



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

Jelena Kovačević¹, Luka Č. Popović¹, Milan S. Dimitrijević¹, Payaswini Saikia¹

¹ Astronomical Observatory Belgrade, Serbia

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

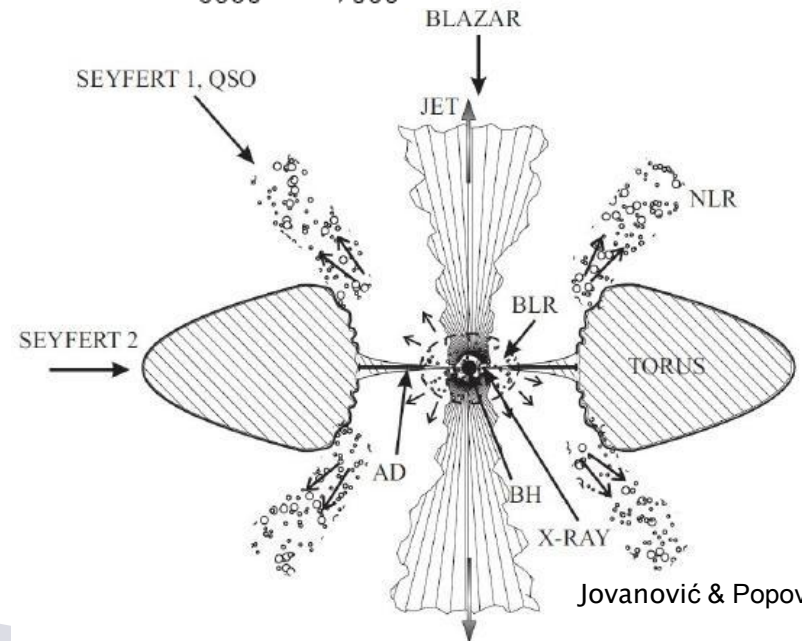
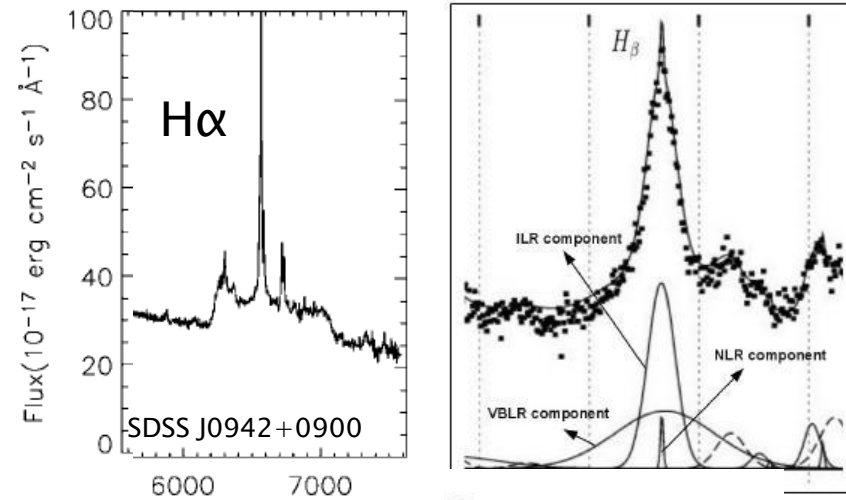
- ❑ Emission lines: **complex profiles!**
- ❑ Different components of emission lines are coming from different layers of emission regions.



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

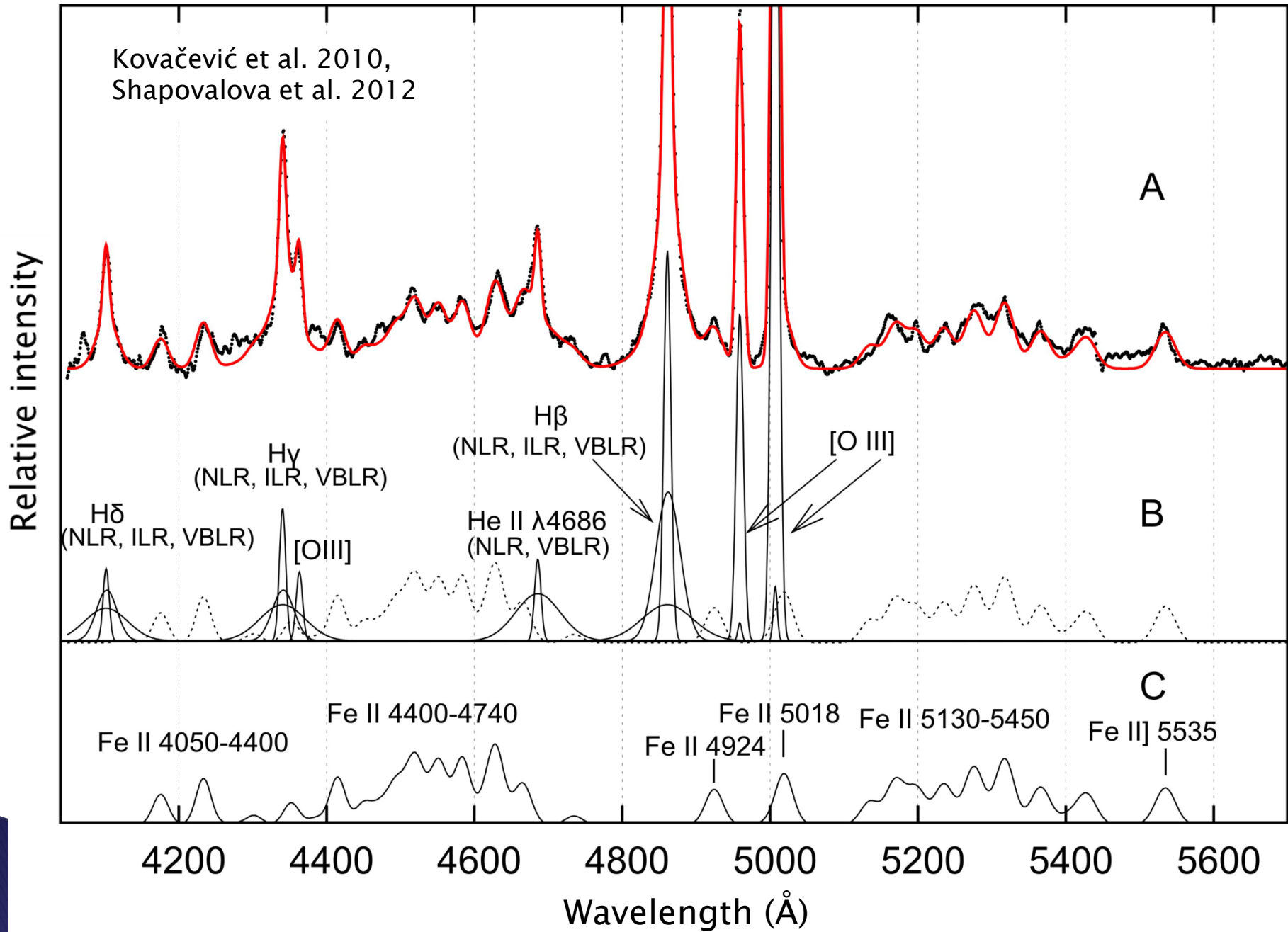


- ❑ Correlations between properties of different lines lead to better insight in the AGN structure, and kinematical and physical properties of gas in AGNs.



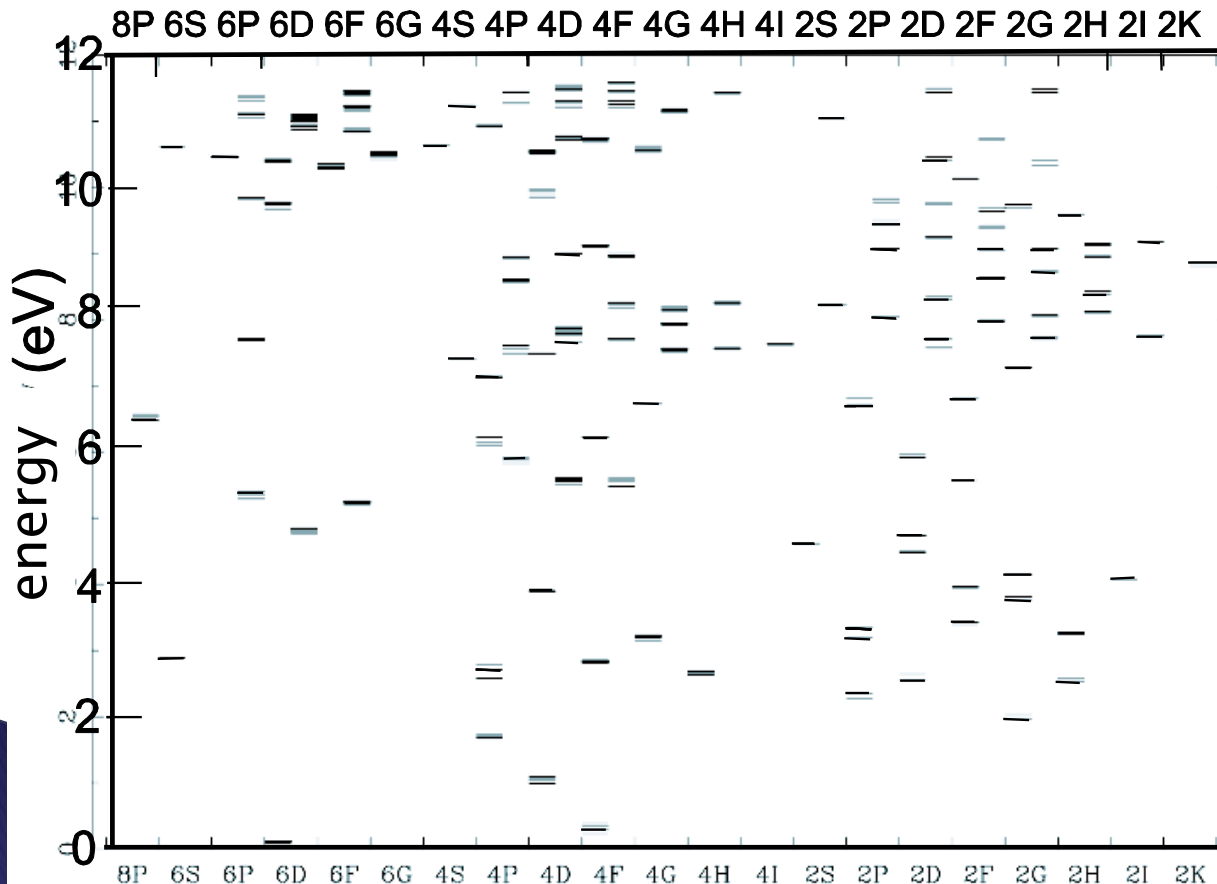
2. The sample and analysis

- ▶ 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 $z\text{Conf} > 0.95$
 4. Small contribution of stellar component: $\text{EW CaK } 3934, \text{Mg } 5177, \text{H}\delta < 1\text{\AA}$
 5. Presence of [O III] and broad $\text{H}\beta$ (EW [O III] and $\text{EW H}\beta > 0$)



2.1 Difficult identification of Fe II lines

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



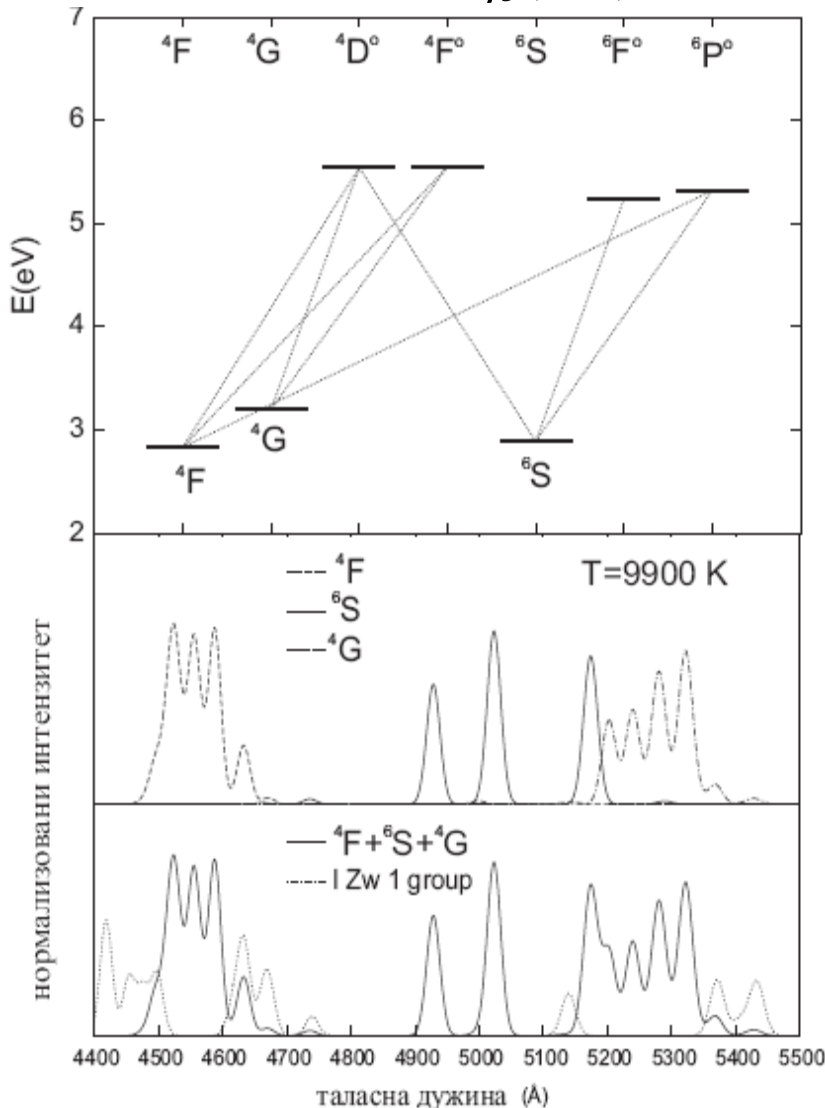
Sigut & Pradhan 2003:
827 energy levels,
23 000 transitions!

(data from Iron Project,
Hummer 1993)

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

2.2 The Fe II (4400–5500 Å) template

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



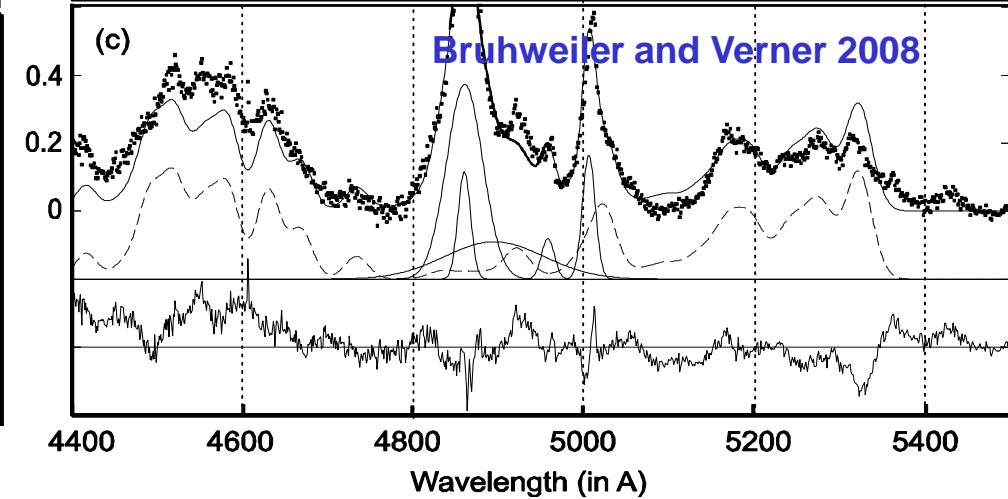
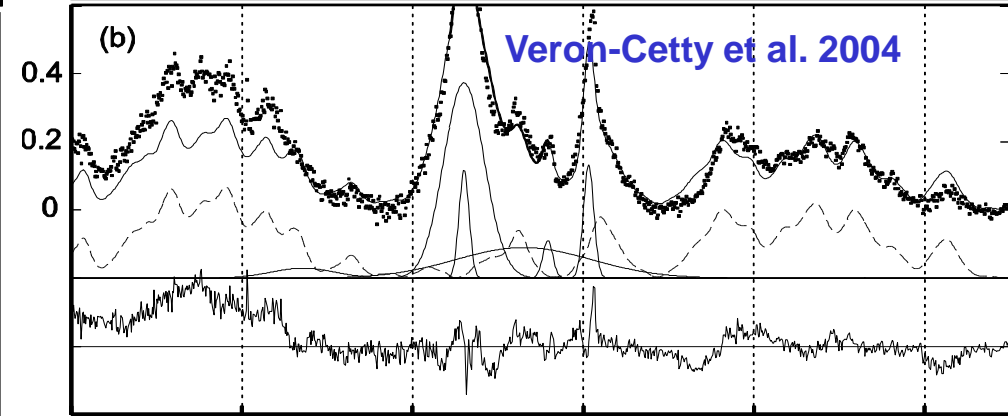
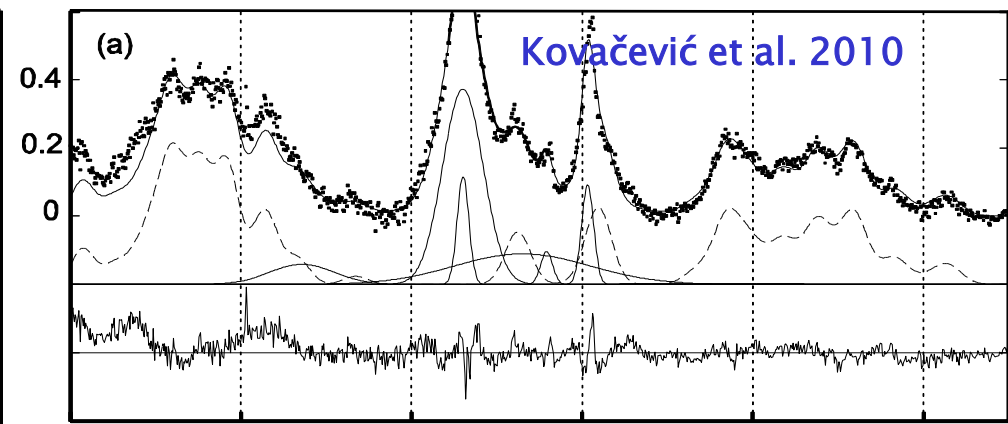
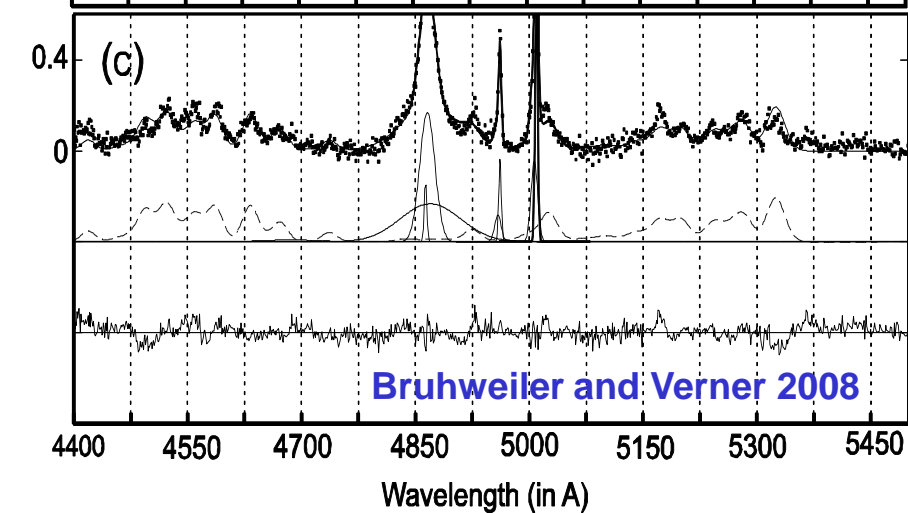
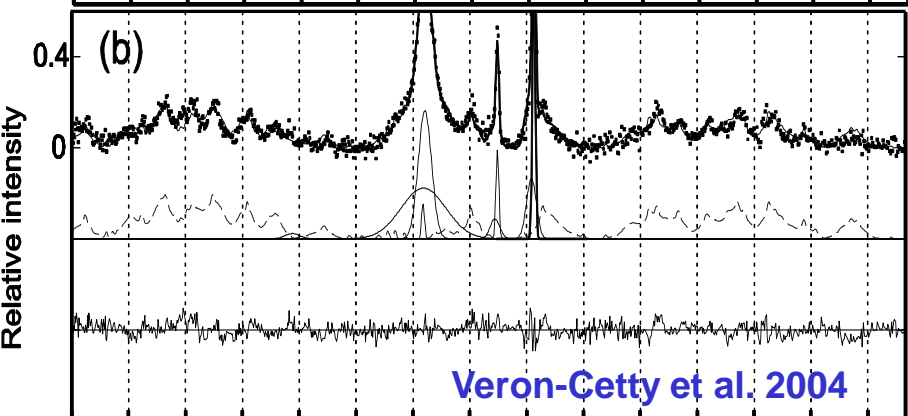
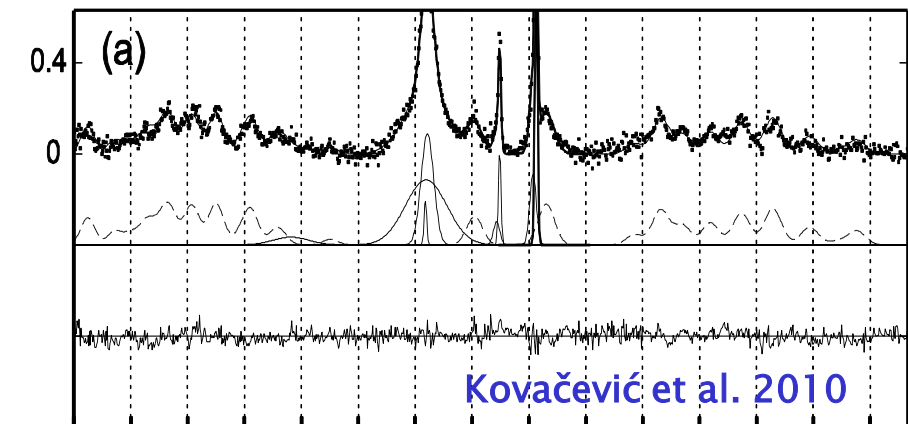
➤ Lower terms of Fe II transitions:

- (1) $3d^6 ({}^3F_2)4s {}^4F \longrightarrow$ **F group** (19 lines)
- (2) $3d^5 4s^2 {}^6S \longrightarrow$ **S group** (5 lines)
- (3) $3d^6 ({}^3G)4s {}^4G \longrightarrow$ **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:

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

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



Fe II (4000-5500 Å) 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](#)

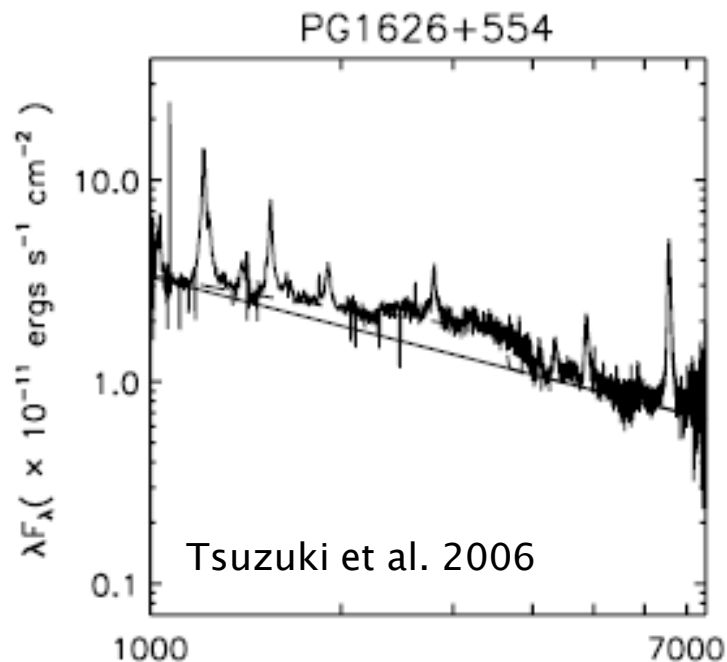
[Fe II template - download](#)

[Jelena Kovacevic](#)

3.1 Balmer continuum

- determination of the UV pseudocontinuum in the sample
- ▶ **Not easy** because of complex shape of UV pseudocontinuum:
Power law + Balmer continuum (Grandi 1982)

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

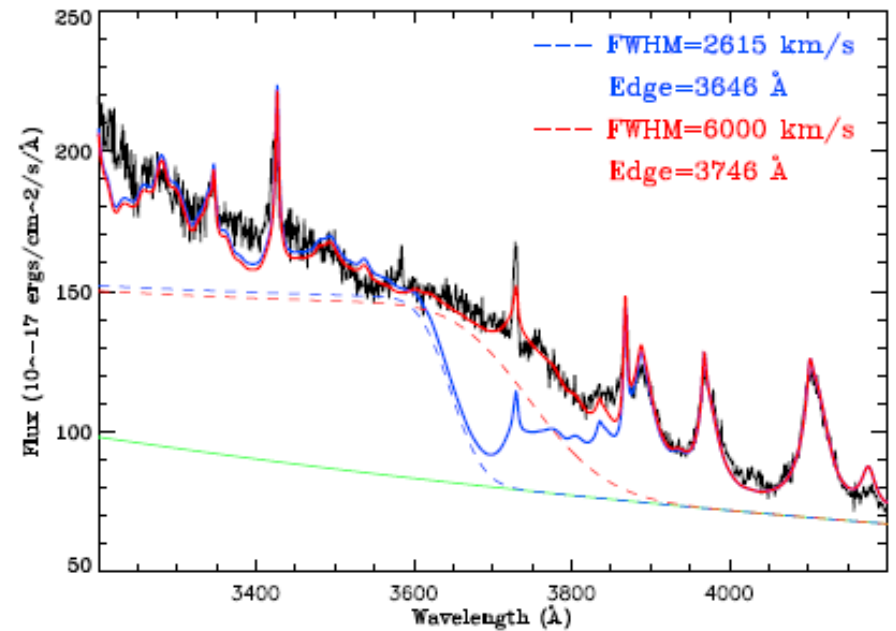
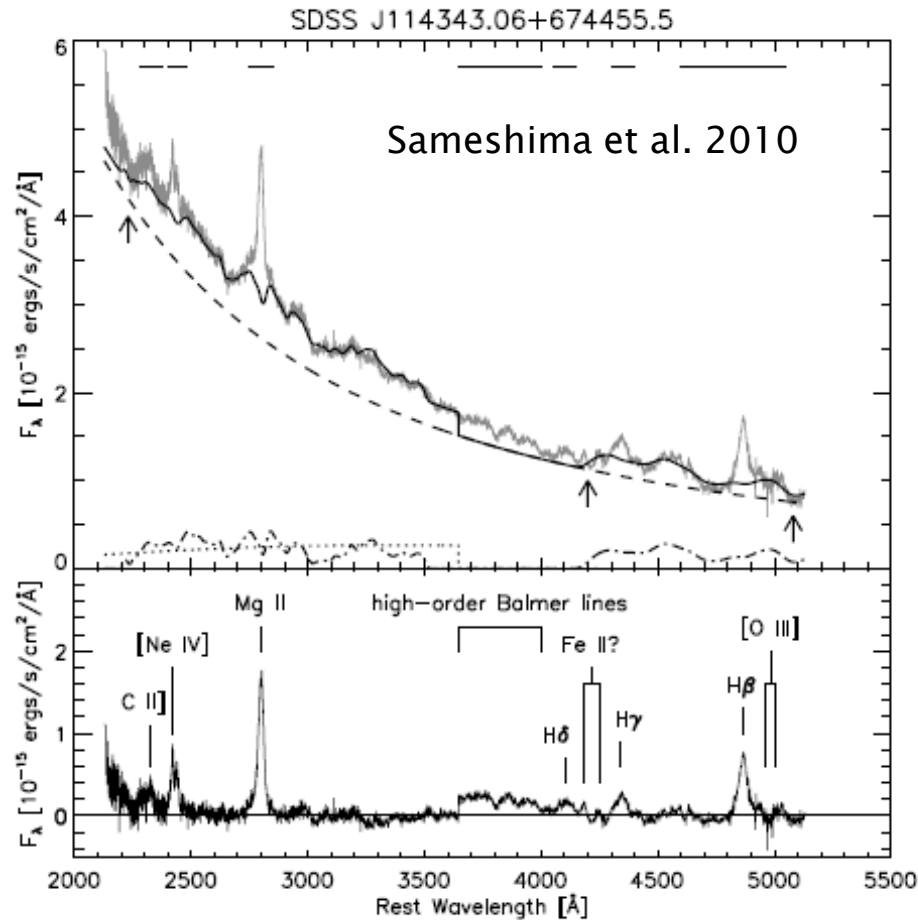


$$B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

Balmer continuum fitting: Problems

Tsuzuki et al. 2006,
Sameshima et al. 2010

Jin et al. 2012



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

Convolving Balmer continuum
equation with Gaussian
(FWHM Gaussian = FWHM broad H β)

Our model of Balmer continuum

▶ We try to make model which:

– we could use for fitting spectra within 2900 Å – 5500 Å 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 Å)!

Our model consists of:

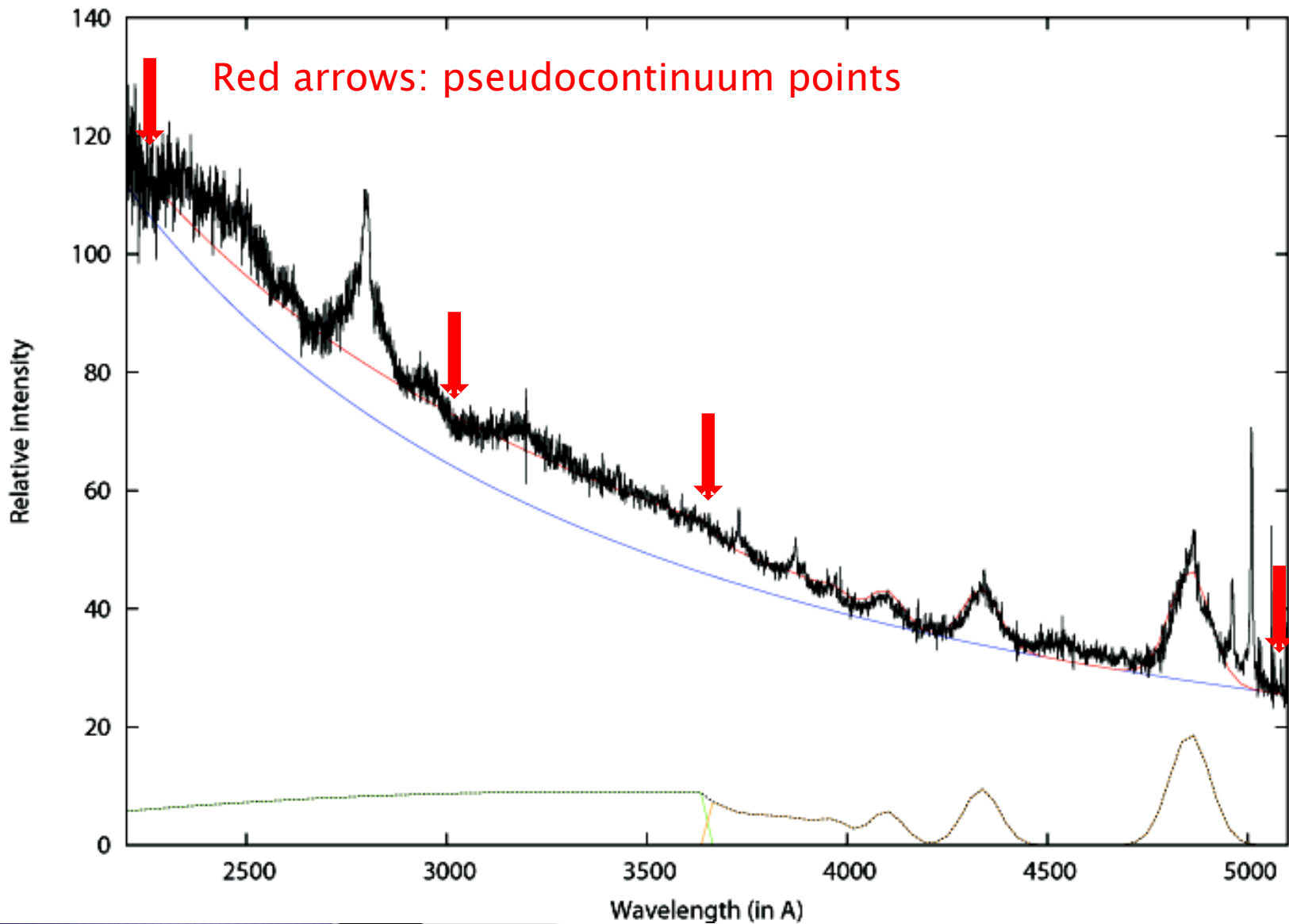
Power law + Balmer continuum ($\lambda < 3646\text{Å}$) + **high order Balmer lines ($n=3-400$), ($\lambda > 3646\text{Å}$)**

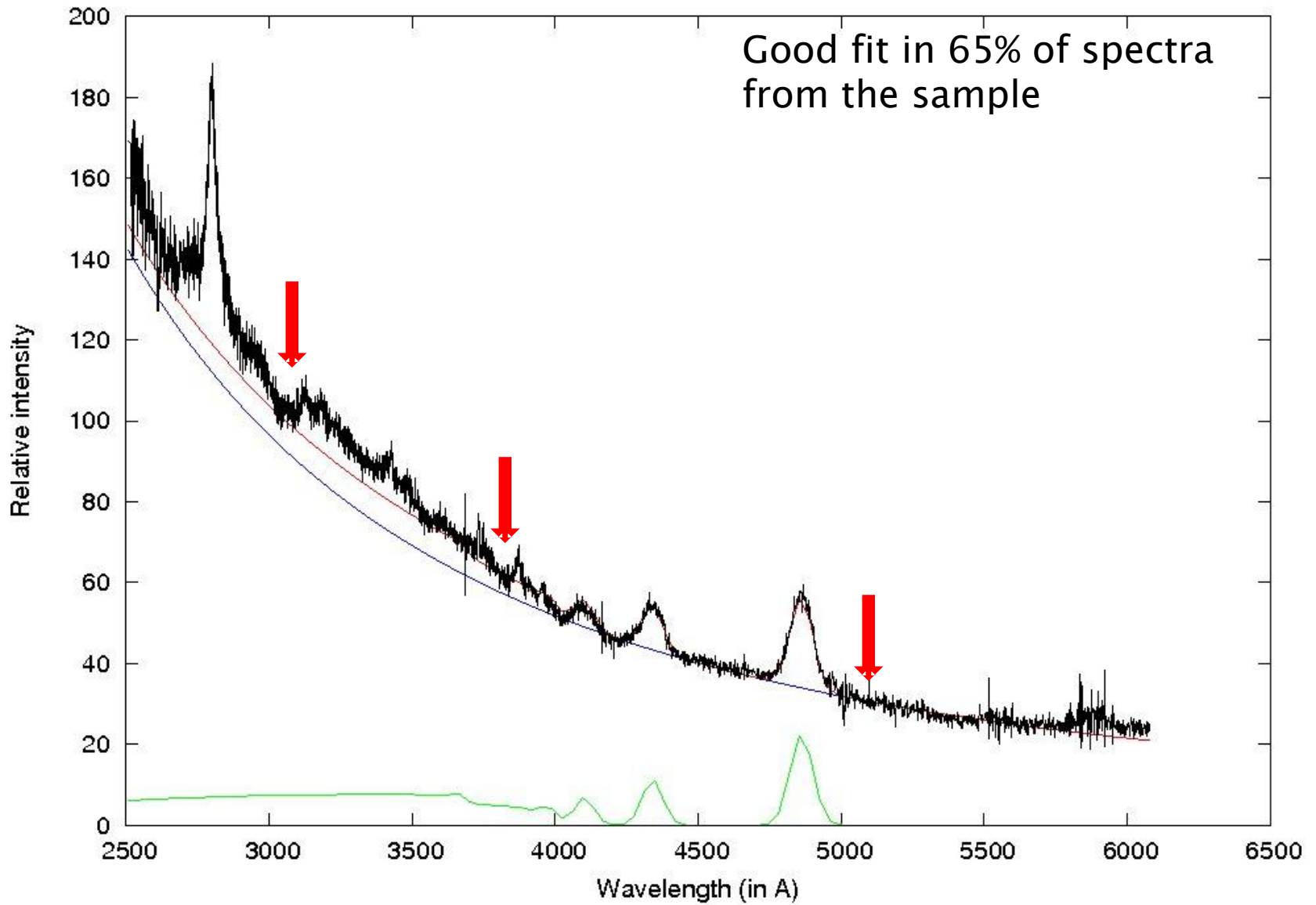
They are fitted by one Gaussian with the same width and shift as H γ .
The relative intensities for Balmer lines with **$n < 50$** are taken from the paper: Storey and Hummer 1995.

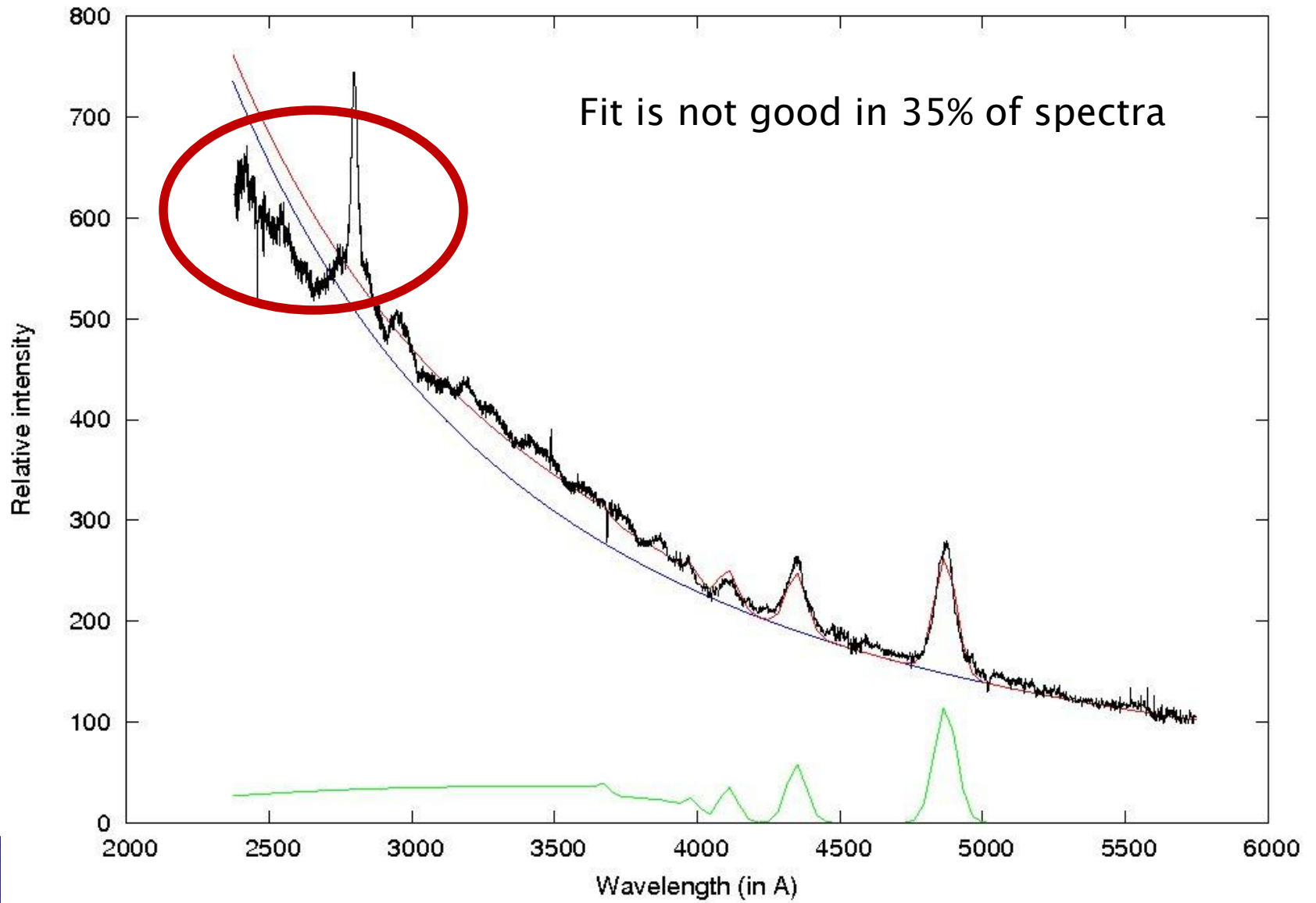
Relative intensities for **$50 < n < 400$** are calculated using approximate formula:

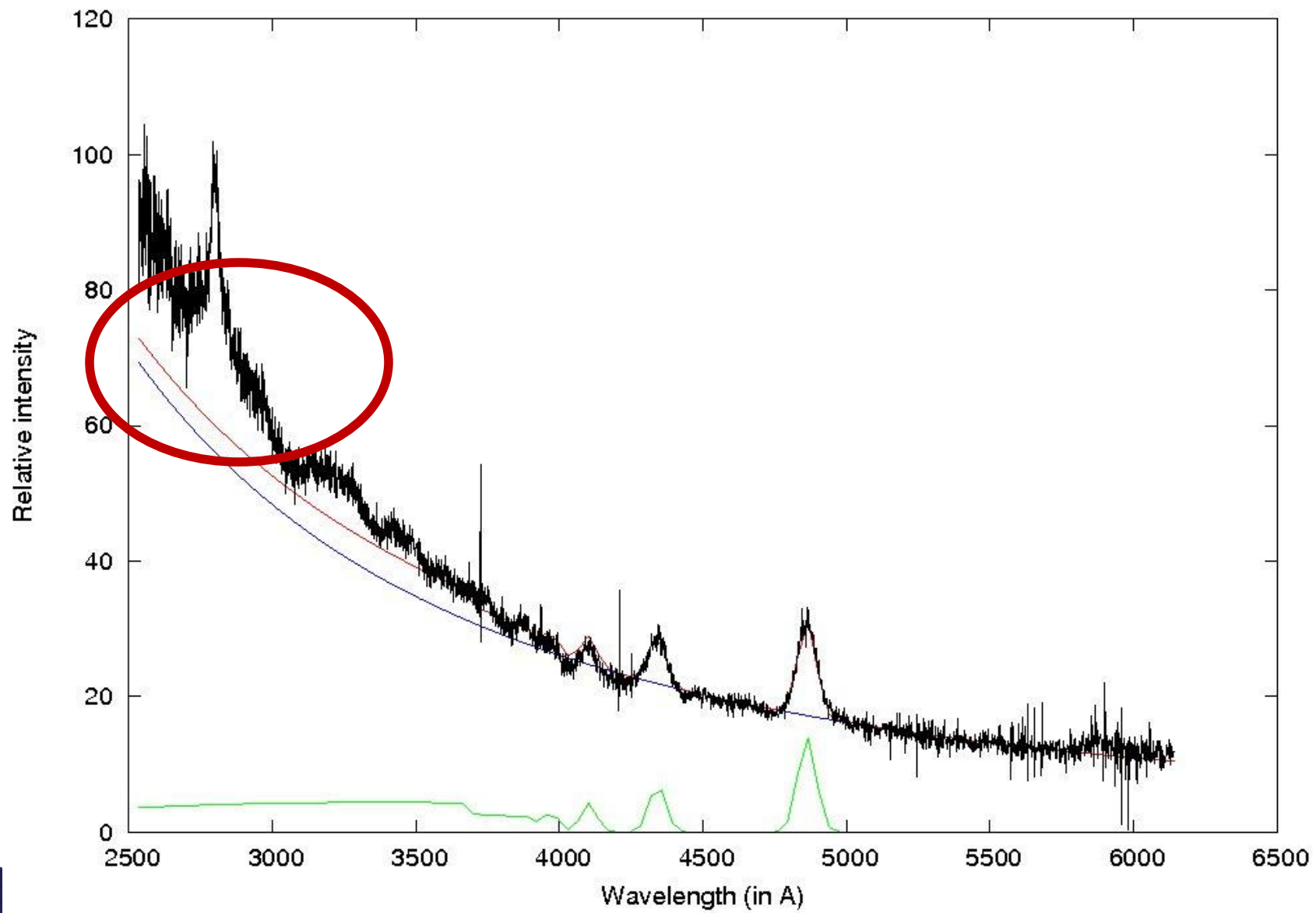
$$\frac{I_1}{I_2} = \frac{b_1(T, N_e)}{b_2(T, N_e)} \left(\frac{\lambda_2}{\lambda_1}\right)^3 \frac{f_1}{f_2} \cdot \frac{g_1}{g_2} \cdot e^{-(E_1 - E_2)/kT} \approx 1$$

Examples of fit:









4. Results

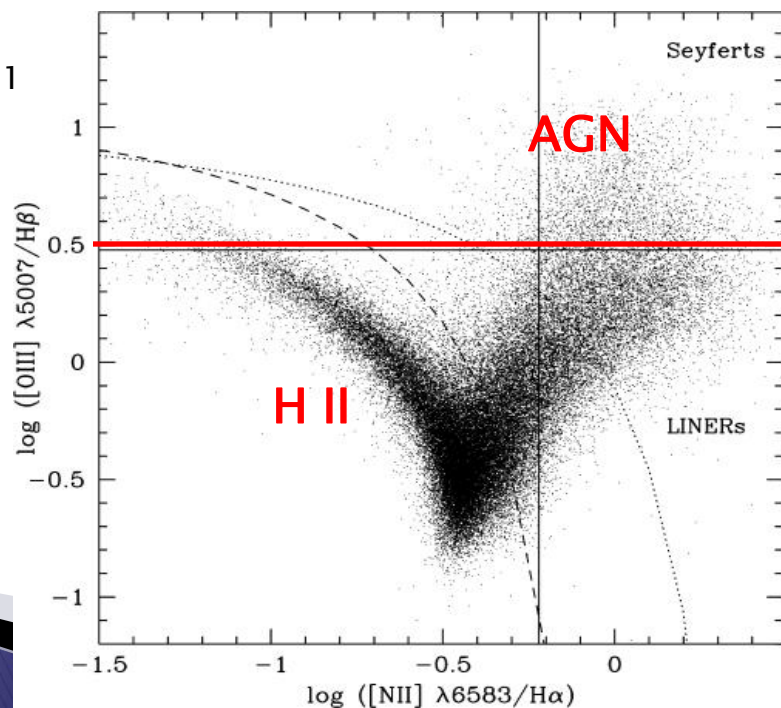
4.3 Contribution of starbursts to AGN spectra: the broad line AGNs

– 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: $R \lesssim \log([\text{O III}]_{5007}/\text{H}\beta)$



Kewley et al. 2001, ApJ, 556, 121

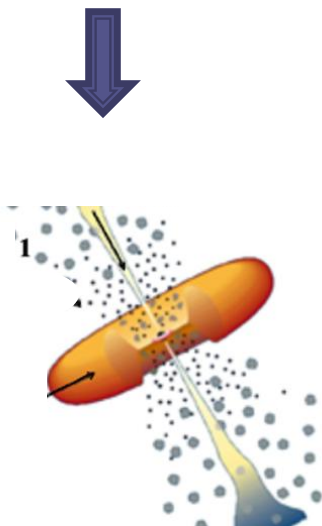
Kauffmann et al. 2003, MNRAS, 346, 1055

4. Results

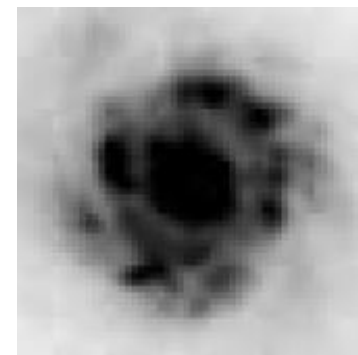
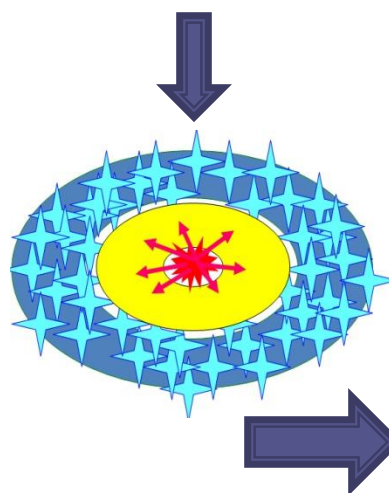
4.3 Contribution of starbursts to AGN spectra: AGNs type 1!

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

$R > 0.5$
"pure AGN"
207 objects



$R < 0.5$
"AGN+ starburst"
95 objects



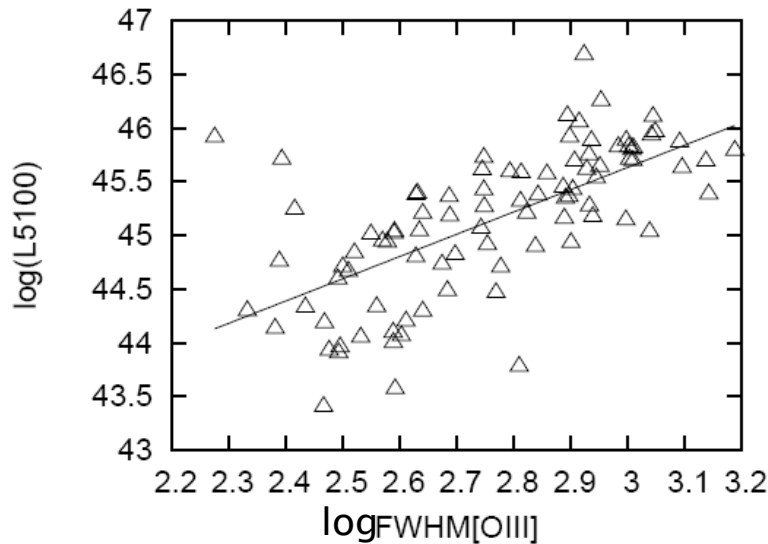
Mrk 493, HST

3.4 Division of the sample according the different source of ionization

- ▶ We try to check is this division criterium correct: $R \log([O III]/H\beta_{NLR}) \lesssim 0.5$
- ▶ Brungardt 1988 observed the correlation between L_{cont} and FWHM [O III] for starbursts.

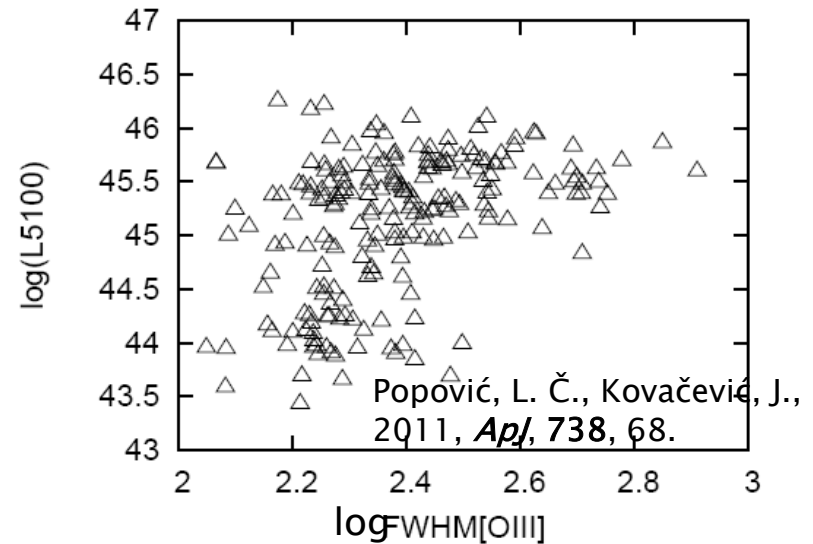
$R < 0.5$

“starburst+AGN” subsample



$R > 0.5$

“pure AGN” subsample



Confirmation of criteria:

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

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

4. Results:

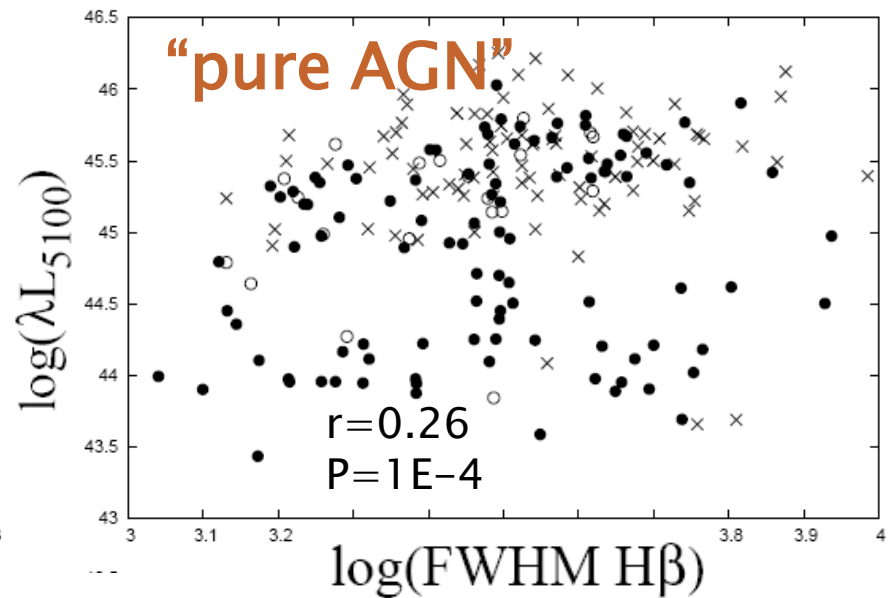
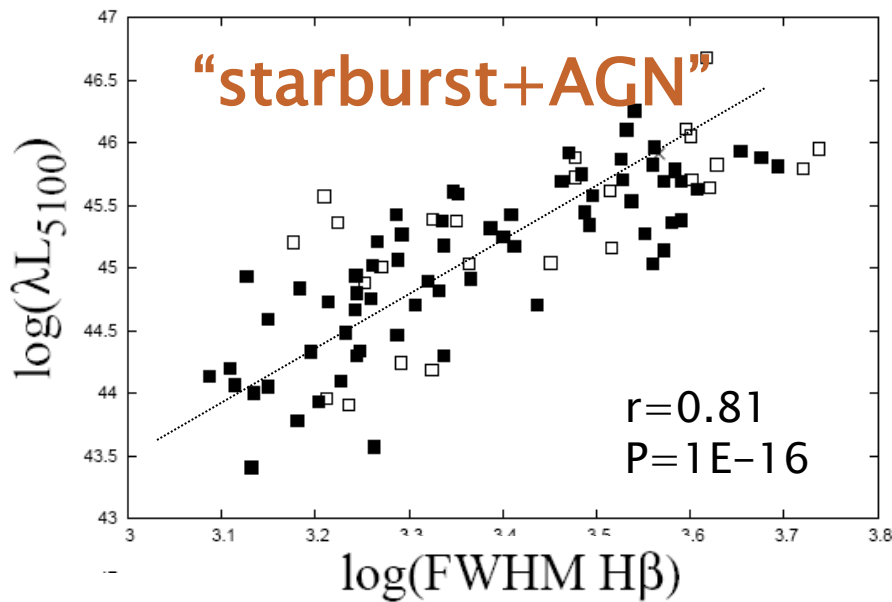
4.1 Differences between spectral properties of “pure AGN” and

“starburst+AGN” subsample ($R = \log([\text{O III}]/\text{H}\beta_{\text{NLR}}) \lesssim 0.5$)

Spectral Parameter	$\log(\lambda L_{5100})$		$\log(\text{FWHM H}\beta)$		$\log(\text{EW [O III]})$		$\log(\text{EW Fe II})$		$\log(\text{EW H}\beta \text{ NLR})$		$\log(\text{EW H}\beta \text{ broad})$		$\log(\text{FWMI 10\% H}\beta)$	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
$\log(\lambda L_{5100})$	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
	(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
$\log(\text{FWHM H}\beta)$	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
	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
$\log(\text{EW [O III]})$	-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
	-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
$\log(\text{EW Fe II})$	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
	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
$\log(\text{EW H}\beta \text{ NLR})$	-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
	-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
$\log(\text{EW H}\beta \text{ broad})$	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
	-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
$\log(\text{FWMI 10\% H}\beta)$	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	
	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)	

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}  EW [O III]  EW H β NLR   Stronger in “pure AGN” subsample
- ▶ L_{cont}  EW H β broad   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 $\lambda > 3646\text{Å}$, **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 Å, 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