F-GAMMA project:
AGN astrophysics via multi-frequency monitoring of gamma-ray blazars in the *Fermi* era

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Abstract

Several models have been suggested to explain the dramatic behavior of blazars. Although the exact physical processes at play are unclear, the study of the temporal behavior of the SED can shed light on the emission and variability mechanism since different mechanisms predict different variability patterns. Hence, multi-frequency monitoring of blazars is essential in understanding the blazar physics.

In order to benefit from the unprecedented opportunities offered by Fermi/LAT, we have initiated in January 2007, a tightly coordinated "alliance" of scientific groups with the common goal to under-stand aspects of the γ-ray emitting AGN/blazar physics via multi-frequency monitoring. The core team consists of the MPIfR 100-m telescope at Effelsberg, the 40-m IRAM telescope at Pico Veleta (Spain) and the 40-m Caltech telescope in Owens Valley (CA). The Effelsberg and IRAM telescopes conduct a monthly monitoring of 60 selected Fermi/LAT blazars. The former covers the cm band from 2.64 GHz to 43.00 GHz in whereas the latter the mm and sub-mm band from 86 GHz to 270 GHz in total intensity and polarization. The OVRO telescope observes a complete sample of 1200 sources at 15 GHz. Occasionally, other observatories join forces at other wave-bands.

Here we discuss the scientific merit of this effort and highlights of our work over the last 2.5 years. Along with the spectral behavior of the selected blazars other data products are also shown.

Blazars: the extreme manifestation of AGN activity

Blazars are among **most dramatic** manifestations of the activity induced in the **nuclei** of **Active Galaxies**. They comprise a unique probe of the **exotic physics**. Their phenomenology is dominated by **extreme characteristics** such as:

- High degree of **linear polarization**
- **Intense variability**, both in total power and polarization and at all wavebands
- **Highly superluminal** apparent motions
- **Brightness temperatures** exceeding the **Compton limit** (e.g. Urry et al. 1999).

This violent behavior is attributed to **relativistic jets oriented very close (~20º to 30º) to the line-of-sight** (e.g. Urry et al. 1995).

Several ideas have been put forth to explain the origin of their variability. Some of them are:

- The **shocks-in-jet** model (e.g. Marscher et al. 1985, Aller et al. 1985, Marscher et al. 1996)
- **Relativistic plasma shells** (e.g. Spada et al. 2001, Guetta et al. 2004).
- Alternatively, it has been suggested that **light-house effect** could be causing variability in cases of **rotating helical jets** or the **helical trajectories** of plasma elements (e.g. Begelman et al. 1980, Camenzind et al. 1992).

F-GAMMA project: Fermi-GST AGN Multi-Frequency Monitoring Alliance

The currently described program is part of a big collaboration involving: the **100-m Effelsberg** telescope, the **30~m IRAM** telescope, the **40~m Owens Valley** telescope, **Skinakas optical** telescope **APEX** telescope and many others (Fuhrmann et al. 2007).

The goal is to understand the **physics** in blazars by monitoring the variability of their SEDs (from radio to TeV) in collaboration with the **LAT** onboard the ***Fermi-GST***. Such an approach can:

- Different **emission mechanisms**
- Shed light on linear scales inaccessible even to interferometric techniques
- Discriminate between **different variability scenarios**

Telescope	Observing Frequency (GHz)	Sampling	# of sources
100-m Effelsberg	**2.6, 4.9, 8.4, 10.5, 14.6, 22.3, 32, 43**	**1/month**	**60**
30-m Pico Veleta	86, 142, 220, 270	1/month	60
40-m OVRO	15	2/week	1200
APEX	345	1/month	60
Skinakas 2.4 m	V, B, R, I	1/month	60

The 100-m Effelsberg radio telescope monitoring: 2.6 - 43 GHz

The **100-m Effelsberg** telescope is pivoting the program covering the band between 2.64 to 43 GHz. The observations have started in **January 2007** and are done **monthly** on a **sample of ~60 sources**. The sources have been selected from the "high-priority blazars" list of the ***Fermi-GST*** AGN team.

There is an overlap with other studies such as **2-cm VLBA survey** (MOJAVE program, Kellermann et al. 1998, Zensus et al. 2002, Kellermann et al 2004), the **Boston 43 GHz VLBI survey** (Jorstad et al. 2001) and other multi-frequency campaigns.

For our monitoring program the receivers at **2.64, 4.85,8.35, 10.45, 14.60, 23.05, 32.00 and 43.00 GHz** have been employed. Almost all of them (except for 32.00 GHz) deliver **polarization** information. The data products are:

- **Monthly simultaneous radio spectra** between **2.6 and 150 GHz** (in collaboration with the IRAM telescope).
- **Multi-frequency light curves**.
- **Monthly sampled polarization** data at almost all frequencies.

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Source Name		
0003-066	1128+592	1611+343,OS319
0059+581	0814+425,TXS0814+425	1622-297,1622-2
0215+015,PKS0215+015	0827+243,OJ248	1633+382,4C38.41
0219+428,3C66A	0836+710,S50836+71	1641+399,3C345
0234+285,4C28.07	0851+202,OJ287	1652+398,Mkn501
0235+164,AO0235+16	0954+658,S40954+65	1730-130,PKS1730-13,NRAO530
0238-084,NGC1052	1038+064,PKS1038+064	1803+784,S51803+78,
0300+470,4C47.08	1101+384,Mkn421	1807+698,3C371
0316+413,3C84	1127-145,PKS1127-14	1823+568,4C56.27
0317+185,1E0317.0+1835	1156+295,TON599	1836+59
0333+321,OE355	1219+285,WCom	1849+67,S41849+6
0336-019,PKS0336-01	1222+216,4C21.35	2155-152,PKS2155-152
0355+508,NRAO150	1226+023,3C273	2155-304,PKS2155-304
0415+379,3C111	1228+126,M87	2200+420,BLLAC
0420-014,PKS0420-01	1253-055,3C279	2223-052,3C446
0430+052,3C120	1308+326,OP313	2230+114,OY150,CTA102
0528+134,PKS0528+134	1406-076,PKS1406-076	2251+158,3C454.3
0716+714,S50716+71	1502+106	2345-16,PKS2345-16
0735+178,PKS0735+17	1510-089,PKS1510-08	
0748+126	1522+314	

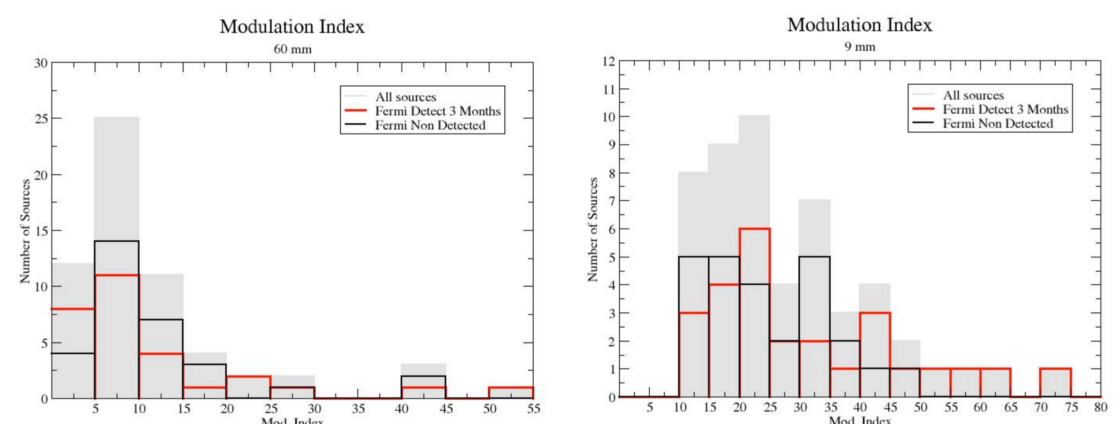
Results

The cross-correlation of the Effelsberg/Pico sample (shown in the table above) with the LBAS list (Abdo et al. 2009) showed that **47%** of our sources are detected by *Fermi*-GST. **Currently we are revising our source list to include source that are all detected by LAT**.

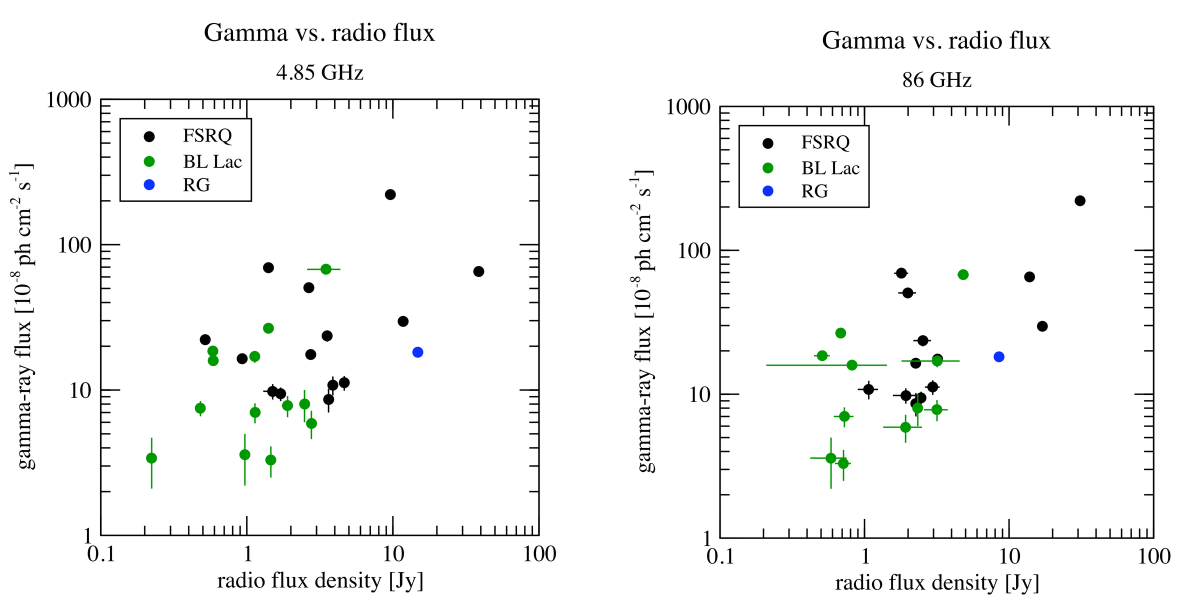
After 2.5 years of observing we have accumulated a large volume of data. The reachable accuracy of calibration ranges from **less than 1 - 5 % at higher frequencies** (Angelakis et al. 2008). See the plots corresponding to the **main calibrator 3C286**. The spectra are **simultaneous within ~40 min** and the coherency with the IRAM telescope within a couple of days so that the spectra are free of variability.

A χ^2 test shows that practically **all our sources are variable** at **all frequencies** at a confidence level of **99.9%**.

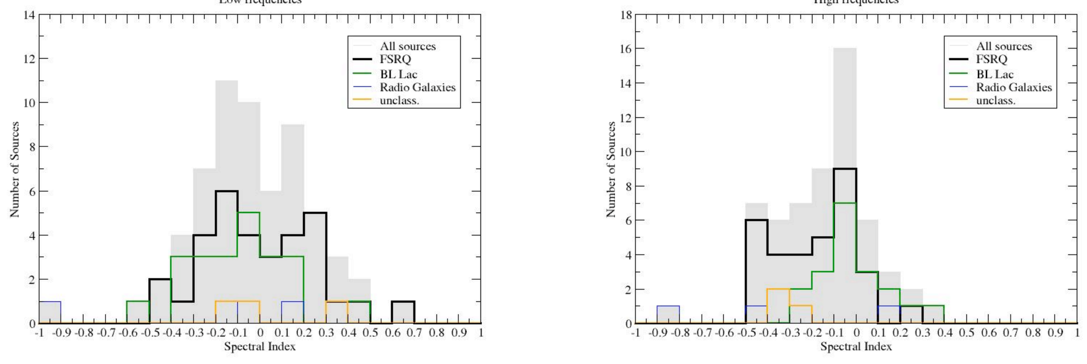
As its is shown in the following plots, there is a tendency for the variability amplitude to increase with frequency as it is expected.



For the LAT detected sources there is a Radio - γ-ray flux correlation (see the poster by Fuhrmann et al. P1-47).

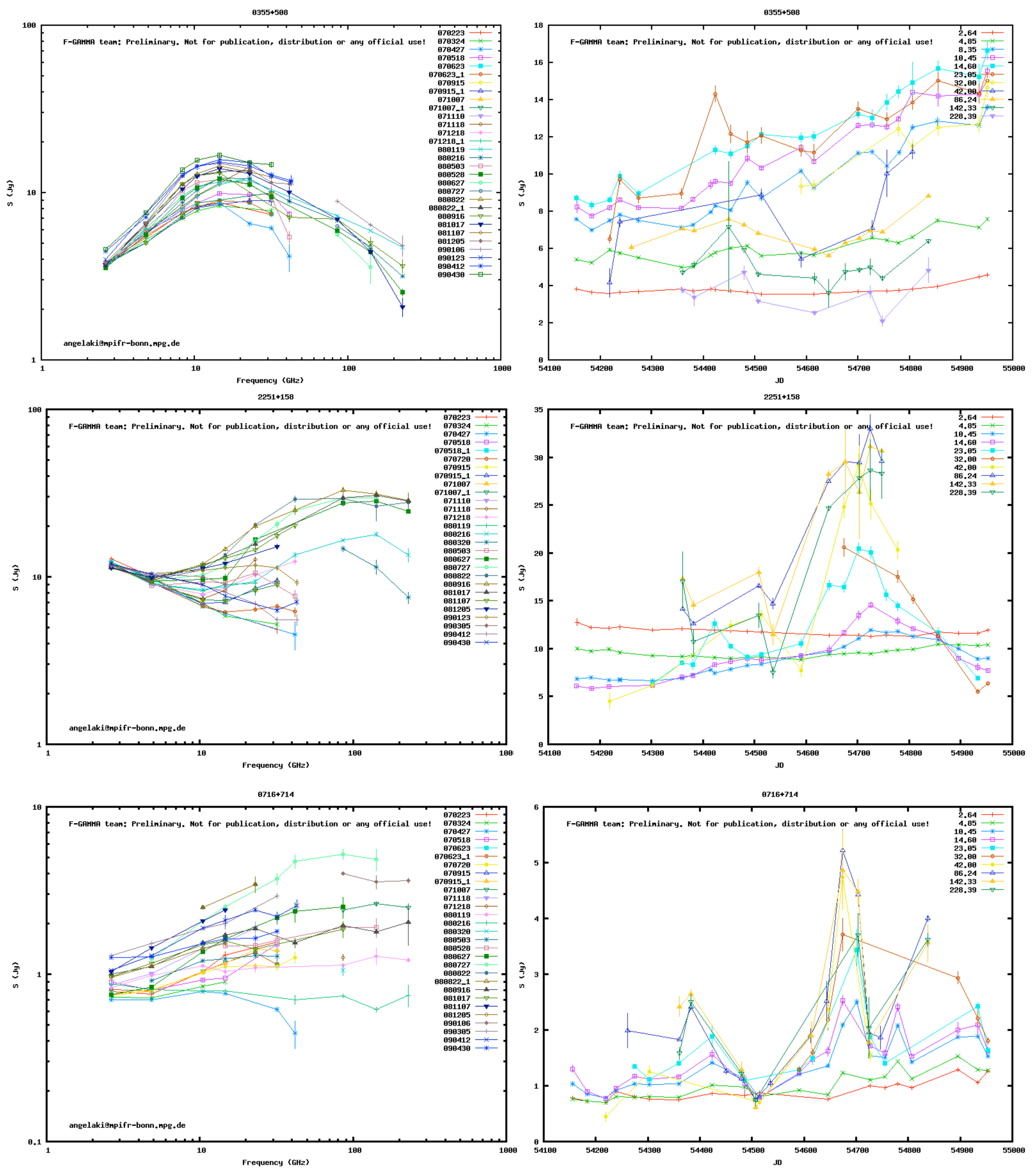


There seems to be an tendency for the high frequency spectral index BL Lacs to move towards positive values indicating a turnover often around 32 GHz.

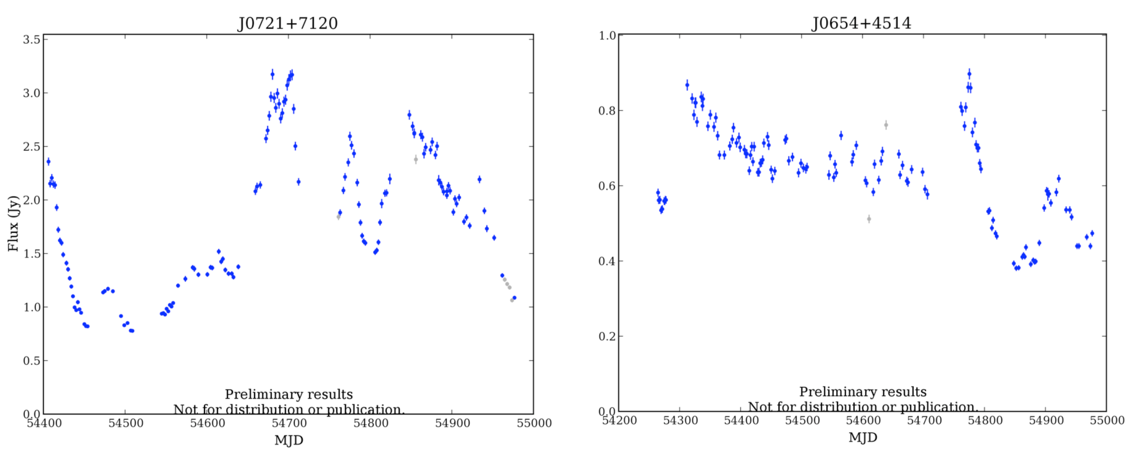


We routinely produce monthly sampled lightcurves at frequencies from cm to mm suitable for:

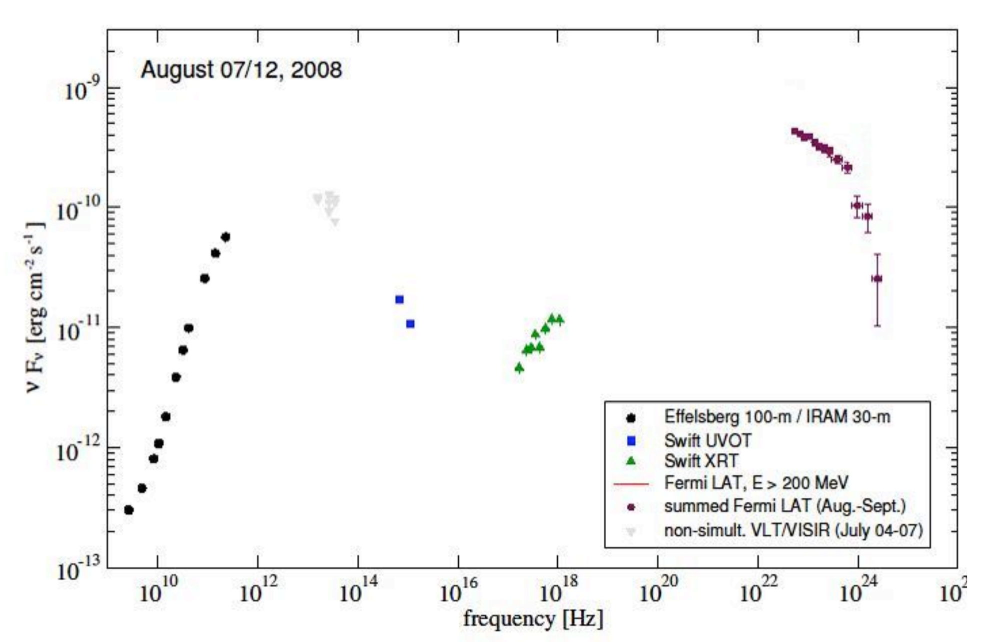
- **Flare evolution** studies which can gives us clues of the physical conditions of the emitting material.
- Correlations with the light-curves from ***Fermi-GST***.
- Time series analysis and variability studies.
- etc...



The OVRO telescope is providing densely sampled (2 points / week) lightcurves at 15 GHz (see the poster by Max-Moerbeck et al. P1-54).



This effort allows the study of the broad band SED variability study that can put constrains of the emission mechanisms (Broetcher et al. 2004).



Discussion

The F-GAMMA project has been running since January 2007 at Effelsberg and June 2007 at OVRO and Pico Veleta. The data products of the first 2.5 years can be publicly accessed at www.mpifr.de/div/vlbi/fgamma. The cross-correlation of the Effelsberg/Pico sample with the LBAS list Abdo et al. (2009) showed that 47% of our sources are detected by *Fermi*-GST. Practically all our sources are variable at all frequencies at a confidence level of 99.9%. The variability amplitude (as parameterized by the modulation index m=rms/<S>) increases with frequency as expected from frequency flare evolution arguments. The characteristic time scales present in the light curves vary from weeks to years while there is a wealth of variability patterns both in the light-curves and in the spectra. The findings are summarized in Fuhrmann et al. (in prep.), Richards et al. (in prep.) and Angelakis et al. (in prep.). Given the limited fraction of our sources in the LBAS list we are currently compiling an updated sample.

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