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B. Kapanadze[1,2,a)], D. Dorner[3,b)], S. Vercellone[2,c)], P. Romano[2,d)], S. Kapanadze[1,e)]
and L. Tabagari[1,f)]

[1] *E. Kharadze Abastumani Astrophysical Observatory, Ilia State University, Colokashvili Av. 3/5, Tbilisi, Georgia, 0162.*
[2] *INAF, Istituto di Astrofisica Spaziale e Fisica Cosmica, Via U. La Malfa 153, I-90146 Palermo, Italy*
[3] *Universität Würzburg, Institute for Theoretical Physics and Astrophysics, Emil-Fischer-Str. 31, 97074 Würzburg, Germany.*

a)Corresponding author: bidzina_kapanadze@iliauni.edu.ge
b)dorner@astro.uni-wuerzburg.de
c)stefano@ifc.inaf.it
d)romano@ifc.inaf.it
e)sergo.kapanadze.1@iliauni.edu.ge
f)lela.tabagari@yahoo.com

Abstract. The TV-detected blazar Markarian 421 is the brightest high-energy peaked BL Lac (HBL) source in the GeV energy range, detectable with 3 sigma significance on daily timescales in medium and higher brightness states with Large Area Telescope onboard *Fermi*. The 0.3–300 GeV flux showed a strong variability on diverse time scales from the flares lasting a few weeks down to intraday flux fluctuations detected mostly in the flaring states. The source also exhibited a GeV spectral variability. We mostly observe a low spectral curvature in this band due to the presence of the Inverse Compton peak at the energies mainly beyond about 100 GeV. The GeV flux generally showed a significantly stronger correlation with the radio–UV fluxes than with those in the X-ray and TeV bands that confirms the hypothesis about the possible stronger connection between radio–UV and GeV emissions due the effect of Klein-Nishina suppression on the IC process, leading to the effective up-scattering of radio–UV photons at the GeV energies by the X-ray emitting electrons.

INTRODUCTION

BL Lacertae objects (BLLs, a blazar subclass) are active galactic nuclei (AGNs) of elliptical galaxies with following features [1]:

- Non-thermal continuum emission stretching from radio to TeV band (17–19 orders of the frequencies)
- Absence of both absorption and emission lines
- Strong flux variability in all spectral bands
- Compact and flat-spectrum radio emission
- Double-humped spectral energy distribution (SED)
- Apparent superluminal motion of some components
- High and variable radio/optical polarization
- strong γ-ray emission: BLLs form a majority of extragalactic TeV sources

The study of multiwavelength flux variability is a powerful tool to draw conclusions about the physics of underlying instable processes, emission processes responsible for the origin of the lower and higher-energy SED components, the structure of innermost AGN area.

Here, we present the results of the GeV-band observations of nearby TeV-detected BLL source Mrk 421 (z=0.031 [2]) performed with Large Area Telescope (LAT) onboard the *Fermi* satellite [3].We have studied the flux and spectral variability on different timescales, as well the cross-correltions between the GeV-band flux variability with those observed in other spectral bands.

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LAT DATA PROCESSING

The data processed with Fermi Science Tools (v10r0p5) with P8R2V6response function using an unbinned maximum likelihood method. The 0.3-300 GeV band selected for a flux extraction due to reasons as follows (see [3]):

- Photons above 0.3 GeV are less contaminated by neighboring sources
- Smaller systematic errors
- A large effective area (>40.5 m^2) and relatively good angular resolution (68% containment angle <2 deg) of the instrument

We used the events of the diffuse class from a ROI of radius 10 deg, centered on Mrk421, and following cuts were adopted:

- Data from Zenith angles $Z > 100$ deg discarded to reduce contamination from the Earth-albedo γ-rays
- data with the rocking angle of the spacecraft >52 deg discarded to avoid contamination from photons from the Earth's limb, produced by cosmic rays interacting with the upper atmosphere

A background model including all sources from the 3FGL catalogue [4] within 20 deg of Mrk 421 was created. The spectral parameters of sources within the ROI were left free during the minimization process while those outside of this range were fixed to the 3FGL values. We include the Galactic and extragalactic diffuse γ-ray emission as well as the residual instrumental background using the model files gll_iem_v06.fits and iso_P8R2SOURCE_V6v06.txt. The fluxes were derived using both optimizers NEWMINUIT and MINUIT. We adopted multiple refit in GTLIKE until reaching the asymptotically close flux values for Mrk 421. The detection significance was calculated as

$$\sigma = \sqrt{TS}, \tag{1}$$

where TS is the corresponding test-statistics. We used The 3σ threshold for a light curve construction. For the spectral modeling of Mrk 421, a simple powerlaw as adopted, as done in 3FGL.

RESULTS

Flux and Spectral Variability

The source was generally detectable from 1-week bins during 2008-2016, except for a few cases, and showed an overall flux variability by a factor 19.8 on timescales from a few days to a few months with the maximum and mean fluxes of 3.34×10^{-7}photon cm^{-2}s^{-1} and 8.45×10^{-8}photon cm^{-2}s^{-1}, respectively (see Fig. 1a). The strongest flare by a factor of ~4 was observed in 2012 June–September.

The flux variability was accompanied by large spectral changes. We have revealed a broad range of the 0.3–300 GeV photon index between Γ=1.37±0.08 and Γ=2.52±0.12 from the 1-week binned data (see Fig. 1b). This parameter varied on timescales of a few weeks. However, no strong spectral variability was seen during the major 0.3–300 GeV flares in 2012-2014. Moreover, no significant correlation is evident between Γ and 0.3-300 GeV flux (in contrast to the 0.3–10 keV band where a "harder-when-brighter" trend was dominant for our target; [5]).

The source was mostly detectable above 3σ significance from 1-d binned observations during the long-term flares in 2012 June-September, 2013 March-April, 2014 March–June. In these epochs, the source sometimes showed an intraday variability in the 0.3-300 GeV flux with 99.9% confidence. For example, it exhibited a drop by a factor of 2.3 within 1 d on 2012 July 10–11 and An increase by a factor of 1.95 within 1 d on 2012 July 14–15, followed by a flux halving during next 1 d interval (Fig. 2a). An IDV with 99.5% confidence occurred on 2013 April 11–12 (in the epoch of a giant X-ray flare; see Fig. 2b).

We also have examined a flux variability in different LAT sub-bands in the periods 2008-2011 and 2013-2016 (see Fig. 3). For this purpose, the 0.3–2 GeV, 2–10 GeV and 10–300 GeV fluxes were extracted from the LAT data using the 2-weeks bins (to ensure a source detection at 3σ significance in each sub-band). In each band, the flux showed a variability around the mean values of 5.66, 1.19, 0.37 (in units of 10^{-8}photon cm^{-2}s^{-1}) for the 0.3–2 GeV, 2–10 GeV, 10–300 GeV sub-bands, respectively. The fluxes from these sub-bands showed a strong correlation to each other with the Pearson correlation coefficient r=0.77(0.05)-0.83(0.04). The fractional rms variability amplitude (see [6]) equals 51.1(1.5)%, 50.8(2.2)% and 60.9(3.0)% for the 0.3–2 GeV, 2–10 GeV, 10–300 GeV fluxes, respectively. That is, the 2–10 GeV flux did not follow a trend of the increasing variability power towards the frequencies that is a common property of BLLs (see, e. g. [2]).

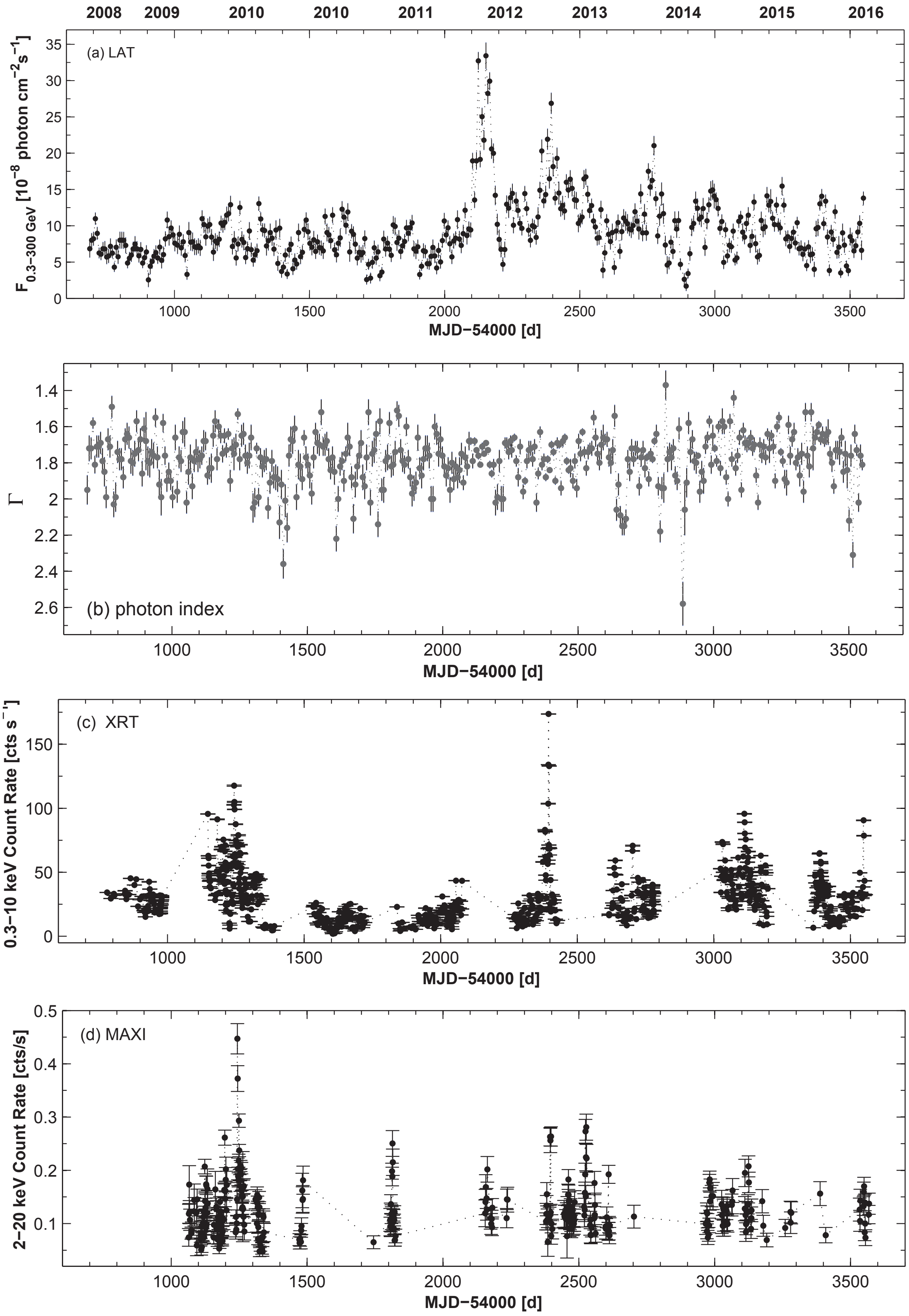

FIGURE 1. The long-term LAT-band light curve of Mrk 421 from the *Fermi* observations in 2008–2016 (panel a), along with the 0.3-300 GeV photon index plotted versus time (panel b) and the contemporaneous *Swift*-XRT (panel c), *MAXI* (panel d) light curves.

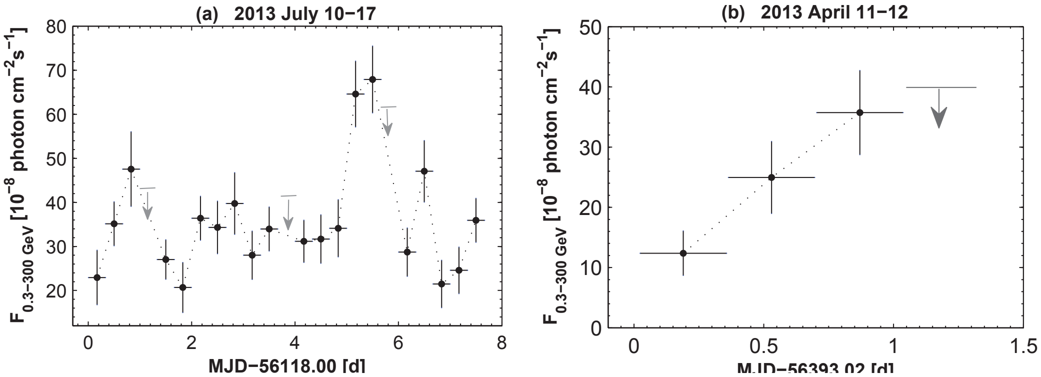

FIGURE 2. Examples of the 0.3–300 GeV intra-day variability.

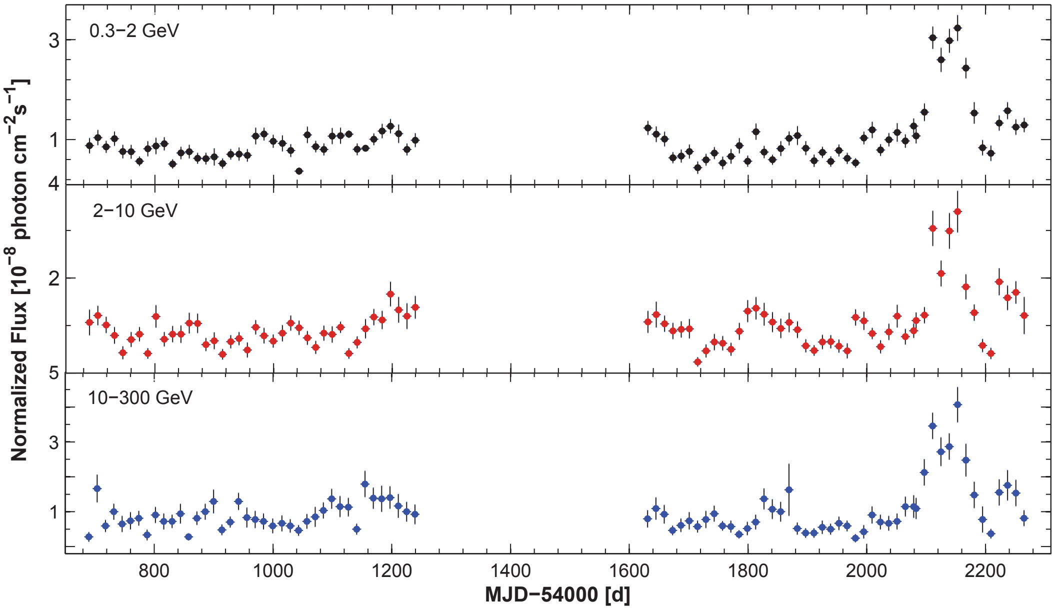

FIGURE 3. The 0.3–2 GeV, 2–10 GeV and 10–300 GeV light curves normalized by the mean values of the corresponding fluxes.

Inter-bad Cross-Correlations

We have revealed a lack of the correlation between the contemporaneous 0.3–300 GeV and 0.3–10 keV fluxes (*Swift*-XRT) in many cases (see Fig. 1c). Namely, some very strong X-ray flares were not accompanied by a comparable activity in the LAT-band and vice versa. In the epoch of the strongest 0.3–300 GeV flare, a strong variability was not seen in the *MAXI* band (2-20 keV, see Fig. 1d; no contemporaneous XRT observations are available). Furthermore, no X-ray flare is evident along with the γ-ray flare of 2014 March–June. A moderate 0.3–300 GeV flare occurred along with the giant X-ray outburst in 2013 April, and no long-term γ-ray flare was observed in the first half of 2010 when the source exhibited a strong X-ray flaring activity.

In contrast, strong optical/radio flares were observed in the epochs of some 0.3–300 GeV flares. The strongest historical LAT-band flare followed by the strongest radio one with 40-70 d later (with respect to the two γ-ray spike, superimposed on long-term flare). Assuming a physical connection between the γ-ray and radio flares, [7] explained the observed sharp radio flare using one-zone SSC model + variable Doppler factor. A similar situation was in 2013 March–April (the 60 d delay in the radio flare): a plausible physical connection between two bands, explained in simpler way via the one-zone SSC model [7]. In contrast, the radio flare advanced both GeV(low-amplitude) and optical flares in 2014 October–December that may hint on the absence of a physical connection between these events.

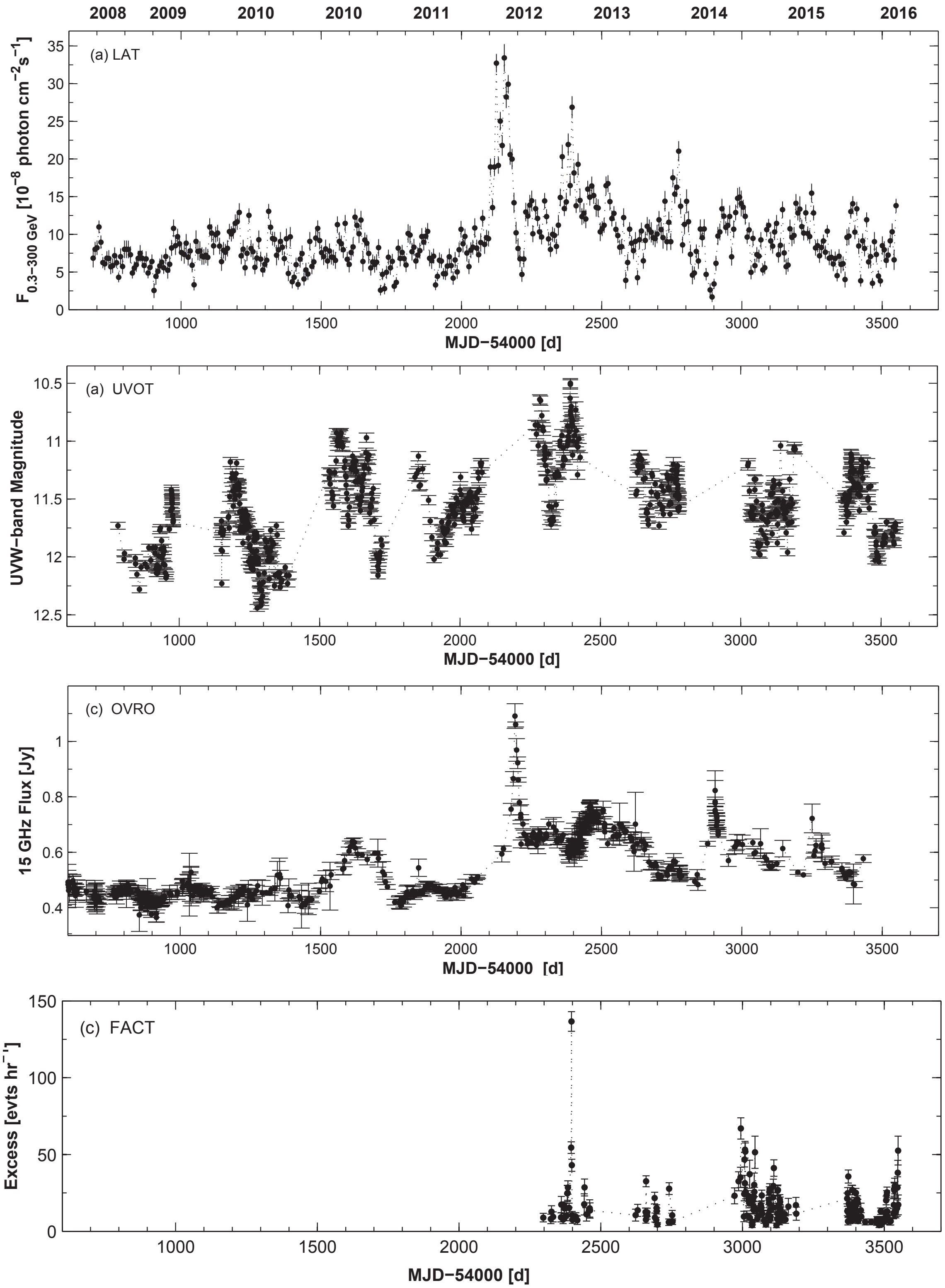

FIGURE 4. The long-rem LAT-band light curve of Mrk 421 from the *Fermi* observations (panel a) in 2008-2016, along with the contemporaneous UVOT UVW2-band (panel b), OVRO 15 GHz (panel c) and FACT (panel d) light curves.

Similar to the GeV-X-ray case, an absence of the correlated GeV and TeV variability was sometimes observed: a LAT-band flare not being accompanied by its TeV-counterpart and vice versa, or there was a time shift between them (very difficult to explain via the one-zone SSC scenario). Generally, the source showed significantly smaller 0.3–300 GeV variability amplitude compared to that in the TeV band.

CONCLUSIONS

- Mrk 421is the brightest HBL in the GeV energy range, detectable with 3σ significance on daily timescales in medium and higher brightness states with Fermi-LAT.
- During 2008–2016, the flux variability in the LAT band was characterized by:
  - A variety of the timescales from IDVs to long-term flares lasting a few months.
  - Significantly smaller amplitudes compared to those observed in the X-ray and TeV bands.
  - Very few, barely detectable GeV-band IDVs, while a great number of violent and very fast X-ray and TeV-band IDVs have been reported (see, e.g., [5]). Caveat: an almost absence of LAT-band IDVs can be partially related to significantly larger errors associated to this instrument.
  - No clearly expressed trend of increasing fractional variability amplitude with frequency as among the different LAT sub-bands, as well a smaller fractional variability amplitude from the whole 0.3-300 GeVband compared to those from X-ray and TeVbands (in contrast to some other BLLs).
- Very small and negligible spectral curvature in the FermLATband due to the presence of the Inverse Compton peak at the energies beyond 40 GeV.
- A wide range of the 0.3-300 GeV photon index, although no variability on long-term timescales and an absence of he spectral hysteresis (in contrast to X-rays).
- A stronger positive UV-GeV correlation compared to that between GeV and X-ray (or between the GeV and TeV) fluxes is explained via the effect of the Klein-Nishina suppression in the IC process, leading to the UV photons to be up-scattered most efficiently at the GeV energies by the electrons radiating in the X-ray [8].
- A strong correlation between the 0.3–2 GeV, 2–10 GeV, 10–300 GeV fluxes, exhibiting no indication on their origin from the different populations of emitting particles.

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