

# Short-Timescale Variability in the Relativistic Jet Plasma of the Black Hole 3C 454.3 from Optical-Gamma Correlations

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## ABSTRACT

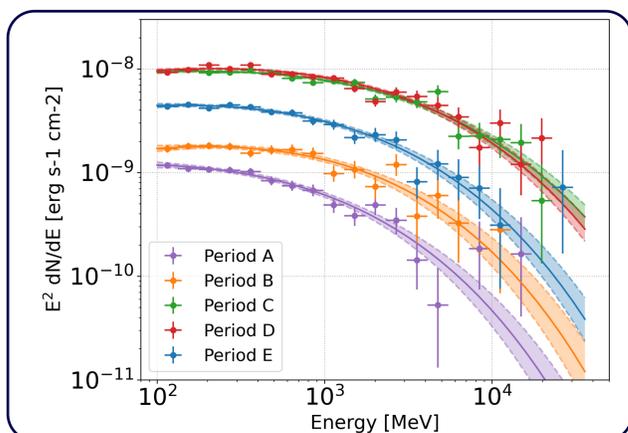
The study of astrophysical plasma in relativistic jets provides a unique laboratory for exploring high-energy particle acceleration and radiative processes. We investigate the **multi-wavelength variability** of the black hole **3C 454.3**, one of the most active extragalactic sources. In leptonic jet-emission scenarios, the optical emission arises from synchrotron radiation from relativistic electrons, while the  $\gamma$ -ray component is produced via inverse-Compton scattering. We analyze the flaring behavior in the optical and GeV bands, their correlations, and variability on sub-day (6-12 h) timescales, aiming to constrain the origin of the variability.

## 1 - INTRODUCTION

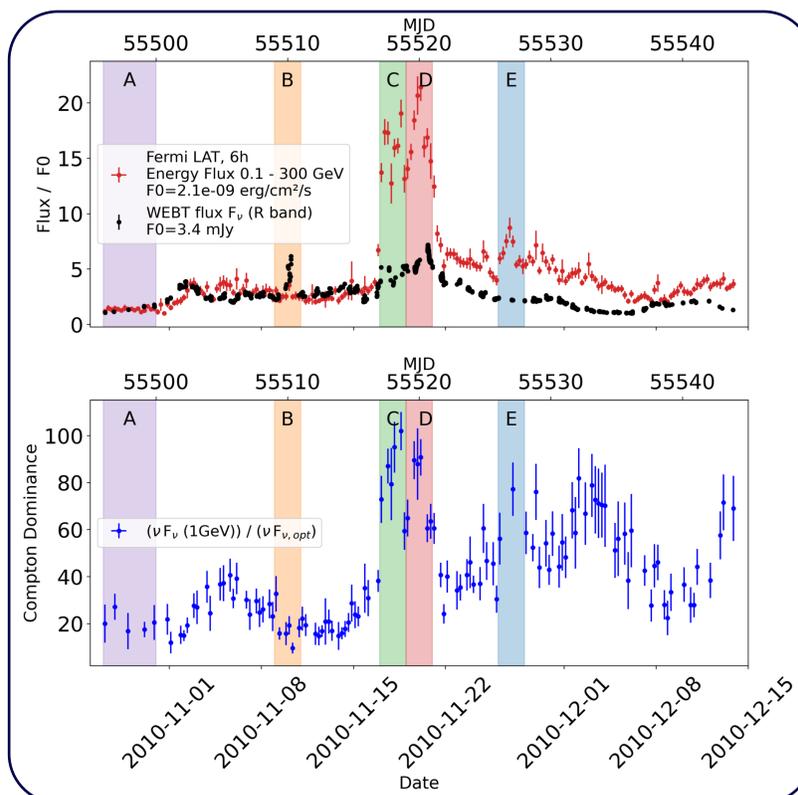
Multiwavelength variability studies provide a powerful alternative to SED modelling, as correlations between different bands directly probe the underlying emission mechanisms. 3C 454.3 is an ideal target, being one of the brightest and most variable  $\gamma$ -ray sources, with extensive  $\gamma$ -ray and optical monitoring. Previous works report a strong optical/ $\gamma$ -ray correlation but were generally limited to 1-day timescales or longer [1,2].

## 2 - DATA ANALYSIS

We analyzed 2008-2025  $\gamma$ -ray data from the **Fermi-LAT** within a  $10^\circ$  region centered on 3C 454.3. Isotropic and Galactic diffuse emission parameters were first estimated on monthly timescales and then fixed for the subsequent analysis. Light curves were computed using a two-step fitting approach: an initial fit with fixed background and all ROI sources free, followed by a fit with only 3C 454.3 free, ensuring robust flux estimates. Optical data were taken and assembled by the **WEBT Collaboration** and published in [3].



**Fig. 2:  $\gamma$ -ray spectra of 3C 454.3 during the highlighted periods in Fig. 1**



**Fig. 1: Light curves (Top) and Compton dominance (Bottom) of 3C 454.3 during the flaring 2010 state**

## 3 - LIGHT CURVES AND SPECTRA

The top panel of **Fig. 1** shows the  $\gamma$ -ray (6h bins) and optical light curves (top panel) during the bright 2010 flaring state [4]. The emission in both bands can be described as a slowly varying baseline (Period **A**) plus several flare types: orphan optical flares (**B**), correlated flares visible in both bands (**C**, **D**), orphan  $\gamma$ -ray flares (**E**).

The bottom panel of **Fig. 1** shows the **Compton dominance** time series, i.e. the ratio between the  $\gamma$ -ray (1 GeV) and optical spectra (R band). It exhibits sharp increases at flare onset, indicating abrupt changes in the jet environment or in the properties of plasma.

**Fig. 2** shows  $\gamma$ -ray spectra for the highlighted periods.  $\gamma$ -ray flares display slightly harder spectra than off-flare states.

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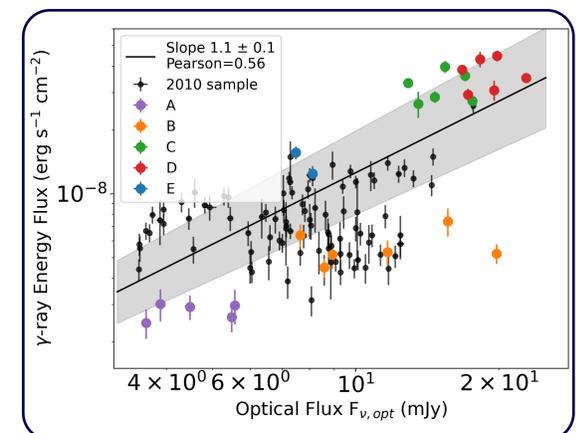
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## 4 - CORRELATIONS

**Fig. 3** shows the correlation between  $\gamma$ -ray and optical flux during the 2010 flaring state. The data show moderate correlation (Pearson coefficient  $\approx 0.6$ ), likely reflecting the superposition of different behaviors in 3C 454.3. Orphan flares (**B**, **E**) form distinct “bars” outside the main correlation band, while the baseline emission (**A**) and correlated flares (**C**, **D**) lie closer to it, albeit at different Compton Dominance levels.



**Fig. 3: Correlation of  $\gamma$ -ray and Optical Flux of 3C 454.3 during 2010**

## 5 - CONCLUSIONS

The data reveal complex variations in the optical- $\gamma$  correlation and Compton dominance across flares.

While tight optical- $\gamma$  correlation is expected in simple one-zone leptonic models, different degrees of correlation or orphan flares suggest **multi-zone emission** or a more complex jet structure. Multiple flare classes on short timescales challenge existing models, indicating that flaring activity cannot be explained solely by particle injection but reflects evolving physical conditions in the emitting plasma. Possible explanations include mirror models [5] or hadronic emission scenarios [6].

## REFERENCES

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## ACKNOWLEDGEMENTS

This work is based on data taken and assembled by the WEBT collaboration and stored in the WEBT archive at the Osservatorio Astrofisico di Torino - INAF (<https://www.oato.inaf.it/blazars/webt/>).  
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