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THE LINE CONTINUUM LUMINOSITY RATIO IN ACTIVE GALACTIC NUCLEI: OR, ON THE "BALDWIN EFFECT"

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ABSTRACT

The luminosity dependence of the equivalent width of C IV in active galaxies, the "Baldwin" effect, is shown to be a consequence of a luminosity dependent ionization parameter, U. The available data, combined with a "standard" photoionization model, yield $U \propto L^{-0.25}$. This law also agrees with the lack of a "Baldwin" effect in Lyα or other hydrogen lines. A fit to the available data gives a weak indication that the mean covering factor decreases with increasing luminosity, consistent with the inference from X-ray observations.

We discuss, in the appendices, the effects of continuum shape and density on various line ratios of interest.

Subject headings: atomic processes — galaxies: nuclei — Galaxies: Seyfert

I. INTRODUCTION

Observations of both high and low redshift quasars (Baldwin 1977; Baldwin *et al.* 1978) and Seyfert I galaxies (Wu, Boggess, and Gull 1983) have shown that the equivalent width of the C IV λ1549 line in these objects is lower for higher luminosity objects, the so-called "Baldwin effect." Such a correlation is important because it offers an empirical method of determining the intrinsic luminosities and distances of quasars (Baldwin *et al.* 1978) and may serve as a probe of the environment near the poorly understood central engine. Such an effect does not seem to be present in Lyα although it may be present in Mg II λ2798 (Baldwin *et al.* 1978). The reality of this "Baldwin" effect for radio-quiet quasars has been questioned by Osmer (1980), even though it seems well established for radio-loud objects.

We wish to show in this paper that the Baldwin effect in active galaxies can be understood primarily as a systematic decrease in ionization parameter with luminosity and secondarily perhaps as a decrease of covering factor with luminosity (although these correlations may not be the only "cause" of the "Baldwin effect"). Previous interpretations have centered on the effects of embedded dust (see Shuder and MacAlpine 1979).

II. MODEL

We use the photoionization code of Ferland (1981) in the manner described by Ferland and Mushotzky (1982). To calculate our models we have used solar abundances and an ionizing input spectrum of the form

$$\frac{dN}{dE} = aE^{-\alpha_1} \exp\left(-\frac{E}{E_0}\right) + bE^{-\alpha_2} \text{ photons cm}^{-2}\text{ s}^{-1}\text{ eV}^{-1}$$

where $\alpha_1 = 2.2$ (Malkan and Sargent 1982), and $\alpha_2 = 1.7$ (Mushotzky 1982), with the ratio of the ionizing photons in the two components given by $A/B \sim 3 \times 10^2$. This reproduces the mean spectrum of Seyfert Is quite well (Wu, Boggess, and Gull 1983), and corresponds to an α_{0x} of ~ 1.5, the mean value for X-ray detected optically selected AGN. We have chosen a cutoff value $E_0 = 200$ eV so as not to exceed the observed soft X-ray flux (see Appendix A). The code uses methods and assumptions very similar to those described by Kwan and Krolik (1981) (see also Davidson and Netzer 1979). We will be primarily interested in lines formed in the highly ionized H^+ zone of the broad-line clouds, where the physical conditions are less sensitive to the exact details of the model such as line trapping or X-ray effects which may strongly effect such lines as Hα, Hβ, or Mg II. As a consequence our theoretical results are basically similar to those found by Davidson (1977), Shuder and MacAlpine (1979), and Weisheit, Shields, and Tarter (1981).

High-luminosity quasars apparently have a lower X-ray-to-optical ratio by a factor of ~ 50 (Reichert *et al.* 1982) than Seyfert galaxies such that a/b can be as large as 1.5×10^4. However, we find that the conclusions we reach about Lyα, C III], and C IV are relatively independent of the optical-to-X-ray ratio because these lines do not come from the "X-ray" heated deep zone (see Appendix A); we do not examine the effect of possible variation in the UV index α_1, on line ratios. Because certain high ionization lines such as O VI and N V and "low ionization" lines such as Mg II and Hβ are more sensitive to the ratio of optical-to-X-ray luminosity, L_0/L_x, one still should be careful in defining the continuum form. We have chosen models with constant density between $\log \rho = 9.5$ and $\log \rho = 10.2$ cm^{-3} and clouds with fixed column density N_H. The assumption of constant density rather than constant pressure seems as reasonable when it is realized that the sound crossing time for typical clouds ($\delta r \sim 10^{13}$ cm, $\tau \sim 1$ year) is of the order of the time scale for continuum variability. Therefore, since the clouds are in virtually instantaneous thermal and ionization equilibrium, they *cannot* be in pressure equilibrium. In our models as long as $\log N_H$ is > 22.4 at cm^{-2}, and $\log U < -1.0$, the C III], Lyα, and C IV line fluxes are almost independent of how thick the cloud is at these densities and ionization parameters. In most of our model runs C III] was saturated by a column density of $\log N_H \sim 22.4$, while Lyα and C IV were saturated at lower N_H.

The model assumes that there is only one "slab" at a given distance from the central source and spherical symmetry in the broad line region (see Davidson 1977). We use the same defini-

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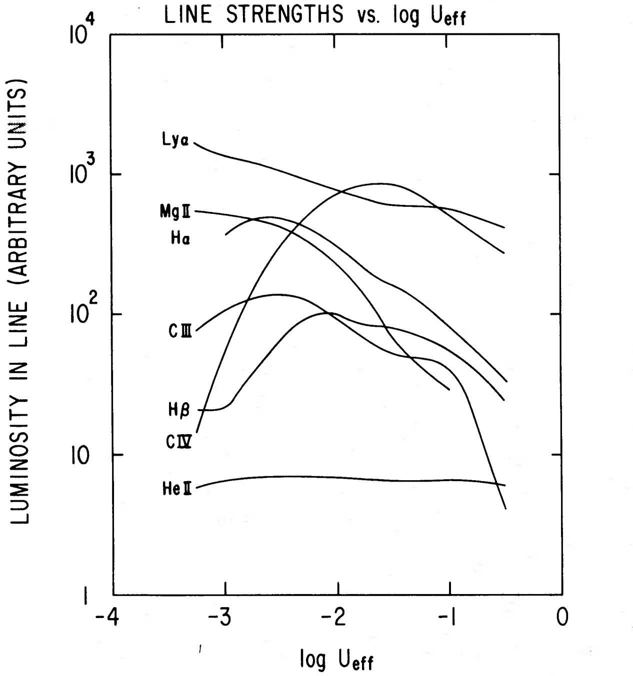

FIG. 1.—Relative line fluxes, $f_L(U)$, for Lyα, C IV, C III] (1909λ), Mg II (2798λ), Hα, Hβ, and He II (4686λ) vs. the ionization parameter log U at a fixed density (log ρ = 10.0) and fixed column density log N_H = 22.8 atoms per cm^2 for the continuum specified in the text.

tion of ionization parameter U as in Ferland and Mushotzky (1982); $U = Q(\mathrm{H})/4\pi r^2 c n_e$ where Q(H) is the number of ionizing photons per second and thus U depends on the continuum shape. Log U is typically on the order of -2 for active galactic nuclei (Davidson and Netzer 1979).

III. RESULTS

As is shown in Figure 1, at a fixed continuum luminosity the C III], Lyα, and C IV luminosities are a strong function of the density and ionization parameters. This has long been well known (see review by Davidson and Netzer 1979). Wu, Boggess, and Gull (1983) point out that several objects with high C III]/C IV ratios have high Lyα/C IV and that several others which have low C III]/C IV have low Lyα/C IV. We wish to point out here that this correlation is very general. In Figure 2 we plot the ratio of C III]/C IV versus Lyα/C IV for all the AGN in the literature we know of. On this graph we also draw lines of constant log ρ *but* varying ionization parameter, log U, from our model calculations. Note that because of the strong thermostat effect of these cooling lines, their strength is not strongly sensitive to the carbon abundance assumed (cf. Shuder and MacAlpine 1979). Virtually all of the points in this diagram lie between the lines log ρ = 10 and log ρ = 9.5. Assuming that this represents "correct" physics we can restrict ourselves to the majority of points that cluster on the log ρ = 9.5 line. We can then assign an effective ionization parameter log U_{eff} for a given object appropriate for Lyα, C III], and C IV, from the location of the object in Figure 2. We have chosen those objects that cluster with $\pm 10\%$ of the theoretical line, consistent with an estimate of observational errors. The many fewer points that appear to cluster around the outer two lines do not allow a good estimate of the dependence of log U_{eff} on L to be determined.

We show in Figure 3 for Seyfert galaxies and QSOs a plot of log U_{eff} versus log L_{1450}, the luminosity of the source at 1450 Å. This latter value may be taken as indicative of the total luminosity of the source as measured by Baldwin and thus is appropriate for the Baldwin relation. It is quite clear from this plot that log U_{eff} is inversely related to log L_{1450}. This

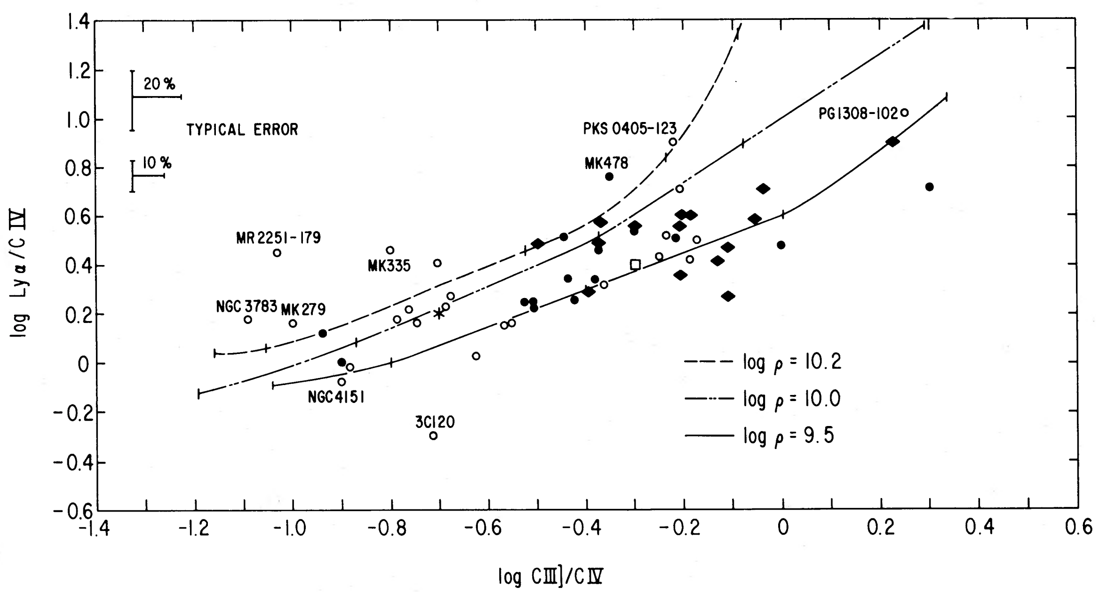

FIG. 2.—Log C III]/C IV vs. log Lyα/C IV for a sample of active galaxies. The lines are theoretical line ratio's from photoionization models. The tick marks are at log $U_{\mathrm{eff}} = -1, -1.5, -2.0, -2.5, -2.75$ for log ρ = 9.5, log $U_{\mathrm{eff}} = -1.5, -2.0, -2.5, -2.75$, and -3.0 for log ρ = 10.0 and at log $U_{\mathrm{eff}} = -1.5, -2.0, -2.5, -2.75$, and -3.25 for log ρ = 10.2. The data marked by an open symbol are from *IUE* (Wu, Boggess, and Gull 1983; Green *et al.* 1980; Ulrich and Boisson 1983; and Malkan 1983). The solid dots are from Baldwin and Netzer (1978), the solid diamonds from Oke and Korycansky (1982). The open square is the "mean value" for Osmers quasars and the star the mean value for Seyferts.

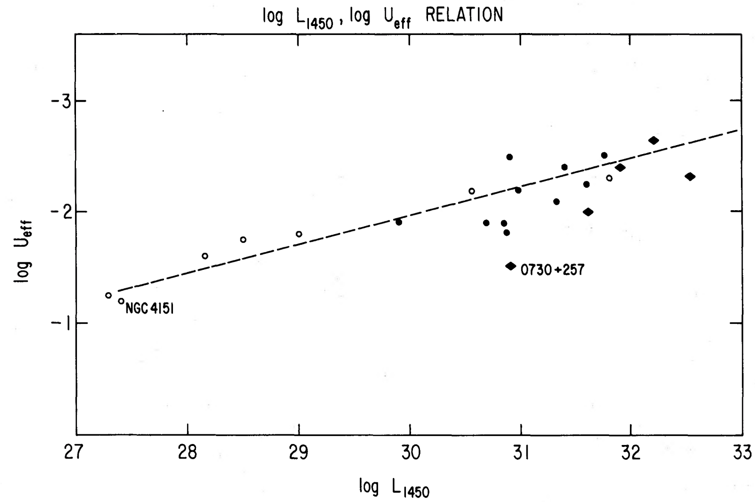

FIG. 3.—Log luminosity at 1450 Å vs. log $U_{\rm eff}$. The data are drawn from Figure 2 from the points that cluster along the log $\rho = 9.5$ line. Symbols have same meaning as in Fig. 2. The line is the best fit power law to the data of slope -0.25. The Oke and Korycansky points have been converted to 1450 Å continua following Wampler *et al.* (1983). Not all points in Fig. 2 have continuum L_{1450} available in the literature and so do not appear in Fig. 3.

relation has a linear regression coefficient $R = 0.90$ and is thus significant at greater than the 99.999% confidence level. The best fit power law gives $\log U \approx -0.25 \log L_{1450}$. The small size of the exponent requires a large total range in L to see (which is why this effect was not noticed in samples restricted to high-luminosity, high-redshift QSOs), but we feel it is quite significant.

It is interesting to note that comparison of the mean of C III]/C IV and Lyα/C IV ratios for quasars and Seyferts separately, which has a much larger number of objects, also shows the same effect. The mean of Lyα/C IV for high z QSOs from Osmer (1980) and Osmer and Smith (1980) is ~2.5 while for Seyferts Is, of considerably lower luminosity, the ratio is 1.5 (Wu, Boggess, and Gull 1983). For C III]/C IV the mean ratio for QSOs is 0.5, while for Seyferts it is 0.2. Since the "mean" luminosity at 1450 Å for the Osmer and Smith QSOs is $\log L_{1450} \sim 31.5$ while for the Wu *et al.* sample it is $\log L_{1450} \sim 29.0$, this also indicates in our representation of the data a luminosity-dependent ionization parameter. One must of course also remember that the C III]/C IV ratio is density sensitive and that some fraction of the observed variation could easily be due to variation in density from object to object (see Appendix B). However Lyα/C IV has only a very weak density dependence (for $\log U = -1.5$, Lyα/C IV $\sim \rho^{+0.07}$, $9.0 < \log \rho < 10.2$ from our calculations) so that most of the Lyα/C IV variation cannot be due to density effects alone. Similarly it is well established that the Lyα/C IV and C III]/C IV ratios are independent of the X-ray-to-optical ratio (Kwan and Krolik 1981; see Appendix A) [which is itself also a function of absolute luminosity (Zamorani 1982)]. We therefore argue, tentatively, that a major fraction of the observed variation in the Lyα/C IV versus C III]/C IV plane is due to variation in ionization parameter and that this variation is luminosity dependent. A similar suggestion for the origin of the C III]/C IV ratio being lower for Seyfert Is than quasars was made by Wu, Boggess, and Gull (1983).

IV. DISCUSSION

a) *Baldwin Effect*

Can this observed luminosity dependent ionization parameter account for the Baldwin effect? Roughly speaking, the luminosity in a given line is $L_{\rm Line} = (\Omega/4\pi) A_L f_L(U) L_{\rm cont}$. In this expression $L_{\rm cont}$ is the luminosity in the continuum integrated over the frequency range appropriate to ionize the ion emitting the given line, $f_L(U)$ for several lines is shown in Figure 1 and A_L is a constant for a given line. In the following discussion the covering fraction, $\Omega/4\pi$, which is the fraction of central continuum photons intercepted by broad-line clouds, is set equal to unity. For C IV we have for $\log U < -2.5$ (Fig. 1) that $f_L(U) \sim U^{7/4}$, while for $-2.5 < \log U < -1.5$, $f_L(U) \sim U^{2/5}$. Thus since $U \sim L_{1450}^{-1/4}$ if we associate $L_{\rm cont}$ with L_{1450} one gets $L_{\rm C\,IV} \sim L_{1450}^{9/16}$ for $\log U_{\rm eff} < -2.5$ and $L_{\rm C\,IV} \sim L_{1450}^{0.9}$ for $-2.5 < \log U_{\rm eff} < -1.5$. Using our calibration in Figure 3 of $\log L_{1450}$ versus $\log U_{\rm eff}$ we see that $\log U_{\rm eff} \sim -2.5$ is achieved at $\log L_{1450} \sim 31.0$. This value of $\log L_{1450}$ is appropriate for Baldwin's (Baldwin 1977; Baldwin *et al.* 1978) sample of high redshift quasars. These authors find that $L_{\rm C\,IV} \sim L_{1450}^{0.33 \pm 0.17}$ compared to our prediction of an index of 0.56 (the recent analysis of Kiang, Cheng, and Zhou [1983] of Osmer's data gives $L_{\rm C\,IV} \propto L_{\rm cont}^{0.33 \pm 0.1}$ for radio-quiet objects). We consider this a reasonable agreement. Of course this requires that $L_{\rm cont}$ be linearly related to L_{1450}. A possible luminosity dependent covering fraction, such as has been observed in the X-ray band could make the agreement almost exact (see discussion in § IV*c*). More data points are necessary to define the log U versus log L relation more clearly (Baldwin 1977; Baldwin *et al.* 1978).

Examination of Figure 6 of Wu, Boggess, and Gull or Figure 6 of Wampler *et al.* (1983) shows that the Baldwin relation starts to fail badly at $\log L_{1450} \sim 29$–29.5 ($M_{1550} = -22$) or in our transformed units (cf. Fig. 3) $\log U_{\rm eff} \sim -1.75$ more or less where $f_L(U)$ for C IV flattens (Fig. 1). That is, we *predict* that the Baldwin effect should become much weaker for lower luminosity AGN. This occurs when $f_L(U) \propto U^{2/5}$; that is, for $\log L_{1450} < 30$. At even higher values of U and thus lower values of L, $f_L(U)$ is flat for C IV, e.g., $L_{\rm C\,IV} \propto U^0$ and thus there should be *no* ionization parameter "Baldwin effect" consistent with the recent results of Wampler *et al.* (1983).

We thus feel that we can account for both the slope of the "Baldwin" relation and the place where it ceases to be significant from the L_{1450} versus U relation. The lack of a "Baldwin" effect in Lyα, e.g., the fact that the luminosity in Lyα is linearly related to the continuum flux, is easily understood as well. Figure 1 shows that $L_{\rm Ly\alpha} \sim U^{-0.25}$. Thus we predict that $L_{\rm Ly\alpha} \sim L_{\rm cont}^{1.06}$ consistent with Osmer's (1980) results.

b) Other Lines

What are the other predictions of such a model? As Kwan and Krolik (1981) point out, high ionization lines such as O VI λ1035 and N V λ1240 are quite sensitive to $\log U$ variations. Our model would predict that low luminosity objects would have considerably stronger O VI and N V lines than high redshift quasars. Unfortunately there are very few data on N V from Seyferts and none on O VI.

If this idea is correct one might also see the "Baldwin effect" in an individual variable object, or if it had the proper ionization parameter perhaps even an "anti-Baldwin effect." An anti-Baldwin effect is predicted for objects with a low luminosity since for large U, $\log U > -1.5$, $f_L(U) \propto U^{-0.5}$. In fact, in NGC 4151, from the 1978 May to 1978 October *IUE* observations (Penston *et al.* 1981) show that the continuum at 2500 Å decreased by 22% but that the flux in C IV did not change. On time scales much longer than the light travel time across the broad-line region (0.1–1 year) reverberation effects such as those discussed by Bahcall and Kozlovsky (1969) and Blandford and McKee (1982) are suppressed. Similarly, in NGC 3783 (Barr, Willis, and Wilson 1983) which has variability on a time scale of a month, longer than the light travel time across the broad-line region of the object, it has been reported that a Baldwin-type relation holds. Fitting the Barr *et al.* data, we find $L_{\rm C\,IV} \propto L_{1450}^{0.25}$. If in this object $U \propto L_{\rm cont}$ (we assume that the cloud position does not change), this gives, using Figure 1, a $\log U_{\rm eff} \gtrsim -1.75$. Matching the variations in the Lyα/C IV versus C III]/C IV plane by using Figure 2 for this object also give $U_{\rm eff} \sim -1.75$. For a luminosity of $\log L_{1450} \approx 27.0$ this value of $\log U$ is in general agreement with the overall $\log L_{1450}$ versus $\log U_{\rm eff}$ relation (Fig. 3). Thus in this one object we get similar estimates for U from variations in line ratios, from its position in the continuum luminosity versus U plane, and from the relationship between C IV and continuum luminosity.

We therefore conclude that much of the available data are consistent with the "Baldwin effect" both in the ensemble of active galaxies and in NGC 3783 being due primarily to luminosity-related variations in the effective ionization parameters.

c) X-Ray Data and Covering Factor

It has been claimed (Holt *et al.* 1980; Mushotzky 1982; Lawrence and Elvis 1982) that the effective X-ray column density is related inversely to the X-ray luminosity L_x. If we *assume* that this is a covering factor effect, we might expect to see it in the Lyα and C IV line fluxes; that is, since the higher luminosity objects have a lower covering factor, this would tend to depress the Lyα and C IV line fluxes systematically with luminosity. Inspection of Figure 6 of Wu, Boggess, and Gull shows that for $\log L < 29.0$ (where we predict that the ionization parameter dependent Baldwin effect should be weak or not present) that $\log L_{\rm C\,IV} \propto L_{\rm cont}^{0.8}$, at roughly 3 σ confidence, behaving as if the covering factor Ω was weakly dependent on L, e.g., $\Omega \propto L^{-0.2}$. This small an effect would *not* be seen over a large dynamic range in L in the Lyα or C IV line fluxes since it would be dominated by the "Baldwin effect" at large L. This variation in covering factor inferred from the C IV line predicts that, in the X-ray energy range, one would see the mean covering factor change from a (postulated) value of 1 at $L_x \sim 42.5$ (for NGC 4151) to 0.6 at $L_x \sim 43.5$ which would *totally* account for the observed X-ray absorption effect seen by Mushotzky (1982). That is, the fact that high luminosity active galaxies do not, typically, show X-ray absorption can be explained by a reduction in the mean covering fraction from 1 for low luminosity objects like NGC 4151 to $\sim$0.7 for objects of a factor 10 higher X-ray luminosity.

If we include this luminosity dependent covering factor in our predictions, the slope of the best fit relation between C IV line flux and continuum luminosity changes from $L_{\rm C\,IV} \propto L_{\rm cont}^{+0.56}$ to $L_{\rm C\,IV} \propto L_{\rm cont}^{+0.36}$, in nearly perfect agreement with that measured by Baldwin and co-workers. We thus feel that all these results are compatible. It is interesting to note that if we extend this fit to the quasars of $\log L_x \sim 46$, we would predict a covering factor of 0.2, which is similar to that inferred for these objects by the Lyman continuum absorption arguments (Osmer 1980).

d) Can the Baldwin Effect be Seen in the Balmer Lines?

Inspection of Figure 3 shows that the other hydrogen lines (Hα, Hβ) show similar weak dependences on $\log U_{\rm eff}$. In particular, to compare with the data of Yee (1980) and Shuder (1981) we find that, roughly $\log L_{\rm H\alpha} \sim -0.4 \log U$, for $\log U$ in the range -1.5 to -2.5 and $\log L_{\rm H\beta} \sim -0.2 \log U$ for $U < -2.25$. Thus we would predict $\log L_{\rm H\alpha} \sim 1.1 \log L_{\rm cont}$ and $\log L_{\rm (H\beta)} \sim 1.05 \log L_{\rm cont}$. The actual fit Yee gives for quasars is $\log [L({\rm H\beta})] \sim 1.00 \log L_{\rm cont}$ and Shuder gives $\log [L({\rm H\alpha})] \sim 1.05 \log L_{\rm cont}$. The agreement between theory and observation again seems quite good. We have not taken possible systematic variations in covering factor (§ IV*c*) into account here.

V. CONCLUSIONS

We have established that there exists a luminosity-ionization parameter correlation for active galactic nuclei (quasars and Seyfert Is). This correlation combined with photoionization model calculations predicts that the luminosity in C IV λ1549 should be proportional to the continuum luminosity to the half-power at high luminosity, e.g., the Baldwin effect. At low luminosity the effect should get weaker and disappear for low luminosity AGNs.

We can further show that such an effect should be present in individual galaxies when their luminosity changes, as has been seen by Barr, Willis, and Wilson (1983) for NGC 3783.

In addition the calculations show that there should *not* exist a Baldwin effect in Lyα, Hα, and Hβ. Observationally this has been shown by Yee (1980), Shuder (1981), and others.

The lack of a Baldwin relation at low luminosity allows us to investigate the covering factor, $\Omega/4\pi$, versus luminosity relation in low luminosity AGN. We find that $\Omega \propto L^{-0.2}$. This weak anticorrelation is important enough to account for both the observed anticorrelation seen in the X-ray between luminosity and X-ray absorption as well as to predict the low covering fractions observed in high luminosity QSOs.

We thank the referee for his careful reading of the manuscript and his insightful comments.

APPENDIX A: CONTINUUM EFFECTS

In this appendix we will consider the effects of varying the continuum form on the strong emission lines Lyα, Hα, Hβ, C III], C IV, and Mg II. We caution the reader that since Hα, Hβ, and Mg II are generated mostly in the thick, cool regions of the cloud whose physics is not yet totally understood that these results are primarily illustrative. We have constant density clouds of thickness $\log N_H = 22.8$ and density $\log \rho = 10.0$. We pick 5 model spectra of the form $F_\nu = a\nu^{-\alpha_1} \exp/-(E)/E_0) + b\nu^{-\alpha_2}$ photons cm^2 s^{-1} eV with $\alpha_2 = 1.7$, $\alpha_1 = 2.2$ and vary E_0 and a/b (see § II).

Model 1 has $A/B = 300$, which corresponds to $\alpha_{0x} = 1.51$ with $E_0 = \infty$.
Model 2 has $E_0 = 200$ eV and $A/B = 300$.
Model 3 has $E_0 = 200$ eV $A/B = 7200$ which corresponds to $\alpha_{0x} = 2.05$.
Model 4 has $E_0 = 200$ eV $A/B = 2.3$ or $\alpha_{0x} = 1.28$.
Model 5 has $E_0 = 200$ $A/B = 0.4$, $\alpha_{0x} = 1.00$.

This range of α_{0x} from 1.00 to 2.05 covers, roughly, the complete range of α_{0x} as seen by Zamorani *et al.* (1981). A quick inspection of Table 1 shows that the line ratios are almost invariant with respect to the models. That is, within the limited range of continuum models we have chosen, the line ratios are almost invariant with respect to the exact form of the soft X-ray (0.2–5 keV) spectrum or to the optical/X-ray ratio. The largest changes between models is seen between models 3 and 4 the $\alpha_{0x} = 2.05$ and 1.28 models. Model 4 has a systematically higher ratio of Mg II/Hβ. Our models are consistent with the observational results of Kriss (1982) on the Lyα/C IV ratio showing only a weak anticorrelation with α_{0x}.

TABLE 1

LINE RATIOS FOR MODELS 1–5

Ratio	Model 1	2	3	4	5
		$\log U = -3.0$			
Lyα/C IV	23.4	22.8	23.9	24.8	28.5
C III]/C IV	1.86	2.05	2.16	2.13	2.0
Hα/Hβ	17.3	13.1	12.1	15.5	18.7
Mg II/Hβ	21.6	13.1	11.1	18.4	2.47
		$\log U = -2.0$			
Lyα/C IV	1.48	1.33	1.42	1.27	1.13
C III]/C IV	0.18	0.155	0.16	0.15	0.13
Hα/Hβ	3.9	4.1	5.52	4.2	3.5
Mg II/Hβ	2.9	1.76	2.00	3.03	1.7
		$\log U = -1.00$			
Lyα/C IV	1.04	1.67	1.92	1.32	0.90
C III]/C IV	0.08	0.12	0.13	0.103	0.08
Hα/Hβ	1.41	1.36	1.33	1.35	1.68
Mg II/Hβ	0.58	0.316	0.22	0.415	0.32

At higher values of L_x/L_0, e.g., $\alpha_{0x} = 1.0$, Model 5, the $\log \rho = 10.0$, $\log N_H = 22.8$ clouds become more ionized all the way through and the nature of the models change since there is no longer a very cool "vasty deep." This strongly affects the Mg II and Hβ lines.

APPENDIX B: DENSITY EFFECTS

The referee has suggested that we should clarify the use of C III] as both a density and ionization parameter diagnostic. In this section we consider the C III]/C IV ratio for a constant continuum and column density but variable density and ionization parameter. In Table 2 of Appendix B we show our results for a model with $A/B = 7200$ (e.g., low X-ray flux $\alpha_{0x} = 2.05$), and no cutoff and constant thickness $\log N_H = 22.8$ for three different densities and ionization parameters.

As is easily seen in Table 2 the results are degenerate. One can get the same values of C III]/C IV for all three densities and ionization parameters. Thus one *cannot use only* the C III]/C IV ratio to determine density or ionization parameter.

TABLE 2

C III]/C IV RATIO

	$\log \rho$		
$\log U$	9.5	10.0	10.2
−2.50	0.817	0.420	0.289
−2.00	0.27	0.129	0.093
−1.50	0.092	0.060	0.053

TABLE 3

Lyα/C IV RATIO AS A FUNCTION OF DENSITY AND LOG U

	$\log \rho$		
$\log U$	9.5	10.0	10.2
−2.50	3.88	3.28	2.85
−2.00	1.26	1.08	0.94
−1.50	0.784	0.755	0.71

However, as Figure 2 and Table 3 show, for a given continuum Lyα/C IV is sensitive almost totally to ionization parameter and not density.

Thus over fairly wide ranges in density and ionization parameter one can estimate *both* log U and log ρ by using the two line ratios Lyα/C IV and C III]/C IV if the measurements have accuracies of better than 10%.

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