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High Energy Gamma-ray Variability of Fermi LAT Blazars

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(on behalf of the Fermi LAT collaboration)

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Some highlights on gamma-ray light curves and variability properties of blazars of the *Fermi* LAT Bright AGN Sample, collected during the first eleven months of all sky survey are introduced. First general characteristics of the gamma-ray (i.e. mono-energy band) variability are investigated using weekly and 3-day bin flux light curves. In addiction some results from an intensive multi-waveband campaign on a new and powerful gamma-ray blazar, PKS 1502+106, discovered by *Fermi* , are introduced as example of multi-waveband variability analysis allowed by *Fermi* -driven multifrequency observing campaigns.

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1. Mono-waveband and multi-waveband blazar variability

Variability is found in blazars at all the timescales and at all the energies, and usually it is referred as multi-wavelength variability. In the analysis of multi-waveband variability both the power density spectra (PDS) of the signal (signal commonly provided by flux light curves in a certain energy band) and the spectral energy distribution (SED) (the total flux density across the entire electromagnetic spectrum) are investigated. The PDS-SED plane (i.e. time-energy plane or spectral-temporal behavior) for blazars is beginning to be explored in a systematic way, along with the investigation of other parameters such as luminosity, Doppler beaming factor, black hole mass, magnetic field intensity, region compactness and distance from the central engine. Such broad-band multi-frequency analysis is useful to investigate cross-correlations, time lags, orphan flares, peak emission and gamma-ray-synchrotron amplitude ratios, spectral index hysteresis, broad-band flare versus quiescence emission, validity of blazar sequence and AGN/blazar taxonomy, and to identify at other wavebands newly discovered gamma-ray sources and to built models reproducing the observed SEDs.

Temporal variability studies on a single energy band (mono-waveband), performed in the past at radio-mm, optical and X-ray bands, are now possible also at high energy gamma-rays thanks to the *Fermi* mission. EGRET showed that blazars are the largest class of highlatitude variable gamma-ray sources in the energy band above 100 MeV, although it was limited by the statistic of the observations and by the pointed operating mode. The *Fermi* Large Area Telescope (LAT) thanks to the large field of view (covering the 20% of the sky at any instant and the full sky in about 3 hours), improved effective area and sensitivity, and the all-sky operating mode is now an optimal instrument to monitor on mid and long term baseline the gamma-ray variability of blazars in the energy band 20 MeV – >300 GeV [1, 3, 5]. The observed variability of blazars and other AGNs at radio, optical, and X-ray bands show usually the typical $1/f^{\alpha}$ PDS trend in a wide range of temporal frequencies f. In particular optical blazar variability is often, but not universally, characterized by outbursts spaced out by long periods of lower flux and lower level of variability resembling flickering fluctuations. The distribution of flux values is similar to a Poissonian, while radio variability presents frequent peaks and long period trends with a quasi-Gaussian distribution of flux values.

2. Mono-waveband variability: bright gamma-ray blazars observed by Fermi LAT

A major result obtained by *Fermi* LAT during the first 3 months of observations has been the publication of the Bright Source List [1], a list of 205 sources detected with $> 10\sigma$ significance. Of these, 106 sources, located at $|b| > 10^{\circ}$, have been associated with high-confidence with known blazars and other AGNs and represents the LAT Bright AGN sample (LBAS). A couple of high-lights on the LAT light curves of LBAS sources over a period of 11 months are briefly reported.

In Figure 1 are reported light curves of the integrated flux ($E > 300$ MeV) on weekly time bins for six gamma-ray bright blazars, showing different temporal trends and timescales, and a variability mode dominated either by flickering (red/pink noise) or by Brownian (brown-noise) fluctuations. In the weekly light curves we have not found strong evidence for periodicity although the range of timescales/frequencies explored was rather limited.

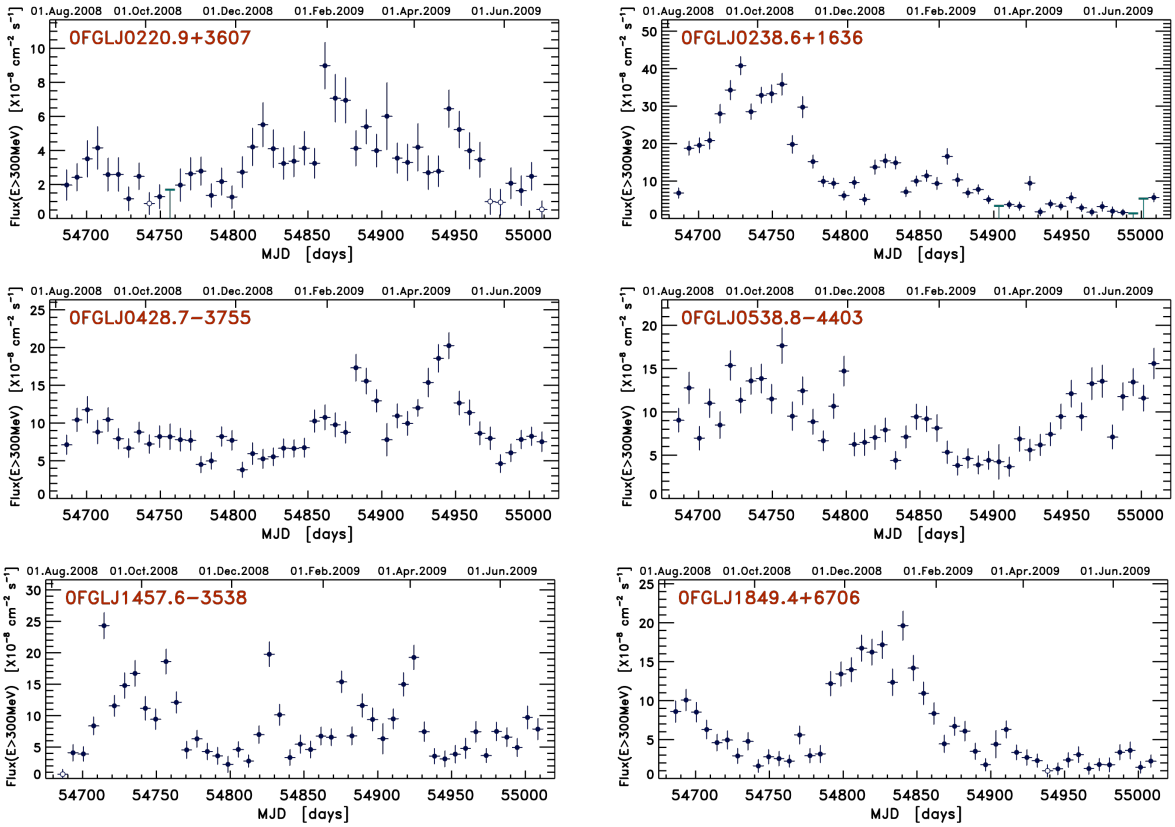

Figure 1: Six examples of 11-month light curves of the integrated flux ($E > 300$ MeV) averaged on weekly time bins. The six sources reported (labeled with the 3-month catalog name 0FGL [1, 2]) are explicitly from the left upper plot: B2 0218+35 (S3 0218+35), B2 0218+35, AO 0235+16 (OD 160), PKS 0426-380, PKS 0537-441, PKS 1454-354, and S4 1849+67.

In Figure 2 are reported weekly and 3-day flux bin light curves of 3C 279 joined with the corresponding discrete autocorrelation function (DACF), first order structure function (SF), power density spectrum (PDS) (time series analysis performed over the global light curve) and functional fitting of the temporal shape of the flares (analysis performed locally on the time series). The analysis of the weekly light curve of 3C 279 points out a $1/f^{\alpha}$ behavior (being $f = 1/t$ the temporal frequency) with a power index $\alpha = 1.6$ (estimated from the power-law trend of the SF for lags below the break point). This means a fluctuation mode placed roughly halfway between flickering ($\alpha = 1$) and the Brownian noise ($\alpha = 2$). Detailed and systematic analysis and results on the whole LBAS sample using these methods are presented in [3].

3. Multi-waveband variability: the *Fermi* -*Swift* campaign on PKS 1502+106

The *Fermi* LAT discovered a rapid ($\sim$ 5 days duration) gamma-ray outburst from a source identified with the blazar PKS 1502+106 (OR 103, S3 1502+10, z=1.839) starting on August 05, 2008 [7] and followed by bright and variable flux over the next months. Results on the gamma-ray localization and identification, as well as spectral and temporal behavior during the first months of the *Fermi* all-sky survey are reported in [4], in conjunction with a multi-waveband characterization as a result of one of the first *Fermi* multi-frequency campaigns. The campaign included a *Swift* ToO (followed up by 16-day observations on August 07-22, MJD 54685-54700), VLBA (within

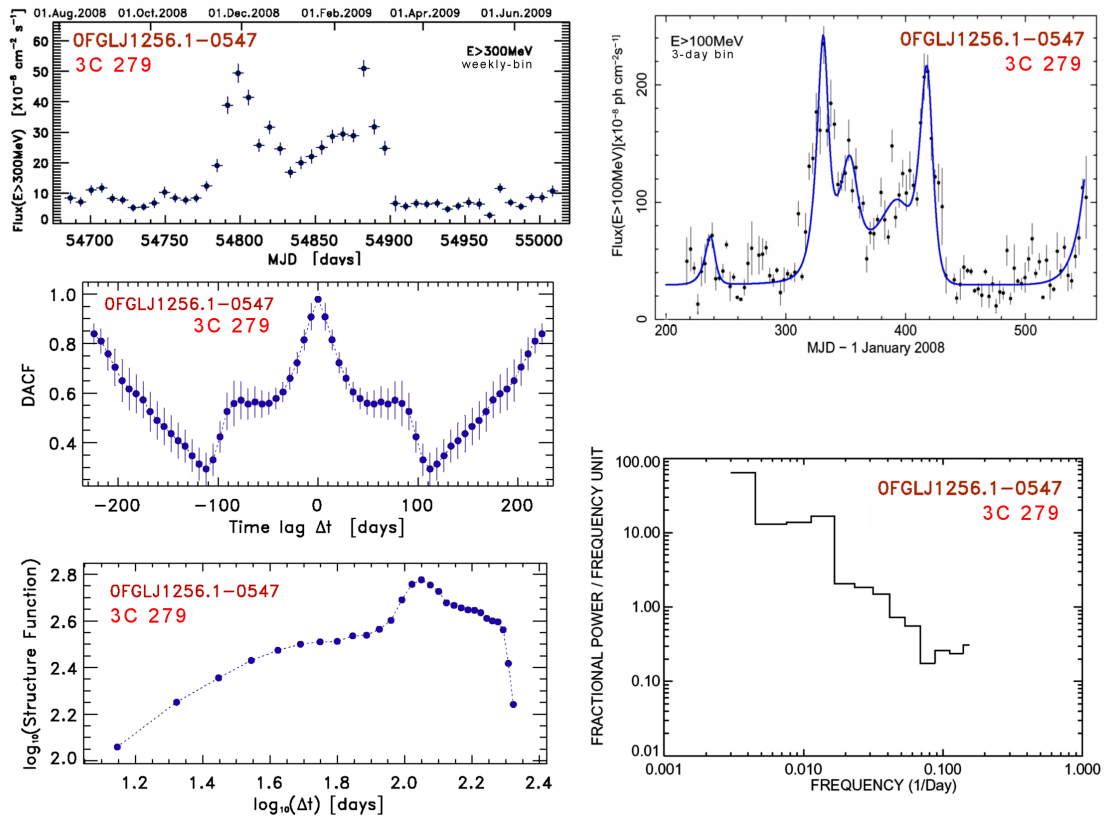

Figure 2: *Left panels from top to bottom*: weekly bin flux ($E > 300$ MeV) light curve of the blazar 3C 279 obtained with the same method of the light curves in Figure 1; corresponding discrete autocorrelation function, and corresponding first order structure function. *Right panels from top to bottom*: 3-day bin flux ($E > 100$ MeV) light curve of 3C 279 with a superposed functional shape fitting and corresponding power density spectrum (PDS) reporting the fractional power over the temporal frequency unit.

the MOJAVE program), Owens Valley (OVRO) 40m, Effelsberg-100m, Metsähovi-14m, RATAN-600 and Kanata-Hiroshima radio/optical observations. Results from the analysis of archival observations by INTEGRAL, XMM-*Newton* and *Spitzer* space telescopes are reported for a more complete picture of this new gamma-ray blazar (Figure 3). In [8] is available the only previous multifrequency analysis (radio to X-ray) of this blazar.

The sky region containing PKS 1502+106 was observed already in the past by INTEGRAL IBIS (83ks, between Jan. 25 and Jan. 27, 2006), and a new soft γ-ray source (IGR J15039+1022) was detected with a flux density of 1.6 mCrab in the 18-60 keV energy range (corresponding to 1.2×10^{-11} erg cm^{-2} s^{-1}). This IBIS source was identified with Mkn 841, a Seyfert galaxy known to display a well detected high energy cut-off around 100 keV making it unlikely to emit in the γ-ray domain. The angular distance of PKS 1502+106 from IGR J15039+1022, $\sim 11'$, points to a clear non-detection during this Jan. 2006 INTEGRAL observation (Figure 4 right panel). A 2σ upper limit for PKS 1502+106 of 0.7 mCrab in the range 18-60 keV (0.52×10^{-11} erg cm^{-2} s^{-1}) is inferred [9]. Furthermore, following the announcement of the *Fermi* LAT outburst in PKS 1502+106 [7], a fast response ToO pointing by INTEGRAL was performed soon after the trigger (200ks of observation between Aug. 09-11, 2008, INTEGRAL revolution 711), but the blazar was not clearly detected as well (Figure 4 left panel, and [6]).

PKS 1502+106 is a sub-GeV peaked, powerful flat spectrum radio quasar (FSRQ) with gamma-

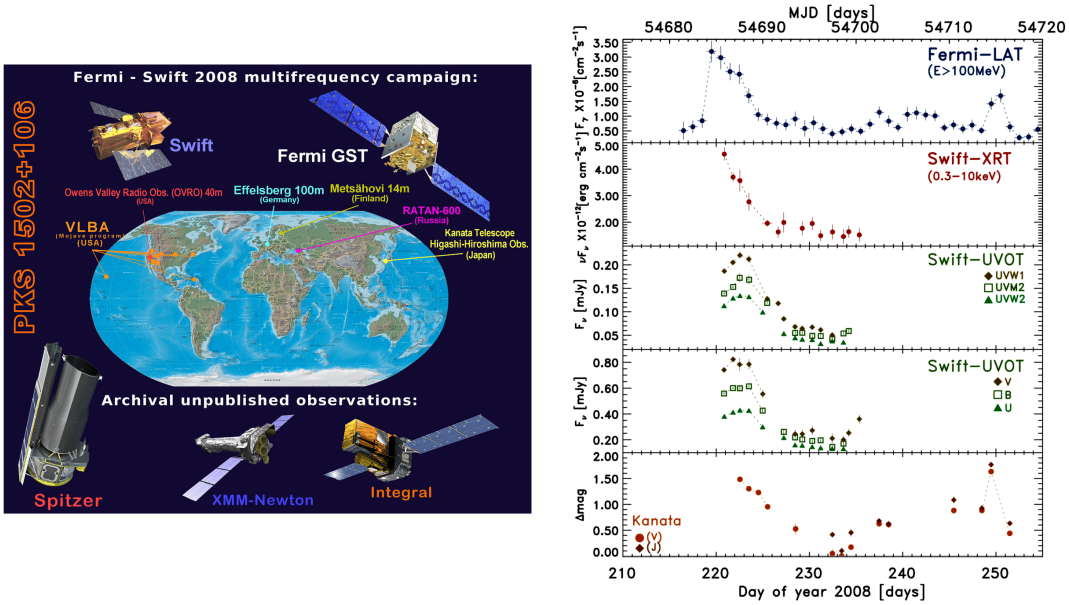

Figure 3: *Left panel*: a pictorial view of the participant facilities to the multi-frequency *Fermi-Swift* campaign on PKS 1502+106, involving the ground-based Owens Valley Radio Observatory (OVRO), USA, the Effelsberg 100m dish radio telescope, Bonn, Germany, the ring radio telescope RATAN-600, Russia, the 13.7m Metsähovi radio telescope of the Helsinki University of Technology, the VLBA within the MOJAVE program, and the Kanata telescope of the Higashi-Hiroshima Observatory. Data from past archival and unpublished observations of PKS 1502+106 by Spitzer, XMM-Newton and Integral (bottom of the figure) are also analyzed in the paper devoted to this campaign [4]. *Right panel*: Simultaneous gamma-ray, X-ray and optical-UV light curves of PKS 1502+106 obtained during the coordinated multiwavelength campaign of August 2008. Data obtained by *Fermi*-LAT, *Swift*-XRT, *Swift*-UVOT, and Kanata-TRISPEC observatories.

ray luminosity at $E > 100$ MeV of about 1.1×10^{49} erg s^{-1}, and black hole mass likely close to 10^9 M$_\odot$). The asymmetric outburst PKS 1502+106 exhibited marked gamma-ray bolometric dominance ($L_\gamma / L_{opt} \sim 100$, and 5-day averaged flux $F_{E>100\,\mathrm{MeV}} = 2.91 \pm 1.4 \times 10^{-6}$ ph cm^{-2} s^{-1}), and was characterized by a factor greater than 3 of flux increase in less than 12 hours. The outburst was observed simultaneously from optical to X-ray bands (Figure 3). The properties of PKS 1502+106 and the optical/UV, X- and gamma-ray cross correlations suggest the contribution of the synchrotron self Compton (SSC), in-jet, process should dominate from radio to X-rays. This mechanism may also be responsible for the consistent gamma-ray variability observed by the LAT on longer timescales, after the ignition of activity at these energies provided by the BLR-dissipated (external-Compton) outburst. Modulations and subsequent minor, rapid flare events were detected in the following months. The averaged gamma-ray spectrum over 4 months showed a deviation from a simple power-law, and can be described by a log-parabola curved model peaking around 0.4-0.5 GeV (Figure 4). The maximum energy of photons detected in this period applying a strict PSF criterium was 15.8 GeV, with no significant consequences on extragalactic background light predictions. A possible radio counterpart of the gamma-ray outburst can be assumed only if a delay of more than 3 months is considered on the basis of opacity effects at cm and longer wavelengths.

Fermi LAT performance in blazar science (as a stand alone observatory, or leading instrument for multifrequency campaigns), and the synergy between *Fermi* and *Swift* in particular, is evidenced by the campaign performed on PKS 1502+106. By itself, this blazar is emerging as a major, luminous, energetic and highly gamma-ray variable source, providing the possibility to deep study

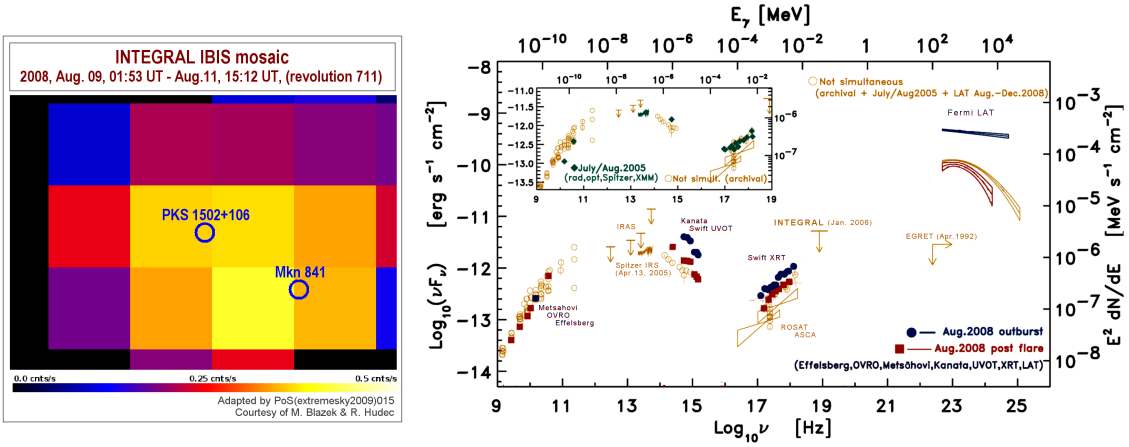

Figure 4: *Left panel*: INTEGRAL IBIS mosaic image following the trigger of the PKS 1502-106 gamma-ray outburst discovered by *Fermi* LAT. INTEGRAL performed a fast response ToO observation of 200ks between Aug. 09-11, 2008 (revolution 711) of the region around PKS 1502+106. The blazar was not clearly detected like in Jan. 2006 [9, 6]). *Right panel*: overall radio-to-gamma-ray spectral energy distribution (SED) of PKS 1502+106 assembled with data of the *Fermi-Swift* multifrequency campaign of August 2008. The two representative, time-averaged phases, the outburst state (2008, Aug. 05-10) and the post-flare (intermediate brightness) state (2008, Aug. 11-22) are reported. High Compton dominance and gamma-ray bolometric luminosity during the outburst state is evident. An upper limit by the INTEGRAL IBIS observations of 2006, Jan.25-27 is also reported. In the inset panel a 2-month averaged (July-August 2005) SED assembled in particular with XMM-Newton and Spitzer IRS unpublished archival observations is reported.

emission models, spectral and temporal variability and the connection among radio and gamma-ray frequency ranges. More details in [4].

4. Acknowledgements

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