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The optical Fe II emission lines in Active Galactic Nuclei

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Abstract. In order to investigate the origin of iron lines and to analyse their correlations with other lines and spectral properties, we constructed the Fe II template in $\lambda\lambda$ 4400-5500 Å range. We selected the 50 Fe II lines identified as the strongest in this wavelength band. The 35 of them are separated in the three line groups according to their lower level of transition, and their relative intensities within the group are calculated. The relative intensities of the rest of 15 lines are obtained from I Zw 1 object. Here we present the description of constructed template and its comparison with some other empirical and theoretical Fe II templates. We found that template can satisfactorily fit the Fe II lines. In spectra where the Fe II emission lines have different relative intensities than in I Zw 1, this template fits better than the templates based on I Zw 1.

Key words. Active galactic nuclei: spectral lines

1. Introduction

Optical Fe II ($\lambda\lambda$ 4400-5500 Å) lines are one of the most interesting features in AGN spectra. They arise in numerous transitions of the complex Fe II ion, and they can be seen only in spectra of AGN type 1 and NLSy 1 galaxies. There are many open questions about iron lines which make them very attractive for investigation. Their origin, i.e. geometrical place of their emission region in AGN, is still not clear, as well as the processes of excitation which produce Fe II emission. Also, there are many 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. One of the most interesting is the relation between optical Fe II and [O III] lines, which physical background is still not explained (Boroson, & Green 1992).

For investigation of the origin of iron lines and for analysis of their correlations with other lines, it is necessary to apply a good template which will fit well iron lines within $\lambda\lambda$ 4400-5500 Å range. But, the construction of iron template is very difficult since the iron lines form the features of a complex shape. In this paper, we present our model of iron template, based on the physical properties of iron region, and we compare it with other models.

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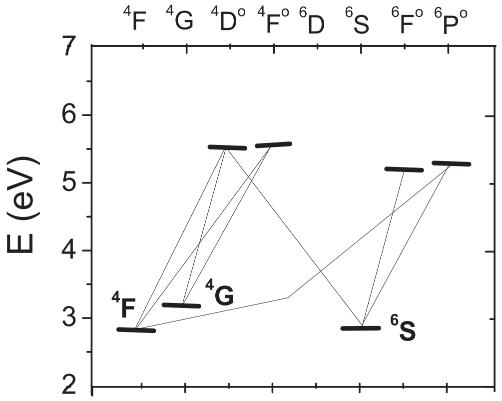

Fig. 1. Grotrian diagram shows the strongest Fe II transitions within $\lambda\lambda$ 4400-5500 Å range: lines are separated in three groups according to the lower levels of transition (^4F, ^6S and ^4G).

2. The Fe II template

We calculated the Fe II template, using the 50 Fe II emission lines, identified as the strongest within the $\lambda\lambda$ 4400-5500 Å range. The 35 of them are separated in the three line groups according to their lower level of transition: $3d^6(\,^3F2)4s\,^4F$, $3d^54s^2\,^6S$ and $3d^6(\,^3G)4s\,^4G$ (in further text ^4F, ^6S and ^4G group of lines). A simplified scheme of those transitions is shown in Fig 1. The ^4F group is consisted of 19 lines and they dominate in the blue bump of iron lines ($\lambda\lambda$ 4400-4700 Å). The lines from ^6S group (5 lines) describe the Fe II emission under the [O III] and Hβ lines, and partly from the red Fe II bump ($\lambda\lambda$ 5150-5400 Å), and ^4G lines (11 lines) dominate in the red bump.

The lines from three line groups describe about 75% of Fe II emission in observed range ($\lambda\lambda$ 4400-5500 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. The missing parts are around ~4450 Å, ~4630 Å, ~5130 Å and ~5370 Å.

There are some indications that the process of fluorescence (self-fluorescences, continuum-fluorescences or Lyα and Lyβ pumping) may have a role in appearing of some Fe II lines (Verner et al. 1999; Hartmann, & Johanson 2000). They could supply enough energy for exciting the Fe II lines with high energy of excitation, which could be one of the explanation for emission in these wavelengths.

In order to complete the template for missing 25%, we selected 15 lines which probably arise with some of these mechanisms, from Kurutcz database[1]. 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 three line groups. The selected lines and their relative intensities are shown in Table 1.

We have assumed that each of lines can be represented with a Gaussian, described by width (W), shift (d) and intensity (I). Since all FeII 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

Table 1. The list of the lines taken from Kurucz (http://kurucz.harvard.edu/linelists.html). In the first column are wavelengths, in the second oscillator strengths and in the third relative intensities measured in I Zw 1.

Wavelength	gf	Relative intensity
4414	2.65E-03	3.00
4449	2.52E-02	1.50
4471	6.40E-03	1.20
4493	3.74E-02	1.60
4611	4.13E-03	0.70
4625	8.51E-03	0.70
4628	1.83E-02	1.20
4631	1.34E-02	0.60
4660	1.15E-03	1.00
4668	3.13E-03	0.90
4734	1.28E-03	0.50
5134	2.48E-03	1.10
5366	5.37E-01	1.45
5401	1.43E-01	0.40
5427	2.17E-02	1.40

[1] http://kurucz.harvard.edu/linelists.html

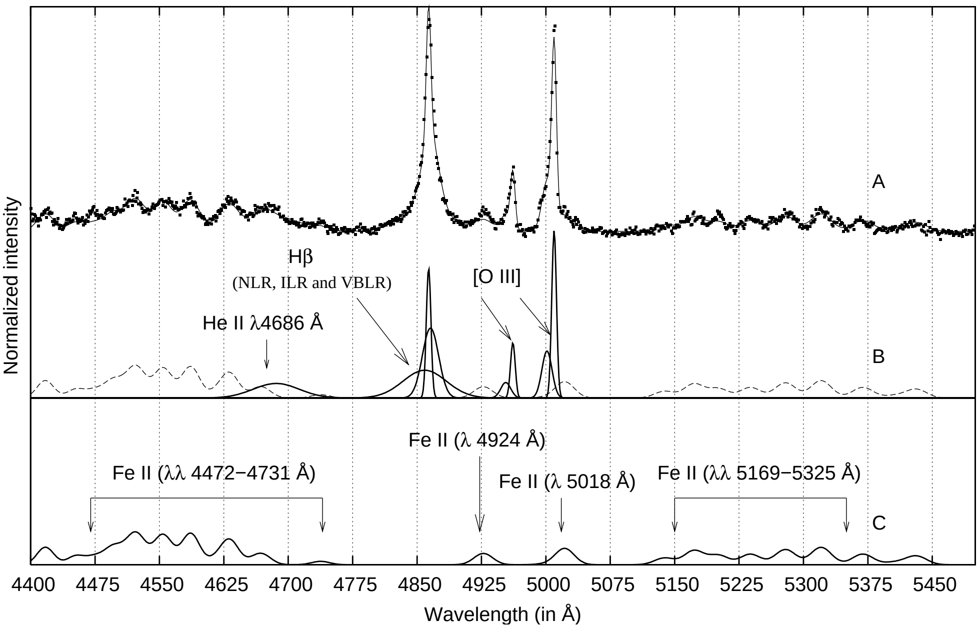

Fig. 2. Spectrum of SDSS J141755.54+431155.8 in the $\lambda\lambda$ 4400-5500 Å range: A) observed spectra (dots) and the best fit (solid line). B) decomposition of lines on Gauss functions. Template of Fe II is denoted with dashed line, and represented separately in panel C (below).

within one line group (^4F, ^6S or ^4G) can be obtained as:

$$\frac{I_1}{I_2} = (\frac{\lambda_2}{\lambda_1})^3 \frac{f_1}{f_2} \cdot \frac{g_1}{g_2} \cdot e^{-(E_1-E_2)/kT} \qquad (1)$$

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

According to that, the template of Fe II is described by 7 free parameters in fit: width, shift, four parameters of intensity - for ^4F, ^6S and ^4G line groups and for lines with relative intensities obtained from I Zw 1. The 7th parameter is excitation temperature included in calculating relative intensities whithin ^4F, ^6S and ^4G line groups.

The fit of the Fe II template is shown in Fig 2. We apply this template on large sample of AGNs (305) from SDSS database, and we found that the template fits well Fe II emission. In cases when Fe II emission of object has different properties than the one in I Zw 1, small disagreement is noticed in lines which relative intensities are obtained from I Zw 1 (see Fig 4, top). The list of 35 selected lines from three line groups, their oscillator strengths and calculated relative intensities for different excitation temperatures are shown in Table 2.

2.1. Comparison with other templates

We applied empirical template from Dong et al. (2008) and Veron-Cetty et al. (2004) and theoretical one calculated by Bruhweiler, & Verner (2008) in order to compare them with our template. Veron-Cetty et al. (2004) constructed the Fe II template by identifying a system of broad and a system of narrow Fe II lines in I Zw 1 spectrum, and measuring their relative intensities in that object.

Table 2. The list of the 35 strongest Fe II lines within the $\lambda\lambda$ 4400-5500 Å range used to calculate the Fe II template. In the first column are wavelengths, in the second terms of transitions, in the third are gf values used for the template calculation, in the fourth are the references for the source of oscillator strengths, and in the 5th-7th columns are relative intensities, calculated for T=5000 K, 10000 K and 15000 K. Intensities of lines from ^4F, ^6S and ^4G groups are normalized on intensities of λ 4549.474 Å, λ 5018.44 Å and λ 5316.6 Å lines (respectively). References for oscillator strengths are: 1 – Fuhr et al. (1981), 2 – Giridhar, & Ferro (1995), 3 – NIST Atomic Spectra Database (http://physics.nist.gov/PhysRefData/ASD/), 4 – Kurucz (1990) and 5 – http://kurucz.harvard.edu/linelists.html.

Wavelength	Terms	gf	ref.	Relative intensity		
				T=5000 K	T=10000 K	T=15000 K
4472.929	b $^4F_{5/2}$ - z $^4F^o_{3/2}$	4.02E-04	1	0.033	0.036	0.037
4489.183	b $^4F_{7/2}$ - z $^4F^o_{5/2}$	1.20E-03	1	0.105	0.110	0.111
4491.405	b $^4F_{3/2}$ - z $^4F^o_{3/2}$	2.76E-03	1	0.226	0.243	0.249
4508.288	b $^4F_{3/2}$ - z $^4D^o_{1/2}$	4.16E-03	2	0.345	0.367	0.375
4515.339	b $^4F_{5/2}$ - z $^4F^o_{5/2}$	3.89E-03	2	0.333	0.348	0.353
4520.224	b $^4F_{9/2}$ - z $^4F^o_{7/2}$	2.50E-03	3	0.235	0.233	0.233
4522.634	b $^4F_{5/2}$ - z $^4D^o_{3/2}$	9.60E-03	3	0.827	0.859	0.870
4534.168	b $^4F_{3/2}$ - z $^4F^o_{5/2}$	3.32E-04	3	0.028	0.029	0.030
4541.524	b $^4F_{3/2}$ - z $^4D^o_{3/2}$	8.80E-04	3	0.075	0.078	0.079
4549.474	b $^4F_{7/2}$ - z $^4D^o_{5/2}$	1.10E-02	4	1.000	1.000	1.000
4555.893	b $^4F_{7/2}$ - z $^4F^o_{7/2}$	5.20E-03	3	0.477	0.474	0.474
4576.340	b $^4F_{5/2}$ - z $^4D^o_{5/2}$	1.51E-03	4	0.136	0.136	0.136
4582.835	b $^4F_{5/2}$ - z $^4F^o_{7/2}$	7.80E-04	3	0.070	0.070	0.070
4583.837	b $^4F_{9/2}$ - z $^4D^o_{7/2}$	1.44E-02	2	1.420	1.353	1.331
4620.521	b $^4F_{7/2}$ - z $^4D^o_{7/2}$	8.32E-04	4	0.080	0.076	0.075
4629.339	b $^4F_{9/2}$ - z $^4F^o_{9/2}$	4.90E-03	4	0.497	0.459	0.447
4666.758	b $^4F_{7/2}$ - z $^4F^o_{9/2}$	6.02E-04	4	0.060	0.055	0.054
4993.358	b $^4F_{9/2}$ - z $^6P^o_{7/2}$	3.26E-04	4	0.041	0.030	0.027
5146.127	b $^4F_{7/2}$ - z $^6F^o_{7/2}$	1.22E-04	5	0.016	0.011	0.010
4731.453	a $^6S_{5/2}$ - z $^4D^o_{7/2}$	1.20E-03	2	0.025	0.030	0.032
4923.927	a $^6S_{5/2}$ - z $^6P^o_{3/2}$	2.75E-02	4	0.656	0.693	0.706
5018.440	a $^6S_{5/2}$ - z $^6P^o_{5/2}$	3.98E-02	4	1.000	1.000	1.000
5169.033	a $^6S_{5/2}$ - z $^6P^o_{7/2}$	3.42E-02	1	0.929	0.854	0.831
5284.109	a $^6S_{5/2}$ - z $^6F^o_{7/2}$	7.56E-04	2	0.022	0.019	0.018
5197.577	a $^4G_{5/2}$ - z $^4F^o_{3/2}$	7.92E-03	5	0.532	0.620	0.652
5234.625	a $^4G_{7/2}$ - z $^4F^o_{5/2}$	8.80E-03	3	0.615	0.695	0.723
5264.812	a $^4G_{5/2}$ - z $^4D^o_{3/2}$	1.08E-03	1	0.075	0.084	0.087
5276.002	a $^4G_{9/2}$ - z $^4F^o_{7/2}$	1.148e-02	2	0.861	0.928	0.951
5316.615	a $^4G_{11/2}$ - z $^4F^o_{9/2}$	1.17E-02	4	1.000	1.000	1.000
5325.553	a $^4G_{7/2}$ - z $^4F^o_{7/2}$	6.02E-04	4	0.044	0.047	0.048
5316.784	a $^4G_{7/2}$ - z $^4D^o_{5/2}$	1.23E-03	5	0.089	0.097	0.099
5337.732	a $^4G_{5/2}$ - z $^4D^o_{5/2}$	1.28E-04	5	0.009	0.010	0.010
5362.869	a $^4G_{9/2}$ - z $^4D^o_{7/2}$	1.82E-03	5	0.142	0.146	0.148
5414.073	a $^4G_{7/2}$ - z $^4D^o_{7/2}$	1.60E-04	5	0.012	0.012	0.013
5425.257	a $^4G_{9/2}$ - z $^4F^o_{9/2}$	4.36E-04	5	0.035	0.035	0.035

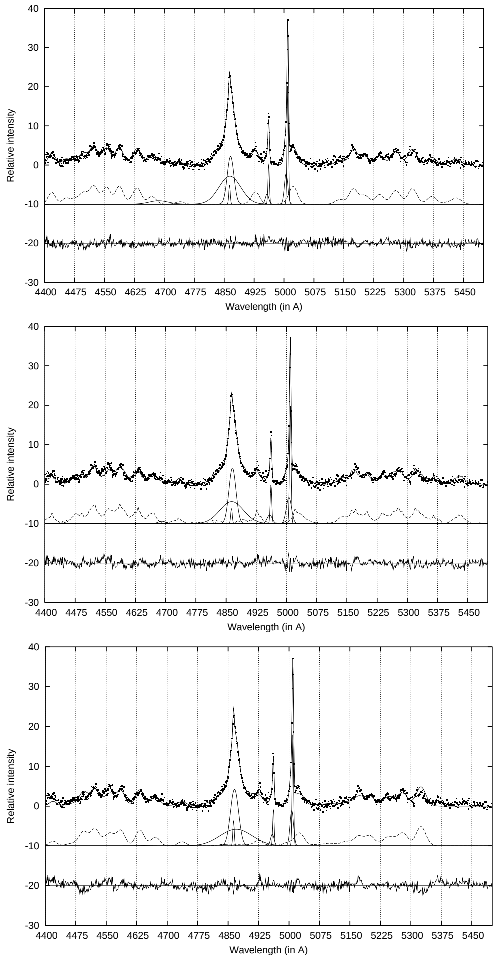

Fig. 3. Examples of fit of SDSS J020039.15-084554.9 object: with our template (top), with empirical template of Dong et al. (2008) (middle) and with theoretical template of Bruhweiler, & Verner (2008) (bottom). Since object have iron emission equally strong in blue and red iron bump (as I Zw 1), all three models fit well observed lines.

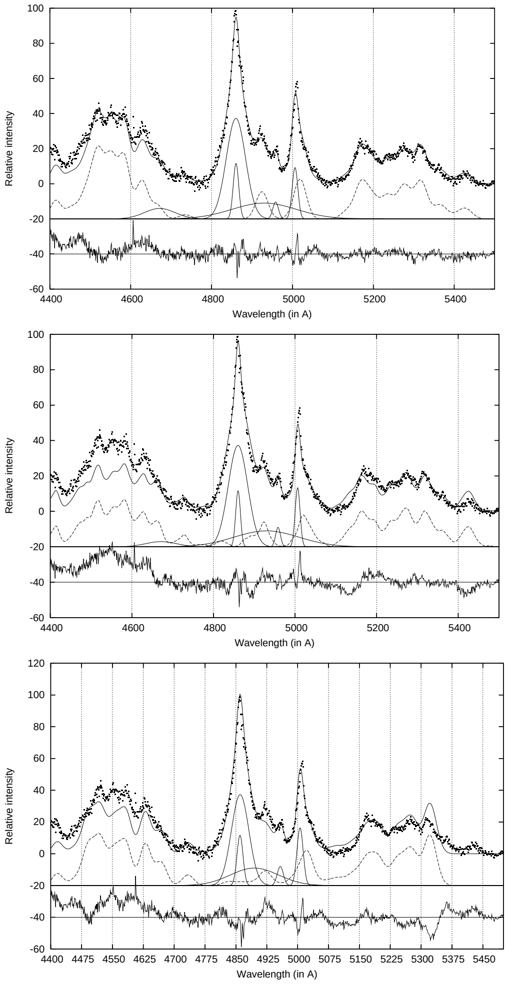

Fig. 4. Examples of fit of SDSS J111603.13 + 020852.2 object: with our template (top), with empirical template of Dong et al. (2008) (middle) and with theoretical template of Bruhweiler, & Verner (2008) (bottom). In this object iron emission is much stronger in the blue then in the red bump. Our template show disagreement in lines which relative intensity is taken from I Zw 1, but other three wavelength regions based on three line groups fit well observed Fe II. Other two models can not fit well this kind of Fe II emission.

In $\lambda\lambda$ 4400-5500 Å range they identified 46 broad and 95 narrow lines. Dong et al. (2008) improved that template by fitting with two parameters of intensity - one for broad, one for narrow Fe II lines.

Bruhweiler, & Verner (2008) calculated Fe II template using CLOUDY and an 830 level model atom, taking into account the processes of continuum and line pumping. In calculation, they apply solar abundances for a range of physical conditions as flux of ionizing photons [Φ_H], hydrogen density [n_H] and microturbulence [ξ]. We found that model with $\log[n_H/(cm^{-3})]=11$, $[\xi]/(1\ km\ s^{-1})=20$ and $\log[\Phi_H/(cm^{-2}\ s^{-1})]=21$ corresponds better than others to Fe II lines in observed spectra. In Fig 3 is shown the spectrum of SDSS J020039.15-084554.9 (NLSy1), fitted with our template (top), with template based on line intensities from I Zw 1 (Dong et al. 2008) (middle) and with template calculated by CLOUDY (Bruhweiler, & Verner 2008) (bottom). Since this object has the Fe II emission similar as I Zw 1, all three templates fit well iron lines. But, in the case of object SDSS J111603.13 + 020852.2 (Fig 4), the iron lines in the blue bump are stronger comparing to those in the red, which is significantly different from I Zw 1 object. In this case our model shows disagreement only in lines which relative intensity is taken from I Zw 1 (Fig 4, top), but other two models show larger disagreement in fit of this kind of Fe II emission (Fig 4, middle and bottom).

3. Conclusions

We found that template can satisfactorily fit the Fe II lines, which enable more precise investigation of the Fe II lines. In the spectra which Fe II emission lines have different relative intensities than in I Zw 1, this template fits better than templates based on I Zw 1 object.

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References

Boroson, T. A., & Green, R. F. 1992, ApJS, 80, 109

Bruhweiler, F., & Verner, E. 2008, ApJ, 675, 83

Dong, X., Wang, T., Wang, J., Yuan, W., Zhou, H., Dai, H., & Zhang, K. 2008, MNRAS, 383, 581

Fuhr, J. R., Martin, G. A., Wiese, W. L., & Younger, S. M. 1981, J. Phys. Chem. Ref. Data, 10, 305

Giridhar, S. & Ferro, A. A. 1995, RMxAA, 31, 23

Hartmann, H., & Johanson, S. 2000, A&A, 359, 627

Kurucz, R.L. 1990, Trans. I. A. U. XXB, ed. M. McNally (Dordrecht: Kluwer), 168

Veron-Cetty, M.-P., Joly, M., Veron, P., 2004, A&A, 417, 515

Verner, E. M., Verner, D. A., Korista, K. T. et al. 1999, ApJS, 120, 101