Hourly Spectral Variability of Mrk 421

F. Krennrich[1,2], I.H. Bond, P.J. Boyle, S.M. Bradbury, J.H. Buckley, D. Carter-Lewis, O. Celik, W. Cui, M. Daniel, M. D'Vali, I.de la Calle Perez, C. Duke, A. Falcone, D.J. Fegan, S.J. Fegan, J.P. Finley, L.F. Fortson, J. Gaidos, S. Gammell, K. Gibbs, G.H. Gillanders, J. Grube, J. Hall, T.A. Hall, D. Hanna, A.M. Hillas, J. Holder, D. Horan, A. Jarvis, M. Jordan, G.E. Kenny, M. Kertzman, D. Kieda, J. Kildea, J. Knapp, K. Kosack, H. Krawczynski, M.J. Lang, S. LeBohec, E. Linton, J. Lloyd-Evans, A. Milovanovic, P. Moriarty, D. Muller, T. Nagai, S. Nolan, R.A. Ong, R. Pallassini, D. Petry, B. Power-Mooney, J. Quinn, M. Quinn, K. Ragan, P. Rebillot, P.T. Reynolds, H.J. Rose, M. Schroedter, G. Sembroski, S.P. Swordy, A. Syson, V.V. Vassiliev, S.P. Wakely, G. Walker, T.C. Weekes, J. Zweerink
(1) Physics & Astronomy Department, Iowa State University, Ames, IA, 50011
(2) The VERITAS Collaboration–see S.P.Wakely's paper "The VERITAS Prototype" *from these proceedings for affiliations*

Abstract

Mrk 421 is the first TeV blazar found to exhibit significant spectral variability during strong flaring activity, showing hardening of the TeV spectrum in high emission states. Mrk 421 is also known to exhibit flux variability on time scales as short as 15 minutes. In this paper we present studies of hourly spectral variability of Mrk 421 in 2001 using data from the Whipple Observatory 10 m gamma-ray telescope.

1. Introduction

The AGN phenomenon is generally associated with strongly varying fluxes at all wavelengths on time scales of hours to several months and years. At TeV gamma-ray energies, flux variability as short as 15 minutes have been observed for Mrk 421 (Gaidos et al., 1996). Flux variations are useful information providing the grounds for dynamical tests for particle acceleration and/or emission models, e.g., constraining cooling time scales and physical parameters of the source such as the magnetic field and size of the emission region.

To further the understanding of non-thermal emission from AGN jets, multiwavelength observations are pursued by measuring the spectrum over many orders of magnitude in energy and its variations. Correlations between X-ray and TeV emission were found in various flaring episodes for Mrk 421 (Buckley et al.

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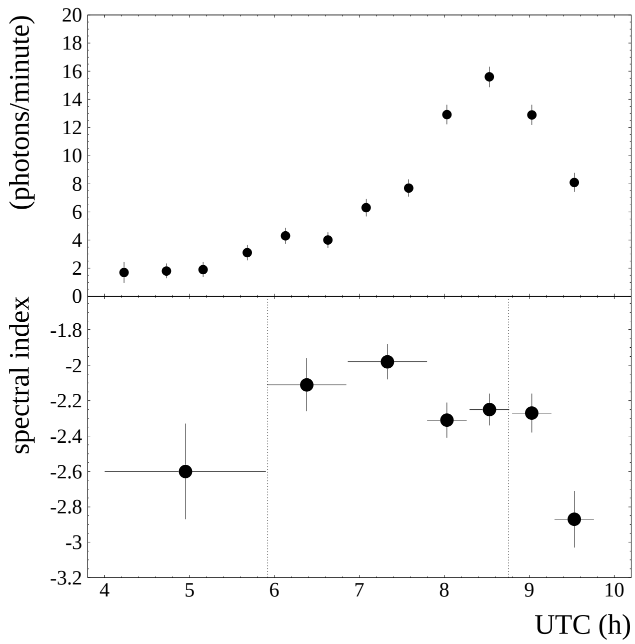

Fig. 1. The lightcurve of a flare of Mrk 421 on March 19 2001 is shown together with the differential spectral index. The probability that the spectral variability is statistical is 3.1×10^{-4} (significance $\approx 3.6\sigma$). The lower plot shows a division (dotted line) into three different stages of the flare into preflare, rising flare and postflare.

1996; Maraschi et al. 1999; Jordan et al. 2001). A next step in testing jet models can be provided by measurements of the spectral variations of an X-ray (Fossati et al. 2000) and contemporaneous TeV gamma-ray flare. Results of spectral variability of Mrk 421 were shown previously (Aharonian et al. 2002; Krennrich et al. 2002) by the HEGRA and VERITAS collaborations. In this paper we discuss spectral variability of flares occuring on two nights in March 2001.

2. Results:

Unusually intense and lasting flaring activity of Mrk 421 in 2001 gave excellent statistics and detailed features of its energy spectrum have been derived: Mrk 421 exhibits a curved spectrum that can be described by a power law with an exponential cutoff around 4 TeV (Krennrich et al. 2001; Aharonian et al. 2002). The energy spectral index varies as a function of flux when averaging over several months of data, but no evidence for variability in the cutoff energy was found when analyzing the entire 2001 data set. Therefore, in the following analysis of spectral variability on hourly time scales, since it is based on spectra from small subsets of the 2001 data with less statistics, we fit the data using a power law

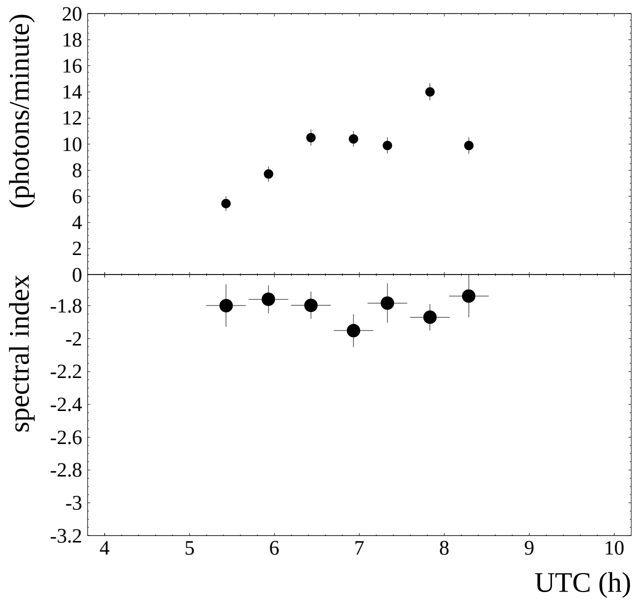

Fig. 2. The lightcurve of a flare of Mrk 421 on March 25 2001 is shown together with the differential spectral index. The spectral index is constant despite the fact that the flux changes by a factor of 2.5.

with a fixed exponential cutoff energy of 4.3 TeV (see also Krennrich et al. 2002).

Figure 1 shows the gamma-ray lightcurve for Mrk 421 on March 19 2001 (Jordan et al. 2001; Buckley 2001) for which the TeV observations provide almost complete sampling of the rise and decay of a flare. The gamma-ray rate ranges from a moderate level ($\approx$ 1 Crab) up to an eight fold flux increase in less than 4.5 hours. The lower part of figure 1 shows the spectral index measured at various times during the flare. The hypothesis that the spectral index is constant during the flare has a chance probability of 3.1×10^{-4}, suggesting spectral variability during this outburst of gamma-ray emission with a significance of $\approx 3.6\sigma$.

When dividing the spectral index measurements into three different episodes, preflare, rising flare and postflare, the hardest spectral index coincides with the rise of the flare, whereas during the preflare and the postflare the spectrum appears to be softer. A similar correlation between hardening/softening of the energy spectrum and flux for Mrk 421 has been reported by the HEGRA collaboration (Aharonian et al. 2002) for the nights of March 21/22 and 22/23 2001. However, observations of flaring activity during other nights suggest that the relation between spectral index and flux variability is more complex than suggested by data from March 19, 21/22 and 22/23 2001. Representative of the complexity of spectral characteristics during flares of other nights is a flare on March 25 2001 measured with the Whipple 10 m telescope. Figure 2 shows its lightcurve with significant flux variations and a flux increase by a factor of 2.5 within ≈ 2 hours.

The spectral index during this flare is exceptionally hard ($\alpha = 1.82 \pm 0.04$) without any indications of spectral variability (hypothesis of constant spectral index has a probability of 78.5%.). Although substantial flux variations occured no significant spectral variations are detected, despite good statistics. It is noteworthy that the data from this flare do not include a preflare episode with fluxes of the level of 1 Crab and do not include the postflare era. This may indicate the spectral variations on hourly time scales may be dependent on the absolute flux.

3. Conclusions

In this paper we present two lightcurves for hourly flaring activity of Mrk 421 together with spectral index variations. During a flare on March 19 2001 significant spectral variability is suggested by the data showing a soft spectral index in the preflare and postflare phase and a hard spectral index during the rising phase of the flare. In contrast no spectral variations are observed for the night of March 25 despite significant flux variations.

One-component models that describe gamma-ray flares solely by an increase in the maximum energy of the radiating particle distribution are ruled out by this observation. A more comprehensive analysis involving a large number of flares is beyond the scope of this paper but will be presented at the conference.

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