Asociación Argentina de Astronomía
BAAA, Vol. 53, 2010
J.J. Clariá, M.V. Alonso, A.E. Piatti & F.A. Bareilles, eds.

PRESENTACIÓN ORAL

Multi-wavelength observations of Mrk 501 during a very high energy flare in May 2009

A. Pichel[1], A. N. Cillis[1] & D. Paneque[2]

(1) Instituto de Astronomía y Física del Espacio (CONICET-UBA), Argentina
(2) W. W. Hansen Experimental Physics Laboratory, Kavli Institute for Particle Astrophysics and Cosmology, Department of Physics and SLAC National Accelerator Laboratory, Stanford University, Standford, USA

Abstract. The very high energy (E > 100 GeV) blazar Mrk 501 was observed between April 17 and May 5, 2009, as part of a 4.5-month-long multi-wavelength campaign from radio to TeV band. This source has a history of spectral variability with extreme outbursts. On the night of May 1, Mrk 501 showed a brief period of activity with a high luminosity flare reaching the level of ∼5 Crabs at very high energy gamma rays, showing a fast variability with an increased of a factor of 4 in 30 minutes and no evidence of correlation with other frequencies. During the next three days after the flare the source remained in high state. We present here the results with the Whipple 10-m telescope, VERITAS, the Fermi Large Area Telescope, Swift and RXTE for the quiescent and high-state observations that were performed within the framework of the organized campaign.

Resumen. El blazar Mrk 501 fue observado desde el 17 abril hasta el 5 de mayo de 2009, como parte de una campaña multi frecuencia de 4.5 meses de duración, que va desde observaciones en radio hasta muy altas energías en rayos gamma. Este blazar ha presentado episodios de variabilidad y de mucha actividad en períodos de tiempo muy cortos en el pasado. En la noche del primero de mayo, Mrk 501 presentó un episodio de mucha actividad detectado a muy altas energías, alcanzando una intensidad máxima de 5 Crab sin evidente correlación a otras frecuencias. Este episodio presentó una rápida variabilidad, mostrando un incremento en el flujo de un factor 4 en 30 minutos. Durante los siguientes 3 días la fuente permaneció en un estado de alta actividad. Se presentan en este trabajo los resultados para el estado de baja y alta actividad de las observaciones realizadas con el telescopio Whipple, VERITAS, Fermi, RXTE y Swift realizadas como parte de la campaña.

1. Introduction

Blazars are a subclass of Active Galactic Nuclei (AGN) where the angle of the jet with respect to our line of sight is small (<10°). These objects are amongst the most powerful astronomical sources known at present. They have high lu-

minosity and are characterized by a rapid and irregular variability in several spectral bands. Fast flaring events at high energies are produced in a relatively compact internal zone of the system. Observations of known blazars in several wavelength bands from radio to TeV energies are very important, to discern between emission models and explain the geometry and structure of the jet.

Mrk 501 was the second extragalactic source detected in 1996 by the Whipple Telescope (Quinn et al. 1996). Since then, several multi-wavelength campaigns were undertaken, most of them in its high state of activity. Also, a large number of flares were observed in all wavelength bands, the most important was the 1997 flare that reached 10 Crabs (Catanese et al. 1997, Pian et al. 1998). Also in 2005 MAGIC detected a very high energy (VHE) flare with flux variations over 20 minutes and flux-doubling times below 5 minutes (Albert et al. 2007).

We report here observations of Mrk 501 taken with Whipple (Kildea et al. 2007), VERITAS (Maier et al. 2007), Fermi (Atwood et al. 2009) Swift and RXTE in 2009 as a part of the large scale multi-wavelength campaign (Abdo et al. 2011), joined by a number of ground-based and space experiments from radio to VHE γ-rays. The correlated analysis of the Fermi LAT, Whipple and VERITAS data taken during 2009 observational season is currently ongoing and it will be presented elsewhere.

2. Results and discussion

Mrk 501 was observed with the Whipple telescope every night between April 17 and May 5 of 2009, for a total of 20 hours. VERITAS took observations during that period for 4 hours (Huang et al. 2009). The observations were made with two telescopes, during the nights of April 30 and May 1, and the rest of the nights with three telescopes due to hardware issues leaving two or three operational telescopes from the full four telescope array. Light curves were produced for each instrument involved in the campaign to better understand the behavior of the flux variability of Mrk 501. In the VHE γ-ray band, the source was found to be variable. That is evident from the light curve shown in Figure 1. The light curves from Fermi at the γ-ray band and Swift and RXTE in the X-ray band are also plotted in Figure 1.

Until the night of May 1 (MJD 54952) the light curve is consistent with the constant baseline emission of the source (3.9×10^{-11} ph cm^{-2} s^{-1}). On May 1 a high-emission state was detected with Whipple and VERITAS. The maximum γ-ray flux observed during the flare was a factor of 10 higher than the average baseline flux, approximately 5 Crabs. Figure 2 shows the Whipple 10-m light curve for May 01, 2009 where each point corresponds to a bin time of 4 minutes. The flux increased by a factor of 4 in the first 30 minutes. The days after the flare (May 2-4), the source continued in high state, and the flux increased a factor of $\sim$2 from the baseline flux for each night. During the VHE flare there were no simultaneous observations from other wavelengths, but there were contemporaneous observations with Swift where the error is too big to make an indication of a correlation between both bands. From the night of the flare and the next three days, Swift showed an increase of a factor of 2 from the baseline flux in the lower and higher band. A more extensive study will be reported on a forthcoming publication with these data.

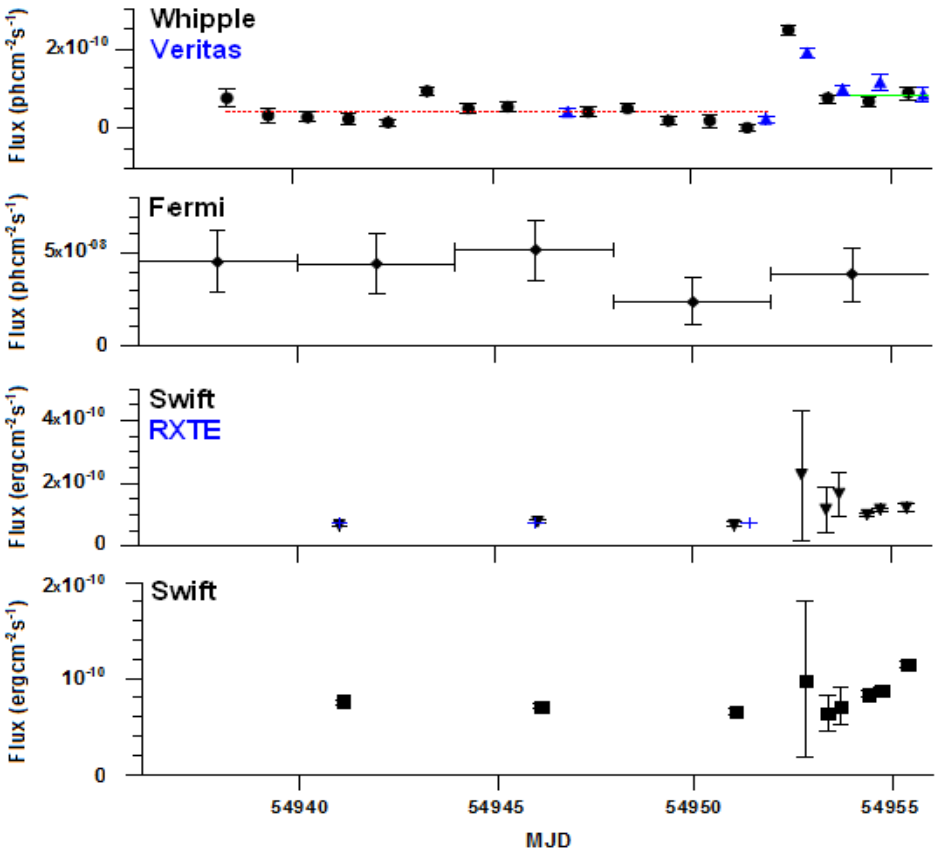

Figure 1. Light curve for Mrk 501 from April 17 to May 5, 2009 with *Upper panel*: VHE gamma rays: Whipple (E > 400 GeV) and VERITAS (E > 300 GeV) in a nightly average rate. The red dotted line is the baseline flux before the flare, the green line is the same after the flare; *Second panel*: HE gamma-ray: Fermi LAT (E > 300 MeV) in a 5-day average rate; *Third panel*: X-ray: RXTE and Swift 2-10 keV in a nightly average rate; *Bottom*: X-ray: Swift 0.3-2 keV in a nightly average rate.

Evolution of the TeV energy spectrum across the short-time flaring state of Mrk 501 is of great importance for understanding the mechanism of particle acceleration in a blazar source. The differential energy spectra of Mrk 501 (see Figure 3) was moleded for the quiescent emission and for the flare state with a simple power law:

$$\frac{dN}{dx} = F_0 \times 10^{-7} \ (E/1 \text{ TeV})^{-\Gamma_{\rm VHE}} \quad \text{photons m}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$$

For the Whipple analysis, best fit parameters of $\Gamma_{\rm VHE} = (2.61 \pm 0.01)$ and $F_0 = (1.16 \pm 0.09)$ were found for the low state. And for the high state the best fit parameters were $\Gamma_{\rm VHE} = (2.3 \pm 0.1)$ and $F_0 = (5.6 \pm 0.4)$.

Clear indications for spectral hardening with increasing flux activity are found in the TeV band. A similar trend had already been found in earlier observations of a flare measured by MAGIC (Albert et al. 2007).

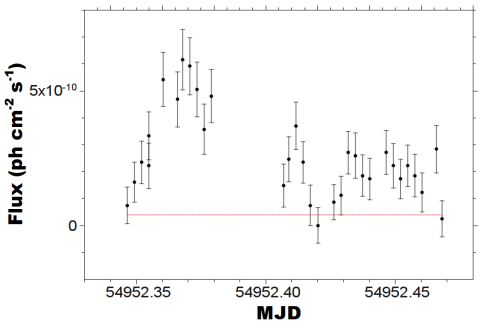

Figure 2. Light curve for the night of the VHE flare, May 1 2009 (Whipple). The dotted line is the baseline for the period excluding the flare.

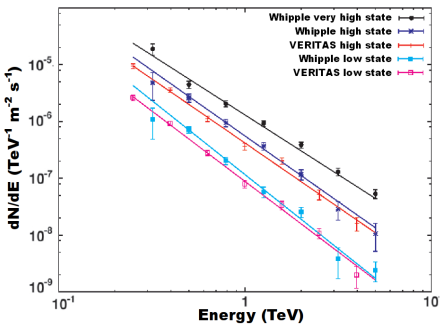

Figure 3. Time-averaged VERITAS and Whipple photon spectra of Mrk 501 for discrete flux levels (see text).

A more detailed report of these results, including additional data at lower energies, will be done on a forthcoming publication.

3. Acknowledgments

This research is supported by grants from the US Department of Energy, the US National Science Foundation, and the Smithsonian Institution, by NSERC in Canada, by Science Foundation Ireland, and by STFC in the UK. We acknowledge the excellent work of the technical support staff at the FLWO and the collaborating institutions in the construction and operation of the instrument. The *Fermi* LAT Collaboration acknowledges support from a number of agencies and institutes for both development and the operation of the LAT as well as scientific data analysis. These include NASA and DOE in the United States, CEA/Irfu and IN2P3/CNRS in France, ASI and INFN in Italy, MEXT, KEK, and JAXA in Japan, and the K. A. Wallenberg Foundation, the Swedish Research Council and the National Space Board in Sweden. Additional support from INAF in Italy and CNES in France for science analysis during the operations phase is also gratefully acknowledged.

References

Abdo, A.A et al. 2011, ApJ 727, 129
Albert, J. et al. 2007, ApJ 669, 862
Atwood, W. B. et al. 2009, ApJ, 697, 1071
Catanese, M. et al. 1997, ApJ, 487, L143
Huang, D. et al. 2009, Proceedings of the Fermi Symposium, Washington, D.C.
Kildea, J. et al. 2007, Astroparticle Physics, 28, 182
Maier, G. et al. 2007, Proceedings of the 30 th ICRC, Merida
Pian, E. et al. 1998, ApJ, 492, L17
Quinn, J. et al. 1996, ApJ, 456, L83