BEPPOSAX OBSERVATIONS OF MARKARIAN 501 IN JUNE 1999

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ABSTRACT We present the preliminary results of a long BeppoSAX observation of the BL Lac object Mkn501 carried out in June 1999. The source was fainter than found during the BeppoSAX pointings of 1997 and 1998, but is still detected with a good signal-to-noise ratio up to ~40 keV. The X-ray spectrum in the energy range 0.1-40 keV, produced through synchrotron radiation, is steeper than in the previous years, it is clearly curved, and peaks (in νF_ν) at 0.5 keV. This energy is much lower than those at which the synchrotron component was found to peak in 1997 and 1998. Some intraday variability suggests that activity of the source on small time scales accompanies the large long time scales changes of brightness and spectrum.

KEYWORDS: BL Lacertae objects: individual (Mkn 501); X-rays: galaxies; radiation mechanisms: non-thermal

1. SCIENTIFIC GOAL OF THE PROGRAM

The radio-to-γ-ray spectra of blazars (νF_ν) are typically "double-humped", with the first peak commonly attributed to synchrotron radiation within a relativistic jet and the second to inverse Compton scattering of relativistic electrons off synchrotron or ambient soft photons (Ulrich, Maraschi & Urry 1997, and references therein). In X-ray bright BL Lacs (XBL) the synchrotron maximum generally occurs in or close to the X-ray band, and the inverse Compton emission peaks above the GeV spectral region extending in some cases to the TeV band, as observed so far for several sources by ground based Cherenkov telescopes. Among these is the nearby

CP599, *X-Ray Astronomy,* edited by N. E. White et al.

($z = 0.034$) BL Lac object Mkn 501, one of the brightest blazars at UV, X- and γ-ray energies, and a typical XBL according to the numerous multiwavelength data taken prior to the BeppoSAX launch. Repeated observations with the satellites ASCA and XTE have detected large amplitude X-ray variability at different time scales, often correlated with strong activity in the TeV band (e.g., Kataoka et al. 1999; Sambruna et al. 2000).

BeppoSAX observations of Mkn 501 in April 1997, during an outburst, revealed a completely new behavior. In fact, the joint LECS, MECS and PDS spectra showed that at that epoch the synchrotron component peaked at 100 keV or higher energies (Fig. 1). Correspondingly the source was extremely bright in the TeV band and exhibited rapid flares (Catanese et al. 1997; Aharonian et al. 1999). The flux at 10 keV was an order of magnitude higher than the historical level, while around 1 keV the flux was only moderately brighter than usual. The X-ray spectrum hardens with increasing intensity, and the peak energy of the synchrotron component varies by more than two decades with respect to the quiescent state, a unique behavior in blazars, if compared with the variations of the peak energy exhibited by similar sources, never exceeding an order of magnitude with respect to quiescence (Fossati et al. 2000; Giommi et al. 1999). A discussion of the SED of Mkn 501 in the frame of the SSC model is reported in Tavecchio & Maraschi (this volume).

Further BeppoSAX observations in April-May 1998 showed that the synchrotron peak energy was located at ~20 keV (Fig. 1), indicating a decrease of an order of magnitude with respect to the previous year (Pian et al. 1999). The simultaneously measured TeV flux was also much lower than in 1997 (Krawczinsky, priv comm.) However, the fact that, despite the radiation losses, the synchrotron peak was still at such high energies one year after the huge outburst, clearly indicates the presence of very powerful, efficient and continuously active mechanisms of particle energization and acceleration in this source.

2. BEPPOSAX OBSERVATIONS: JUNE 1999 CAMPAIGN

We have carried out observations with BeppoSAX in June 1999, simultaneously with TeV Cherenkov telescopes and coordinated with XTE, to investigate the

- X-ray variability of the continuum on short (hours and sub-hour) time scales;
- the presence of possible time lags between soft and hard X-ray emission;
- the correlation between X-ray and gamma-ray flux and spectral index variations.

A single, 180 ks long BeppoSAX pointing has been performed between 1999 June 10, 23:01:18 UT and June 16, 02:11:08 UT, during one of the longest observing windows of the Cherenkov telescopes Whipple, HEGRA, CAT and CELESTE. The X-ray data have been cleaned and linearized at the BeppoSAX Science Data Center (SDC). Spectra and light curves have been extracted from the images with the

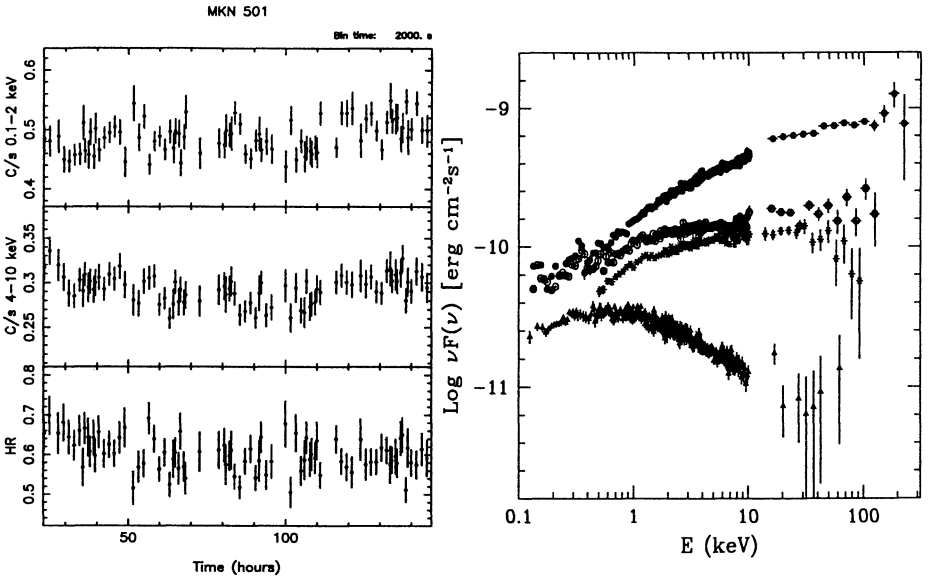

FIGURE 1. Left panel: Light curves (0.1-2 keV and 4-10 keV) and Hardness Ratio of Mkn 501 during the 1999 June observation. Right panel: History of the X-ray spectrum of Mkn 501. From top to bottom: 1997 Apr. 16 (filled circles), 1997 Apr. 7 (open circles), 1998 Apr. 28 (stars) and 1999 June (triangles).

standard XSELECT package. For the spectral analysis, we used the background files and response matrices distributed by the SDC.

3. RESULTS

The source has been clearly detected by the BeppoSAX LECS and MECS instruments, and by the PDS up to 40 keV. The flux exhibits variability of up to 20-30% in amplitude on time scales of 10-12 hours or more (Fig. 1).

The June 1999 flux level at 1 keV is similar to the one observed for Mkn 501 prior to 1997 ("historical" state), namely more than a factor of 2 fainter than detected by BeppoSAX in April-May 1998 and in 1997 April 7, and an order of magnitude fainter than observed by BeppoSAX during the outburst of 1997 April 16 (Fig. 1).

The 0.1-40 keV spectrum is steeper than found in 1997 and 1998 and is progressively steepening with energy. It is not well fitted ($\chi^2_r \sim 5$) by a single power-law plus Galactic absorption ($N_H = 1.73 \times 10^{20}$ cm^{-2}), therefore two power-laws have been used to fit the data. The fitted energy break is around 1 keV and the spectral indices are $\alpha_1 = 0.89 \pm 0.03$ and $\alpha_2 = 1.44 \pm 0.02$ (errors are at 90% confidence level; $\chi^2_r = 1.4$). Therefore, the X-ray spectrum is consistent with being produced with a unique emission component, which we identify with synchrotron radiation.

In a νf_ν representation, the X-ray spectrum appears to peak at the energy of $\sim$1 keV, which can be identified with the maximum of the synchrotron component. The comparison with the BeppoSAX spectra of the previous years (see Fig. 1) indicates that in 1999 the synchrotron peak has shifted toward lower energies, following the

trend already noted in 1997 and 1998, when the peak was observed at >100 keV and ~20 keV, respectively.

Optical and TeV coverage simultaneous with the present BeppoSAX campaign was limited due to bad weather. The optical flux level is similar to that usually observed for Mkn 501. At TeV energies, only marginal detections have been obtained on each night. The analysis of these data is still underway.

Our preliminary conclusions are that

- The energy at which the synchrotron component peaks can vary on long term by a large amount (more than a factor of $\sim$ 200), in correspondence with long time scale large amplitude flux variations (2 orders of magnitude at 10 keV).
- This "shift" in energy takes place on much longer time scales (years) than the synchrotron cooling times at X-ray energies, estimated from multiwavelength energy distribution fitting (e.g. Tavecchio & Maraschi, this volume). This further indicates that electrons are continuously accelerated, while the high state is gradually turning to quiescence.
- The low TeV flux in June 1999 indicates that the TeV flux variations are probably correlated with the X-ray variations.

ACKNOWLEDGEMENTS

We thank the BeppoSAX SDC and Mission Planning Team for their support of this project.

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