The Nature of Gamma-ray Outburst in the BL Lac Object 1749+096

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Layout

• Introduction

• 1749+096 (ongoing study)

• Early Results

• Summary
Extragalactic sky at gamma-ray (> 10 GeV) observed by Fermi-LAT.

~75 % of the sources are blazar (BL Lac Obj. + FSRQ) in total (Ajello et al. 2017).
Intro. Gamma-ray Sky

- Gamma-ray bright blazars consist of powerful radio jet!
Intro. SED of Blazars with Radio Jet

- SED of blazar (Mrk 421).
- Two humps – lower energy part (synchrotron) and higher energy part (IC process).
- Fossati et al. 1998: The two humps are strongly correlated (blazar sequence)!
- Radio Jet – the main emitting source in the SED & an important role in the G-emissions.

Beckmann & Shrader 2012
Intro. Gamma-ray vs. Radio (mm)

- Luminosity - Luminosity plane between gamma-ray and mm wavelengths.
- Planck luminosities in (sub-)mm bands vs. 27 months average Fermi luminosities.

Leon-Tavares et al. 2012
**Intro. Gamma-ray vs. Radio (cm)**

- Flux – Flux plane between gamma-ray and cm wavelengths (2–22 GHz) obtained from VLBI.
- Physical relation between gamma-ray and radio emission in blazar!

*Lico et al. 2017*

Blue, green, and red → HSP, ISP, and LSP blazars respectively
Intro. Motivations

• Where is the gamma-ray production site in blazar jets?

• What physical configuration behind gamma-ray flares? (e.g. the origin of seed photons?)

• How gamma-ray flares correlated with jet evolution?
Intro. Candidates of the Gamma-ray Site?

- General model of blazar jet.
- BH (left side)
- Radio jet (background image)

Multi-wavelength plus VLBI campaigns will provide important observational evidences!
1749+096 (OT 081)

- 1749+096 (LSP BL Lac object; $z = 0.32$; [Ra, Dec] = [267.88, 9.66] in degree).
- Gamma-ray image (left) and VLBI image at 43 GHz (right).
- Huge gamma-ray outburst in the middle of 2016.
1749+096 (OT 081)

- **Fermi-LAT**: Gamma-ray at 0.1 – 300 GeV (weekly binned & 3 day binned)

- **Swift XRT**: X-ray (0.3 – 10 keV)

- **ASAS-SN**: Optical (V-band)

- **KVN, OVRO, and SMA**: Radio (15 – 225 GHz)

- **VLBA**: BU 43 GHz (selected 6 epochs only)
Early Results

- Multi-waveband light curves.
- Gamma-ray outburst: in 2016-07-19; MJD 57588
- Red color region. → gamma-ray active period
- Gamma-ray enhancement: in 2016-10-02; MJD 57663
- A huge radio outburst in 2015, but no significant features at gamma-ray.
- Counterparts at all wavebands. (consistent within a few days) → “co-spatial” in location!
Early Results

• Linear & monotonic relationship between gamma-ray and the other wavelengths during the active period

• Pearson coefficient
  G–X-ray  ~0.87
  G–Opt.  ~0.88
  G–Radio  ~0.69

• Spearman coefficient
  G–X-ray  ~0.75
  G–Opt.  ~0.92
  G–Radio  ~0.87

• Statistically significant results
  (i.e. p-value < 0.05, overall)
  → strong evidence against the null hypothesis (no correlation).

• Spearman's p-value at G–X-ray is higher than the criterion.
  → due to lowering in r-value and N.
Early Results

- Spectral properties at gamma-ray (0.1 – 300 GeV).
- Fitted power-law index. (blue dashed: the gamma-ray peak)
  - Average = –2.34 (7d) & –2.27 (3d) → close to a typical value (–2.2) for LSP blazars (Lico et al. 2017).
- Distribution of the index with the average value suggests a spectral break at a few (1 – 10) GeV. → suffering severe cooling at 0.1–300 GeV.
- Rising feature; coincidence between spectral hardening and brightening. → enhancement of the source & movement of peak frequency of the IC hump to lower ν; blazar sequence.
Early Results

• Evolution of linear polarization of 1749+096 at 43 GHz obtained from BU data (polarized emission & EVPA).
• About 33 degree rotation in EVPA (from ~17 to ~50 degree) after the gamma-ray outburst.
• Enhancement in polarized emission from 208 to 232 mJy after the gamma-ray outburst.
• Two propagating features started in Jul. 31 and Oct 06 (two red dashed lines).
  → Strong evidence of relativistic shocks (new ejection) propagating through the core region (CR).

(Ros et al. 2000; Marscher et al. 2008; Pushkarev et al. 2008)
Early Results

• Total intensity contour maps & circular Gaussian components.
• Levels in factors of two from 0.25 % to 64 % plus 85 % of the Stokes I peaks.
• Tracing the possible new ejections via model fit was difficult.
• Alternative could be investigating flux evolution by dividing the jet into three regions.
  : Region A (r < 0.2 mas; one Comp.), B (0.2 < r < 1.0 mas; two Comps. “usually”), and C (r > 1.0 mas; one Comp.)
Early Results

- Flux evolution of total flux and the VLBI core. → the origin of the radio counterpart.

- Flux evolution in the three regions. 
  Green: region A ($r < 0.2$ mas)
  Blue: region B ($0.2 < r < 1.0$ mas)
  Pink: region C ($r > 1.0$ mas)

- The inner jet component (region A) shows strong radio emission in Sep. 05 (no significant changes in the B and C). → meaning the rising started in August!

- Decrease in the flux of the core after the gamma-ray outburst, contrary to the polarized emission (i.e. anti-correlation) → early stages in the evolution of relativistic shock (Ros et al. 2000).
Summary

• We present our early results of ongoing study of the 2016 gamma-ray outburst occurred in the LSP BL Lac object 1749+096.

• The multi-waveband light curve indicates that the gamma-ray outburst and the corresponding counterparts are co-spatial and physically connected.

• The spectral hardening around the time of the gamma-ray outburst is consistent with the expectation of the blazar sequence; luminosity \propto (peak frequency of the IC hump)^{-1} (Fossati et al. 1998; Ghisellini et al. 1998).

• The behaviors in the linear polarization and the flux evolution of the Gaussian components support relativistic shock propagating down the jet. Furthermore, the anti-correlation between the polarized emission and the Stokes I flux represent early stages of a relativistic shock.

• The origin of the gamma-ray outbursts might be located at upstream of the core region, and caused by the interaction between a propagating disturbance and the recollimation shock.