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THE Fe II LINES IN AGN SPECTRA

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Abstract. We present a study of optical Fe II emission in 302 AGNs selected from the SDSS. We group the strongest Fe II multiplets into three groups according to the lower term of the transition (b ^{4}F, a ^{6}S and a ^{4}G terms). We calculate an Fe II template which takes into account transitions into these three terms and an additional group of lines, based on a reconstruction of the spectrum of I Zw 1. This Fe II template gives a more precise fit of the Fe II lines than other templates. We notice that the ratios of blue, red, and central parts of the iron shelf depend on some spectral properties as continuum luminosity and FWHM Hβ. We examine the dependence of the well-known anti-correlation between the equivalent widths of Fe II and [O III] and we found possible connection with the Baldwin effect.

1. INTRODUCTION

There are many unresolved questions concerning optical Fe II (λλ4400-5400 Å) lines. Some of them are: geometrical place of the Fe II emission region in AGN, processes of excitation which produce Fe II emission, as well as some correlations of the Fe II lines and other AGN spectra properties which need a physical explanation. It is established that the Fe II emission depends on the radio, X and IR parts of the continuum and also some correlations with other lines in spectra are observed (for review see Lipari and Terlevich, 2006). One of the most interesting is the relation between equivalent widths of the Fe II and [O III] lines, which physical background is still not explained (see Boroson and Green, 1992).

In this paper, we investigate the Fe II emitting region by analyzing the correlations between the optical Fe II lines and the other emission lines within a sample of 302 AGN from the SDSS. To do this, we construct an Fe II template. The strongest Fe II multiplets within the λλ4400-5400 Å range are sorted into three groups, according to the lower terms of the transitions. We analyze relationships between ratios of Fe II line groups and other spectral properties, as well as anticorrelation between EW Fe II and EW [O III].

2. THE SAMPLE AND ANALYSIS

Spectra for our data sample are taken from the 7th data release (Abazajian et al., 2009) of the Sloan Digital Sky Survey (SDSS). We used an SQL search to obtain the best sample of AGN spectra, with following requirements: high signal to noise ratio (S/N>20), good pixel quality, high redshift confidence (zConf > 0.95) and with z < 0.7, negligible contribution from the stellar component (EW CaK 3934 Å, Mg 5177 Å and Hd 4102 Å > -1).

Spectra are corrected for Galactic reddening, using procedure described in paper Schlegel et al. (1998). Continuum emission is substracted by DIPSO software.

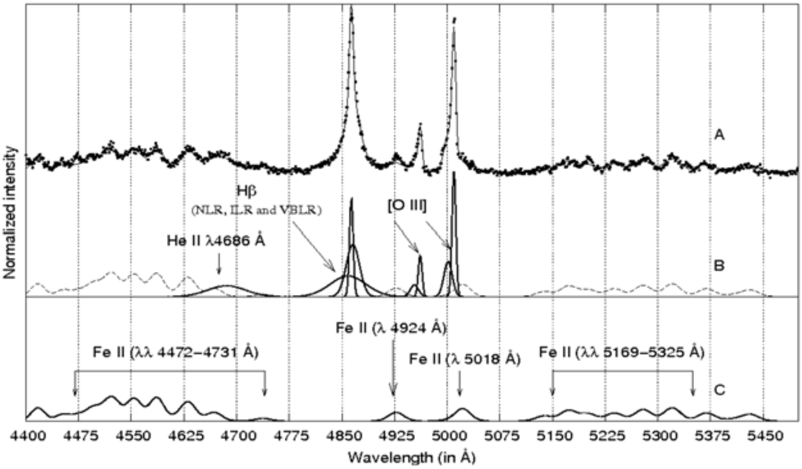

Figure 1. Example of fit of the SDSS J141755.54+431155.8 in the λλ4400-5500 Å range.

We fit all considered lines in λλ4400-5500 Å range (Fe II, [O III], Hβ), with a sum of Gaussian functions of different shifts, widths and intensities, which reflects physical conditions of emission regions where those components arise (see Fig. 1). We assume that Balmer lines have three components: NLR, ILR and VBLR (Ilić et al., 2006; Bon et al., 2006 ; Hu et al., 2008), and we fited them with three Gaussians of different width and shift. Optical Fe II lines were fited with calculated template.

3. RESULTS

The Fe II template

We calculated the Fe II template, using the 50 Fe II emission lines, identified as the strongest within the λλ4400-5500 Å range. The 35 of them are separated in the three line groups according to their lower level of transition: $3d^6$ (^{3}F2)4s ^{4}F, $3d^5 4s^2$ ^{6}S and $3d^6$ (^{3} G)4s ^{4}G (in further text F, S and G group of lines).

The lines from three line groups describe about 75% of Fe II emission in observed range (λλ4400-5500 Å), but about 25% of Fe II emission can not be explained with permitted lines which excitation energies are close to these of lines from the three line groups.

In order to complete the template for missing 25%, we selected 15 lines which probably arise with some of these mechanisms, from Kurutcz database (http://kurucz.harvard.edu/linelists.html). The selected lines have wavelengths on missing parts, strong oscillator strengh and their energy of excitation goes up to ~11 eV. Relative intensities of these 15 lines are obtained from I Zw 1 spectrum by making the best fit together with Fe II lines from the three line groups.

We have assumed that each of lines can be represented with a Gaussian, described by width (W), shift (d) and intensity (I). Since all Fe II lines from the template probably originate in the same region, with the same kinematical properties, values of d and W are the same for all Fe II lines in the case of one AGN, but intensities are assumed to be different. We suppose that relative intensities between the lines within one line group (F, S and G) can be obtained as:

$$\frac{I_1}{I_2} = \left(\frac{\lambda_2}{\lambda_1}\right)^3 \frac{f_1}{f_2} \cdot \frac{g_1}{g_2} \cdot e^{-(E1-E2)/kT}$$

where I_1 and I_2 are intensities of the lines with the same lower level of transition, λ_1 and λ_2 are line wavelengths, g_1 and g_2 are corresponding statistical weights, and f_1 and f_2 are oscillator strengths, E_1 and E_2 are energies of upper level of transitions, k is Boltzman constant and T is the excitation temperature.

According to that, the template of Fe II is described by 7 parameters of fit: parameter of the width, parameter of the shift, four parameters of intensity – for F, S, G and group of lines obtained from I Zw 1 object, as well as excitation temperature.

We applied this template to our sample of 302 AGNs from SDSS database, and we found that the template can satisfactorily fit the Fe II lines.

The ratios of Fe II line groups vs. other spectral properties

Since line intensities and their ratios are indicators of physical properties of the plasma where those lines arise, we have investigated relations among the ratios of Fe II line groups with various spectral properties. The F, S and G line groups correspond approximately to the blue, central and red part of the iron shelf, respectavely.

We find that the ratios of different parts of the iron shelf (F/G, F/S, and G/S) depend on some spectral properties such as: continuum luminosity and Hβ FWHM. Also, it is noticed that spectra with Hβ FWHM greater and less than ~3000 km/s have different properties which is reflected in significantly different coefficients of correlation between the parameters.

We found that all three ratios (F/G, F/S and G/S) are in significant correlation with FWHM Hβ for subsample with FWHM Hβ > 3000 km/s. The obtained coefficients of correlation are: F/G vs. FWHM Hβ (r = 0.36, P = 1.2E-5), F/S vs. FWHM Hβ (r = 0.59, P = 1.3E-14) and G/S vs. FWHM Hβ (r = 0.44, P = 6.1E-8).

No correlations between these parameters are observed for subsample with FWHM Hβ < 3000 km/s. Also, we found the correlation between F/G ratio and continuum luminosity log(L_{5100}), which is more significant for FWHM Hβ < 3000 km/s subsample: r = - 0.51, P = 5.7E-12. The correlation between F/S and log(L_{5100}) is also observed (r = - 0.41, P = 7.9E-8), for the same subsample.

EW Fe II vs. EW [O III]

One of the problems mentioned in the introduction is the anti-correlation between the equivalent widths of the [O III] and Fe II lines which is related to Eigenvector 1 in the analysis of Boroson and Green (1992). Some physical causes proposed to explain Eigenvector 1 correlations are: (a) Eddington ratio L/L_{Edd}, (b) black hole mass M_{BH}, and (c) inclination angle (for detailed review see Kovačević et al., 2010). Wang et al. (2006) suggested that EV1 may be related to AGN evolution.

We confirmed the EW Fe II vs. EW [O III] anti-correlation in our sample (r = - 0.39, P < 0.0001, see Fig 2).

To try to understand the EW Fe II vs. EW [O III] anti-correlation, we examined its relationship to continuum luminosity. We examined the relations of equivalent widths of Fe II and [O III] lines vs. L_{5100}. We confirmed a strong Baldwin effect (see Baldwin, 1977) for [O III] lines (r = - 0.43, P = 4E-15), and an inverse Baldwin effect for EW Fe II lines (r = 0.30, P = 2E-7), i.e. we found that as continuum luminosity increases, EW Fe II also increases, but EW [O III] decreases (see Fig 3). In Fig 3, objects with redshift within range z < 0.1 are denoted with open squares, 0.1< z < 0.2 with filled triangles, 0.2 < z < 0.3 with open circles, 0.3 < z < 0.4 with filled squares, 0.4 < z < 0.5 with open triangles, 0.5 < z < 0.6 with filled circles and 0.6 < z < 0.7 with stars.

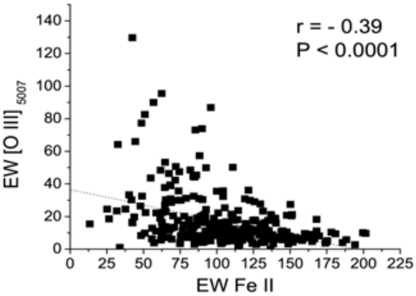

Figure 2. Relationship between the EW [O III] l5007 Å vs. EW Fe II.

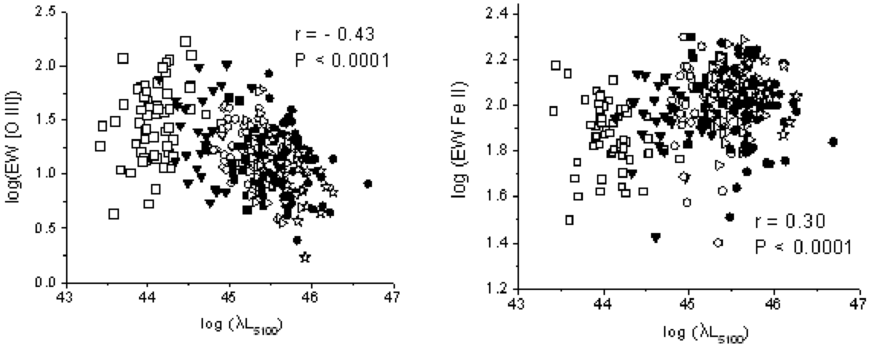

Figure 3. The Baldwin effect significant for the [O III] lines (left panel), while an inverse Baldwin effect is detected for the optical Fe II lines (rigth panel).

This implies that the EW Fe II - EW [O III] anti-correlation may be influenced by Baldwin effect for [O III] and an inverse Baldwin effect for Fe II lines. Also, in our analysis we found that the strength of the Baldwin effect depends on the FWHM Hβ of the sample. Note that FWHM Hβ is one of the parameters in Eigenvector 1.

The origin of the Baldwin effect is still not understood and is a matter of debate. The increase of the continuum luminosity may cause a decrease of the covering factor, or changes in the spectral energy distribution (softening of the ionizing continuum) which may result in the decrease of EWs. The inclination angle may also be related to Baldwin effect. The physical properties which are usually considered as a primary cause of the Baldwin effect are: M_{BH}, L/L_{Edd}, and changes in gas metalicity. Also, a connection between Baldwin effect and AGN evolution is possible (for detailed review see Kovačević et al., 2010).

Conclusions

1. We have proposed an optical Fe II template for the λλ4400-5500 Å range, which consists of three groups of Fe II multiplets, grouped according to the lower terms of transitions (F, S and G), and an additional group of lines reconstructed from the I Zw 1 spectrum. We found that template can satisfactorily fit the Fe II lines.
2. We find that the ratios of different parts of the iron shelf (F/G, F/S, and G/S) depend of some spectral properties such as: continuum luminosity and Hβ FWHM. Also, it is noticed that spectra with Hβ FWHM greater and less than ~3000 km/s have different properties which is reflected in significantly different coefficients of correlation between the parameters.
3. We confirm in our sample the anti-correlation between EW Fe II and EW [O III] which is related to Eigenvector 1 (EV1) in Boroson and Green (1992) and we examined its dependence on the continuum luminosity. We found an inverse Baldwin effect for Fe II lines, and Baldwin effect was confirmed for the [O III] lines. Since EW Fe II increases, and EW [O III] decreases with increases of continuum luminosity, the observed EW Fe II vs. EW [O III] anti-correlation is probably due to the same physical reason which causes the Baldwin effect. Moreover, it is observed that the coefficients of correlation due to Baldwin effect depend on Hβ FWHM range of a sub-sample, which also implies the connection between the Baldwin effect and EV1.

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