Extensive Multifrequency Campaigns on the Classical TeV Blazars Mrk421 and Mrk501 in the Fermi Era

David Paneque, L.Stawarz, J.Finke, M. Georganopoulos, A.Reimer and D.Tescaro
On behalf of the Fermi, MAGIC, VERITAS collaborations and the participants/groups of the MW campaigns on Mrk421 and Mrk501 in 2009, which include GASP-WEBT, F-GAMMA and many others

Summary:

We are performing an unprecedentedly long and dense monitoring of the multifrequency (radio to TeV) emission from the classical TeV blazars Mrk 421 and Mrk 501. These objects are among the brightest X-ray/TeV blazars in the sky and among the few sources whose Spectral Energy Distributions (SED) can be almost completely characterized by the current instruments. This is a multi-year, multi-instrument program involving the participation of VLBA, Swift, RXTE, MAGIC, VERITAS, Whipple, F-GAMMA, GASP-WEBT, and other collaborations and instruments which provide the most detailed temporal and energy coverage of these sources to date. In this conference, we report on some of the results we obtained with the multifrequency data from 2009. We show that, when Mrk421 and Mrk501 are in low states, their SEDs are very comparable and can be similarly modeled in the framework of a 1-zone Synchrotron self-Compton scenario with an electron energy distribution parameterized by three power laws with two breaks (in the electron energy distribution) at roughly the same energies, and a size of the emitting region comparable to the size of the partially resolved VLBA radio core.

1 – We do NOT know well 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)

Long observation times (with EGRET and "old" IACTs) were needed for signal detection *Data NOT simultaneous*, and *most of the knowledge we* have on High Synchrotron Peaked BL Lac (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 ~7 years (low E_{th}, high sensitivity)

LAT in operation since ~3 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-HSP

2- Motivation to observe (again) Mrk421 and Mrk501

Exquisite characterization of the high energy component, which can be detected with Fermi and Cherenkov Telescopes over 5 orders of magnitude (0.1 GeV – 10 TeV)

Excellent laboratory for studying High Energy blazar emission

Strong gamma ray source &
Nearby object; z = 0.03; "low" EBL absorption, we see "almost" intrinsic features

Knowledge acquired with Mrk421 and Mrk501 might be applied to other objects (fainter and/or larger z). *Or maybe not… some sources might be special. CAVEAT (!!)*

Things we know about those classical TeV sources (and HBLs 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 correlated (in general)**

3 – Campaigns on Mrk421 and Mrk501

In general, blazars emit over a **broad energy range + emission is variable.**
→ Contemporaneous multi-instrument observations are required to study them

We organized extensive campaigns on Mrk421 and Mrk501

Mrk421 (Jan19th, 2009-Jun1st ,2009: 4.5 months)
https://confluence.slac.stanford.edu/display/GLAMCOG/Campaign+on+Mrk421+(Jan+2009+to+May+2009

Mrk501 (Mar15th, 2009-Aug1st,2009: 4.5 months)
https://confluence.slac.stanford.edu/display/GLAMCOG/Campaign+on+Mrk501+(March+2009+to+July+2009

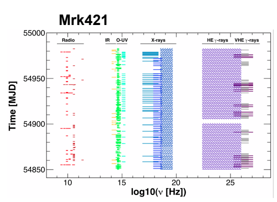
Source monitored regardless of activity

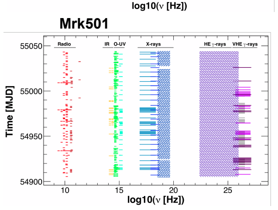
•25ish instruments participated covering frequencies from radio to TeV

Radio: VLBA, OVRO, Effelsberg, Metsahovi…
mm: SMA
Infrared: WIRO, OAGH
Optical: GASP, GRT, MITSuMe ..
UV: Swift-UVOT
X-ray: Swift-XRT, RXTE-PCA, Swift/BAT
Gamma-ray: Fermi-LAT
VHE: MAGIC, VERITAS, Whipple

4 – Results obtained for Mrk501 (*Abdo, A. A. et al. 2011, ApJ, 727, 129*) and Mrk421 (*Abdo, A. A.* submitted to ApJ)

4.1 – Time and energy coverage





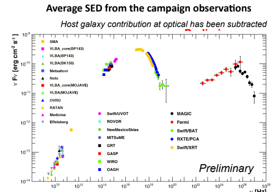
Most complete Time & Energy coverage of Mrk421 and Mrk501 to date

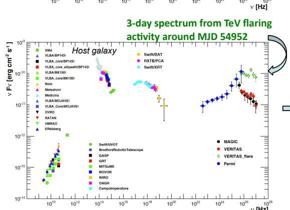
Collected data can be used as a robust representation of the SED

Reliable interpretation of the SED (!!)

4.2 – Spectral Energy Distribution (SED)

Average SED from the campaign observations





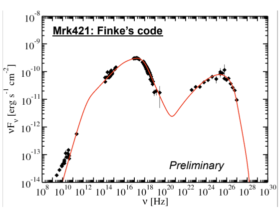
Fermi+MAGIC/VERITAS spectra cover, for the first time, the complete high energy component over 5 orders of magnitude without gaps

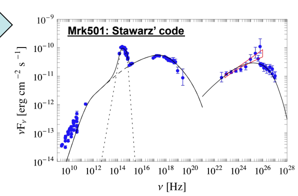
Both sources were found in relatively quiescent state with low variability. Agreement in overlapping energies among instruments (with different time coverage) indicates that we managed to get the true average SED of Mrk421 and Mrk501 during the 4.5 months campaign. The VHE spectra was EBL corrected using Franceschini et al 2008

4.3 – SED modeling with 1-zone Synchrotron self-Compton scenario

Two breaks in the electron energy distribution are required to fit the data

$$n'_e(\gamma) \propto \begin{cases} \gamma^{-s_1} & \text{for} \quad \gamma_{min} \leq \gamma < \gamma_{br,1} \\ \gamma^{-s_2} & \text{for} \quad \gamma_{br,1} \leq \gamma < \gamma_{br,2} \\ \gamma^{-s_3}\exp\left[-\gamma/\gamma_{max}\right] & \text{for} \quad \gamma_{br,2} \leq \gamma \end{cases}$$





Mrk501: Stawarz' code

R [cm]	1.3e17
B [G]	1.5e-2
delta	12.0
η_e	56
γ_{min}	600
s1	2.2
γ_{brk_1}	4.e4
s2	2.7
γ_{brk_2}	9.e5
s3	3.7
γ_{max}	1.5e7

Mrk421: Finke's code

R [cm]	5.2e16
B [G]	3.8e-2
delta	21.0
η_e	10
γ_{min}	800
s1	2.2
γ_{brk_1}	5.e4
s2	2.7
γ_{brk_2}	3.9e5
s3	4.7
γ_{max}	1.0e8

Similar model parameters for Mrk421 and Mrk501 (both during relatively low activity)
→ *Size of emitting region is comparable with the partially resolved VLBA core*

Mrk501: 0.15 mas ~ 3e17 cm → 3 times the size of the SSC blob
Mrk421: 0.06-0.12 mas ~ 1 – 2 e17 cm → 2 – 4 times the size of the SSC blob
Have we found the location of blazar emission for these objects ?

→ *First break intrinsic to electron distribution, second break is probably due to cooling*

Is it by chance that we find very comparable modeling parameters ? Or are we dealing with some common properties for these 2 objects ? In case these are common properties of Mrk421 and Mrk501 in quiescent state, can we extrapolate this behaviour to other HSP - BL Lacs ??

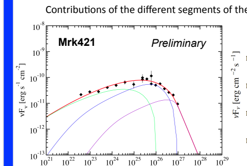
High γ_{min} and s1=2.2 is consistent with the models of diffuse (1st order Fermi) particle acceleration in relativistic, proton-mediated shocks

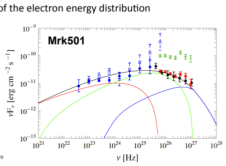
Efficient acceleration for electrons above γ_{min} = 600-800

4.4 – Discussion: High Energy Component

Close look to the high energy component of Mrk421 and Mrk501

Contributions of the different segments of the electron energy distribution





green	$\gamma_{min} < \gamma < \gamma_{br,1}$	↔	red	$\gamma_{min} < \gamma < \gamma_{br,1}$
blue	$\gamma_{br,1} < \gamma < \gamma_{br,2}$	↔	green	$\gamma_{br,1} < \gamma < \gamma_{br,2}$
purple	$\gamma_{br,2} < \gamma$ (emit at $\nu > 10^{17}$ Hz)	↔	blue	$\gamma_{br,2} < \gamma$ (emit at $\nu > 10^{17}$ Hz)

Electrons above $\gamma_{br,2}$ emit X-rays

The electrons above 2nd break are responsible for the X-rays, and electrons above 1st and 2nd break responsible for the TeV emission
→ Correlation X-ray/TeV must exist but the relation is NOT trivial
MeV/GeV Fermi photons produced mostly by electrons BELOW 1st break

5 – Summary of the results

The MW data collected during 4.5 month long campaigns allowed us to produce the most complete SED ever measured for both Mrk501 and Mrk421

→ **includes the full coverage of the γ-ray component.**
→ ***Both sources were in relatively low/quiescent states.***

The SED can be described with a 1-zone SSC model with an electron distribution with 2 breaks:
break Internal to particle acceleration (20 GeV and 25 GeV electron energies for Mrk501 and Mrk421)
break related to synchrotron cooling (500 GeV and 180 GeV electron energies for Mrk501 and Mrk421)

Electron distribution consistent with being produced through 1st order Fermi acceleration in relativistic, proton-mediated shocks
X-ray produced mostly by electrons above 2nd break
TeV dominated by electrons above 1st and 2nd break
MeV/GeV (Fermi) produced mostly by electrons below 1st break, but also above 1st break

Similar SED modeling parameters for Mrk421 and Mrk501: is it by chance ?? Or is it a common property of these two objects ?
→ Can we extend this behaviour to other HSP-BL Lacs ??

6 – Conclusions and outlook

Study of the classical (bright) TeV sources has the advantage that, Fermi+IACTs can strongly constrain the high energy component
- Fermi data open a "new window" to study those objects
→ Spectra reaching E>0.1 TeV; overlap with IACTs
- Collection of MW data is ESSENTIAL for understanding these complex objects.

This presentation shows "first" results from the 2009 MW campaigns on Mrk421/Mrk501. Work ongoing to extract further results from these MW campaigns from 2009, as well as from the campaigns we had in 2010.

This is a multi-instrument and multi-year effort:
Extensive (6 months) campaigns were done in 2010 and are ongoing in 2011 for Mrk421 and Mrk501. Stay tuned for new results.