Long term multi-wavelength analysis of the Flat Spectrum Radio Quasar OP 313 – ID 231

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Abstract

The flat spectrum radio quasar OP 313 showed extremely intense γ-ray activity from November 2023 to March 2024, as observed by the Large Area Telescope on board of the Fermi Gamma-ray Space Telescope. This initiated a vast follow-up campaign at all wavelengths, resulting in a confirmation of the increase of the source activity from the radio to very high energy (VHE) bands. Remarkably, it also led to the first detection of the VHE emission from OP 313 by the Large-Sized Telescope (LST-1) of the Cherenkov Telescope Array Observatory at La Palma, making it the most distant AGN detected at TeV energies. We present a complete multi-wavelength analysis covering 15 years of Fermi-LAT observations, from August 2008 to March 2024. From the Fermi-LAT study of the 15-year lightcurve, we can identify different periods of activity states of the source: one quiescent and one flaring state that can be compared with the data available from other instruments. In our study, we include X-ray, optical and radio data collected by Neil Gehrels Swift Observatory (Swift), the Nordic Optical Telescope, and the Medicina radio telescope, respectively. The study aims to model the multi-wavelength Spectral Energy Distribution of OP 313 in the flaring states with different theoretical leptonic and hadronic models to explain the source's behavior, understand the mechanisms involved in particle acceleration inside the jet and how radiation in different wavelengths is connected.

Why are Blazars so fascinating?

Blazars are a fascinating class of Active Galactic Nuclei characterized by highly luminous and rapidly variable continuum emission at all observed frequencies from radio to γ-rays [1]. This category of active galaxies includes both FSRQ and BL Lacs objects. Flat Spectrum Radio Quasars are characterized by a non-thermal continuum, like BL Lacs, and by strong and broad optical emission lines. They have higher bolometric luminosities than BL Lacs [2] and can exhibit signs of thermal activity possibly related to an accretion disk in their optical and UV spectra [3].
Blazars have a powerful jet pointed toward the observers and hence their SED is dominated by the relativistically beamed emission from the jet.
Furthermore, the SED is characterized by a double hump structure: the first hump is generally attributed to the synchrotron radiation in the radio to X-ray bands, whereas there is intense debate about the origin of the second hump. The commonly accepted emission mechanism is via inverse Compton scattering of the low-energy photons by high-energy electrons from GeV to TeV energies. However, an alternative scenario involve hadronic interactions producing neutral pions. These pions decay to generate photons in the GeV-TeV energies [4].

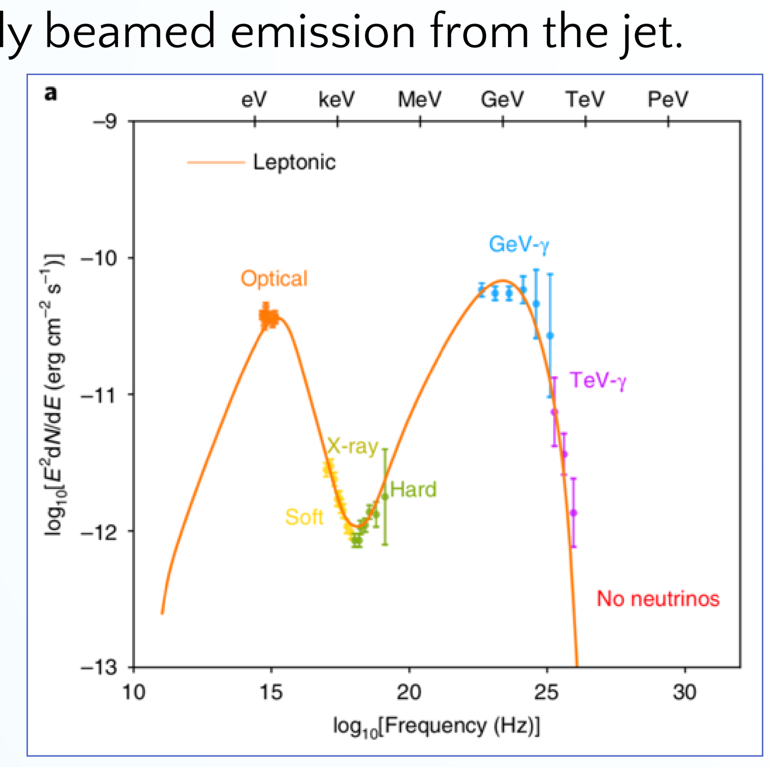

Figure 1 SED of a Blazar fitted with a leptonic model [5].

Methodology and Preliminary Results

We perform a long-term analysis of OP 313 in different wavelengths, from radio to γ-rays, to unveil the mechanism able to produce the intense γ-ray activity reported in the Astronomers Telegram's #16356 and #16497 [6,7]. We analyzed Fermi-LAT data starting from August 15, 2008, until March 9, 2024, and we obtained the 15-year Fermi-LAT lightcurve shown in Figure 2. Since we want to focus on the γ-ray flaring periods of OP 313, highlighted in red and yellow in Figure 2, we used the same approach described in [8]. Firstly, we used an Adaptive Binning method to obtain more bins in the periods in which the flux uncertainties varied 20% than the 15-year average value and we used the Bayesian Blocks to identify the brightest flares. Then, we found the average flux weighted in each bin in the low-activity period from December 2014 to October 2018 as equal to 4.93×10^{-8} photon $cm^{-2} s^{-1}$. All the fluxes below this value are part of the quiescent periods, all the other are indications of an activity of the source.
Furthermore, we distinguished between two periods of activity: the hard flares (in red) are periods in which the average photon index in each bin is smaller than the average 15-year photon index (Γ<2.14, hardening of the spectrum), the soft flares (in yellow) are the periods in which the photon indexes are compatible to the average index and error (green line and green band respectively) observed between December 2014 and October 2018 (soft spectrum).
Figure 3 shows the preliminary SED of OP 313 in three different periods: an 8-year quiescent period in blue, a soft flare period in yellow, and two hard flare periods corresponding to the flares reported in [6] and [7]. The data were fitted with a simple power-law model. Further investigation will involve more complex models to understand where a curvature is present in the three different periods.

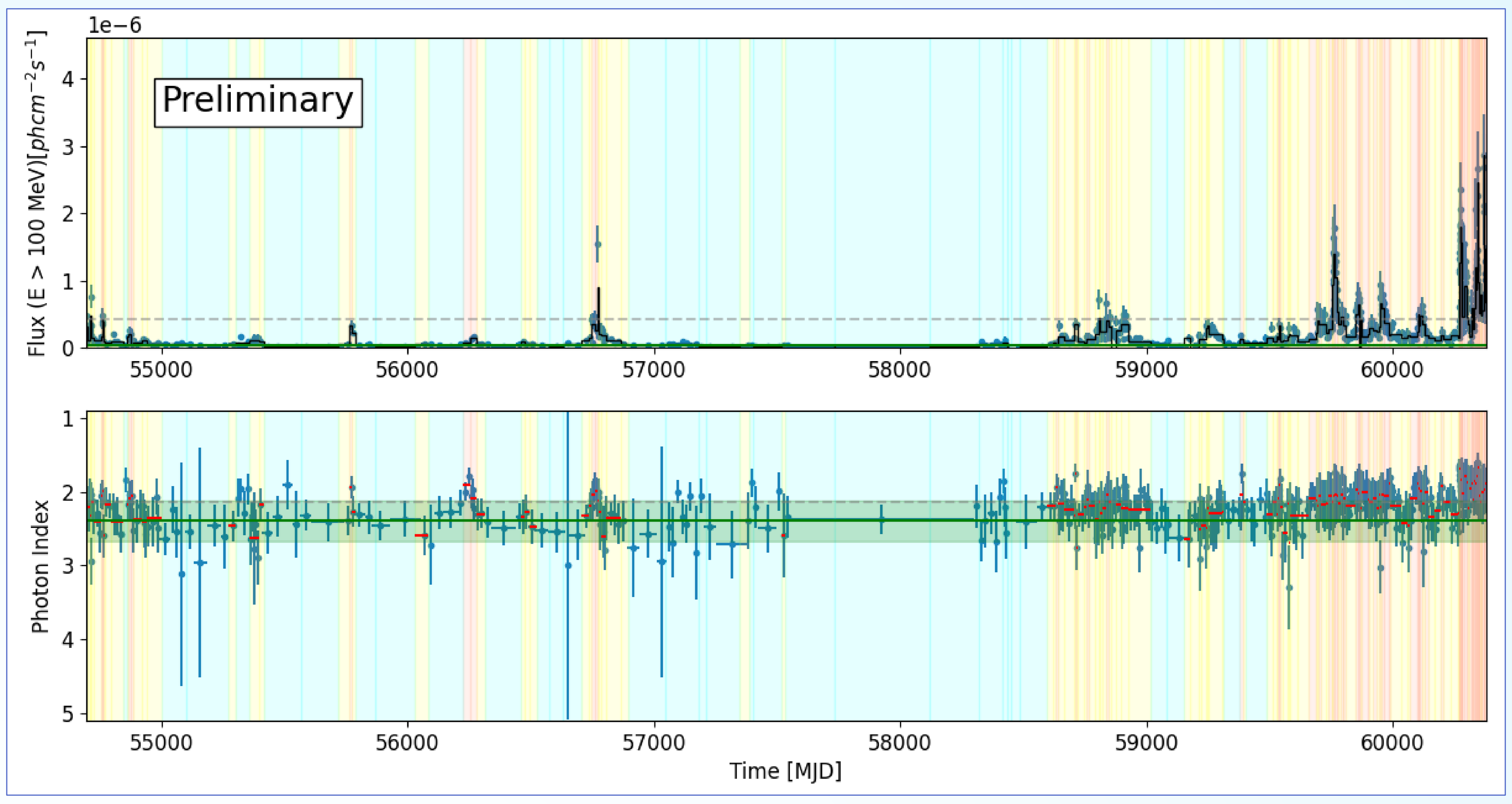

Figure 2 Top: OP 313's Fermi-LAT lightcurve from August 15, 2008, to March 9, 2024. The blue bands represent the quiescent periods when the flux is smaller than the green line value. The yellow bands represent the periods of soft flares and the red bands the hard flares. The grey line is the average 15-year flux weighted for every bin. Bottom: 15-year photon indexes of OP 313. The green line shows the average photon index in the quiescent period (Γ=2.4) with its 1σ uncertainty. The average photon indexes in each bin inside this green band represent the soft flares, while the other the hard flares.

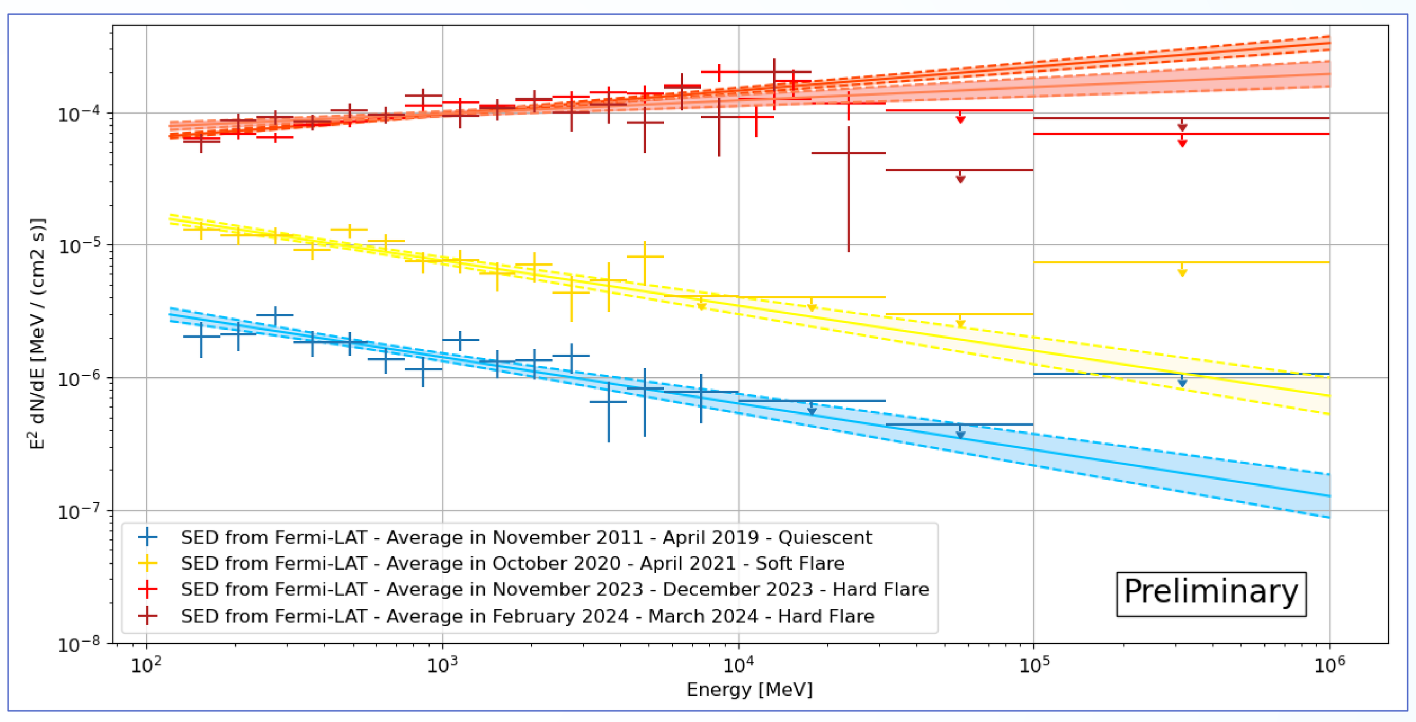

Figure 3 OP313's Fermi-LAT SED in 4 different periods: an 8-year quiescent period (blue), a soft flare period (yellow), and 2 hard flare (red) periods corresponding to the ones reported in [6] and [7]. The colored contours show the power-law fit where normalization and spectral index were free to vary. The arrows represent the 95% upper limits.

Then, we looked at the available Swift-XRT and Swift-UVOT datasets in the same 15 years of Fermi-LAT observation and we realized the SED of OP 313 (Figure 4). The Swift SED is useful to understand how the X-ray synchrotron emission changes with time and to localize the frequency at which there is the passage between the first and second hump.

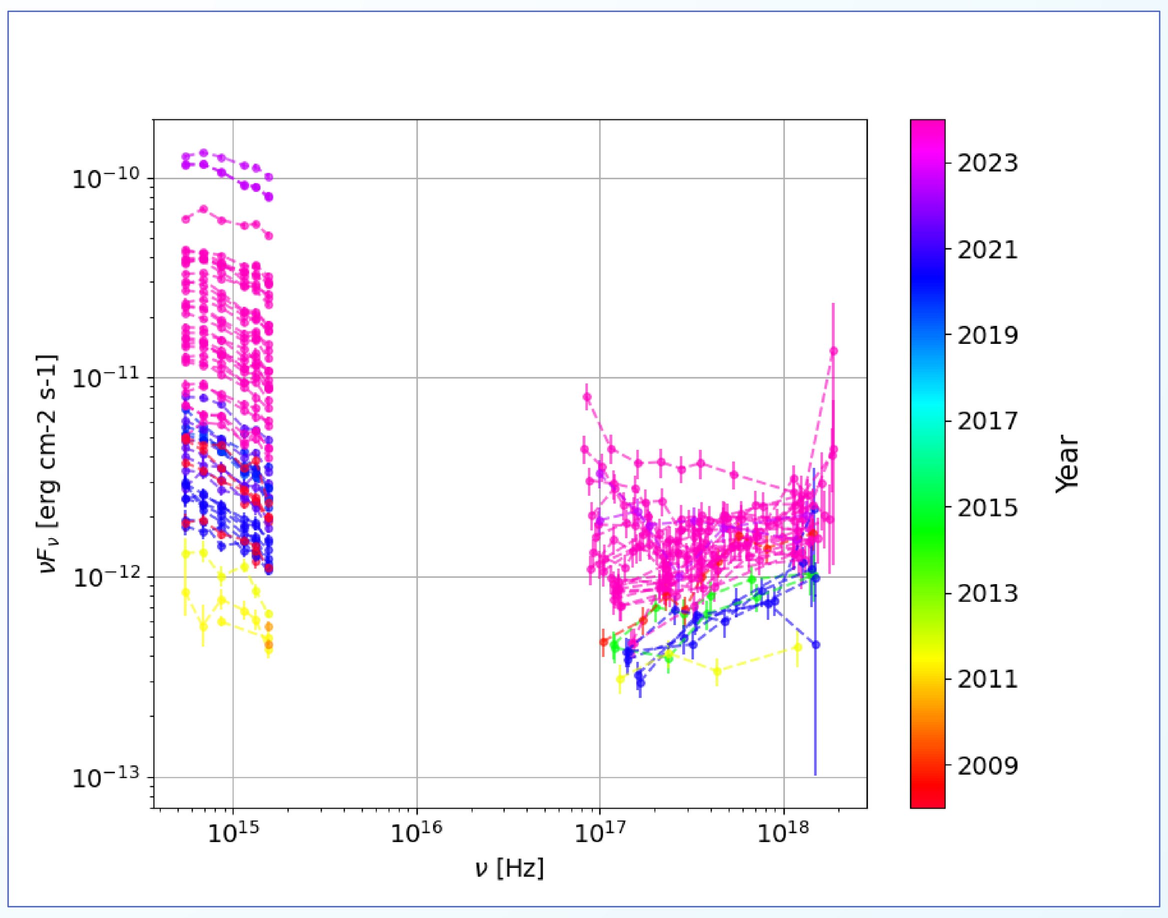

Figure 4 A 15-year SED analysis of OP 313 using Swift-XRT (on the right) and Swift-UVOT (on the left) observations.

Conclusions and Next Steps

We performed a multi-band analysis of OP 313, selecting quiescent and flaring states. The next steps are realizing a SED that takes into account also Optical and Radio datasets of this source in the periods of OP 313 activity and find a theoretical model able to explain how this emission is produced.

References and Acknowledgements

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