Study of the Classical TeV blazar Mrk421 with Fermi

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on behalf of the Fermi Large Area Telescope Collaboration
and the instruments/people participating on the Mrk421 MW campaign

Summary:

•**First continuous monitoring of the 1-year gamma-ray activity from the TeV blazar Mrk421 with Fermi.**

•**Most complete Spectral Energy Distribution from radio to TeV, which includes the unprecedented coverage of the high energy bump from 0.1 GeV to almost 10 TeV without energy gaps**

Abstract

Despite High Synchrotron Peaked BL Lacs (BL Lac-HSP) being observed for tens of years, the existing experimental data set is not sufficient to unambiguously identify the physical mechanisms responsible for the electromagnetic emission. The Fermi-LAT instrument, which started operation in August 2008, provides continuous source coverage with high sensitivity in the band 0.1-100 GeV, which is rather unexplored for BL Lac-HSP and hence it is meant to play a key role in understanding the high energy emission in these objects.

In this contribution we report on the Fermi-LAT observation of the classical TeV blazar Markarian 421 (Mrk421), which provides, for the first time, a continuous monitoring of the 1-year gamma-ray activity of this source. In addition, we also show results from the multi-frequency (radio to TeV) observations performed within the almost 5 months long campaign that we organized on this object from January to June 2009. During this campaign we collected the most complete simultaneous multi-frequency data set from Mrk421 to date. One of the most interesting results is the unprecedented coverage of the high energy bump from 0.1 GeV to almost 10 TeV without energy gaps, which could be achieved by combining the spectra of the Fermi-LAT and MAGIC Telescope. The implications of this exquisite data set for the models describing the gamma emission from blazars are briefly described.

1 – We do NOT know how blazars work

Culprits for the relatively poor knowledge of these objects

1 - Time-evolving broad band spectra

Coordination of instruments covering different energies needed

2 - Poor sensitivity to study the high-energy part (E>0.1 GeV)

Large observation times (with EGRET and "old" IACTs) were required for signal detection *Data NOT simultaneous*, and *most of the knowledge we have on BL Lac-HSP relates to the high state*

Recently, we had two "performance jumps" with respect to the past:

New Generation of IACTs online since ~4 years (low E_{th}, high sensitivity)

LAT in operation since almost 1 year (~30 times more sensitive than EGRET)

~100 times more sensitive at E>~10 GeV

Enhanced observational capability can be used to improve our knowledge on BL Lac-HSPs

2- Motivation to observe (again) Mrk421

Exquisite characterization of the high energy component, which can be detected with Fermi and Cherenkov Telescopes (20 MeV – 20 TeV)

Excellent laboratory for studying High Energy blazar emission

Bright gamma ray source && nearby object (z=0.031)
"low" EBL absorption→ we see "almost" intrinsic features

Knowledge acquired with Mrk421 could (in principle) be applied to other objects (fainter and/or larger z)

Things we know about Mrk421 (and BL Lac-HSPs in general)

Dominant gamma-ray emission mechanism is believed to have a leptonic origin (SSC) , at least in high (flaring) state

- Fast variations (down to hours and sub-hours in VHE)
- X rays- Gamma-rays correlation (in general)

3 – Multi-frequency campaign on Mrk421

•**4.5 months long (Jan 20th – June 1st , 2009)**
•**19 instruments participated covering frequencies from radio to TeV**
•**2-day sampling at optical/X-ray and TeV (when possible*; breaks due to moon, weahter…*)**

Observations performed/planned during the MW campaign available on the web

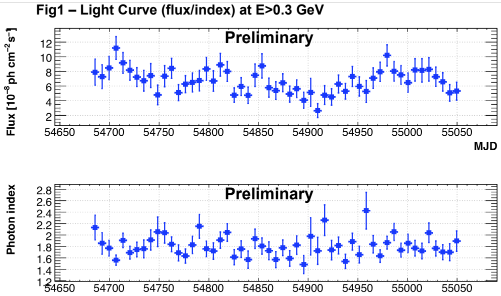
http://www.slac.stanford.edu/~dpaneque/MW_Mrk421_2009/Obs.html

Date	MJD	Radio	Optical	X-ray	Gamma-ray	VHE	Other
2009/01/19	54850	------	**GRT**; --- / ---	------	**Fermi-LAT**; 00:00 / 23:59	------	------
			MITSuMe; 15:16 / 15:32				
			GASP; 05:36 / ---				
2009/01/20	54851	------	**GRT**; 08:20 / 08:21	**RXTE**; 02:19 / 02:47	**Fermi-LAT**; 00:00 / 23:59	**MAGIC**; --- / ---	------
			GASP; 21:10 / ---			**Whipple**; 08:27 / 08:54	
2009/01/21	54852	**OVRO**; 06:35 / 06:36	**GRT**; 08:15 / 08:16	------	**Fermi-LAT**; 00:00 / 23:59	------	------
			GASP; 17:44 / ---				
2009/01/22	54853	**OVRO**; 07:00 / 07:01	**GRT**; --- / ---	**RXTE**; 02:58 / 03:23	**Fermi-LAT**; 00:00 / 23:59	**MAGIC**; 01:48 / 03:45	------
			GASP; 16:39 / ---				
2009/01/23	54854	------	**GRT**; 08:08 / 08:09	------	**Fermi-LAT**; 00:00 / 23:59	------	------
			MITSuMe; 14:54 / 15:05				
			GASP; 04:59 / ---				
2009/01/24	54855	------	**GRT**; --- / ---	**RXTE**; 02:02 / 02:28	**Fermi-LAT**; 00:00 / 23:59	**MAGIC**; 01:37 / 03:39	------
			MITSuMe; 14:55 / 15:06				
2009/01/25	54856	**OVRO**; 06:21 / 06:22	**GRT**; 08:00 / 08:01	------	**Fermi-LAT**; 00:00 / 23:59	**Whipple**; 07:59 / 11:51	------
			MITSuMe; 14:55 / 15:06				
			GASP; 04:50 / ---				
2009/01/26	54857	------	**GRT**; --- / ---	**RXTE**; 02:43 / 03:07	**Fermi-LAT**; 00:00 / 23:59	**MAGIC**; 01:31 / 02:48	------
			MITSuMe; 14:47 / 15:03				
2009/01/27	54858	------	**GRT**; --- / ---	**Swift-XRT**; 12:11 / ---	**Fermi-LAT**; 00:00 / 23:59	**Whipple**; 09:23 / 10:29	------

Observations and preliminary fluxes updated once/twice a week
Different instruments could plan ahead when to observe the source
Request additional observations if source shows outstanding activity

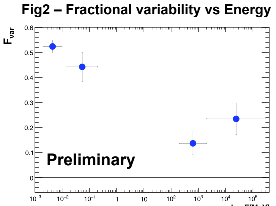
4 – Unprecedented 1-year monitoring of gamma-ray activity

Fig1 – Light Curve (flux/index) at E>0.3 GeV



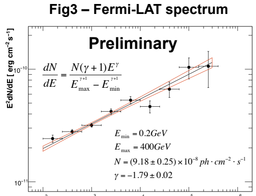
Gamma-ray flux at E>0.3 GeV (top) and spectral photon index from a Power Law fit (bottom) from Mrk421 for weekly time intervals from August 4th 2008 to August 10th 2009. Vertical bars denote 1 sigma uncertainties and the horizontal error bars denote the width of the time interval.
Mrk421 showed very little activity at gamma-rays during this period of time.

Fig2 – Fractional variability vs Energy



Fractional variability parameter for 1 year data (Aug4,2008-Aug10 2009) from 3 all-sky-monitoring instruments: RXTE/ASM (2-10 keV); Swift/BAT (15-200 keV) and Fermi/LAT for 2 energy ranges 0.2-2 GeV and 2-300 GeV. The fractional variability was computed according to Vaughan et al. (2003). Vertical bars denote 1 uncertainties and horizontal bars indicate the width of each energy bin.
X-rays varied more than gamma-rays during this time interval

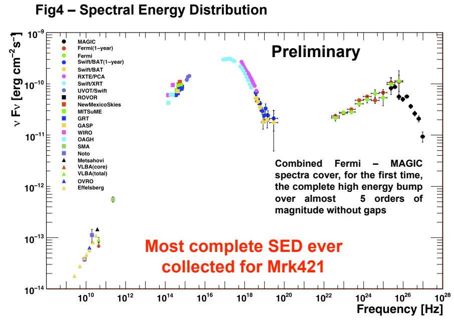
Fig3 – Fermi-LAT spectrum



Fermi-LAT spectrum of Mrk421 during the period Aug4th 2008 to Aug13 2009. Black line is the likelihood PL fit; red contour is the 68% uncertainty of the fit and the black data points show the energy fluxes computed on differential energy ranges.
The Fermi spectrum can be described by pure power law with photon index 1.79 +/-0.02

5 – SED from the 4.5 months long MW campaign

Fig4 – Spectral Energy Distribution



Spectral energy distribution of Mrk421 averaged over all the observations taken during the multi-frequency campaign on 2009 (Jan20-Jun01). The inlay reports the correspondence between the instruments and the measured fluxes. The host galaxy has been subtracted, and optical/X-ray data were corrected for the galactic extinction. The TeV data from MAGIC were corrected for the absorption in the Extragalactic Background Light using Franceschini et al 2008

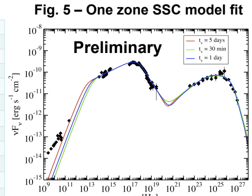
6 – Modeling/interpretation

Low activity shown by Mrk421 during last year points to a low/quiescent state

The SED was modeled as prescribed in Finke, Dermer, & Boettcher, 2008, ApJ, 686, 181

t_var	5 days	1 day	30 min
B [G]	3.2e-2	5.9e-2	0.14
delta	12.4	18.0	53.7
Γ	12.4	18.0	53.7
γ_{min}	2.e3	2.e3	1.e3
γ_{brk}	5.1e5	3.2e5	1.2e5
γ_{max}	1.e7	1.e7	1.e7
p_1	2.5	2.5	2.5
p_2	4.6	4.6	4.6
L_jet_B [erg/s]	3.1e43	1.7e43	3.2e42
L_jet_elect. [erg/s]	1.3e44	8.7e43	6.4e43
L_jet_prot. [erg/s]	1.3e45	8.7e44	6.4e44
Radius [cm]	1.6e17	4.5e16	2.8e15

Fig. 5 – One zone SSC model fit



One-zone SSC models can describe the overall SED

In both the synchrotron and the SSC components, the spectrum continues as a power law at energies above which the νF_ν spectrum peaks, and also shows a change Δα in spectral index that is greater than the canonical value Δα =0.5 expected from radiative cooling (the break is Δα ≈ 1 for both components). The break appears approximately at the frequency that is expected due to radiative cooling, but is larger than expected. This can be the result of magnetic field or flow velocity gradients, with particle acceleration preferentially taking place in the faster/higher magnetic field parts of the flow. The observed breaks and the study of multi-frequency variability of the source can provide us with unique constraints on the jet structure.

7 - Conclusions

Fermi operates survey mode since beginning of August, boosting our current capabilities to study AGNs.

Uniform exposure
Coverage of 20% sky at any time
Large effective area, small PSF …

In-depth study of individual sources is important to understand the physical processes occurring in those objects

Study of the classical (bright) TeV sources has the advantage that, together with the IACTs, Fermi data constrain the high energy bump
- Fermi data opens a "new window" to study those objects
→ Spectra reaching energies beyond 0.1 TeV; overlap with IACTs
- Collection of MW data is ESSENTIAL for understanding those complex objects.

We are collecting an exquisite data set that will surely help us to understand Mrk421, and the blazar phenomenon in general. In this poster we report on the results from Mrk421. We organized similar campaigns for Mrk501 and 1es1959+650

Mrk421 was found in a rather low/quiet state from August 2008 to August 2009. During this time interval, the variability at X-rays was found to be larger than that at gamma-rays, which would be consistent with flux variations produced by injection of fresh (high energy) particles.

The MW data collected during 4.5 month long campaign allowed us to produce the most complete SED ever determined for Mrk421. This SED, which for this time interval represents the quiescent state of Mrk421, can be described with simple one-zone SSC models. *Further details on Mrk421 will be found on a dedicated forthcoming publication.*