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Multiwavelength observations of the TeV blazar Mrk 501 in March 1996. The first report of the detection by *EGRET*

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Abstract

We present the results of a multiwavelength campaign for Mrk 501 performed in March 1996 with *ASCA*, *EGRET*, *Whipple*, and optical telescopes. We report here for the first time the detection of a GeV γ-ray flux from Mrk 501 with *EGRET* with 3.5σ significance ($E > 100$ MeV). A higher flux was also observed in April/May 1996, with 4.0σ significance for $E > 100$ MeV, and 5.2σ significance for $E > 500$ MeV. We find that the multiband spectrum in March 1996 is consistent with that calculated from a one-zone SSC model, except for the extremely 'flat' TeV spectrum. We show that the discrepancy cannot be explained by either second order Comptonization or the contribution of the 'seed' IR photons from the host galaxy. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

The overall electromagnetic spectra of blazars, when plotted in the νF_ν space, generally reveal two broad peaks; one located between IR and X-rays, and another in the γ-ray regime. The lower energy emission is most likely due to the synchrotron process, while the inverse-Compton mechanism is thought to be dominant for the high energy γ-ray emission (e.g., Ulrich, Maraschi and Urry 1997). During the April 1997 multiwavelength campaign for Mrk 501, both X-rays and TeV γ-rays increased by more than one order of magnitude from quiescent level (Catanese et al. 1997, Pian et al. 1998). However, in the GeV band, observations of HBLs (High-frequency peaked BL Lacs) are difficult because HBLs are faint in this energy band. We report here the new *EGRET* detection of Mrk 501; no *EGRET* detection has been reported previously.

2. Observations

We observed Mrk 501 four times with *ASCA* during 1996 March 21.3–April 2.9 UT. Each pointing was about 10 ksec in duration. The flux change between the observations 2 and 3 indicates variability on a time scale of about a day. The spectrum obtained in each observation was well fitted using a broken power

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law model with Galactic absorption. A clear correlation between the X-ray flux and the photon index was found, where the spectrum tends to steepen as the source gets fainter. The difference of photon index above/below the break was roughly constant, ~ 0.5, for all periods, which is expected from the synchrotron cooling process.

The *EGRET* results of likelihood analysis (Mattox et al. 1996) of all viewing periods (VP) are summarized in Kataoka et al. (1999). Note that for VP 519.0 (April 1996), the result is a 4.0σ detection, barely meeting the acceptance criterion used in the construction of *EGRET* catalogs. Within 5 degrees of Mrk 501 are three flat spectrum radio quasars: (1) 3C 345 and (2) NRAO 512 and (3) 4C +38.41. To verify that the source detected in VP 519.0 really was Mrk 501, an analysis was done for $E > 500$ MeV. The extent of the PSF for the higher-energy photons is reduced by a factor of about 6 in solid angle, enough to remove the possibility of confusion with the other nearby objects. The result of the $E > 500$ MeV analysis is a 5.2σ detection, and source location contours clearly pinpoint Mrk 501 as the source of the γ-ray emission. The VP 516.5 (March 1996) and 519.0 observations have been examined for a possible time variability. For the 21 March–3 April 1996 *EGRET* observation, Kuiper's variant of the KS test indicates variability with 98.9% confidence. This interval was therefore analyzed through a likelihood analysis of four equal length intervals with $E > 100$ MeV. The sub-interval 24.96–28.17 March 1996 showed a detection significance of 3.5σ, and a flux of $(32 \pm 13) \times 10^{-8}$ cm^{-2} s^{-1}, $E > 100$ MeV. The differential spectral photon index was measured to be 1.6 ± 0.5 in the 30 MeV–10 GeV energy range.

Mrk 501 was observed at $E > 350$ GeV with the *Whipple Cherenkov Telescope* as a part of the multiband campaign. The average emission level for the observation period is approximately 15% that of the corresponding rate from the Crab Nebula. A χ^2 analysis for constant emission indicates variability at the 97% level (a 2.3σ effect). *HEGRA* also observed Mrk 501, partially overlapping our observation (Petry et al. 1997). The photon index was measured to be 2.5 ± 0.4 (total error).

A few optical observations were carried out using the 70 cm telescope of the Landessternwarte in Heidelberg. The observed magnitude at 650 nm was $m_R = 11.80 \pm 0.02$ for March 26 and $m_R = 11.72 \pm 0.02$ for March 27. The probability of variability within the two nights was 2.3σ.

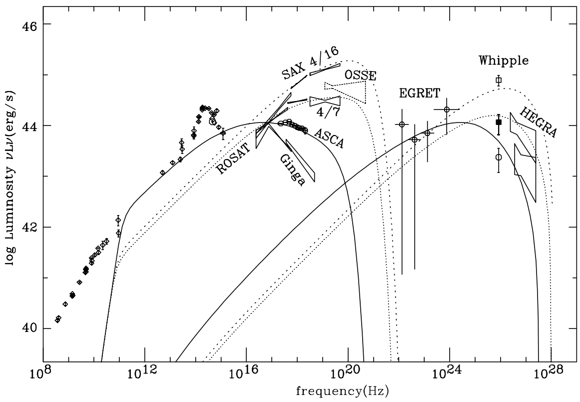

Fig. 1. Multiband spectrum of Mrk 501. Circle: March 25–28 1996 campaign. Open Square: *Whipple* flux on Apr 16, 1997. Filled Square: *Whipple* flux on Apr 7, 1997. Full details of this figure are given in Kataoka et al. (1999).

3. Discussion

The multiband spectra of Mrk 501 taken during our campaign and at other times are shown in Fig. 1. We also plot in Fig. 1 the spectra for the pre-1995 quiescent state, and the April 1997 flare. We apply a one-zone, homogeneous SSC model to the March 1996 multiband data (Inoue and Takahara 1996). From the argument of the allowed parameter space on the magnetic field strength and beaming factor, we set the value at $B = 0.2$ G, $\delta = 15$, and source radius $R = 4.5 \times 10^{15}$ cm (Kataoka et al. 1999). The whole 1996/1997 spectra are adequately represented, except for a discrepancy in the TeV spectrum in 1996. We investigated two possible causes of this discrepancy. The first is the external soft photons from the host galaxy and the other is the multiple Comptonization. To account for the flat TeV spectrum with such external radiation, the observed external Compton luminosity must be at least comparable with the synchrotron luminosity. Thus we obtain the constraint on the soft photon density as $u_{ext} \geq 10^{-8}$ erg cm^{-3}. While the typical values for the total luminosity of the galaxy and effective radius yields the energy density of $u_{ext} \sim 3 \times 10^{-11}$ erg cm^{-3} – hence the IR photons from the host galaxy are not expected to affect the TeV spectrum. The second possible cause of the TeV spectral discrepancy is the contribution of photons produced by multiple Compton scattering (e.g., Bloom and Marscher 1996). Our calculation shows that it is greatly suppressed due to the Klein–Nishina effect. The flux ratio for Comptonization of first and second order is $f_{2nd}/f_{1st} \leq 10^{-3}$ at 1 TeV. Thus, the second order SSC process does not make a significant contribution to the spectrum. Together with more refined SSC models such as Marscher and Travis (1996), an exact evaluation of Comptonized emission from external IR photons, such as dust emission around the nuclei and accretion disk photons, may be useful for the understanding of the origin of the flat TeV spectrum. In particular, if the IR photons arise in a region comparable to a parsec-scale torus, postulated to exist in Seyfert galaxies, then such a photon field can be important (e.g., Sikora et al. 1994).

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