The correlations between spectral properties in the spectra of AGNs type 1

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Outline:

1. Correlations between spectral AGN properties – a tool to investigate the AGN nature
2. The sample and analysis
3. Fe II template construction
4. Balmer continuum model
5. Contribution of starbursts to spectra of AGN type 1
6. Conclusions

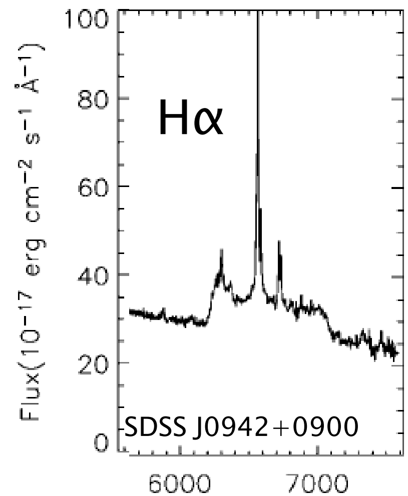
1. Correlations between spectral parameters – tools for discovering AGN nature

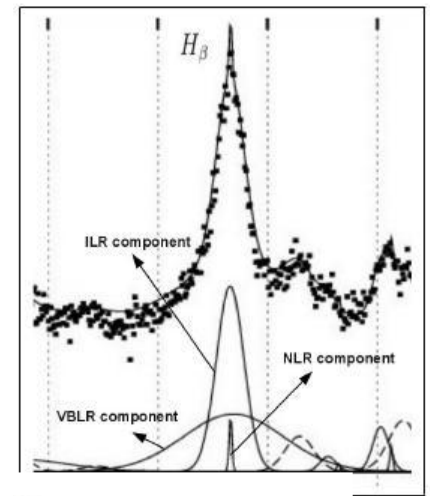
- Emission lines: **complex profiles**!

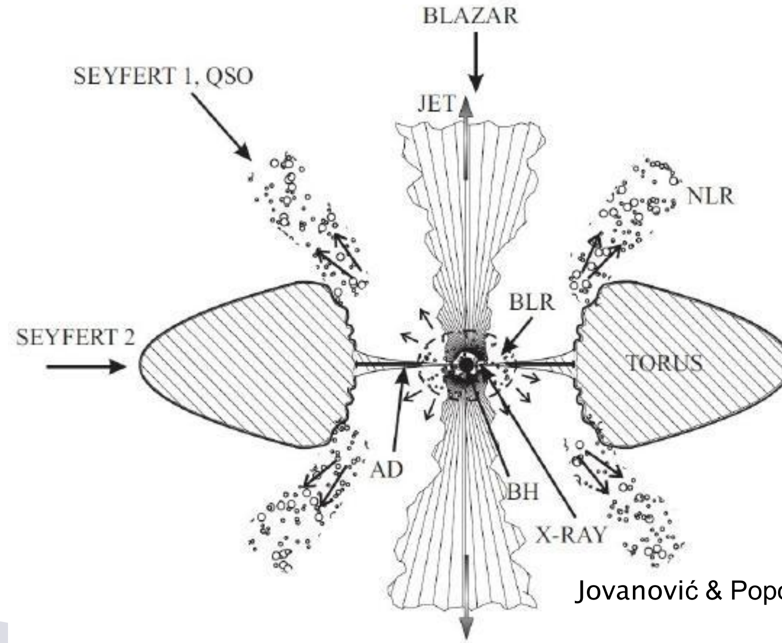
- Different components of emission lines are coming from different layers of emission regions.

- Each component (represented as Gaussian) reflects the **physical and kinematical properties of emission region where it arises.**

- Correlations between properties of different lines lead to better insight in the AGN structure, and kinematical and physical properties of gas in AGNs.





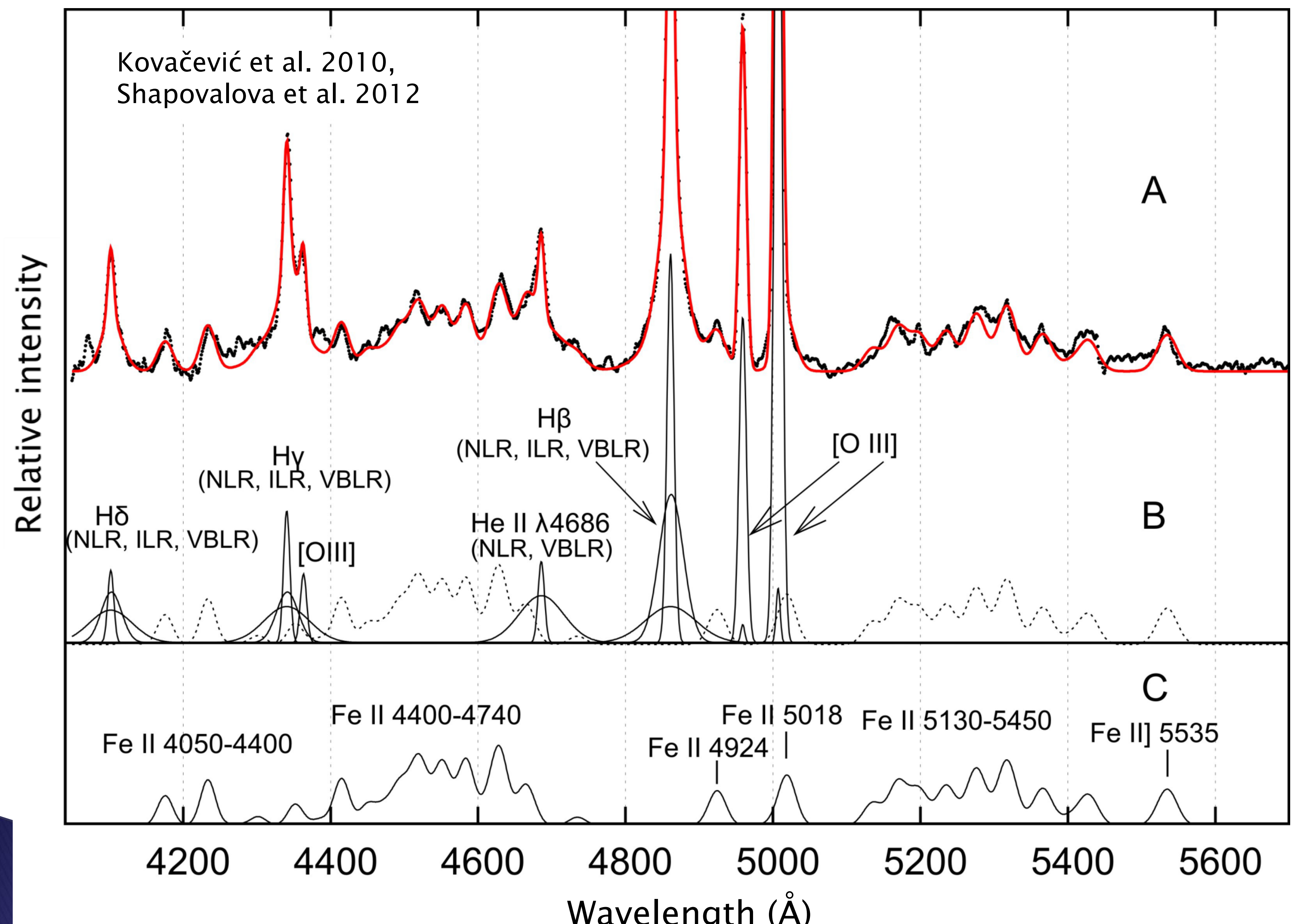


Jovanović & Popović, 2009

2. The sample and analysis

- We obtain ~330 spectra from SDSS DR7 database, using SQL with criteria:

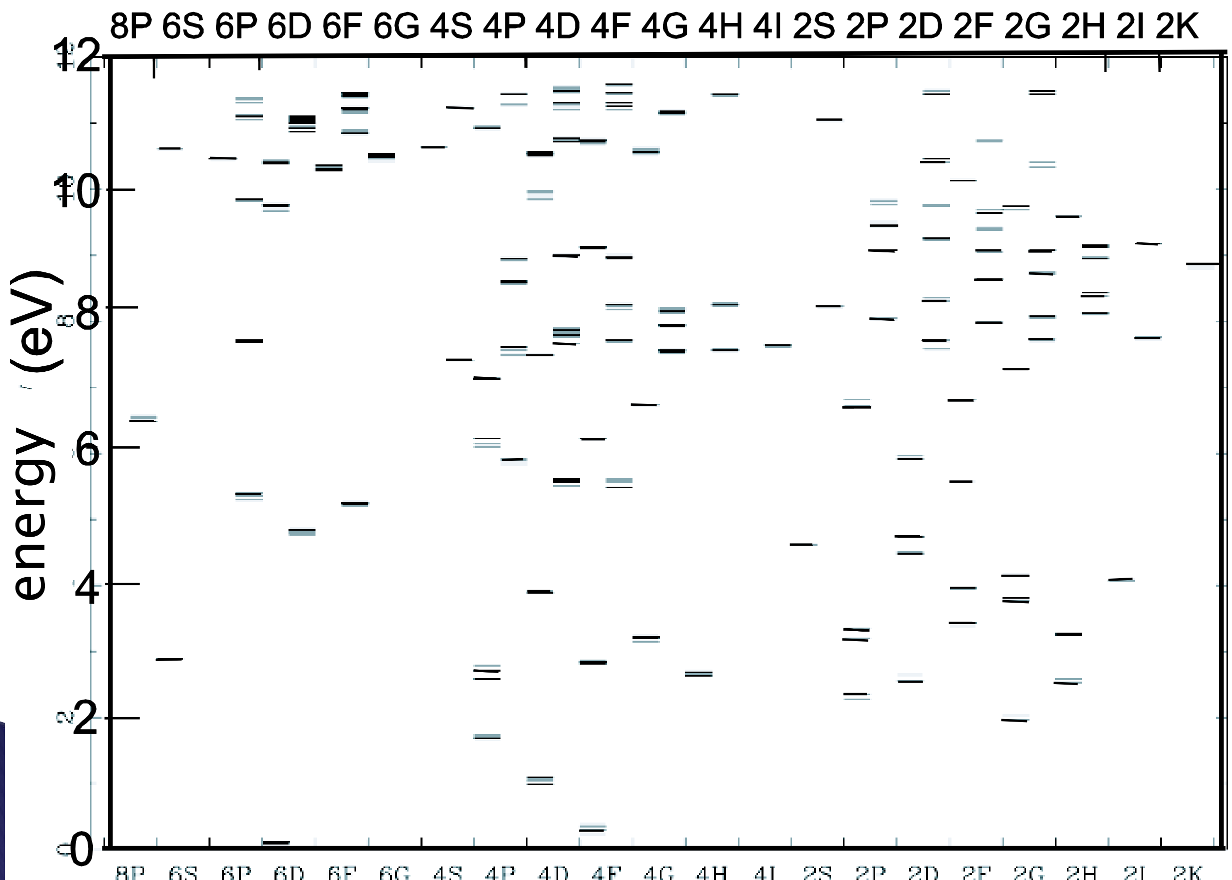
1. $S/N > 20$
2. Good quality of pixels
3. $z < 0.7$ and zConf > 0.95
4. Small contibution of stellar component: EW CaK 3934, Mg 5177, Hδ < 1Å
5. Presence of [O III] and broad Hβ (EW [O III] and EW Hβ > 0)



Kovačević et al. 2010,
Shapovalova et al. 2012
A
B
C
Relative intensity
Hδ
(NLR, ILR, VBLR)
Hγ
(NLR, ILR, VBLR)
[OIII]
He II λ4686
(NLR, VBLR)
Hβ
(NLR, ILR, VBLR)
[O III]
Fe II 4050-4400
Fe II 4400-4740
Fe II 4924
Fe II 5018
Fe II 5130-5450
Fe II] 5535
4200
4400
4600
4800
5000
5200
5400
5600
Wavelength (Å)

2.1 Difficult identification of Fe II lines

complex Fe II ion: produces huge number of Fe II lines in UV, optical and IR;



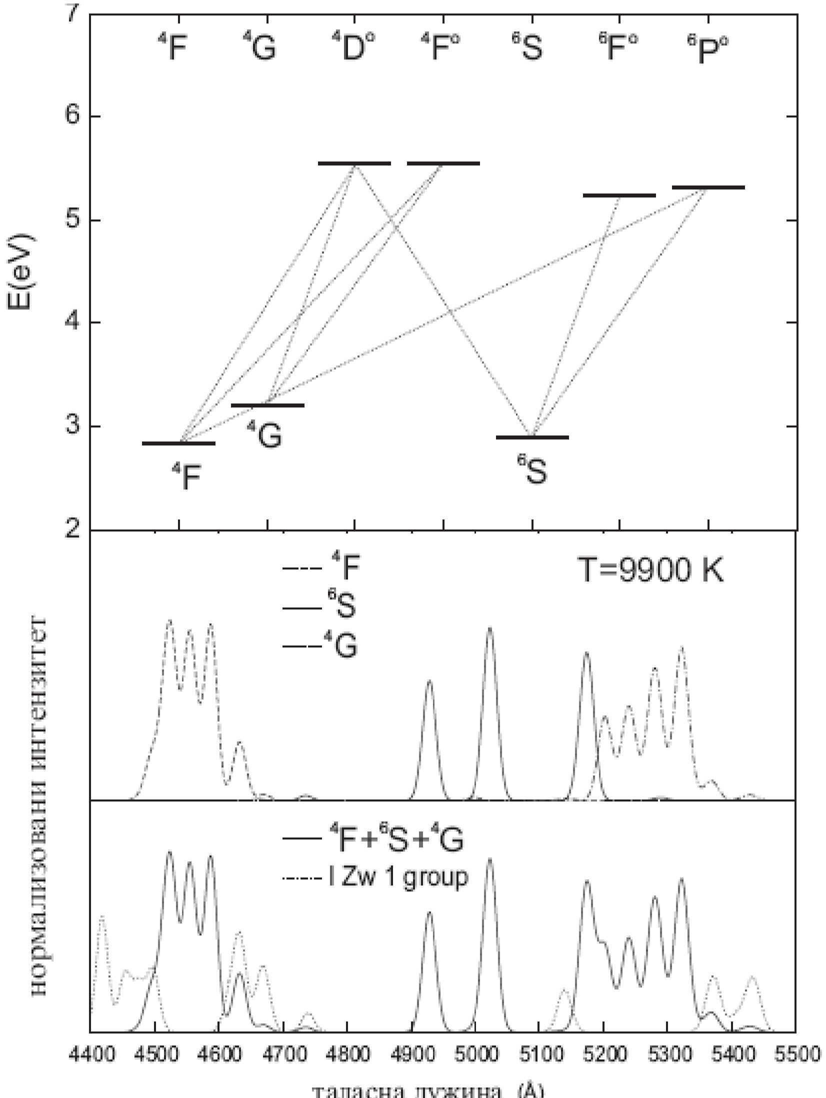
Sigut & Pradhan 2003:
827 energy levels,
23 000 transitions!

(data from Iron Project, Hummer 1993)

Nave & Johansson 2013:
1027 energy levels,
12 900 transitions!

2.2 The Fe II (4400–5500 A) template

Kovačević et al. 2010. *ApJS*, **189**, 15.



- Lover terms of Fe II transitions:

(1) $3d^6\,(^3F2)4s\ ^4F$ ⟹ **F group** (19 lines)

(2) $3d^5\,4s^2\ ^6S$ ⟹ **S group** (5 lines)

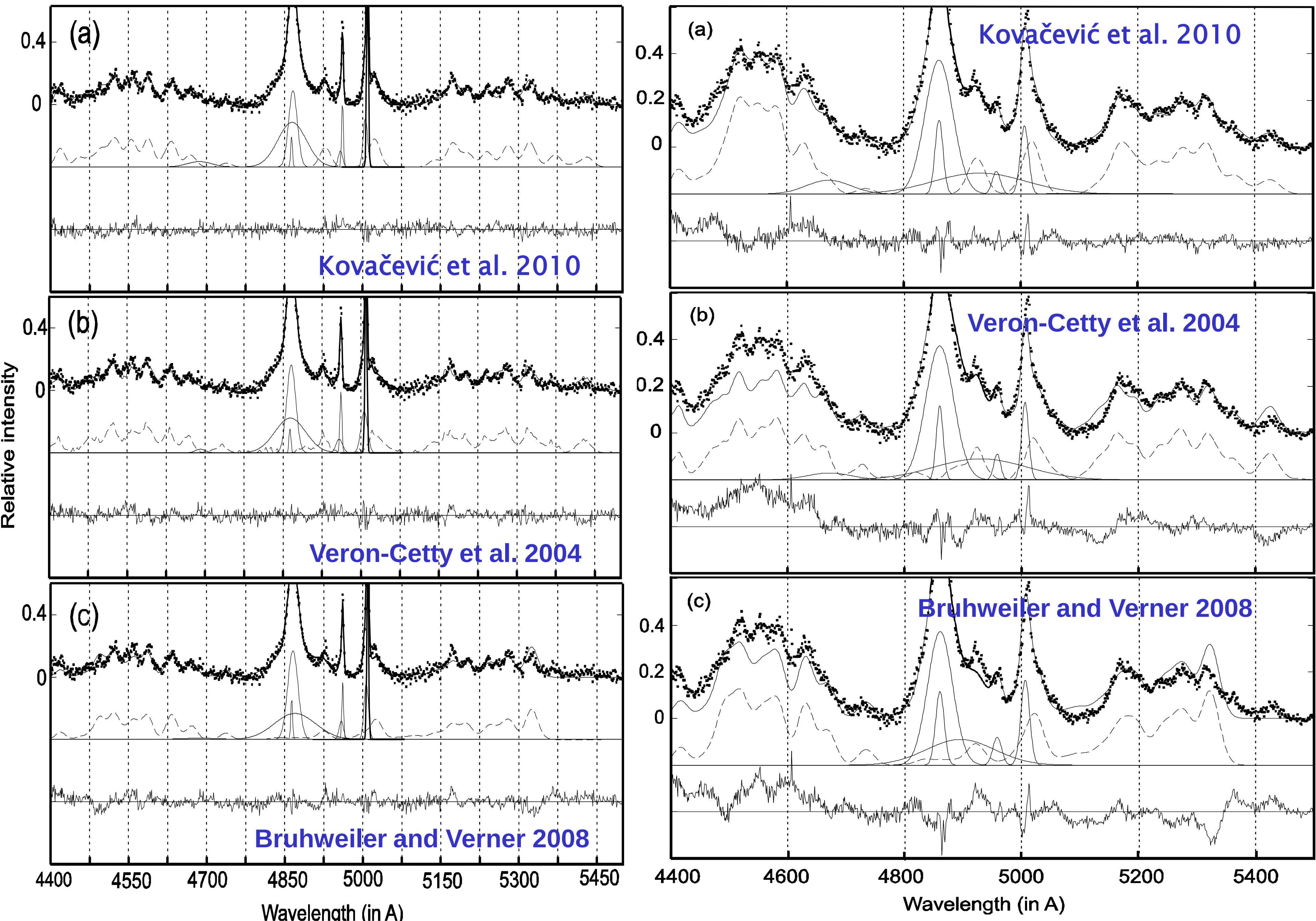
(3) $3d^6\,(^3G)4s\ ^4G$ ⟹ **G group** (11 lines)

(4) 15 lines, which probably originate from higher levels. Their relative intensities are taken from I Zw 1 object (I Zw 1 group).

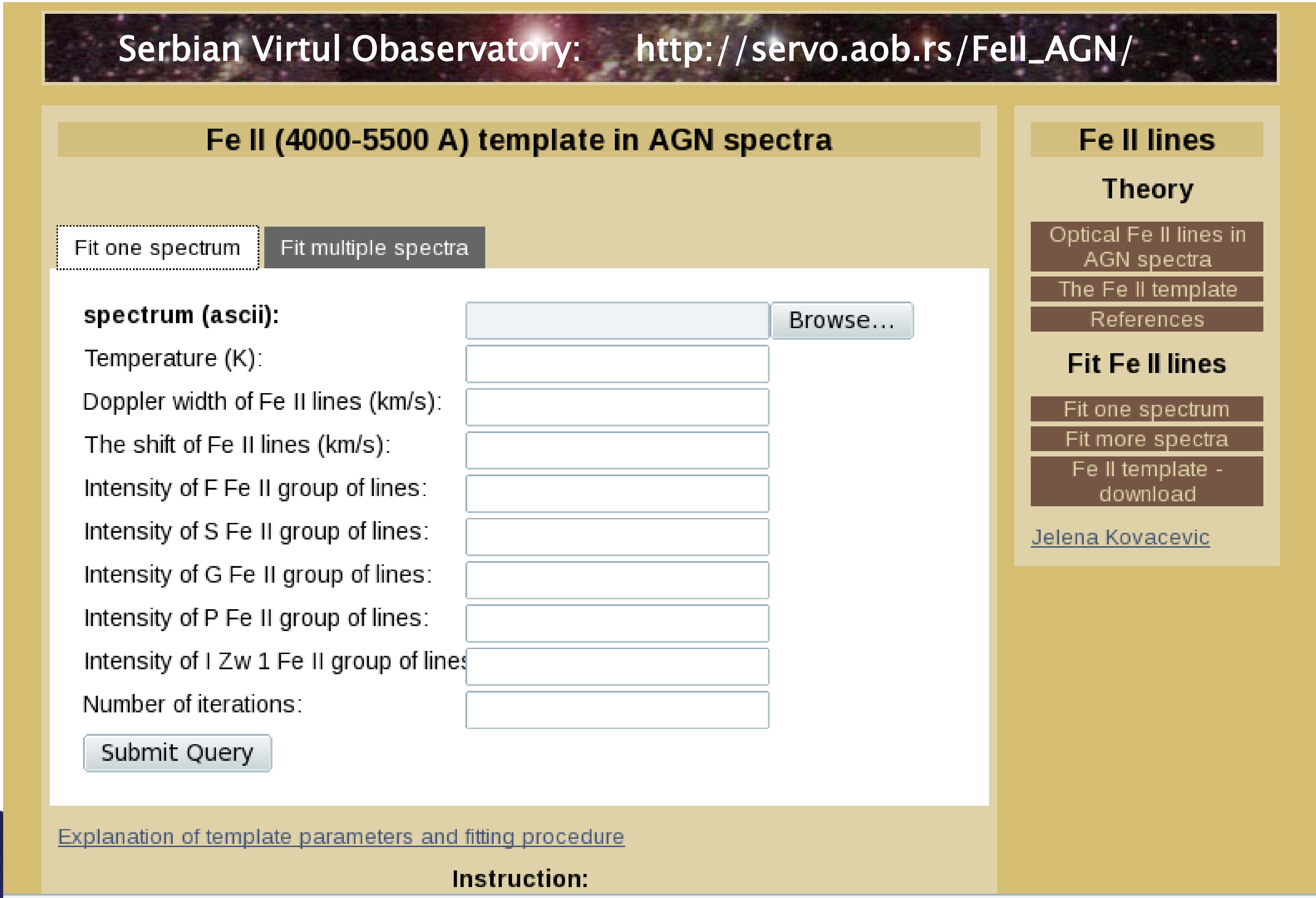
- All Fe II lines have the same widths and shifts, and their relative intensities are calculated as:

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

- f – oscillator strength, g – statistical weight, E – energy of upper level of transition, T – excitation temperature, k – Boltzmann constant



(a)
Kovačević et al. 2010
(b)
Veron-Cetty et al. 2004
(c)
Bruhweiler and Verner 2008
Relative intensity
0.4
0.2
0
4400
4550
4700
4850
5000
5150
5300
5450
4600
4800
5200
5400
Wavelength (in A)


Serbian Virtul Obaservatory: http://servo.aob.rs/FeII_AGN/
Fe II (4000-5500 A) template in AGN spectra
Fit one spectrum
Fit multiple spectra
spectrum (ascii):
Browse...
Temperature (K):
Doppler width of Fe II lines (km/s):
The shift of Fe II lines (km/s):
Intensity of F Fe II group of lines:
Intensity of S Fe II group of lines:
Intensity of G Fe II group of lines:
Intensity of P Fe II group of lines:
Intensity of I Zw 1 Fe II group of lines
Number of iterations:
Submit Query
Explanation of template parameters and fitting procedure
Instruction:
Fe II lines
Theory
Optical Fe II lines in AGN spectra
The Fe II template
References
Fit Fe II lines
Fit one spectrum
Fit more spectra
Fe II template - download
Jelena Kovacevic

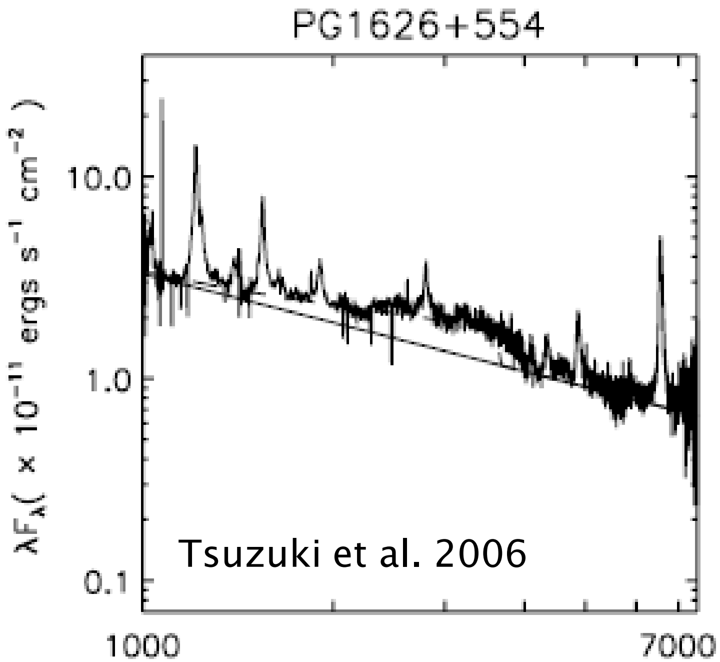
3.1 Balmer continuum

- determination of the UV pseudocontinuum in the sample
- **Not easy** because of complex shape of UV pseudocontinuum:

Power low + Balmer continuum (Grandi 1982)

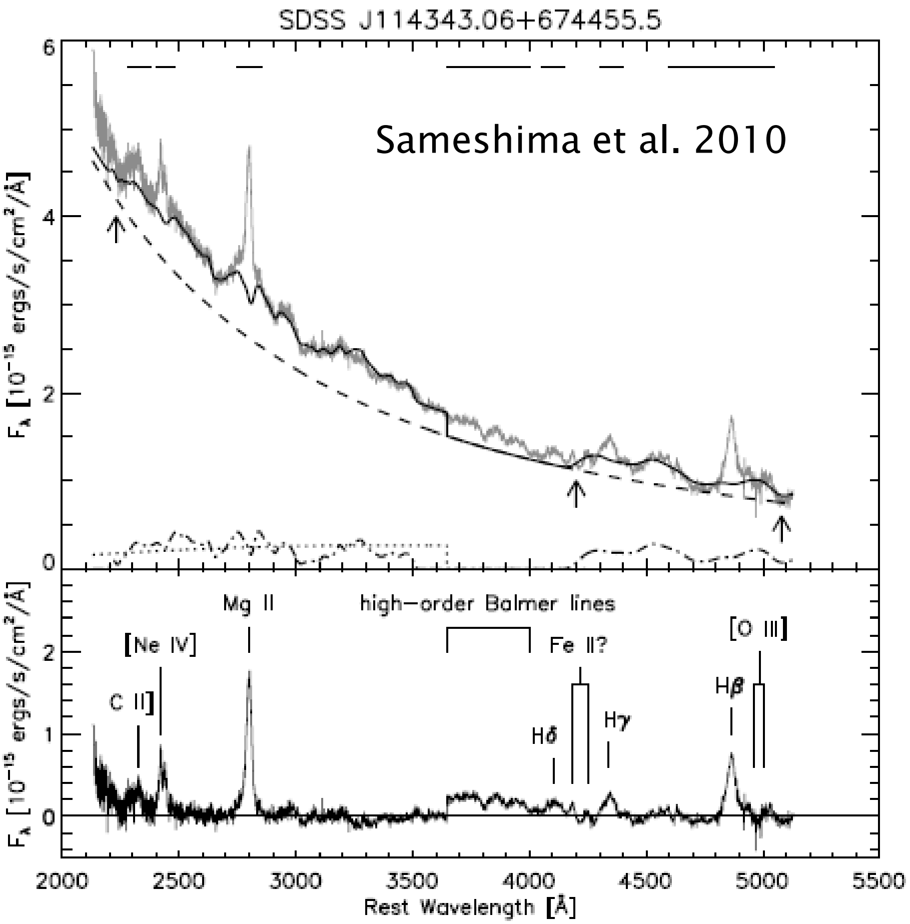
$$F_\lambda^{cont} = F_{5100}\left(\frac{\lambda}{5100}\right)^\alpha + F_{BaC}B_\lambda(T_e)\left[1 - \exp\left\{-\tau_{BE}\left(\frac{\lambda}{\lambda_{BE}}\right)^3\right\}\right]$$

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

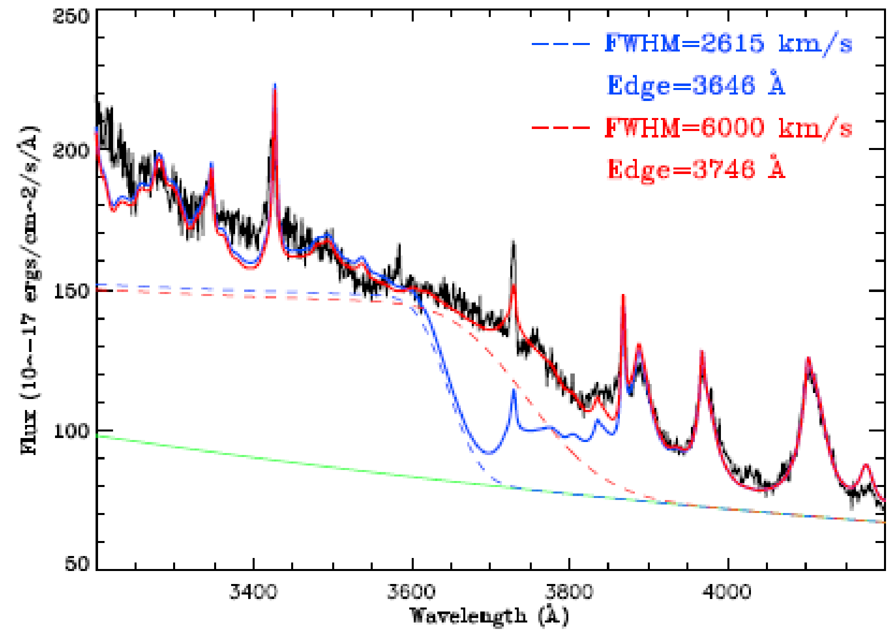


Balmer continuum fitting: Problems

Tsuzuki et al. 2006,
Sameshima et al. 2010



Jin et al. 2012



$$F_\lambda^{BC} = F_\lambda^{BE} e^{hc/(\lambda_{BE} k T_e)} \int_0^{+\infty} e^{-hc/(\lambda k T_e)} G(\lambda_1 - \lambda) d\lambda_1 \quad (2)$$

Convolving Balmer continuum equation with Gaussian (FWHM Gaussian = FWHM broad Hβ)

Our model of Balmer continuum

- We try to make model which:

  – we could use for fitting spectra within **2900 A – 5500 A** range (with two continuum windows). It could be done by reducing number of free parameters: **calculating** the intensity of Balmer continuum!

  – we try to make good fit near Balmer edge (3646 A)!

Our model consists of:

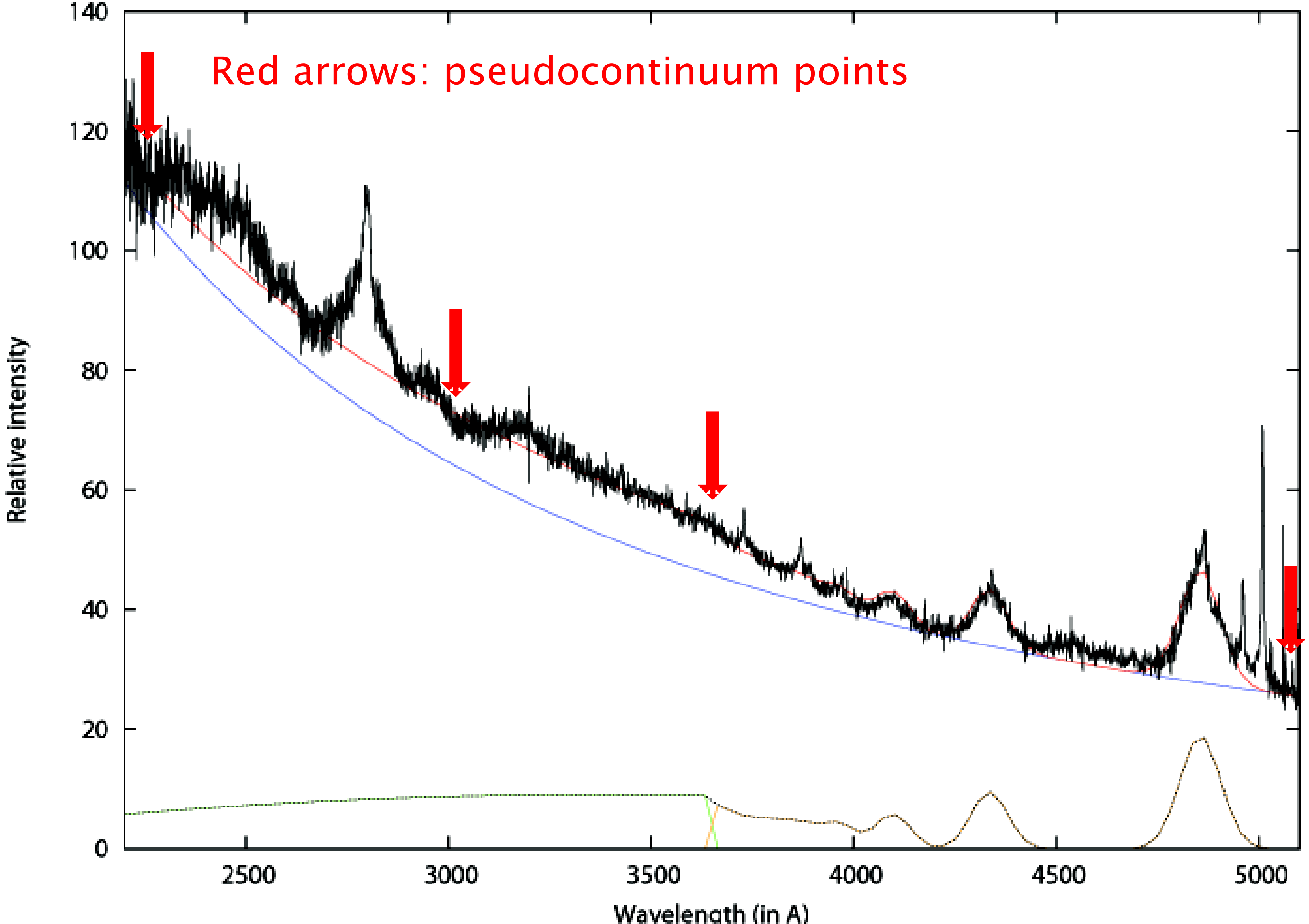
Power law + Balmer continuum (λ<3646A) + **high order Balmer lines** (n=3-400), (λ>3646A)

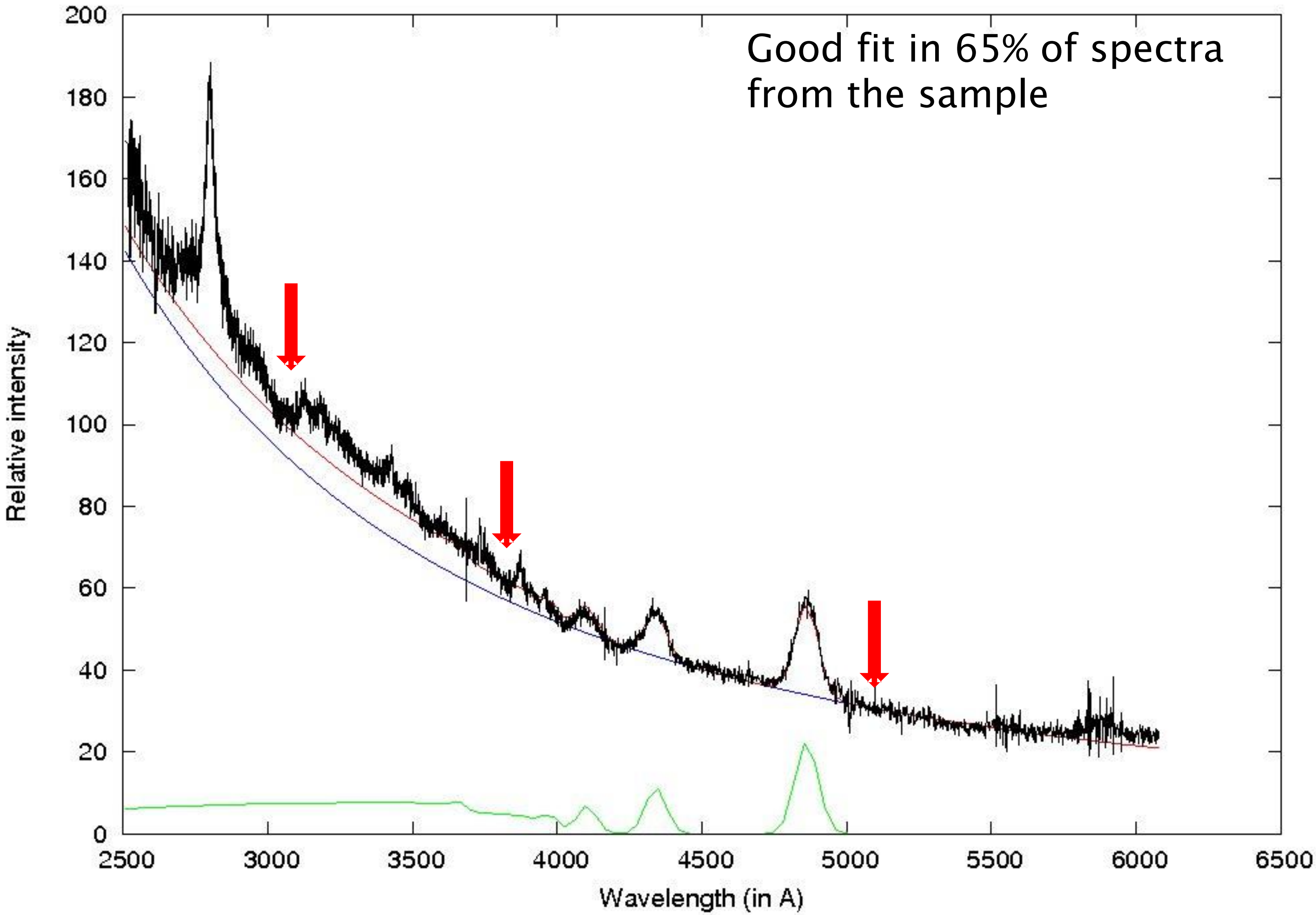
They are fitted by one Gaussian with the same width and shift as Hγ.
The relative intensites for Balmer lines with **n<50** are taken from the paper: Storey and Hummer 1995.
Relative intensities for **50<n<400** are calculated using approximate formula:

$$\frac{I_1}{I_2} = \frac{b_1(T,N_e)}{b_2(T,N_e)}\left(\frac{\lambda_2}{\lambda_1}\right)^3 \frac{f_1}{f_2}\cdot\frac{g_1}{g_2}\cdot e^{-(E1-E2)/kT}$$

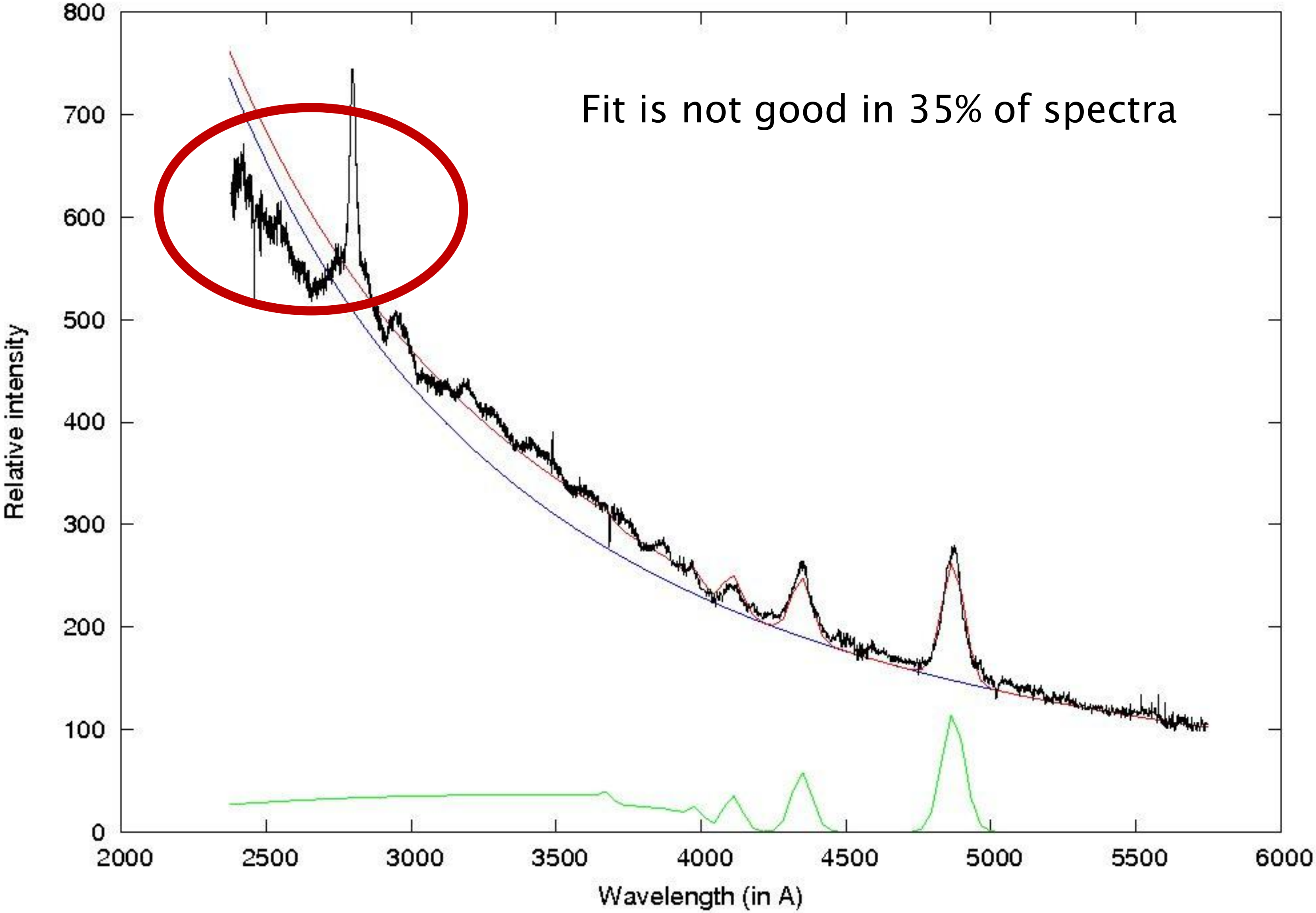
≈1

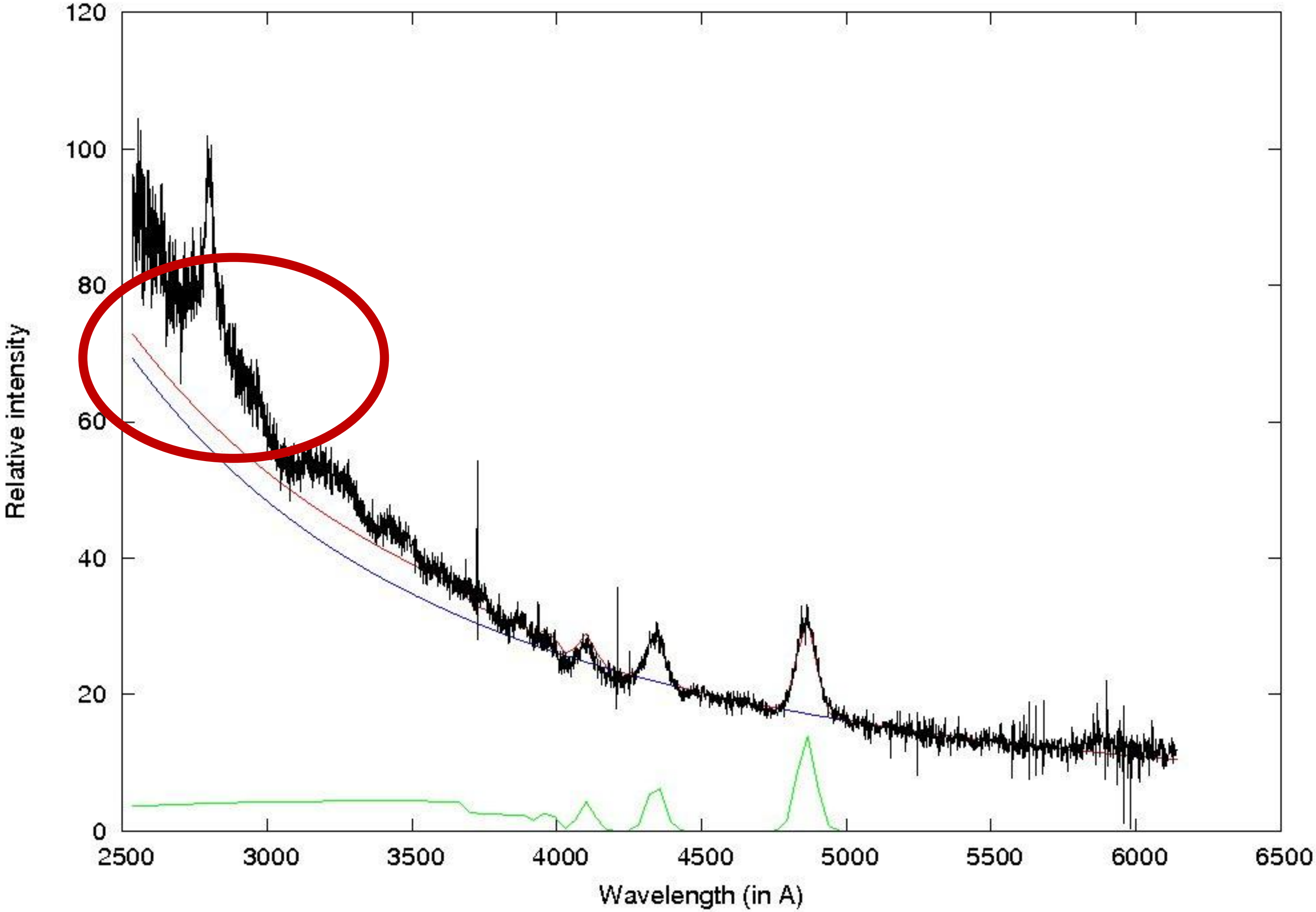
Examples of fit:





Good fit in 65% of spectra from the sample
Relative intensity
Wavelength (in A)
0
20
40
60
80
100
120
140
160
180
200
2500
3000
3500
4000
4500
5000
5500
6000
6500


Fit is not good in 35% of spectra
Relative intensity
Wavelength (in A)
800
700
600
500
400
300
200
100
0
2000
2500
3000
3500
4000
4500
5000
5500
6000



Relative intensity
Wavelength (in A)
0
20
40
60
80
100
120
2500
3000
3500
4000
4500
5000
5500
6000
6500

4. Results

4.3 Contribution of starbursts to AGN spectra: the broad line AGNs

– Some indications that AGN+starbursts could coexist in one phase of evolution (Wang & Wei 2006, 2008, Mao et al. 2009).

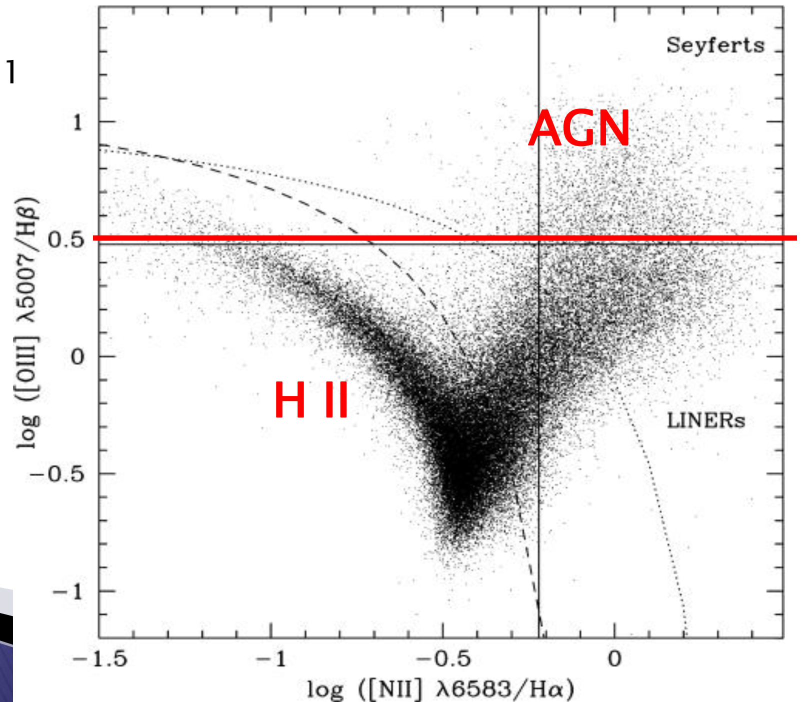
– NLSy 1: Starburst contribution in narrow lines (Mao et al. 2009)

Division of the sample by different source of ionization:

- Diagnostic BPT diagram (Baldwin, Philips Terlevich 1981)
- We adopt division: $R \lessgtr \log([O\ III]_{5007}/H\beta)$

Kewley et al. 2001, ApJ, 556, 121

Kauffmann et al. 2003, MNRAS, 346, 1055



4. Results

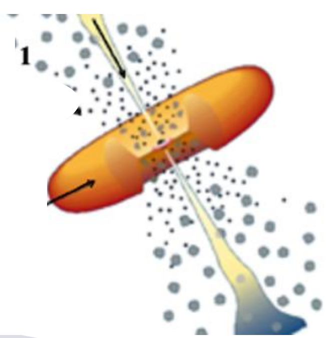
4.3 Contribution of starbursts to AGN spectra: AGNs type 1!

$$R = \log([O\ III]_{5007}/H\beta\ NLR)$$

R > 0.5

“pure AGN”

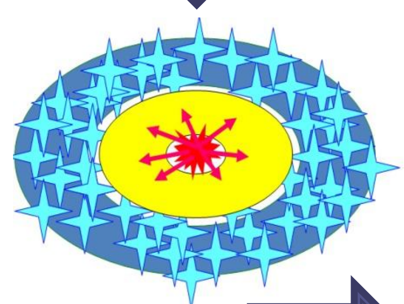
207 objects

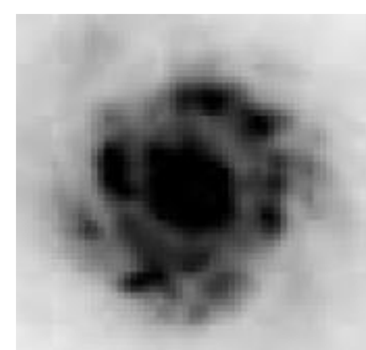


R < 0.5

”AGN+ starburst”

95 objects





Mrk 493, HST

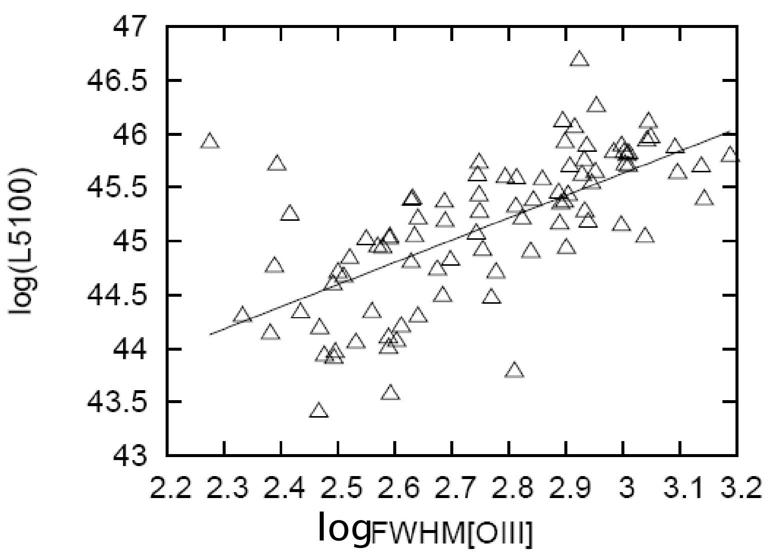
3.4 Division of the sample according the different source of ionization

- We try to check is this division **criterium** correct: R $\log([\mathrm{O\ III}]/\mathrm{H}\beta_{NLR}) \lessapprox 0.5$

- Brungardt 1988 observed the correlation between L_{cont} and FWHM [O III] for starbursts.

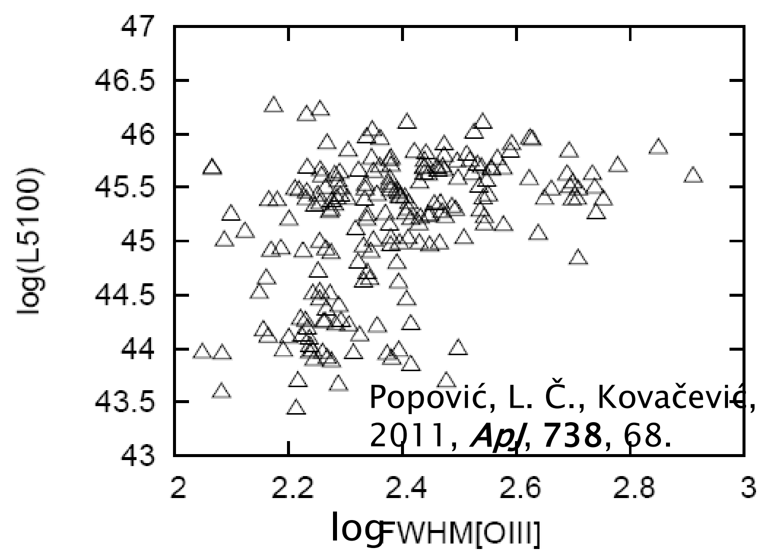
R < 0.5

“starburst+AGN” subsample



R > 0.5

“pure AGN” subsample



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Confirmation of criteria:

R= $\log([\mathrm{O\ III}]/\mathrm{H}\beta_{NLR}) \lessapprox 0.5$

Popović, L. Č. & Kovačević, J., 2011, *ApJ*, **738**, 68.

4. Results:

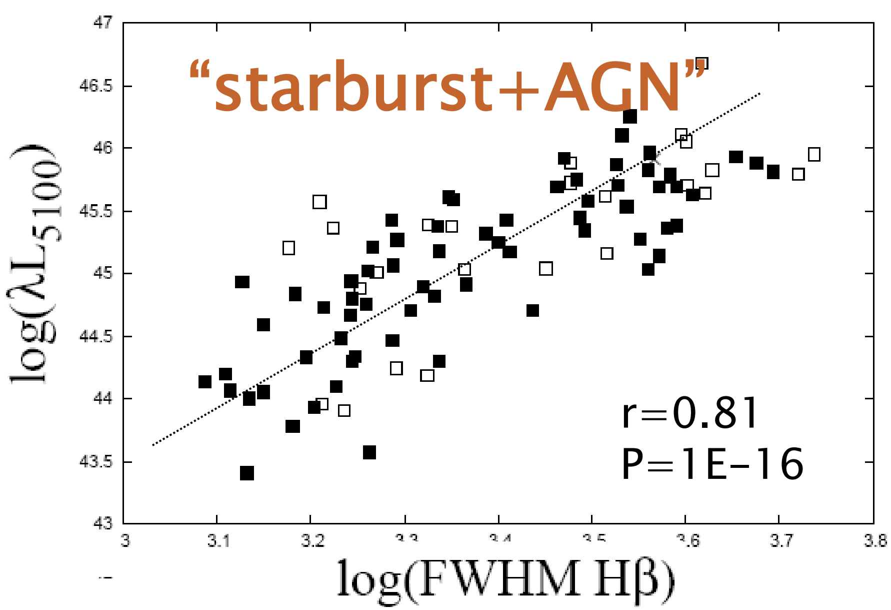
4.1 Differences between spectral properties of “pure AGN” and “starburst+AGN” subsample (R= $\log([\mathrm{O\ III}]/\mathrm{H}\beta_{NLR}) \lesssim 0.5$)

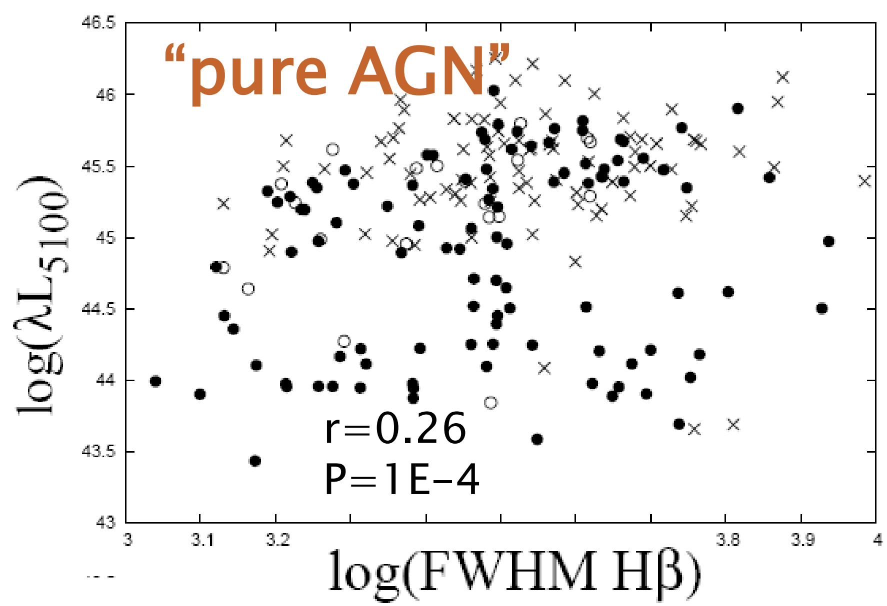
Spectral Parameter	$\log(\lambda L_{5100})$ *r*	*P*	log(FWHM Hβ) *r*	*P*	log(EW [O III]) *r*	*P*	log(EW Fe II) *r*	*P*	log(EW Hβ NLR) *r*	*P*	log(EW Hβ broad) *r*	*P*	log(FWMI 10% Hβ) *r*	*P*
	Total sample		0.42	2.3E-14	−0.45	2.2E-16	0.27	1.6E-6	−0.41	9.4E-14	0.14	0.02	0.43	5.1E-15
$\log(\lambda L_{5100})$	(1)		0.26	1.1E-4	−0.51	3.6E-15	0.29	2.4E-5	−0.56	0	−0.03	0.67	0.29	2.3E-5
	(2)		0.81	0	−0.46	4.2E-6	0.26	0.01	−0.27	0.01	0.56	9E-9	0.81	0
	0.42	2.3E-14	Total sample		−0.07	0.24	−0.24	2.3E-5	−0.34	1.5E-9	0.48	0	0.90	0
log(FWHM Hβ)	0.26	1.1E-4	(1)		−0.08	0.24	−0.37	3.2E-8	−0.25	1.9E-4	0.38	1.2E-8	0.88	0
	0.81	0	(2)		−0.42	4.1E-5	0.26	0.01	−0.15	0.16	0.53	4.8E-8	0.89	0
	−0.45	2.2E-16	−0.07	0.24	Total sample		−0.41	6.8E-14	0.32	2.1E-8	0.24	2.4E-5	−0.05	0.38
log(EW [O III])	−0.51	3.6E-15	−0.08	0.24	(1)		−0.38	7.9E-9	0.73	0	0.26	1.1E-4	−0.05	0.51
	−0.46	4.2E-6	−0.42	4.1E-5	(2)		−0.27	0.01	0.53	5.9E-8	−0.11	0.29	−0.48	1.5E-6
	0.27	1.6E-6	−0.24	2.3E-5	−0.41	6.8E-14	Total sample		−0.01	0.80	0.07	0.23	−0.26	6.3E-6
log(EW Fe II)	0.29	2.4E-5	−0.37	3.2E-8	−0.38	7.9E-9	(1)		−0.28	3.9E-5	0.04	0.57	−0.38	1.4E-8
	0.26	0.01	0.26	0.01	−0.27	0.01	(2)		−0.04	0.67	0.49	9.4E-7	0.27	0.01
	−0.41	9.4E-14	−0.34	1.5E-9	0.32	2.1E-8	−0.01	0.80	Total sample		−0.16	0.005	−0.36	1.6E-10
log(EW Hβ NLR)	−0.56	0	−0.25	1.9E-4	0.73	0	−0.28	3.9E-5	(1)		0.08	0.23	−0.25	2.4E-4
	−0.27	0.01	−0.15	0.16	0.53	5.9E-8	−0.04	0.67	(2)		−0.21	0.05	−0.21	0.05
	0.14	0.02	0.48	0	0.24	2.4E-5	0.07	0.23	−0.16	0.005	Total sample		0.50	0
log(EW Hβ broad)	−0.03	0.67	0.38	1.2E-8	0.26	1.1E-4	0.04	0.57	0.08	0.23	(1)		0.42	1.5E-10
	0.56	9E-9	0.53	4.8E-8	−0.11	0.29	0.49	9.4E-7	−0.21	0.05	(2)		0.49	6.4E-7
	0.43	5.1E-15	0.90	0	−0.05	0.38	−0.26	6.3E-6	−0.36	1.6E-10	0.50	0	Total sample	
log(FWMI 10% Hβ)	0.29	2.3E-5	0.88	0	−0.05	0.51	−0.38	1.4E-8	−0.25	2.4E-4	0.42	1.5E-10	(1)	
	0.81	0	0.89	0	−0.48	1.5E-6	0.27	0.01	−0.21	0.05	0.49	6.4E-7	(2)	

Popović, L. Č. & Kovačević, J., 2011, *ApJ*, **738**, 68.

4. Results:

Differences between spectral properties of “pure AGN” and “starburst+AGN” subsample





Popović, L. Č., & Kovačević, J., 2011, *ApJ*, **738**, 68.

4. Results:

4.1 Differences between spectral properties of “pure AGN” and “starburst+AGN” subsample – Baldwin effect!

- $L_{cont} \nearrow$ EW [O III] $\searrow$ EW Hβ NLR $\searrow$ ⟹ Stronger in **“pure AGN”** subsample
- $L_{cont} \nearrow$ EW Hβ broad $\nearrow$ ⟹ Only in **“AGN+starburst”** subsample

⟹ **Influence of starbursts to Baldwin effect correlations!**

Conclusions:

- The calculated optical iron template (4000 –5500 Å) gives **very good fit of Fe II** lines and enables detailed investigation of Fe II lines in AGN spectra.

- Model with high order Balmer lines n=3–400, for λ>3646A, **improve the fit near Balmer edge**, and enables **the calculation of the intensity of Balmer continuum.** This is specially important in case of using luminosity at 3000 A, for calculation of black hole mass.

- The presence of starbursts nearby AGNs, i.e. influence of additional source of ionization to AGN emission regions, reflects in some significantly different correlations between spectral properties. **Possible influence of starbursts to emission of broad lines?** (in that case – problem with measuring of black hole mass!)

- The Baldwin effect correlations depend on dominant source of ionization in a sample (accretion disc or starburst?).

THANK YOU FOR YOUR ATTENTION