Localization of the gamma-ray emission site using multi-waveband data and mm-VLBI

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http://www.bu.edu/blazars
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Different Points of View on Sites of Gamma-Ray Emission in Blazars

**Within 1 light yr.**:
- Dermer & Schlickeiser 1994
- Tavecchio et al. 2010
- Poutanen & Stern 2010

**VLBI Core**:
- Jorstad et al. 2001, 2010
- Lähteemäki & Valtaoja 2003

**Dust Torus**:
- Sikora, et al. 2008
- Costamante et al. 2010

**BLR**:
- Sikora, Begelman, & Rees 1994
- Vercellone, et al. 2010
- Finke & Dermer 2010

**Various Sites**:
- Marscher et al. 2008, 2010
- Katarzynski & Ghisellini 2007
Flaring Blazars in the Gamma-Ray Sky

1. A high $\gamma$-ray state lasts for months as an excited state of the mm-wave core.
2. A low $\gamma$-ray state coincides with a quiescent state of the mm-wave core.
Multi-Frequency Light Curves of the Quasar 3C 273

1. Strong correlation between 225 GHz emission from the whole source and 43 GHz VLBI core flux with delay of the core variability by ~70 days.

2. Good correlation between 225 GHz and IR emission with delay of sub-mm waves by ~25 days.

3. General trend of optical emission behavior similar to mm/sub-mm/IR waves.

4. General γ/X-ray behavior is different from variability at longer wavelengths.

5. Beginning of γ-ray high activity state coincides with flux increase at sub-mm/mm waves.
Correlation between High Energy Light Curves of the Quasar 3C 273
1. Significant increase of degree of polarization in the 43 GHz core during the most pronounced $\gamma$-ray activity.
2. Flare of degree of optical polarization along with the pronounced $\gamma$-ray outburst.
3. The maximum of degree of optical polarization precedes the $\gamma$-ray peak.

First: ordering of magnetic field  
Second: $\gamma$-ray peak
Kinematics of Parsec Scale Jet of 3C 273

<table>
<thead>
<tr>
<th>$\beta_{\text{app}} (c)$</th>
<th>$S_{\text{max}}$</th>
<th>$T_o (\text{RJD})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>9.8±0.4</td>
<td>4560±32</td>
</tr>
<tr>
<td>K2</td>
<td>6.9±1.4</td>
<td>4731±58</td>
</tr>
<tr>
<td>K3</td>
<td>9.4±0.6</td>
<td>4915±29</td>
</tr>
<tr>
<td>K4</td>
<td>10.7±2.4</td>
<td>5066±32</td>
</tr>
<tr>
<td>K5</td>
<td>9.0±1.8</td>
<td>5110±45</td>
</tr>
<tr>
<td>K6</td>
<td>6.1±1.2</td>
<td>5165±36</td>
</tr>
<tr>
<td>K7</td>
<td>?</td>
<td>5275?</td>
</tr>
</tbody>
</table>
Gamma-Ray and Parsec Scale Jet Behavior of 3C 273

Actor I: Gamma-ray light curve -
7-day binning – August 2008 – June 2009
1-day binning – July 2009 – May 2010

Actor II: Total intensity images of parsec scale jet at 43 GHz - 89 images based on 23 VLBA images obtained from August 2008 to May 2010
The Quasar 1633+382 (Z=1.814)

1. Simultaneity of a relatively quiescent state at γ-rays and at optical, mm wavelengths and in the mm-wave VLBI core from 2008 September to 2009 June, RJD: 4750-5000.
2. Increase of γ-ray variability coincides with the beginning of an optical flare and an increase of the flux in the VLBI core at RJD~5000.
3. A possible rise of X-ray activity at the same time.
1. Optical polarization flare (p from ~3% to ~20%) simultaneous with the γ-ray/optical flare and with the beginning of the VLBI core flux increase.  
2. Some increase of degree of polarization in the VLBI core during the γ-ray/optical flare.  
3. Rotation of optical polarization position angle during the γ-ray/optical flare.  
4. Similar trend in EVPA of the VLBA core at 43 GHz behavior.
Gamma-Ray/Optical Flare in 1633+382
Kinematics of Parsec Scale Jet of 1633+382

<table>
<thead>
<tr>
<th>$\beta_{\text{app}}$</th>
<th>$7.8 \pm 2.2$ c</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{\text{max}}$</td>
<td>$1.42 \text{ Jy}$</td>
</tr>
<tr>
<td>$T_0$ (RJD)</td>
<td>$5096 \pm 54$</td>
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</table>
Timing of the Disturbance with respect to Gamma-Ray/Optical Flare
The Quasar 1222+216 (Z=0.435)

1. Quiescent period at all wavelengths from 2008 August to 2009 September:
   - γ-ray flux, $S_\gamma < 10^{-9}$ ph cm$^{-2}$ s$^{-1}$
   - V-band flux, $S_V \sim 1.3$ mJy, $P_R < 2\%$; low flux in VLBA core, $S_{43\text{GHz}} \sim 0.25$ Jy,
   - stable optical and 43 GHz EVPAs.

2. Active period started at all wavelengths in the end of 2009 September:
   - $S_\gamma^{\max} \sim 10^{-5}$ ph cm$^{-2}$ s$^{-1}$
   - $S_V^{\max} \sim 4.7$ mJy
   - $S_{43\text{GHz}}^{\max} \sim 1.1$ Jy
   - $P_R^{\max} \sim 4.8\%$
   - Strong variability of optical EVPAs.
Polarization behavior of the Quasar 1222+216
Parsec Scale Jet of 1222+216

Beam: $0.36 \times 0.16$ mas, PA=$-10^\circ$

$S_{\text{max}} = 0.32$ Jy/beam;

$S_{\text{max}}^p = 17$ mJy/beam
Timing of the Disturbance with respect to Gamma-Ray/Optical Flare
Conclusion

1. Gamma-rays of blazars originate in their relativistic jets.
2. A high $\gamma$-ray state is connected with disturbance(s) propagating down the jet.
3. An interaction between a disturbance and the mm-wave VLBA core causes a $\gamma$-ray flare.
4. A $\gamma$-ray flare associated with a disturbance is simultaneous within a day with an optical synchrotron flare.
5. A pronounced rotation of optical polarization position angle is often observed during the rising branch of such $\gamma$-ray/optical flares.
6. Position angle of optical polarization aligns with jet direction in second half of $\gamma$-ray/optical flares, consistent with transverse shocks.
7. Maximum degree of optical polarization during a flare tends to lead the $\gamma$-ray peak.