High Energy Flares of FSRQs

(searching for FSRQs flares dissipating beyond the BLR)

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γγ absorption from BLR via γγ → e⁺e⁻ interaction

Liu & Bai 2006
Liu, Bai, Ma 2008
\(\gamma\gamma\) absorption from BLR

Liu & Bai 2006; Liu, Bai, Ma 2008

\[ L_{\text{BLR}} = 2.6 \times 10^{44} \text{ erg/s} \] (this is the case of 3C 279, but for 3C 454.3 the BLR is \(>10\) times more luminous)

\(\tau_{\gamma\gamma}\) scales as \(L_{\text{BLR}}^{1/2}\)
KN suppression

(External Compton on BLR photons)


Klein-Nishina suppression for a dissipation region at:
solid curves: 0, $R_{\text{in}}$, $R_{\text{out}}$ (from Bottom Up)
solid dashed curve: at the center of the shell
dashed curves: 0.95 $R_{\text{out}}$, 1.25 $R_{\text{out}}$, 1.5 $R_{\text{out}}$, 2 $R_{\text{out}}$
SEARCH within the FERMI-LAT FSRQs sample
We started to search for relevant signal at $E > 10$ GeV in the FERMI-LAT archive from FSRQs and on incoming gamma-ray data (and triggering ToO observations to Swift).

High energy (HE) activity period is defined as the period of time in which the HE photon rate is $> 3 \times$ mean HE rate.
Search within the FERMI-LAT FSRQs sample

We obtained ~40 flares candidates with detections with TS significance $26 < \text{TS} < 136$ ($E_{\text{THR}} > 10$ GeV,

but now we have changed the $E_{\text{THR}}$ definition)

and

High Energy activity periods
lasting from 1 to 12 days in the host galaxy frame

We selected for flares with MWL coverage, for sources with available Broad lines luminosities (to infer the disk luminosity using the mean ratios of Broad Lines luminosities in Francis 1991 and in Celotti 1997, and assuming $L_{\text{disk}} = 1/10 L_{\text{BLR}}$).

We obtained 10 sources up to Sept. 2013
(3 ToO from HE flares triggered by our program:
PKS 0454-234, PMN J2345-1555, 3C 454.3)

apart GB6 J1239+0443 (Pacciani et al., 2012),
PKS B1424-418 (Tavecchio, Pacciani et al., 2013, ToO triggered by us),
3C 279, 4C +21.35, PKS 1510-08

(but we collected other HE flares within the last year)
Search within the FERMI-LAT FSRQs sample (I)
Search within the FERMI-LAT FSRQs sample (II)
Search within the FERMI-LAT FSRQs sample (III)

PKS 1502+106

Flux \(10^{-6} \text{ph cm}^{-2} \text{s}^{-1}\)

MJD

54900 54920 54940 54960 54980
Search within the FERMI-LAT FSRQs sample (IV)

Ghisellini & Tavecchio 2009
SEDs and modeling (i)

- **PKS 0250-225**
  - $z = 1.427$
  - $\text{dist} = 3 \text{ pc}$
  - $B = 25 \text{ mG}$
  - $L_{\text{disk}} = 5.3 \times 10^{45} \text{ erg/s}$

- **PKS 0454-234**
  - $z = 1.0$
  - $\text{dist} = 2.5 \text{ pc}$
  - $B = 35 \text{ mG}$
  - $L_{\text{disk}} = 3.7 \times 10^{45} \text{ erg/s}$

- **PKS 0805-07**
  - $z = 1.84$
  - $\text{dist} = 0.8 \text{ pc}$
  - $B = 315 \text{ mG}$
  - $L_{\text{disk}} = 24 \times 10^{45} \text{ erg/s}$

- **PKS 1502+106**
  - $z = 1.84$
  - $\text{dist} = 2 \text{ pc}$
  - $B = 110 \text{ mG}$
  - $L_{\text{disk}} = 15 \times 10^{45} \text{ erg/s}$

*IGM absorption in UV*
SEDs and modeling (ii)

- **B2 1520+031**
  - $z=1.49$
  - $\text{dist}=1.3 \text{ pc}$
  - $B=63 \text{ mG}$
  - $L_{\text{disk}}=8 \times 10^{45} \text{ erg/s}$

- **B2 1633+38 (4C+38.41)**
  - $z=1.81$
  - $\text{dist}=0.5 \text{ pc}$
  - $B=250 \text{ mG}$
  - $L_{\text{disk}}=50 \times 10^{45} \text{ erg/s}$

- **B2 1846+32A**
  - $z=0.60$
  - $\text{dist}=0.2 \text{ pc}$
  - $B=620 \text{ mG}$
  - $L_{\text{disk}}=3.4 \times 10^{45} \text{ erg/s}$

- **PMN J2345−1555**
  - $z=0.62$
  - $\text{dist}=0.7 \text{ pc}$
  - $B=210 \text{ mG}$
  - $L_{\text{disk}}=1.5 \times 10^{45} \text{ erg/s}$
SEDs and modeling (iii)

dist=0.5 pc
B=230 mG
$L_{\text{disk}} = 33 \times 10^{45}$ erg/s

dist=0.3 pc
B=140 mG
$L_{\text{disk}} = 41 \times 10^{45}$ erg/s
**GB6 J1239+0443 (z=1.76) Multiepoch SED (I)**

**AGILE/GRID and simultaneous data in red**

**FERMI-LAT data (4-day integration around the flare) and simultaneous data in black**

**FERMI-LAT data in green (30-day integration around the flare)**

**FERMI-LAT data in cyan (2FGL catalog)**

**Dissipation region at 0.2 pc from the SMBH**

(Just outside the BLR)

$R_{blob} = 6.7 \times 10^{16}$ cm

$B = 0.6$ Gauss

**Dissipation region at 7 pc from the SMBH**

$R_{blob} = 2 \times 10^{18}$ cm

$B = 1 \times 10^{-2}$ Gauss

This model gives a satisfactory gamma-ray spectral shape, but the expected variability is $\sim 10^2$ days
Model is for a dissipation region at 5 pc from the central BH, a blob radius of $1 \times 10^{17}$ cm, $B=7 \times 10^{-2}$ Gauss

$R_{\text{blob}} = 0.0067 R_{\text{diss}}$ in agreement within a factor 2 with Bromberg and Levinson 2009 ($R_{\text{blob}} = 10^{-2.5} R_{\text{diss}}$)

inverting $R_{\text{diss}} = 2.5 L_{\text{jet,46}} (R_{\text{BLR}}/0.1 \text{ pc})^{-1}$ and using $R_{\text{diss}} = 5 \text{ pc}$, we obtain $L_{\text{jet}} = 3.5 \times 10^{46} \text{ erg/s}$.

We need to assume that the p/e number ratio is $\sim 0.1$ to accomplish such a luminosity.
From the broad Mg II line: $L_{\text{Mg II}} = 5.4 \times 10^{43}$ erg/s (Stickel 89) we derived the BLR luminosity (Celotti 1997) and in turn the disk luminosity (we assumed a BLR/disk luminosity ratio 0.1) $L_{\text{disk}} = 1 \times 10^{46}$ erg/s

$B = 6 \times 10^{-3}$ G

$\Gamma = 20$

Dist = 7 pc

R = 1-1.2 pc

Variability time Scale 30 d, comparable with long term modulation of the light curve, but not with the daily variability.
A pessimistic evaluation of attenuation ($\gamma\gamma$ abs + KN) at 100 GeV (sat frame) is < 3.

So the emission region must be at the edge or outside the BLR.
Fast HE flares

From the 4 brightest HE flares we searched for fast variability at HE (E> 10 GeV).

For all these 4 sources we found short periods (period A) lasting from 1.5 hours to less than 6 hours of very bright HE emission and hard spectra.

**NB:** in the following, the gamma-ray photon index of periods A ($\Gamma_{\text{ph}}$) are evaluated in the energy range 0.2-10 GeV (they are not biased by the selection criteria, i.e. the search for bright emission at HE, E>10 GeV)
Fast HE flares and spectral evolution (i)

PKS 1502+106

PERIOD A

\[ \Delta t/(1+z) = 0.11 \text{ d} \]
\[ \Gamma_{ph} = 1.99 \pm 0.31 \]

PERIOD B, C

\[ \Delta t/(1+z) = 1.4, 2.8 \text{ d} \]

PKS 0805-07

PERIOD A

\[ \Delta t/(1+z) = 0.12 \text{ d} \]
\[ \Gamma_{ph} = 1.51 \pm 0.34 \]

PERIOD B, C

\[ \Delta t/(1+z) = 2.8, 2.8 \text{ d} \]
**Fast HE flares and spectral evolution (ii)**

**CTA 102**

**PERIOD A**

\[ \frac{\Delta t}{1+z} = 0.076 \text{ d} \]

\[ \Gamma_{ph} = 1.73 \pm 0.14 \]

**PERIOD B, C, D**

\[ \frac{\Delta t}{1+z} = 1.5, 2.0^*, 2.0 \text{ d} \]

*period C starts 5 d after period B due to a gap in the telemetry*

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**3C 454.3**

**PERIOD A**

\[ \frac{\Delta t}{1+z} = 0.30 \text{ d} \]

\[ \Gamma_{ph} = 1.77 \pm 0.17 \]

**PERIOD B, C, D**

\[ \frac{\Delta t}{1+z} = 1.6, 1.6, 1.6 \text{ d} \]

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Note: The diagrams show the energy distribution of gamma-ray emissions for CTA 102 and 3C 454.3, with periods A and B, C, D, respectively, along with their spectral indices \( \Gamma_{ph} \) and the time intervals \( \frac{\Delta t}{1+z} \) at which these changes occur.
Fast HE flares and spectral evolution (ii.j)

CTA 102 and 3C 454.3 gamma-ray spectra of period B are consistent with the slow cooling scenario, with:

- low energy $\Gamma_{\text{ph}}$ consistent with $\Gamma_{\text{ph}}$ of period A,
- and

\[
\Delta \Gamma_{\text{ph}} = 0.75 \pm 0.32 \ (3C \ 454.3) \\
\Delta \Gamma_{\text{ph}} = 0.72 \pm 0.35 \ (CTA \ 102)
\]

In the dusty torus photon field, the expected cooling time is $\sim 1$ hour for electrons with $\gamma = 30000$ ($\sim 30$ GeV EC photons)
Fast HE flares and spectral evolution (iii)

We have some source (B2 1520+031, 4C 38.41, PKS 0250-225) with a gamma-ray spectrum that mimics the BLR absorption features proposed in Poutanen & Stern 2010.

We performed the time-resolved spectral analysis for the brightest of these sources: 4C 38.41, revealing a pattern similar to the 4 sources above.

The absorption like feature of the gamma-ray spectrum integrated on long periods is produced by integrating together the two periods: the hard flare (period A) and its spectral evolution (period B).

\[ \Delta t/(1+z) = 0.048 \text{ d} \]

\[ \Gamma_{\text{ph}} = 1.85 \pm 0.23 \]

\[ \Delta t/(1+z) = 1.4, 2.8 \text{ d} \]
The distant scenario

- The bright HE emission witnesses against BLR absorption and Klein-Nishina suppression (for EC on BLR photons)
- The leptonic SED modeling is only consistent with a dissipation region at parsec scale
- The spectral evolution from an hard spectrum is consistent with the slow cooling scenario (chromatic cooling) on Torus seed photons (while the cooling on BLR photons is in Klein-Nishina regime and it is expected to be achromatic).
- **But the CTA 102 light curve** shows a variability pattern which is **inconsistent with slow cooling** (what is the lower activity period in between two higher activity periods, with a duration of 0.5 days?).
what is the engine?

Reasonable engines acting at large distance from the SMBH are:

- Magnetic reconnection (Giannios 2013)
- Turbulence in the jet (Narayan & Piran 2012, Marscher 2014)
Variability time scale from the SED modeling is ~30 d, comparable with long term modulation of the light curve, but we observe also sub-daily variability.

Recent scenario for magnetic reconnections proposed for strongly magnetized jets (Giannios 2013) includes an envelope emission (lasting ~1 day) powered by plasmoids, together with fast flares (lasting ~10 min) generated by grown “monster plasmoids”.

In low magnetized plasma (such as at several parsec), reconnection time scales are longer and longer flares (days to weeks) could arise (Giannios 2013).

“Monster plasmoids” contain energetic particles freshly injected by the reconnection event (Uzdensky et al. 2010)

Figure 2. A sketch of the envelope-flare structure of the emission from a reconnection layer. The envelope duration corresponds to that of the reconnection event: $t_{\text{env}} = t'/\Gamma_1\epsilon c$. Monster plasmoids power fast flares which show exponential rise and last for $t_{\text{flare}} = 0.1t'/\delta_p c$. For an envelope of ~1 d blazar flaring, the model predicts that monster plasmoids result in ~10-min flares.

Giannios 2013
Turbulence in the jet

electron acceleration is caused by standing conical recollimation shocks.

Flux and polarization variability originates from turbulence in the flow, approximated as cylindrical cells.
But there are also short HE flares for which the slow-cooling scenario does not work
(we did not have it in the 12 source sample because of the request of simultaneous Swift data)

$$Z=0.7, \ L_{\text{disk}} \sim 1.5 \times 10^{45} \text{erg/s}$$

But see also Britto 2015 (3C 454.3 may-July 2015 flares), Hayashida 2015 (3C 279, December 2013 – April 2014).
HOW MANY SOURCES?
HOW MANY FLARES?

Work in progress
HOW MANY SOURCES?  
HOW MANY FLARES?

Work in progress

• We slightly changed the search criteria, we scan the FERMI-LAT data sample searching for HE emission from FSRQs (with almost the same method shown before:
  – We defined HE gamma-ray with a threshold
    \[ E_{\text{THR}} > \min \left( 10 \text{ GeV}, 20 \text{ GeV} \frac{1+z}{1+z} \right) \]
  – Selecting periods with HE gamma-ray counting rate
    greater than 3 times the average counting rate
  – at least 3 HE gamma-rays \( E > E_{\text{THR}} \) within the period
  – TS > 25 \( (S/NR > 5) \) for \( E > E_{\text{THR}} \)
HOW many sources?  
HOW many FLARES?  
(work in progress)

- We are investigating 85 sources
  - 40 FSRQs with PowerLaw spectrum from the 2\textsuperscript{nd} FERMI-LAT CATALOG
  - 45 FSRQs with LogParabola spectrum from the 2\textsuperscript{nd} FERMI-LAT CATALOG
- for a total of 275 flares
PowerLaw photon-index distribution for HE flares (I) (fitting below $E_{\text{THR}}$: 200 MeV - $E_{\text{THR}}$)
PowerLaw photon-index distribution for HE flares (II) 
(fitting below $E_{\text{THR}}$: 200 MeV – $E_{\text{THR}}$)

sources with PowerLaw spectrum in the 2nd FERMI-LAT catalog:
PowerLaw photon-index distribution for HE flares (III)
(fitting below $E_{\text{THR}}$: 200 MeV – $E_{\text{THR}}$)

sources with LogParabolic spectrum in the 2nd FERMI-LAT catalog:
Jet B – Accretion connection

From a sample of 76 Radio Loud AGN, Zamaninasab 2014 evaluated the jet magnetic field from self absorption consideration at different radio wavelength. Typical distances from SMBH are of the order of $10^4 r_s$.

We are studying a region like this.
HE flares and disk Connection (II)

(See Sbarrato 2014 for the 2 years averaged 0.1-500 GeV gamma-ray Vs Disk luminosity correlation)

E< 20 GeV/(1+z) Luminosity

E> 20 GeV/(1+z) Luminosity
HE flares and disk Connection (III)

The prominent HE gamma-ray emission in HE flares suggests their dissipation region is placed toward the edges, or outside the Broad Line Region to avoid gamma-gamma absorption (mainly for bright disks $\sim 10^{46}$ erg/s).

The Correlations with disk emission requires that the bulk of the HE flares sample is powered or “catalysed” by accretion (by B?) (Narayan 2003, Tcheckhovskoy 2011, Ghisellini 2014). Does this fact rules out reconnection and turbulences?

Resonably, Zamaninasab 2014, showed that for a sample of 76 Radio Loud AGN the $B^2$ field at $10^4 r_s$ correlates with $L_{\text{disk}}$. 
Trigger to VHE Cherenkov Telescopes (Mother of ToO proposal to MAGIC Telescope)

- S3 0218+35 FSRQ? at z=0.944 (Raised both our trigger and FERMI-LAT monitoring)

- S4 0954+65 BL Lac z=0.368 (Raised both FERMI-LAT monitoring and our trigger Atel #7080, MAGIC triggered first in Optical)

- PKS 1441+25 FSRQ at z=0.939 (Raised our trigger, Atel #7416)

- S2 0109+22 BL Lac z=0.265 (Raised our trigger, Atel #7844)

- We successfully triggered 2 FSRQs (of a total of 5 FSRQs detected at VHE)

Some other Trigger had no VHE follow-up due to bad weather conditions or visibility.
Papers and Atels

- ATEL 6086, 6165, 7267, 7402, 7526, 7588, 7783, 7844, 8323
Due to the large amount of useful triggers to the High Energy AstroPhysics community, we are going to share new incoming triggers on a webpage without restrictions.
Conclusions

- We discussed **12 flare candidates with MWL data (but we triggered ~47 HE flares ToO within the last 2.5 years)**
- Gamma-ray spectra, MWL SED modeling, and spectral evolution are consistent with a **dissipation region at parsec scale**
- we identified **short periods** lasting 1.5-6 hours characterized by **hard gamma-ray spectra**.
- for those 12 FSRQs the following period corresponds to a **cooling phase**?
- Anyway we identified **other HE flares characterized by a faster Light Curve development** in the whole FERMI-LAT band (within less than a day).
  
  But see also Britto 2015 (3C 454.3), Hayashida 2015 (3C 279).
- recollimation and turbulence models could account for the acceleration at pc scale
- The HE trigger method allowed for the **discovery of VHE emitting FSRQs** up to redshift 0.94.

- There are a huge number of gamma-ray FSRQs (**85 sources**), showing HE flares (**275 HE flares**).
- Their **HE flaring luminosity correlates with disk luminosity**. **Does it rules out the reconnection scenario?**
- Does the **shortest HE flares** confirms the previous picture, being the intermediate cases of **flares dissipating within the BLR shell, near the outer edge**?