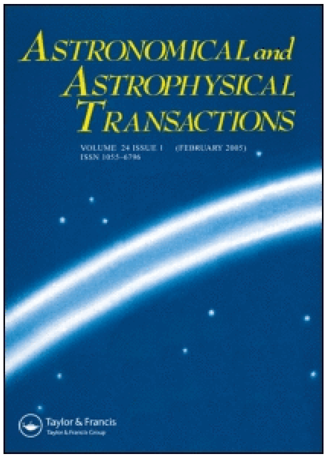

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X-ray and γ-ray emission from Markarian 421 in 2003

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The very-high-energy (VHE) γ-rays from BL Lac object Mrk 421 were observed with the twin stereoscopic Cerenkov system GT-48 in 2003. The observations in April–May have revealed a directional excess of VHE γ quanta with a statistical significance 5.46σ. The observed source was located within $0^\circ.1$ of the coordinates of Mrk 421. Evidence for similar source emission behaviour of X-rays is correspondingly seen in nearly simultaneous data obtained from the all-sky monitor of the Rossi X-ray Timing Explorer. In the high-energy state of the object at $E > 1$ TeV, the source emission exceeded the relatively quiescent state by nearly three times and coincided within about 1.5 days with increased activity in the 2–10 keV energy band.

Keywords: γ-rays; Galaxy observations; Individual observations; Mrk 421

1. Introduction

The characteristic feature of many active galactic nuclei (AGN) are large-scale relativistic plasma jets ejected from the nuclear regions. If these jets are oriented close to the observer's line of sight, the AGN belongs to the class of blazars. If a blazar exhibits no emission line or weak emission lines, the object is classified as BL Lac type. The BL Lac types are extremely luminous objects, in some cases emitting maximum power at γ-ray energies. This emission admittedly is caused by inverse Compton (IC) scattering of soft synchrotron photons by high-energy electrons.

In general the observed spectral energy distribution of blazars shows two broad peaks coincident with the synchrotron and IC components [1]. The first peak may appear between the radio band and the ultraviolet–X-ray band and the second peak may reach gigaelectronvolt to teraelectronvolt energies. Observing BL Lac objects nearly simultaneously in X-rays by means of space-based observatories and at very high energies (VHEs) with ground-based experiments, we may study the source emission behaviours of two peaks correlated in different ways and contribute to the understanding of the nature of radiation processes in blazars.

Because only BL Lac objects with the exception of radio galaxy M 87 have, so far, been the origin of teraelectronvolt γ-ray emission from extragalactic objects, they are the focus

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of intensive investigation [2]. The nearby Markarian galaxy Mrk 421 ($z = 0.031$) was the first extragalactic object from which the flux of VHE γ quanta was detected [3]. In active periods, Mrk 421 may be brighter at teraelectronvolt energies than the Crab Nebula [4]; in the periods of outburst of teraelectronvolt photons from its AGN the flux from Mrk 421 may exceed relatively quiescent state value by a factor of 50 [5]. The teraelectronvolt energies of Mrk 421 have been studied for more than 10 years; nevertheless, interest in observations of Mrk 421 is still active.

2. Observations

The results reported here are based on observations of Mrk 421 at $E > 1$ TeV with the twin Cerenkov system GT-48 [6] in comparison with the data in the 2–10 keV energy band obtained from the all-sky monitor (ASM) of the Rossi X-ray Timing Explorer (RSTM) (quick-look results provided by the RXTE ASM team). The system consists of two identical altitude–azimuth mountings, or sections, northern and southern, separated by 20 m. Each section is equipped with four cameras, consisting of 37 photomultiplier tubes (PMTs) that have the same numbers of channels. Each camera, mounted in the focal plane of four mirrors with diameters of 1.2 m, records the images of atmospheric Cerenkov radiation from extensive air showers produced by VHE γ-rays and cosmic rays. Each PMT in the camera views a field of $0^\circ.4$; the total field of view of each camera is $2^\circ.6$.

Cerenkov flashes are detected in the optical band. The signals from the channels of four cameras in each section are linearly added. Flashes are recorded only when the amplitudes of the signals for any two of the 37 channels exceed a certain threshold. Both sections operate in the coincidence mode. The time resolution for the coincidence is 15 ns. The total area of mirrors on both sections of telescope is 36 m^2. The mountings are geared by a control system with a pointing accuracy of $\pm\, 0^\circ.05$. The effective threshold energy for the detection of γ-rays is about 1 TeV.

Observations were made in the ON–OFF mode; in the ON runs, the source was located at the centre of the field of view (FoV) and, in the OFF runs, both telescopes tracked the background with shifting on the right ascension by 40 min. Both ON and OFF runs were 35 min in duration and were carried out at the same levels of elevation. After clearing observation data for bad-weather conditions, a total of 455 min observation time for the source and the same time for the background, obtained between 4 April 2003 and 4 May 2003, have been taken for further processing of the Cerenkov light flashes produced by VHE γ-rays and cosmic rays, mainly protons.

3. Data reduction and analysis

The flashes were processed by obtaining the centres of the brightness distribution and the effective dimensions of flash images. Most of the recorded showers, coming both from the source direction and from the background region, are induced by the hadronic component of cosmic rays. Using the differences between the orientations of the two types of shower and the forms and dimensions of their images, we can distinguish γ-like events from the dominant background. The Cerenkov flashes produced by VHE photons have smaller angular dimensions and more homogeneous forms of their images than flashes from hadronic showers do [7]. Moreover, their images are oriented by their major axes to the source position in the FoV of the camera, while images from proton-induced showers have an isotropic distribution.

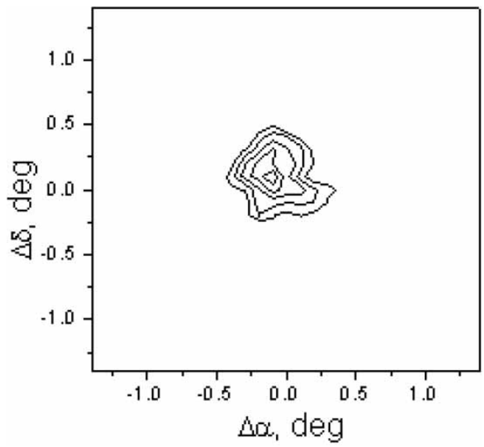

Figure 1. Contour map of detected VHE γ quanta for various directions in the sky close to the Mrk 421 position. The external contour corresponds to 18 events; the next contours are 22, 27, 31 and 36 events.

This selection may be considerably improved by inclusion of the limits of the recorded amplitudes of the showers. The computational criterion of the imaging pattern ratio (IPR), which takes into account the fragmentation level of flash images, was used.

The detected candidates for γ-like events were selected using the following selection (N indicates the north section and S the south section). IPR(N) $= 1$ and IPR(S) $= 1$. A value of 0 is assigned to the most compact images, and values of 1–7 to more fragmented images (0, simple flash; 1, no single array flash; 2, curve flash; 4, camel flash; other values are combinations of these). $0° < L(\mathrm{N}) < 0°.28$ and $0° < L(\mathrm{S}) < 0°.28$, and $0°.05 < W(\mathrm{N}) < 0°.19$ and $0°.05 < W(\mathrm{S}) < 0°.19$, where L and W are the effective lengths and widths respectively of the flash images [8]. $5 \leq C(\mathrm{N}) \leq 6$ and $5 \leq C(\mathrm{S}) \leq 6$, where C is the numbers of channels included in Cerenkov light processing. $0° < D(\mathrm{N}) < 1°$ and $0° < D(\mathrm{S}) < 1°$, where D is the distance of the image centre from the source. $\alpha < 19°$, $V(\mathrm{N}) < 125$ discrete units (du) and $V(\mathrm{S}) < 150$ du, where α is the angle between the direction from the flash centre towards the source and the direction of the major axis of the flash image and V is the amplitude of the detected signal, where 150 du correspond to approximately 106 photoelectrons.

This selection procedure has resulted in the highest excess of 39 γ quanta where the deviation from the source in the right ascension is $\Delta\alpha = -0°.1$ and declination $\Delta\delta = 0°.1$ (figure 1). The accuracy of definition of the coordinates from the Cerenkov data is about $0°.1$.

4. Source variability

Figure 2 shows kiloelectronvolt–teraelectronvolt light curves for Mrk 421 on a daily basis in the late April–early May moonless period. The error bars are purely statistical. Because of low statistics and selection of ON–OFF pairs with nearly equal sky conditions the systematic errors are negligible. To aid comparison, each of the two light curves has been scaled to approximately the same arbitrary flux at the time of the first teraelectronvolt observation (MJD52755.9).

The maximum counting rate at $E > 1$ TeV was detected on 30 April 2003 (MJD52760). On this night, the source state was approximately three times the relatively quiescent state. This night also contributed about 20% to the average count rate with a statistical significance of approximately 2.5σ.

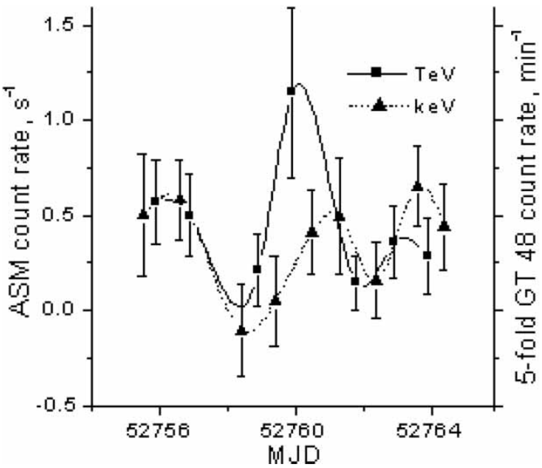

Figure 2. Light curves at $E > 1$ TeV and in the 2–10 keV energy band.

The intensity features at $E > 1$ TeV are replicated in a similar way in the 2–10 keV light curve. In the first high-energy state, the kiloelectronvolt counterpart of the teraelectronvolt flare was increased relative to the average counting rate by about 1.4 times at the 1.6σ level. In the second high-energy state, the ASM count rate was increased by about 1.8 times relative to its average rate at approximately the 3σ level.

The count rates in both energy bands are significantly variable, with amplitudes of 200% and 115% for VHE γ-rays and X-rays, respectively, where the amplitudes are the differences between the maximum and positive minimum count rates, divided by the mean count rates [9].

5. Conclusion

A strong excess of detected VHE γ-rays near the centre of the field of the camera is detected. The point source of teraelectronvolt emission may be identified with the BL Lac object Mrk 421 at approximately the 5.5σ level. The near-simultaneity of high-energy states in two energy bands supports the correctness of identification of the observed object and suggests the co-spatial nature of the emission processes in its active nucleus.

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