Spectral studies of flaring quasar PKS 1424-418 above 100 MeV with Fermi-LAT

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Abstract

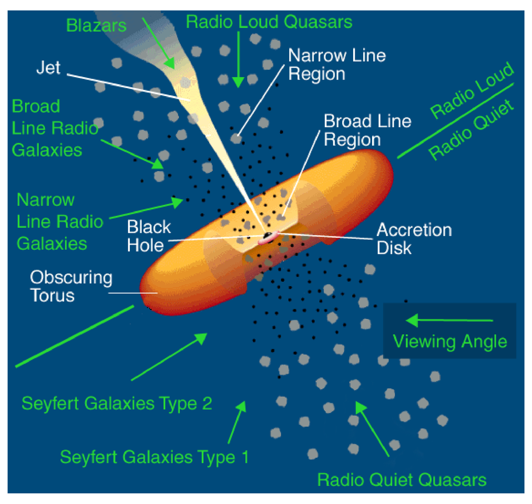
Flat Spectrum Radio Quasar (FSRQ) PKS 1424-418 is an Active Galactic Nucleus (AGN) located at a redshift z = 1.522. This source has shown several flaring episodes through the whole electromagnetic spectrum in recent years. Fermi-Large Area Telescope (Fermi-LAT), a space-based gamma-ray detector, has been collecting all sky data since 2008. It detected four outbursts during the October 2012 to September 2013 period, which were also followed up by the Hartebeesthoek Radio Astronomy Observatory (HartRAO). We present an analysis of Fermi-LAT data on PKS 1424-418 during this period. This study of the flaring pattern of PKS 1424-418 can provide interesting constraints related to the physics of the gamma-ray production in FSRQs.

1 Introduction

According to the unified scheme of active galactic nuclei (AGNs), blazars are radio-loud subclass of AGN that display highly variable, polarized, non-thermal emission, covering a broad range from radio to gamma-ray energies [1]. The blazar class encompasses BL Lacertae (BL Lac) and flat spectrum radio quasars (FSRQs) objects, whose main differences appear in their emission lines and their spectral energy distribution (SED) properties. Flat Spectrum Radio Quasar (FSRQ) PKS 1424-418 variability may helps us to constrain the emission regions (e.g distance core to jet base), information about the particle acceleration and interaction in the jet [2].

Blazars

- viewed when radio jet is along observers line of sight [4].
- Classification:
  - FSRQs (high luminosity, low energy peaking (LBL), strong emission line)
  - BL Lacs (low luminosity, High energy peaking (HBL), emission lines weak or non existent)

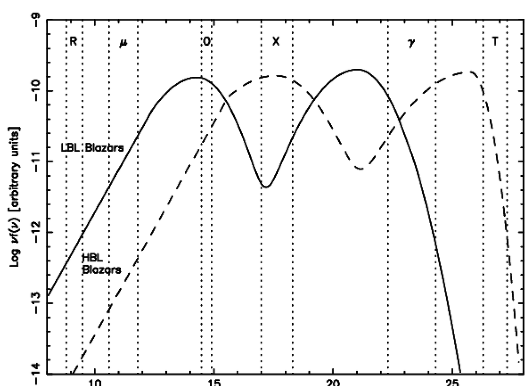


https://www.cta-observatory.ac.uk/wp-content/uploads/2013/04/advagnunification.png

Emission: non-thermal origin

- Synchrotron emission
  - Peaking in (IR-Opt) LBL & (UV-X-rays) HBL
- Inverse Compton emission
  - Peaking in γ-rays (GeV) LBL & γ-rays (TeV) HBL.

Blazars identified by the position of the synchrotron peak [1], (Low: $\nu_s < 10^{14}$Hz, Intermediate: $10^{14}\text{Hz} < \nu_s < 10^{15}$Hz or High: $\nu_s > 10^{15}$Hz).



The SED of different types of Blazars represented by Synchrotron-Self-Compton models with emission peaking at different energies. [3]

2 Fermi-LAT Analysis

Time interval: 2012 Oct. 01 to 2013 Sep. 30 (56201 to 56565 MJD)

▷Data Set: Pass 7 REP
▷Event class: SOURCE
▷Radius of interest (ROI): 10°
▷Science tools version: v9r33p0
▷Diffuse backgrounds:
Galactic diffuse emission & isotropic background

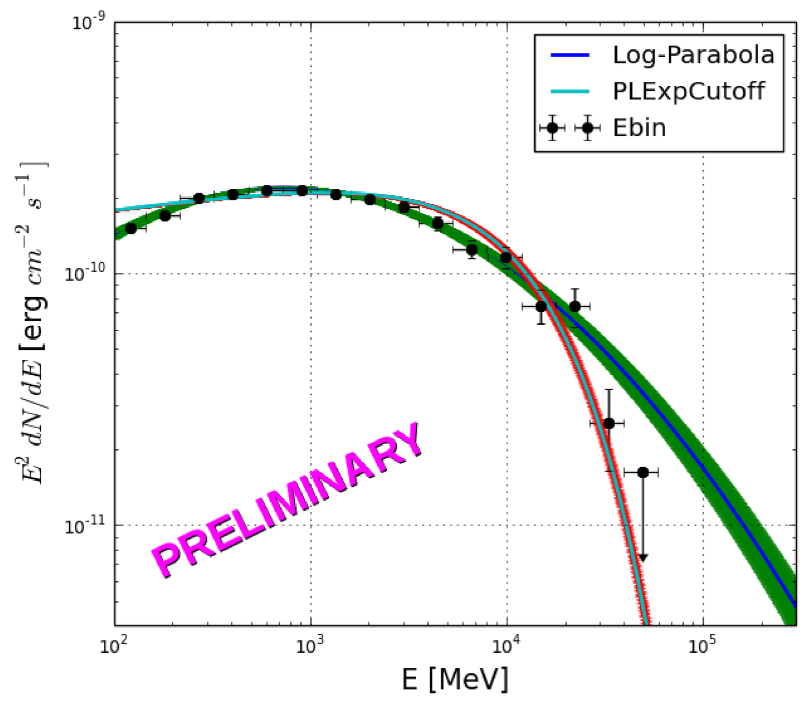
▷ Energy: 100 MeV - 300 GeV
▷Maximum zenith angle : 100°
▷IRFs: P7REP_SOURCE_V15
▷Enrico software:
used to analyse the SED

Spectral fitting functions

Log-parabola (LP): $E^2\frac{dN(E)}{dE} = E^2 N_0 \left(\frac{E}{E_b}\right)^{-\left(\alpha+\beta\log\left(\frac{E}{E_b}\right)\right)} \left[\frac{\text{erg}}{\text{cm}^2\,\text{s}}\right]$

Power law exponential cut-off (PLExpCutoff):

$$E^2\frac{dN(E)}{dE} = E^2 N_0 \left(\frac{E}{E_0}\right)^{\gamma_1} \exp\left(-\left(\frac{E}{E_c}\right)\right) \left[\frac{\text{erg}}{\text{cm}^2\,\text{s}}\right]$$

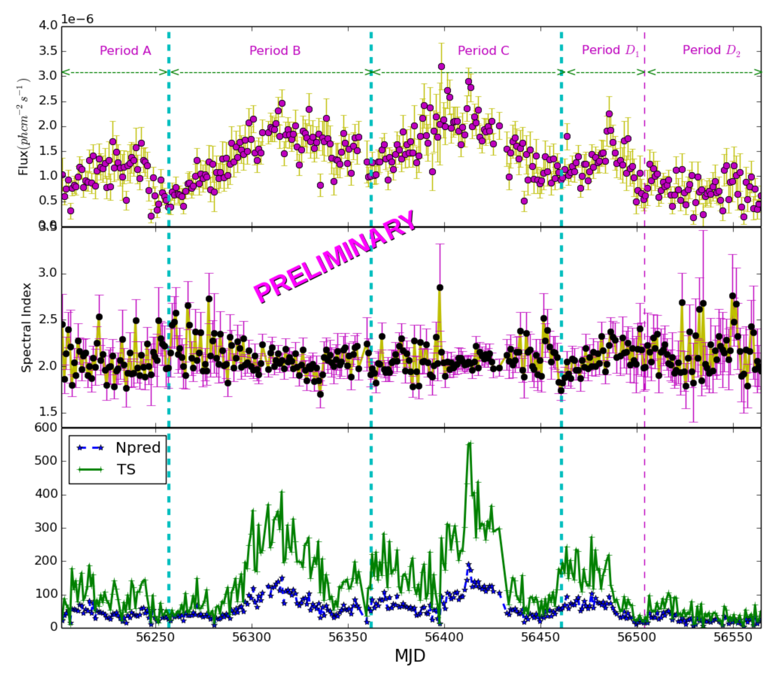


SED of PKS 1424-418, from 01 October 2012 to 30 September 2013 (56201 MJD - 56565 MJD) fitted with LP (fitting parameters: $N_0 = 7.63 \times 10^{-10}{}^{+8.6\times10^{-12}}_{-8.7\times10^{-12}}$ erg^{-1}cm^{-2} s^{-1}, $\alpha = 1.87 \pm 0.01$, $\beta = 0.11 \pm 0.01$, $E_b = 415.78$ MeV, -loglike =150379.3 and PLExpCutoff (with fitting parameters: $N_0 = 1.12 \times 10^{-8}$ erg^{-1}cm^{-2} s^{-1}, $E_0 = 100$ MeV, $E_c = 11687.76^{+864.69}_{-1145.73}$ MeV, $\gamma_1 = -2.0$ & -loglike =150394.0).

3 Light curve

Source periods	Start & Stop date(MJD)	Start & Stop date (UTC)	Duration (days)
Period A	56201.0 - 56257.0	2012 Oct. 01 - 2012 Nov. 26	57
Period B	56257.0 - 56362.0	2012 Nov. 26 - 2013 Mar. 11	105
Period C	56362.0 - 56461.0	2013 Mar. 11 - 2013 Jun. 18	99
Period D_1	56461.0 - 56504.0	2013 Jun. 18 - 2013 Jul. 31	43
Period D_2	56504.0 - 56565.0	2013 Jul. 31 - 2013 Sep. 30	61

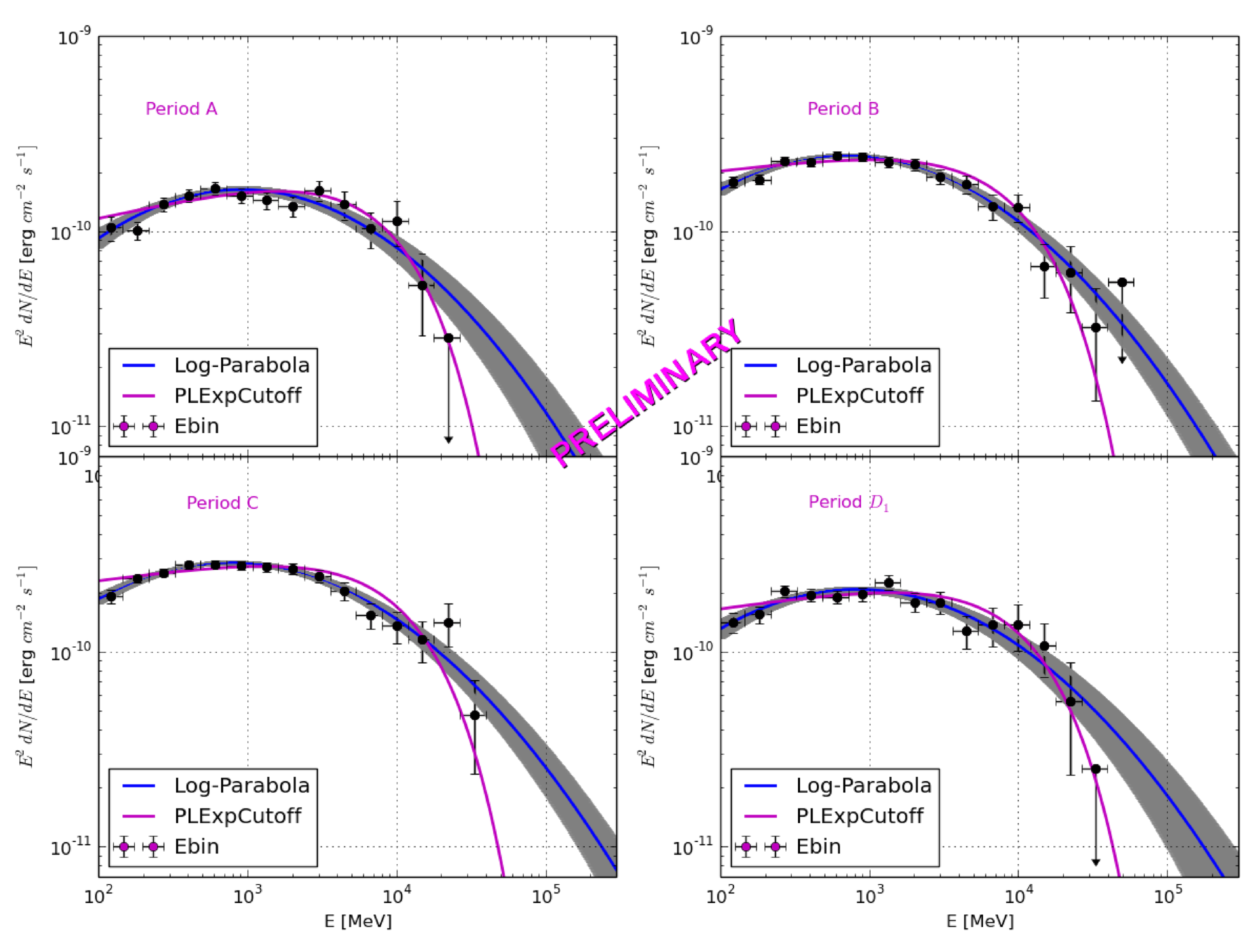
Table 1. Flaring activity of PKS 1424-418 from 2012 Oct. to 2013 Sep.



Top panel: Light curve of daily flux (according to Table 1). Middle panel: Photon spectral index as a function of time and Bottom panel: TS and Npred versus time.

- A first flare was observed from the beginning of October 2012 and lasted for almost two months. During 2012 October 27-November 12, a high daily peak flux was observed.
- The second flare was observed in January 2013. It was significantly brighter than the flare detected in October 2012.
- The third flare was observed in April 2013 with a very high daily flux and spectral index harder than what was recorded in November 2012 and January 2013.
- The fourth flaring episode was observed in July 2013 with a high daily flux—around 1×10^{-6} ph cm^{-2} s^{-1}. During the post flare observations, the source spectrum was soft and faint, with a photon index ranging between about 1.8 and 2.8.
- Results from the photon spectral index study suggest that hardening did not happen when the source was brighter (as it is the general trend for FSRQs). There is rather a hint of hardening after the flaring peak of period B. However statistical uncertainties are too large to clearly exhibit this feature.

4 Spectral energy distribution



SEDs of four flaring period fitted by LP (blue line) and PLExpCutoff (magenta line) models from energy range 100 MeV to 300 GeV. Fitting parameters of both models are illustrated in Tables 2 and 3.

The SED shapes have not changed significantly, though flux varied from one flaring episode to another. A particular hint of flattening of the SED was observed when the source became brighter around energy 1 GeV (as shown in Figure of period C) and well fitted by a log-parabola function with $\chi^2_{\text{red}} = 0.73$ over the whole energy range covered ($\text{E} > 100\text{MeV}$).

Time Range	N_0 (erg^{-1}cm^{-2} s^{-1})	α	β	E_b (MeV)	-loglike	χ^2(ndf)	χ^2_{red}
Period A	$\left(5.47 \times 10^{-10}\right)^{+1.85\times10^{-11}}_{-1.81\times10^{-11}}$	1.81±0.04	0.12 ±0.02	415.776	46443.3	12.01(14)	1.33
Period B	$\left(8.58 \times 10^{-10}\right)^{+1.67\times10^{-11}}_{-1.64\times10^{-11}}$	1.89±0.02	0.11±0.02	415.776	72051.0	10.45(15)	1.05
Period C	$\left(9.93 \times 10^{-10}\right)^{+1.84\times10^{-11}}_{-1.83\times10^{-11}}$	1.87±0.02	0.10±0.01	415.776	67736.0	7.36(15)	0.74
Period D_1	$\left(5.55 \times 10^{-10}\right)^{+1.48\times10^{-11}}_{-1.45\times10^{-11}}$	1.85±0.03	0.12±0.02	415.776	38742.6	9.61(15)	0.96

Table 2. Unbinned likelihood spectral fitting parameters PL.

Time Range	N_0 (erg^{-1}cm^{-2} s^{-1})	E_0 (MeV)	E_c (MeV)	γ_1	-loglike	χ^2(ndf)	χ^2_{red}
Period A	$\left(7.30 \times 10^{-09}\right)^{+5.07\times10^{-10}}_{-5.00\times10^{-10}}$	100.00	$9297.68^{+2291.46}_{-1715.58}$	$-1.83^{+0.04}_{0.0}$	46442.5	14.65 (14)	1.63
Period B	$\left(1.28 \times 10^{-08}\right)^{+4.72\times10^{-10}}_{-4.63\times10^{-10}}$	100.00	$11086.88^{-1938.06}_{-1533.57}$	-1.91 ±0.02	72058.9	25.20 (15)	2.52
Period C	$\left(1.45 \times 10^{-08}\right)^{+5.18\times10^{-10}}_{-5.30\times10^{-10}}$	100.00	$12694.21^{+1989.53}_{-1710.75}$	-1.90 ±0.02	67742.6	27.83(15)	2.78
Period D_1	$\left(8.04 \times 10^{-09}\right)^{+4.37\times10^{-10}}_{-4.30\times10^{-10}}$	100.00	$10820.97^{+2301.81}_{-1764.96}$	-1.89 ±0.03	38744.2	14.77(15)	1.48

Table 3. Unbinned likelihood spectral fitting parameters PLExpCutoff.

5 Summary

- The analysis of four flaring periods from October 2012 to September 2013 outburst was presented.
- The spectral shapes of PKS 1424-418 during the whole period of flaring and the post flaring episodes were analysed using two spectral models, namely LP and PLExpCutoff.
- On the light curve, we do not see higher flux coinciding with the hardening of the photon spectral index.
- The SEDs of individual flares were plotted and show that the spectrum was also curved during the single flaring episodes.
- The spectral shapes do not vary significantly between the four flaring states despite dramatic flux variations.

Acknowledgements

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