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BeppoSAX Observations of the BL Lac Object Mkn 501 in an Intermediate State

E. Pian, E. Palazzi

ITESRE, C.N.R., Via Gobetti 101, I-40129 Bologna, Italy

L. Chiappetti

IFCTR, C.N.R., Via Bassini 15, I-20133 Milan, Italy

L. Maraschi, F. Tavecchio, G. Ghisellini, G. Tagliaferri

Osservatorio Astronomico di Brera, Via Brera 28, I-20121 Milan, Italy

G. Fossati

SISSA/ISAS, Via Beirut 2-4, I-34014 Miramare (Trieste), Italy

A. Treves

Dip. di Fisica, Università di Como, Via Lucini 3, I-22100 Como, Italy

C. M. Urry

STScI, 3700 San Martin Drive, Baltimore, MD 21218

G. Vacanti

ESA ESTEC, Space Science Department, Astrophysics Division, Postbus 299, NL-2200 AG Noordwijk, The Netherlands

Abstract.

The BL Lac object Mkn 501 was observed with the BeppoSAX satellite at three epochs in April-May 1998, simultaneously with the Whipple and HEGRA Cherenkov telescopes. The X-ray spectrum is well detected up to 70 keV and it exhibits, at all epochs, a continuous curvature, which is here modeled with three power-laws of increasingly steeper index at larger energies. In the νF_ν representation the spectrum exhibits a peak at $\sim$ 20 keV, which is interpreted as the maximum of the synchrotron emission. This implies that the synchrotron peak energy has lowered by an order of magnitude with respect to the powerful X-ray outburst observed in April 1997. The simultaneous TeV flux was comparable to the lowest levels observed for Mkn 501, possibly suggesting that the peak of the inverse Compton radiation had also shifted toward lower energies.

1. Introduction

Mkn 501 is one of the closest (z=0.034) BL Lacertae objects, and one of the brightest at all wavelengths. It is one of the only four extragalactic sources detected so far at TeV energies [1,2]. Based on observations prior to 1997, its spectral energy distribution (νF_ν) resembles that of BL Lac objects selected at X-ray energies, having a peak in the EUV-soft X-ray energy band. Accordingly, the 2-10 keV spectra observed for this source were relatively steep, with energy spectral indices α larger than unity ($F_\nu \propto \nu^{-\alpha}$), meaning the power output peaks below this band [3-6]. BeppoSAX observations of Mkn 501 in April 1997 revealed a completely new behavior. The spectra showed that at that epoch the synchrotron component peaked at 100 keV or higher energies, implying a shift of at least two orders of magnitude of the peak energy with respect to the quiescent state [7]. Correspondingly the source was extremely bright in the TeV band and exhibited rapid flares [8,9]. We have reobserved Mkn 501 with BeppoSAX at three epochs in April-May 1998, simultaneously with ground-based optical and TeV Cherenkov telescopes (Whipple and HEGRA). We will illustrate here the preliminary results of the spectral analysis performed on the three average spectra and will briefly discuss the correlated X-ray and TeV variability.

2. Observations, analysis and results

Mkn 501 was pointed by the BeppoSAX Narrow Field Instruments on 28, 29 April and 1 May 1998 for ~10 hours in each occasion. Data reduction was done following standard methods (see e.g., [10,11]). LECS data have been considered in the range 0.1-4 keV, MECS data in the range 1.8-10.5 keV, HPGSPC data in the range 6-30 keV, and PDS data in the range 13-70 keV. For all epochs, fits to all data either with a single or a broken power-law are unacceptable. Therefore, joint fits with a broken power-law to the LECS and MECS spectra on one hand and to the MECS, HPGSPC and PDS spectra on the other have been performed. The fit parameters, obtained by fixing the value of the hydrogen column density to the Galactic value (1.73×10^{20} cm^{-2}, [12]), are reported in Table 1. The χ^2 values associated with these fits are all very close to unity. The spectral steepening at the lower and higher break energies is ~0.3 and ~0.4, respectively, at all epochs. The data suggest that the actual spectrum is continuously curved.

Table 1. Fit Parameters for BeppoSAX Spectra of Mkn 501 in 1998.

Epoch	α_1	$E_{break,1}$ keV	α_2	$E_{break,2}$ keV	α_3
April 28	0.50 ± 0.04	1.2 ± 0.4	0.81 ± 0.05	17 ± 5	1.20 ± 0.05
April 29	0.48 ± 0.04	1.3 ± 0.4	0.83 ± 0.05	17 ± 5	1.15 ± 0.05
May 01	0.62 ± 0.04	1.9 ± 0.4	1.00 ± 0.05	23 ± 5	1.45 ± 0.05

3. Discussion

The X-ray flux of Mkn 501 in the 2-10 keV range observed in April-May 1998 was averagely at the same level as that seen on 7 April 1997, namely the lowest state observed during that campaign [7], but brighter than ever previously observed (see Fig. 1). We still observe that the synchrotron peak is located at a very high energy, ~20 keV, which is unprecedented for any other blazar, although an order of magnitude lower than seen in April 1997 in this source. This has allowed BeppoSAX to fully resolve the peak of this emission component. The spectrum has an almost constant slope at the softer energies, and it steepens with decreasing flux at the highest energies (Fig. 1). It is noticeable that, although the flux and the spectrum up to ~20 keV in the present observations were very similar to those of 7 April 1997, the PDS spectrum is considerably steeper. The TeV flux measured in this period by the Whipple and HEGRA telescopes was rather small (comparable to the first detection level, [13]), and definitely lower than observed in 1997 at the beginning of the simultaneous X-ray and TeV outburst. Since the TeV emission of Mkn 501 is produced through inverse Compton scattering off the same relativistic particles which radiate via the synchrotron mechanism, we are led to conclude that, analogously to the synchrotron radiation peak, also the inverse Compton peak has shifted toward the lower energies. A more quantitative discussion of the correlated X-ray and TeV variability should await a specific model and is deferred to a future paper.

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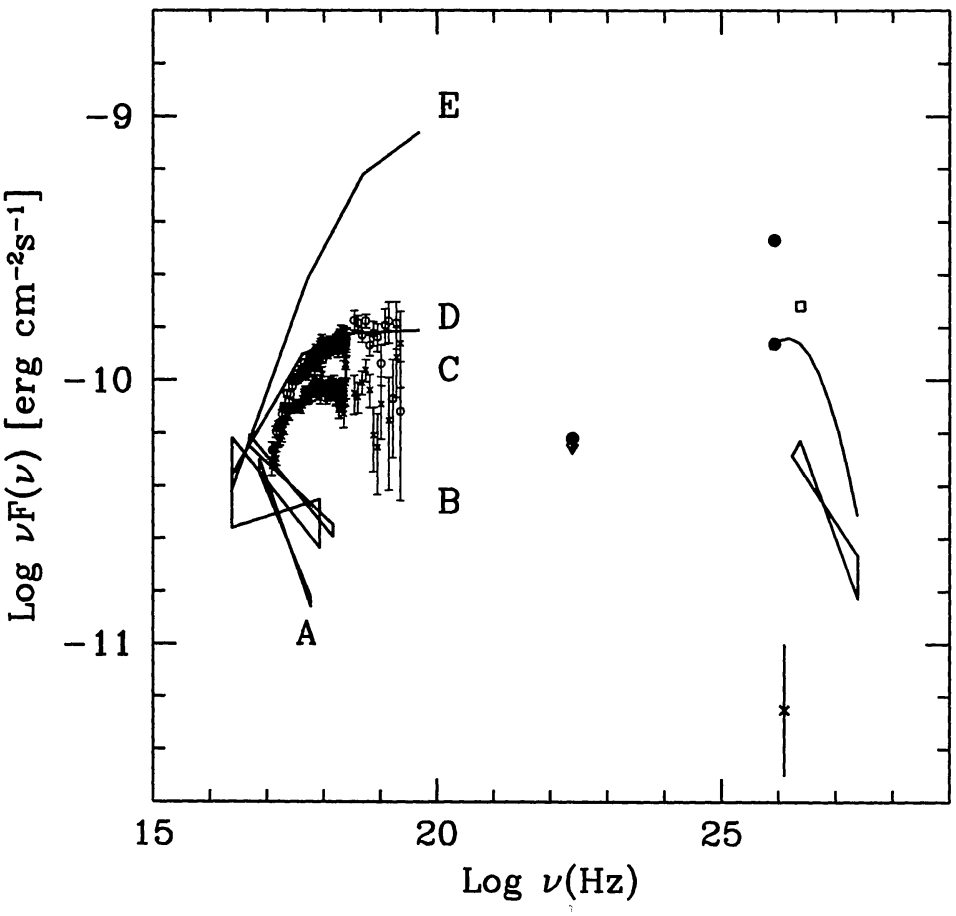

Figure 1. X-ray-to-TeV energy distributions of Mkn 501. X-ray spectral fits in low state (A) are collected from the literature (see [7] for references). Best-fit to the BeppoSAX spectra on 1997 April 7 and 16 are labelled with D and E, respectively. The X-ray data points represent the unfolded spectra of 1998 April 29 (C, open circles) and May 1 (B, crosses). Whipple and HEGRA TeV data and EGRET upper limit nearly simultaneous to 7, 16 April 1997 and April-May 1998 are indicated as open square, filled circles, and cross, respectively [8,9,14,15]. The TeV spectral fits are from HEGRA (power-law, 15-20 Mar 1997, [9]) and from Whipple (parabolic law, Feb-Jun 1997, [16]).