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THE FAR-ULTRAVIOLET CONTINUUM OF QUASARS AND THE UNIVERSE AT $Z > 4$[1]

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ABSTRACT

Recent observations of quasars are combined with present theoretical ideas to show a serious energy budget problem in many of these objects. If no reddening is assumed, then the total broad-line flux is a factor of 2 larger than predicted by so-called successful photoionization models. Energy conservation requires a $F_\nu \propto \nu^{-0.4}$ or flatter ionizing continuum, in conflict with many observations. Alternatively, some unconventional ideas, such as extremely thick or extremely dense broad-line clouds, must seriously be considered. Reddening of the broad emission lines helps to solve the problem and bring present day models to better agreement with the observations. The continuum is likely to be reddened or partially obscured as well, and a rising ionizing component should seriously be considered. The far-ultraviolet continuum of quasars is observed to be very steep because of dust, intervening gas, or both. In any event, it would be extremely difficult to observe all wavelengths below ~ 500 Å in quasars and possibly in other high-redshift objects. The ultraviolet spectrum of $Z \approx 5$ objects may never be observed.

Subject headings: quasars — ultraviolet: spectra

I. INTRODUCTION

Recent observations of quasars give new information on two important spectral regions. Bechtold *et al.* (1984) looked at several objects with the *IUE* and confirmed earlier findings by Green *et al.* (1980) that the $\lambda < 912$ Å continuum is much steeper than at longer wavelengths. Wills, Netzer, and Wills (1985, hereafter WNW) looked at the 2000–5000 Å region, in many quasars, and found a large flux excess originated in the broad-line zone. There is of course a close relation between these two observations, since the ultraviolet continuum is the main energy input source to the broad-line gas.

Photoionization models are reasonably successful in explaining most observed features in the spectra of quasars and similar objects (Davidson and Netzer 1979, and references therein; Kwan and Krolik 1981; Weisheit, Shields, and Tarter 1981; Mushotsky and Ferland 1984). They provide information about the physical conditions in the line-producing gas, by comparing predicted and observed line ratios. Are these models compatible with the new observations? The present paper investigates this problem and shows that very general considerations indicate a severe energy conservation problem in most so-called successful photoionization models. Section II presents the data, and § III discusses the consequences for quasar models and cosmology.

II. THE OBSERVED SPECTRUM

a) Broad Emission Lines

The data used in the following analysis are taken from a variety of papers discussing the spectra of quasars. The main sources are Baldwin (1975), Baldwin and Netzer (1978), Uomoto (1984), Osmer and Smith (1977, 1980), WNW, Oke, Shields, and Korycansky (1984), Green *et al.* (1980), and Oke and Korycansky (1982). All these references are used to obtain a "mean quasar spectrum" as given in Table 1. This should apply to strong Fe II objects, and the following discussion is mainly about them. Listed in the table are many emission lines and different hydrogen and helium continua. Some of these (marked by "?") are not directly observed, and their strength is estimated from photoionization model calculations (e.g., WNW). The uncertainty in the total emitted flux due to these is very small.

TABLE 1

ENERGY BUDGET FOR QUASARS

Line	Mean Observed Spectrum	Corrected for Reddening[a]
Lyα	1	1
Hα	0.8	0.085
Hβ	0.15	0.02
All other Balmer lines	0.3	0.04
All other H lines	0.1	0.01
Balmer continuum	1.1	0.2
Paschen continuum	0.3?	0.07?
Other H bound-free and 2-photon	0.1?	0.01?
He II Lyα	0.2?	0.2?
Other He II lines	0.08	0.05
All He I lines	0.1	0.01
Bound-free He and metals	0.17?	0.04?
Free-free (H, He, metals)	0.2?	0.1?
O VI λ1035	0.25	0.41
O IV] λ1402	0.1	0.07
C IV λ1549	0.45	0.25
C III] λ1909	0.15	0.05
N V λ1240	0.2	0.19
Mg II λ2798	0.3	0.06
Fe II (2000–3000 Å)	1.1	0.27
Fe II (3000–6000 Å)	0.4	0.06
Other Fe II lines	0.2	0.08
All O I lines	0.1	0.07
Other O III, C II], N IV], S IV, O III] lines	0.15	0.05
Total	8.0	3.4

[a] $A_V = 0.66$, λ^{-1} extinction.

Crucial to the argument presented in this paper are the new

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observations of intermediate-redshift quasars reported by WNW. These observations and line-fitting analysis show that a large fraction of the broad-line flux is emitted between 1900 and 4000 Å, where it forms a "small bump" of excess emission over the underlying nonstellar continuum (see also Grandi 1982). This is mostly due to thousands of Fe II lines and Balmer continuum emission. (WNW find that the total observed Fe II line emission exceeds that of Lyα.) The new results indicate that the total flux emitted by the broad-line cloud is much larger than previously assumed. From Table 1 we find a total observed broad-line flux that is about 8 times the Lyα flux. The uncertainty in this number is mainly due to the modeling of the Fe II lines and the Balmer continuum, as discussed in detail by WNW. It is unlikely that the total small-bump flux (Fe II + Balmer continuum ~ 3 times the Lyα flux) could be uncertain by more than a factor of 2. Thus in many objects the total flux in the broad-line cloud region is probably between 6.5 and 9.5 times the Lyα flux.

A possibility that must also be considered is internal reddening, (e.g., Netzer and Davidson 1979; Shuder and MacAlpine 1979). The dust is probably not mixed in with the broad-line gas (Ferland and Netzer 1979), and it may affect line and continua differently depending on its location. The dust properties are not necessarily Galactic, and different extinction laws, with or without the 2200 Å features, must be considered. As a particular example, we chose a λ^{-1} extinction law, normalized such that $A_V = 0.66$ mag. This amount of visual extinction is consistent with Netzer and Davidson's (1979) estimates, as well as with several measurements of reddening in Seyfert nuclei (e.g., Ward and Morris 1984). The last column of Table 1 gives the intrinsic quasar spectrum assuming this extinction. The total flux in this case is about 3.5 times the Lyα flux. (Note that the lines and continua marked by "?" are estimated from theoretical calculations, relative to some other observed lines. Their intensity should not be corrected by the reddening law used.) Other values can easily be obtained by assuming different amounts of extinction. For example, $A_V = 0.3$ mag gives (total flux)/Lyα (flux) ≈ 5.

b) The Nonstellar Continuum

It is customary to fit the nonstellar quasar continuum by a power law of the form $F \propto \nu^{-\alpha}$. Inspection of spectra observed over a wide frequency range indicates that a single power law is not a good fit (e.g., Neugebauer *et al.* 1979). The infrared continuum is usually steep ($\alpha > 1$), and the optical and near-UV continuum is much flatter ($\alpha \sim 0.5$). The change of slope occurs at a rest wavelength of ~ 5000 Å and gives an impression of a "big bump" extending well beyond Lyα (not to be confused with the small bump discussed above between 1900 and 4000 Å). Recently (Malkan 1983; Malkan and Sargent 1982), there has been some attempt to fit this big bump by a hot disk component. There are some difficulties with this idea, but for the present study we assume this to be equivalent to an ultraviolet spectral index of -0.33. A single power law gives a good fit in the X-ray region from about 0.5 keV to the limit of detection at 150 keV (see Petre *et al.* 1984, and references therein).

The aim of the present work is to estimate the total energy absorbed by the broad-line clouds and the energy of the mean ionizing photon. For this we need the value of α at $\lambda < 912$ Å. This is very difficult to obtain. Ground-based observations of high-redshift quasars do not cover a large enough wavelength range below the Lyman limit (e.g., Osmer 1979; Oke and Korycansky 1982), and the existing ultraviolet space telescopes are too small to observe this region in most objects. Recently, Bechtold *et al.* (1984) have used the *IUE* to observe the Lyman continuum of nine high-redshift ($1.0 < Z < 2.2$) quasars. Their results confirm the earlier discovery by Green *et al.* (1980) and Oke and Korycansky (1982) of a noticeable steepening below a rest wavelength of 1200 Å. In this wavelength region, $\alpha \gtrsim 2$ with extreme cases up to $\alpha = 5$. Bechtold *et al.* (1984) suggested that the intrinsic continuum is flatter, but it suffers absorption by material along the line of sight, associated with galactic halos and intergalactic clouds. Eastman, MacAlpine, and Richstone (1983) suggested a model in which the continuum steepening is due to fast-moving Lyα clouds, outside the broad-line zone.

The slope of the Lyman continuum has been discussed also in several theoretical papers (see review by Davidson and Netzer 1979). Values often used are $0.5 \lesssim \alpha \lesssim 1.5$, since they were found to be successful in reproducing many observed line ratios. Kwan and Krolik (1981), who were motivated by the Green *et al.* (1980) observations, have considered the case of a two-component continuum: a $F_\nu \propto \nu^{-0.5}$ ultraviolet component, up to 100 eV, and an X-ray component of $F_\nu \propto \nu^{-0.5}$ at shorter wavelength. An extensive grid of models, calculated by Kwan (1984), uses the same continuum. This has been critized by several authors, in particular MacAlpine (1981), who noted the extremely weak He II lines produced in such cases, in contradiction to observations of many Seyfert 1 galaxies and several quasars.

To proceed, we assume a two-component continuum given by

$$F_\nu(\lambda < 912\ \text{Å}) = a\nu^{-\alpha} + b\nu^{-0.7} \tag{1}$$

(ν in rydbergs). There are no indications for a change of slope of the X-ray component (the second term) for all energies above 0.5 keV (Petre *et al.* 1984), so we assume an abrupt cutoff of the ultraviolet component at

$$\nu_{\text{cut-UV}} = 30\ \text{R}\ .$$

The ratio a/b gives the relative flux of the two components at 1 R and is directly observed. Zamorani *et al.* (1981) defines an optical-to-X-ray spectral index, α_{ox}, combining the observed continuum at 2500 Å and at 2 keV by a single power law of $F_\nu = c\nu^{-\alpha_{ox}}$. The radio-loud quasars in the Zamorani *et al.* (1981) sample are also stronger X-ray emitters, and for them $\langle\alpha_{ox}\rangle \approx 1.3$. Combined with the WNW measurements of $\alpha(912\text{–}2500\ \text{Å}) \approx 0.5$, one gets $a/b \approx 45$. Radio-quiet quasars are weaker X-ray emitters with $\langle\alpha_{ox}\rangle \approx 1.5$. In this case, $a/b \sim 150$. Very luminous optically selected quasars have much larger a/b, and Seyfert 1 galaxies have the smallest ratio: $a/b \approx 20$. (See, however, Cheng *et al.* 1984 for a claim of an intrinsic $\alpha_{ox} \approx 1.5$ for all optically selected active galactic nuclei; see also Kriss 1984.) Note here that the Kwan and Krolik (1981) or the Kwan (1984) continuum has a very small a/b. It overestimates the X-ray-to-ultraviolet flux of a typical radio-loud (radio-quiet) quasar by a factor of ~ 6 (~ 20). This has important implications for the calculated line intensities, as explained in WNW.

III. ENERGY BUDGET AND THE VALUE OF α

We proceed by making the standard assumptions about the broad-line region. We consider a system of numerous small high-density clouds near a central massive object. All heating and excitation is due to absorption of the nonthermal central continuum. The ionization parameter U (incident ionizing photon flux divided by the gas number density) is in the range

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10^8–10^9 cm s^{-1}. Models with this value of U, solar composition, and densities in the range 10^8–10^{10} cm^{-3} are quite successful in producing the observed strength of many emission lines. Processes in a very deep partly neutral zone, where $N(\mathrm{H}^0)/N(\mathrm{H}) \gtrsim 0.5$, are important in exciting some of the strongest observed lines, such as Fe II and Mg II (Netzer 1980; Kwan and Krolik 1981; Weisheit, Shields, and Tarter 1981; Netzer and Wills 1983). Models that give the best agreement with the observations require $\tau(912\ \text{Å}) \sim 10^4$–$10^6$.

A possible way to investigate the line-continuum relation is by constructing detailed photoionization models. This, however, is not needed since very general energy budget considerations are good enough to demonstrate the problem. The main assumption here is simply that the broad-line clouds are in equilibrium, and all the energy they absorb is reemitted as line emission and diffuse continua. There are two other requirements:

1. The column density of a typical cloud is of the order of 10^{23} H atoms cm^{-2}.
2. The emitted Lyα flux is *at least* equal to the "case B Lyα." The latter means a case where the number of Lyα photons escaping the cloud equals the number of ionizing photons absorbed by it.

Condition (1) determines the fraction of X-rays absorbed by the cloud (see below); a range up to $\sim 10^{24}$ atoms cm^{-2} is still consistent with present ideas. Condition 2 is more crucial for the following discussion. It is in fact fulfilled in most or all published photoionization calculations. In older models, like those of Baldwin and Netzer (1978), where X-ray heating processes are not very important, Lyα(total)/Lyα(case B) ~ 2 (see also Ferland and Netzer 1979). In more recent models (Netzer 1980; Weisheit, Shields, and Tarter 1981; Kwan and Krolik 1981; Mushotzky and Ferland 1984; WNW; Kwan 1984), this value is between 1 and 1.5 depending on α and U used. Even the extremely high density case, $N_e = 10^{11}$ cm^{-3}, suggested by WNW as a possible explanation for the strong Fe II lines, gives Lyα(total)/Lyα(case B) ≈ 0.9.

The amount of the energy absorbed by the gas depends on the clouds' optical depth. Figure 1 shows the optical depth structure of a typical high-density cloud with a column density of 10^{23} H atoms cm^{-2}. In this case $U = 4 \times 10^8$ cm s^{-1}, $a/b = 45$, and $\alpha = 0.5$. The two curves are for solar composition and for a case where all metals are enhanced, relative to hydrogen and helium, by a factor of 3. All of the ultraviolet continuum is absorbed by the cloud, and the fraction of X-ray photons absorbed depends on the column density. The main opacity is in the partly neutral zone, where H and He are mostly neutral and all metals are neutral (O, N, Ne) or singly ionized (Fe, Mg, C, S, Si). Models with different U have very similar optical depth structure. (Electron scattering is an important opacity source at high energies—see dashed line in figure. We do not include it since the amount of energy absorbed by the gas, as a result of recoil, is very small for $h\nu < 100$ keV.)

According to Figure 1, the energy at which half the photons are absorbed is about 300 R (450 R) for the case of solar (3 × solar) composition. At these energies $\tau \propto \nu^{-2.3}$, to a good approximation, so an effective X-ray cutoff for the solar composition case is

$$\nu_{\text{cut-X}} \approx 300(\text{COL}/10^{23})^{0.43}\ \text{R}\ , \tag{2}$$

where COL is the cloud column density [$450(\text{COL}/10^{23})^{0.43}$ R for the 3 × solar case]. The total energy absorbed by the cloud is roughly

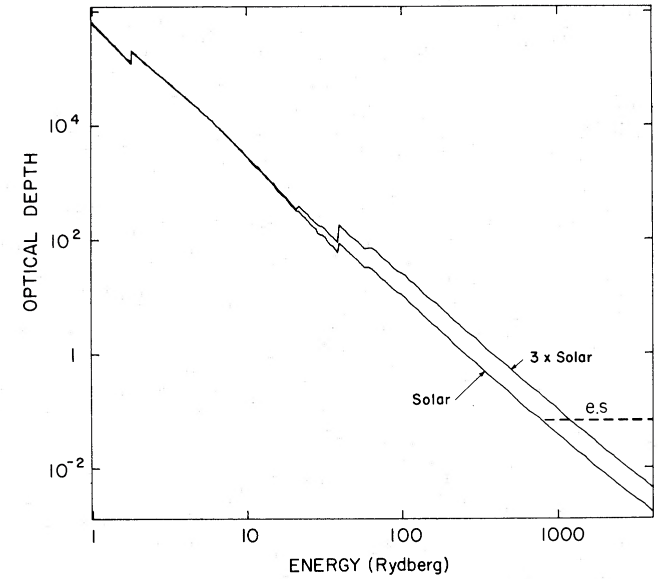

FIG. 1—Optical depth at different frequencies of a typical broad-line cloud with a column density of 10^{23} H atoms cm^{-2}. The two curves represent different metal abundances. The dashed line is the electron-scattering optical depth.

$$E_t = \int_1^{\nu_{\text{cut-UV}}} a\nu^{-\alpha} d\nu + \int_1^{\nu_{\text{cut-X}}} b\nu^{-0.7} d\nu$$

$$= \begin{cases} \dfrac{a}{1-\alpha}(30^{1-\alpha} - 1) + \dfrac{b}{0.3}\left[300^{0.3}\left(\dfrac{\text{COL}}{10^{23}}\right)^{0.13} - 1\right] & (\alpha \neq 1) \\ a \ln 30 + \dfrac{b}{0.3}\left[300^{0.3}\left(\dfrac{\text{COL}}{10^{23}}\right)^{0.13} - 1\right] & (\alpha = 1)\ , \end{cases} \tag{3}$$

and the number of photons absorbed is

$$Q_t = \int_1^{\nu_{\text{cut-UV}}} \frac{a}{h}\nu^{-\alpha-1} d\nu + \int_1^{\nu_{\text{cut-X}}} \frac{b}{h}\nu^{-1.7} d\nu$$

$$\approx \begin{cases} \dfrac{a}{\alpha h}(1 - 30^{-\alpha}) + \dfrac{b}{0.7h} & (\alpha \neq 0) \\ \dfrac{a}{h}\ln 30 + \dfrac{b}{0.7h} & (\alpha = 0)\ . \end{cases} \tag{4}$$

The minimum Lyα flux set by condition 2 is

$$E(\text{Ly}\alpha,\ \text{case B}) = Q_t h\nu(\text{Ly}\alpha)$$

$$\approx \begin{cases} \dfrac{3}{4}\left[\dfrac{a}{\alpha}(1 - 30^{-\alpha}) + \dfrac{b}{0.7}\right]\text{R} & (\alpha \neq 0) \\ \dfrac{3}{4}\left(a \ln 30 + \dfrac{b}{0.7}\right)\text{R} & (\alpha = 0)\ . \end{cases} \tag{5}$$

If both conditions are satisfied, then the total flux emitted by broad-line clouds exceeds the Lyα (case B) flux by a factor of $E_t/E(\text{Ly}\alpha,\ \text{case B})$. This ratio, as calculated from equations (3) and (5), is plotted in Figure 2 as a function of α for COL $= 10^{23}$ cm^{-2}, solar composition, and two values of a/b: 45 and 150.

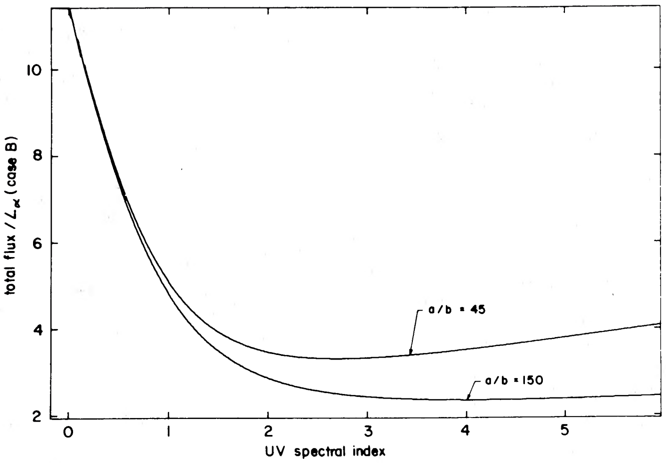

FIG. 2.—Predicted E_t/E(Lyα, case B) for different ultraviolet spectral indices, α. The two curves are for different ratios of the ultraviolet-to-X-ray flux ratio: $a/b = 45$ is typical of radio-loud quasars, and $a/b = 150$ is for most radio-quiet ones.

IV. DISCUSSION

a) *The Intrinsic Ultraviolet Continuum*

Comparison of Figure 2 and Table 1 raises a severe problem: no value of α in the range 0.4–6 can produce the observed unreddened value of (total flux)/(Lyα flux) ~ 8. Moreover, flat continuum photoionization models predict Lyα that is much greater than Lyα(case B), and $\alpha \lesssim 0$ may be required. [If Lyα(emitted)/Lyα(case B) = 2, the value to consider is 16 instead of 8.] The observed Lyman continuum slope, of $\alpha > 2$, implies total line flux relative to Lyα flux which is a factor of nearly 3 smaller than observed in radio-loud quasars (more than 3 in radio-quiet ones). Detailed photoionization models published to date with $\alpha \geq 0.5$ demonstrate the same difficulty. For example, in the Kwan and Krolik (1981) standard model, the total emitted flux is about 5 times the Lyα flux, and Lyα(emitted)/Lyα(case B) = 1.1. The model predicts total line energy which is a factor of 2 too small compared with the observations of many objects. The Mushotzky and Ferland (1984) grid of models fails by more than a factor of 2, and a similar problem is found in Netzer (1980) model a and the Kwan (1984) and Weisheit, Shields, and Tarter (1981) models. Several other models (Netzer 1980, model b; WNW) are better in this respect, but they are not very satisfactory in several other aspects.

An even more severe problem is the strength of the Fe II, Mg II, and C II] lines. Models suggest that these lines are produced in the partly neutral zone, where most of the heating and excitation is by penetrating X-ray photons. The fractions of the total absorbed energy, due to the X-ray component (second term in eq. [1]), are 0.044, 0.11, 0.29, and 0.45 for $\alpha = 0.5$, 1, 2, and 3, respectively, *and* the observed ratio is I(Fe II + Mg II + C II])/I(Lyα) ≈ 2, so the X-ray continuum component fails to produce the observed ratio by a factor up to 6, depending on α. (The exact value depends on model details since some of the excitation of Fe II, Mg II, and C II] is due to energy deposited by softer photons.)

A possible way to reduce the discrepancy is to consider absorption of the nonstellar continuum at longer wavelength. Recent models (Netzer 1980; Kwan and Krolik 1981; Netzer and Wills 1983) suggest that τ(Bac 3646 Å) ~ 1 in the broad-line clouds. Some of the $\lambda < 3646$ Å continuum will be absorbed by the gas and reemitted mainly as Balmer continuum (Bac) emission or low-excitation lines. The increase of E_t/E(Lyα, case B) due to this is less than 20% for $\alpha = 1$, and $\sim 5\%$ for $\alpha = 0.5$; far from what is needed to solve the problem. (The fractional increase for $\alpha < 1$ is larger, but at those values the discrepancy between observations and theory is already too big. Also the *observed* slope, at $\lambda > 912$ Å, is $\alpha \sim 0.5$, and eq. [3] cannot simply be extrapolated to longer wavelengths.) The problem cannot in fact be solved even for τ(Bac 3646 Å) > 1.

We are led to the conclusion that the observed ultraviolet continuum and most photoionization models are inconsistent with the observed broad-line flux, if reddening is negligible. More specifically one or both conditions listed above may not apply in quasar clouds. Increase in column density (condition 1) up to 10^{24} H atoms cm^{-2} improves the situation only slightly, so much larger column density is required if high-energy photons are to supply the missing energy. Although such ideas are not entirely new (see Oke, Shields, and Korycansky 1984), they have not yet been worked out in detail, and there is still the problem of whether or not the hard X-ray or γ-ray flux is large enough. Models of such large column density clouds, where more than half the energy is supplied by photons of $h\nu > 20$ keV, must be very different from present photoionization models. Condition 2 may not apply in parts or in all of the broad-line zone. Some clouds may have very high densities so Lyα is collisionally suppressed. Such ideas have been suggested by Collin-Souffrin, Dumont, and Tully (1982), Joly (1981), Hubbard and Puetter (1984), and WNW. These ideas are not fully developed yet. Collin-Souffrin *et al.* and Joly assume an additional (not photoionization) heating source, and the Hubbard and Puetter suggestion has not been tested in a multi-element model and is in conflict with the strength of many intercombination lines (Kwan 1984). WNW have considered densities up to 10^{11} cm^{-3} but the E_t/E(Lyα, case B) problem is still present, and there are other serious problems. Such models are bound to considerably change our view of the quasar emission-line region.

b) *Reddening and Covering Factor*

The situation is very different if some dust is present. If line reddening is as suggested in the last column of Table 1, then spectral indices as large as 1.5 are acceptable. This amount of dust is given only for illustrative purposes, and we expect some variation from object to object. The main point is that some dust must be present if the intrinsic $\lambda < 1200$ Å continuum is not flatter than the one observed at longer wavelength.

Is the continuum reddened as well? The arguments presented above require only the reddening of the broad-lines, but this leaves a continuum which is still flatter than observed, and there are other indications that the continuum is also obscured. For this we ought to consider the covering factor and the equivalent width of Lyα.

There are several indications that the broad-line covering factor is small: 10% or less. There are a very small number of objects with an observed cutoff at the Lyman limit edge and no indications for strong absorption features due to Lyα and other resonance lines (Davidson and Netzer 1979; Baldwin and Smith 1983; Carswell and Ferland 1980; Bechtold *et al.* 1984).

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This should be evaluated in view of the Lyα equivalent width, predicted by condition 2 and equation (5):

$$EW(\mathrm{Ly}\alpha,\ \text{case B}) = \left\{\frac{3}{4}\left[\frac{a}{\alpha}(1 - 30^{-\alpha})\right] + \frac{b}{0.7}\right\}\Big/\left[a\left(\frac{4}{3}\right)^{\alpha}\right]\frac{\Omega}{4\pi}$$

$$\approx \frac{(3/4)^{1+\alpha}}{\alpha}(1 - 30^{-\alpha})\frac{\Omega}{4\pi}\,\mathrm{R}$$

$$= \frac{1215}{\alpha}\left(\frac{3}{4}\right)^{\alpha}(1 - 30^{-\alpha})\frac{\Omega}{4\pi}\ \text{Å} \quad (\alpha \neq 0)\,, \qquad (6)$$

where in the last step we neglected the X-ray contribution. (Note again that this is only for no change of slope at the Lyman limit.) The slope with $\alpha = 0.5$ gives $EW(\mathrm{Ly}\alpha$, case B) $\approx 1720\ \Omega/4\pi$ Å, and a typical observed equivalent width is ~ 100 Å, so a covering factor of $\Omega/4\pi \sim 0.06$ is deduced, in agreement with observations. If, on the other hand, Lyα is reddened and the continuum is not, then the intrinsic Lyα equivalent width is much larger than observed. For example, $A_V = 0.66$ mag and $\alpha \sim 0.5$ required full coverage, in contradiction with the other observations. A slope of $\alpha > 0.6$ is completely excluded, since in this case $\Omega/4\pi > 1$. The problem does not arise if the intrinsic continuum, near 1215 Å, is much brighter than observed. Some continuum reddening, not necessarily by the same amount as for the broad emission lines, is one possible solution. Another possibility is some special geometry (e.g., a disk inclined to our line of sight) where the continuum shining on the broad-line clouds is brighter than the one seen by us.

If the continuum is indeed reddened, then very little can be said about its shape. Not only do we not know the geometry or the exact amount of reddening, but we are also not sure about the extinction law. It is interesting to note, however, that ν^0 or $\nu^{1/3}$ intrinsic power laws, with a λ^{-1} extinction law and $A_V \approx$ 0.25–0.5 mag, give a reasonable fit to many observed continua both above and below the Lyman edge (see also Davidson and Netzer 1979, Fig. 11). We also note the gradual continuum steepening in several of the objects observed by Bechtold *et al.* (1984) as expected from most extinction laws. If disk models are to be applied, then the maximum allowed temperature is of great importance.

There are several problems with the idea that the ultraviolet continuum is heavily reddened. First, reradiation by dust should be detected at IR wavelengths. The dust temperature, r_{pc} parsecs from a continuum source of luminosity L_{46} (10^{46} ergs s^{-1}), is $T_d \approx 1700 L_{46}^{0.2} r_{\mathrm{pc}}^{-0.4}$ K. Such radiation could not be detected by present-day instruments if $r_{\mathrm{pc}} \gtrsim 10{,}000$ (e.g., in the disk of the host galaxy). Similar considerations indicate a minimum r_{pc} of about 1. The total IR flux is not necessarily as large as the missing UV flux, since the dust covering factor may be small. In any event, the dust properties must be different from the Galactic dust since the 2200 Å feature is not observed. Another consideration is the dust opacity at soft X-ray energies. The galactic dust-to-gas ratio predicts nonnegligible opacity below 1 keV for the amount of extinction discussed above. If the dust composition and grain-size distribution is similar in QSOs, then such X-ray opacity could be detected. This paper does not intend to answer all these questions but to point out that they should be investigated in view of the new evidence for reddening. Finally, few well-studied quasars show clear indications of continuum reddening (Smith and Spinrad 1980), and their further study will help to clarify this issue for other, not so clear-cut, cases.

c) Cosmological Implications

Bechtold *et al.* (1984) proposed that the steepening of the UV continuum is due to intervening material, most likely the low column density end of metal-containing absorption-line systems. Galactic halos seem to be the most likely explanation. The correlation they found, between the change of spectral index at 1200 Å and $(1 + Z)$, supports this idea. They also found very little intrinsic reddening: $E(B-V) \leq 0.05$, and they discussed the suggestion by Ostriker and Heisler (1984) of intergalactic dust, which they do not consider plausible on the ground of the large amount of gas that should be associated with it. The intergalactic dust idea is in fact in conflict with observations of quasar emission lines. For example, the Lyα/Hα ratio is similar in high- and low-redshift quasars (e.g., Allen *et al.* 1982), and there is no indication of any line ratio dependence on redshift. The idea of dust in the intervening galaxies should be further investigated since this may be a probable location, provided the gas is highly ionized.

If the observed continuum steepening is due to dust or intervening gas or both (which is probably the case), the effect is most noticeable at shorter wavelengths. Absorption by dust is likely to increase with decreasing wavelength down to some (yet unknown) wavelength below 900 Å, so the region below $\lambda \sim 500$ Å will be extremely difficult to observe. If several intervening systems are present, each with $\tau(912\ \text{Å}) \approx 0.1$, then there are other opacity sources due to them. In particular, the He I and He II absorption edges, at 1.8 and 4 R, respectively, must be considered. The state of ionization of the intervening gas is now known, but one of these edges is likely to be more pronounced than the hydrogen edge at 1 R. For relatively low degrees of ionization, $\tau(1.8\ \mathrm{R}) > \tau(1\ \mathrm{R})$, and for very high ionization, $\tau(4\ \mathrm{R}) > \tau(1\ \mathrm{R})$. Thus, the material absorbing the quasar Lyman continuum is likely to absorb even more efficiently at shorter wavelengths. It is possible therefore that no radiation of rest wavelength shorter than the corresponding helium edges will ever be detected.

Much intrinsic reddening could completely obscure from view quasars with very high ($\gtrsim 5$) redshift and much of the energy of those with $Z \sim 4$. If intervening material is the main cause of the observed continuum steepening, then the short-wavelength spectrum of *all objects* in the universe with $Z \gtrsim 5$ may never be observed. There may not be too much to see at those redshifts, especially if galaxies have been formed at $Z < 5$, but it is important to recognize this as a real limit.

V. CONCLUSIONS

New observations and line measurements in quasars present a severe energy budget problem and a challenge to present models of such objects. The observed ultraviolet continuum is too faint and too steep to produce the observed emission-line flux, if no or very little reddening is present. Putting it differently, the energy of the mean ionizing photon must be much larger than observed. The assumption of no reddening in the lines leads to a complete change of view of these objects and suggests extremely high densities or very large column densities. Emission-line reddening helps to ease this problem but suggests from equivalent width considerations that the intrinsic 1200 Å continuum is brighter than observed. Continuum reddening and/or special geometry could explain this. These new ideas have important implications for the physical conditions in quasars and the visibility of all objects with $Z \gtrsim 5$.

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