Revisiting the Blazar Sequence

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Abstract Summary

We re-visit the blazar sequence based on extensive radio (UMRAO, Metsahovi), optical (Tuorla, WIYN), X-ray (Swift), and gamma-ray (Fermi) observations of 26 blazars in 2008 and 2009. The observations deliver broadband spectral energy distributions and allow us to study how well individual sources fit into the blazar sequence.

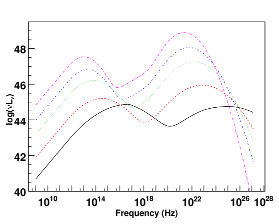
Abstract

From observations with EGRET we know that the frequencies at which the low-energy and high-energy components of the spectral energy distributions (SEDs) of blazars peak anti-correlate with their bolometric luminosities. Following the discovery of this anti-correlation, Fossati et al. (1998) and Ghisellini et al. (1998) proposed a simple physical explanation for the anti-correlation in the "blazar sequence", namely that the radiative electron cooling in the more powerful objects accounted for the rather low frequencies of their SED peaks. Except for the most powerful sources, EGRET was only able to make time- and source-averaged statements about the gamma-ray SEDs of blazars. We now re-visit the blazar sequence based on extensive radio (UMRAO, Metsahovi), optical (Tuorla, WIYN), X-ray (Swift), and gamma-ray (Fermi) observations of 26 blazars in 2008 and 2009. The observations deliver broadband spectral energy distributions with unprecedented signal to noise ratio, and allow us to study how well individual sources fit into the blazar sequence. Furthermore, it becomes possible to study how sources move "along" and "perpendicular" to the blazar sequence as they cycle through quiescent and flaring phases. In this contribution, we scrutinize the time resolved blazar SEDs. Using observational tools as broad band cross-correlation analyses, and theoretical tools like snapshot and time-dependent SED modeling, we discuss the implications of the observations for the physical mechanisms which govern the emission properties.

Introduction

Blazar: a subclass of Active Galactic Nuclei (AGN), viewed at a small angle of the jet. They are high-luminosity objects, showing strong variability in all accessible wavebands. Multiwavelength observations of gamma-ray emitting blazars are important in order to test models of non-thermal emission from these objects. Measurements of the temporal correlation between flux variations at different wavelengths during flares are particularly useful, simultaneously providing constraints on the emission models in various energy regimes.

Blazar Sequence: a correlation between the luminosity of the continuum emission and the frequencies at which the low-energy and the high-energy emission components exhibit their νF_ν−peaks (Fossati & Ghisellini, 1998).



The blazar sequence derived from combining EGRET data with multiwavelength data for blazars divided into different luminosity classes (Fossati & Ghisellini, 1998). Fermi can improve on the EGRET results, by measuring individual high energy SEDs to much higher accuracy, while the wide availability of contemporaneous multiwavelength coverage from instruments such as Swift and Fermi combined can resolve different states of the studied sources at multiple parts of the SED.

Source List

26 blazars monitored by Swift, including the twenty strongest sources of the 3[rd] EGRET catalog plus six sources that were added because they had been detected by ground based TeV gamma-ray observatories.

We have reduced the broadband data from all 26 sources. We focus on eight high signal to noise ratio sources which have lightcurves and energy spectra of exceptional quality.

Participants

Gamma-ray

- Fermi [200 MeV - 300 GeV]

X-ray

- Swift (The X-ray Telescope [0.3-10 keV] and The Burst Alert Telescope [15-50 keV])
- RXTE (All Sky Monitor [2-10 keV])

Optical [R]

- Tuorla, Finland
- WIYN, Kitt Peak, Arizona
- Swift (UVOT [170-650 nm])

Radio

- UMRAO, Michigan [4.8 GHz, 8 GHz, 14.5 GHz]
- Metsahovi, Finland [37 GHz]

Note: XRT data is preliminary.

Acknowledgements

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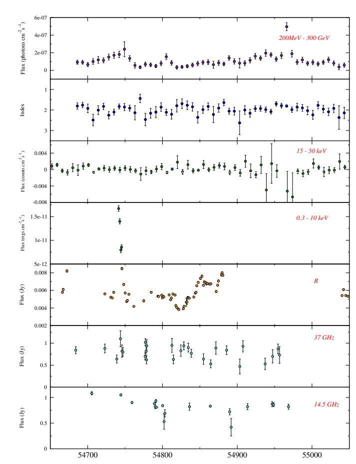
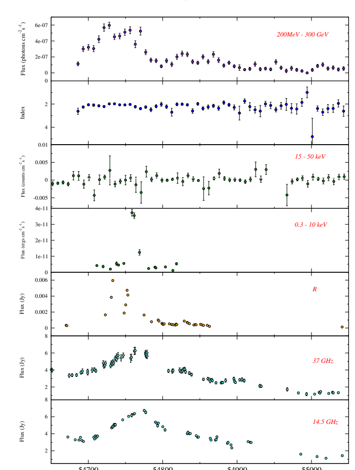
Multiwavelength Lightcurve

3C 66A



- Strong variability in all wavebands.

PKS 0235+164



- Strong flare in all wavebands except X-ray.
- Gamma-ray flare followed by optical and radio flares.
- Gamma-rays may mark injection of new radio blobs (Acciari et al. 2009).

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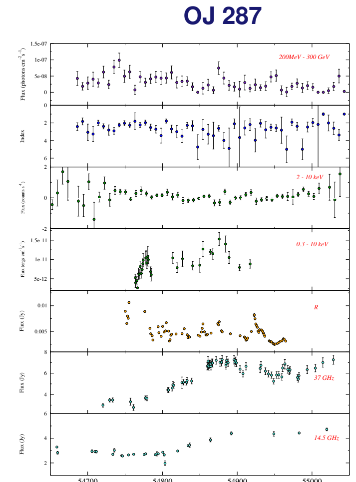
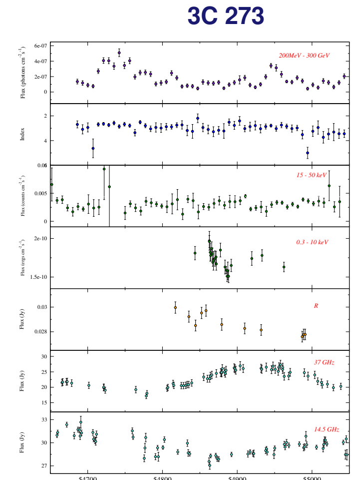


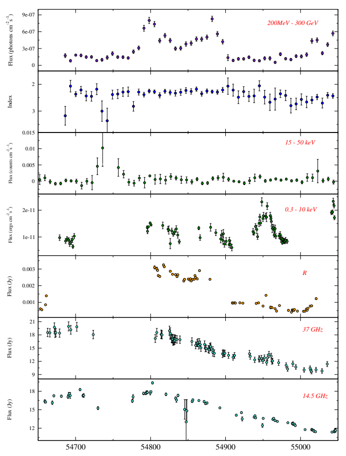
- Strong variability in all wavebands.

3C 273



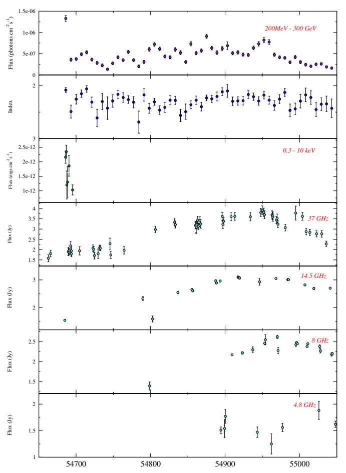
- Strong variability in all wavebands.

3C 279



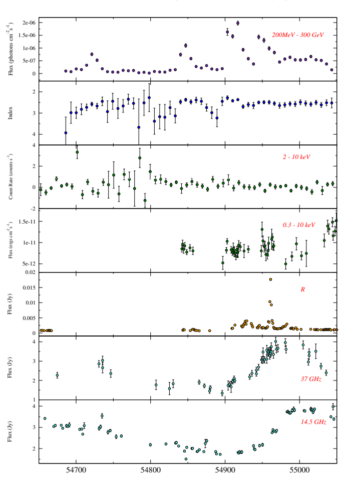
- Strong variability in all wavebands.

PKS 1502+106



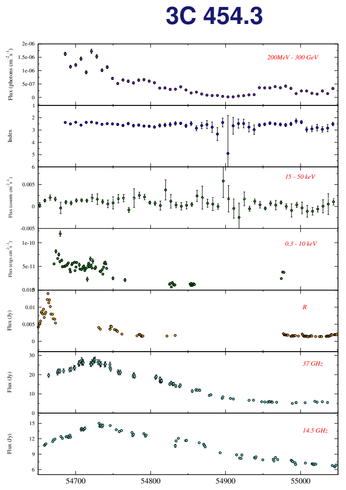
- Strong variability in all wavebands.
- No optical data avaliable.

PKS 1510-089



- Strong variability in all wavebands.

3C 454.3



- One strong flare in most of the wavebands.
- Gamma-ray flare followed by optical and radio flares.
- Gamma-rays may mark injection of new radio blobs (Acciari et al. 2009).

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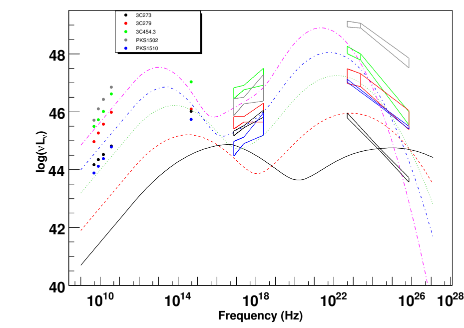
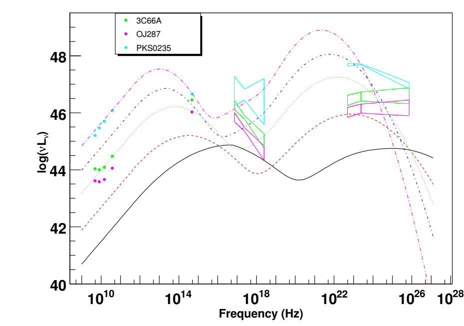
Blazar Sequence for Different Sources

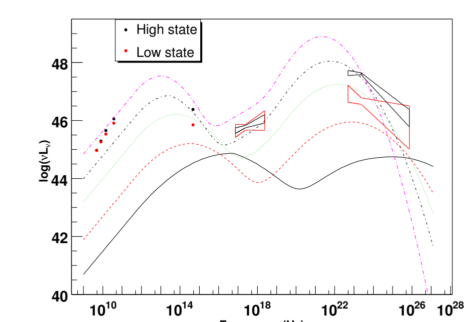


The averaged SEDs of the five FSRQ sources are overlaid to the blazar sequence. Most of the X-ray fits into the blazar sequence while some Gamma-ray does not fit well.



The averaged SEDs of the three BL Lac sources are overlaid to the blazar sequence.
The three BL Lac sources do not fit well into the blazar sequence.

SEDs for One Source (3C 279) in Different Gamma-ray Emission States



The SEDs of 3C 279 in two different Gamma-ray states, high state (MJD 54780) and low state (MJD 54950).

Summary

- 26 blazars broadband data has been reduced, eight sources with high signal-to-noise ratio results are shown.
- Most of the lightcurves showed variability in all wavebands.
- Two sources (PKS 0235+164 & 3C 454.3) indicate that Gamma-ray may mark injection of new radio blobs (Acciari et al., 2009).
- The averaged SEDs of the eight sources were overlaid to the blazar sequence.
- Luminosity alone does not characterize SED.

Future Work

- Time resolved SEDs.
- Fitting the SEDs with parametric models.
- Correlations between various model parameters.
- Detailed model calculations based on a time dependent synchrotorn-Compton code (Krawczynski, Coppi, Aharonian, 2002, Coppi, 1992, Coppi & Aharonian, 1999).

References

- Acciari, V. A., et al. 2009, Science Magazine, 325, 444.
- Fossati, G., et al. 1998, MNRAS, 299, 433.
- Ghisellini, G., et al. 1998, MNRAS, 301, 451.
- Coppi, P.S. 1992, MNRAS, 258, 657.
- Coppi, P.S., Aharonian, F.A. 1999, ApJ, 521, L33.
- Krawczynski, H., Coppi, P.S., Aharonian, F.A. 2002, MNRAS, 336, 721.
- Nieppola, E. et al. 2008, A&A, 488, 867.