Narrow line Sy 1 AGN Ark 564: long-term optical monitoring

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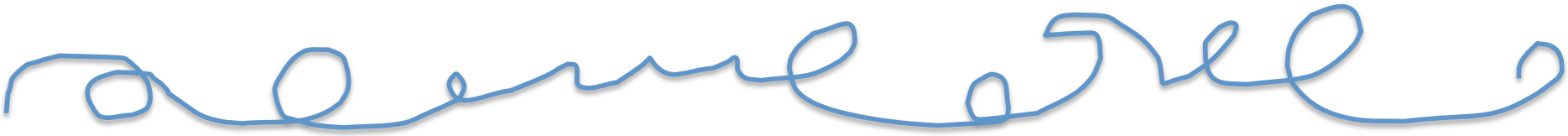
A. N. Burenkov, A. Kovačević, J. Kovačević, W. Kollatschny, V. H. Chavushyan, et al.



OUTLINE

- The possibilities and importance of the long term monitoring of AGN

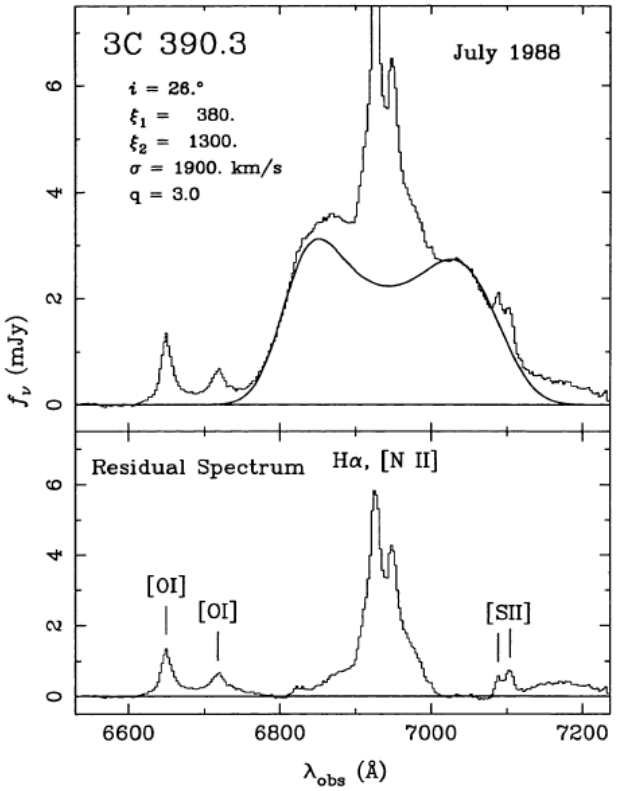
- Ark 564
  - Introduction
  - Observation and measurments
  - Results of the optical monitoring

Long-term monitoring

- PIs: Alla I. Shapovalova (Russia)
  Vahram H. Chavushyan (Mexico)
- constantly observing well known AGN:
  - NGC 5548 – 9 years (Shapovalova et al. 2004, Ilić 2007, Popović et al. 2008)
  - NGC 4151 – 11 years (Shapovalova et al. 2008, 2009, 2010a)
  - 3C390.3 – 13 years (Shapovalova et al. 2010b, Popović et al. 2011, Jovanović et al. 2010)
  - Ark 564 – 11 years (Shapovalova et al. 2012, submitted to ApJS)
  - Arp 102B – 12 years (in prep.)
- Study of variability: continuum flux, line shapes, line fluxes …

What Emission Lines can tell us?

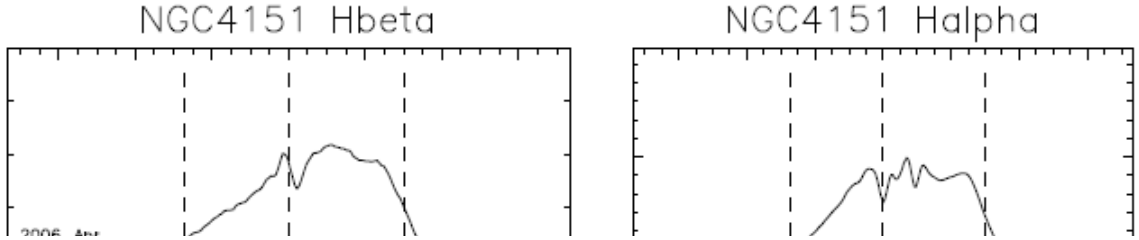
- Physical conditions of the region
  - temperature
  - density
  - ionization state
- Kinematics
  - velocities (line widths)
  - size (reverberation – time delays)
  - geometry (line shapes)

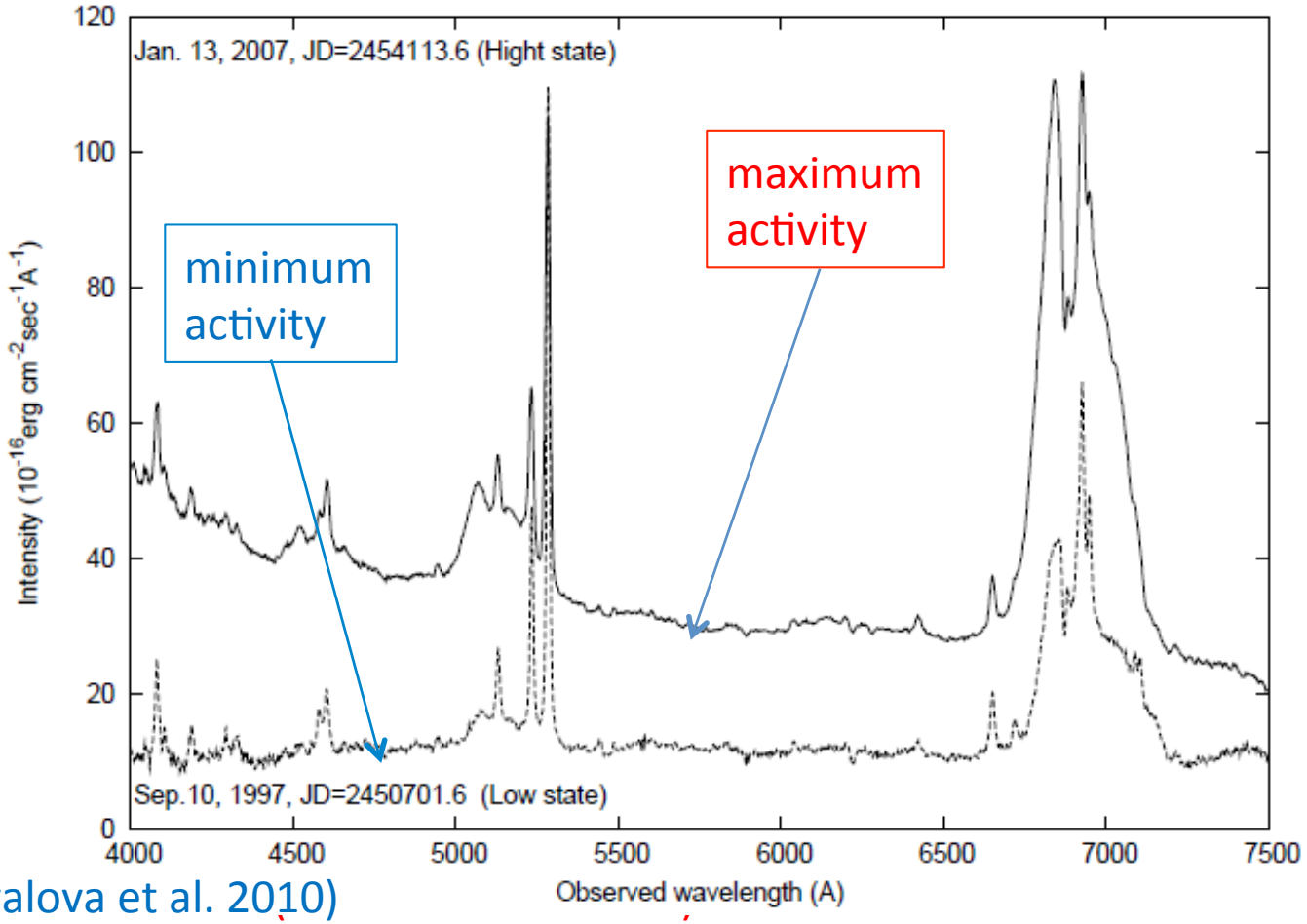


+ variability (line & continuum) + monitoring → powerful diagnostics

Why long-term monitoring?

- line flux and con
- change of AGN t
- line profile variability





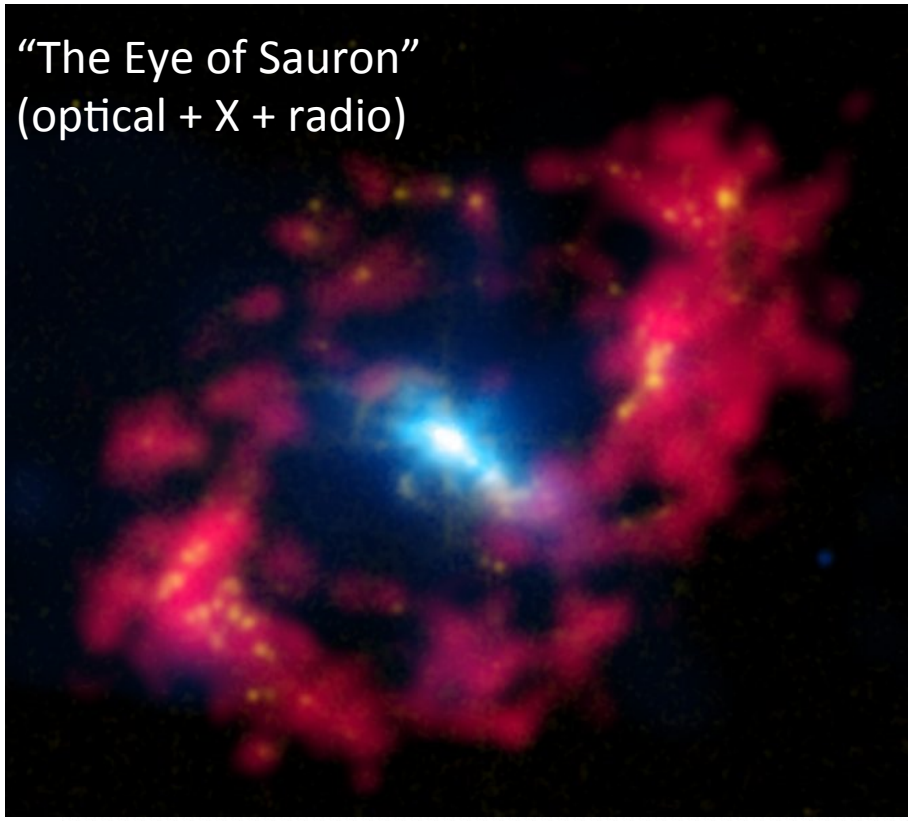
(Shapovalova et al.

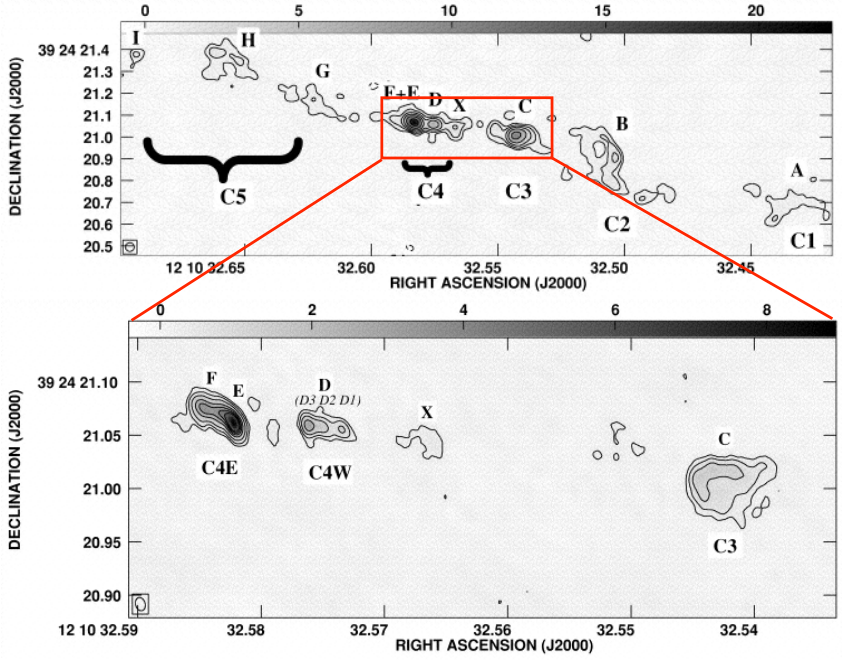
3c390.3 (Shapovalova et al. 2010)

Long-term monitoring: some results

NGC 4151

- bright active galaxy
- one of the closest
- variable continuum and emission line source (e.g. Peterson 1988; Sergeev et al. 2001)
- complex and unusual line profiles
- parsec scale radio-jet (Mundell et al. 2003; Ulvestad et al 2005)





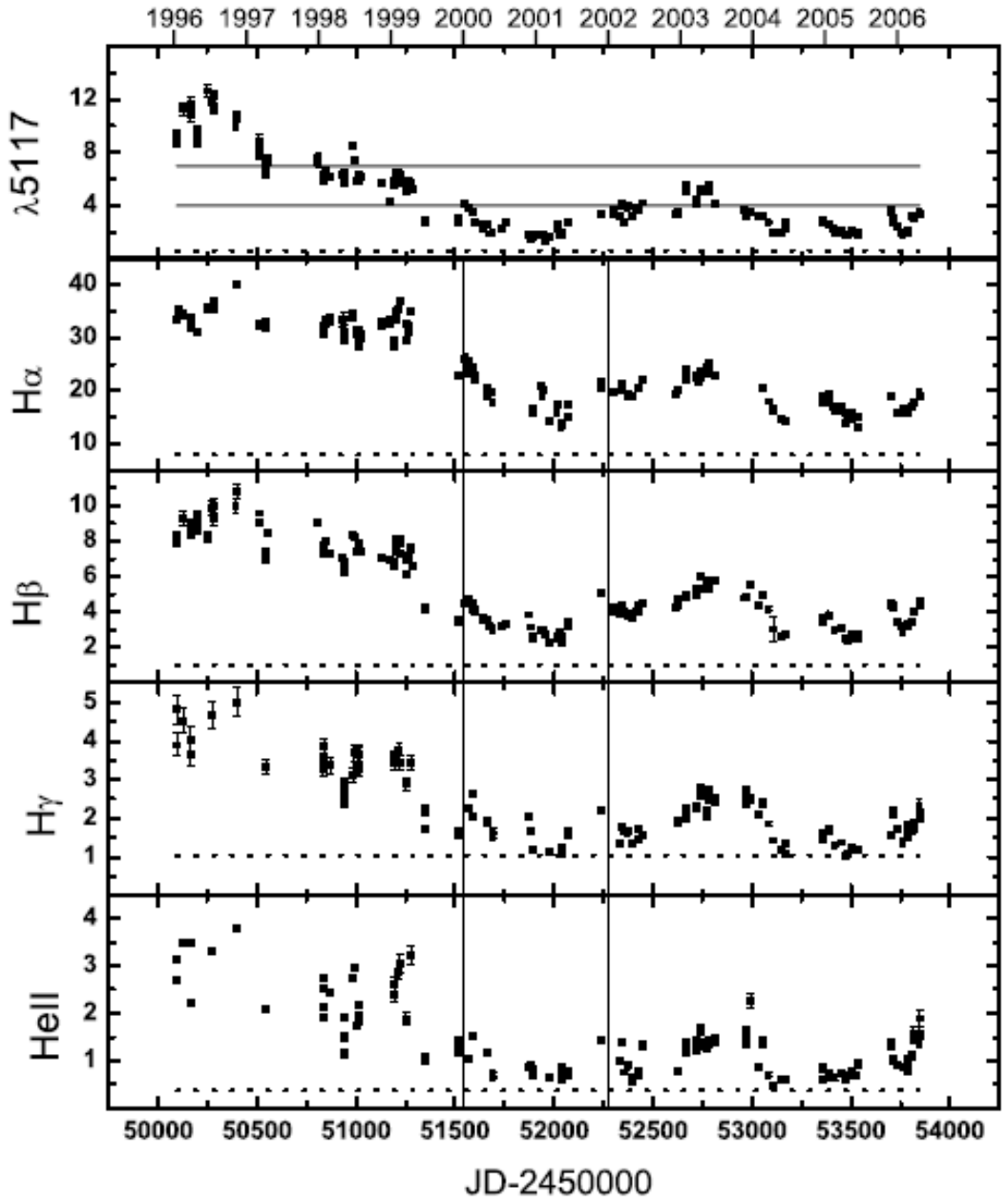
NGC 4151

- data from 11 years
- CCF analysis

⇒extremely compact BLR

⇒~ 0-2 light days!!

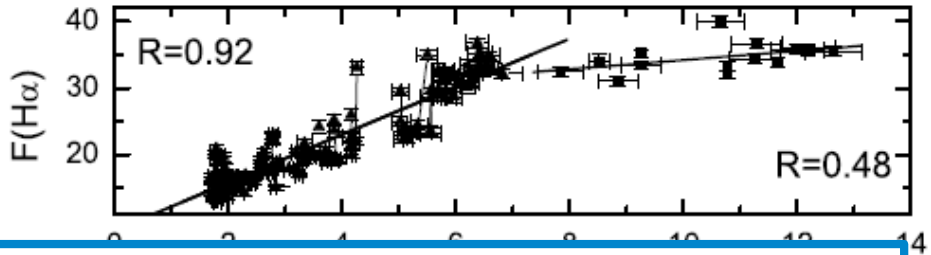
- 3 characteristic periods



Shapovalova et al. 2008, A&A, 486, 99

Shapovalova et al. 2010a, A&A, 509, 106

NGC 4151



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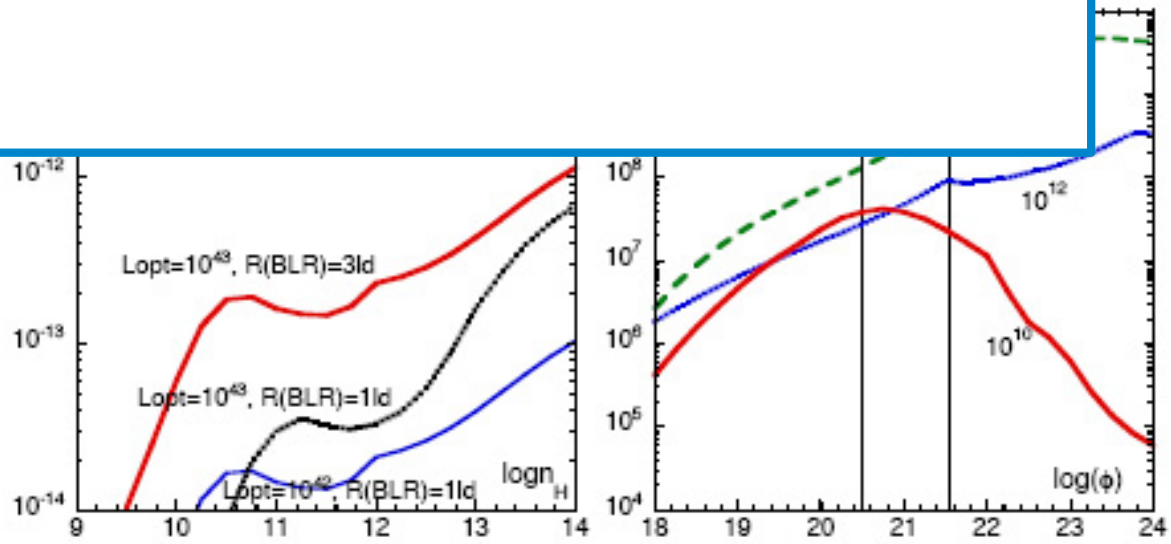
  contributes to the BEL
  (could be associated
  with radio jet)

Shapovalova, Popović,
et al. 2008, A&A, 486, 99

Could we apply the reverberation method to estimate

the mass of the black hole

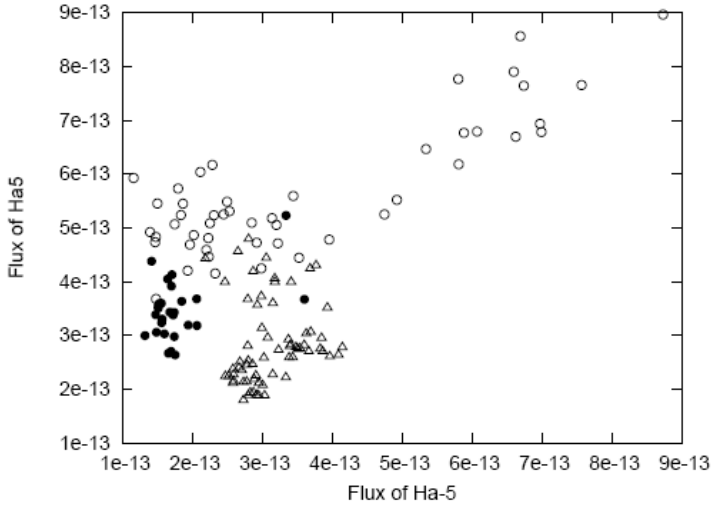
in case of NGC 4151?

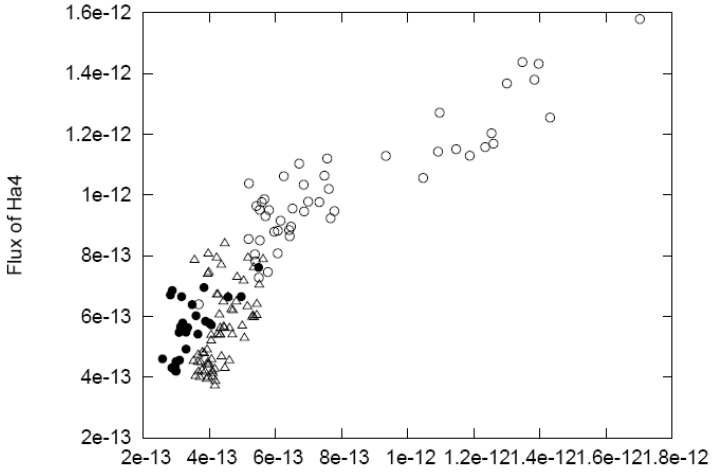


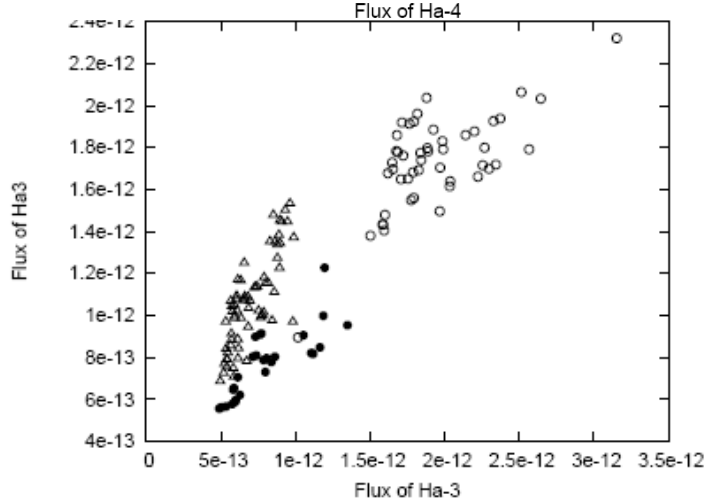
Line fluxes vs. density (left) and ionizing flux (right)

NGC 4151 – Hα line

- divide Hα lines into segments (e.g. segments -5,-4 are in the blue-wing)
- for different periods, red line segments respond differently than the symmetrical blue segments
- multi-component BLR with geometry changing during 11 years
- 3 kinematically different regions: blue wing and line core (jet or outflow), red wing (photoionization)



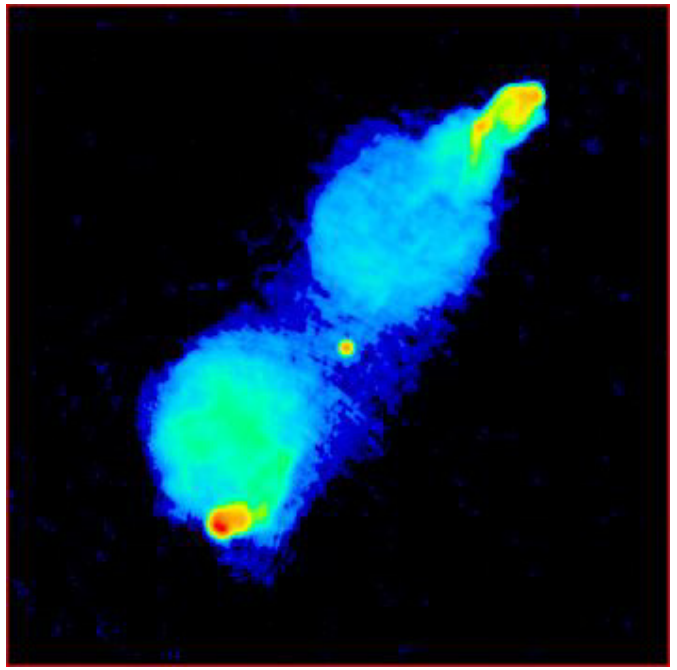


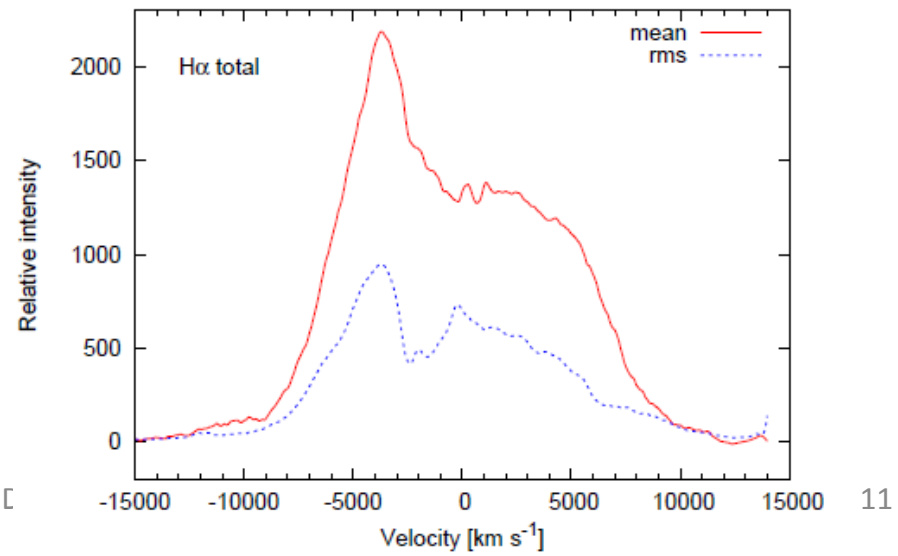


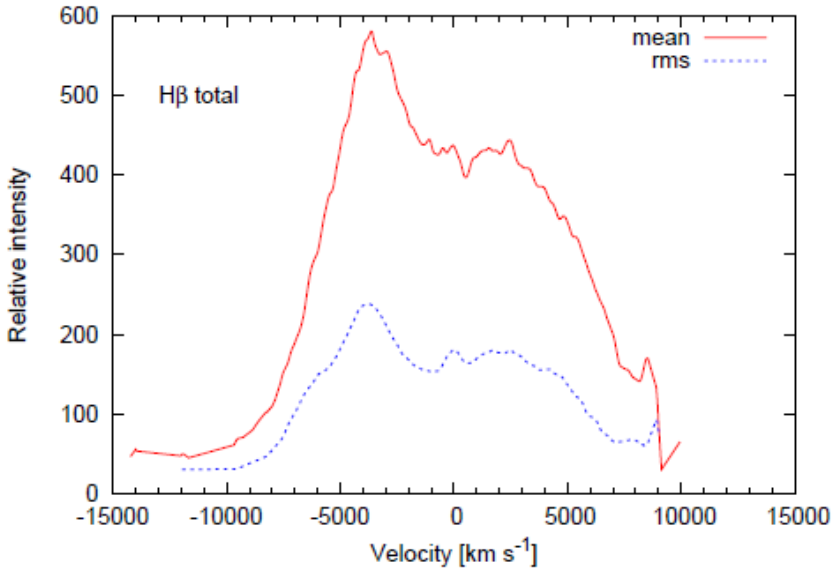
Shapovalova , Popović, Ilić, et al. 2010a, A&A, 509, 106

3c390.3

- double-peaked broad line
  (Eracleous & Halpern 1994)
  - line disk-emission
- variable line profiles ⇒ different complex BLR models: binary BLR, disc precession, disk perturbation, etc.







3c390.3

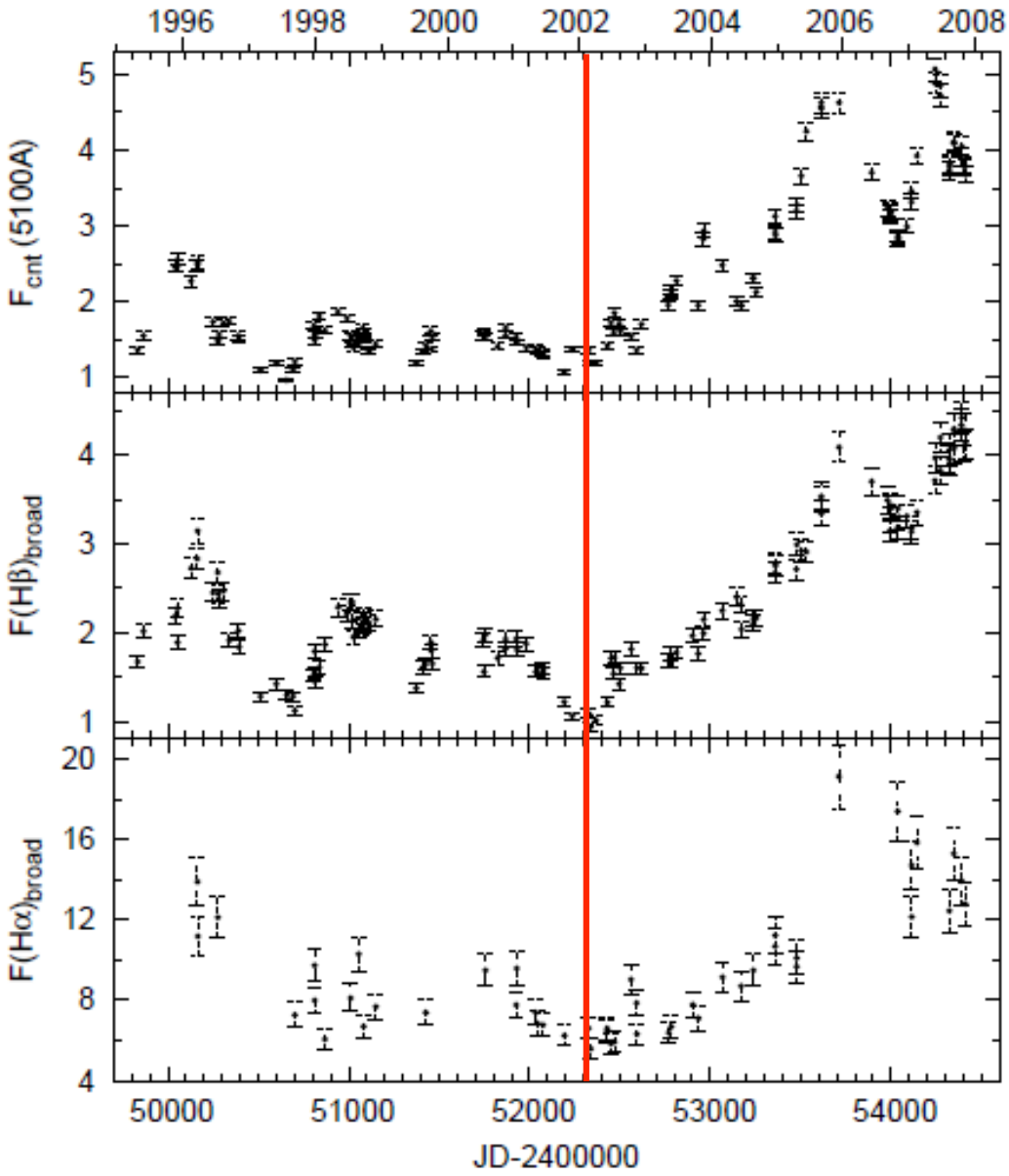
- 13-year data
- several max & min
- CCF analysis (ZDCF, ICCF)

⇒ Hα ~ 120 light days

⇒ Hβ ~ 95 light days

⇒ stratified BLR

- minimum in 2002 ⇒ 2 characteristic periods

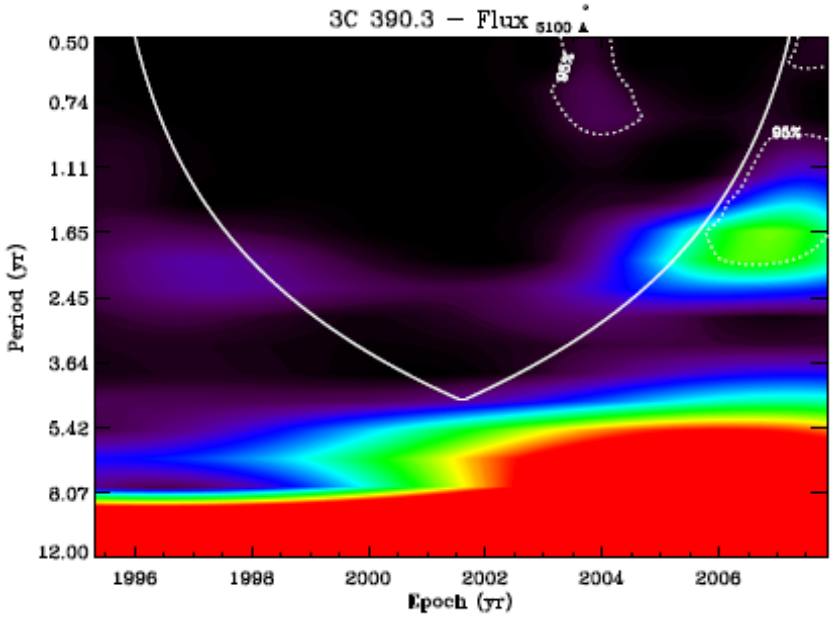


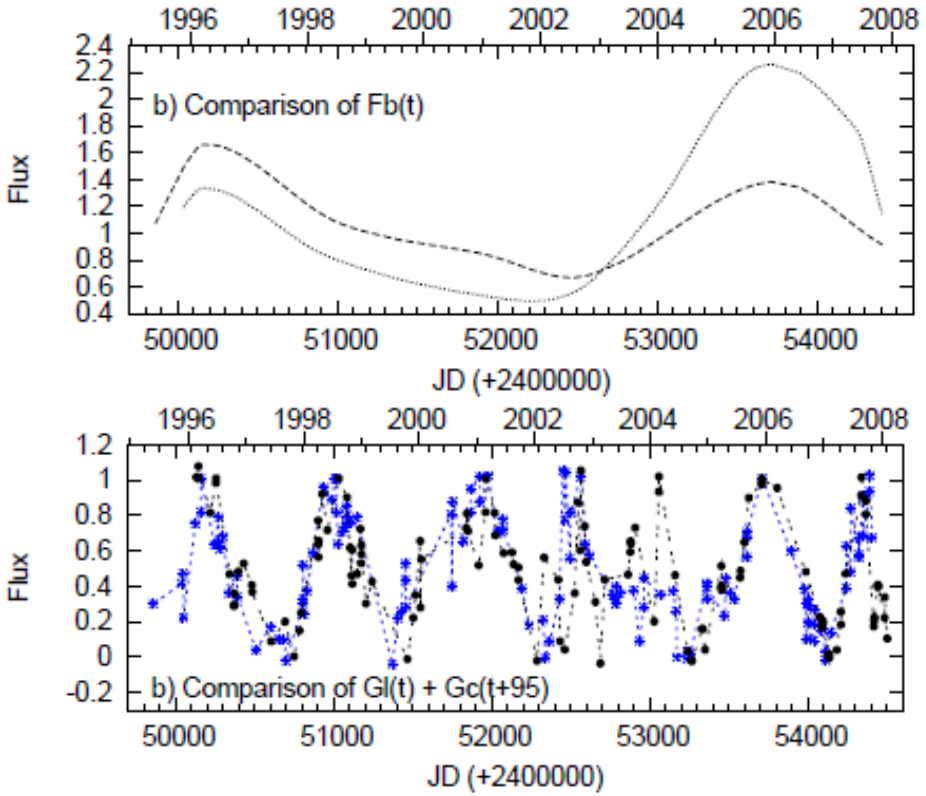
Shapovalova, Popović, Ilić, et al. 2010b, A&A, 517, 42

3c390.3 - QPOs

- quasi-periodic oscillations (QPOs)
  - Morlet wavelet transformation
  - analysis of the minima and maxima of Hβ and continuum
- QPOs with periods:
  ~ 10 years (Veilleux & Zheng 1991)
  ~ 2-4 years
- shock waves near the SMBH spreading in the outer part of the disk OR contribution of either ejection or jets to QPOs

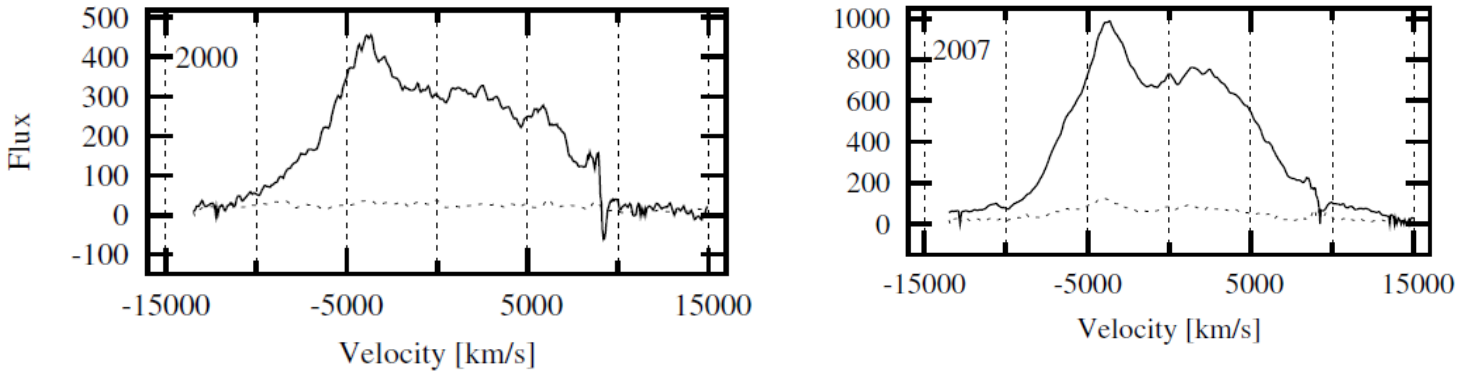
Shapovalova , Popović, Ilić, et al. 2010b, A&A, 517, 42



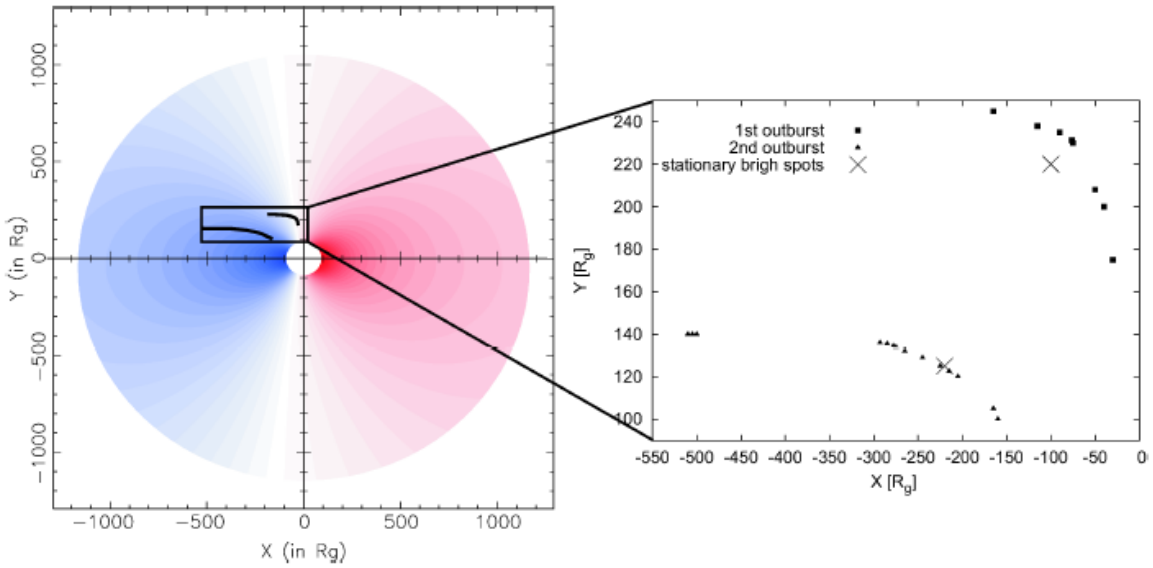


3c390.3 – line profiles

- line profiles vary dramatically: disk-like profile with strong blue peak always present, BUT sometimes also the central peak appears ⇒ additional emission region



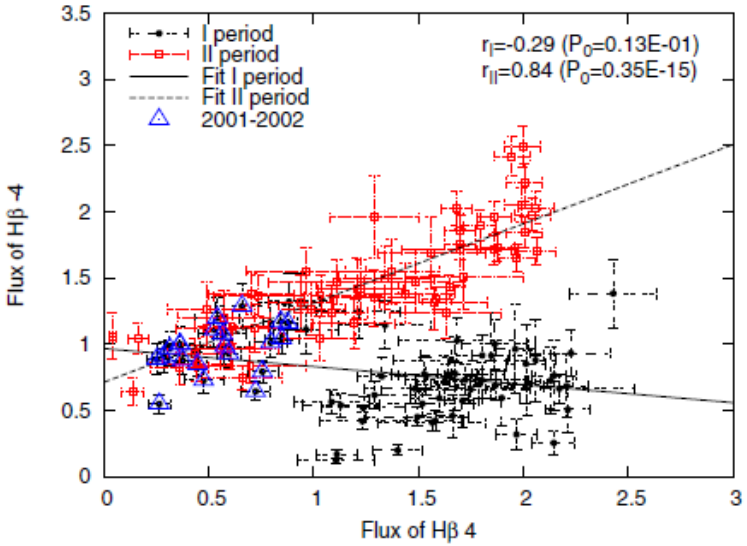
- describe the line profiles with disk perturbations



Jovanović, Popović, Stalevski, Shapovalova 2010, ApJ, 718, 168

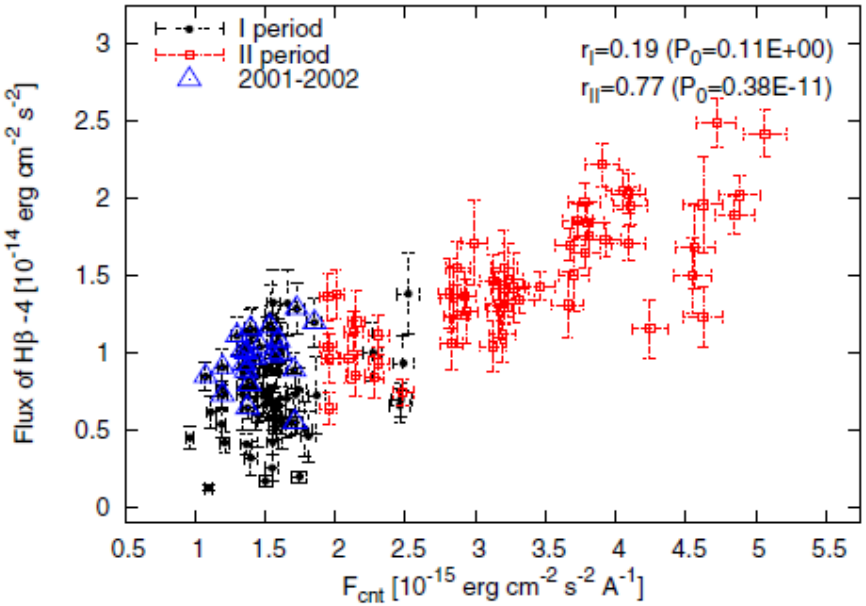
3c390.3 – Hβ line

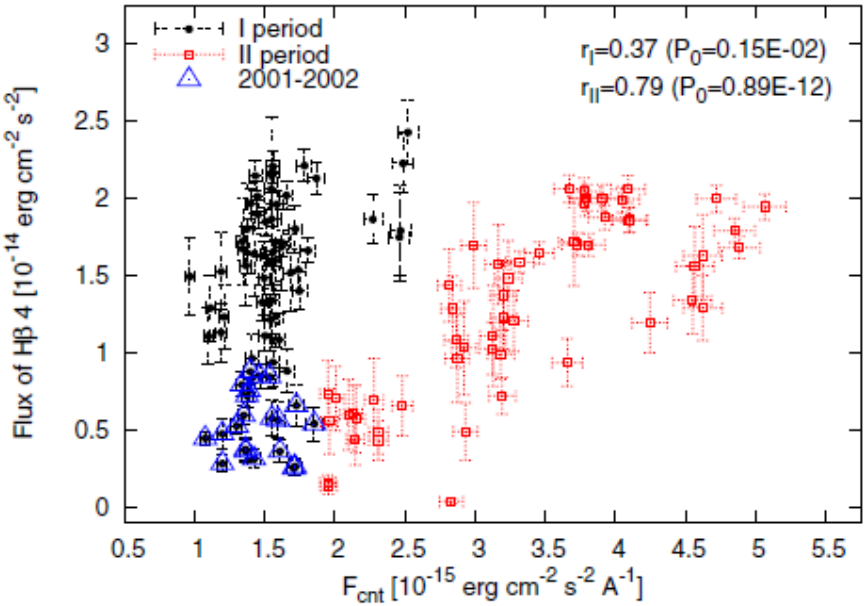
- blue and red wings of Hβ ↔ segments -4 and +4



- Period I and II: different response of line wings to the continuum variations

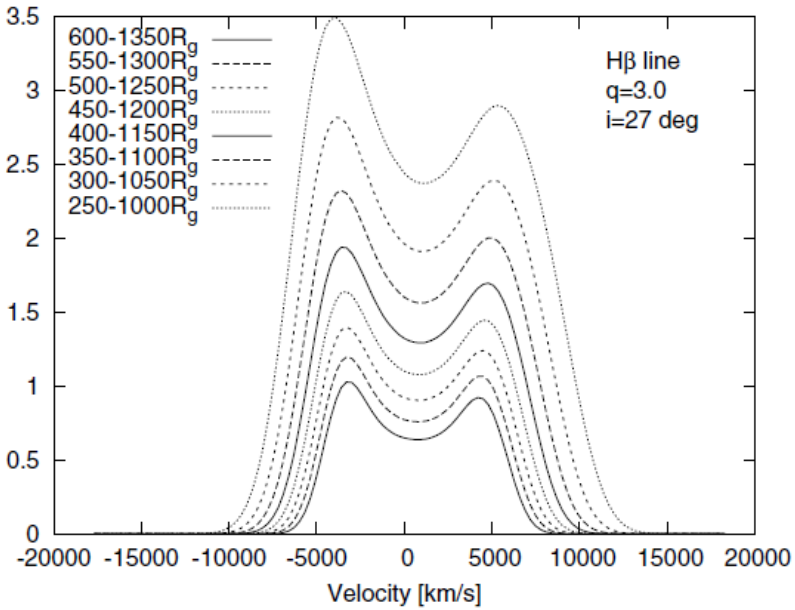
Popović, Shapovalova, Ilić, et al. 2011, A&A, 528,130

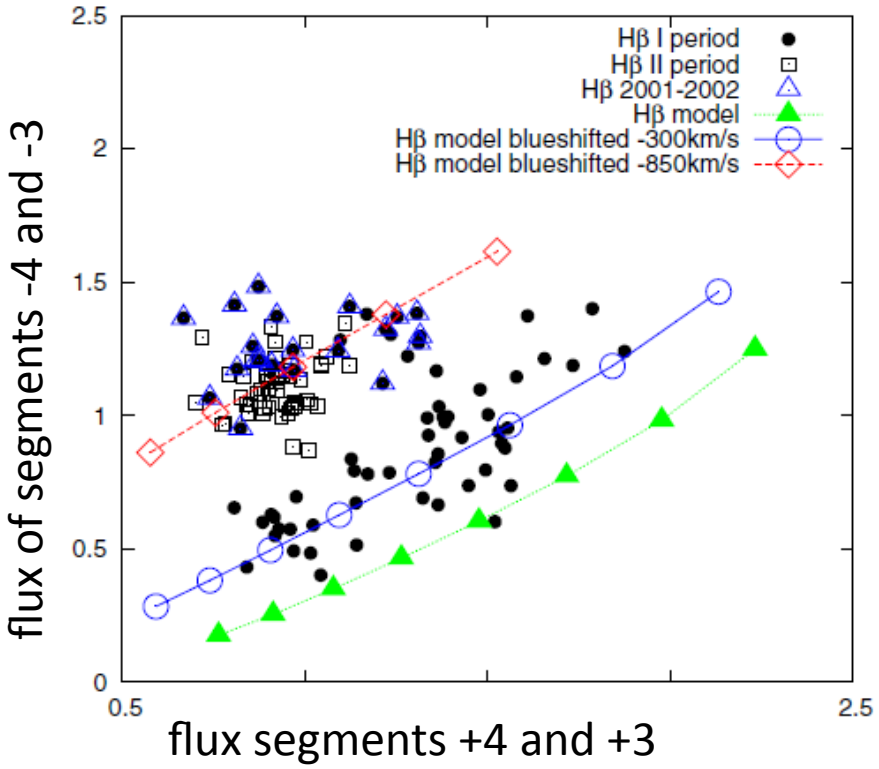




3c390.3 – models

- part of the disc that is emitting lines is shifted along the radius



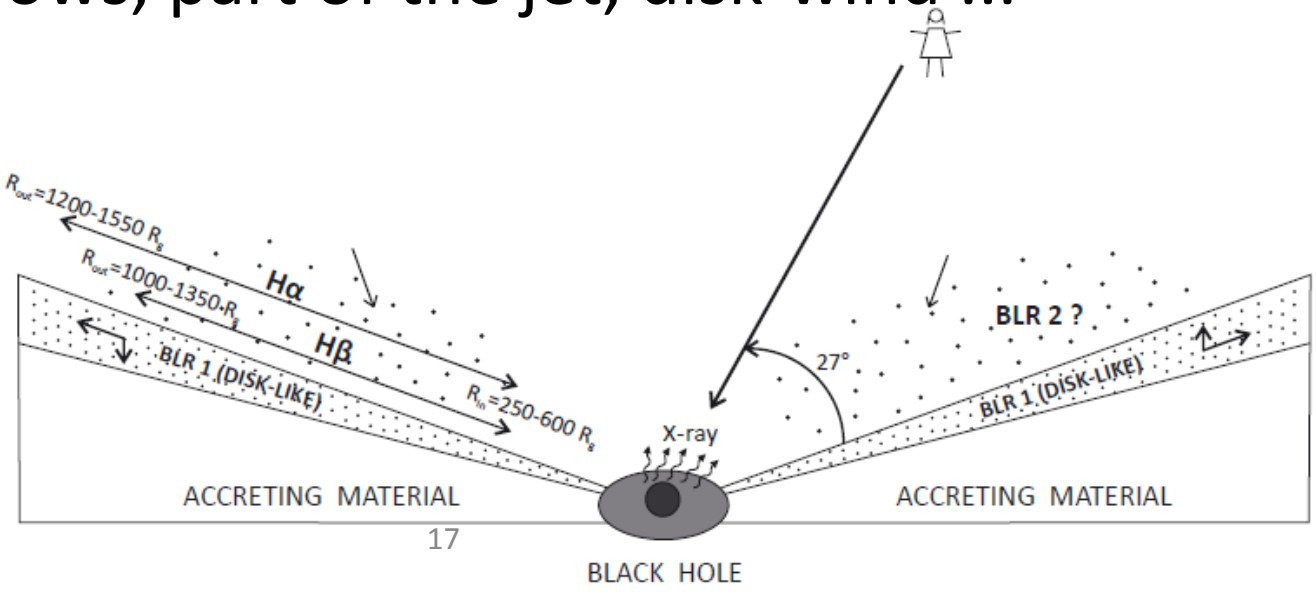


- models vs. observations
- Period I: the change can be explained with the change of the disk position with respect to the BH
- Period II (when burst starts): disc position is fixed

Popović, Shapovalova, Ilić, et al. 2011, A&A, 528,130

3c390.3 – two-component BLR

- disk-like BLR1 = optically thick accretion material, where the ionization from the central source can photoionize only the thin layer of gas above(below) the thick disk – this region follows the kinematics of the disk
  - line parameters depends on the size and position of the region with respect to the black hole in the center (variation of R_{inn} & R_{out})
- BLR2? – outflows, part of the jet, disk-wind ...



Narrow line Sy 1 AGN Ark 564

Results from the paper

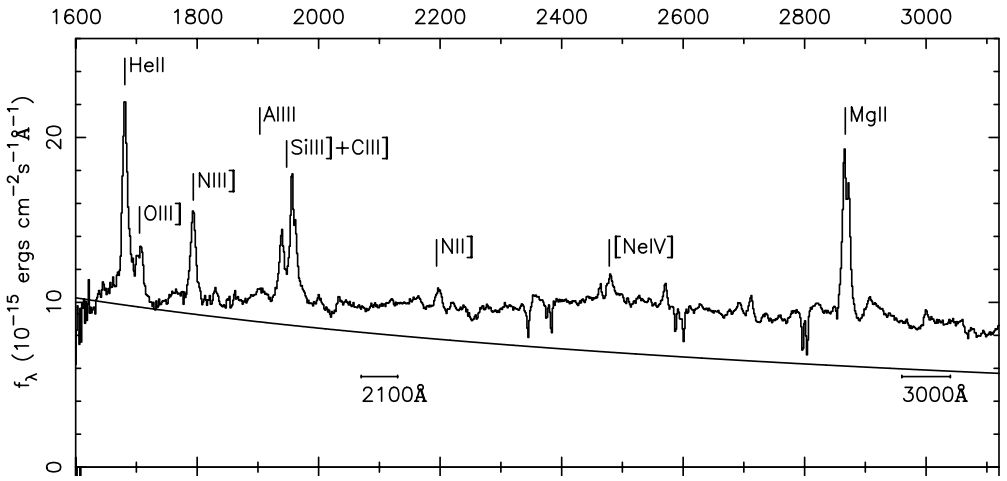
Shapovalova et al. 2012, submitted to ApJS

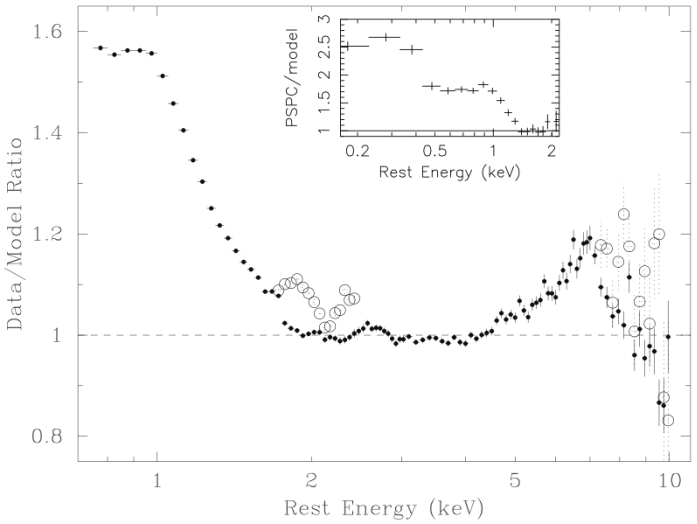

Observations

- 6m + 1m telescopes - SAO RAS (Russia)
- 2.1 m telescope - Guillermo Haro Observatory, Cananea, Sonora, Mexico
- 2.1 m telescope - Observatorio Astronómico Nacional, San Pedro Martir, Baja California, Mexico

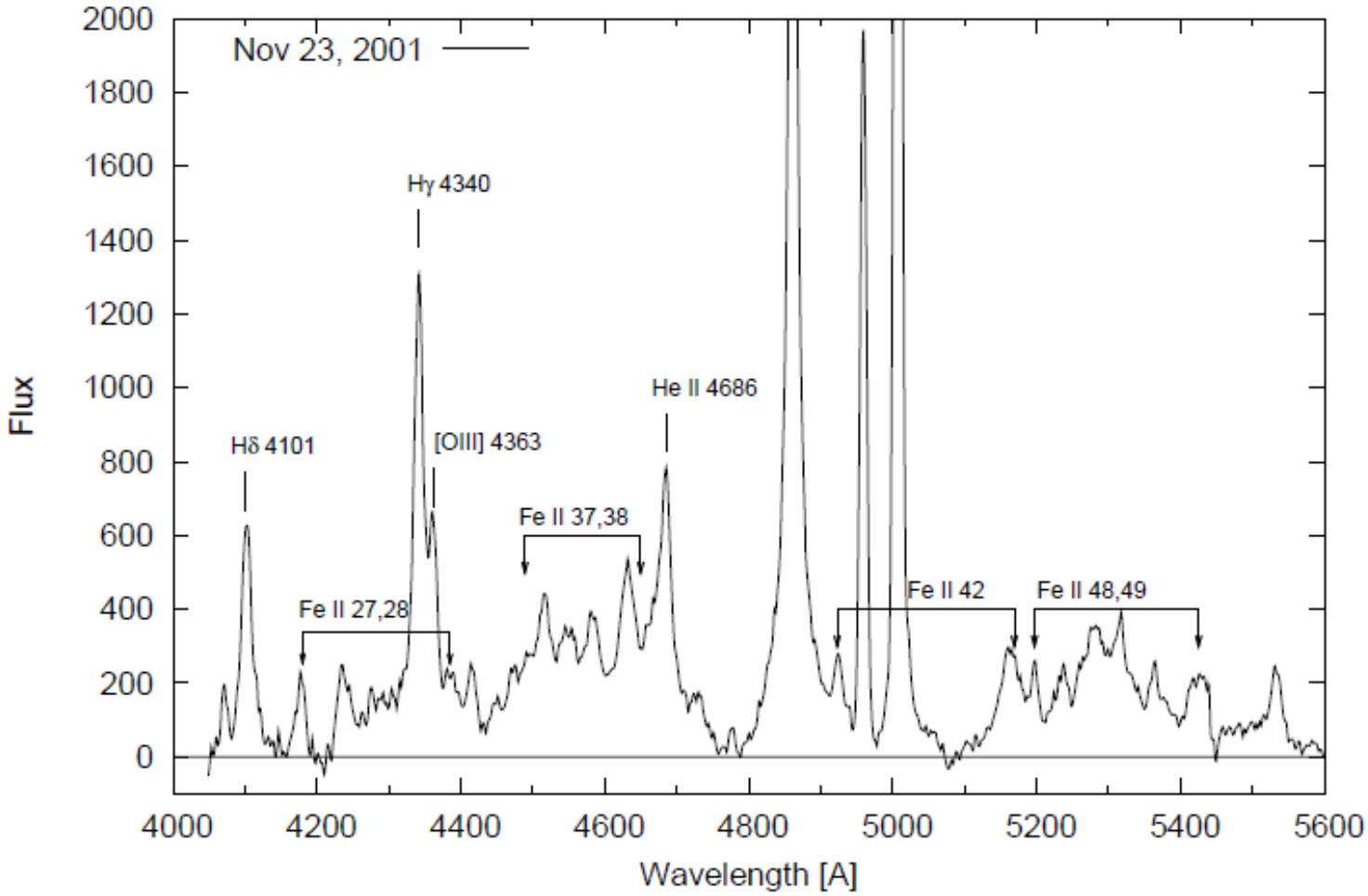
Ark 564: a peculiar AGN

- nearby narrow-line Sy 1 galaxy (z = 0.02467)
- one of the brightest NLS1s in the X-ray band
- narrow permitted lines; strong Fe II emission
- 2-year multi-λ monitoring campaign (Turner et al. 2001, Shemmer et al. 2001, Collier et al. 2001)





Strong Fe II emission

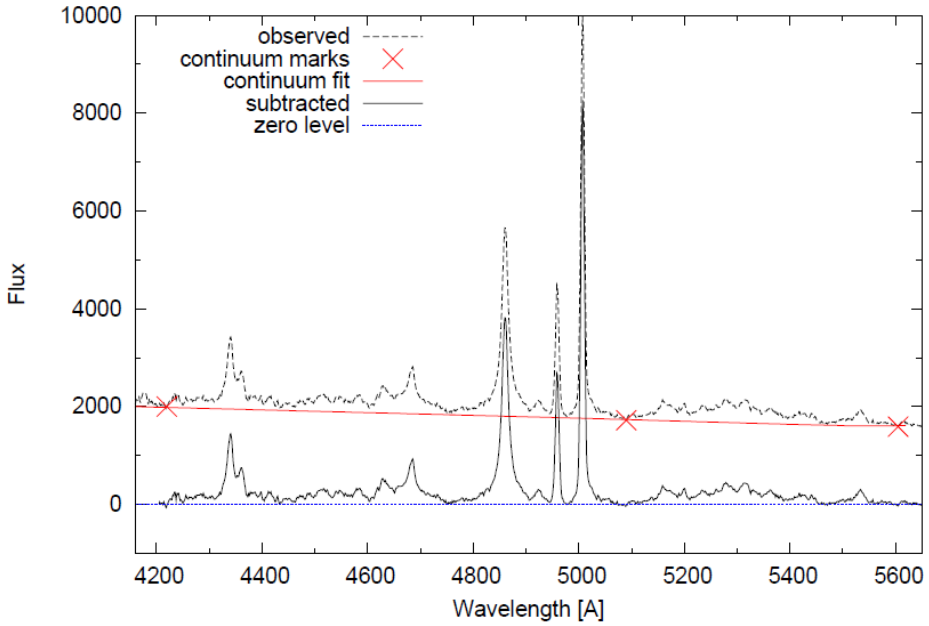


Our monitoring of Ark 564

- 1999–2010: 6 m and 1 m telescopes of the SAO RAS
- 1999–2007: 2.1 m telescope GHO, Mexico
- 2005–2007: 2.1 m telescope of OAN-SPM, Mexico
- spectral resolution R=5–15 Å, S/N ratio > 50
- SAMPLING: mean rate 33.20 days
  median rate 2.95 days
- our final data set: 91 blue and 50 red spectra
- calibration (details in Shapovalova et al. 2004):
  - flux scaled to [OIII]5007 or [OI]6300
  - **corrected for aperture effects, host galaxy contribution**

Measurements of the spectra

- continuum subtraction

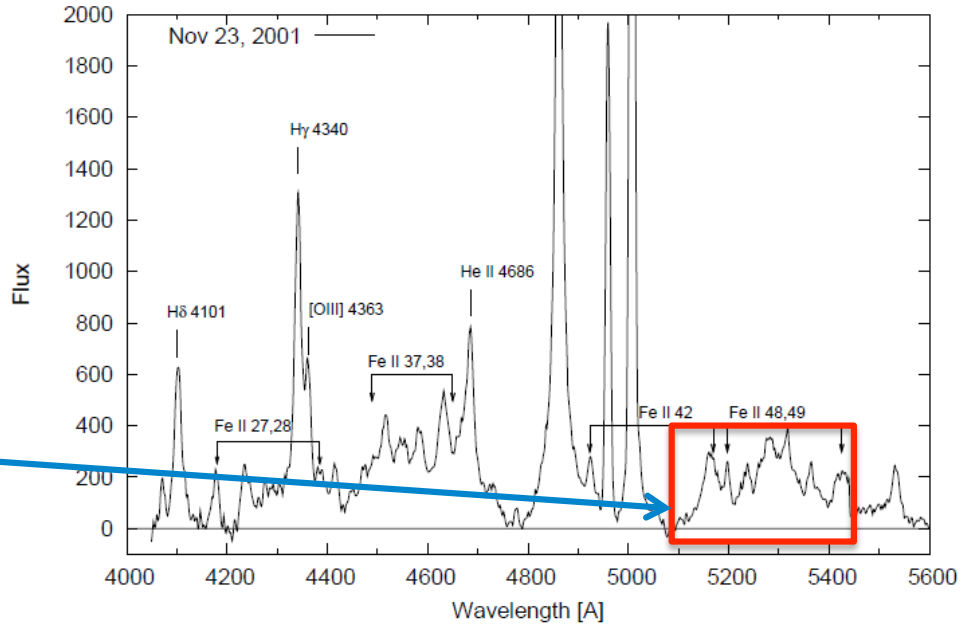


line fluxes=BLR+NLR:

⇒ Hα (30% NLR)

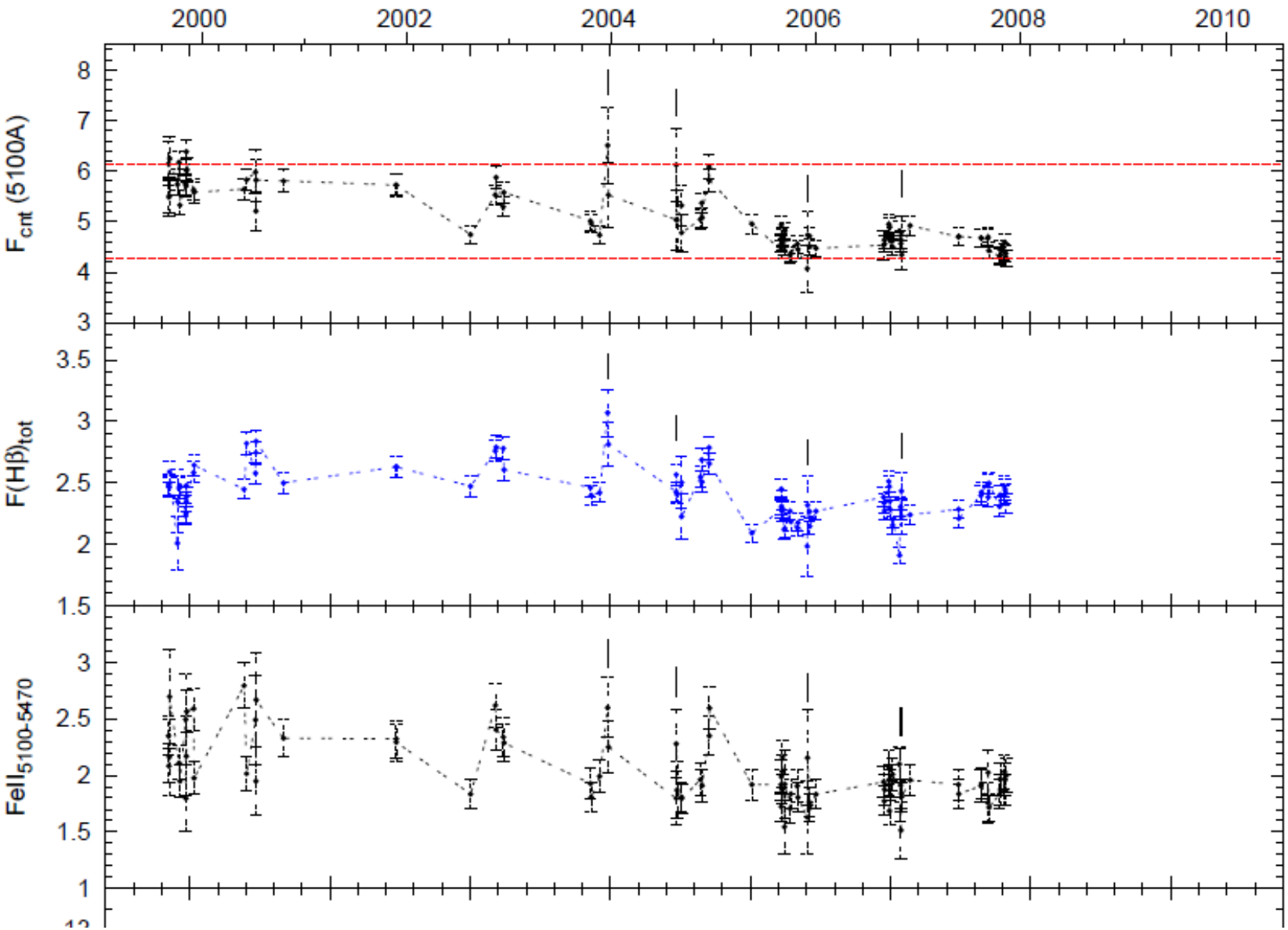
⇒ Hβ (20% NLR)

⇒ Fe II 5100-5470



For Fe II 5100-5470:
- no fitting
- 48,49 multiplets

Light curves: continuum, Hb, Fe II

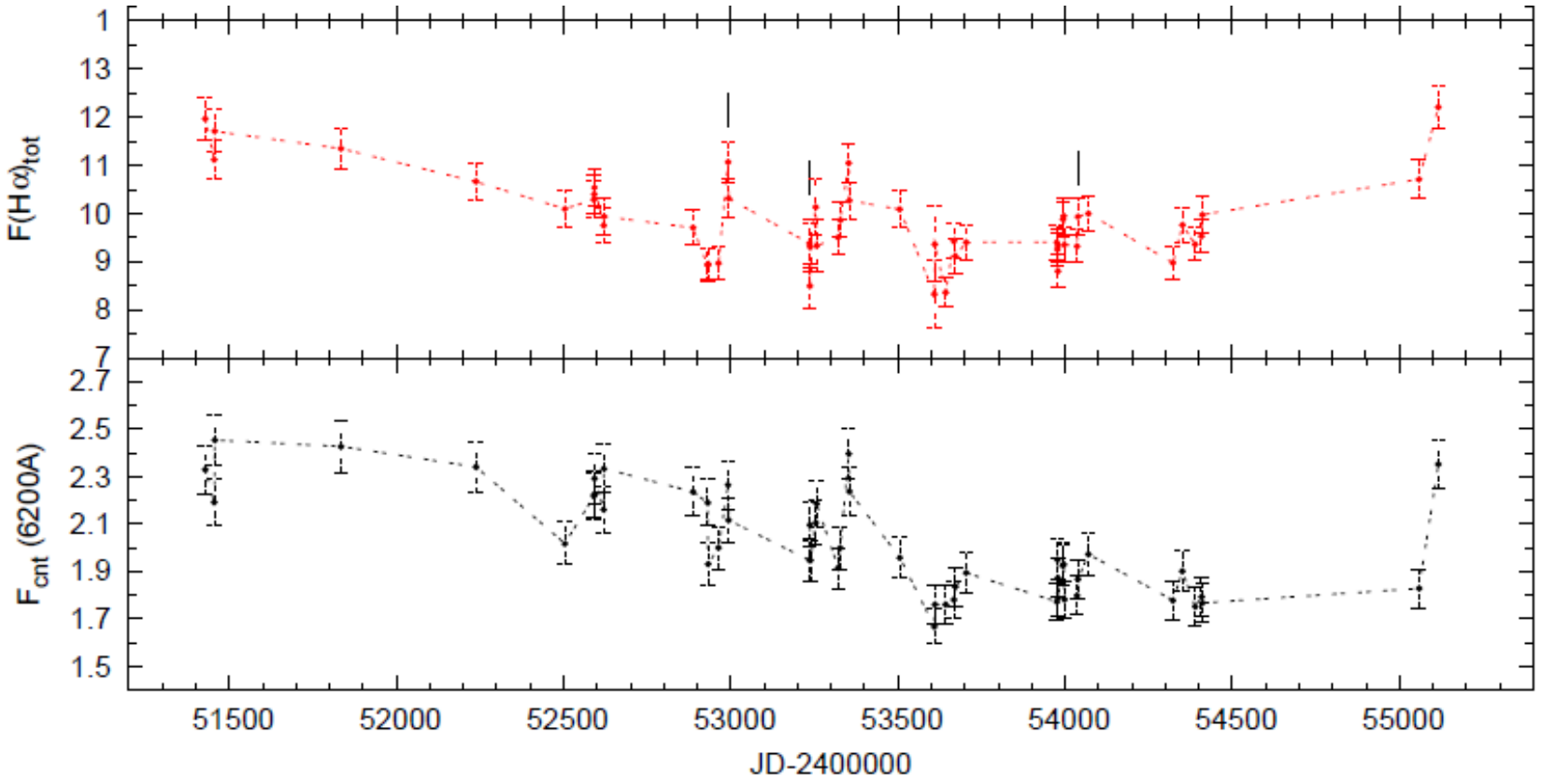


Flare-like events

- registered five flare-like events
  - two prominent and three possible
  - lasting ~1-3 days

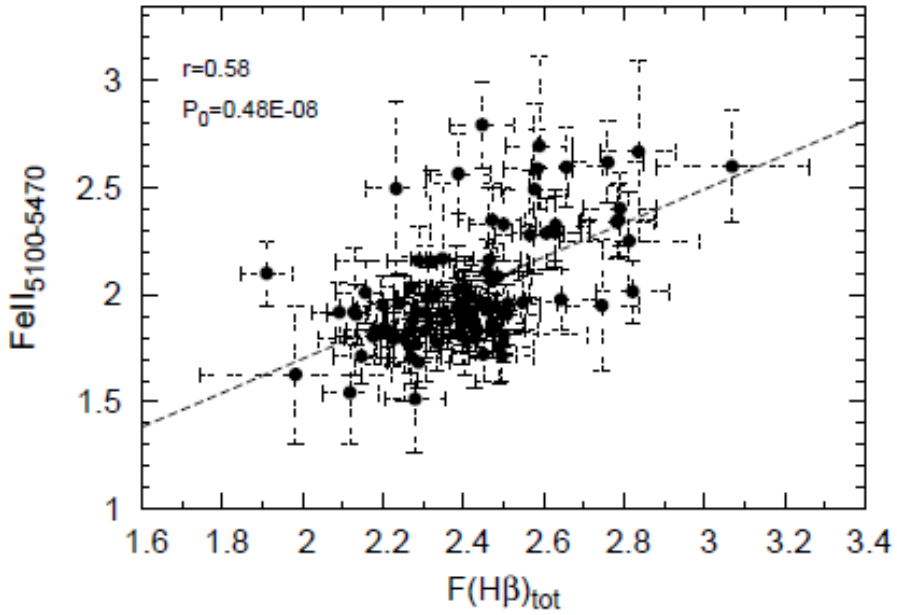
- fluxes in continuum and lines changed for ~20% (continuum and Fe II emission) and ~10% for Balmer lines

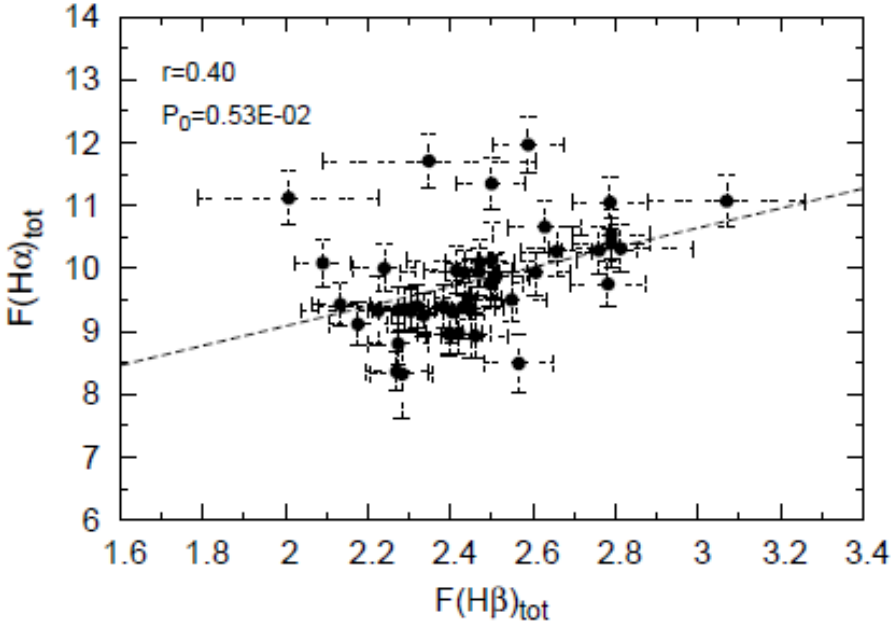
Light curves: Ha and red continuum



Correlations: continuum vs. lines

- Hb follows the change in the continuum flux
- Hα and Hβ: low level of correlation!



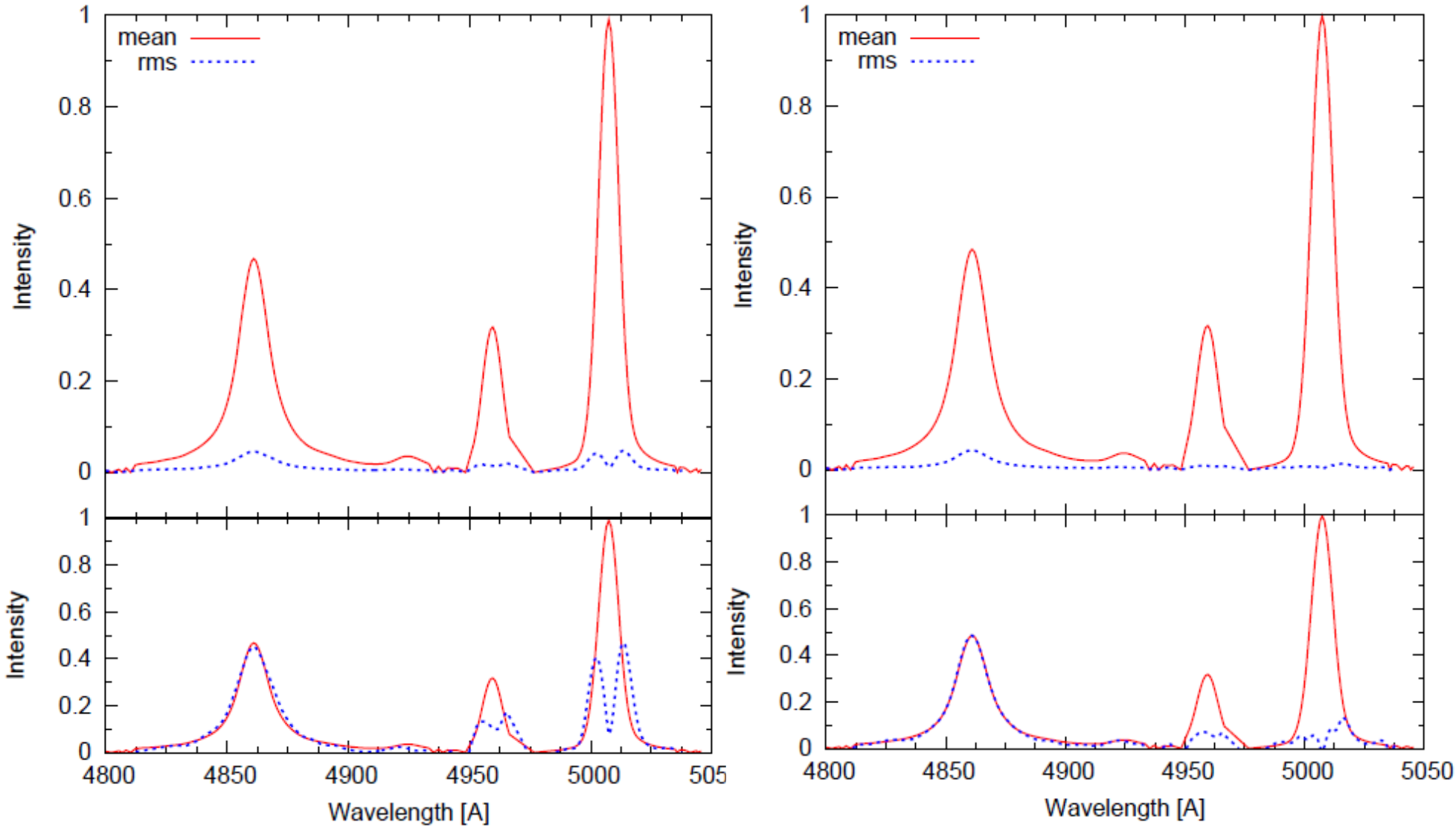


CCFs and lags

- Performed both ZDCF (Alexander 1997) and ICCF (Bischoff & Kollatschny 1999)
- Fe II lines tend to have shorter lags than Hβ and Hα
- strong stratification in the emitting region of Ark 564

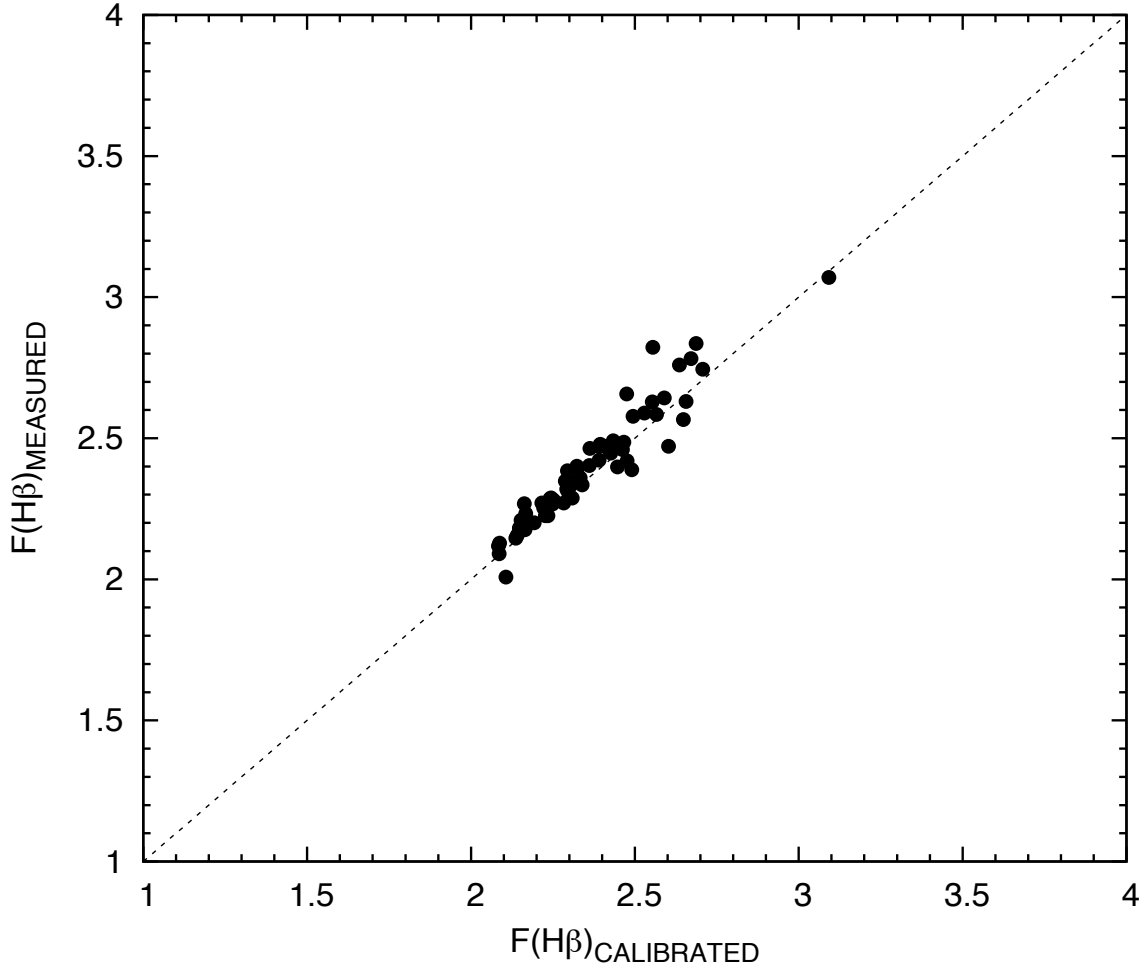
LC1-LC2	lag (days)	CCF
cnt-H$\beta_{\rm tot}$	$3.56^{+27.44}_{3.56}$	$0.49^{+0.08}_{-0.09}$
cnt-Fe II	$0.02^{+2.02}_{2.08}$	$0.52^{+0.08}_{-0.08}$
cnt-H$\alpha_{\rm tot}$	$4.54^{+5.54}_{14.46}$	$0.49^{+0.01}_{-0.01}$

Intercalibration



Intercalibration

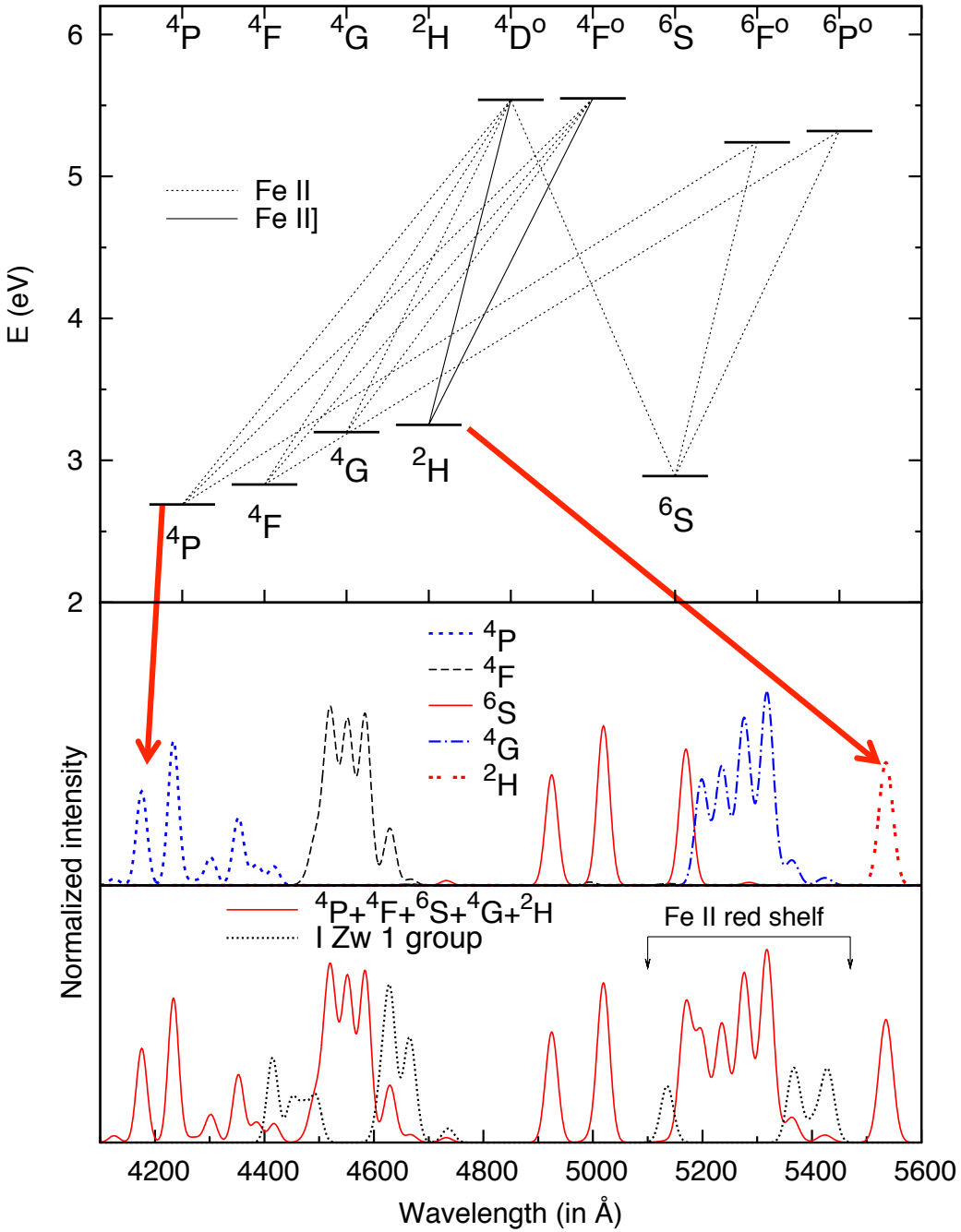
- Comparision of the Hβ flux before and after the caalibration



Fe II fit

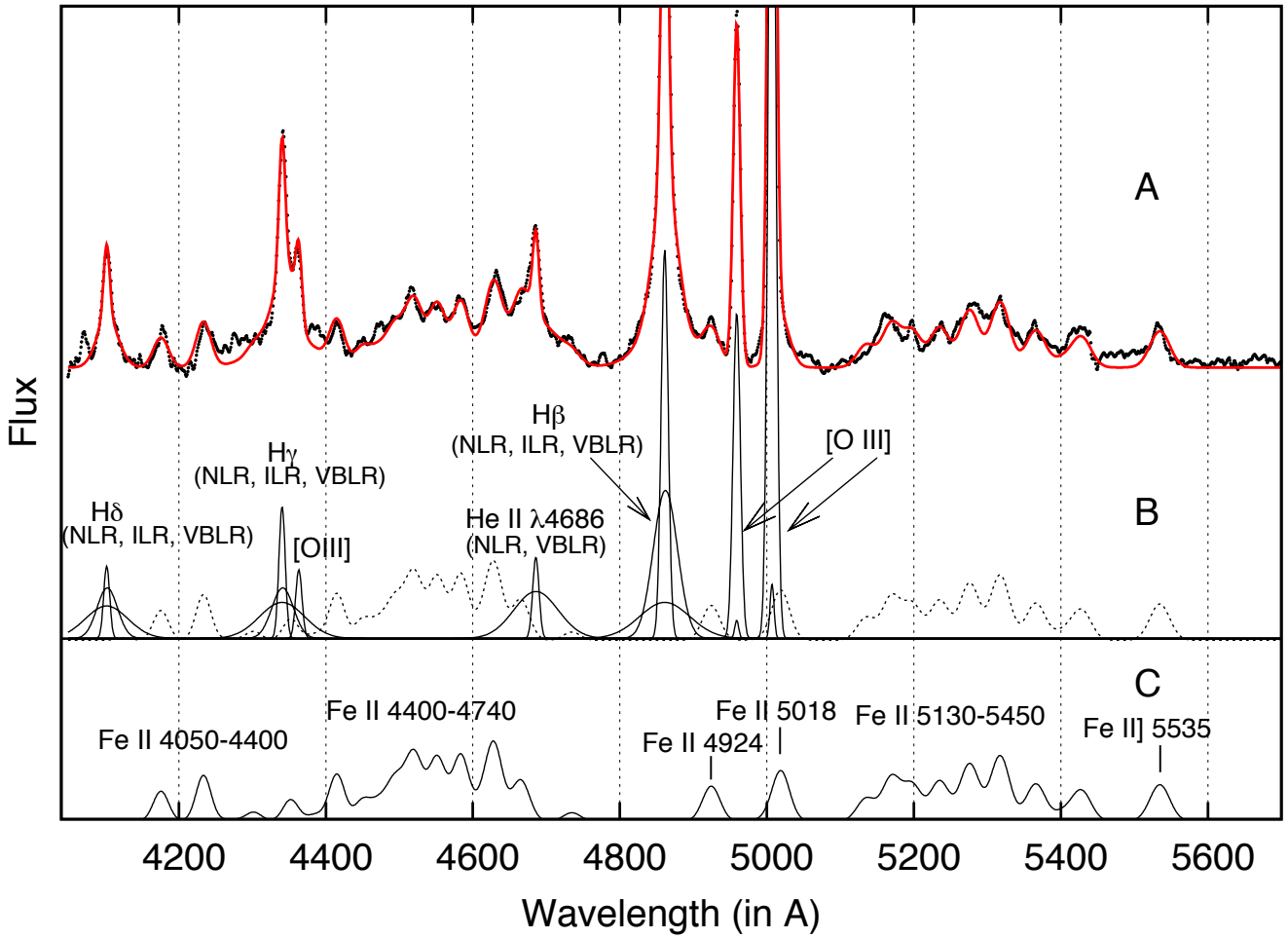
- Extended template for Fe II fitting (Kovacevic et al. 2010)

- New transitions:
  ^4P (Fe II 27,28)
  ^2H (Fe II] 55)

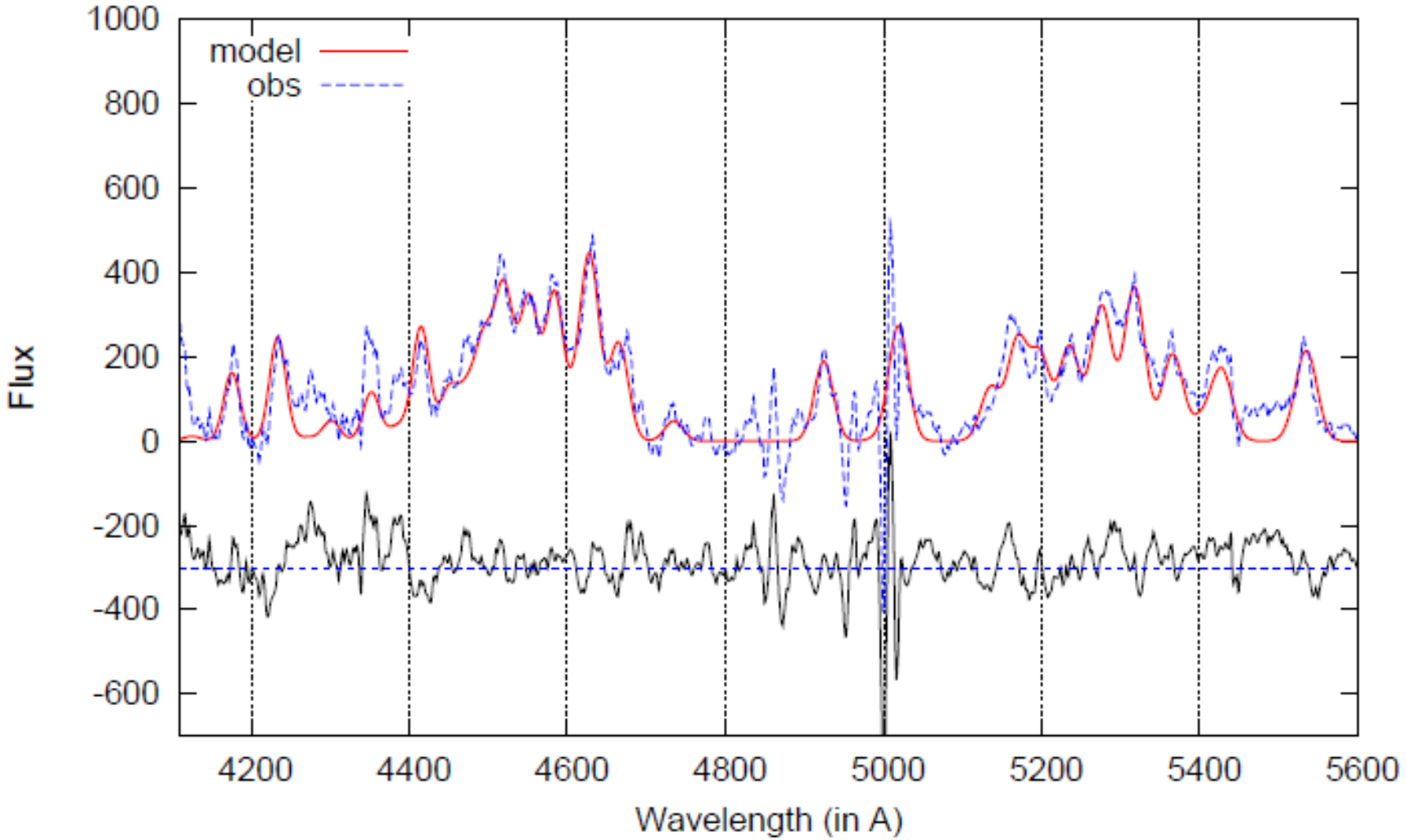


Fe II fit: one example

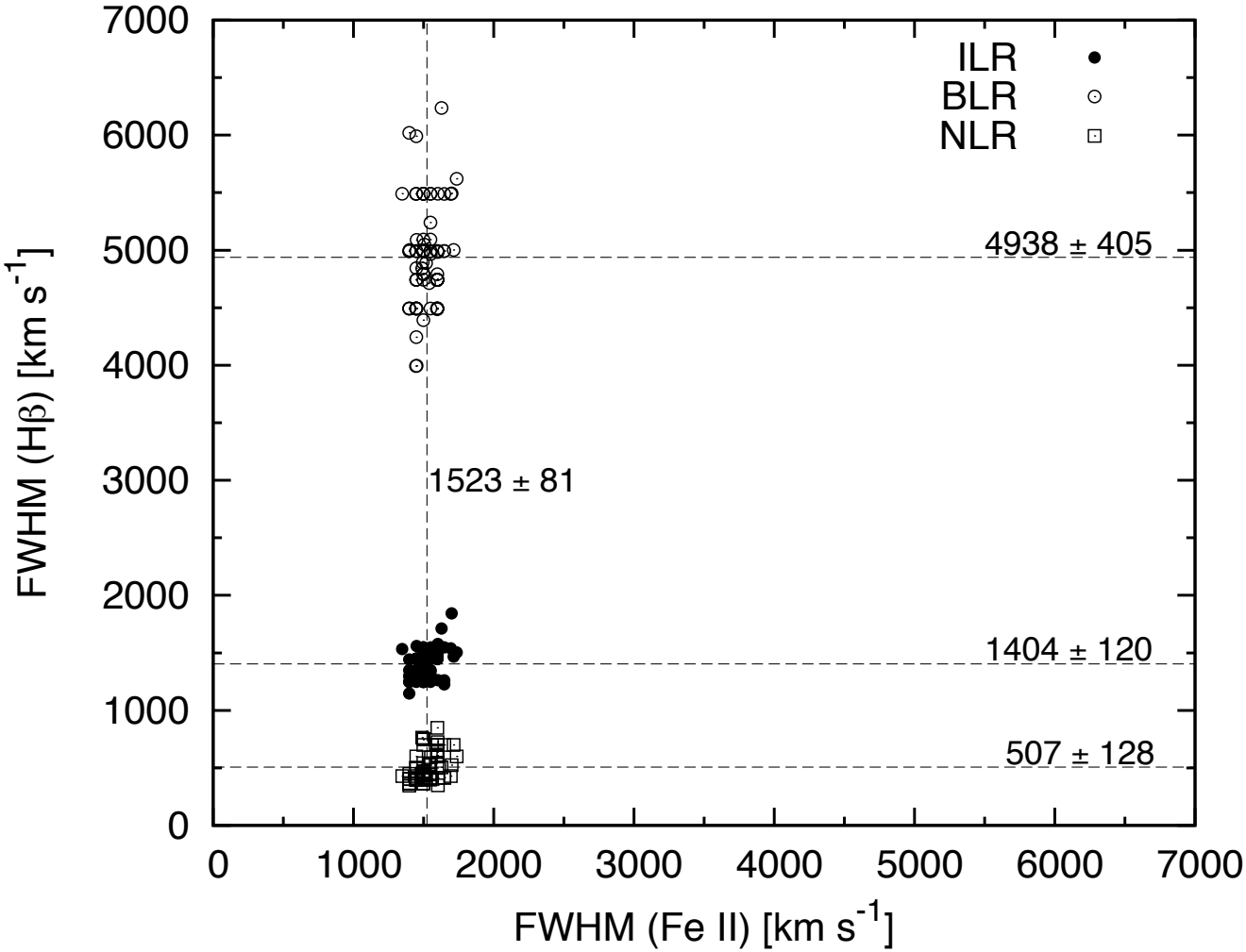
- Hβ,Hγ,Hδ: BLR, ILR, NLR with same parameters
- HeII: BLR, NLR
- [OIII]
- Fe II template



The residual of the Fe II fit: an example



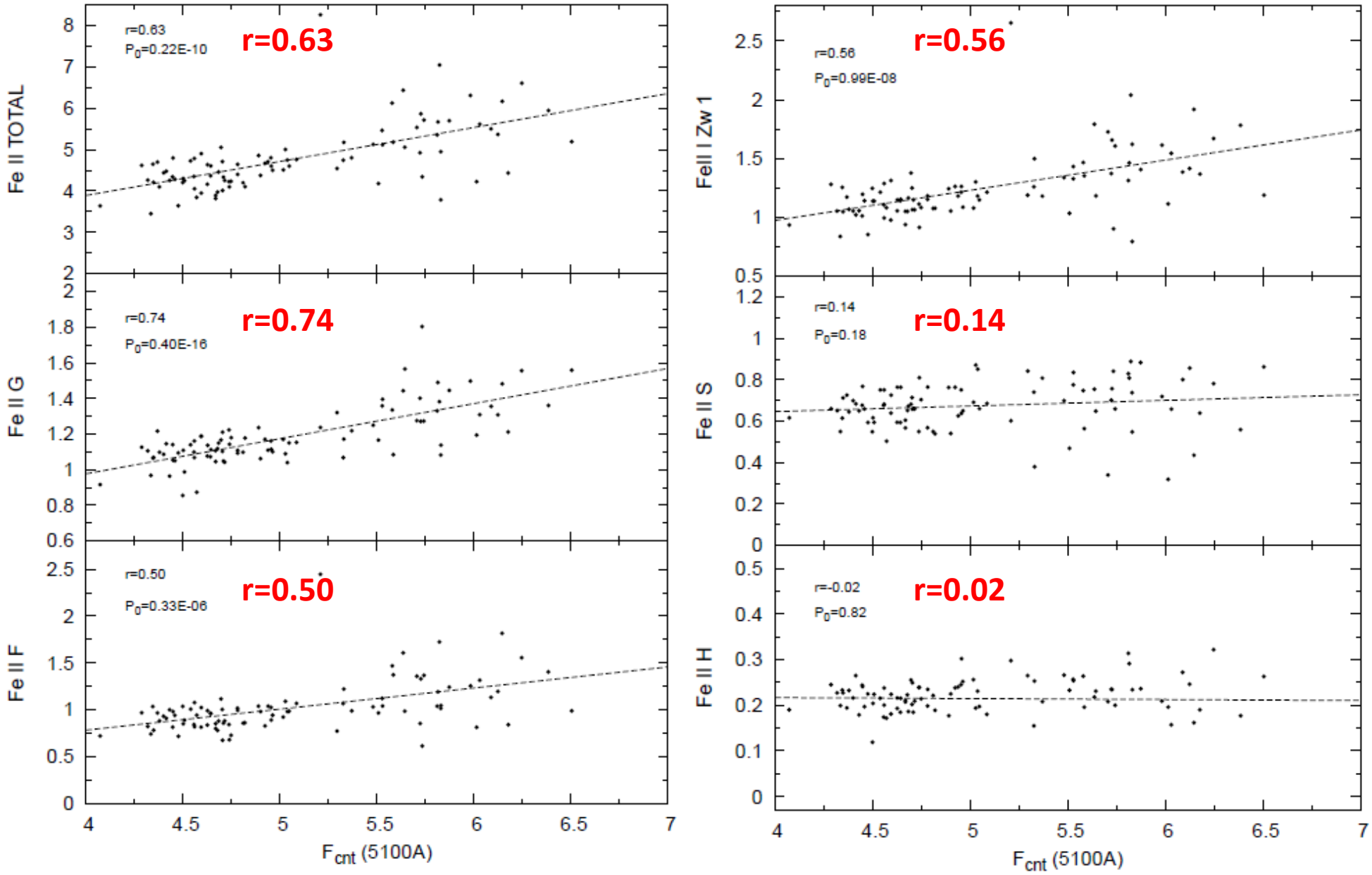
Fe II origin: ILR



width of Fe II is the same as for Hβ ILR component

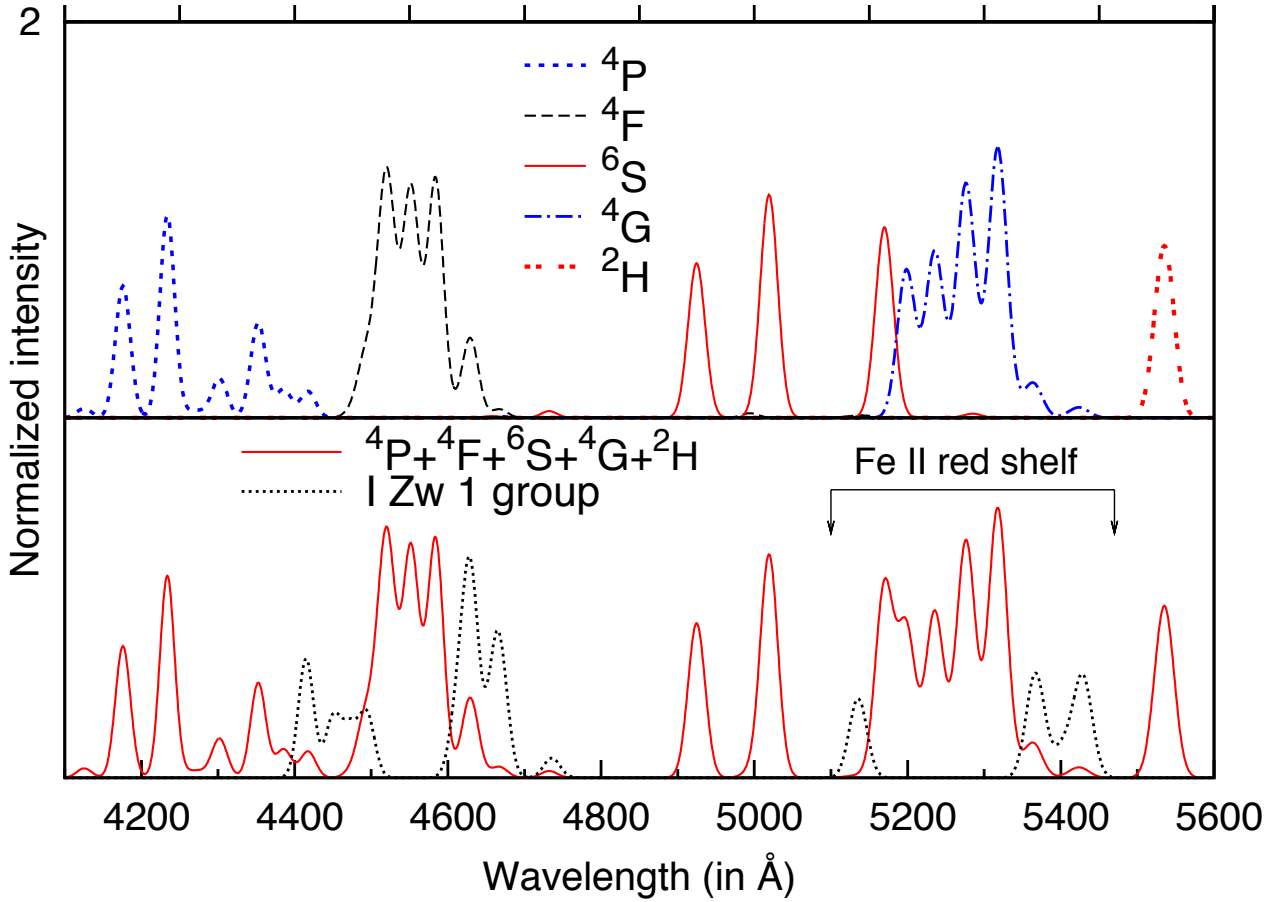
(see e.g. Kovačević et al. 2010, ApJS)

Fe II correlations



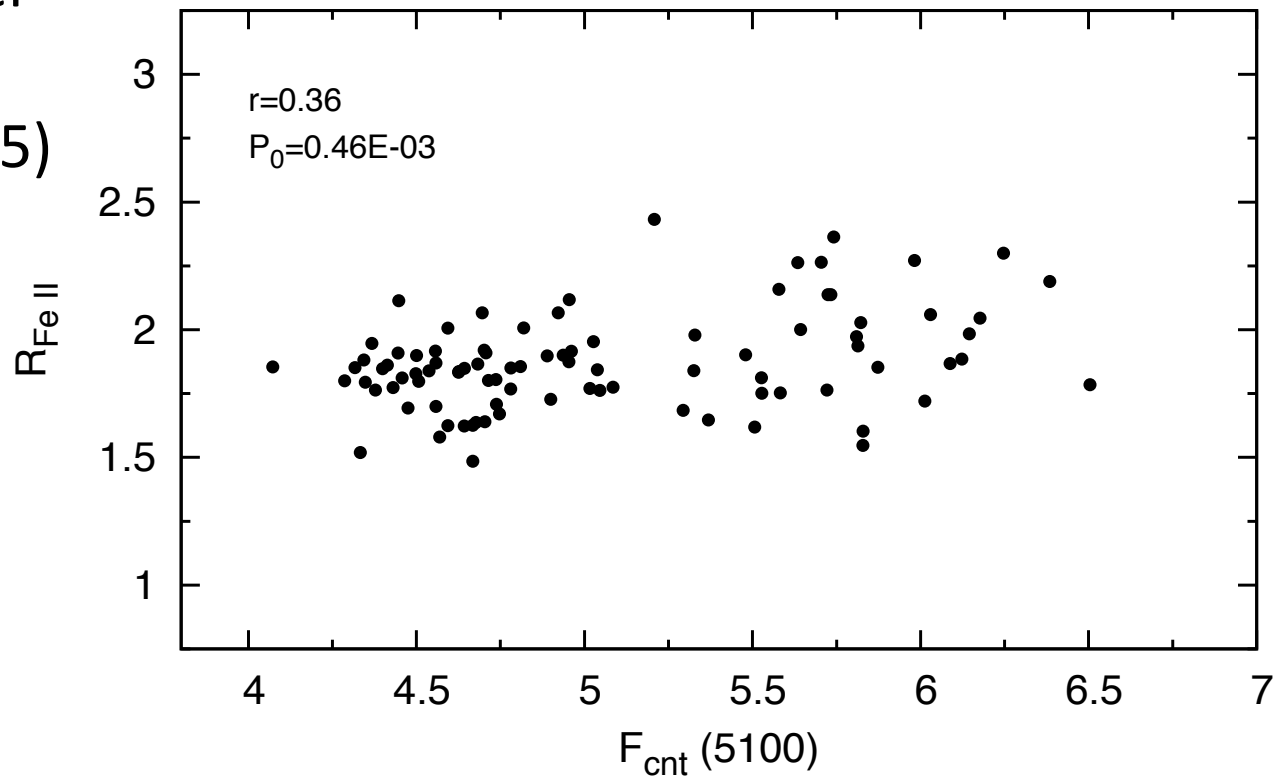
Fe II emission

- blue shelf: $^4P + {}^4F + I\ Zw1$
- red shelf: $^4G + I\ Zw1$
- ^2H:
  Fe II] 55



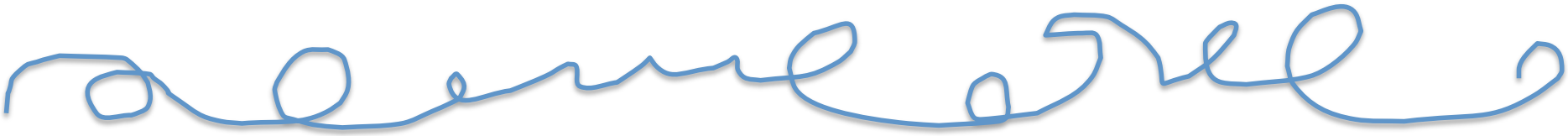
R_{Fe} vs. continuum

- R_{Fe}= flux ratio of optical Fe II and Hβ line
- positive correlation (low significance)
  - same as for other NLSy1 (Wang et al. 2005)



Conclusions on Ark 564

1. during the monitoring period (1999–2010) the mean continuum and lines fluxes decreased for ~20%-30%
2. 5 flare-like events (2 prominent and 3 possible) registered
3. the correlation between the Fe II (in the red shelf of the Fe II) and continuum is slightly higher (and more significant) than between the Balmer lines and continuum
4. almost lack of correlation between the Hα and Hβ line fluxes -> beside the photoionization some additional physical processes may be present
5. lag of 2–6 days, but with large errorbars
6. the Fe II emission is probably coming from the intermediate line region with velocities around 1500 km/s



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