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Fermi-LAT Discovery of a Gamma-ray Outburst from Comptact Steep Spectrum object 3C 216

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Abstract. From November 2022 *Fermi*-LAT observed an enhancement in the gamma-ray activity of a Compact-Steep Spectrum radio source, 3C 216, which culminated in a strong outburst in May 2023. The event was followed up by the *Swift* telescope. We performed a careful analysis of the multifrequency data collected in the first week of May 2023. The result of the analysis supports the idea that the gamma-ray emission can be interpreted within a single zone Synchrotron Self-Compton model.

1 Introduction

On May 1, 2023 the Large Area Telescope (LAT) on board the *Fermi Gamma-ray Space Telescope* detected enhanced gamma-ray activity from a source at r.a.= $(137.51 \pm 0.11)^\circ$ and dec.= $(42.96 \pm 0.11)^\circ$ (J2000), consistent with gamma-ray source 4FGL J0910.0+4257 reported in the 4FGL-DR3 catalog [1] and associated with 3C 216. Preliminary data analysis revealed that this source exhibited an elevated gamma-ray emission state with an average daily flux (E$>$ 100 MeV) of $\langle\Phi\rangle_\gamma = (1.32 \pm 0.15) \times 10^{-6}$ photons cm^{-2} s^{-1} (statistical uncertainty only) [2]. This flux represents an increase of $\sim$ 180 times higher than the value reported in the 4FGL-DR3. The corresponding photon index estimated on May 1, 2023 was $\Gamma = 2.11 \pm 0.08$, harder than the cataloged value of $\Gamma = 2.57 \pm 0.10$. 3C 216 is an active galactic nucleus (AGN), classified as an extragalactic Compact Steep Spectrum (CSS) radio source, characterized by a low-frequency spectral peak and an extended radio structure with a blazar-like core viewed at a small angle [3, 4]. In the 4FGL-DR3 only five sources are classified as CSS. Such extreme gamma-ray flaring activities are unusual for sources of this type, and a comprehensive multi-wavelength (MWL) analysis is important to shed light on origin of its radiative emission. In this work, we present optical, UV, X-ray and gamma-ray analysis to investigate the source variability during the flaring state, along with a physical model to explain the observed phenomena.

2 MWL data analysis

2.1 *Fermi*-LAT observations: gamma-ray analysis

The *Fermi*-LAT data were analysed using *Fermipy v. 2.2.0* and *Fermitools v. 2.2.0*. Three distinct time intervals were examined: (i) the peak flare period from April

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28 to May 11, 2023; (*ii*) the extended flare period from November 14, 2022 to June 6, 2023, including the onset of enhanced gamma-ray activity reported in December 2022 [5]; and (*iii*) the entire *Fermi*-LAT observation period up to June 6, 2023. The analysis parameters are summarized in Table 1:

Table 1. Fermipy analysis parameters.

Parameter name	Value
Energy range	100 MeV to 300 GeV
Class of Photons	SOURCE
IRF	`P8R3_SOURCE_V3`
Event Type	FRONT + BACK
Point Source Catalog	4FGL-DR3
ROI size	$15° \times 15°$
Pixel size	$0.1°$
Bins per energy decade	8
Galactic diffuse model	`gll_iem_v07.fits`
Isotropic diffuse model	`P8R3_SOURCE_V3_v1.txt`

To minimize contamination from the Earth's limb, cuts on photons arriving at zenith angles larger than 90° for energies $E < 1$ GeV otherwise greater than 105° have been applied.

The spectral energy distributions (SEDs) for both flare and peak flare periods exhibit flux levels one to two orders of magnitude higher than those observed over the full *Fermi*-LAT dataset (see Fig. 1).

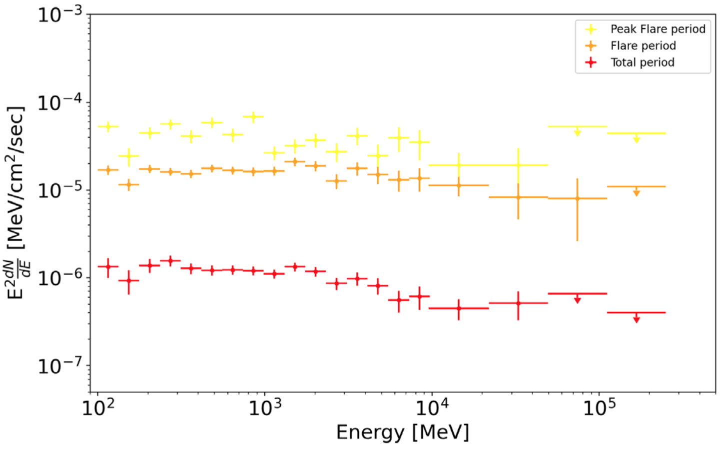

Figure 1. The SED of *Fermi*-LAT data for three periods: in *yellow* PF (Peak Flare) period, in *orange* flare period, in *red* total *Fermi*-LAT period. An upper limit is reported when $TS \leq 10$.

The spectral analysis indicates an hardening of the LAT spectrum during the flare and peak flare periods. A log-parabola model is the preferred spectral representation for all periods, in agreement also with the results reported in 4FGL-DR4 [6]. We investigated also spectral index versus flux behaviour of the source to investigate the radiative emission mechanism at work during the flaring activity: a loop-like pattern was observed for the gamma-ray emission during the peak activity, suggesting synchrotron emission as the dominant process. This finding will be further confirmed through MWL SED analysis.

2.2 SWIFT data observations

The event was followed up with five observations (May 3, 4, 6, 8, 9, 2023) by the Neil Gehrels Swift Observatory [7], covering optical, UV and X-ray energy ranges. During these observations, the X-Ray Telescope (XRT) operated in photon counting mode, while the UV/Optical Telescope (UVOT) conducted a sequence of exposures using six photometric filters (V, B, U, UVW1, UVM2, UVW2). Both analyses incorporated spectral corrections to account for physical effects during the propagation of radiation, as the Galactic extinction for the optical/UV data analysis, and an HI-column density set to the Galactic value in the direction of the source for the X-ray data analysis, respectively.

After the outburst, the UVOT and XRT shown a gradual decrease of flux over time, except in the hard X-ray regime. Therefore the observed trend suggests an initial simultaneous injection of energy into the synchrotron and inverse Compton (IC) components, followed by a radiative cooling phase.

3 Results and Conclusion

The time variability of the MWL SED was analysed using the JetSet tool [8], an open-source C/Python framework designed for modelling observed data with numerical simulations. In this study, we investigated the physical processes driving the flare activity in 3C 216. The radiative mechanisms included in the tool are Synchrotron Self-Compton (SSC), external Compton (EC), and EC off the cosmic microwave background. We tested the model using SED built with five-day bins, revealing that the flare activity is driven by an energy injection into the SSC component, followed by radiative losses and cooling. A detailed discussion of these results will be presented in an upcoming publication.

In conclusion, the analysis of the combination of Swift and *Fermi*-LAT data allowed the characterisation of gamma-ray flaring activity in the CSS 3C 216 during 2022-2023. The flare emission is best modelled as SSC across all frequencies, with a cooling phase occurring one day after the flare peak. Archival VLBA data are available for studying the source morphology [9]; however, these data do not capture the flaring state analysed in this work.

4 Acknowledgment

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