Connection between γ-ray and radio activity of blazars from Fermi-LAT and cm/mm radio monitoring with the Effelsberg 100-m and IRAM 30-m telescopes

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Summary: We study the radio/gamma-ray connection for a sample of LBAS blazars observed by Fermi-LAT and the Effelsberg 100-m and IRAM 30-m radio telescopes. In particular, a first significant flux-flux correlation is presented as well as a first attempt to compare the blazar activity/flaring states at both bands.

Abstract

Radio cm/mm monitoring of a sample of blazars has been carried out within the F-GAMMA project at multiple frequencies with the Effelsberg 100-m and IRAM 30-m telescopes since 2007. A larger sample of blazar candidates from the CGRaBS sample has been observed with the OVRO 40-m telescope. Using these quasi-simultaneous observations we study the connection between the gamma-ray behavior of blazars as detected by Fermi-LAT and the cm/mm bands. In particular, comparing the first detailed Fermi gamma-ray light curves with those at cm/mm bands for a larger number of sources it is possible to study in more detail the possible relation between the gamma and radio activity of LAT gamma-ray blazars and its physical implications. Furthermore, we present for the first time the study of a statistically significant cm/mm and γ-ray flux-flux correlation. We here show first results using the cm/mm band data obtained with the Effelsberg and IRAM PV telescopes.

Introduction:

Since radio-loud Active Galactic Nuclei (AGNs) - and blazars in particular - are known to be the most prominent class of extragalactic γ-ray emitters (3EG, Hartman et al. 1999), the ultimate physical connection between the radio and γ-ray emission in these objects is a matter of debate. Past direct studies of possible radio vs. γ-ray flux density and luminosity correlations could not convincingly demonstrate a true correlation taking into account the inherent, statistical biases and selection effects involved (e.g. Mücke et al. 1997, Kovalev et al. 2009). Furthermore, previous studies of the γ-ray emission side (e.g. core-region/jet-base or standing/moving shocks downstream the jet) and the related question of a correlation between γ-ray and radio activity/flares (e.g. correlations, time lags; e.g. Lähteenmäki & Valtaoja 2003) as well as VLBI component ejections (e.g. Jorstad et al. 2001) were hampered by the modest sensitivity and limited time coverage of EGRET.

With Fermi-GST in orbit, the unprecedented quality γ-ray data delivered by the LAT in combination with large radio projects will allow to study this radio/gamma connection in much greater detail for a much larger number of sources. **Here, we present a first attempt using early LAT γ-ray data in combination with simultaneous cm- to short-mm band data (mean fluxes and light curves). See also the related posters/talks by W. Max-Moerbeck, M. Giroletti, S. Ciprini and E. Angelakis.**

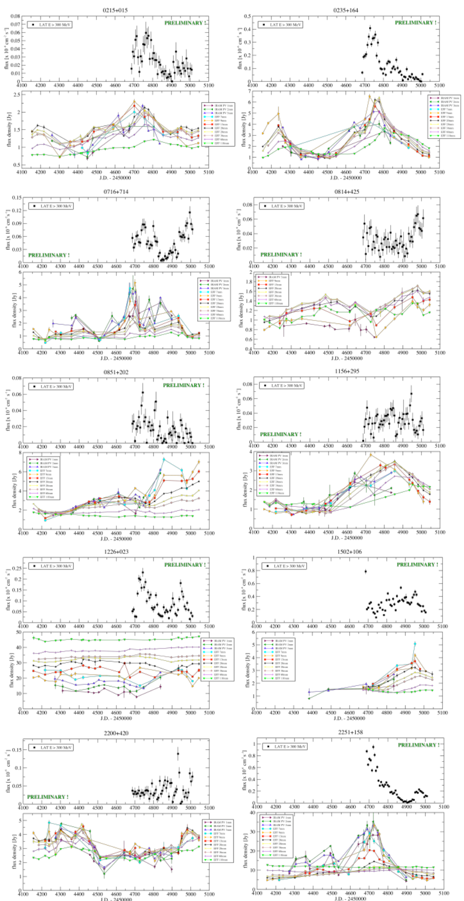

Fig. 2: Examples of radio/ γ-ray light curves showing various different behaviors.

Radio data: The F-GAMMA project

In 2007, we have jointly started a coordinated, Fermi-related radio cm to (sub-) mm monitoring of γ-ray blazars:

- **telescopes:** Effelsberg 100-m, OVRO 40-m, IRAM 30-m and APEX
- **12 frequencies** between 2.6 and 345 GHz
- **two samples: (1) 'prominent sample'** of ~60 usually bright, "famous", flat-spectrum and EGRET detected blazars (monthly monitoring); **(2) 'parent sample':** statistically well-defined sample of ~ 1200 CGRaBS sources (OVRO team: ~2 times per week at 15 GHz)

The studied sample:

The LBAS three months list (Abdo et al. 2009) contains 29 sources of the F-GAMMA 'prominent sample'. These early LAT-detected sources constitute the basis of the study presented here.

Fuhrmann et al. 2007, Angelakis et al. 2008, Richards et al. in prep., Fuhrmann et al. in prep.

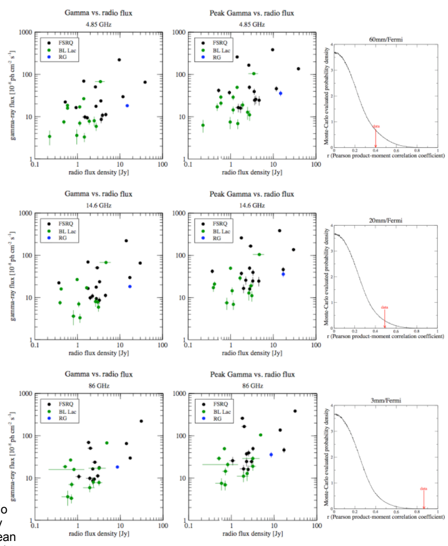

Fig. 1: Examples of radio (5, 15, 86 GHz) vs. γ-ray (LBAS three months mean and peak flux) plots. Right: The distributions of MC simulated *r*-values for the given radio frequencies are shown. The "observed values" are superimposed (see text for details).

Table 1: Monte-Carlo simulation results

Radio frequency	total pairs	surviving pairs	observed r	chance probability
2mm	5508	1287	0.892	3.6×10^{-5}
3mm	15000	3567	0.855	1.5×10^{-5}
7mm	7600	2698	0.831	7.0×10^{-4}
9mm	18954	4607	0.735	6.1×10^{-4}
13mm	6498	1592	0.59	1.1%
20mm	16900	4468	0.486	2.8%
28mm	21168	5296	0.4274	5.1%
36mm	18954	4572	0.3975	6.3%
60mm	21168	5324	0.3968	8.1%
110mm	11638	4026	0.4273	6.1%

Combination and analysis of Fermi-LAT and radio data:

Our study presented here is two-folded:

(1) a flux-flux correlation analysis using the LBAS 3 months γ-ray fluxes (Abdo et al. 2009) and simultaneous, averaged 3 months flux densities at cm to short-mm wavelengths:

- **Examples are shown in Fig. 1:** an apparent correlation is clearly seen. BUT: given the biases and selection effects involved (e.g. small sample, small flux/luminosity dynamical range, no statistically well defined sample), the significance of such a correlation can only be tested using dedicated Monte Carlo (MC) simulations
- **THUS: a large set of simulations is needed!** For each simulated data set (a total of 10^7 pair combinations were produced): calculate the Pearson product-moment correlation coefficient *r* and compare with the actual, observed value (see Fig. 1). Consequently, obtain the chance probability for the observed *r* to have occurred through uncorrelated fluxes. The distribution of MC simulated *r*-values for the given radio frequencies is shown in Fig. 1. The observed *r*-values and obtained chance probabilities are shown in Table 1

(2) A comparison of the γ-ray and radio activity during the first 11 months of LAT γ-ray data: We use:

- **weekly 11 months LAT light curves** of the LBAS sources including variability analysis (Abdo et al. in prep.; see poster by S. Ciprini for details)
- **cm/mm radio light curves** obtained within the F-GAMMA project (2.5 yrs) including variability analysis
- **comparison of variability behavior at cm/mm/γ-ray,** e.g. presence of variability at both bands (11 months), study of mean radio fluxes: 11months vs. 2.5 years, **cross-correlation (CCF) analysis** of the radio and γ-ray light curves

First results and conclusions:

(1) The chance probability values strongly decrease towards higher radio frequencies - to values ~10^{-5} demonstrating for the first time a statistically significant flux-flux correlation, though for this selected sample. This implies a direct link between the radio and γ-ray emission processes

(2) Examples of variable radio/γ-ray light curves are presented in Fig. 2 often showing (quasi-) simultaneous variability/flares at both bands. This is confirmed by our analysis: many of the sources are variable and in high radio states (in particular at higher radio frequencies) during γ-ray activity/flares. Our CCF analysis reveals a variety of behaviors: radio lagging or correlation close to zero lag. For several other sources no such correlation has been found.

However, the analysis presented here is, so far, limited by the short LAT light curves and small number of "events". Future LAT data will allow more detailed studies and rigid conclusions!

References:
Abdo et al. 2009, ApJ, 700, 597;
Jorstad et al. 2001, ApJ, 556, 738
Kovalev et al. 2009, ApJ, 696, L17
Laehteenmaeki et al. 2003 ApJ, 590, 95
Muecke et al. 1997, AnA, 320, 33