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

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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 (LAT) 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.

Methodology and Early Results

We perform a long-term analysis of OP 313 (z=0.997; [1]) 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 [2,3]. 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 1. 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 [4]. We used an Adaptive Binning method and 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 $4.93 \times 10^{-8} \mathrm{photon\ cm^{-2} s^{-1}}$. All the fluxes below this value are part of the quiescent periods, all the other are indications of an activity of the source.

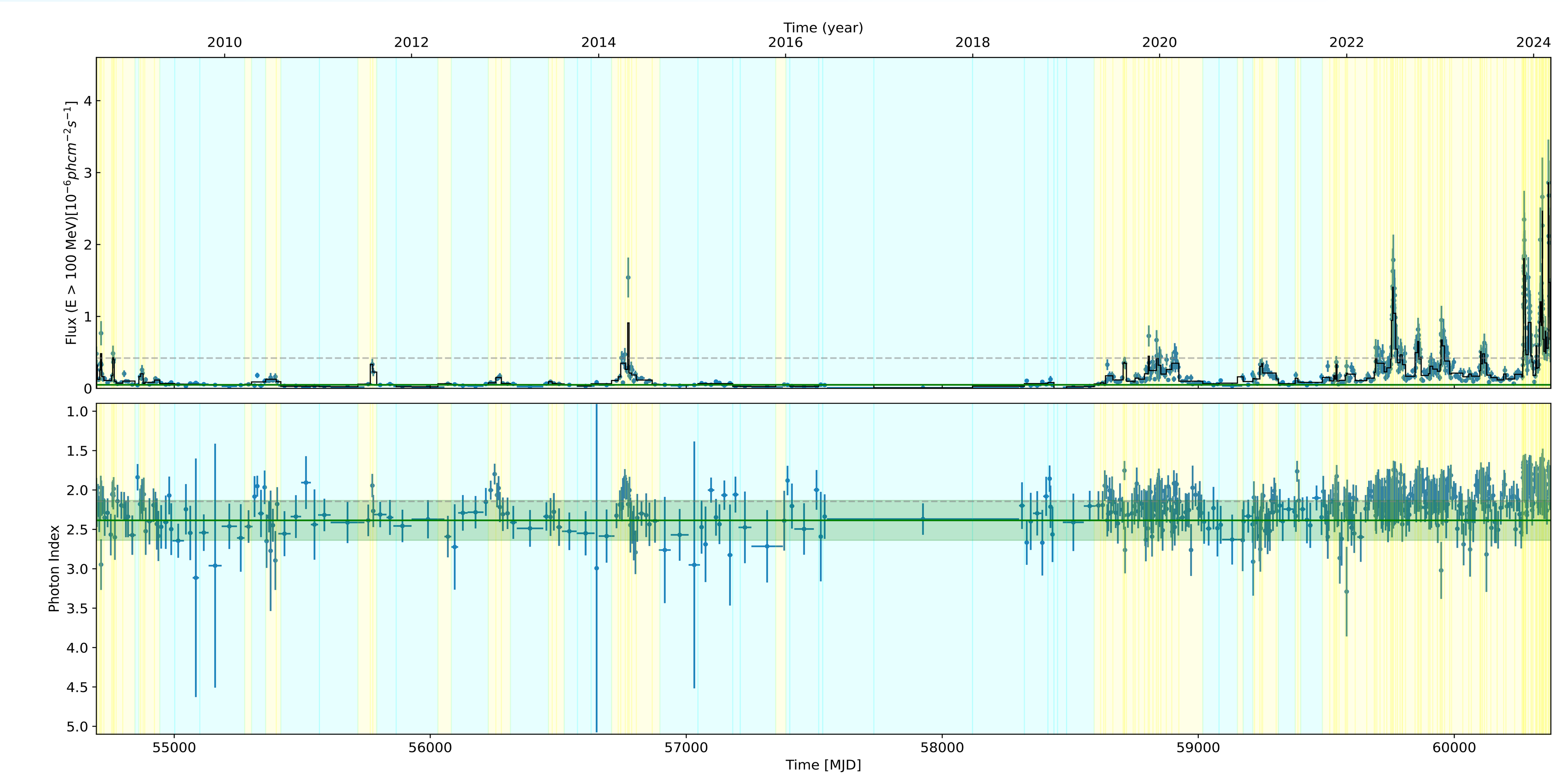

Figure 1 Top: OP 313's *Fermi*-LAT lightcurve from August 15, 2008, to March 9, 2024. The blue bands represent the quiescent periods when the flux is smaller than the green line value that represent the weighted, by the time duration of each bin, flux in a quiescent period starting from 2014 and ending in 2018. The yellow bands represent the periods of 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 lightcurves from gamma-ray to radio frequencies are shown in Figure 2. The ultraviolet dataset (c) is from Neil Gehrels *Swift* Observatory (*Swift*) UVOT instrument, while the optical dataset (d) is from different projects: cV stands for Catalina Real-Time Transient Sirvey (CRTS) V-filter data, kR for Katzman Automatic Imaging Telescope (KAIT) R-filter data, tR for Tuorla R-filter data, Ao and Ac for ATLAS o and c-filter data, and zG, zR, zGzR and zI for Palomar ZTF data. In e) plot are presented the *FERMI*-GST AGN Multi-frequency Monitoring Alliance (F-GAMMA) public data from 2.64 to 14.60GHz as well as MOJAVE public data at 15GHz. In f) plot are shown F-GAMMA data from 23.05 to 225.538GHz, the Submillimeter Array (SMA) public data at 300 and 353GHz, Metsähovi data at 37GHz and the VLBA-BU_BLAZAR data at 43GHz.

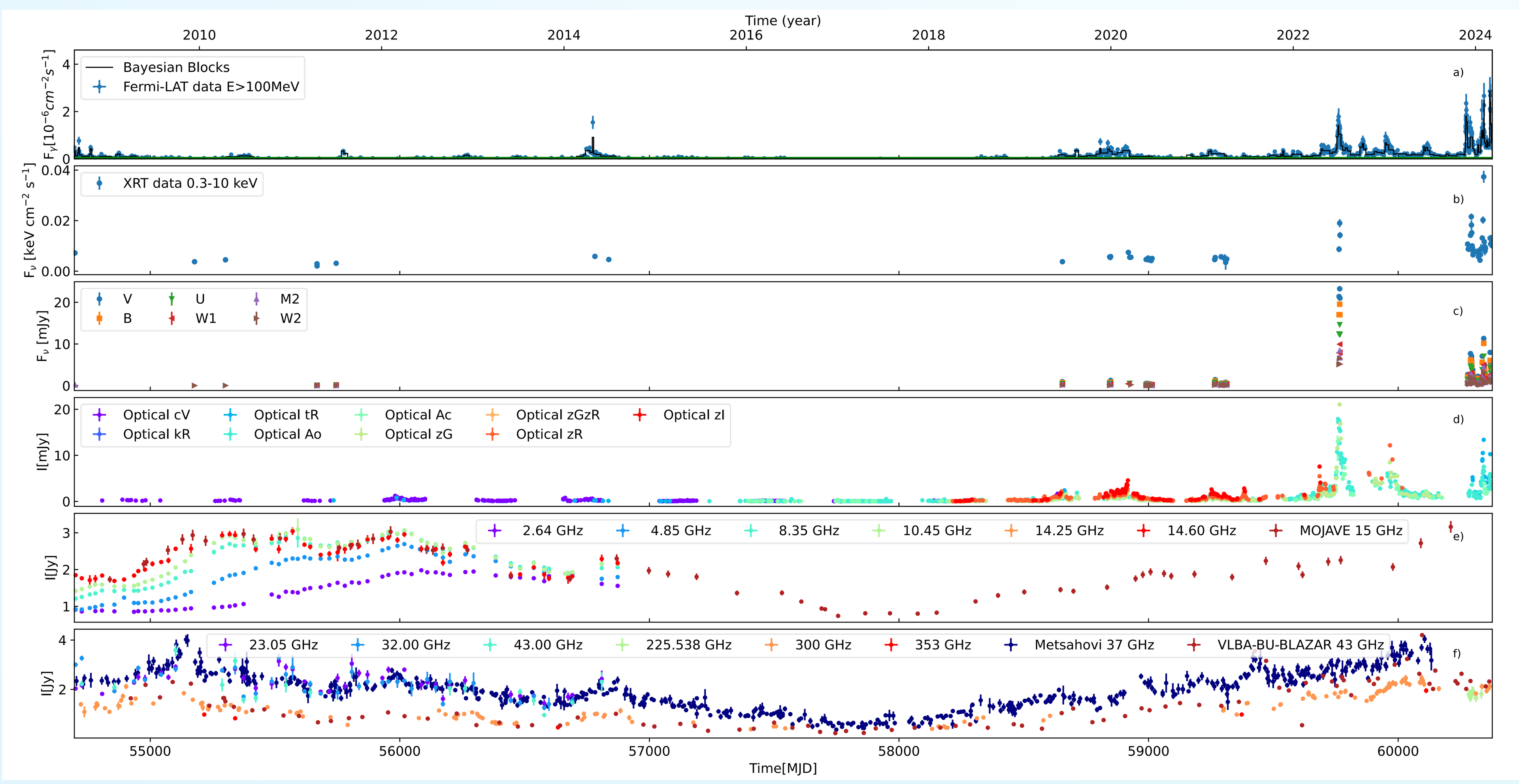

Figure 2 a: OP 313's *Fermi*-LAT lightcurve from August 15, 2008, to March 9, 2024. b: *Swift*-XRT X-ray lightcurve from 0.3 to 10 keV. c: *Swift*-UVOT lightcurve. d: Optical lightcurve from different datasets and filters. e: Radio Single Dish F-GAMMA lightcurve below 15GHz and MOJAVE VLBI lightcurve. f: Radio Single Dish F-GAMMA lightcurve above 15GHz, SMA at 300GHz and 353GHz lightcurve, Metsähovi at 37GHz and VLBA-BU-BLAZAR at 43GHz lightcurves.

Figure 3 shows the good correlation between Optical and *Fermi*-LAT data in particular starting from the beginning of 2022. Using the same approach presented in [5] and [6], we identified 7 different flares to compare with the VLBI data. In particular, we want to identify the brightest γ-ray flares and study their multi-wavelength behavior including the jets kinematics using VLBI data.

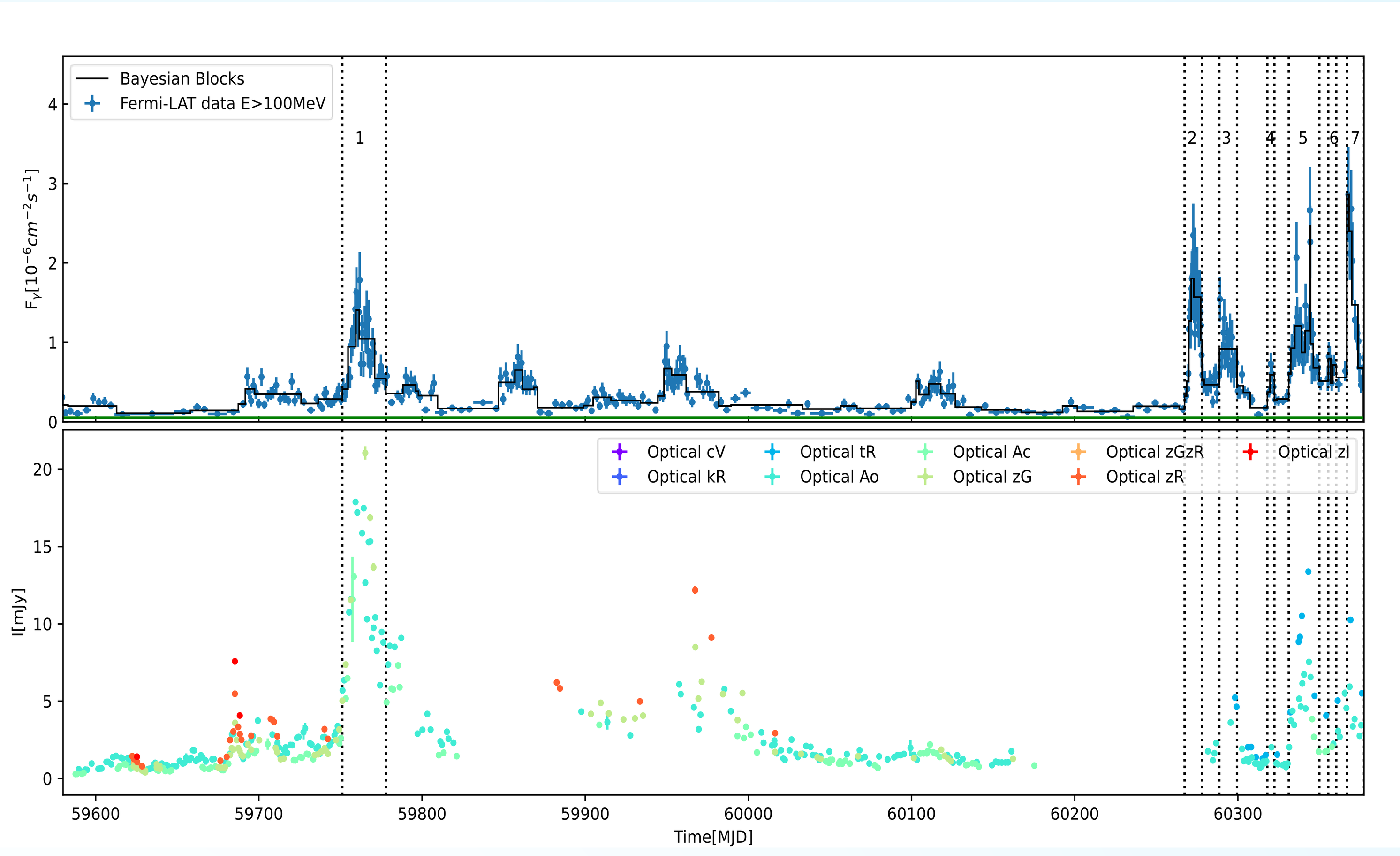

Figure 3 *Fermi*-LAT (top) and Optical Lightcurves (bottom) from the 1st of January 2022 to 9th of March 2024. The dashed black lines indicate the brightest γ-ray flaring periods in which we want to focus. For each γ-ray flare there seems to be a corresponding optical flare.

Figure 4 shows the comparison between the broad-band SEDs of the 1st and 5th flares of Figure 3. It is clear the 5th flare is more Compton dominated than the 1st flare. This means we have to consider different scenarios to explain them.

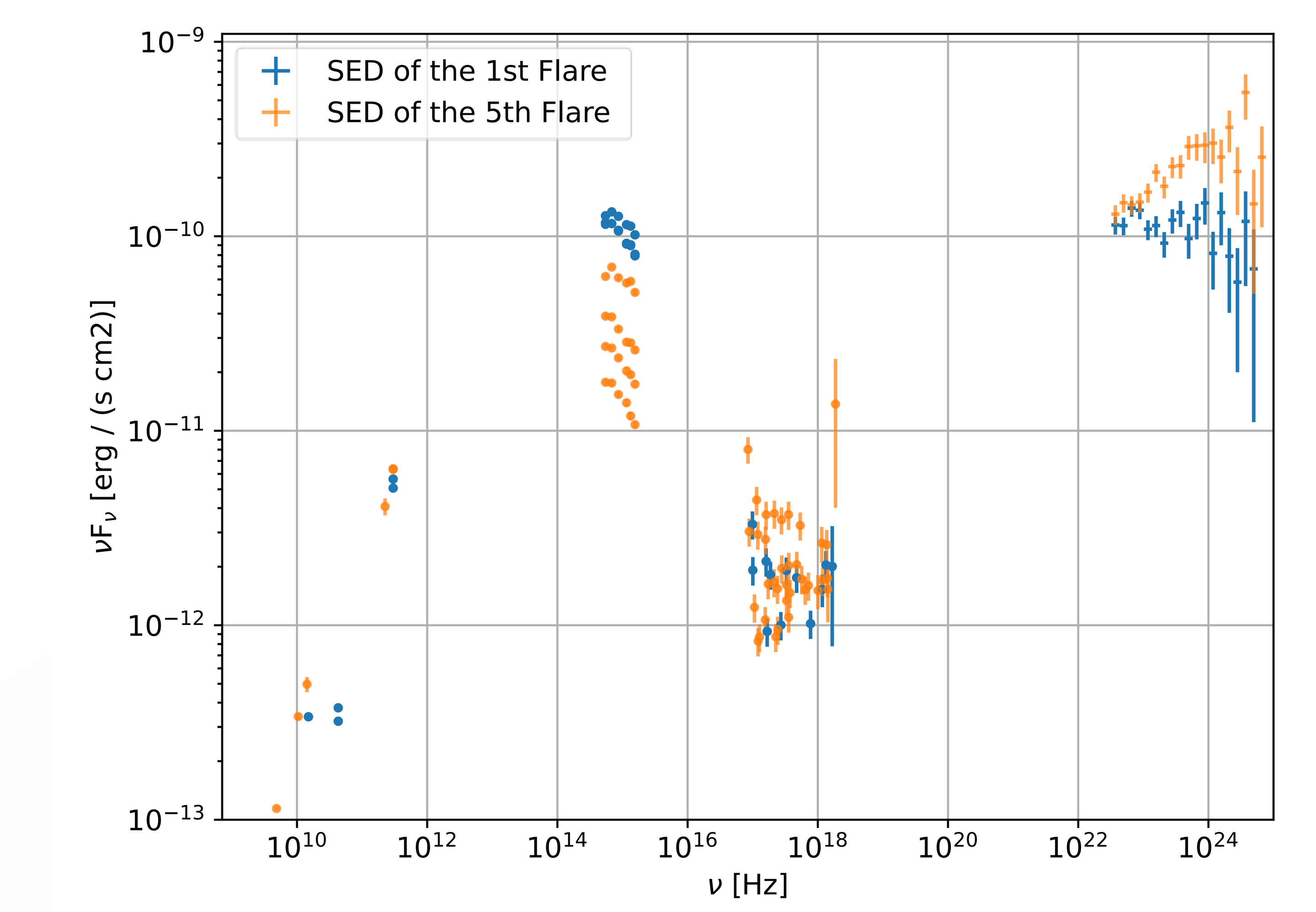

Figure 4 Broad-band SED comparison between the 1st flare (blue) and the 5th flare (orange). γ-ray data are from *Fermi*-LAT, X-ray data are from *Swift* XRT instrument, UV data are from *Swift* UVOT instrument, while radio data are from F-GAMMA, MOJAVE, SMA and VLBA-BU-BLAZAR projects.

Conclusions and Next Steps

We are performing a multi-band analysis of OP 313, focusing on recent γ-ray activity. The activity period consists of multiple γ-ray flares that show different MWL behavior. The next steps are the study the kinematics of the radio jet, using the VLBI available data to understand the origin of the differences between the flares.

References and Acknowledgements

[1] Schneider et al., 2010, *AJ* **139**, 2360;
[2] https://www.astronomerstelegram.org/?read=16356;
[3] https://www.astronomerstelegram.org/?read=16497;
[4] Rodrigues et al, 2021, *APJ*, **912**, 54-64;
[5] Marscher et al, 2010, *APJ*,**710**, 126-131;
[6] MacDonald et al, 2015, *APJ*,***804***, 111-122.

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