Analysis of Five Fermi-LAT LBL/IBL BL Lac Objects:
Examining the June 2011 Gamma-ray Flare of BL Lacertae

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Outline

- History of cosmic gamma-ray detection
- Fermi analysis of 5 blazars
- Emission processes in AGN
- BL Lacertae June 2011 flare
- Edge Sensors
- Conclusion
Brief History

- First space detections in 1960's
- Large Array Telescope on Fermi Gamma-ray Space Telescope satellite launched in June 2008
- Pair production
- Complimented by VERITAS (Very Energetic Radiation Imaging Telescope Array System) ground-based detector → Cherenkov

http://fermi.asdc.asi.it/images/glast1_small.jpg
Objects of Interest

Table of low- and intermediate-frequency peaked ($\nu_{\text{sync}} < 10^{15}$ Hz) BL Lac objects detected both by ground-based gamma-ray telescope, VERITAS, during high flux states as well as the Fermi Large Area Telescope.

<table>
<thead>
<tr>
<th>Blazar</th>
<th>Type</th>
<th>Redshift</th>
<th>(RA, DEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C 66A</td>
<td>IBL</td>
<td>0.444</td>
<td>(35.662, 43.036)</td>
</tr>
<tr>
<td>BL Lac</td>
<td>LBL</td>
<td>0.069</td>
<td>(330.680, 42.278)</td>
</tr>
<tr>
<td>PKS 1424+240</td>
<td>IBL</td>
<td>&lt;0.660</td>
<td>(216.760, 23.795)</td>
</tr>
<tr>
<td>S5 0716+714</td>
<td>LBL</td>
<td>0.300</td>
<td>(110.473, 71.343)</td>
</tr>
<tr>
<td>W Comae</td>
<td>IBL</td>
<td>0.102</td>
<td>(185.374, 28.239)</td>
</tr>
</tbody>
</table>
Fermi Analysis

- Binned analysis performed for 5 LBL/IBLs
- Unbinned analysis:
  - Preferred method
  - Done for BL Lac flare
- In general, only leave free parameters for BL Lacertae in the model
  - Used in generating light curves

Counts map of the region of interest for BL Lac (~12 degrees) summed over photon energies; object appears at center.
Light curves of the five LBL/IBL sources from Fermi-LAT data. Notice the large flare of BL Lac at t≈55700~June 2011.
A closer look at BL Lac flare in June 2011

Closer look at June 2011 light curve for BL Lac over full energy range; created using unbinned (i.e. number of events in each time bin is expected to be small) Fermi analysis.
Flux and spectral index of BL Lac plotted for June 2011 for the full energy range.
Spectral Index vs Flux

- Spectral index plotted against flux for the full energy range
- There is indeed an anti-correlation behavior present.
- A constant spectral index would imply no flux variation.
Blazars

Theoretical spectral energy distributions

Bradt (2008)
Compton Scattering

- Photon collides with stationary free electron
- Energy of scattered photon is function of $\theta$:
  - $m = \text{electron mass}$
  - $\lambda_s = \text{scattered wavelength}$

$$\lambda_s - \lambda = \frac{h}{mc} (1 - \cos \theta),$$

$$h \nu + mc^2 = h \nu_s + \gamma mc^2 \quad \text{(Energy conservation)}$$

$$\frac{h \nu}{c} = \frac{h \nu_s}{c} \cos \theta + \gamma \beta mc \cos \phi \quad \text{(Longitudinal momentum)}$$

$$0 = \frac{h \nu_s}{c} \sin \theta - \lambda \beta mc \sin \phi. \quad \text{(Transverse momentum)}$$
Inverse Compton Scattering

- Photon energy increases
- Electron is of high, relativistic energy (such electrons are found in supernovae and active galactic nuclei)
- Electron with Lorentz factor: \( \gamma = \frac{U}{mc^2} \)
- Final (average, scattered) photon energy:
  \[ h\nu_{\text{s,iso}} = \frac{4}{3} \gamma^2 h\nu, \]

**Example:** In the Crab nebula, an electron with Lorentz factor equal to \( 2 \times 10^4 \) would be able to shift a millimeter-wavelength radio photon of frequency \( 10^{12} \text{ GHz} \) to a scattered frequency of \( 4 \times 10^{20} \text{ Hz} \), well into the gamma-ray region (\( h\nu \approx 2 \text{ MeV} \)).
Synchrotron self-Compton
External Compton Scattering

- Various energy densities present:
  - Direct disc radiation
  - Radiation from the X-ray corona
  - **BLR radiation**
  - Radiation from the IR torus
  - Cosmic background radiation
  - Magnetic field
  - Internal radiation

Ghisellini and Tavecchio (2009)
Comparison of light curves for BL Lac during June 2011. The top plot shows the lower energy bin while the bottom contains the higher energy data.
2008 August 20–September 9 simultaneous SED of BL Lac assembled with data from the coordinated campaign, and some archival data from the literature for comparison. The data are modeled with a single-zone pure-SSC (top panel), two-zone pure SSC description (center panel), and a single-zone SSC plus ERC descriptions (bottom panel).

- Composite SEDs and modeling show double-peaked behavior, as expected
  - Lower peak
  - Higher peak reaches gamma-ray regime

Abdo, A. A., et al. (2011)
A couple of image samples made with the Linux picture-taking software, Cheese. The left image is from a configuration using 3 voltage laser power and an aperture size of 2 mm. The right image also was fed a 3 V laser, but the aperture opening was diminished to 0.1 mm.

- Continue to test cameras and configurations
- Edge sensor systems to be implemented in next generation of ground-based gamma-ray telescopes
- Wrote “snapshotv3.cpp” code to calculate centroids of images
- Have taken 300 images trials to evaluate the distribution of centroid measurements
Conclusions and Future

- More to be studied in BL Lacertae flare, e.g. spectral index behavior
- June 2011 flare can be explained by external Compton scattering
  - Incorporate jet+BLR model for BL Lac flare analysis
- Determine most accurate and practical components for edge sensors
Thank you

- Prof. Humensky and Prof. Mukherjee
- The VERITAS group
- John Parsons
- REU students
References

- Errando, Manel. "Discovery of very high energy gamma-ray emission from 3C 279 and 3C 66A/B with the MAGIC telescope." PhD diss., Universitat Autonoma de Barcelona, 2009.
- Ghisellini, G. & Tavecchio, F. 2009.