Hard Times for FSRQs
(searching for FSRQs emitting 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

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

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

(External Compton on BLR photons)


Klein-Nishina suppretion for a dissipation region at:
solid curves: 0, R_{in}, R_{out} (from Bottom Up)
solid dashed curve: at the center of the shell
dashed curves: 0.95 R_{out}, 1.25 R_{out}, 1.5 R_{out}, 2 R_{out}
SEARCH within the FERMI-LAT FSRQs sample

(first achieved results)

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

3C 454.3
Sept. 2013 HE flare
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)
Search within the FERMI-LAT FSRQs sample (IV)

Ghisellini & Tavecchio 2009
SEDs and modeling (i)

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

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

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

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

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

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

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

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

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

dist=0.5 pc
B=230 mG
$L_{\text{disk}}=33\times10^{45}$ erg/s

dist=0.3 pc
B=140 mG
$L_{\text{disk}}=41\times10^{45}$ erg/s
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**

\[ \Delta t/(1+z) = 0.076 \text{ d} \]

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

**CTA 102**

**PERIOD B, C, D**

\[ \Delta t/(1+z) = 1.5, 2.0*, 2.0 \text{ d} \]

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

**3C 454.3**

**PERIOD A**

\[ \Delta t/(1+z) = 0.30 \text{ d} \]

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

**3C 454.3**

**PERIOD B, C, D**

\[ \Delta t/(1+z) = 1.6, 1.6, 1.6 \text{ d} \]
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 $\Gamma_{ph}$ consistent with $\Gamma_{ph}$ of period A,

and

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

In the dusty torus photon field, the expected cooling time is $\sim 1 \text{ hour}$ for electrons with $\gamma = 30000$ ($\sim 30 \text{ GeV EC photons}$)
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).
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?

- 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).
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 10 source sample because of the request of simultaneous Swift data)

\[ Z = 0.7, \; L_{\text{disk}} \sim 1.5 \times 10^{45} \text{ erg/s} \]
HOW MANY SOURCES?
HOW MANY FLARES?

Work in progress
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
    \[ E_{\text{THR}} > \min (10 \text{ GeV}, 20 \text{ GeV} / (1+z) ) \]
  - Selecting periods with HE gamma-ray \textit{counting rate} \textit{grater than 3 times the average} counting rate
  - \textit{at least 3 HE gamma-rays} \((E > E_{\text{THR}})\) within the period
  - \(TS > 25\) \((S/NR > 5)\) for \(E > E_{\text{THR}}\)
  - \textit{we still have to select for the FSRQs with the most luminous accretion disks} \((L_{\text{disk}} > 10^{45} \text{ erg/s})\)
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 (80 flares, to be confirmed)
  - 45 FSRQs with LogParabolic spectrum from the 2\textsuperscript{nd} FERMI-LAT CATALOG (155 flares, to be confirmed)
• for a total of 235 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:
Conclusions

- We discussed 10 flare candidates with MWL data (but we triggered other HE flares ToO within the last year)
- 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 10 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).
- recollimation and turbulence models could account for the acceleration at pc scale

- There are a huge number of gamma-ray FSRQs (85 sources), showing HE flares (235 HE flares, we did not select for the most disk-luminous FSRQs)
- Does the shortest HE flares confirms the previous picture, being the intermediate cases of flares dissipating within the BLR shell, near the outer edge?