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FE II EMISSION IN AGN

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RESUMEN

El espectro óptico de las galaxias Seyfert 1 muestra una gran variedad de líneas de emisión producidas por FeII. Damos tres ejemplos e investigamos la formación de estas líneas con el fin de determinar las condiciones físicas de las regiones en donde se emiten.

ABSTRACT

The optical spectrum of Seyfert 1s reveals a great variety of Fe II emission lines. We give three examples and investigate the formation of these lines in order to determine the physical conditions of the emission regions.

Key Words: galaxies: Seyfert

1. INTRODUCTION

A major characteristic of type 1 AGN is the emission of Fe II lines from UV to near IR. This Fe II emission is highly variable from object to object. The Fe II blend at $\lambda4570$ can be as high as several times Hβ (0< Fe II$\lambda4570$/Hβ <10), and the total strength of Fe II varies from zero to several tens of Hβ in different objects. In a few cases it is the strongest contributor to the line spectrum: it is the case for the ULIRG galaxy IRAS 07598+6508 (Boroson & Meyers 1992; Schmidt & Hines 1999; Lipari 1994; Ogle et al. 1999).

In spite of such a predominance, explaining this Fe II emission is still a problem.

2. THE EMISSION REGIONS

From line widths and correlations with other species we know that Fe II is emitted mainly in the BLR (cf. e.g. Sulentic et al. 2000) but it can be also emitted in the NLR, as was shown for example in the nucleus of I Zw 1 (e.g. Véron-Cetty et al. 2004).

In order to disentangle the different regions, a detailed spectrum analysis is necessary. All the emission lines must be identified and their line ratios measured. Such a study was carried out for I Zw 1 and IRAS 07598+6508 (Véron-Cetty et al. 2004, 2006). It shows that optical Fe II is emitted in regions as different as:

- The NLR of I Zw 1, a low-excitation region emitting a number of lines from neutral and single ionized atoms including H I, Ni II, Ti II, Si II, Cr II, [N II], [S II], [Ca II], [O I] in addition to permitted and forbidden Fe II lines, but no [O II] and [O III] lines.
Fe II$\lambda4570$/H$\beta_{\rm narrow}$ = 3.1; L($\lambda4570$) = 7.10^{41} ergs/s.
- The BLR of I Zw 1 emitting permitted lines of H I, He I, Na I D, Ti II, Si II, but no He II.
Fe II$\lambda4570$/H$\beta_{\rm broad}$ = 1.9; L($\lambda4570$) = 5.10^{42} ergs/s.
- The BLR of IRAS 07598+6508 emitting only H I, Ca II and Na I D, but no He I, He II. No NLR is detected.
Fe II$\lambda4570$/Hβ = 8.0; L($\lambda4570$) = 10^{43} ergs/s.

2.1. *The physical conditions in the NLR of I Zw 1*

From the intensity line ratios of the forbidden lines we can infer some characteristics of this emission region:

- [N II]$\frac{5755}{6548+6583}$ indicates that the electron density, n_e, should be larger than 10^5 cm^{-3} (if T $\sim$ 8000 K).
- [S II]$\frac{4069+4076}{6716+6731}$ suggests 10< n_e < 10^5 cm^{-3}.
- [O I]$\frac{5577}{6300+6363}$ rather implies $n_e \sim 10^7$ cm^{-3} (again if T $\sim$ 8000 K).
- Some forbidden lines such as [O I]$\lambda6300$, [N II]$\lambda5755$, [S II]$\lambda4072$, [Ca II]$\lambda7300$, [Ni II]$\lambda7400$ have high critical densities suggesting that n_e should be at least of the order of 10^6–10^7 cm^{-3}.
- The presence of permitted Fe II lines implies n_e > 10^6 cm^{-3}, while the presence of forbidden [Fe II] lines limits this density to 10^8 cm^{-3}.
- Finally the absence of [O II] and [O III] lines imposes a very low ionization parameter.

With such a range of parameters in mind, photoionization models have been computed using CLOUDY (Ferland 2002) with a low ionization parameters, U = 2.10^{-5}, a column density $\mathcal{N}_{\rm H} \sim 5.10^{17}$ cm^{-2} and an overabundance of iron by a factor of three.

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The models giving the best fits to the line intensities predict Fe II lines much too weak compared to the observed ones:
Fe IIλ4570/H$\beta_{\rm cal}$ = 0.30; Fe IIλ4570/H$\beta_{\rm obs}$ = 3.

2.2. *The physical conditions in the BLR of AGN*

From variability and reverberation mapping we have an insight on the size of the BLR (c.f. e.g. Kaspi et al. 2005): it is of the order of a few tens of light days, depending on the luminosity of the AGN.

Using again the code CLOUDY with standard parameters for a BLR, i.e. $n_e=10^{12}\,{\rm cm}^{-3}$, $U=10^{-2}$, $\mathcal{N}_{\rm H}=10^{23}\,{\rm cm}^{-2}$, the predicted line ratio Fe IIλ4570/H$\beta_{\rm cal}$=0.9 which has to be compared with the observed ratio of 1.9 and 8.0 for I Zw 1 and IRAS 07598+6508 respectively. Furthermore, some computed lines are found to be too strong by factors 3 to 30 (He IIλ4686, He Iλ5876, Lyα, Mg II, the Balmer continuum).

From these results we deduce that standard photoionization models do not explain the Fe II emission. They do not account neither for the total Fe II luminosity nor for the line intensity ratios with respect to other species. The intensity ratios between Fe II multiplets themselves are also difficult to explain, like for instance FeII$_{\rm Opt}$/FeII$_{\rm UV}$. This is why it is often assumed that the optical and UV multiplets are not emitted in the same region (cf. e.g. Baldwin et al. 2004; Tsuzuki et al. 2006). The physical processes have to be reconsidered.

3. EXCITATION PROCESSES

In photoionization models the excitation mechanisms are continuum and line fluorescence and collisional excitation, the latter being the most efficient.

The Locally Optimally emitting Clouds model (LOC, Baldwin et al. 1995) accounts for the Low Ionization Lines (LIL, Collin-Souffrin 1986) H I, He I, Mg II, Ti II, Na I, Ca II, Balmer Continuum including a small contribution of Fe II and [Fe II]. But to get a large Fe II emission another process is needed.

Photoionization heating being not sufficient, an additional efficient heating like a mechanical one is necessary in a medium of high density and high column density. The goal is to weaken the H II region and to strengthen the H I* region.

3.1. *Radiative plus collisional models*

In these models a non radiative heating is added to photoionization, in order to increase the collisional excitation of the lines.

Several models have been computed: varying the density ($n_e=10^{12}$ to $10^{14}\,{\rm cm}^{-3}$), the column density ($\mathcal{N}_{\rm H}=10^{22}$ to $10^{25}\,{\rm cm}^{-2}$), the distance to the central source of radiation (1 to 10 pc), the additional heating (always smaller than the bolometric luminosity).

Under such conditions, it is possible to obtain a strong intensity of the optical Fe II lines but some other lines are much too strong (Lyα, Mg II, Fe IIUV, Ca II, Na ID) and the models are not acceptable.

TABLE 1

PURELY COLLISIONAL MODEL

	I Zw 1	IRAS 07598
Lλ4570 (erg/s)	5.10^{42}	10^{43}
n (cm^{-3})	10^{14}	10^{15}
$\mathcal{N}_H$ (cm^{-2})	10^{24}	10^{25}
Heating (erg/s)	2.10^{44}	6.10^{44}
Covering Factor	5%	5%

3.2. *Purely collisional models*

Finally what we look for is a region producing only Fe II lines, the other features of AGN spectra being produced in regions under the physical conditions of the LOC models.

A region completely shielded from the central source of radiation would emit only Fe II lines with a small contribution of Ca II and Na I D. Excitation and ionization are then only due to the mechanical heating.

Table 1 gives the luminosity of Fe IIλ4570 observed in the BLR of I Zw 1 and IRAS 07598+6508 and displays the physical parameters of the models accounting respectively for the two spectra. Assuming that the emission region is located at a few 10^{17}cm from the centre, the covering factor is of the order of 5%, which means that only a small emission surface is necessary to account for the observed luminosity.

4. CONCLUSION

The Fe II emission is highly variable from object to object.

It is emitted in both the BLR and the NLR.

In strong Fe II emitters the emission region might be shielded from the central source of radiation and mechanically heated. This region has probably a high density and column density.

In order to make more progress in the understanding of the AGN Fe II emission, we need (i) better theoretical models and atomic data, and (ii) high resolution, high S/N spectra of NLS1s to be able to identify individual lines.

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