THEORETICAL STUDIES OF THE LINE EMISSION SPECTRUM

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ABSTRACT. Our knowledge of the physical conditions and of the structure of the broad line emissive region -the BLR- is reviewed. First we derive the model independent constraints on the different zones emitting the broad lines. Then we discuss photoionized models. In a first step the BLR is assumed to be made only of one type of cloud emitting all the broad lines. We show that this model is unable to explain the observed spectrum. We thus assume that the high and low ionization lines are emitted by different clouds, still photoionized. This assumption is also in contradiction with the observations and we are led to the idea of a large variety of emitting clouds. Finally the hypothesis of a purely radiative heating mechanism should also be questioned.

In this review, I will consider only the broad emission line region (BLR), the main reason being that the BLR lies very near the centre, so any information concerning its structure, dynamics and kinematics, abundances, mechanism of heating, is important for our understanding of the central engine. Nevertheless one must not forget that the physics and kinematics of the narrow line region may be linked in some sense with that of the BLR. Due to the lack of space, I will concentrate on the methods which are used in the computation of line intensities (dropping the studies of line profiles).

In spite of considerable progress in the last decade, many problems concerning the BLR remain to be solved, and the areas of controversies are still numerous. So my aim will be to summarize which conclusions can be taken for granted, and try to show that some of the most widespread ideas concerning the BLR are in fact not firmly established. The plan is as follows : section 1 gives an outline of the overall properties of the BLR, i.e. its structure and physical properties as they can be deduced almost directly from the observations. Section 2 presents a review of photoionized models, of line excitation mechanisms, and a discussion of some related problems. Some conclusions are given in the third section.

I. General properties of the BLR (non model-dependent)

In the following, I shall refer to "high ionization lines", HIL, for $L\alpha$

G. Swarup and V. K. Kapahi (eds.), Quasars, 295–306.

and CIII], CIV, HeI, HeII, NV, OVI lines and to "low ionization lines", LIL, for Balmer, MgII, CII, FeII lines. A fundamental idea of my talk will be to relax the generally accepted assumption of a unique emitting region for these two kinds of lines. Indeed, B. WILLS has shown in her talk, on the basis of kinematical arguments, that the LIL and HIL are most probably emitted by different regions. In the following I will show that similar conclusions can be reached using physical arguments derived from photoionized models : in fact, there is probably a large range of physical conditions in the regions producing the different lines.

I.a. electron density, n_e

The absence of a broad component in the forbidden lines is interpreted as due to collisional de-excitation so that n_e must be greater than 10^7 cm^{-3}. On the other hand, the presence of the broad semi-forbidden CIII] 1909 line (which starts being de-excited at $n_e > 10^9$) implies $n_e < 10^{10}$ cm^{-3} in the HIL region. More refined arguments based in particular on HeI line intensities suggest a value in the range 10^9-10^{10} cm^{-3} (cf the review of DAVIDSON and NETZER 1979, for instance). However, if the assumption that all the HIL including the CIII] line are emitted by the same region is relaxed, then the upper limit on the density is higher : the critical density of a given line depends on the optical thickness. For instance it is $\simeq 10^{12}$ cm^{-3} for $L\alpha$ if it is produced in clouds which are optically thick to the Lyman continuum and it can even be higher if $L\alpha$ is emitted by optically thin clouds.

I.b. temperature, T_e

There is no direct way to know T_e in the BLR contrary to the NLR, except when both the lines CIII]1909 and CIII]977 are observed. In this case the ratio of these lines always indicates that T_e<30000 K. This is not enough to produce C^{++} by collisional ionization so that ionization is definitively radiative in the HIL region.

I.c. overall dimension, R

An upper limit to the size of the BLR can be set from the variation time scale of the emission lines ; this method is obviously restricted to dimensions of a few light years at most, which is the case of Seyfert galaxies : .01<R<.1 pc.

I.d. ionization parameter, U

This parameter is defined as the ratio of the ionizing photon number density to the electron density : if the emitting region with an electron density n_e is located at a distance R from a continuum source of luminosity $L\nu$ at the Lyman edge, U is equal to $L\nu/(\alpha 4\Pi R^2 hcn_e)$, α being the spectral index of the Lyman continuum (notice that different definitions of U are used in the literature). In the case of a radiative ionizing mechanism -i.e. in the HIL region- it is this parameter which determines the degree of ionization of the elements. The computation of detailed "photoionized models" can provide the line intensity ratios as functions of U. In particular, the line ratios $L\alpha$/CIV 1549/CIII]1909 indicate $U \sim 10^{-2}$ in most objects (cf. DAVIDSON and NETZER, 1979). Although this result is not obtained directly from the observations it can be considered as firmly established, if all HIL are produced by the same region, since it depends only weakly on future improvements possibly introduced in photoionized models and on the yet unknown parameters -column density, spectral shape - (cf. below). An immediate deduction from the observed or extrapolated value of L_ν is the size of the emitting region, R, $\simeq$.1 to 1 pc for Seyfert galaxies, $\simeq$1 to 10 pc for quasars. This value is larger in Seyfert galaxies than the value deduced from the variation time scales, especially for high ionization lines (CIV, HeII): it means that in fact all HIL are not produced by the same region and that, at least in these objects, the highest ionized lines are emitted closer to the central source.

The remarquable constancy of the ionization parameter has impelled an important discussion. It can be well explained in the framework of the 2-phase model of KROLIK, McKEE and TARTER, 1981: these authors assume that the BLR is made of small dense clouds confined by the external pressure of a hot dilute medium. KROLIK et al have shown that, owing to a thermal instability, the two phases can coexist only for a small range of radiation-to-gas pressure ratio corresponding to the "measured" value of U. From the comparison of the intensity ratios Lα/CIV/CIII] observed in a number of quasars and AGN with those computed in a grid of photoionized models, MUSHOTZKY and FERLAND, 1984, have shown that the ionization parameter decreases as the luminosity, $U \simeq L^{-0.25}$. This decrease would be the cause of the well-known BALDWIN effect. (Notice that recently NETZER, 1985a, has suggested another interpretation of the BALDWIN effect which could be due to the different contribution of the continuum emission of an accretion disk, when viewed at various angles of sight). Finally FERLAND and ELITZUR, 1984, have shown that the value of U depends, through the line radiation pressure, on the density and on the column density of the emitting gas: clearly there is a strong link between the dynamical and physical state of the emitting gas which is not yet understood and deserves further studies.

I.e. covering factor, $\Omega/4\Pi$

This parameter represents the fraction of the continuum source covered by the BLR. From direct observations of Lyman discontinuity in high redshift quasars as well as from detailed photoionized models, it is generally concluded that the covering factor is small, $\simeq$.03 to .3. However it could be of the order of unity in NGC4151 (cf FERLAND and MUSHOTZKY, 1982) and more generally in low luminosity objects.

I.f. abundances and dust

Photoionized models are consistent with heavy element abundances in quasars being equal to the cosmic ones (cf. for instance GASKELL, SHIELDS and WAMPLER, 1981). However a factor $\simeq$3 discrepancy is not excluded. These last authors conclude that dust exists in large amounts. In any case, if dust were present inside the BLR, it would be heated by Lα and X-rays to a temperature larger than 500K and would radiate in the near IR range (RUDY and PUETTER, 1982). On the other hand, the presence of a large amount of dust surrounding the BLR is a subject of controversy on which I will come back in the next section.

I.g. geometrical structure

It is widely admitted that the BLR is made of a large number of high

velocity clouds which fill only a small fraction, f, of the emitting volume ($f \simeq 10^{-6}$, from our previous estimation of R, and using the observed luminosity of $L\alpha$, which is about equal to a pure recombination case B). The reasons of this consensus are: the great widths of the lines, due to Doppler motions (although a broadening due to electron scattering is not excluded in the wings), the absence of broad absorption with P-Cygni profiles due to an emitting-absorbing continuous medium, like in BAL quasars, (contrarywise, the narrow absorption components observed in the line wings of some Seyfert nuclei indicate that the velocity dispersion or the "turbulent" velocity inside a given cloud is small, as it can also be inferred from dynamical arguments), the overall size of the BLR, as compared with the effective emitting volume, and the irregularities of the profiles in some objects (which actually can also be due to temporal variations of the ionization rate in a continuous medium).
One can get around any of these arguments, by assuming for instance a disk shaped structure whose emitting region is confined to a thin outer shell. In any case a most important parameter of these models is the column density, N, of the emitting region in the direction of lowest size. If one assumes that all the lines are emitted by the same clouds detailed photoionization computations (KWAN and KROLIK, 1981) show that N is limited to the range 10^{22}-$10^{23}cm^{-2}$.

II. Detailed computations: photoionized models and line excitation mechanisms

II.a. photoionized models

Let us compute different time scales implied by the physical conditions of the BLR:
1-ionization time scale: (flux of ionizing photons x absorption cross-section)$^{-1} \simeq 10^{-2}$s
2-cooling time scale: n_e x kT/(rate of cooling $\simeq 10^{-23} n_e{}^2$) $\simeq 10^2$s
3-recombination time scale: (n_e x rec. coef.)$^{-1} \simeq 10^4$s
4-dynamical time scale: thickness of the cloud/sound velocity $\simeq 10^6$s
5-life-time: it is not known in general but in several dynamical models proposed for the BLR it is of the order of R/(macroscopic velocity)$\simeq 10^8$s.
From the comparison of these time scales, it is clear that the BLR clouds are in thermal and ionization equilibrium. Pressure equilibrium should also be achieved unless variations of the ionizing flux take place in a time smaller than about one week. Therefore the BLR can be described by clouds or shells in thermal, ionization and pressure equilibrium, photoionized by an external source of UV and X-ray continuum: we shall call hereafter the computation of such a model a "photoionized model" (sometimes constant density is assumed instead of pressure equilibrium).
The parameters needed to build a photoionized model are: the ionization parameter U, the density n, the column density N, the spectral shape of the continuum, the chemical abundances, the velocity dispersion.
The first models (cf the extensive review of DAVIDSON and NETZER, 1979) were mainly similar to models of planetary nebulae, except that they had a harder ionizing spectrum, which induces a mixing of many stages of ionization, and a higher density. They produced hydrogen line ratios very near to the pure recombination values case B, except for a small increase

of the Balmer decrement due to the influence of collisional excitations when the density was large enough ($\simeq 10^9$). In particular the ratio Lα/Hβ was $\simeq$ 40

Then BALDWIN (1977) discovered that the observed Lα/Hβ is $\simeq$ 5 in quasars and this was found later on, with IUE observations, to be also the case in Seyfert nuclei. Corrected for galactic extinction Lα/Hβ is $\simeq$ 10. Actually since 1975, several works aiming at computing the HI spectrum in conditions of high density and large optical thickness, have drawn the attention to the fact that line ratios are very different from case B: in particular, Lα photons are destroyed by collisions during the many diffusions they undergo (we shall say that Lα is thermalized), while Balmer photons are actively produced by collisional excitations from the second level (which is then in thermodynamical equilibrium with the first level). These computations were made for an homogeneous shell with given temperature and density, using a "mean escape probability", p_e, which is the probability that a photon created at the center of a shell escapes outside. Finally, FERLAND and NETZER, 1979, and KWAN and KROLIK, 1979, using p_e as a local quantity and taking into account the ionization from excited HI-levels, produced the first photoionization models really adapted to the BLR (the previous high density models can be however considered as being good for the HIL).

The difficulty of the problem lies in the particular structure of BLR clouds. Each cloud consists of 3 different regions: facing the continuum source is a highly ionized region -the HII zone-emitting Lα and the OVI, NV, CIV, CIII, HeII, HeI lines; its column density is about 10^{23}U. The far side possibly consists of a completely neutral and cold region. In between there is a partially neutral gas (the degree of ionization running from .5 to .01), relatively warm (5000 to 8000 K), which we call the excited HI zone - the HI* zone-emitting the MgII, FeII, CII lines and the bulk of the Balmer lines: in this zone, which is heated by the X-ray continuum, trapped Lα photons insure a high population of the second level of HI, and the gas is ionized by the incident Balmer continuumn, by collisions due to thermal electrons (from the excited HI levels) and/or due to high energy non thermal electrons (produced by inner shell photo-ionizations of heavy elements, as stressed first by WEISHEIT, SHIELDS ans TARTER, 1981).

One should realize that they are many unknown parameters in this study, so the uniqueness of any solution is controversial.

First we have to ask what is the real intrinsic broad line spectrum ? Are there good reddening indicators ? We have seen that HI line ratios are strongly model-dependent. The narrow lines cannot be used since the reddening of the BLR and NLR are not necessarily the same. The intensity ratio OI 1302/8446 which is generally taken as a constant, because these lines are issued from the same level, is modified by fluorescence processes in a thick shell (cf GRANDI, 1983). The only potential reddening indicator is the intensity ratio HeII 4686/1640 (cf NETZER et al, 1985) but there are only very few observations of this ratio. On the other hand, the 2200A feature which is also a potential reddening indicator, is always weak in quasar spectra.

KWAN and KROLIK, 1981, have shown that a model called by them "Standard Model" fits roughly an average quasar spectrum. In this model the HII and HI* zones have respectively a density of 4 10^9 and of 2 10^{10} cm^{-3}, and a thickness of 10^{12} and 5 10^{12} cm. It has largely been adopted in the literature to represent a standard BLR cloud. They were followed by different computations aiming at finding the best parameters accounting for the BLR spectrum of a given object (FERLAND and MUSTHOTZKY, 1982, for NGC 4151, NETZER, WILLS and WILLS, 1982, for 3C351). BOLDT and LETTER, 1984, computed models for flat UV and X-ray spectra assumed to represent young quasars, MARTIN and FERLAND, 1980, studied the influence of dust, NETZER, 1980, WILLS, NETZER and WILLS, 1985, COLLIN-SOUFFRIN et al, 1985, produced models trying to fit the observed FeII spectrum, Mac Alpine, 1981, and NETZER, ELITZUR and FERLAND, 1985, discussed the HeII problem. Kwan, 1984, has produced the most extensive grid of models and given some useful spectral diagnostics for physical parameters. However his results should be taken with some caution because he restricted himself to a peculiar spectral shape which overestimates the X-ray flux with respect to the optical and UV flux, and also because his results for large column densities are uncertain.

II.b:the transfer problem

There has been a great debate these last years concerning the use of the escape probality formalism in conditions of finite but very high optical thickness (the optical thickness of Lα reaches 10^{10} and that of Hα 10^5 ; even the Balmer continuum may have an optical thickness larger than one). CANFIELD and PUETTER, 1981, CANFIELD, PUETTER and RICCHIAZZI, 1981a and 1981b, PUETTER et al, 1982, HUBBARD and PUETTER, 1985, have extensively discussed the ability of escape probability to account for non local effects in radiative transfer and they have proposed a more elaborate probabilistic method. Unfortunately for now their method has been applied only to a pure hydrogen cloud, so temperature gradients are not consistently computed. On the other hand, COLLIN-SOUFFRIN et al, 1982, and COLLIN-SOUFFRIN and DUMONT, 1985, have compared the escape probability formalism to the exact transfer treatment in the case of BLR clouds and shown that it gives good results (within 50% for most of the line intensities) provided that it is used correctly : in particular if the Balmer continuum has a non negligible thickness, a method developed by ELITZUR and NETZER, 1985, for line fluorescence, and extended to the case of the overlapping of lines and continuum by NETZER, ELITZUR and FERLAND, 1985, is very appropriate . (Notice that line fluorescence processes are common in the formation of broad line spectrum : OI 8446 is formed through Lα fluorescence (cf NETZER and PENSTON, 1976, and GRANDI, 1981 and 1983), OIII Bowen lines through HeII fluorescence (cf NETZER et al, 1985), and highly excited FeII lines through resonance FeII lines (cf NETZER and WILLS, 1983)). However a large incertainty (by a factor 2 or 3) remain on the intensities of resonance lines emitted by the H I* zone, such as MgII 2800, until realistic generating functions are proposed for these photons from exact transfer calculations. Finally the transfer of the diffuse Balmer continuum should be solved exactly in order to compute correctly UV line intensities. Note that the constraint found by KWAN and KROLIK on the column density from the ratio CII 2326/Lα,N<10^{23} is not valid because the line 2326 is reabsorbed in the HI* zone by ionizing excited HI atoms (cf COLLIN-SOUFFRIN et al, 1985).

Another problem tighly linked with transfer is the anisotropy of the emitted radiation, stressed by FERLAND, NETZER and SHIELDS, 1979 : due to their different depths of formation, the line intensities depends on the angle between the surface and the direction of emission, like in a stellar atmosphere. COLLIN-SOUFFRIN et al, 1985, have shown that the anisotropy could be very large for some lines, namely that Lα, FeII UV multiplets, MgII 2800, are emitted preferentially towards the ionizing source, but that unfortunately this effect is strongly model-dependent. It will clearly be a very large factor of uncertainty in the computation of line spectra or of line profiles in a kinematic model.

II.c:comparison of computed and observed line ratios

As a matter of fact, all the models produced so far fail to account for at least some features (which might be of fundamental importance). Let us for instance consider the Standard Model, which fits best the overall features of an average quasar :

- the ratio CIII]1909/CIV1549 is too weak. It means that the density of the HII zone is too large.
- the ratio Hα/Hβ (which is actually slightly larger than computed by KWAN and KROLIK, owing to their escape probability approximation) is too large. It means that the density of the HI* zone is too small, (cf the discussion of COLLIN-SOUFFRIN, DUMONT and TULLY, 1982).

In other words, HIL and LIL should be emitted by different clouds, HIL by clouds having n_e<2 10^9 and small column densities (<10^{23}U) and LIL by clouds having n_e>10^{10} and much larger column densities.

- the lines of highest ionization, OVI, NV, HeII, are too weak ; the problem of the OVI and NV lines cannot be solved in the framework of a one component model for HIL - i.e. only one type of clouds -, as was already noted by DAVIDSON in 1977 : clouds with a larger ionization parameter are required (more dilute or closer to the source of continuum) or clouds with a small column density (<< 10^{23}U). The problem of the HeII line spectrum has been debated (Mac ALPINE, 1981) but it seems now well understood with the improvements in the computation of the ionization and thermal structure of the He^{++} zone (NETZER et al, 1985).
- the FeII lines are too weak. The "FeII" problem has raised up a strong controversy. The FeII spectrum consists of numerous UV and optical blends which carry about 1/4 of the whole broad line luminosity. PHILLIPS,1978, proposed an excitation by a continuum fluorescence but COLLIN-SOUFFRIN et al, 1979, 1980, and GRANDI, 1981, showed this mechanism to be insufficient and suggested a collisional excitation in a relatively hot (T ≃ 10000K) gas. NETZER, 1980, included FeII for the first time in a photoionized model. JOLY, 1981, using a sophisticated atom (14 levels) showed that the FeII excitation requires a temperature > 10000K and a high electron density ≃ 10^{11} cm : such values seemed difficult to reach in the HI* zone of a photoionized model. COLLIN-SOUFFRIN et al, 1982, considering that the intensity ratio (FeII lines/HI lines) was too weak in existing photoionized models suggested as well as later CLAVEL et al, 1983, that the BLR contains a non radiatively heated dense region producing mainly FeII lines. NETZER and WILLS, 1983, and WILLS et al, 1985, considered a very elaborate FeII atom, including more than 3000 lines, taking into account the fluorescence processes between all the lines and introduced this atom in a photoionization computation. Then, by

synthetizing a whole broad line spectrum and comparing it to the observations, they put into evidence what they called a"Lα/FeII problem", namely that the computed FeII line intensities were too weak by a factor 3 with respect to Lα in any photoionized model. COLLIN-SOUFFRIN et al, 1985, tried an ultimate experience : assuming particularly favorable conditions for the emission of FeII lines (a large flux in hard X-rays, very large column density and density) they computed several photoionized models, none of which gives a sufficient energy in FeII lines emitted in the optical range compared to Hβ, still by about a factor 3 (notice for the further discussion on the energy budget that this conclusion is independent of the assumed reddening). A last possibility in the framework of a radiative heating is a Compton heated cloud if there is a very intense flux of γ rays : this possibility has not yet been explored. FERLAND and MUSHOTSKY, 1984, have also proposed cosmic ray heating. Other possibilities, such as the emission of a disk atmosphere, could also be explored.

II.d:the energy budget problem

NETZER, 1985b, has pointed out an important problem concerning the energy budget of the BLR : the total observed luminosity of the BLR amounts to 8 Lα (taking into account the bound-free and free-free emission). Assuming a column density $N = 10^{23}$ cm^{-2} and a power law spectrum in the range 200 eV to 40 keV having the average observed slope of .7, he computed the ratio of the total luminosity to Lα, as a function of the spectral index α in the range 13.6 to 200 eV and he found that the observed ratio corresponds to $\alpha \simeq .4$, in clear contradiction with the observations which give $\alpha \simeq 2$. To reduce the discrepancy, NETZER proposed : i. that the BLR spectrum is reddened so the intrinsic ratio is lower than the observed one; for instance E(B-V) = .2 gives an emitted ratio of 3.4 which corresponds to $\alpha = 1.$; besides, ii. that the ionizing continuum itself is also reddened and/or intrinsically more brighter than the observed one owing to a special geometry (if it is due to the surface emission of a disk for instance).
However I would like to propose an alternative solution. Actually the total observed luminosity of the BLR is shared between the HIL (2.7 Lα) and the LIL (5.2 Lα), the latter consisting of FeII emission (1.7 Lα) and the other lines and continua (3.5 Lα). Assuming a small amount of reddening (E(B-V) = .1) it is easy to account for the HIL luminosity with a relatively steep index $\alpha = 2$. For the LIL we have two possibilities. We have seen that the medium emitting the FeII lines should be heated by a non radiative mechanism. So it would be a natural solution to assume that all the LIL or at least a non negligible part of them are emitted by this non radiatively heated medium. It is also possible that only the FeII lines are emitted by such a medium. In this last case the other LIL could be produced in clouds of very large column density, $N \gg 10^{23}$ cm^{-2} which are able to absorb high energy X-rays, $h\nu \simeq 10$ keV. However in order to be efficient enough without producing hard X-ray absorption in the observed continuum, these "clouds" should have a special geometry, for instance a disk illuminated from above.

III. Conclusions

It is clear from the previous discussion that no firm conclusion concerning the structure and even the physical parameters of the BLR can be drawn from the computation of photoionized models alone : we can only ascertain that there is a large range of physical parameters in the BLR, from low density and/or column density clouds emitting lines of the most ionized species up to large density and column density clouds emitting the LIL, and there are good reasons to think that the LIL or at least the FeII lines are emitted by a non radiatively heated region. To better understand the situation, other constraints should be introduced :
i. from dynamical arguments concerning for instance the structure and the evolution of the clouds. This will be the subject of the talk of J. PERRY;
ii. from kinematical models built to fit the line profiles.
A considerable amount of work which cannot be reviewed here has been recently devoted to the computation of line profiles. They deal with different kinematics - rotation, radial outflow or inflow - and use different descriptions of the line emission which is generally parametrized as a function of the distance to the center. An important problem is the anisotropy of the emission, mentioned previously. Unfortunately no clear conclusion is yet reached since every model is able, according to the choice of some arbitrary parameters, to give results in agreement with the observations (logarithmic profiles, asymmetries...). It seems nevertheless that the most satisfactory results are obtained by assuming that rotation (or bound orbits) and radial outflow are both present. A complete self consistent description would require a dynamical model able to relate the velocity field to the matter distribution and to the physical parameters of the clouds and to compute simultaneously the - anisotropic - line emission of each cloud, a real Titan work ! Actually a most powerful potential tool which can avoid such an effort would be to reduce the free parameters by detailed and very accurate observations of line profile variations.

Acknowledgments : I gratefully aknowledge G. Stasinska for a careful reading and critical discussion of the manuscript.

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https://doi.org/10.1017/S0074180900152891 Published online by Cambridge University Press

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https://doi.org/10.1017/S0074180900152891 Published online by Cambridge University Press

DISCUSSION

Saslaw : Recently Mark Whittle and I have been calculating emission line profiles for the broad line region of AGN. We have been particularly interested in the effects on line profiles of including distributions of cloud properties (such as radii, velocities and masses) in any region of the nucleus. For any given model, these distributions are derived by injecting an initial distribution of clouds and following their thermal and mechanical evolution along their resulting trajectories. We have developed an analytical technique which provides insight into simple models, and have computed more complicated models numerically. The results show that the dispersion of cloud properties in any region can alter the line profiles substantially compared to the case where all clouds in the region are represented by their mean properties. The ratio of flux in the core to that in the wings is especially sensitive to the cloud distribution. The moral seems to be that it will require a much better detailed understanding of gas dynamical processes as well as observations of many line profiles with high spatial resolution to constrain models usefully. It is usually easy to fit one or two profiles of an AGN reasonably well, but much more difficult to fit the whole gamut with physically self-consistent cloud distributions.

Malkan : You mentioned the observation of Netzer and Wills, that FeII UV lines seem to make a surprisingly high fraction of the BLR output, and the total energy is so high, it could require a rather flat FUV continuum. I would just like to warn that measuring the flux of these low-contrast FeII lines is very tough.When we draw in a curved (thermal) UV continuum we measure FeII to be much weaker (a factor of 2 or more). So it may still be too soon to be sure that the "FeII problem" is as serious as they have suggested.

Wills : One can reduce the measured strength of Fe II + Bac lines may be by 20% (or even 30% in a few cases) if the continuum underneath the FeII is like that from an accretion disk with a narrow range of temperature. Such a (relatively) narrow peaked disk distribution seems unlikely, although more theoretical work on the expected emergent continuum is needed. More likely there is a very broad peak to any disk component, which will not alter the measured FeII + Bac significantly. The observed continua may not even require a disk component at all, but just a steepening component in the IR and a flatter component in the optical-UV region.

Kembhavi : (1). It has been reported that the soft X-ray spectra of radio quiet quasars are harder than those of radio-loud quasars. Could this fact be used to explain some of the differences in the emission line spectra of these objects ?

(2). It has been suggested that most quasars are radio-quiet because the radio emission is absorbed by clouds very close to the continuum emitting region. Could such a model be constrained using emission line observations ?

https://doi.org/10.1017/S0074180900152891 Published online by Cambridge University Press

Collin-Souffrin : (1). Up to now, there have been no suggestions made to attribute the differences between emission line spectra of radio quiet and radio loud quasars to their different X-ray spectra. It should be looked at in the future. To my knowledge, the only explanation, concerning the weakness of FeII lines in radio loud objects, has been proposed by Ferland and Mushotsky (1984): they suggest that an extra heating due to cosmic rays - related to the presence of a radio source - quenches the FeII lines.

(2). On the otherhand, Krolik, Tarter and McKea (1981) have suggested that the extra heating due to the absorption of radio emission could lead to the suppression of the thermal instability which is at the origin of the two phase-medium in some objects containing very compact radio sources (BLLac objects for instance). This could cause the disparition of the BLR.

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