On the origin of gamma-rays in broad-lined Blazars:

to BLR or not to BLR?

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Are we sure on External Compton (BLR)??

\[ L_{BLR} \sim 10\% \ L_{disk} \]

\[ R_{BLR} \approx 0.1 \times L_{46}^{1/2} \ \text{pc} \]
\[ \text{(Bentz et al. 2006; Kaspi et al. 2007)} \]

\[ R_{HD} \approx 2.5 \times L_{46}^{1/2} \ \text{pc} \]
\[ \text{(Cleary et al. 2007; Nenkova et al. 2008)} \]

\[ U_{rad} \propto \frac{L}{R^2} \sim \text{const.} \]
BLR opacity: optical depths $\gg 1$

\[ \gamma\gamma \rightarrow e^+e^- \quad x_1 x_2 \geq \frac{2}{1 - \cos \theta} \quad x \equiv h\nu/m_e c^2 \]

Expected in FSRQ: no VHE detections, cutoff $\sim 10-20$ GeV
Sometimes gamma-rays beyond the BLR:

a) FSRQ detected at VHE

![Graph showing FSRQ detected at VHE]

Detections 4C 21.35 (Magic)

PKS 1510-089 (HESS, Magic)

b) >10 GeV in LAT

![Graph showing >10 GeV in LAT]

PMN J1016+0512:

$\log(E (\text{GeV}))$ -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5

$\log(E (\text{Hz}))$ -1

$\log(dN/dE)$ (GeV cm$^{-2}$ s$^{-1}$) (erg cm$^{-2}$)

Log($\nu F_\nu$) [erg cm$^{-2}$ s$^{-1}$]

L$_{\text{disk}}$ $\sim$ $9 \times 10^{45}$ erg/s, R$_{\text{blr}}$ $\sim$ $3 \times 10^{17}$ cm

if $R_{\text{diss}}$ $\sim$ $2.5 \times 10^{17}$ $\Rightarrow$ $\tau_{\text{BLR}}$ $>$ 16 !

Aleksic et al. (MAGIC Coll) 2011

e.g. Costamante et al. 2009, 2010
Sometimes gamma-rays beyond the BLR:

a) FSRQ detected at VHE

Detections 4C 21.35 (Magic)

PKS 1510-089 (HESS, Magic)

b) >10 GeV in LAT

PMN J1016+0512:

\[ L_{\text{disk}} \sim 9 \times 10^{45} \text{ erg/s} , \quad R_{\text{BLR}} \sim 3 \times 10^{17} \text{ cm} \]

if \( R_{\text{diss}} \sim 2.5 \times 10^{17} \) \( \Rightarrow \tau_{\text{BLR}} > 16 \)

e.g. Costamante et al. 2009, 2010
For population studies
EC(BLR) still most common SED model in FSRQs

1) is BLR absorption a common phenomenon?
2) is it consistent with EC modeling?
3) different location in high-flaring vs steady state?

100 highest-significance Gamma-ray FSRQs in the 3LAC
+ 6 large-BLR cases

Fermi-LAT Data, PASS8, 7.3-years exposure

106 in total, 83 with $L_{BLR}$ estimates

Costamante, Cutini, Tosti, Antolini, Tramacere 2018,
MNRAS, in press (arXiv 1804.06282)
Methodology

Intrinsic band model: Power-law or Log-parabolic

- Intrinsic extrapolated
--- Fitted free $\tau_{BLR}$
--- Expected $\tau_{BLR}$ (deep in BLR, $\sim R_{BLR}/2$)
- Log-parabolic Full band (no BLR)

Upper limit if:
- $TS < 4$ or
- $N_{pred} < 3$ or
- $Err > 50$

NB: Rest-Frame Energies! $E^*(1+z)$

B21520+31 $z=1.487$ $L_{BLR} = 4.5e+44$

Log $\nu F_{\nu}$ [erg cm$^{-2}$ s$^{-1}$]

$E_{rest-frame}$ [GeV]
BLR spectrum

**BBody** (same as for EC) is a good approximation for attenuation shoulder

**BLR at different ionization parameter**

![Graph showing BLR spectrum with different ionization parameters](image)

![Graph showing BLR absorption feature with different ionization parameters](image)

Stern & Poutanen 2014
**BLR spectrum**

**BBody** (same as for EC) is a good approximation for attenuation shoulder

**BLR at different ionization parameter**

- **BBody** (same as for EC) is a good approximation for attenuation shoulder.

**BLR absorption feature**

- **BBody** (same as for EC) is a good approximation for attenuation shoulder.

![Graph](image)
NO evidence of BLR cut-offs!

2/3 of the sample: $\tau_{\text{max}} < 1$

9/10 objects: $\tau_{\text{max}} < 3$

Only 1 out of 10 FSRQ compatible with significant BLR absorption
NO evidence of BLR cut-offs!

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9/10 objects: \( \tau_{\text{max}} < 3 \)

Only 1 out of 10 FSRQ compatible with significant BLR absorption
Sample 83 objects with $L_{BLR}$ estimate for EC(BLR)
BLR optical depth

All 106 objects

73% $\tau_{\text{max}} < 1$

87% $\tau_{\text{max}} < 3$

Total Sample of 106 objects
No evidence of strong interaction with BLR photons
VHE-detected FSRQs: also in Low state

4C+21.35

PKS 1510-08

$\log(\nu F_\nu) \text{ [erg cm}^{-2} \text{s}^{-1}]$

$E_{\text{rest-frame}} \text{ [GeV]}$

$F_{\text{rest-frame}} \text{ [GeV]}$
Even 3C 454.3!

Better fitted with intrinsic electron cutoff!
Conclusion:

NO evidence of jet interaction with BLR photons!

EC(BLR) seems the exception, not the normality, of the gamma-ray emission in Fermi Blazars.
Alternatives?
to reduce absorption but staying within the BLR?

1. Much larger BLR (~100x) \( \tau \propto 1/R_{\text{BLR}} \)

2. Shift \( \gamma \gamma \) threshold by selecting angles ("Flattened BLR")
1. Energy density $U_{BLR}$ goes down $10^{-4}$

$U_{BLR}$ becomes lower than any other radiation field $\rightarrow$ EC(BLR) disfavoured
2. Shift threshold 5x (to ~100 GeV) $\rightarrow \vartheta \leq 30 \: \text{deg}$

$$R_{\text{diss}} = \tan(\alpha) \times R_{\text{BLR}} \geq 1.7 \times R_{\text{BLR}}$$
Alternatives?
to reduce absorption but staying within the BLR?

1. Much larger BLR (~100x) \( \tau \propto 1/R_{BLR} \)

2. Shift \( \gamma\gamma \) threshold by selecting angles ("Flattened BLR")

Both do NOT keep EC(BLR) viable
Two Caveats:

1) Long integration time (years)

2) Kinematics of the emission (localized dissipation vs moving blob)

Doppler effect: \[ \Delta R \simeq \Delta t_{obs} \times \beta \times \Gamma^2 \]

\[ \Gamma = 10 \]

\[ \Delta t_{obs} \geq 10^5 \text{s} \quad \implies \quad \Delta R \geq 10^{17} \text{cm} \]
BLR \( \tau \equiv \tau(\ell, E) \)

\[ e^{-\tau} \]

\[ \frac{1 - e^{-\tau}}{\tau} \]
We can gain a factor $\sim 3$ in path length

Absorption shapes

- **a)** local. $\ell = 3 \times 10^{16} \text{ cm}$
- **b)** local. $\ell = 1 \times 10^{16} \text{ cm}$
- **c)** mov. $\ell = 3 \times 10^{16} \text{ cm}$
- **d)** mov. (50% out) $\ell = 3 \times 10^{16} \text{ cm}$

Arbitrary Flux vs. Energy (GeV)
It does NOT change the main result.
Conclusion & Consequences

1) EC(BLR) is disfavoured as gamma-ray emission mechanism in Broad-line Blazars (~9/10, EC-IR or SSC or EC-ambient)
   ⇒ re-model SED for jet parameters
Conclusion & Consequences

1) EC(BLR) is disfavoured as gamma-ray emission mechanism in Broad-line Blazars ($\sim$9/10, EC-IR or SSC or EC-ambient) ⇒ re-model SED for jet parameters

2) Gamma-ray spectrum is mostly intrinsic (particle distribution) ⇒ new diagnostic possibilities
ON THE SPECTRAL SHAPE OF RADIATION DUE TO INVERSE COMPTON SCATTERING CLOSE TO THE MAXIMUM CUTOFF

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Table 1
The Index of the Exponential Cutoff in the Energy Spectrum of IC Radiation \( \beta_C \) Calculated for Three Different Target Photon Fields, in the Thomson and Klein-Nishina Regimes

<table>
<thead>
<tr>
<th>Scattering regime</th>
<th>Thomson</th>
<th>Klein-Nishina</th>
<th>Thomson</th>
<th>Klein-Nishina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation field electrons</td>
<td>( \beta )</td>
<td>( \beta )</td>
<td>( \infty )</td>
<td>( \infty )</td>
</tr>
<tr>
<td>Monochromatic photons</td>
<td>( \beta/2 )</td>
<td>( \beta )</td>
<td>( \infty )</td>
<td>( \infty )</td>
</tr>
<tr>
<td>Planckian photons</td>
<td>( \beta/(\beta + 2) )</td>
<td>( \beta )</td>
<td>( 1 )</td>
<td>( \infty )</td>
</tr>
<tr>
<td>Synchrotron photons</td>
<td>( \beta/(\beta + 4) )</td>
<td>( \beta )</td>
<td>( 1 )</td>
<td>( \infty )</td>
</tr>
</tbody>
</table>

Note. The index \( \beta \) characterizes the exponential cutoff in the electron energy distribution given by Equation 1.
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1) \textbf{EC(BLR)} is disfavoured as gamma-ray emission mechanism in Broad-line Blazars ($\sim$9/10, EC-IR or SSC or EC-ambient)  
   ⇒ \textit{re-model SED for jet parameters}

2) Gamma-ray spectrum is mostly intrinsic (particle distribution)  
   ⇒ \textit{new diagnostic possibilities} (e.g. Lefa et al 2014)

3) Without BLR suppression, FSRQs luminous at VHE  
   ⇒ \textit{CTA sky much richer of FSRQs}
3C 454.3 can be easily detectable at VHE!

Pacciani et al. 2014 - flare

HBL-like flare!
Conclusion & Consequences

1) EC(BLR) is disfavoured as gamma-ray emission mechanism in Broad-line Blazars (~9/10, EC-IR or SSC or EC-ambient) ⇒ re-model SED for jet parameters

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4) Differences FSRQ/BLLac ?

What about the Gamma-BLR connection then?
What about the Jet-Accretion connection then?

BLR acts as proxy of the disk, does not affect Jet radiation

Ghisellini et al 2013
Sbarrato et al 2011, 2014
Conclusion & Consequences

1) \textbf{EC(BLR)} is disfavoured as gamma-ray emission mechanism in Broad-line Blazars ($\sim$9/10, \textit{EC-IR or SSC or EC-ambient}) \implies \textit{re-model SED for jet parameters}

2) Gamma-ray spectrum is mostly intrinsic (particle distribution) \implies \textit{new diagnostic possibilities} (e.g. Lefa et al 2014)

3) Without BLR suppression, FSRQs should be luminous at VHE \implies \textit{CTA sky much richer of FSRQs}

4) Differences FSRQ/BLLac are intrinsic to how the jet is born: accretion and jet power