 1) is ∿1.5-2.0, and that inferred for a composite QSO is ∿1.5 (Shuder and MacAlpine 1979), differential extinction of a factor 3-4 between λλ1640 and 4686 may be inferred. Using the reddening law of Code *et al.* (1976), this corresponds to E_{B-V} ∿ 0.29-0.36. The same reddening would yield differential extinction by a factor 5.5-8.3 between Lα and Hβ.

Netzer and Davidson have also suggested that the O I lines λλ1303, 8446 provide another good reddening indicator. Approximately equal numbers of photons are expected in these two lines, so that F(λ1303)/F(λ8446) ≈ 6.5. O I λ1303 is typically quite weak in high redshift quasars and this ratio is therefore difficult to measure accurately, but Netzer and Davidson conclude F(λ1303)/F(λ8446) ≈ 1.5 generally. The FOT observation of 3C 273 yielded a marginal detection of O I λ1303 which gave F(λ1303)/F(Lα) = 0.06 (Hartig 1978). Oke and Shields (1976) give F(λ8446)/F(Hβ) = 0.33, so that F(λ1303)/F(λ8446) ∿ 1.0. The implied reddening is E_{B-V} ∿ 0.26. The FOT observation of NGC 4151 (Davidsen and Hartig 1978) detected no O I λ1303 (see Table 2). When combined with the O I λ8446 flux (Netzer and Penston 1976) the data give F(λ1303)/F(λ8446) $\lesssim$ 1.

We see that the ratios Lα/Hβ, He II λλ1640/4686, and O I λλ1303/8446 all may be consistent with reddening by a normal extinction law with E_{B-V} ∿ 0.3-0.4. As Netzer and Davidson point out, the extinction must occur outside the broad emission line regions because internal dust would affect the ratios differently. In some objects reddening of the narrow line gas surrounding the nucleus had already been deduced from the [S II] λλ4072, 10320 lines (Wampler 1968, 1971). In NGC 4151, for example, this method gives E_{B-V} = 0.24 ± 0.08. Thus, perhaps there is dust surrounding all of these objects. If this is the case, then the continuua are also reddened, and one is lead to the conclusion that the luminosities of quasars and Seyfert nuclei are intrinsically an order of magnitude larger than previously thought. In many cases the intrinsic continuum must then be rising toward higher frequencies in the ultraviolet (Netzer and Davidson 1979). If this conclusion is supported by further work it will surely represent a very significant contribution of ultraviolet studies to our understanding of active nuclei and quasars.

https://doi.org/10.1017/S0074180900068613 Published online by Cambridge University Press

Let me return now to some of the more recent observations with IUE that are relevant to this problem. Lα was measured in the quasar PG 0026 + 129 by Baldwin *et al*. (1978), while Puetter *et al*. (1978) measured Hβ and Pα in the same object. The ratios are Lα/Hβ/Pα = 6:1:1.4 and are consistent with reddening by normal intervening material (Baldwin *et al*. 1978), contrary to the result for 3C 273.

Oke and Zimmerman (1979) observed the galaxies 3C 120 and Markarian 79 with IUE and found a depression at ∿2200 Å in both objects. Interpreting this as evidence for the 2175 Å interstellar extinction feature, they find E_{B-V} = 0.22 and 0.38 in Mrk 79 and 3C 120, respectively. The small observed Lα/Hβ ratios (see Table 1) are then at least partially or completely (for 3C 120) explained by the inferred reddening.

An extremely important observation relevant to this problem has recently been reported by Ferland *et al*. (1979), who observed the radio galaxy 3C 390.3 with IUE. They were able to measure separately the broad and narrow components of Lα (and some other lines) and calculate separately Lα/Hβ for the broad line gas and the more extended, lower density narrow line gas. The results are listed in Table 1. We see that the narrow line gas displays normal ratios, perhaps reddened slightly by dust within our Galaxy ($E_{B-V} \gtrsim 0.1$), but the broad line component has the severely depressed uv to optical line ratios of the other objects which have been observed. (All the previous measurements referred to broad line gas). Thus Ferland *et al*. conclude that external reddening cannot generally explain the reduced Lα/Hβ ratios observed. They also use an energy budget analysis to argue convincingly that Lα has not been severely attenuated by internal dust, since it carries its expected fraction of the total cooling (>25 per cent) in both the broad and narrow line gas in 3C 390.3 and also in 3C 273. Ferland *et al*. conclude that it is not that Lα has not been reduced, but that the Balmer lines have been enhanced by collisional processes at $N_e \gtrsim 10^{10}$ cm^{-3}.

The observation of NGC 4151 by the FOT (Davidsen and Hartig 1978) is also relevant to this problem. The spectrum obtained is shown in Figure 1 and fluxes are given in Table 2, where they are compared with the results of preliminary IUE observations (Boksenberg *et al*. 1978). Because of the small redshift of NGC 4151, Lα is contaminated by geocoronal emission, for which a substantial correction has been made in the fluxes quoted in Table 2. Lα may also be affected by interstellar absorption within our Galaxy. The Lα/Hβ ratio is 2.7 ± 0.8 (FOT) and 4.4 ± 2 (IUE, Boksenberg *et al*. 1978). The He II λ1640/λ4686 ratio is 1.3-2.0 when the total line strengths are compared, but the situation here is similar to that for 3C 390.3. The λ4686 profile consists mostly (∿80 per cent) of a very broad component with FWHM ∿6000 km s^{-1} (Osterbrock and Koski 1976) along with a narrow component having FWHM ∿ 450 km s^{-1}. Figure 2 shows the observed profile of He II λ1640, which is much narrower than the broad component of λ4686. (The feature longward of λ1640 is identified as O III] λ1663, while the rise toward shorter λ is the beginning of the very broad wings of C IV.) The

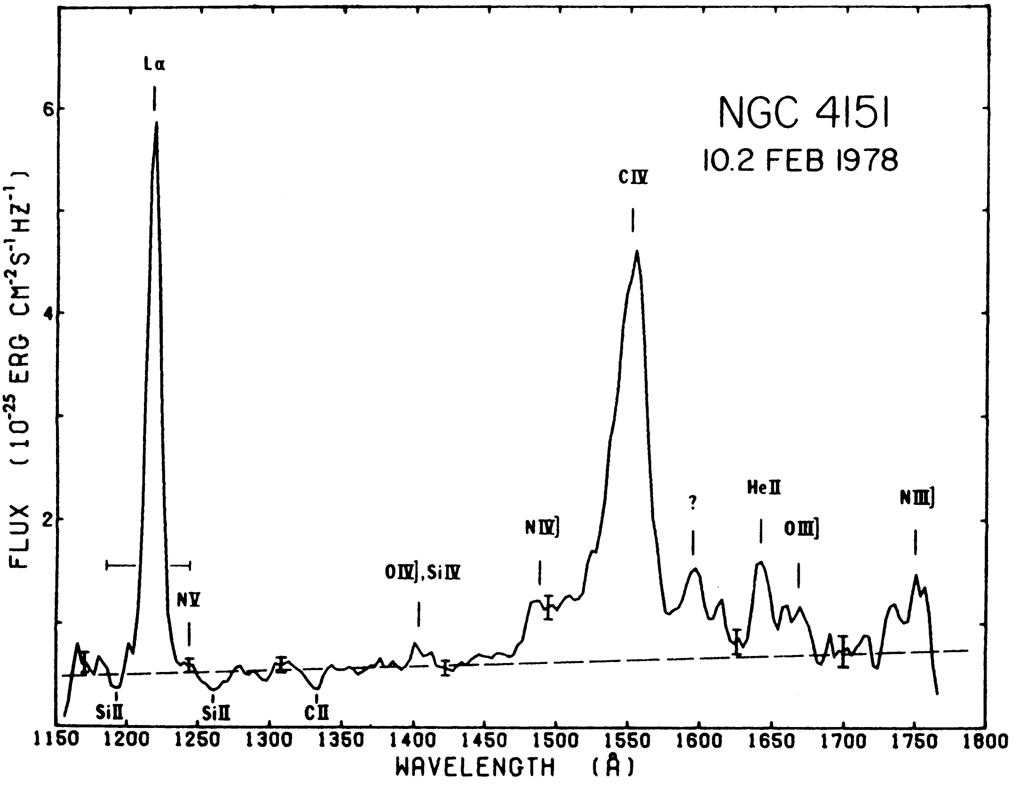

Figure 1. Far-ultraviolet spectrum of NGC 4151 as observed with the FOT. The Lα profile has been corrected for geocoronal emission extending across the width of the horizontal bar. The dashed line shows the assumed continuum level.

uv/optical ratios must therefore be very different for the broad and narrow line gas, just as Ferland *et al.* (1979) found in 3C 390.3. A best fit for the He II λ1640 profile yields F(1640)/F(4686) $\approx$ 5 for the narrow line gas, consistent with only a small amount of reddening $E_{B-V} \lesssim 0.15$ (Hartig 1978). The broad line ratio is much smaller but undetermined. External reddening therefore does not appear capable of explaining the uv/optical line ratios in NGC 4151.

Two very recent papers (Canfield and Puetter 1979, Kwan and Krolik 1979) have reported improved photoionization calculations for purely gaseous emission line clouds, incorporating excitation and ionization from excited states of hydrogen. In these calculations it is found that at large optical depths within the cloud the n=2 level is strongly populated, and both photoionizations and collisional ionizations from this level are important. The ionized fraction is therefore maintained at a very significant level deep within the cloud, and the Balmer lines become the major coolant. The resulting Lyman/Balmer line ratios agree well with the observations, without recourse to dust. They also show that Lα is not reduced in these models, but rather the Balmer lines are substantially enhanced. The results are consistent with the conclusions of Baldwin (1977), Puetter, Smith and Willner (1979), and Ferland *et al.* (1979). It still remains to be seen whether other uv/optical line ratios, e.g. those of O I and He II, can also be explained without resorting to dust.

It is clear that ultraviolet spectrophotometry of quasars and Seyfert galaxies is having a major impact on efforts to understand their emission line regions. It is also clear that the problems are still not resolved. On the one hand there is some direct evidence (Oke and Zimmerman 1979) that reddening has significantly affected the uv/optical flux ratio in two cases, while on the other hand there is also direct evidence that reddening alone cannot explain the observed effects in two other cases (Ferland *et al.* 1979, Hartig 1978). Also there is not yet agreement on whether the hydrogen line problem is telling us that Lα is too weak or that the Balmer lines are too strong. Several authors (e.g. Baldwin 1977, Peutter, Smith, and Willner 1979) have argued that the covering factor ε (the per cent of the sky which appears opaque to the central source at the Lyman limit) in quasars is < 0.1 and that Lα therefore has the correct equivalent width while the Balmer lines are enhanced. However, Boggess *et al.* (1979) have argued that $\varepsilon \sim 1/3$ and that the Balmer lines have the correct equivalent width while Lα is severely attenuated. A much better determination of the value of ε is certainly needed. For high

TABLE 2. Comparison of Observations of NGC 4151 by IUE and FOT

Identification	λ_o (Å)	Flux(10^{-12} erg cm^{-2} s^{-1}) FOT	IUE
Lα	1216	14(±3)	29(±13)
N V	1240	< 0.4	(abs)
O I	1303	< 0.4	(abs)
O IV]+Si IV	1400	0.5	(abs)
N IV	1486	$\lesssim$ 1.8	0.7
C IV	1550	12-20	24
He II	1640	1.4	2.3
O III]	1663	0.7	0.9
F_ν(continuum) (10^{-26} erg cm^{-2} Hz^{-1})	1450	6.3(±1.6)	16

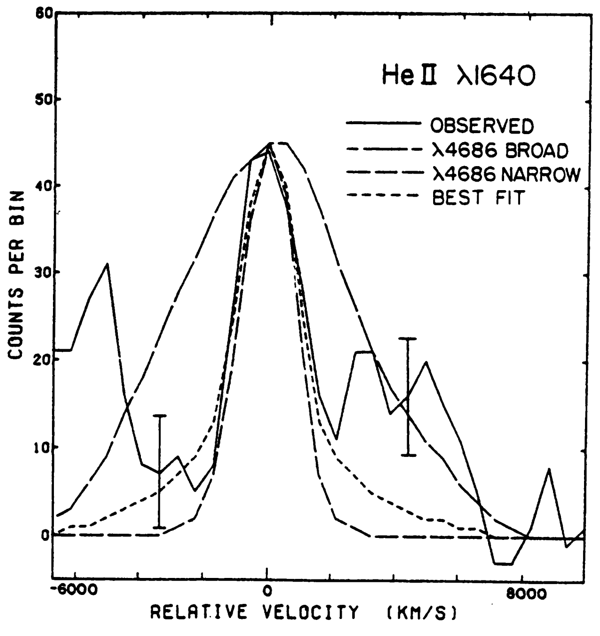

Figure 2. Line profile of He II λ1640 in NGC 4151, with continuum subtracted. The observed profile is much narrower than the broad He II λ 4686 profile, implying that F(1640)/F(4686) is larger for the narrow line gas than for the broad line gas.

redshift quasars observations at the Lyman limit can be done from the ground, but for low redshift quasars they require IUE and eventually the Space Telescope. For Seyfert galaxies the redshifts are too small, so that Lyman limit observations to determine ε cannot be performed with any existing or currently planned instrumentation.

Another interesting problem which the ultraviolet observations have raised concerns the absence of absorption or emission in the uv resonance lines of Fe II which were expected from optical observations of Fe II in the spectra of many Seyferts and some quasars (Phillips 1978, Boggess *et al*. 1979, Oke and Zimmerman 1979). This problem is closely related to that of the covering factor, since the most likely excitation mechanism for the Fe II lines is resonance fluoresence, requiring a very efficient conversion of uv continuum photons to Fe II line emission (Phillips 1978).

In conclusion, it seems likely that at least a small amount of reddening affects the spectra of many, if not all, active galaxies and quasars. Perhaps some internal dust is also involved in some cases. In addition, collisional processes and radiative transfer effects in the dense clouds in these objects produce significant modifications of the line intensities expected in simple models. In order to unravel all these effects accurate ultraviolet (and optical) spectrophotometry is required. Improvements in sensitivity are needed to measure weak lines, and improved resolution is needed to clearly separate the broad and narrow components of emission in objects with Seyfert 1 type spectra. The needed improvements will be available with the instrument complement planned for Space Telescope.

Research in ultraviolet astronomy at The Johns Hopkins University is supported by NASA grant NGR 21-001-001. I also acknowledge the support of the Alfred P. Sloan Foundation.

REFERENCES

Baldwin, J. A.: 1977, Mon. Not. R. astr. Soc. 178, pp. 67P-74P.
Baldwin, J., and Netzer, H.: 1978, Ap. J. 226, pp. 1-20.
Baldwin, J. A. *et al.*: 1978, Ap. J. 226, pp. L57-L59.
Boggess, A., *et al.*: 1979, Ap. J. (Letters) 230, pp. L131-L136.
Boksenberg, A., *et al.*: 1978, Nature 275, pp. 404-414.
Brocklehurst, M.: 1971, Mon. Not. R. astr. Soc. 153, pp. 471-490.
Canfield, R. C., and Puetter, R. C.: 1979, preprint.
Chan, Y.-W.T., and Burbidge, E. M.: 1975, Ap. J. 198, pp. 45-55.
Code, A. D. *et al.*: 1976, Ap. J. 203, pp. 417-434.
Davidsen, A. F., and Hartig, G. F.: 1978, *Proc. COSPAR/IAU Symposium on X-Ray Astronomy*, Eds. W. A. Baity and L. E. Peterson, Pergamon, N. Y.
Davidsen, A. F., Hartig, G. F., and Fastie, W. G.: 1977, Nature 269, pp. 203-206.
Davidson, K.: 1972, Ap. J. 171, pp. 213-231.
Ferland, G.. and Netzer, H.: 1979, Ap. J. 229, pp. 274-290.
Ferland, G. J. *et al.*: 1979, Mon. Not. R. astr. Soc., pp. 65P-71P.
Grasdalen, G. L.: 1976, Ap. J. (Letters) 208, pp. L11-L12.
Hartig, G. F.: 1978, Ph.D. thesis, The Johns Hopkins University, Balto.Md.
Hyland, A. R., Becklin, E. E., and Neugebauer, G.: 1978, Ap. J. (Letters) 220, pp. L73-L75.
Krolik, J., and McKee, C.: 1978, Ap. J. Suppl. 37, pp. 459-483.
Kwan, J., and Krolik, J.: 1979, preprint.
London, R.: 1979, Ap. J. 228, pp. 8-12.
MacAlpine, G. M.: 1972, Ap. J. 175, pp. 11-30.
Netzer, H., and Davidson, K.: 1979, Mon. Not. R. astr. Soc. 187,pp.871-882.
Netzer, H., and Penston, M.: 1976, Mon. Not. R. astr. Soc. 174,pp. 319-325.
Oke, J. B. and Lauer, T. R.: 1979, Ap. J. 230, pp. 360-372.
Oke, J. B., and Zimmerman, B.: 1979, Ap. J. 231, pp. L13-L17.
Osterbrock, D. E., and Koski, A. T.: 1976, Mon. Not. R. astr. Soc. 176. pp. 61P-66P.
Peutter, R. C. *et al.*: 1978, Ap. J. (Letters) 226, pp. L53-L56.
Peutter, R. C., Smith, H. E., and Willner, S. P.: 1979, Ap. J. (Letters) 227, pp. L5-L7.
Phillips, M. M.: 1978, Ap. J. 226, pp. 736-752.
Shuder, J. M., and MacAlpine, G. M.: 1979, Ap. J. 230, pp. 348-359.
Soiffer, B. T. *et al.*: 1979, Ap. J. (Letters) 227, pp. L1-L3.
Wampler, E. J.: 1968, Ap. J. (Letters) 154, pp. L53-L56.
Wampler, E. J.: 1971, Ap. J. 164, pp. 1-9.
Wu, C.-C.: 1977, Ap. J. (Letters) 217, pp. L117-L120.

DISCUSSION

Smith: An observation that may be relevant is the data on polarization in NGC 4151, which shows that the narrow emission line components are unpolarized, while the broad components are polarized, as if the broad lines may have been scattered by dust, while the narrow lines are not.

Rieke: Unpublished infrared spectroscopy of NGC 4151 by Lebofsky, Thompson, Tokunaga, and me indicates that the broad component of Bγ (2.16 μm) is somewhat stronger than predicted from the Balmer lines and recombination ratios, whereas the narrow component is undetected, requiring that its strength follow recombination ratios more closely than the broad component does. Thus, the same general trend seen for 3C390.3 in the ultraviolet is continued into the infrared for NGC 4151.

Oke: A large group of us have made IUE, visual and infrared observations of NGC 1068, which is a type II Seyfert where all the lines have comparable breadths. There are four pairs of lines which we have measured to derive the reddening; Lα/Hβ, λ1640/λ4686 of He II, Hα/Hβ, Pα/Hβ. There is available in the literature a Brackett line measure- which gives a Brackett/Balmer ratio. The [S II] lines also have been used by Wampler to derive the reddening. Within the accuracy of the measurements, all these ratios are consistent with E (B-V) = 0.40, provided simple recombination theory is used for the permitted lines. It is probably significant that NGC 1068 has no $N_e \approx 10^{10}$ cm^{-3} region, but a maximum N_e of the order of 10^6 cm^{-3}. The abnormal Lα/Hβ ratio found in quasars and type I Seyferts probably is confined to the 10^{10} cm^{-3} gas.

Rees: The model considered by Kwan and Krolik and by Canfield and Puetter requires that there must be a substantial energy input into parts of the cloud with very large optical depth in the Lyman continuum. Is photoionization by a power-law continuum sufficient, or does this require some additional energy input (e.g., Compton recoil from hard X-rays, or fast particles)?

Davidsen: Photoionization of helium and heavier elements by the unobserved extrapolation of the power-law continuum to soft X-ray energies is all that is required to provide the heating of the deep layers of the emission line clouds.