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NARROW EMISSION LINE REGION OF ACTIVE GALACTIC NUCLEI

Sueli M. V. Aldrovandi
Instituto Astronômico e Geofísico, USP
Brasil

ABSTRACT: An overview of theoretical models for the narrow emission line region of the active galactic nuclei is presented and their possibility to account for the observations is discussed.

Key words: active galactic nuclei, emission line region, theoretical model

I. INTRODUCTION

In the last years a variety of galactic nuclei has been observed and classified as active galactic nuclei (AGN). All of them show an energy output not usually associated with normal stellar processes and centered in a small nuclear region. Seyfert galaxies (Sy) are the most frequent type of galaxies with active nuclei, but this class also includes radiogalaxies (RG) and quasi-stellar objects (QSO). More recently, the X-ray narrow line galaxies (NLXG) and the low ionization emission region galaxies (LINERS) have also been classified as AGN.

From the spectroscopic point of view, these objects are characterized by a continuum, observable in nearly all wavelength bands from radio to X-ray, emission lines and, in some cases, absorption lines. This review paper will concern with the emission lines, formed near the central region, and the continuum radiation which can give information about the nature of the energy source. Absorption lines can be produced outside the AGN, and their analysis is not within the scope of this paper.

The continuum is generally represented by a power law of the $F_\nu \propto \nu^{-\alpha}$, but some recent data seem indicate that a power law can only partially fit the spectrum (Neugenbauer et al., 1979; Malkan, 1983).

The emission lines have been extensively observed. Line profiles of AGN can show full width at half maximum of about 1000 Km s^{-1} to 500 Km s^{-1}. Broad permitted emission lines are characteristic of Seyfert type 1 nuclei (Sy1) broad-line radiogalaxies (BLRG) and QSOs, though narrow lines appear also in their spectra. The remaining AGN, Seyfert type 2, narrow-line radiogalaxies (NLRG), NLX and LINERS show only the narrow-line component which includes both permitted and forbidden lines. It was suggested that the broadening of lines is chiefly due to mass motions (Osterbrock, 1978), but its origin is still unkown.

The next sections will be devoted to an overview of theoretical models for the narrow emission line region of the AGN, their possibility to account for the observations and the importance of a good determination of the UV continuum.

II. PHOTOIONIZATION MODELS

From the observed [OIII] line intensity ratio, the narrow emission line region (NELR) of the AGN has a temperature, T, of the order of 1-2 x 10^4 K. Concerning the electron density, the [OII] and/or [SII] line ratios indicate $n_e \geq 10^3$ cm^{-3}, and the presence of several forbidden lines tell us that $n_e < 10^7$ cm^{-3}. Such physical conditions are also found in planetary nebulae and suggest that photoionization models could be adopted to fit the emission lines from the NELR. However, no collection of hot stars will give the observed line spectrum, composed by lines produced by ions in very different ionization stages. Moreover, the infrared and optical continua of AGN indicate the presence of a non-thermal radiation with a power law spectrum. Many authors tried to fit the observed emission line spectrum of the AGN to photoionization models, taking a power law spectrum for the ionizing UV radiation. Some of them consider the ionizing radiation with a high energy cutoff: $F_\nu \propto \nu^{-\alpha} \exp(-\beta\nu)$.

All these models calculate the emergent line spectrum from the NELR by solving the ionization equations of several elements coupled to the thermal balance. The input parameters are: elemental abundances, hydrogen density and the ionizing radiation spectrum. Its is customary to define the ionization parameter (Davidson, 1972).

$$U = Q/(4\pi R^2 n_e) \qquad (1)$$

with Q being the number of ionizing photons with energy E > 13.6 eV, R the distance of the NELR from the central energy source, and n_e the electron density.

From (Eq. 1), it can be seen that the ionization parameter is related to the hydrogen ionization rate, and, so, to the H^+/H^0 ratio; U gives the speed of adjustment between recombination and ionization times (Netzer, 1983). For NELR, $10^5 < U < 10^9$ cm s^{-1}.

The first theoretical models roughly described the narrow emission line spectrum of the AGN (Davidson, 1972; MacAlpine, 1972; Shields, 1974; Shields, Oke, 1975). However the theoretical [OII] λ3727 intensity was always too small. It must be noted that the same problem occurred with models of planetary nebulae. The problem was solved taking into account the charge transfer reaction $O^{++} + H^{o} \rightarrow O^{+} + H^{+}$ in the oxygen ionization equations (Pēquignot et al., 1978; Butler, Dalgarno, 1980).

More recent photoionization models includes the charge transfer reactions for several ions (Ulrich, Pēquignot, 1980; Aldrovandi, 1981; Halpern Steiner, 1983; Ferland, Netzer, 1983), and also the dielectronic recombinatio at low temperature (Nussbaumer, Storey, 1983; Pēquignot, 1984; Stasinska, 1984 a,b).

Some of the models cited above were constructed to fit the emission line spectrum of a given AGN, the other papers give a grid of models, by varying th input parameters, in order to describe a large sample of objects having simila characteristics. In any case, it seems to be necessary to consider the theoretical emission line spectrum produced by several emitting clouds (Pēquignot, 1984; Stasinska, 1984b). At least two components are needed: a low density cloud ($\sim 10^{3}$ cm^{-3}) to allow for the emission of nebulae lines and a high-density ($\sim 10^{6}$ cm^{-3}) cloud where auroral lines are enhanced. High dispersion observations show that the line profiles have a composite structure corroborating that the narrow emission lines come from different filaments with different velocities (Pelat, Alloin, 1981).

Even considering that the NELR is composed of several filaments, there are some problems with photoionization models: (a) [OII]λ3727 line intensities are too small, (b) it is difficult to explain a large [NI]λ5199/ [NII] λλ(6548 6584) ratio for objects with small [OI]λλ(6300+6364)/ [OII] λ3727 and (c) the large scatter in the observed HeIλ5876/Hβ ratio (Stasinska, 1984b). These models were constructed with the input parameters varying in a large range: $10 < U < 10^{8}$ cm s^{-1}, $n_e = 10^{3}$, 10^{6} cm^{-3}, $\alpha = 1, 1.5$ and 2. It must be noted that if the line broadening is due to motion of the emitting filament ($v \lesssim 500$ km s^{-1}) through a dilute medium ($n_H \sim 300$ cm^{-3}), the physical conditions of the gas cloud are determined by the effect of the shock front, rather than by photoionization, for $U < 10^{7}$ cm s^{-1} (Contini, Aldrovandi, 1983).

Concerning the ionizing radiation spectrum, a single power law can not account for all emission features, particularly for HeIIλ4686/Hβ ratio, and a black-body spectrum (T > 50000K) with a soft X-ray tail seems to be more adequate (Pēquignot, 1984; Stasinska, 1984b).

III. COMPOSITE MODELS

The medium where the emitting filaments are moving is generally assumed to be a dilute hot gas, in equilibrium with the cool emitting line gas and heated by compton scattering of the X-rays from the central source or other processes (Krolik, et al., 1981). The filament motion through this dilute medium will provide the formation of a shock front at the leading edge of the filament. So, even if photoionization can account for many observed features, the effect of the shock must be considered.

On the other hand, several active nuclei present a compact radio source. The relativistic electrons, after emitting the synchroton radiation, can reach the line emitting filaments and contribute to the heating. This process could explain the temperature difference between Sy2 and NLRG (Cohen, Osterbrock, 1981).

From these facts it seems that models for the NELR must take into account the effect of shock waves and relativistic electrons besides photoionization. At present, such a model is not yet available in the literature. However, some results have been obtained for composite models including (a) photoionization and shock effects (Contini, Aldrovandi, 1983; Aldrovandi, Contini, 1984a,b hereinafter referred as Paper I, II and III respectively) and (b) photoionization and relativistic electrons (Cesar et al., 1984).

The model including both photoionization and shock effects consider a filament moving radially through a dilute gas. The ionizing radiation from the central source reaches the filament: (i) on the shock front edge, in the case of infalling matter, (ii) on the edge opposite to the shock front, in the case of ejection. Both cases were studied, since it is not clear if the filament motion is outwards or inwards.

Besides the input parameters of photoionization models, there are other two: the velocity of the filament, v_0, and the preshock density, n_0.

Considering the great number of observational data, the AGN, according to the emission line ratios, were distributed in 11 groups (Table 1, Paper I).

The infalling model (Paper I, II) showed that the narrow emission line regions of the AGN can be separated in two types: radiation dominated (RD) and shock dominated (SD) objects. For the RD nuclei, the ionization parameter is $5 \times 10^8 < U < 5 < 10^{10}$ cm s^{-1}, with $200 \leq v_0 \leq 500$ km s^{-1}, $n_0 = 300$ cm^{-3} and $\alpha = 0.5$ and includes objects of groups 1,2 and 6. Nuclei belonging to groups 5, 7, 8, 9 and 10 are SD type, with $100 \leq v_0 \leq 300$ Km s^{-1}; groups 0,3 and 4 are ambiguously identified as RD or SD types by the infalling model.

In the ejection case (Paper III), the ionizing radiation from the central source reaches the gas on the edge opposite to the shock front. For a given filament the gas zones facing the central source are ionized and heated by the central radiation and by diffuse radiation. On the other hand, zones facing outwards are compressed and heated by the shock and ionized by thermal collisions and diffuse radiation. An important point in this model is the role of the diffuse radiation which bridges the effect of the shock front on one side of the filament to the effect of the central radiation on the other side. For clouds with geometrical thickness less than 10 pc, the neutral zone inside the filament is very narrow, so that for objects presenting low ionization lines a geometrical thickness $\gtrsim$ 10 pc must be adopted. The objects of groups 0, 3, 4 are now well defined as RD nuclei. In fact, using the ejection model, groups 0, 1, 2, 3, 4 and 6 are RD objects, with $5 \times 10^7 < U < 5 \times 10^9$ cm s^{-1} and velocities $200 < v_o < 500$ Km s^{-1}, whereas groups 5, 7, 8, 9 and 10 were confirmed as SD objects. It must be noted that velocities $v_o \lesssim 500$ Km s^{-1} were deduced from observations for galaxies of groups 1 and 2 (Shuder, Osterbrock, 1981), and ejection velocities $v_o < 300$ Km/s were also reported by Heckman et al (1981).

Concerning the coupled effect of photoionization and relativistic electrons, a model considering a gas cloud optically thin to the central radiation showed that the effect of the relavitistic electrons can be important for $\phi/n_H \geq 10^4$ cm s^{-1}, ϕ being the relativistic electron flux and n_H the hydrogen density (Cesar et al., 1984). The optically thick calculations are now in progress.

In order to compare the different models, Fig. 1 gives an example of a diagnostic diagram, where theoretical results for [OII]λ3727/Hβ versus [OIII] λλ(5007+4959)/Hβ are plotted as well as the averaged values for groups 0 to 10. Thin lines refer to photoionization models (Stasinska, 1984a,b), and thick lines to composite models including photoionization and shock effects (Contini, Aldrovandi, 1983; Aldrovandi, Contini, 1984). The solid thin line corresponds to $n_H = 10^4$ cm^{-3}, with different U values, and dashed thin lines to photoionization models with different n_H values, for $U = 3 \times 10^6$ and 3×10^7 cm s^{-1}. Solid thick line refers to the ejection case, for $U = 6 \times 10^8$ cm s^{-1} and $200 \leq v_o \leq 600$ Km s^{-1}, and dotted dashed thick line to the infalling case, for $U = 5 \times 10^8$ cm s^{-1} and $1 - 200 \leq v_o \leq 2000$ km s^{-1}. The dashed thick line gives the results for the shock dominated case, for $100 \leq v_o \leq 600$ Km s^{-1}. Finally, dotted lines give the results for the composite model including photoionization (optically thin case) and relavitistic electrons (Cesar et al., 1984). Each curve correspond to a given value of U (1.5×10^7, 7×10^6 and 4×10^6 cm s^{-1}), with $10^4 \leq \phi/n_H \leq 3 \times 10^5$ cm s^{-1}.

In Fig. 1, it can be seen that photionization models could fit some groups, in particular group 8, which was classified as shock dominated, but U must be equal to 5×10^6 cm s^{-1}, and we know that the effects of a shock front becames important for $U < 10^7$ cm s^{-1}. On the other hand, the effect of relativistic electrons seems very important for groups 1, 2, 3, 4, 5, 6, 7, 9 and 10. Evidently, any conclusion depends on a more sophisticated analysis, including other diagnostic diagrams.

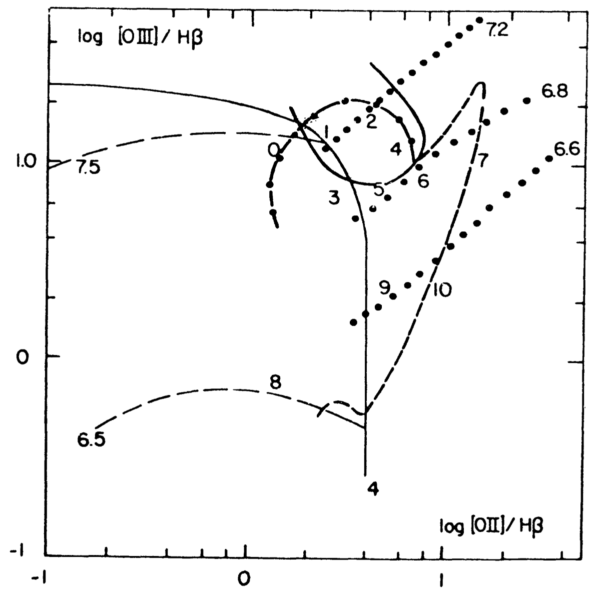

Figure 1 - [OIII]λλ(5007+4959)/Hβ versus [OII]λ3727/Hβ. Thin lines correspond to photoionization models: solid line is labelled by log n_H and dashed lines by log U. Thick lines correspond to composite model (photoionization and shock): solid line gives the ejection model results and dotted - dashed line refers to infalling model; dashed line correspond to shock dominated case. Dotted lines give the results of coupled photoionization and relativistic electrons effects, and are labelled by the corresponding log U values. The position of each group of galaxies is also indicated.

IV. FINAL REMARKS

All the models presented in this paper, which agree quite well with observations, indicate that elemental abundances are within a factor of 2 from the standard cosmic abundances.

Concerning the spectrum of the ionizing radiation, photoionization models point out that a hot black body with a soft X-ray tail gives a better fit to the observed narrow emission lines of several objects. A careful analysis of the observed infrared and optical continua indicate that a single power law is unsatisfactory (Neugenbauer et al., 1979). For some Sy1 and QSOs these continua are composed by a power law, $0.9 \leq \alpha < 1.1$, and a black-body with $25000 \leq T < 30000$ K (Malkan, 1983). A recent analysis for six Sy2 indicate that the observed infrared optical continuum agrees with a three-component spectrum: a power law spectrum, $0.9 < \alpha < 1.9$, a black-body with $T \sim 4000$ K and another cooler black-body $T \sim 200$ K (Lagua, Aldrovandi, 1984, in preparation). In these cases, for three objects the power law extrapolated to the UV region is sufficient to explain the Hβ luminosity as well as the HeIIλ4686/Hβ observed ratio. For the reimaning three objects, another component (perhaps a hot black body) is needed to match the emission-line observations. On the other hand, the component represented by the cool black-body (T $\sim$ 200 K) could be associated to dust. The presence of dust in the AGN is a controversial point. If present the effect on the emission-line models crucially depends on its location, distribution and composition.

Finally, it must be said that the choice among different models for the NELR depends on the intensity of weak lines like [OIII]λ4363, HeIλ5871, [NI]λ5199. If dust is taken into account these results can be completely modified. The ideal would be a model including all the mechanisms cited in this paper, coupled with a physical theory of the central radiation source, and which describes both the narrow and broad-line regions.

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Sueli M.V. Aldrovandi: Instituto Astronômico e Geofísico, USP, Av. Miguel Stefano, 4.200, CEP 04301, São Paulo, SP, Brasil.