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Interpretation of the Ionizing Photon Deficit of AGN

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ABSTRACT. Correlations of slope unity between the optical continuum luminosity and the Balmer line luminosities (Yee 1980; Shuder 1981) have been traditionally used to demonstrate that photoionization is the excitation mechanism of the emission lines in active galactic nuclei. This correlation can be expressed in terms of a constant and universal equivalent width of Hβ over five decades in optical-UV continuum luminosity. It is found that the equivalent width $EW_{H\beta}$ of narrow-line objects (Seyfert 2's, NLRG) is not systematically different from that of broad-line dominated objects (QSO's BLRG, Seyfert 1). Based on empirical evidence as well as on recent BLR models we argue that the global efficiency for reprocessing the number of ionizing photons into Hβ line photons is equal to or less than that given by recombination case B. Assuming a canonical cloud covering factor of $C_f=0.1$ of an isotropic UV source, for any reasonable value of the power-law index α ($L_\nu \propto \nu^{+\alpha}$), we find a substantial deficit of ionizing photons in all AGN. For instance, an index of -1.4 or as flat as -0.6 leads to a deficit in ionizing photons of a factor of 25 and 4, respectively. A lower reprocessing efficiency as that characterizing the more recent BLR models brings the deficit in the range 8–15 (for $\alpha=-0.6$). The solution envisaged to account for the apparent deficit and to explain how $EW_{H\beta}$ can be aspect independent from Seyferts to radio galaxies and quasars is that the *observed* optical continuum originates from or near the line-emitting clouds (i.e., "hazy" nucleus) and is distinct from the primary ionizing radiation directly impinging on the clouds. Evidence for this is provided by the detection of continuum emission associated with the spatially resolved emission-line gas in radio galaxies and nearby Seyferts. The possible mechanisms envisaged to explain the spatial association of continuum emission and line emission are electron scattering, dust scattering, and *in situ* generation of continuum by high-velocity shocks, by thermal gas emission, or by inverse self-Compton scattering. The main observable consequences of this spatial association between the continuum and line emission are that (1) it can explain in a natural way the observed narrow range of $EW_{H\beta}$ in AGN whether or not the primary ionizing source is anisotropic (2), it can result in similar temporal behavior of continuum and line emission (i.e., short time lags of the BLR lines) as a result of intermixed continuum and line reverberation, (3) and it explains why dust extinction of the nuclear continuum emission never exceeds that of the BLR lines (e.g., in Seyferts 1.8 and 1.9) since both emission processes being co-spatial are characterized by a similar path length to the observer.

1. INTRODUCTION

The most direct evidence of photoionization as the main excitation mechanism of the emission lines in active galactic nuclei (AGN) lies in the observation of a strong featureless UV continuum in QSOs and Seyfert galaxies as well as in a large fraction of radio galaxies. It is found that the luminosity of the strong lines such as Lyα, C IV (see Kinney et al. 1990; Netzer 1990), Hα (Shuder 1981), Hβ (Yee 1980), and to a lesser extent [O III] (Boroson and Green 1992) correlate with the luminosity of the optical-UV continuum. There are other arguments which independently support photoionization. Variability studies, for instance, confirm that the broad lines respond rapidly and in a coherent way with the optical-UV continuum (see review by Peterson 1992, 1993). Furthermore, the line ratios observed in both the narrow-line region [NLR, see Stasinska 1984, Ferland and Osterbrock 1985 (hereafter FO86), Binette et al. 1988] and the broad-line region (BLR, see Rees et al. 1989, and references therein) are broadly consistent with those of photoionization calculations. In this work, without altering the picture of photoionization as the main excitation mechanism of the lines, we propose an alternative view of the relation between the

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observed optical continuum and the primary ionizing continuum.

The simplest picture of an AGN proposes an isotropic central ionizing source illuminating relatively distant gas clouds (distant in terms of source size). A consistency check on this picture is directly provided by estimating the number of ionizing photons available to excite the gas. If the blue-UV featureless continuum observed in AGN *is* truly the optical counterpart of the ionizing continuum, the number of ionizing photons derived from extrapolating the continuum into the far UV should be sufficient to account for the observed line intensities. Such a test was initially carried out by Weedman (1976) for Seyferts and Yee and Oke (1978) and Penston and Fosbury (1978) for radio galaxies with generally positive results. More complete studies were later performed combining QSOs, quasars, Radio Galaxies, Seyferts 1 and 2 by Yee (1980) and Shuder (1981) which are now text book material for proving the validity of the photoionization mechanism (Osterbrock 1989). It is the direct connection between the observed optical-UV continuum and the generation of the emission lines which we now question. Kinney et al. (1991, hereafter KAW3) has presented strong evidence for a deficit of ionizing photons in Seyfert 2's. We show in Sec. 2.1 and 2.2 that the deficit problem may encompass all AGN (except BL Lacertae objects).

A simple way to resolve the deficit problem is to postulate that the ionizing source is an anisotropic emitter (either intrinsically or as a result of a thick obscuring torus). In this case, the deficit is only apparent as a result of the observer not lying in the direction of the collimated radiation. In Sec. 2.3, we discuss how the anisotropy hypothesis forces us to revise our understanding of the nature of the *observed* nuclear optical-UV continuum. Bluntly, if the "observed" emission continuum is *not* the one ionizing the gas, what is it and what is its relationship to the emission-line gas?

A deficit of ionizing photons has also been established in the case of the large-scale ionized gas around powerful radio galaxies (which are usually much less obscured than Seyfert 2's). For instance, Danziger et al. (1984), Tadhunter et al. (1988), and Prieto et al. (1993) found that the nuclear continuum of PKS 0349−27, PKS 2152−69, and 3C 227, respectively, was too weak to account for the ionized gas line luminosities observed at distances of 10–100 kpc from the nucleus. In these objects, the line ratios are nevertheless consistent with photoionization by a power law (and not by hot OB stars). From detailed studies of the *extended* narrow-line region (ENLR or EELR) in Seyferts, Wilson et al. (1988) find a similar deficit of ionizing photons for a substantial fraction of their sample. In the case of the ENLR of the Seyfert 1.5 NGC 4151, Penston et al. (1990) conclude in a deficit of a factor 13. Amongst the various solutions discussed, Penston et al. favor that of anisotropy of the nuclear source.

Alternative solutions to anisotropy have been considered in the past. One consisted in postulating that the large-scale ionized gas had been ionized during a higher state of nuclear continuum emission. Binette and Robinson (1987) showed, however, that the spectrum of a fossil nebula rapidly changes towards a small ratio of [O III]/He II (λ5007/λ4686)(<1), inconsistent with the high excitation of the large-scale ionized gas observed around many AGN.

Another possibility explored by Binette et al. (1988) (see also Robinson et al. 1987) was that the ionizing flux could peak in the extreme UV and therefore be much stronger than inferred from an extrapolation of the optical power law of index $\alpha \sim -1 (F_\nu \propto \nu^{+\alpha})$. The line ratios using a blackbody ionizing continuum of $T_{bb} \approx 120{,}000$ −140,000 K were shown to be quite similar to that obtained with the canonical power law $\alpha = -1.4$ (e.g., FO86). The insurmountable difficulty with hypothesizing such distributions is their positive spectral index ($\alpha \leqslant +2$) while the observed index in the optical UV is always found to be negative. By superposing an underlying $\alpha = -1.4$ power law (contributing significantly to the visible and to the X rays) to the blackbody continuum, Binette et al. (1988) obtained an α of the combined distribution which is more consistent with optical observations but which still shows a strong upturn to positive α's somewhere in the far UV (10–20 eV). This is not observed in high-redshift QSOs for which *IUE* satellite observations extend beyond the Lyman limit.

These three distinct classes of explanation could be called "geometric," "temporal," and "spectral," respectively. Another possibility is that the deficit is simply the result of large extinction by dust of the nuclear continuum source as proposed by Boisson and Durret (1988), Carleton et al. (1987), and Binette et al. (1993, hereafter BWVM3). Extending this idea from Seyfert 2 to all AGN could imply that the universal (unreddened) continuum energy distribution would have to be as flat as $\alpha \approx 0$ (Sec. 2.2). As discussed in Sec. 3.2, however, the simplest version of this picture appears inconsistent with the detection (in polarized light) of a BLR in Seyfert 2's.

Clear indications that a significant part of the ionizing radiation escapes the nucleus in a nonisotropic way was provided by the work of Haniff et al. (1988) who found that the extended emission region (ENLR) in their sample of Seyferts was significantly elongated and, interestingly, that the elongation angle (derived from the [O III] image) was aligned with the radio major axis. The best evidence for the geometrical explanation is certainly that provided by the biconical distribution of ionized gas seen in the Seyferts NGC 5252 (Tadhunter and Tsvetanov 1989) and Mrk 573 [Haniff et al. (1991) (see also review by Wilson 1992)]. The "alignment effect" seen in high-redshift radio galaxies (McCarthy et al. 1987; Chambers et al. 1987) has also been interpreted as a result of anisotropic nuclear radiation (see Cimatti et al. 1993, and references therein).

Much interest in studying the physical conditions of the extended emission-line gas lies in the hope that the understanding gained at that level could be applicable to the spatially unresolved inner regions of AGN. From such studies could we, for instance, gain some understanding of the relationship between the optical-UV continuum and the line-emitting gas within the inner 50 pc of AGN? This appears to be the case following the exciting discovery that spatially resolved continuum emission is associated in some object with the extended emission-line gas component. One spectacular case is the detached bright emission-line cloud at 8 kpc from the radio-galaxy PKS 2152−69, which emits a significant optical-UV continuum. In Seyferts, despite the difficulties in detecting a similar continuum underlying the ENLR because of strong stellar light, a significant breakthrough has been recently achieved by Pogge and De Robertis (1993) who successfully detected convincing evidence of an extended near-UV continuum (3600 Å) in the Seyferts Mrk 3 and Mrk 573 and NGC 1068. The extended continuum shows a striking morphological resemblance to that of the extended [O III] line (Sec. 3.1).

Could these findings give us some clues to the nature of the nuclear optical continuum? On account of the photon deficit which in Sec. 2 we argue is possibly universal to all AGN, we question in Sec. 3 the standard interpretation of the optical-UV nuclear continuum which leads to many inconsistencies. In Sec. 4 we explore alternative relationships between the unseen (and possibly collimated) primary ionizing continuum and the directly observed (but apparently uncollimated) secondary optical continuum. We propose the picture of the "hazy" nucleus whereby the observed optical-UV continuum (in part or in whole) comes not from a central emission source of negligible size but originates rather from larger regions *closely* associated with both the BLR and the NLR emission-line gas components.

2. PHOTON COUNTING IN AGN

We first recall the standard assumptions behind the photon-counting test (Sec. 2.1). In Sec. 2.2, we find that this test generally fails for typical AGN and in Sec. 2.3 we discuss the implications of anisotropy on the interpretation of the observed constancy of the Hβ equivalent width.

2.1 The Photon-Counting Test as Applied to AGN Classes

Assuming photoionization as the excitation mechanism of the gas, the photon-counting test follows from the expectation that the intensities of the hydrogen Balmer lines be proportional to the amount of ionized hydrogen and, therefore, proportional to the *number* of ionizing photons absorbed. Adopting the geometry of a single nuclear ionizing source surrounded by gas clouds, the validity of the test rests on three basic assumptions: the source emits isotropically, the clouds are fairly thick to the ionizing photons (at least for photons in the range 13.6–300 eV), and radiative recombination is the dominant process populating the excited states of hydrogen.

For the lower-density narrow-line region (NLR) clouds which dominate the observed line spectrum of Seyfert 2's and NLRG, recombination is the dominant excitation process of the hydrogen Balmer lines. Gaskell and Ferland (1984) showed Hβ to be much less sensitive to collisional excitation than Hα which makes it a better choice for deriving the number of ionizing photons. For case B conditions (Osterbrock 1989) in which radiative recombination followed by de-excitational cascade are the only processes affecting the population of level $n=4$, we obtain that the reprocessing efficiency $\xi^{\rm eff}_{\rm H\beta}$ of the *number* of absorbed ionizing photons converted into Hβ line photons is simply

$$\xi^{\rm eff}_{\rm H\beta}=\xi^{\rm rec}_{\rm H\beta}\equiv\alpha^{\rm eff}_{\rm H\beta}/\alpha_B\cong 0.117 T_4^{-0.05}, \qquad (1)$$

with $T_e=10^4\ T_4$ and where $\alpha^{\rm eff}_{\rm H\beta}$ is the effective Hβ recombination coefficient (Osterbrock 1989) and α_B the total hydrogen recombination coefficient to excited states.

Under physical conditions more extreme than the NLR for which Eq. (1) is a good approximation, the reprocessing efficiencies can differ significantly from that given by pure recombination $\xi^{\rm rec}_{\rm H\beta}$. For instance, at sufficiently high densities, collisional excitation, induced recombination, or three-body recombination may result in $\xi^{\rm eff}_{\rm H\beta}>\xi^{\rm rec}_{\rm H\beta}$ while sufficiently large line optical depths may lead to the opposite $\xi^{\rm eff}_{\rm H\beta}<\xi^{\rm rec}_{\rm H\beta}$. It is not clear at this stage whether for the BLR as a whole the global reprocessing efficiency departs significantly from $\xi^{\rm rec}_{\rm H\beta}$. Earlier models of individual BLR clouds which considered in detail the effect of large Lyα line opacity and collisional excitation from excited levels derived significantly higher values $\xi^{\rm eff}_{\rm H\beta}\approx 4\xi^{\rm rec}_{\rm H\beta}$ (cf. standard model of Kwan and Krolik 1981). The current trend, however, is towards smaller reprocessing efficiencies (mostly on account of the much larger mean BLR densities in new models which are proposed to account for the surprisingly short variability time lags of the lines, see Peterson 1992, 1993). For instance, if we consider an individual cloud of high density ($n_{\rm H}=10^{11}$ cm^{-3}) in which significant line opacities are reached in most lines (that is models of high ionization parameter in the range $0.1\leqslant U\leqslant 1$), a value of $\xi^{\rm eff}_{\rm H\beta}$ in the range 0.6–0.12 $\xi^{\rm rec}_{\rm H\beta}$ is derived for the models of Ferland et al. (1992).We may also consider the comprehensive BLR model of Rees et al. (1989) who computed a more sophisticated geometry in which the contribution of different clouds of different densities (ranging from 10^{13} to $10^{8.5}$ cm^{-3}) and different ionization parameter are integrated radially. The *effective* reprocessing efficiency averaged over the whole geometry is $\xi^{\rm eff}_{\rm H\beta}\cong 0.6\xi^{\rm rec}_{\rm H\beta}$. If we argue that such models which consider a *range* of input parameters rather than ad hoc individual values for $n_{\rm H}$ or U are probably more realistic, we are justified in assuming that for the BLR as a whole $\xi^{\rm eff}_{\rm H\beta}\simeq\xi^{\rm rec}_{\rm H\beta}$ keeping in mind that the actual efficiency might be somewhat lower.

An indirect empirical argument in favor of $\xi^{\rm eff}_{\rm H\beta}\cong\xi^{\rm rec}_{\rm H\beta}$ follows from the observed correlation between the Hβ luminosity, $L_{\rm H\beta}$, and the "nonthermal" continuum luminosity, $L_{\rm NT}$, in different classes of AGN. Yee (1980) found a correlation of a slope of unity between $L_{\rm H\beta}$ and $L_{\rm NT}$ which holds over five orders of magnitude in $L_{\rm NT}$. If we define type I objects as those where the BLR is directly observed (QSR, QSOs, Seyfert 1, BLRG), and type II as those with a NLR only (Seyfert 2's and NLRG), the absence in the correlation of any apparent break between type I and type II's [where the assumption of $\xi^{\rm eff}_{\rm H\beta}\cong\xi^{\rm rec}_{\rm H\beta}$ is more secure] can be used to argue against any radical change in reprocessing efficiency between these. We cannot rule out that a discontinuous change in $\xi^{\rm eff}_{\rm H\beta}$ between the two types is being masked by an opposite and equal change in the mean value of C_f although this possibility appears rather contrived.

We find no reason not to adopt the same simple interpretation of the correlation $L_{H\beta}$ (or $L_{H\alpha}$) vs. L_{NT} of Yee (1980) and Shuder (1981) which states that neither the covering factor C_f nor the shape of the continuum appear to vary in a systematic way with L_{NT}. We may imagine the complex situation in which all of these quantities α, C_f, τ_0 (see next paragraph), or $\xi_{H\beta}$ conspire to vary with L_{NT} in a way that produces a slope of unity. But this does not seem very likely. Although we may expect the scatter in the correlation at a given L_{NT} to be due to real variations about the mean of some of the quantities α, C_f, τ_0, or $\xi_{H\beta}$, our working hypothesis will be that none of these vary in a *correlated* way with L_{NT} and that $\xi^{\rm eff}_{H\beta} \simeq \xi^{\rm rec}_{H\beta}$.

Concerning the mean opacity of the clouds to the ionizing continuum, it is reasonable to assume the emission-line clouds are fairly thick to the soft ionizing radiation. As is customary, let us define the cloud opacity to the ionizing radiation by the quantity $\tau_0 = 6.3 \times 10^{-18}\ N_{H^0}$ defined at $h\nu_0 \equiv 1$ Ry. For BLR dominated objects, most models favor clouds which are very thick to the soft ionizing radiation. In the case of the Seyfert 2's (and for the NLR in general), the presence of [O I] lines in the spectra indicates that the clouds must be quite thick ($\tau_0 \gg 10^2$) in order to give rise to a significant partially ionized zone. Because the [O I] lines are nevertheless predicted too strong in radiation-bounded photoionization calculations, this is solved by truncating the partially ionized zone ($\tau_0 \approx 10^2$; cf. Viegas and Prieto 1992). A reduction of a factor of 4–7 in [O I] is typically achieved by allowing 1%–2% of ionizing photons to leak out. This entails no real reduction in reprocessing efficiency for such marginally matter bounded clouds.

An alternative approach to truncating the partially ionized zone is that of Viegas and Prieto (1992) who proposed a dual-component model of the ENLR to account for the high He II/Hβ observed for instance in 3C 227 and Centauri A. One component is radiation bounded (RB) and contribute the low and intermediate excitation lines while the other component is matter bounded (MB) and contribute the high excitation lines (He II, Ne V,...). Although a rigorous treatment is beyond the scope of this paper and would require assigning different covering factors to each gas component, we can nevertheless estimate how this would affect our photon-counting test for the NLR. If we consider that our adopted value $C_f = 0.1 = C^{\rm MB} + C^{\rm RB}$ includes both components, the dual-component approach simply has the effect of reducing significantly the average reprocessing efficiency since $\xi^{\rm eff}_{H\beta}({\rm MB}) \ll \xi^{\rm rec}_{H\beta}$. This would exacerbate further the photon deficit problem discussed in Sec. 2.2. If we suppose on the other hand that the matter bounded gas is sufficiently thin that it does not produce an observable Lyman limit absorption trough ($\tau_0 \ll 1$) and simply attribute the MB Hβ flux contribution $F^{\rm MB}_{H\beta}$ to an increase in efficiency of the RB component (i.e., setting $C_f \equiv C^{\rm RB}$), this will translate into an enhanced reprocessing efficiency. Because both components emit Hβ and He II in fairly well-defined ratios, the effective efficiency is simply given by

$$\xi^{\rm eff}_{H\beta} = \left(1 + \frac{F^{\rm MB}_{H\beta}}{F^{\rm RB}_{H\beta}}\right)\xi^{\rm rec}_{H\beta} = \left(1 + \frac{[\text{He II}]^{\rm RB} - [\text{He II}]^{\rm obs}}{[\text{He II}]^{\rm obs} - [\text{He II}]^{\rm MB}}\right)\xi^{\rm rec}_{H\beta}, \tag{2}$$

where $[\text{He II}]^{\rm MB}$ and $[\text{He II}]^{\rm RB}$ correspond to the intrinsic line ratio He II/Hβ (4686/4861) emitted by the matter-bounded and ionization-bounded components, respectively, while $[\text{He II}]^{\rm obs}$ is the line ratio observed. Let us adopt the standard values of $[\text{He II}]^{\rm RB} = 0.2$ and $[\text{He II}]^{\rm MB} = 1.1$ given by photoionization calculations by power laws. For the ENLR, $[\text{He II}]^{\rm obs}$ can reach a value as high as 0.6, implying $\xi^{\rm eff}_{H\beta}({\rm RB}) = 1.8\xi^{\rm rec}_{H\beta}$. For the NLR, however, $[\text{He II}]^{\rm obs} \leqslant 0.35$ which leaves $\xi^{\rm eff}_{H\beta}({\rm RB}) \leqslant 1.2\xi^{\rm rec}_{H\beta}$. So even if the geometry proposed by Viegas and Prieto (1992) applied to the NLR and the MB component was extremely thin and had been missed from direct observations, our conclusions on the photon deficit would not be significantly altered.

2.2 The General Shortage of Ionizing Photons in AGN

To illustrate the problem of the ionizing photon deficit in AGN, we adopt the data sample presented by Yee (1980) which consists of Hβ luminosities ($L_{H\beta}$) and the continuum luminosity, L_{NT}, *integrated* from 9500 to 3000 Å. This sample comprises quasars, QSOs, QSR, radio galaxies (NLRG and BLRG) and Seyfert 1 and 2's from the compilation of the following works: Neugebauer et al. 1979, Yee and Oke (1978), de Bruyn and Sargent (1978), Neugebauer et al. (1976), Richstone and Oke (1977), and Oke et al. (1970). Yee clearly established that $L_{H\beta}$ scales *linearly* with L_{NT} with a slope of 0.97 ± 0.04. Since the errors on individual entries were typically 0.05–0.2 dex, the slight departure of the slope from unity was not considered significant. Since this result implies a constant ratio of $L_{H\beta}/L_{NT}$ at all luminosity, we prefer to plot the rest frame equivalent width of Hβ, ${\rm EW}^0_{H\beta}$ $[={\rm EW}^{\rm obs}_{H\beta}/(1+z)]$, which is simply the line flux divided by the *monochromatic* underlying continuum flux (F_λ). For QSOs and quasars, the equivalent width is directly drawn from the original published papers. For the less luminous objects, it is crucial to remove the underlying stellar continuum component as was done by Yee and Oke (1978) and Yee (1980). In Fig. 1, we present the equivalent width versus L_ν (evaluated at 4861 Å) relation derived from the stellar subtracted data sample of Yee (1980). We also add the Seyfert 2 data of KAW3. Open and filled symbols represent type I and II objects, respectively. Two further objects are plotted: Cygnus A (Stockton 1993) and the high ionization cloud in PKS 2152−69 (Tadhunter et al. 1988). In the few cases of objects common to both Yee and KAW3, only those of KAW3 are plotted.

The absence of any systematic trend in ${\rm EW}_{H\beta}$ over five decades in luminosity is certainly remarkable and to some extent puzzling considering the number of conditions which must be simultaneously satisfied in the case of photoionization by a central "point" source. The significant

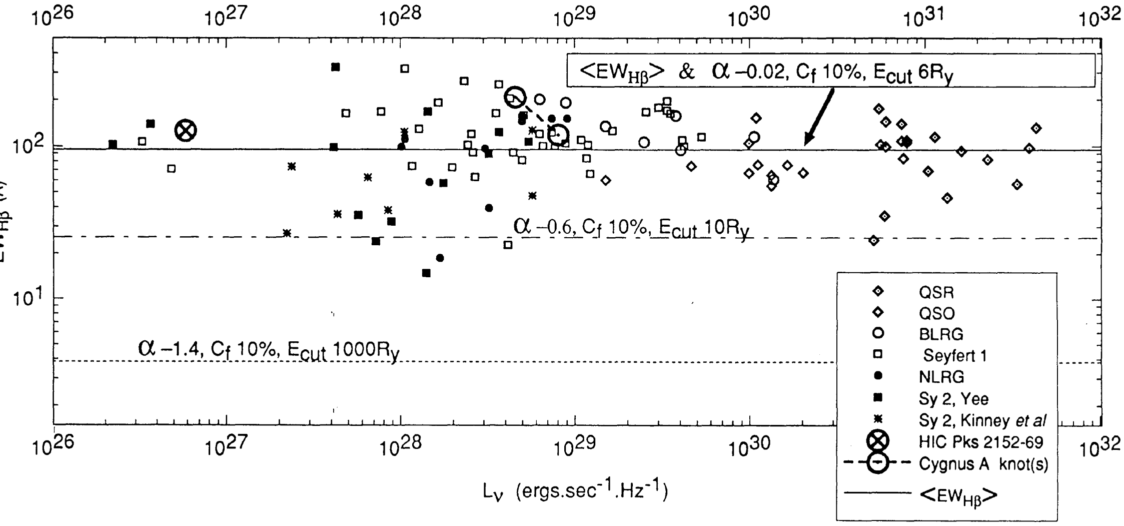

FIG. 1—The observed rest frame equivalent width of $H\beta$ in Å as a function of the luminosity of the underlying "nonstellar" continuum. $H_0=55$ km s^{-1} Mpc^{-1} and $q_0=0$ were assumed. The data sample is from Yee (1980) complemented by Seyfert 2 data by Kinney et al. (1991). EELR data corresponding to the high ionization cloud (HIC), in PKS 2152−69 is from Tadhunter et al. (1988), while the Cygnus A (3C405) results from right to left are from Stockton (1993) for a 5″ aperture and for a smaller aperture centered on the $H\beta$ high surface brightness knot, respectively.

increase of the scatter around $L_\nu \sim 10^{28}$ in Fig. 1 might partly be due to the increasing difficulty (and error) of separating in low-power AGN the featureless underlying "nonstellar" continuum from the dominant stellar continuum. The histogram shown in Fig. 2 corresponds to the distribution of the equivalent widths of all the objects plotted in Fig. 1. It is characterized by a mean of $\log \mathrm{EW}^0(H\beta)$ of 95 Å and a standard deviation of 0.26 dex. The median of the distribution is 103 Å. The distribution is skewed towards objects of lower equivalent width.

In the case of an energy distribution of the isotropic nuclear continuum source luminosity which is described by a power law of index α: $L_\nu = L_0(\nu/\nu_0)^\alpha$, the luminosity in ionizing photon number is simply given by

$$Q_{\mathrm{H}} = \int_{\nu_0}^{\nu_{\mathrm{cut}}} \frac{L_\nu}{h\nu} d\nu = \frac{L_0}{h} \int_1^{E_{\mathrm{cut}}} \left(\frac{\nu}{\nu_0}\right)^{\alpha-1} d\frac{\nu}{\nu_0}, \qquad (3)$$

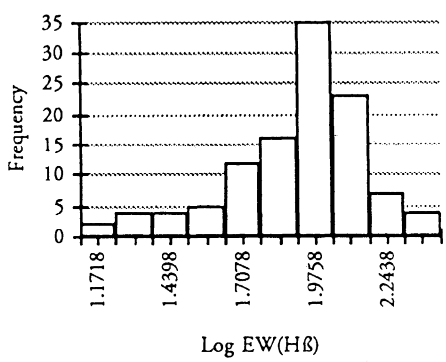

FIG. 2—Histogram of the equivalent widths of $H\beta$ plotted in Fig. 1. The mean value is 95 Å with a standard deviation of 0.26 dex. The median is 103 Å.

where E_{cut} is the cut-off in Rydbergs of the extrapolated power law. Assuming that the emission-line clouds are optically thick to the ionization radiation and cover a fraction C_f of the sky of the nuclear ionizing source, the equivalent width of $H\beta$ in Å, $L_{H\beta}/L_{\lambda(=4861\,Å)}$, is given by

$$\mathrm{EW}^0_{H\beta}(Å) = \lambda_{H\beta} C_f \, \xi^{\mathrm{eff}}_{H\beta} \, \alpha^{-1}(16/3)^\alpha (E^{\,\alpha}_{\mathrm{cut}} - 1)$$
$$\approx 570 C_f (\xi^{\mathrm{eff}}_{H\beta}/\xi^{\mathrm{rec}}_{H\beta}) \alpha^{-1} (16/3)^\alpha (E^{\,\alpha}_{\mathrm{cut}} - 1), \qquad (4)$$

where $\xi^{\mathrm{eff}}_{H\beta}$ is the *effective* reprocessing efficiency (see Sec. 2.1). The mean covering factor can be estimated statistically from the proportion of high-redshift QSOs which show a deep Lyman limit absorption trough. The value inferred for C_f in QSOs is in the range 0.10–0.15 (Oke and Korycansky 1982; Green et al. 1980; Netzer 1985, and references therein). [The work of Antonucci et al. (1989) would suggest an even lower value.] We hereafter adopt the value $C_f = 0.10$.

When exploring different values of α, it is important not to exaggerate the importance of the X-ray contribution. Zamorani et al. (1981) found a mean X-ray to UV index of $\alpha_{\mathrm{OX}} = -1.4$ (α_{OX} relates the fluxes at 2000 Å and 2 keV). For any optical index flatter than $\alpha \geqslant -1.4$, the power law cannot be extrapolated very far in the soft X rays and for this reason a sensible cut-off energy E_{cut} is introduced. Since the number of ionizing photons depend on $L_\nu/h\nu$, any contribution of the X rays beyond E_{cut} at a level consistent with the mean α_{OX} can be shown to be negligible when $\alpha \geqslant -1.4$.

Serious difficulties with the photoionization interpretation of the continuum clearly appear when we infer the hardness of the ionizing continuum required to generate a sufficient number of ionizing photons. The unsettling fact derived from the photon-counting test is that one requires an unrealistically flat continuum of $\alpha = -0.02$ in order to generate a sufficient luminosity of ionizing photons. With such a flat continuum, it is necessary to truncate the ionizing energy distribution at a fairly low energy, $E_{\rm cut}(\leqslant 6$ Ry), in order to remain in agreement with the level of soft X ray fluxes measured and with the fact that soft X-ray excess objects are rare. The insuperable difficulty with $\alpha \approx 0$ is that it is inconsistent with the mean UV index $\alpha \approx -0.6$ observed in QSOs (e.g., Neugebauer et al. 1979). Even with $\alpha = -0.6$, the expected equivalent width of 25 Å is already too small implying a deficit of a factor ~ 4 in the number of ionizing photons. The deficit problem worsens in Seyferts if we adopt the much steeper slope of $\alpha \approx -1.35$ which is the mean index found in both Seyfert 2's (e.g., KAW3, FO86) and Seyfert 1 (see KAW3 and references therein). Such a steep index leads to an equivalent width of only 3.8 Å which is a factor 25 too low if we assume the same $C_f = 10\%$ as for QSOs. A systematic change from $C_f \approx 0.10$, $\alpha = -0.6$ in QSOs to $C_f = 1.0$ and $\alpha = -1.4$ in Seyferts while conceivable still falls short in Seyferts by a factor of 2.5. Furthermore, if we considered the lower reprocessing efficiencies of more recent BLR models (cf., Sec. 2.1), the deficit easily attains a factor ≈ 10 in QSOs, assuming $\alpha \approx -0.6$.

Our main conclusion is that we find a serious deficit problem in the flux of ionizing photons based on the weakness of the nuclear optical continuum not only in Seyfert 2's as found by KAW3 [where they favored a mean index value of $\alpha = -1.3$] but in *all* AGN even after considering spectra as flat as $\alpha \approx -0.6$. This deficit is in the *number* of photons and should be distinguished from the energy budget problem described by Netzer (1985) which depends on the *shape* of the continuum (from 1 Ry up to the very hard X rays). In our opinion, both the photon deficit and the energy budget problems must be resolved simultaneously. We note in passing that, while the standard BLR model of Kwan and Krolik (1981) has a significant energy budget problem, it is not short in ionizing photons because $\xi_{\rm H\beta} \approx 4\xi_{\rm H\beta}^{\rm rec}$. On the other hand, later models which use large ionization parameters and/or large column densities [e.g., Ferland et al. (1992) and Ferland and Persson[1] (1989)] while not penalized by energy problems [to the extent that Ly α(emitted)/Ly α(case B) < 1, see Sec. 3 in Netzer (1985)], all suffer from a strong deficit in the number of ionizing photons because $\xi_{\rm H\beta}^{\rm eff} < \xi_{\rm H\beta}^{\rm rec}$ (see Sec. 2.1). The energy budget problem can be resolved by invoking extinction by dust as discussed by Netzer (1985). With the photon number deficit problem, we have the additional constraint imposed by the constancy of $\mathrm{EW}_{\rm H\beta}$ (see Sec. 3.2) which tells us that similar amount of extinction must affect both the lines *and* the continuum.

[1]An energy distribution often used in recent photoionization calculations [e.g., Rees et al. (1989); Ferland et al. (1992)] is the one defined by Mathews and Ferland (1987) based on observations in the near UV, in the far-infrared and in the soft and hard X rays, which suggest that the continuum of AGN peaks in the 200–2000 Å region. It is characterized by an $\alpha_{\rm OX} = -1.4$ and a large UV bump with $E_{\rm cut} \approx 4$. Adopting $C_f = 0.1$ and $\xi_{\rm H\beta}^{\rm eff} = 0.6\xi_{\rm H\beta}^{\rm rec}$ from Rees et al., we derive $\mathrm{EW}_{\rm H\beta} = 25$ Å.

2.3 Anisotropy of the Ionizing Radiation

A solution to this deficit problem may be that the ionizing source is anisotropic and preferentially emits in directions not coinciding with that of the observer. In this picture, the radiation impinging the BLR and/or the NLR can be much stronger than the one observed along our line of sight. The observation of spatially resolved ionization cones lends support to this picture (Tadhunter and Tsvetanov 1989, Haniff et al. 1991, Wilson 1992). The detection in polarized light of a weak BLR component in some Seyfert 2's certainly suggests that perspective plays an important role in the perception of the AGN phenomenon (cf., Sec. 3.3). The photon deficit in Seyfert 2's has been used by KAW3 as a further argument in favor of anisotropy of the ionizing source. In the case of the ENLR of NGC 4151, Penston et al. (1990) similarly favor anisotropy to resolve the photon deficit. If, as shown here, the deficit is so general as to encompass the nuclei of Seyfert 1, radio galaxies and QSOs as well, can we generalize the solution of anisotropy to all AGN? KAW3 explained the "visibility" of the continuum as resulting at least in part from reflection by dust and/or scattering, a possibility which we defer to Secs. 3 and 4. Our point here is simply that anisotropy per se (without any reflection or continuum reprocessing) would be untenable since it would imply that our line of sight for all objects[2] in Fig. 1 always falls outside the collimated radiation cone (which has an opening angle in the range $\sim 30°$–$70°$). Furthermore, with anisotropy, we are unable to make any sense of the universality of $\mathrm{EW}_{\rm H\beta} \approx 100$ Å across five decades in continuum power if we persist in ascribing the observed continuum L_ν *directly* to the primary source. In effect, the hypothesis that the ionizing radiation is "beamed" towards the ionized clouds does not in any *natural* way lead to a constant $\mathrm{EW}_{\rm H\beta}$ for an observer who is only allowed to see the "uncollimated" (and therefore irrelevant) continuum component. If we suppose that the collimation of the photon stream is caused by an optically thick absorbing torus near the source and that our line of sight lies outside this distribution, we would not expect to see any continuum at all emerging *directly* from the central source and at the very least we should not directly see the BLR region (but this is the kind of inconsistency which apparently emerges in the case of NGC 4151, see Sec. 3.3). If we suppose on the other hand that the source itself is intrinsically anisotropic (beamed), it is still puzzling to find that the *off-beam* continuum correlates so well with $L_{\rm H\beta}$ despite our line of sight being at a random angle relative to the beam axis. This imposes on the anisotropic source the perplexing property that its off-beam intensity always appears in a fixed and universal ratio relative to the beamed intensity which powers the lines, this for *all* angles greater than the beam opening angle.

We conclude that even though anisotropy effectively removes any evidence of an ionizing photon deficit, it does so

[2]Presumably, only BL Lac (excluded from the Yee sample) would qualify as "beam on" objects or "bare nuclei" since they show comparatively weak lines [cf. Stickel et al. (1991); Urry (1993a,b)].

at the price of severing the intuitive connection between the observed continuum and the photoionized emission-line gas which was at the core of the canonical interpretation of the L_ν vs. $L_{\mathrm{H}\beta}$ correlation. In our opinion, the combination of the generalized ionizing deficit coupled with the narrow range in $\mathrm{EW}_{\mathrm{H}\beta}$ is telling us something more fundamental about AGN than just lending support to the anisotropy hypothesis.

3. DISCUSSION

The finding of an apparent ionizing photon deficit in AGN may be indicative that the true ionizing source does not manifest itself directly to us (because of anisotropy and/or scattering). In order to explain the constancy of $\mathrm{EW}_{\mathrm{H}\beta}$ with L_ν, we propose to dissociate the observed continuum emission from the primary ionizing source (the ultimate cause of the observed phenomena) and relate it instead physically and spatially to the line-emitting regions (an associated effect). In this section, using the limited data available from ENLR continuum studies, we review the evidence which supports this interpretation.

3.1 Empirical Spatial Association of Continuum and Line Emission

Let us suppose that the ionizing source is somehow dimmed or not directly seen and that each photoionized cloud is a source of *optical* continuum as well as emission lines. To derive a constant equivalent width, all that is required is that the efficiency of generating this optical continuum be proportional to the impinging ionizing radiation (as is the case for $L_{\mathrm{H}\beta}$ when assuming that the clouds are ionization bounded). If the emission-line clouds possessed that property, $\mathrm{EW}_{\mathrm{H}\beta}$ would be totally independent of C_f (or α) since both L_ν (of the clouds) and $L_{\mathrm{H}\beta}$ would scale linearly with each other. Collimation of the *ionizing* radiation or the presence of an obscuring torus would not affect $\mathrm{EW}_{\mathrm{H}\beta}$ except when the observer is lying inside the beam opening angle for which the extreme example is given by BL Lac.[3] Furthermore, any intervening dust between the various emitting clouds and the observer would not significantly affect $\mathrm{EW}_{\mathrm{H}\beta}$ since both L_ν and Hβ would be subject to similar extinction.

There are two possibilities for producing such continua in the neighborhood of the emission-line regions. (Various physical mechanisms are briefly discussed in Sec. 4). Either it is generated *in situ* or it corresponds to a scattered component of the primary continuum as in the obscuration/reflection picture of Antonucci (1989) (see also KAW3 and references therein). In the event of scattering, the possibility that some fraction of the observed flux comes directly from the nuclear source need not be excluded. Considering the simplest case of a scattering spherical shell surrounding a small continuum source, the question of the shell opacity which hides the central source from a clear view is not well defined and probably more a question of semantics.

One prediction of our proposed association of continuum emission with the ionized gas is that we ought to detect such continuum underneath the spatially resolved extended emission-line gas (EELR) in radio galaxies and in Seyfert galaxies. In principle, such a verification is much easier to perform in radio galaxies (than in Seyferts) since the EELR in this case extends much beyond the bright stellar continuum of the bulge.

One object which clearly shows such underlying continuum is the detached, highly excited cloud observed at 8 kpc from the nucleus of PKS 2152−69 ($\mathrm{EW}_{\mathrm{H}\beta}\approx 10^2$ Å). This cloud shows very bright emission lines which are indistinguishable in their excitation from that of the NLR of Seyferts. The continuum energy distribution is, however, extraordinarily blue with an index $\approx +3\pm 1$ (see Tadhunter et al. 1988) and is polarized (di Serego Alighieri et al. 1988).

Although PKS 2152−69 (z=0.028) is unusual amongst low-redshift radio galaxies, it might be the archetype of the very strong radio galaxies observed at higher redshift and which present a UV continuum and emission-line component aligned with the radio axis. Polarization is detected in many such objects, the fraction of which increasing with redshift (although the spatial resolution is insufficient in general to ascribe it exclusively to the aligned extended continuum). As demonstrated by Cimatti et al. (1993) [see also review by Fosbury (1993)], this increase in polarization is consistent with the increasing dilution of the stellar continuum as the (bluer) scattered emission is progressively redshifted inside the observer's filter.

Cygnus A is a very powerful and relatively nearby classic double-lobe radio galaxy which presents a very complex morphology in both continuum and line emission. Pierce and Stockton's (1986) detailed study shows that the continuum is spatially extended (see also van den Bergh 1976). The morphology of the emission is double peaked. The line emission is double peaked. The line emission is also extended but with a clumped and filamentary structure which looks quite different from the more uniform and symmetric (relative to the position of the central radio core) morphology of the continuum. The peak in Hβ emission brightness coincides with the second brightest continuum peak emission (NW knot). After subtracting the stellar continuum contribution, Stockton (1993) determines the nuclear region's equivalent width at $\mathrm{EW}_{\mathrm{H}\beta}$= 119 Å (through a 5″ aperture). The equivalent width through a smaller aperture encompassing only the NW emission-line peak is determined to be higher at 209 Å (Stockton 1993). Both values are shown in Fig. 1. Pierce and Stockton

[3]The ionization cones of Seyferts with opening angles (30°–75°) are likely to possess quite different properties from that of the presumably very narrow light beams of BL Lac. If the hazy nucleus picture proposed in Sec. 3.3 is valid, whether or not our line of sight falls within the wide ionization cones of Seyferts does not necessarily affect the $\mathrm{EW}_{\mathrm{H}\beta}$ provided the BLR and the scattering intercloud disk are in full view and that there is no boosting of continuum inside the cone. Supposing that Seyfert 1 and quasars are objects for which our line of sight fall within the ionization cones, since the $\mathrm{EW}_{\mathrm{H}\beta}^{\mathrm{narrow}}$ which characterizes *separately* the NLR in type I objects is typically $\lesssim$(10 Å) (Netzer and Laor 1993), such a low value is consistent with the number of ionizing photons inferred and with the idea that the NLR and ENLR are excited by radiation filling the ionization cones.

(1986) made the interesting suggestion that the extended continuum emission resulted from scattering (probably by dust) of a hidden nuclear continuum source [see also Tadhunter et al. (1990); Vestergaard and Barthel (1993)].

Detection of extended continuum emission in Seyferts has been recently reported. Against a strong stellar background, Pogge and De Robertis (1993) have found convincing evidence of an extended UV continuum (3600 Å) in the nearby Seyferts NGC 1068, Mrk 3 and Mrk 573. This continuum is aligned in direction of and superposed on the brightest extended emission-line regions in the light of [O III]. Their favored interpretation of the continuum is dust scattering. What is most striking is the correspondence between the morphology seen in the [O III] images with that of the UV-red continuum difference images. The diffuse UV continuum emission excess in all cases apparently shares the striking conical (NGC 1068) or biconical (Mrk 3 and Mrk 573) morphology of the [O III] "ionization cones." Furthermore, in Mrk 3 and NGC 1068, the nuclear UV excess knot is displaced from the nucleus proper by a similar amount with that of the [O III] emission peaks. In NGC 1068, the region of extended UV excess is directly correlated with the extended scattering region discovered first by Elvius (1978) and later mapped in detail by Miller et al. (1991) with imaging polarimetry.

3.2 Dust Obscuration in Seyfert 2's

The problem of the spatial distribution of the obscuring dust in Seyfert 2 leads to another conundrum within the classical picture of a "point" continuum source. There is strong evidence that the emission *lines* of Seyfert 2's are significantly obscured by dust [Gaskel (1984); Boisson and Durret (1986); Carleton et al. (1987); Binette et al. (1990); KAW3; BWVM3]. Because the continuum source in the standard AGN model is effectively considered point-like, change obscuration of this source by intervening clouds along the line of sight ought to result in a much larger dispersion in $EW_{H\beta}$ than that of Seyfert 1. Even if the continuum source of Seyfert 2's was somehow always fully visible while the lines are reddened, we would assuredly expect a much smaller Hβ equivalent due to line obscuration. As discussed in Sec. 3.1, if the regions emitting the lines were also responsible for scattering the nuclear continuum, it would make sense that $EW_{H\beta}$ be independent of obscuration.

Let us consider the recently studied Seyfert 2 sample of KAW3 who obtained matching aperture line and continuum measurements using optical and *IUE* observations. As is apparent in Fig. 1, these Seyfert 2's (filled stars) as a whole are at most a factor 2 below the mean value of the whole AGN sample (or of other Seyfert 2's in the Yee sample). Given the small number of objects involved, this significance of this difference is doubtful. This should be contrasted with dust opacities of the emitting-line regions proposed to be as high as τ_v=0.5–2.5 according to the BWVM3 model of the Balmer and Lyman decrements of the same sample. Whether the continuum originates from the nuclear source or is spatially associated with the ionized gas, the obvious way to explain why $EW_{H\beta}$ is not strongly affected by extinction is to suppose that *both* the continuum and the lines suffer very similar amounts of extinction. This is conceptually much easier to achieve with a continuum which is scattered towards us from those same regions which produce the lines than from a point source which (luckily enough!) we always see between the dusty clouds.

Combining the sample of KAW3 with their own radio-loud *HST* data, Wills et al. (1993) concluded that two explanations (foreground reddening and internal dust) were required to explain how the observed Lyα/Hβ could be much below case B while at the same time the ratio Hα/Hβ appeared either reddened or near case B. BWVM3 carried a similar analysis in which they fully considered the effects of cloud perspective as well as of dust scattering on the transfer of the lines. After putting stringent limits on the applicability of pure dust foreground extinction, BWVM3 suggested that the simplifying assumption that clouds do not overshadow each other might not be valid. They showed that a single explanation of the observed range in Lyα/Hβ and Hα/Hβ was possible if the coverage of the dust/gas clouds approached unity while not being uniform. The question of cloud coverage and perspective is quite important. If the scattering dust *does* cover most of the emitting region then blue asymmetries and blue shifts of the lines cannot any longer be interpreted as an inflow of opaque clouds (Wills et al. 1993) but rather as a general gas/dust *outflow*.

Can extinction be involved in the resolution of the photon deficit problem? BWVM3 looked at the case of dust extinction of an *isotropic* source as proposed earlier by Boisson and Durret (1986) and Carleton et al. (1987). Using a crude geometrical model consisting of a shell-like dust/gas screen fully covering the continuum and the ionized gas shell, BWVM3 modeled the steepening of the UV spectral index and the increase of the *apparent* deficit of ionizing photons as a function of the shell extinction. They suggested that such a trend in α might be present in the data sample of KAW3 and showed that an intrinsic energy distribution with $\alpha=-0.3$, if common to all these objects, would succeed in producing enough photons to accommodate a covering factor of C_f=0.15. In this oversimplified picture, the $EW_{H\beta}$ is relatively unaffected by the amount of extinction since both the lines and the continuum are passing through similar amounts of dust. The absence of the 2175 Å absorption feature in these objects may simply imply that the dust component responsible for it has been destroyed. For instance, if such feature was the result of PAHs (see Joblin et al. 1992; Lee and Wdowiak 1993), it would not be a surprise if they could not survive in the UV-rich environments of AGN.

This simple picture of dust extinction of an isotropic source by BWVM3 appears nevertheless flawed as it is inconsistent with the hidden BLR seen in polarized light in many of the Seyfert 2's of the same KAW3 sample (cf., Miller and Goodrich 1990; Tran and Kay 1992), a point discussed further in Sec. 3.4.

3.3 The Ionizing Cones of NGC 4151

NGC 4151 ($EW_{H\beta}\sim 160$ Å) is a well-studied nearby Seyfert 1.5 which is highly variable in both line and continuum emission. Evans et al. (1993) have reported narrowband line and continuum imaging of the innermost portion of its NLR using *HST*. They find a biconical distribution of the [O III] emitting gas. The cone opening angle projected on the sky is $75° \pm 10°$. The geometry of the ENLR inferred by Evans et al. clearly places our line of sight *outside* the ionization cones. This appears to rule out the possibility that a thick molecular torus surrounding the BLR is responsible for collimating the ionization radiation (but see Pedlar et al. 1993; Vila 1993).

One alternative mechanism discussed by Evans et al. (1993) to collimate the radiation from a point-like isotropic ionizing source is a flattened configuration of BLR clouds. If instead of assuming a point source, we consider the properties of a "hazy" nucleus—which for the sake of the discussion could be the result of electron scattering (see Sec. 4.4)—we can predict some of its general properties concerning the interpretation of X-ray and UV absorption line data.

From Ginga observations of NGC 4151, Yaqoob and Warwick (1991) found that the variations in the line of sight absorption column can be interpreted by BLR clouds covering $\approx 90\%$ of a very small X-ray source (see also Holt et al. 1980). The typical BLR cloud column density inferred by Yaqoob and Warwick (1991) for the partial covering model is of order $10^{22.6}$ cm^{-2} with an average of ≈ 2.5 clouds along the line of sight to the source. Let us suppose some degree of electron scattering in the intercloud medium with a total electron opacity of the region of $\tau_s \approx 1$. Because the BLR clouds are individually fairly transparent ($\tau_a \lesssim 1$) to the high-energy X rays, a fraction $\approx \exp(-\tau_s - \tau_a)$ emerges without any scattering and will have suffered relatively little absorption. Due to multiple electron scattering between the clouds, reverberation of the complementary fraction of the continuum $[\approx 1-\exp(-\tau_s)]$ will take place and cause a time delay response of the scattered component. This effect will be somewhat damped by the increased path length of the multiply scattered component which has to cross many more BLR absorbing clouds. At lower X-ray energies, however, because individual clouds absorb most of the flux, the small fraction of photons which emerge from the BLR will have done so exclusively through multiple electron scattering within the intercloud scattering medium. The soft X rays will therefore be seen as an excess component over that of a single absorber model, which is observed. Because of the intercloud scattering, a soft X-ray excess would still be produced even if the covering factor of the source by the clouds was unity. The purely scattered component (dominant for any λ such that $\tau_a \gg 1$) will be characterized by a fairly long time response since it will emerge exclusively through reverberation. It is therefore conceivable that a hazy nucleus with a larger covering factor of the source might eliminate the need for the uniform component added by Yaqoob and Warwick (1991) to their partial covering model. This additional component of column density $\approx 10^{22}$ was required to explain the constancy of the low-energy X-ray measurements of EXOSAT (Yaqoob et al. 1989).

A high energy, the X-ray source is resolved into flares characterized by a short rise time followed by a much longer decay time ≈ 2 light days (Lawrence 1980). This decay time can be interpreted as an *effective* size for the pure electron scattering region which is not much shorter than the size of the C IV emitting region 4 ± 3 light days derived by Clavel et al. (1990). In fact the problem of the scattering model is that it predicts virtually no delay in the line time response to changes in the continuum in the case where the UV source is hidden (i.e., covered by BLR clouds which can be individually opaque to the continuum, $\tau_a \gg 1$, because of internal dust). This problem could in principle be alleviated by having lower optical cloud opacities or a flattened BLR distribution sufficiently inclined towards the observer.

The hazy nucleus picture can be used to resolve the inconsistency between the column density of intervening gas $\approx 10^{19.3}$ cm^{-2} determined from the equivalent widths of the UV absorption lines (see Kriss et al. 1992) and that of the uniform component invoked by Yaqoob and Warwick (1991) which is 500 times larger. As suggested above, the hazy nucleus would eliminate the need for a thick uniform component covering the source. Kriss et al. (1992) proposed that the absorbing material corresponds to disintegrating remnants of BLR clouds which are radiatively accelerated away (to explain the blueshift of the absorption lines). They also concluded that the coverage of the continuum source *and* the BLR must be substantial. In the hazy nucleus picture, the blue-UV continuum would emerge following many scatterings between clouds (as for the soft X-ray excess component). The absorption lines might then be the result of the multiple scattering across small column density debris behind opaque BLR clouds.

3.4 The Occultation/Reflection Model

Antonucci and Miller (1985), using spectropolarimetric observations of the brightest Seyfert 2 NGC 1068, inferred that it contained a hidden Seyfert 1 nucleus inside an occulting torus. Miller et al. (1991) found evidence of reflection by dust over quite a large nuclear volume. At the location of the nucleus proper, they favored electron scattering instead of dust on account of the broader BLR line profile observed there ($EW_{H\beta}\approx 80$ Å). The sum of these data and the discovery of further Seyfert 2's showing evidence of a reflected BLR (see Antonucci 1992, and references therein) lend strong support to the occultation/reflection model of Antonucci and coworkers. Our contention is that continuum scattering is already operative well within the BLR, blurring the primary nuclear source for any outside observer.

In the particular case of NGC 1068, the continuum appears to be scattering over a region exceeding significantly the BLR region. Ebstein et al. (1989), using speckle imaging, concluded that the nuclear continuum in NGC

1068 extends over several arcseconds (see also Pogge and De Robertis 1993). Lynds et al. (1991) with *HST* imaging of the nucleus at 5470 Å confirms the spatial extension of the continuum and even resolve the strong continuum peak. FOS spectroscopy with a 0.3-arcsec aperture centered on the continuum peak by Caganoff et al. (1991) reveals broad Hβ (and [O III]), although at a lower $EW_{H\beta}$ than found by ground-based spectropolarimetry by Miller et al. (1991). Caganoff et al. (1991) and Antonucci (1992) suggest furthermore that the continuum peak may correspond to starlight rather than nonthermal emission, which would explain the small $EW_{H\beta}$ at that location.

Independently of the general validity of the occultation/reflection picture, it is still debatable, however, whether a thick torus is an essential ingredient of the rather successful idea developed by Antonucci and Miller. Cameron et al. (1993) for instance proposed intervening thick molecular clouds as an alternative to the parsec scale thick torus for hiding the BLR. They based their argument on the fact that no single point source in the infrared could be found in the NGC 1068 nucleus to account for more than ~40% of the 10.3 μm nuclear emission.

Further evidence that intervening opaque gas clouds affects the observed strength of the BLR as well as its associated continuum has been provided by Goodrich (1989) who studied the variability of the three Seyferts NGC 2622, NGC 7603, and Mrk 1018 of types 1.8 and 1.9. These galaxies have been reported to have undergone a transition to/from type 1. In all three cases, changes in flux of the broad lines (Hα and Hβ) *and* in the continuum (near Hα and Hβ) were found to be consistent with changes in extinction. Goodrich finds that the NGC 7603 variability episodes were consistent with a single incident of a dust cloud passing through the line of sight to the nucleus. The tangential velocity implied is ~4000–8000 km s^{-1}, typical of BLR cloud velocities. Such a synchronism between the BLR lines and continuum coverage is certainly suggestive. No documented case in the AGN literature is known to the authors of a smaller cloud eclipsing exclusively the point size continuum source and not the BLR. This may naively be interpreted as evidence for a "hazy" continuum component extending throughout the inner BLR since in such picture any occulting cloud if large enough could only eclipse both the continuum and the BLR.

An argument which favor *in situ* generation of the continuum (cf., Sec. 4.3) in Seyfert 2's rather than scattering, however, is provided by the absence of broad Hβ in direct light while its strength in polarized light (relative to the polarized continuum) is similar to type I objects ($EW_{H\beta}^{BLR}$ (pol.) ≈70–170 Å; cf., Miller and Goodrich 1990). In effect, supposing that the photon deficit in Seyfert 2's is explained by the occultation/reflection picture as proposed in KAW3 and therefore that the observed continuum is seen as a result of reflection/scattering, we would expect the reflection of the broad Hβ to take place with the same efficiency as that of the nuclear continuum. Similar inconsistencies apply to the hazy nucleus picture as well as to the simple dust model of the Seyfert 2 continuum by BWVM3.

One alternative to *in situ* processes is to have the continuum intensity much stronger along some privileged directions close to our line of sight (the polarized $EW_{H\beta}^{BLR}$ would still result from off-axis mirrors). In this case, geometrical cancellation of the **E** vector of the boosted continuum would result in little polarization. This runs counter, however, to current unification picture of Seyfert 2's. Another alternative is to have the optical domain dominated by starlight from very hot stars (cf., Terlevich and Melnick 1985; Antonucci et al. 1992 for the case of NGC 1068).

4. MECHANISMS OF CONTINUUM EMISSION ASSOCIATED WITH THE IONIZED GAS

Modeling of NLR or BLR clouds has been so far mostly concerned with the emission lines and relatively little with the continuum which they could deflect or generate. Two exceptions to this are the *small* UV bump in the $\lambda\lambda$2000 to 4000 Å region which has been modeled by Wills et al. (1985) as resulting from Balmer continuum emission and Fe II multiplet line emission, and the continuum emitted by extremely dense thermal clouds immersed in hard radiation (Ferland and Rees 1988). We hereby expand on the idea that the optical-UV continuum observed (including the big UV bump) should not be equated to the (primary) nuclear ionizing continuum but rather to a scattered or reprocessed (secondary) energy source.

Apart from our suggestion concerning the spatial association of line and continuum emission which is invoked to explain the narrow range in $EW_{H\beta}$, we must expect from any alternative interpretation of the observed optical continuum that it alleviates or cures the photon deficit problem. We have to postulate either some form of energy reprocessor (e.g., dust *absorption*) of the primary source which hides its true power from us, or that the primary source is an intrinsically anisotropic emitter with most of its energy directed away from our line of sight.

We briefly summarize in this section possible physical processes which would make the optical nonstellar continuum appear fuzzy and co-spatial with the line-emitting regions.

4.1 Dust Scattering

Dust scattering is a plausible explanation for the aligned UV continuum in radio galaxies (see Cimatti et al. 1993, and references therein). Fosbury et al. (1991) showed how pure scattering of an optical-UV power law ($\alpha=-1$) by small grains can qualitatively reproduce the energy distribution ($\alpha\approx+3$) of the detached continuum emission in PKS 2152−69 (see Sec. 3.2). Di Serego Alighieri et al. (1988) reported the detection of 8%–12% (depending whether the lines are polarized or not) polarization in the *B* band continuum with an **E** vector perpendicular to the cloud–nucleus axis. The orientation of the **E** vector is therefore consistent with reflection of a photon beam emanating from the nucleus of the radio galaxy.

Adopting an energy distribution of the incident collimated beam corresponding to the well-known BL Lac, Mrk 501, and using a numerical transfer solution across the dust which considers both effects of scattering and absorption, Magris et al. (1993) improved the fit to the detached cloud energy distribution. Their grain size distribution was confined to very small values as in Fosbury et al. (1991) [500 Å$\leqslant a \leqslant$50 Å] (otherwise it is not possible to reproduce the reflected energy distribution) and their geometry consisted of reflection from a thick slab of dust.

In the three Seyferts in which they detected extended UV emission, Pogge and De Robertis (1993) similarly favored the interpretation of dust scattering. In the case of NGC 1068, Miller et al. (1990) showed that the degree of polarization of the off-nucleus reflection increases towards the blue. The wavelength dependence of the polarization and the redder energy distribution of the off-nucleus reflection in NGC 1068 could indicate that the dust responsible of the extended continuum reflection may bear more resemblance to that of the local ISM than to the small grains used in the models of PKS 2152$-$69.

In the case of the BLR, little dust appears present in the fully ionized layers of the clouds although it is conceivable that some may survive in the deeper neutral zones. At the position of the nucleus proper in NGC 1068, Miller et al. (1990) has presented convincing evidence favoring electron scattering (at $T_e \approx 10^{5.4}$ K) over dust scattering for explaining the wider line profile of the reflected BLR. On a much smaller scale, however, a combination of dust extinction inside the neutral core of BLR clouds with electron scattering by the intercloud medium are worth investigating in cases where the cloud coverage exceeds unity as discussed in Secs. 3.3 and 4.4. Netzer and Laor (1993) made the interesting suggestion that dust outside the BLR radius could be reprocessing most of the ionizing energy (explaining the gap between BLR and NLR) up to the larger NLR radius at which point line emission is favored over dust absorption (because of the lower extinction depth of the ionized column when the ionization parameter becomes smaller).

4.2 *In Situ* Continuum Generation

Since the extended emission line gas in radio galaxies and in Seyferts is aligned with the radio superstructure, we might imagine that the jet of particles at the interaction point with ISM clouds results in the production of *in situ* ionizing continuum which in turn photoionize nearby clouds. This scenario has been proposed by Bicknell (1991) and Sutherland et al. (1993) to explain the excitation of the optical filaments in Centaurus A. They computed the interaction of transonic streams with stationary gas clouds and derived Hβ luminosities consistent with those of the optical filaments in Cen A. The resulting shocks, if of sufficient velocity ($V_s \gg 200$ km s^{-1}, see radiative high-velocity shock models by Binette et al. 1985), generate a hard continuum from cooling gas behind the shock which can produce high excitation line ratios (by photoionization of the downstream shocked gas).

Other mechanisms involving the radio jet power are possible such as extended synchrotron emission and thermal bremsstrahlung from hot gas in the vicinity of radio lobes. From their study of extranuclear ionized gas in Seyferts, Haniff et al. (1991) concluded, however, that the lack of detailed correspondence between the extended emission line morphology and the radio morphologies precluded these mechanisms as the primary source of extranuclear ionization.

To generate the aligned optical (and ionizing) continuum observed in high-redshift radio galaxies, Daly (1992) has proposed the mechanism of inverse compton scattering of microwave background radio photons by relativistic electrons. One advantage of this mechanism is that it would explain the observed relation between the emission-line strength and the radio power (cf., McCarthy et al. 1991). More recently, Harris et al. (1993) proposed self-Compton upscattering (of the local radio photons) to explain the observed X-ray flux associated with the radio hot spots in the radio lobes of Cygnus A.

Terlevich et al. (1992) propose a radically different origin for the high-velocity ($\sim$5000 km s^{-1}) shocks which they use to reproduce the BLR line ratios. In their model, the shocks are driven by supernova remnants evolving in a high-density medium ($\sim 10^7$ cm^{-3}). Because both the supernova rate and the blue light of a starburst is dominated by hot stars in the starburst AGN model, the equivalent width of Hβ was shown by Aretxaga (1993) to be constant in such a model (see also Aretxaga and Terlevich 1993) to the extent that type II SN explosions generate similar amount of energy. Interestingly, the value derived by Aretxaga is $EW_{H\beta} \approx 40$ Å$[\epsilon_{51}/(1+0.17\epsilon_{51})]$, where ϵ_{51} is the energy of type II SN in units of 10^{51} ergs, and was shown to be independent of the initial mass function, the age, and the mass of the starburst cluster.

4.3 Continuum Emission from the BLR Gas

Another process which generates *in situ* continuum is that proposed by Antonucci and Barvainis (1988) and Barvainis (1993) in which the big UV bump is reprocessed light emitted by a hot, optically thin plasma within the broad line region. Ferland et al. (1990) expanded this model in their study of the Seyfert 1 Mrk 590 ($EW_{H\beta} \approx 150$ Å) and of its line response to continuum variability. They noticed that the broad wings of the Balmer lines did not vary and interpreted this as a result of a matter bounded component of temperature $\sim 10^5$ K, which would lie relatively close to the ionizing source and would reprocess the softer X rays into line emission and continuum emission (which they associate to the observed and variable big blue bump). The continuum emission in this case is the result essentially of optically thin hydrogen–helium continuous emission. Ferland and Rees (1988) showed that apart from accounting for the big UV bump, a very soft X-ray excess can also be produced depending on the density and filling factor of the "thermal" clouds.

Since this leads to a model where neither the lines nor the continuum vary much at all and one which fails to provide a sufficient number of ionizing photons [in the case of Mrk 590, Ferland et al. 1990 required that $C_f = 1$], we propose to modify the picture in the following manner. Suppose that the nuclear energy source consists of an X-ray beam which is obstructed by a large dispersive obstacle within the BLR (either high electron column density or a cold and very dense gas component). This will result in a fraction of the beam filling up sections of the BLR volume with scattered X-ray radiation. As in Ferland et al. (1990) and Ferland and Rees (1988), we suppose that the X-ray radiation is reprocessed inside very dense (matter bounded) gas condensations distributed within the BLR volume. Changes in the properties of the (X-ray) scattering obstacle will modulate the fraction of X-ray radiation diverted from the beam as well as its angular phase function, illuminating at different times different portions of the BLR. Variability in the blue bump and in the lines emitted by the "thermal" clouds would therefore be the indirect result of changes in the properties of the X-ray scattering medium intersecting the beam.

4.4 Electron Scattering within the BLR

In the case of the BLR, a mechanism which is likely to play an important role is that of electron scattering. In the recent model of Ferland et al. (1992), the line-emitting clouds themselves possess a significant electron scattering opacity. One feature of a scattering BLR volume in which emission-line clouds are immersed is that the primary source variability will be partly smoothed out as a result of continuum travel time effects across the BLR. The line time lags will be short since both line and continuum are characterized by similar transfer functions. This might explain the short time scale variability of C IV and Ly α in some quasars (Gondhalekar 1990). Part of the width of the BLR lines might be the result of electron scattering broadening within the cloud (cf., Ferland et al. 1992) as well as within the intercloud medium.

Models which combine BLR clouds with internal opacity due to dust (confined to the interior neutral zones of clouds) with that of intercloud electron scattering can present interesting features as discussed in Sec. 3.3. A flattened distribution of such clouds (i.e., with a cloud coverage tending towards zero towards the poles) immersed in a spherical or toroidal electron scattering atmosphere would lead by default to a collimation of the ionizing radiation along the poles. Such a geometry might account for the ionization cones extending beyond the nucleus and when sufficiently inclined towards the observer would result in a scattered soft X-ray component. Dopita and Coleman (1992) have recently provided a theoretical framework for a flattened BLR by studying the properties of a twisted accretion disk within an electron scattering thick photosphere.

The total electron scattering opacity τ_s of the hazy nucleus should not greatly exceed unity since otherwise the short time response of the X-ray source would be lost. A problem with electron scattering by the intercloud medium is that it would be opaque to X rays if the Fe K shell is not fully ionized. Assuming solar Fe/H abundance ratio, the K-shell opacity is $\tau_K \approx y\tau_s$, where y is the mean filling factor of the K shell. Mathews and Ferland (1987) have shown that the typical AGN energy distribution leads to an equilibrium Compton temperature of the intercloud medium of only 10^7 K ($\sim 10^9$ K would be required to have $y \ll 1$). Other heat sources may exist to bring up the temperature of the confining medium. Alternatively, y can be made very small if the ionizing radiation density is very high, that is, for very high ionization parameters $\hat{U} \approx 10^{3.5}$ (Mathews and Ferland 1987) but this in turn would imply that the immersed BLR clouds have $U_{\rm BLR} \approx 0.8$ which is much higher than typical values assumed in BLR models (but see Ferland et al. 1992). To resolve this, we may have to confine τ_s to be ≈ 1 only within the core of the BLR, at the radius inferred from C IV variability studies.

In the radio domain, electron scattering should result in a diffuse extended component. Only detail modeling which considers both scattering and free–free absorption could determine the expected contrast between the extended and core radio components.

The gain in reprocessing efficiency of a flattened BLR is provided by the larger covering factor along the equatorial plane. Unification models (e.g., Barthel 1989) of AGN propose that QSOs are objects for which our line of sight falls within the opening angle ($\approx 45°$) of their collimated nuclear radiation. This raises the interesting possibility that the small covering factor inferred from high-redshift QSOs (cf., Netzer 1985; Netzer and Laor 1993) is only reflecting the value of C_f along the collimated radiation as suggested by Antonucci et al. (1989). Since QSOs are extremely luminous objects, we may expect the ionization cones to extend well beyond the boundary of the galaxy (as is observed in powerful radio galaxies) with a probability as low as ≈ 0.1 of encountering any ENLR absorbing cloud along the line of sight. This new interpretation of the fraction of QSOs showing Lyman limit absorption drastically reduces the photon deficit problem since it does not constrain C_f along the equatorial plane. It also provides a powerful argument in favor of the orientation-dependent models of Browne (1983) and Barthel (1989). The fact that broad lines are observed in the parent "uncollimated" population (e.g., in radio galaxies where our line of sight clearly lies outside the collimated distribution) but with the same $EW_{H\beta}$ as QSRs can be explained with the hazy nucleus picture as argued in previous sections.

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