Disentangling the optical spectral variability of gamma-ray bright blazars through statistical studies

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Introduction

Blazars are variable objects typically dominated by the non-thermal synchrotron emission of relativistic jet. However, other components such as the accretion disk or the host galaxy can contribute significantly to their optical emission.

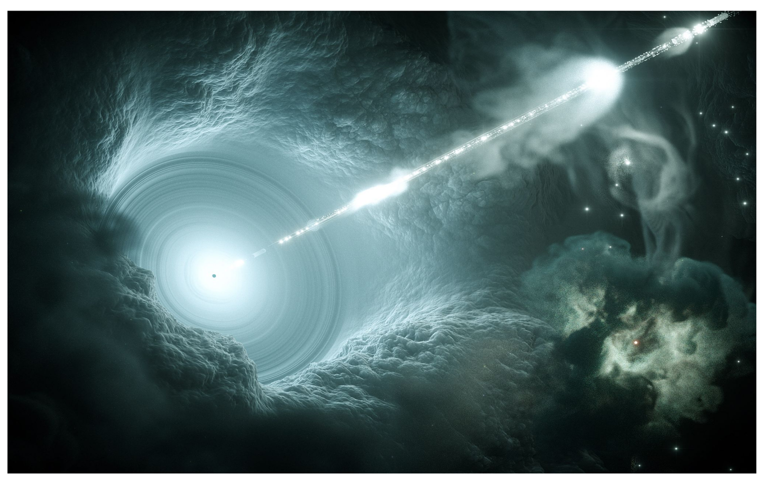


Fig. 1: Artistic representation of an Active Galactic Nucleus (*Credit: DESY, Science Communication Lab*)

Disentangling the different contributions is challenging, but it is crucial to study and understand their variability. For this, we use the statistical technique for dimensionality reduction named Non-Negative Matrix Factorization (NMF) [1].

Data set

We made use of the spectropolarimetric data taken by the Steward Observatory in Arizona, USA, thanks to its 10-year monitoring program for observational support to the *Fermi*-LAT gamma-ray space telescope [2].

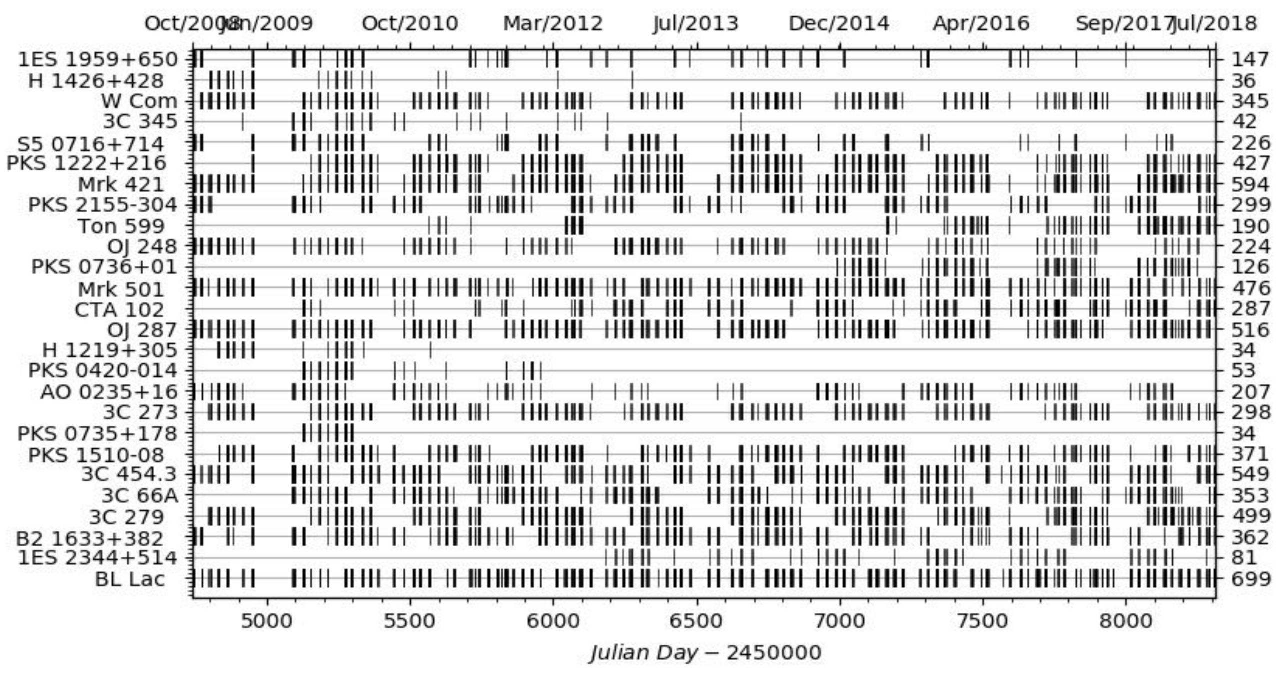


Fig. 2: Observational coverage of the data sample from 2008 to 2018 for each monitored source. Only targets with >15 spectra available were considered.

The final sample includes 11 BL Lac objects, 12 Flat Spectrum Radio Quasars (FSRQs) and 3 sources dominated by the stellar emission of the host galaxy.

Methodology

We use a methodology based in a reconstruction made with *a priori* known components that can be easily associated with the different parts of the AGN. BL Lac objects have an almost featureless optical spectrum, dominated by the jet. On the other hand, FSRQs display broad emission lines from the broad line region (BLR). In addition, galaxy-dominated sources show a lower jet contribution. Thus, the stellar emission that can dominate their optical emission. Under these considerations, we use different components for the different types of AGNs:

- BL Lac objects: 2 power law (PWL) components (jet)
- FSRQs: 2 power law components (jet) and 1 quasi-stellar object (QSO) template [3] (BLR)
- Galaxy-dominated sources: stellar emission template obtained with pPXF [4] (host galaxy) and power law (jet)

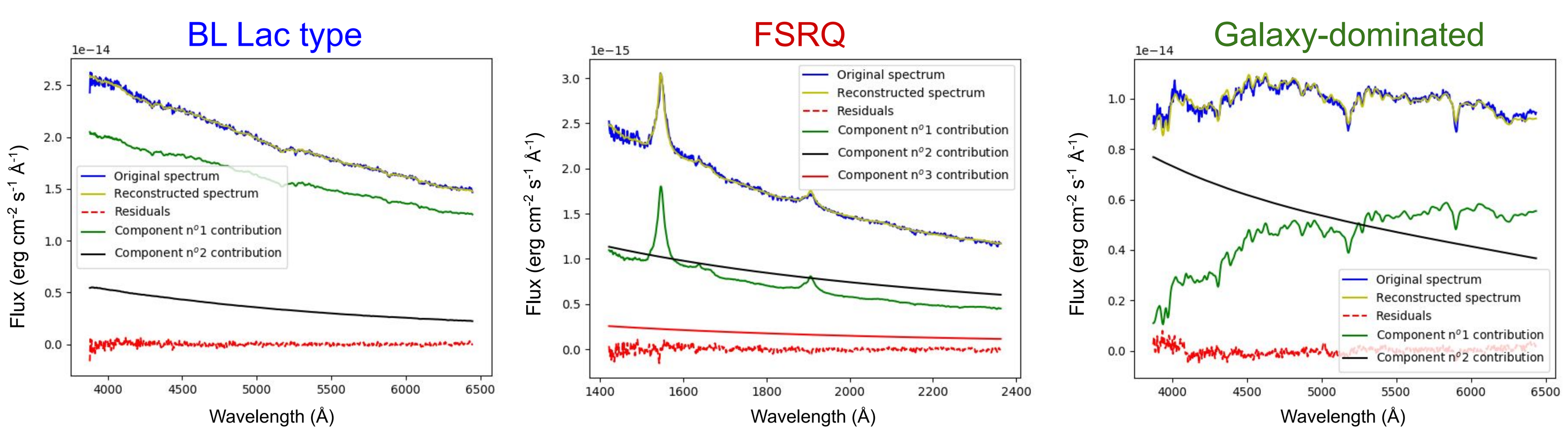
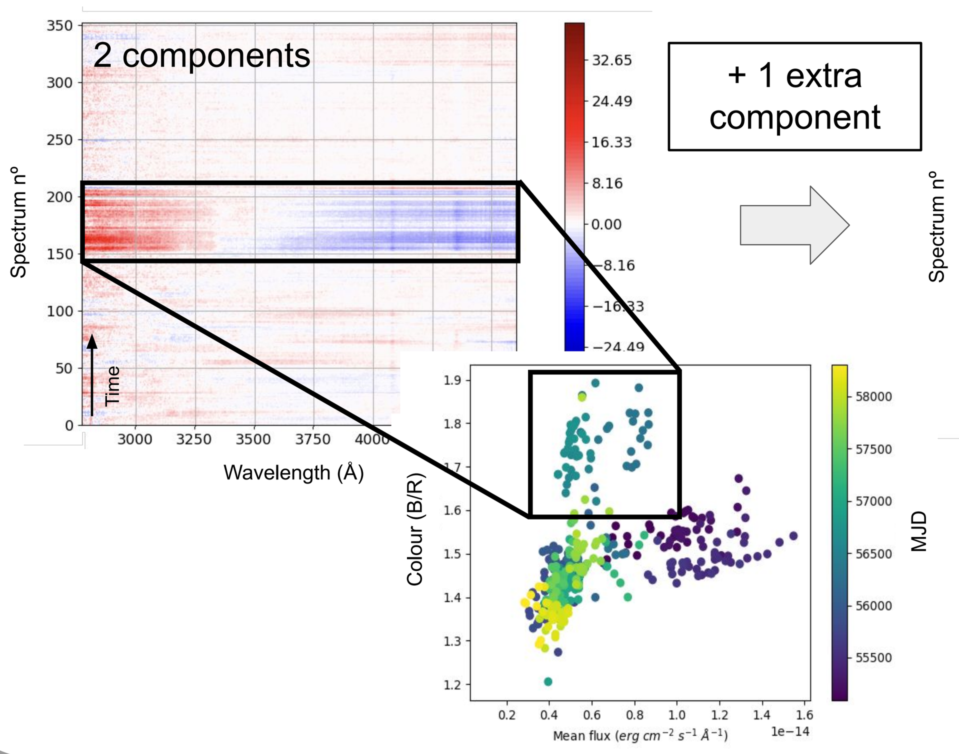


Fig. 3: Example of the reconstruction performed on different blazars. *Left:* Mrk 421 (BL Lac object). *Center:* B2 1633+38 (FSRQ). *Right:* Mrk 501 (galaxy-dominated blazar).

The accuracy of the reconstruction is evaluated with the residual map. Extra components are added if the residual of the reconstruction is high.



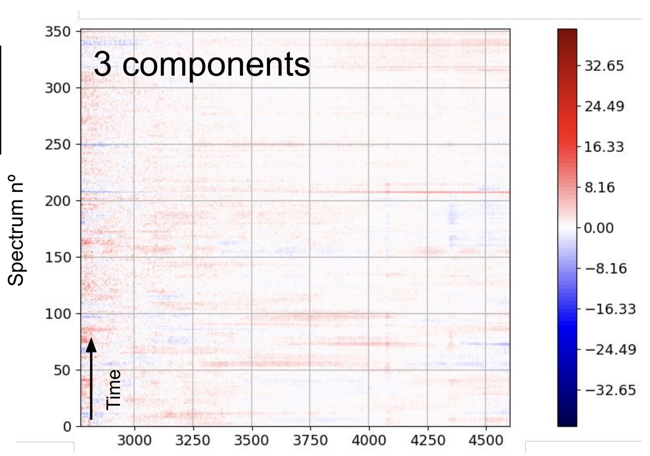


Fig. 4: Scheme of the methodology adopted to define the components used for the reconstruction.

Results

- Our method **reproduces** with high accuracy (explained variance > 99%) the **variability** observed in each blazar of the data sample.

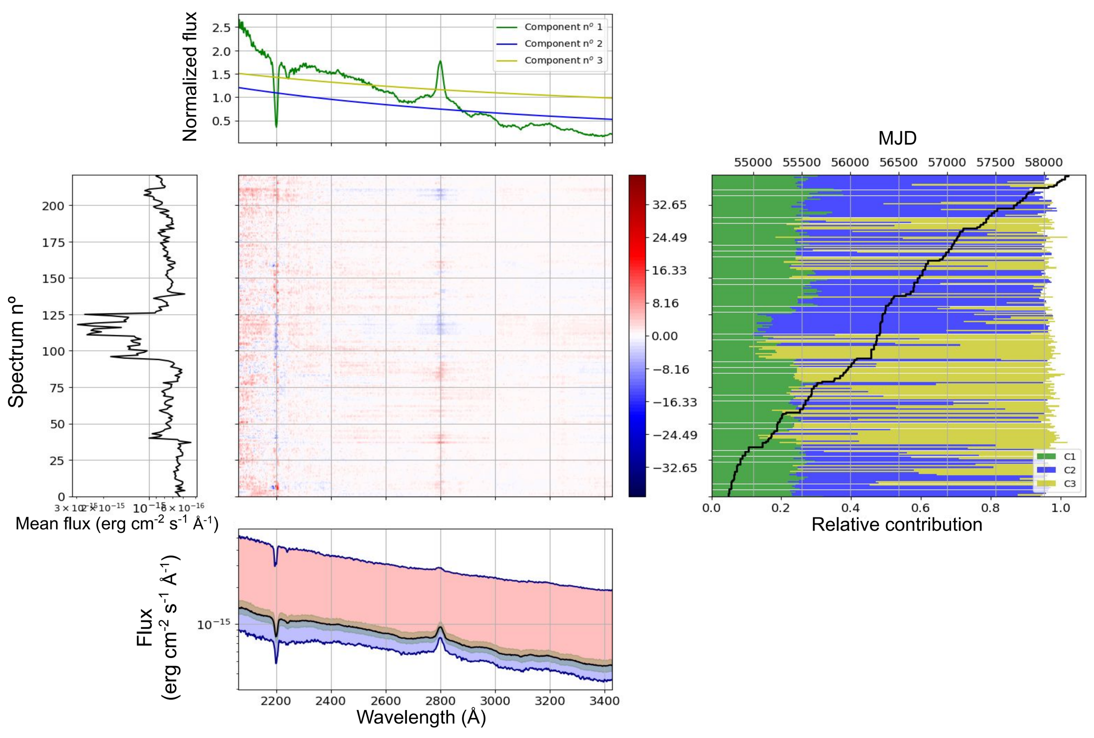


Fig. 5: *Middle:* Residual map of the reconstruction of OJ 248. *Top:* Normalized reconstructed components. *Right:* Relative contributions of each component. *Left:* Mean flux. *Bottom:* Maximum, median and minimum spectra.

Source type	N° and type of the components
BL Lac objects	2 to 4 PWL components
FSRQs	3 to 4 PWL and QSO template
Galaxy-dominated blazars	2 PWL and stellar template

Table 1: Number of components used for the reconstruction of each type of blazar.

- Different **colour trends** that reveal different **states** or **processes** in the blazar can be associated with the prevalence of different components obtained by the NMF [5].

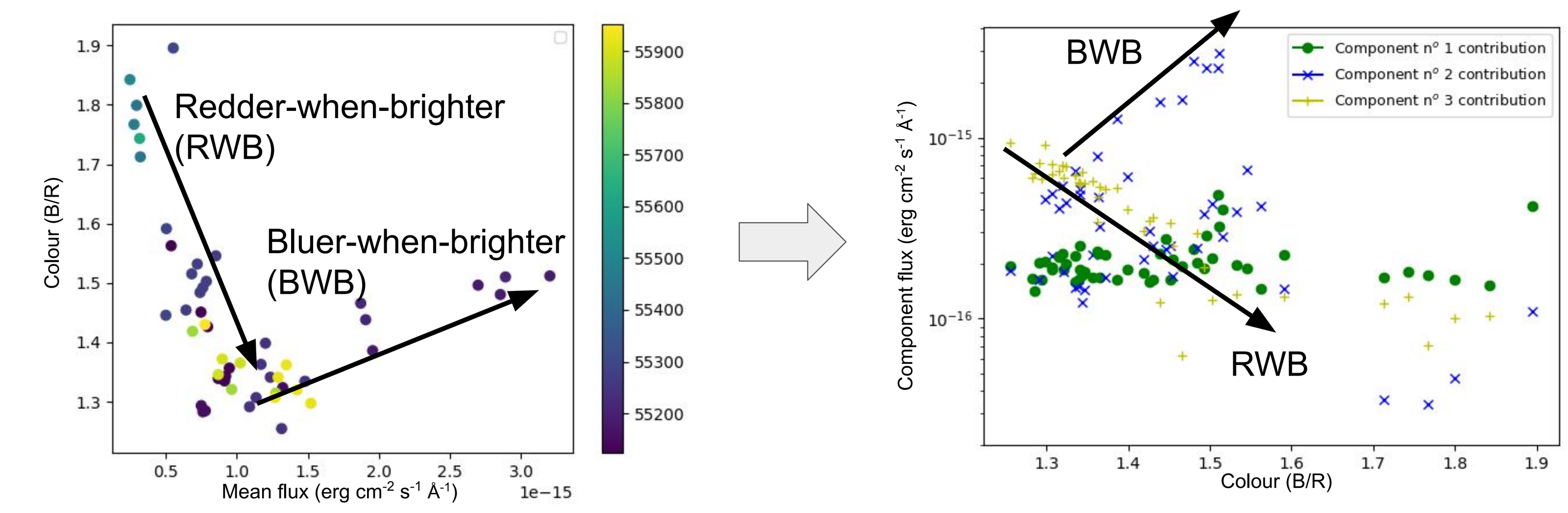


Fig. 6: *Left:* Colour evolution of the FSRQ PKS 0420-014 with the mean flux. The colour is calculated as the ratio between the blue (B) and the red (R) parts of the spectra. Thus, a higher (B/R) indicates a bluer spectrum. Right: Colour evolution of each component of the reconstruction.

- **Transient behaviours** that can be explained by **instabilities or blobs** propagating through the jet can be identified with this method.

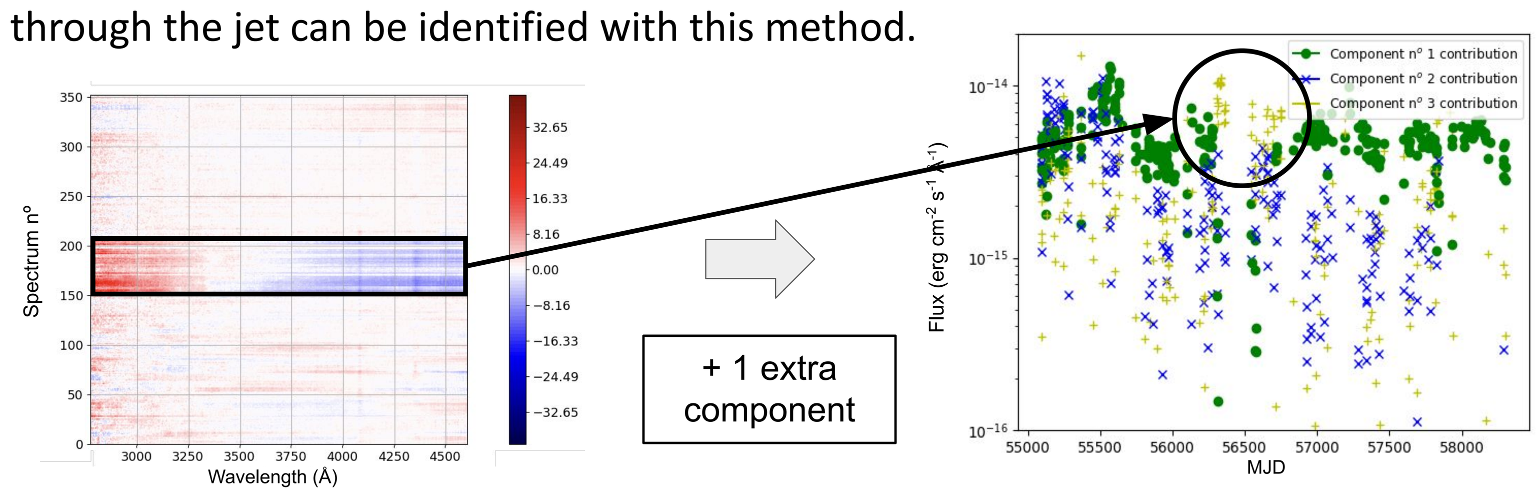
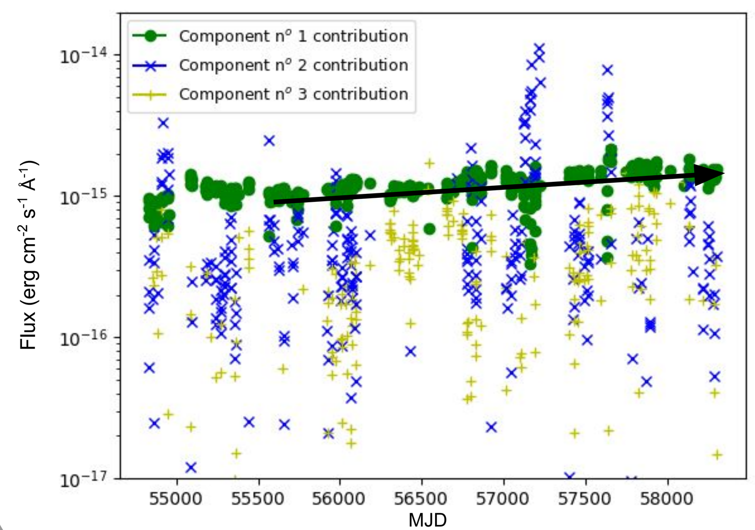


Fig. 7: Transient component observed in the reconstruction of 3C 66A. *Left:* Residual map. *Right:* Light curve of the reconstructed components.



- Some FSRQs display a low amplitude and **slow varying trend** in their BLR component. This evolution could be associated to the slower variability expected from the **accretion disk**.

Fig. 8: Light curve of the FSRQ PKS1510-089 for each reconstructed component. The first component, associated with the BLR, shows a slow increasing trend that could be associated with the accretion disk.

Conclusions

The NMF can be a very useful tool to study variability in blazars. It allows us to:

- **Reproduce** > 99% of **the variability** of the sources with a small number of components
- Associate the components with the **different parts of the AGN**
- Identify **different emission mechanisms or physical processes** in the jet
- Identify possible **transient behaviours** due to **instabilities or blobs** in the jet
- Study the **colour evolution** and relate it to the different components

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Acknowledgements

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