

New method for spectroscopic data analysis in AGN variability studies

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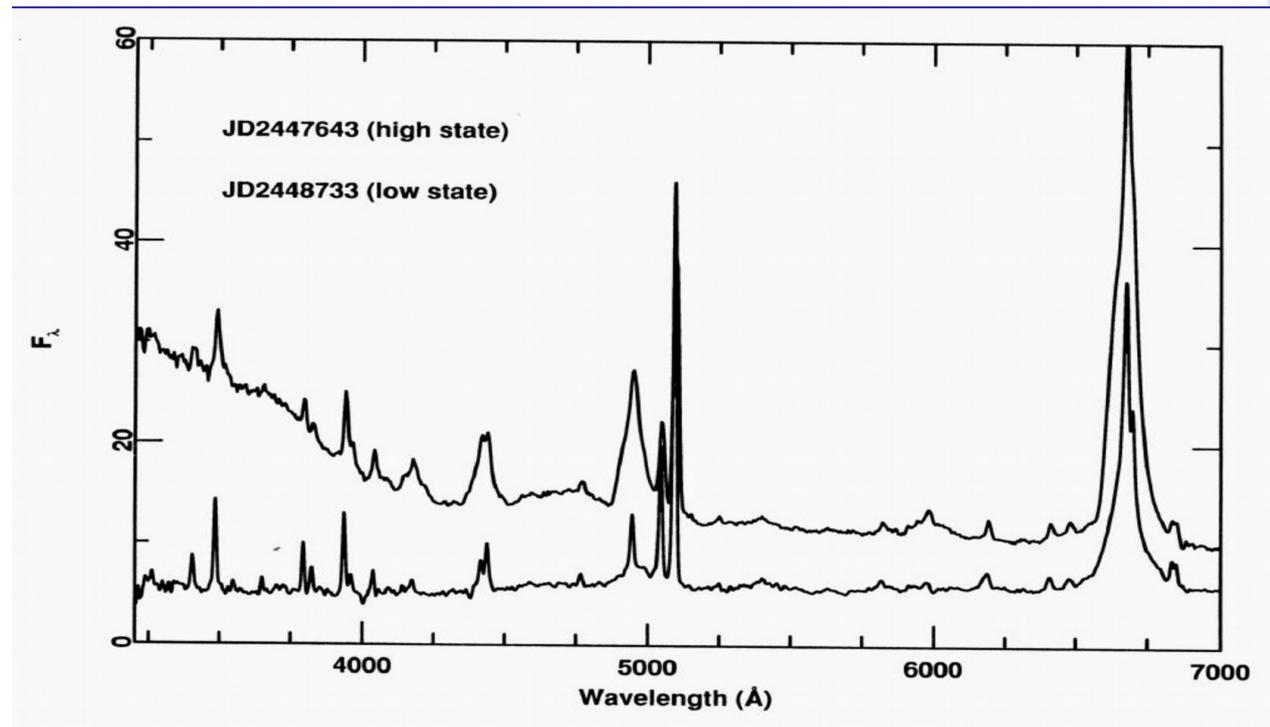
Outline

- We developed a method for unification of spectra used in long term variability studies of AGN
- This method allows simultaneous analysis of all components in AGN spectra
- Here we present advantages of our methods to other used methods
- Line shape and flux analysis, including continuum variability in AGN
- As an example we present result obtained from 43-year-long monitoring of NGC 5548, where we found evidence for periodicity of 15.7 years.

Variability in AGN spectra

- AGNs have been found to be variable at all wavelengths at which they have been observed.
- While variability in high-luminosity AGNs was reported soon after their discovery, variability in lower-luminosity AGNs was not reported until 1967, and was less dramatic.

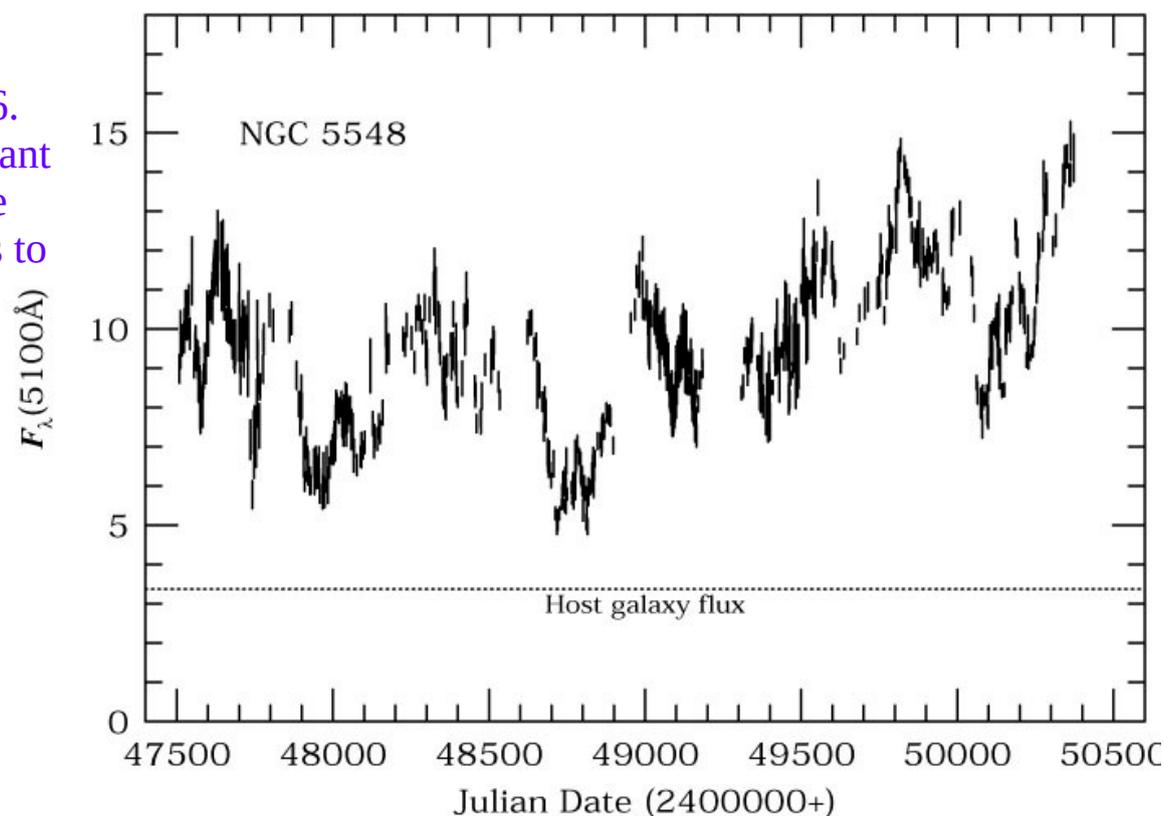
Spectra of a typical Seyfert 1 galaxy, NGC 5548, which is one of the best-studied objects of this class in low and high state of activity.



Emission-Line Variability

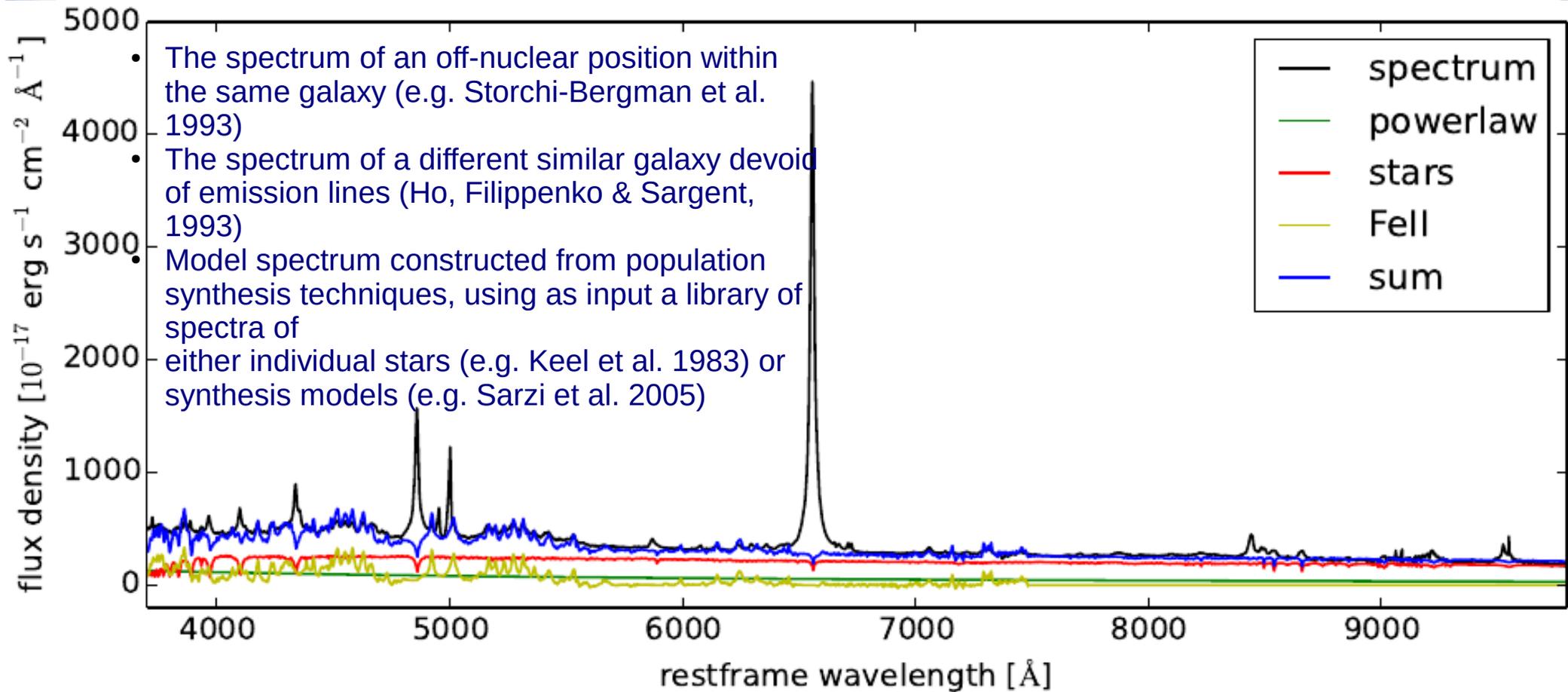
- The broad emission lines in AGN spectra can vary both in flux and in profile. Over time scales of months and years, the changes can be very dramatic, but on shorter time scales they are more subtle.
- Spectra could change even type, as broad components of emission lines appeared or disappeared.

Optical (5100 Å) light curve of NGC 5548 from late 1988 to late 1996. The horizontal line indicates the constant contribution from starlight through the standard aperture used, which projects to 5" × 7".5. From Peterson et al. 1999 AAS.



Analysis of AGN spectra in previous works

Methods for removing the starlight from an integrated spectrum:



Full spectrum fitting: ULySS

Uses all informations from the spectrum

Insensitive to the extinction and flux calibration

ULySS (University of Lyon Spectroscopic analysis Software) is an Open-source software package written in the GDL/IDL language to analyse astronomical data (Koleva et al. 2009)

Package is used to study stellar populations of galaxies and star clusters and atmospheric parameters of stars.

ULySS fits a spectrum with a linear combination of non-linear components convolved with a line-of-sight velocity distribution (LOSVD) and multiplied by a polynomial continuum.

The stellar population models are spline interpolated over an age-metallicity grid of models, generated with PEGASE.HR.

Modelling the integrated AGN spectrum

We added new components in the ULySS model: a featureless continuum, represented with a power law function, emission lines, represented with Gaussian (tied or free) and FeII multiplets.

$$M(x) = P(x) ([T(x) \otimes G(x)] + C(x) + N(x) + B(x) + \sum_{i=1}^4 FeII_i(x) + \sum_{j=1}^n S_j(x)),$$

T(x)-single stellar population (SSP) model

G(x)-Gaussian/Gauss-Hermit broadening function

C(x)-AGN continuum model represented by power law function

P(x)-multiplicative polynomial

S(x)-emission line model

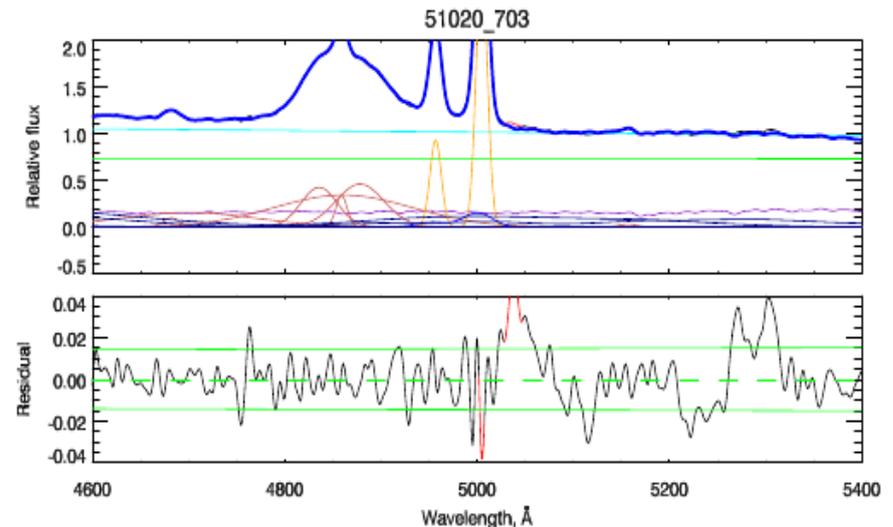
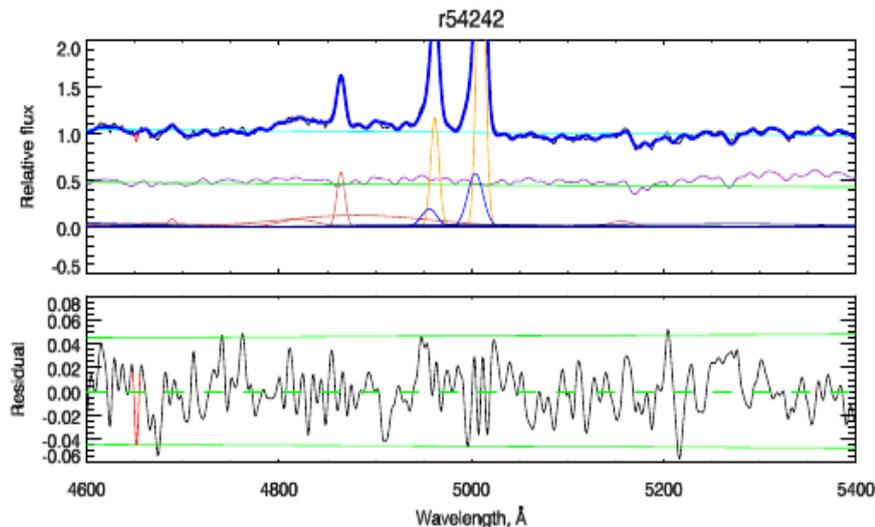
N(x) and B(x) – tied narrow and semi-broad components of emission lines

Fe II – model of Fe II multiplets

Spectra analysis – ULySS

NGC 5548 (E. Bon et al. 2016, submitted to ApJS)

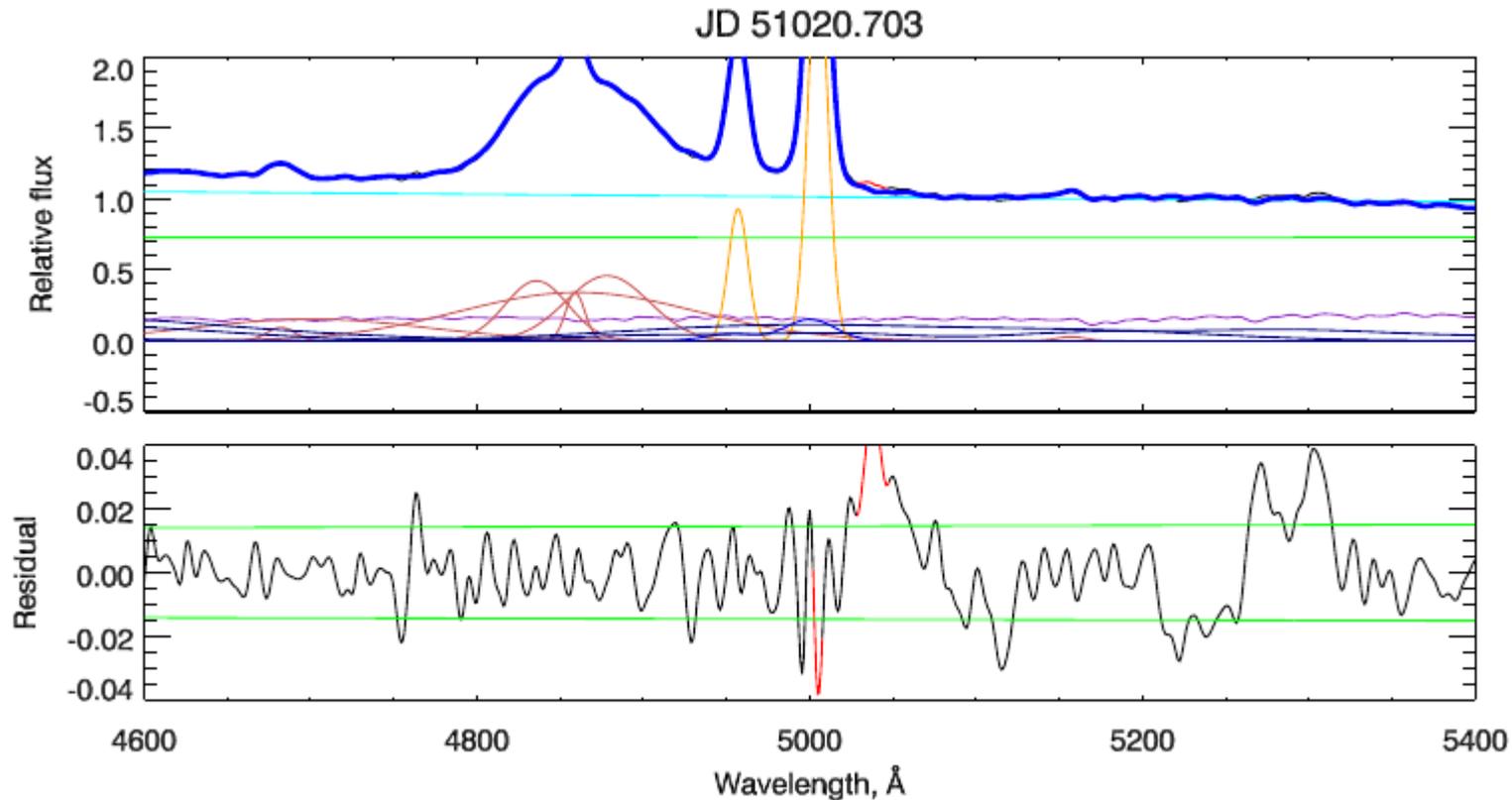
$$M(x) = P(x) ([T(x) \otimes G(x)] + C(x) + N(x) + B(x) + \sum_{i=1}^4 FeII_i(x) + \sum_{j=1}^n S_j(x))$$



Example of the best fit with the UlySS fitting method . In the upper panel the black line represents the input spectrum, the blue line represents the best fit model, and the cyan line represents multiplicative polynomial, while red, yellow, blue, dark blue and violet lines represent components of the best fit model: violet – stellar population, red – components of HII and H β lines, yellow – narrow [OIII] lines, blue – broad [OIII] lines, dark blue – Fe II multiplets and green – AGN continuum. The bottom panel represents residuals from the best fit (black line). The green solid line shows the level of the noise, and the dashed line is the zero-axis.

Spectra analysis – ULySS

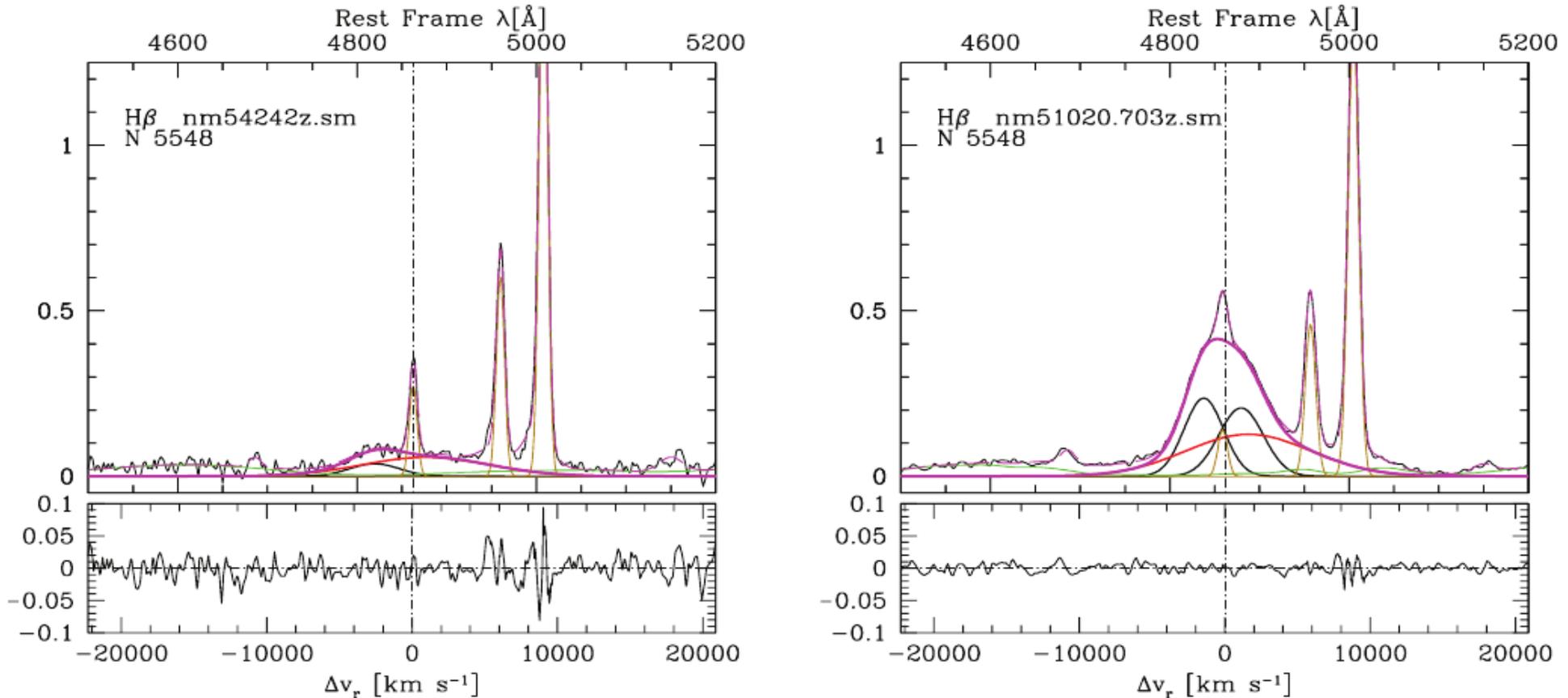
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Spectra analysis – Specfit

NGC 5548 (E. Bon et al. 2016, submitted to ApJS)

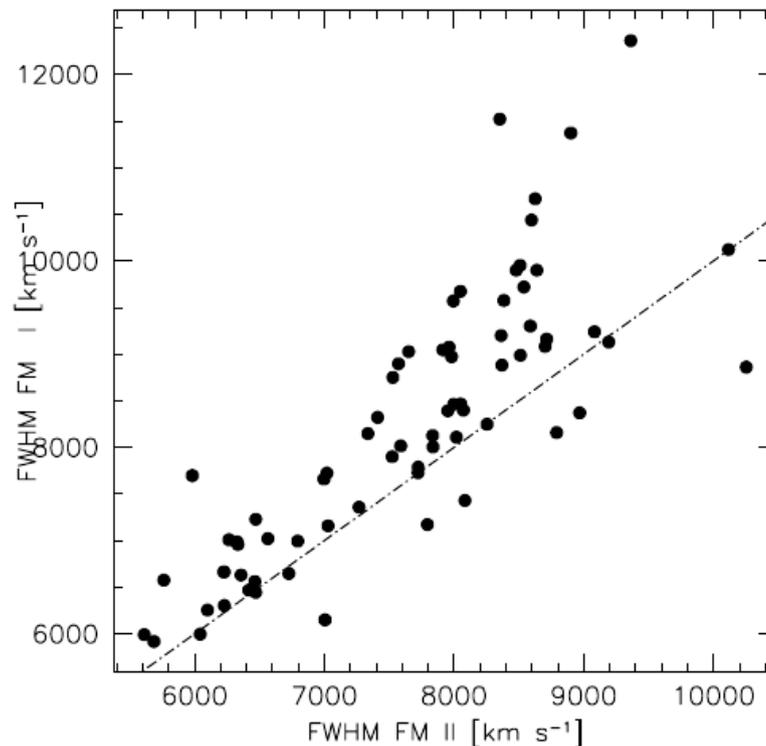


Model fitted using Specfit. The left panel represents the model fit of emission line in the low state, while the right panel represent the model fit in the high state. The spectra are shown after continuum subtraction. The full model spectrum is traced by a thin dashed magenta line. The thick magenta line: full H β BC models, sum of two BC components (black) and VBC (red). Gold lines: total [O III] λ 5007 and H β NC; green: adopted Fe II template. The bottom panels show the difference model observed spectrum in radial velocity scale.

Comparison of fitting methods

UlySS vs. Specfit

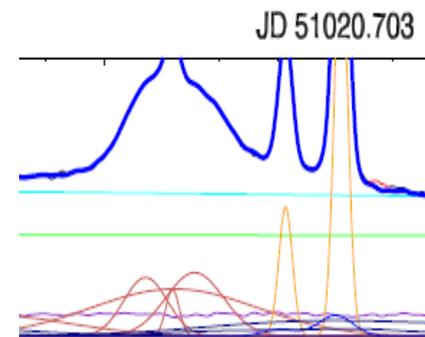
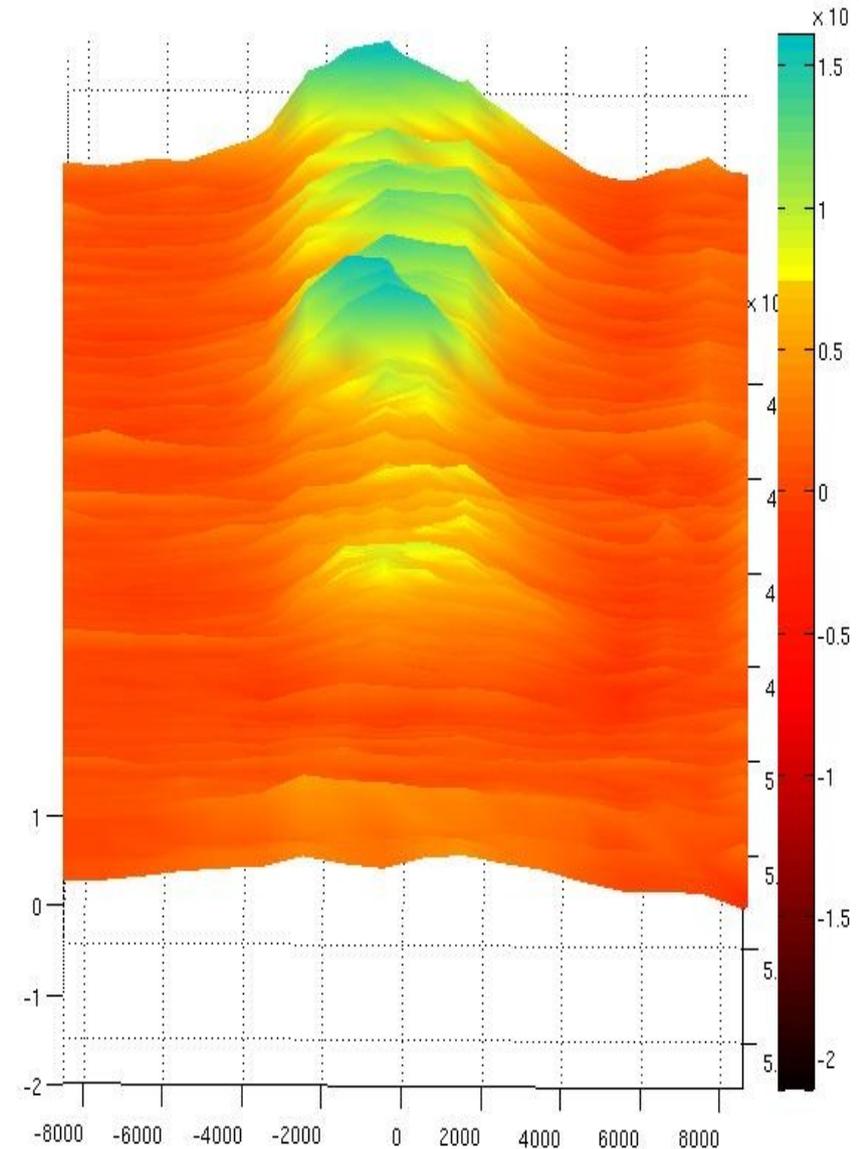
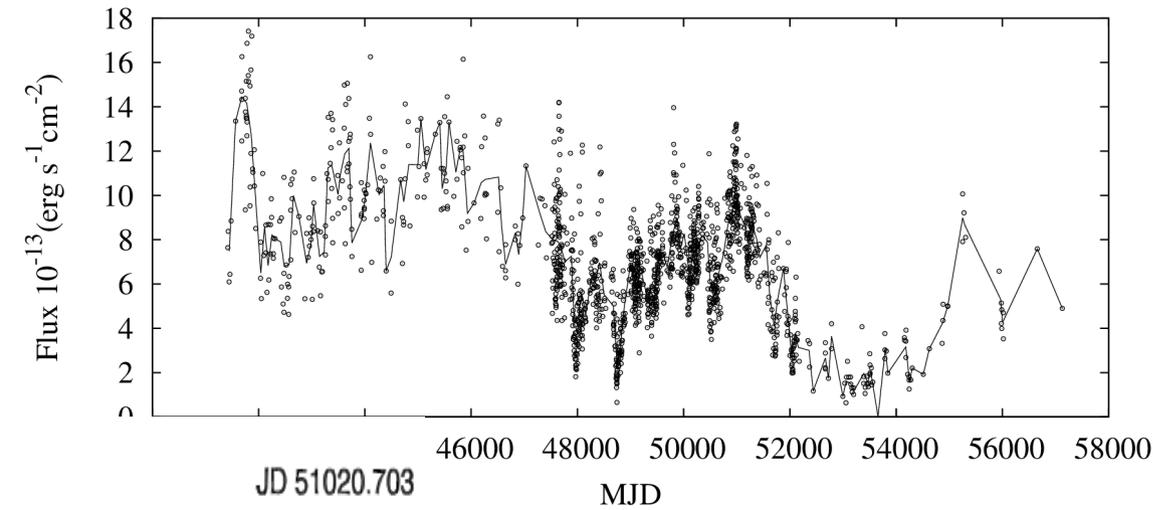
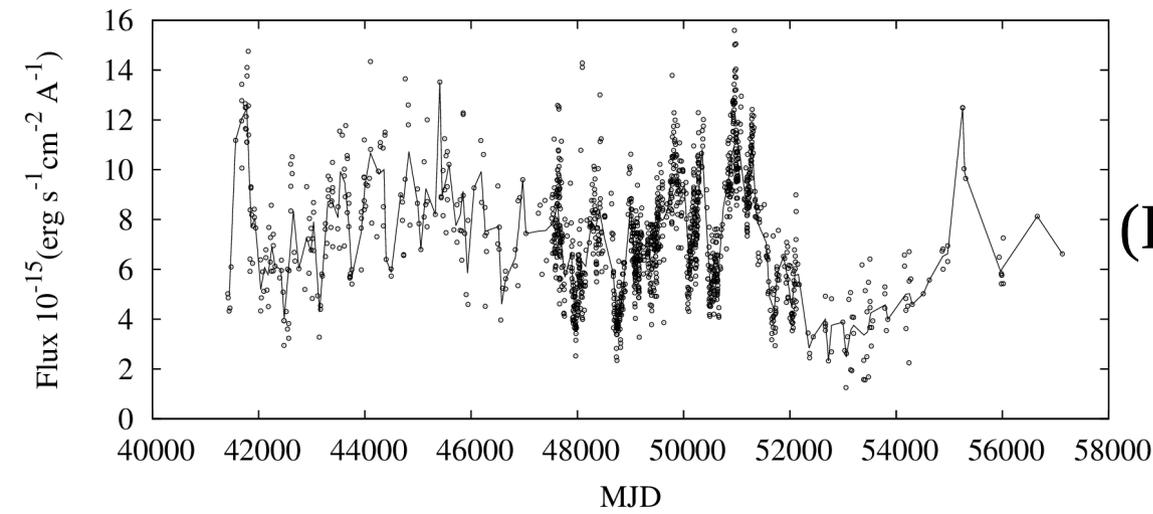
Fitting methods were compared to most critical monitored interval, of recent new observations when was galaxy mainly in low activity state. That means that the stellar continuum contribution to a total flux is very high.



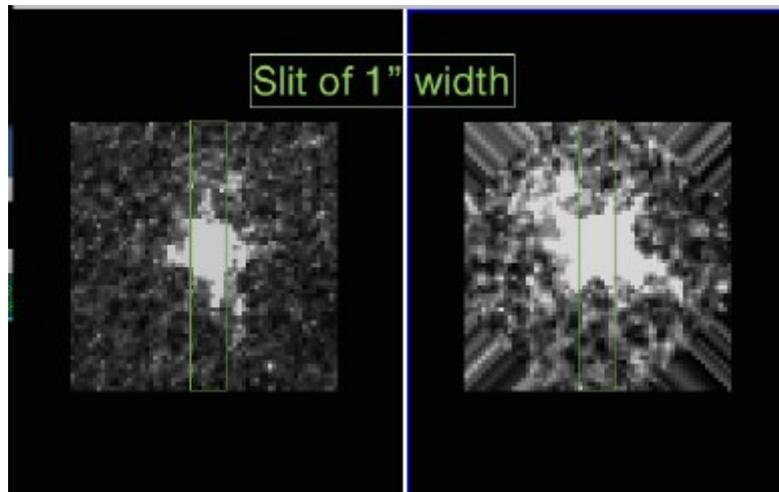
H β emission line FWHM measured of fitting model I and II for the epochs of the new observation data set.

NGC 5548

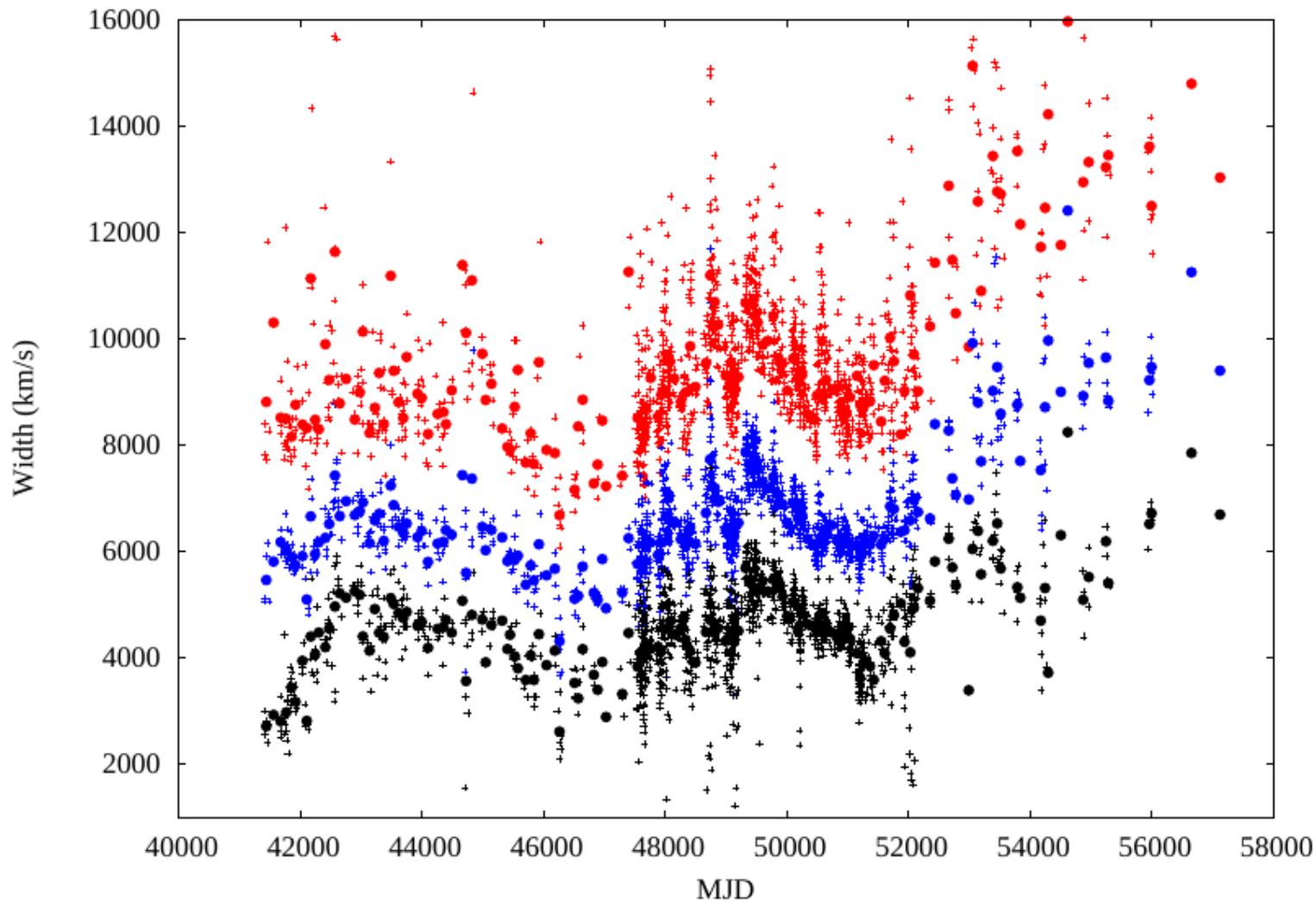
(E. Bon et al. 2016, submitted to ApJS)



O III =>



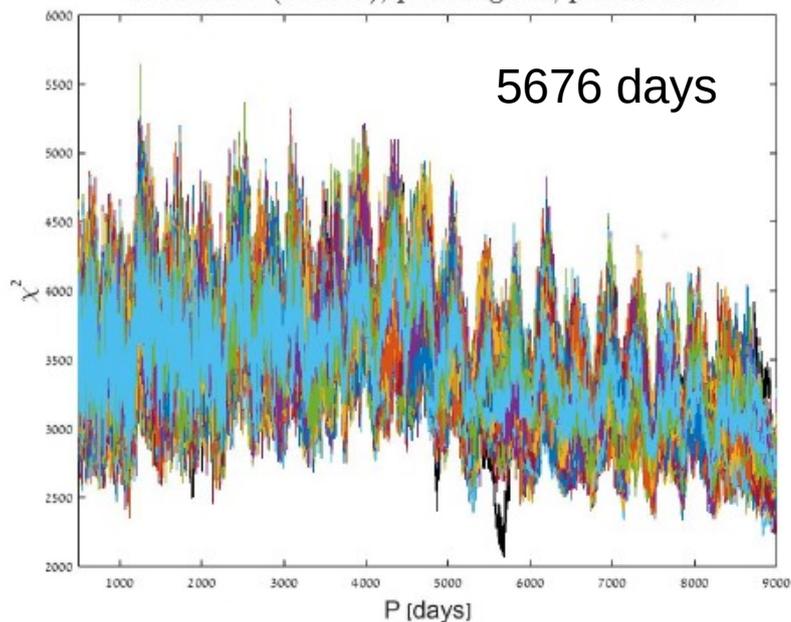
Radial velocity curves of $H\beta$ widths in NGC 5548



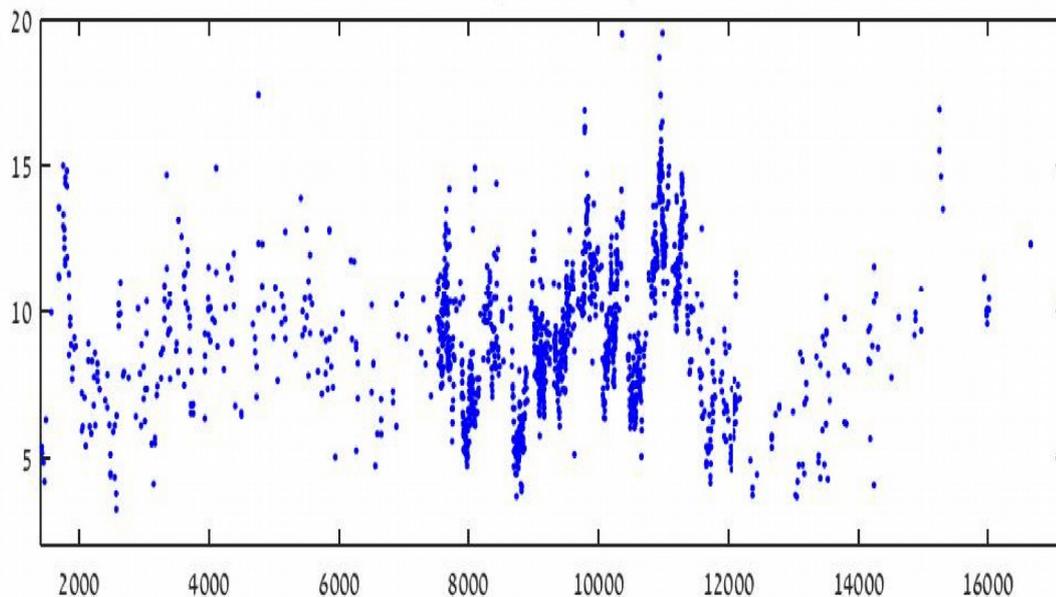
Curves of the full width at different heights of the broad $H\beta$ line in a: FWQM (red), FWHM (blue), FW3QM (black). The observations are presented with crosses, while the binned averaged data are plotted with full circles.

Phase dispersion minimization method gives periodicities:

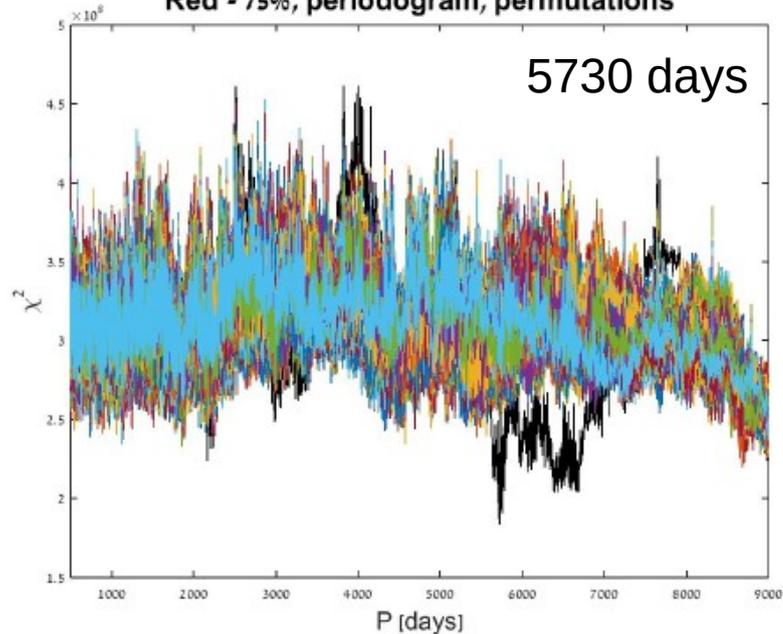
Continuum (5100 Å), periodogram, permutations



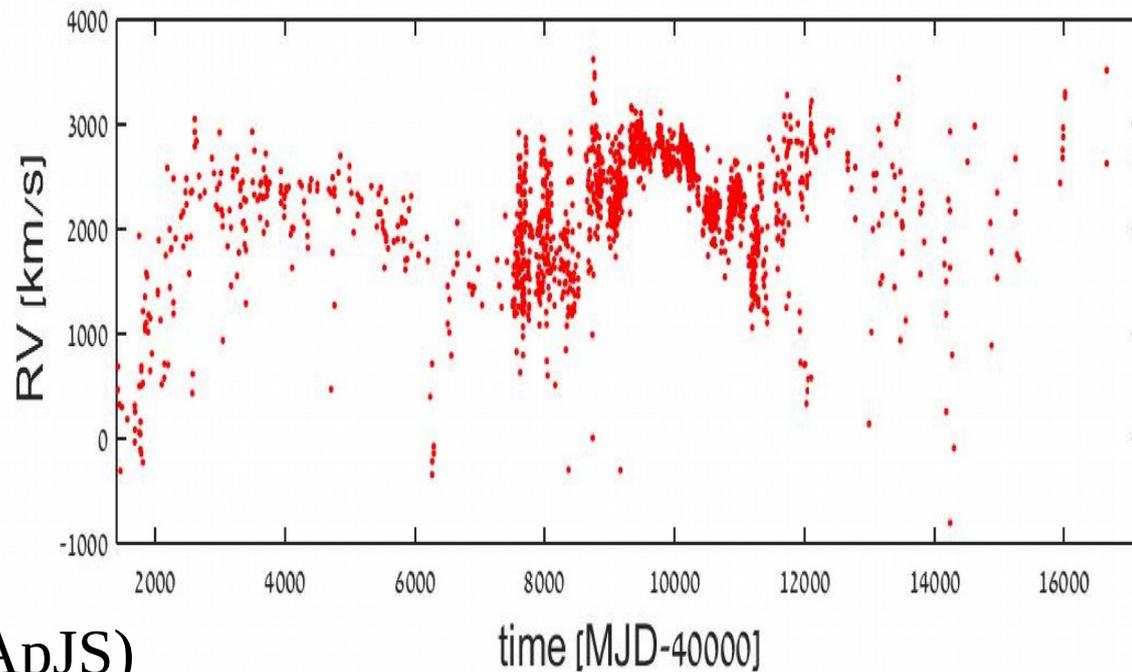
Continuum (5100 Å) lightcurve



Red - 75%, periodogram, permutations



red 75% RV curve



(E. Bon et al. 2016, submitted to ApJS)

Possible interpretations

The detected periodicity is consistent with orbital motion inside the BLR of the source. We examined various physical scenarios that can explain the observed periodicity:

- binary BHs,
- a TDE of a massive star,
- orbiting dust-free and dusty clouds around the central BH and the polar axis of the system,
- and orbiting object periodically colliding with the accretion disk

Thank you for your attention!