X-Ray Luminosity and Spectral Variability in the TEV BL Lac 1ES2344+514

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The results of a series of five *BeppoSAX* observations of the TeV BL Lac object 1ES2344+514 are briefly presented. Large amplitude luminosity variability, associated to impressive spectral changes in the hard X-rays, have been found. The shape of the lightcurve depends on energy, with the flare starting and ending in the hard band, but with maximum intensity possibly reached earlier in the soft X-rays. The luminosity and spectral changes may be due to a shift of the peak of the synchrotron emission from the soft X-rays to the hard X-ray band similar to that detected during *BeppoSAX* observations of MKN 501.

1. Introduction

BL Lac objects are a peculiar type of radio loud AGN emitting highly variable non-thermal radiation over an extremely wide energy range from radio waves to TeV energies. Synchrotron emission followed by Inverse Compton scattering is generally thought to be the mechanism responsible for the production of non-thermal radiation over such a wide energy range (e.g. Bregman et al. 1994). Relativistic beaming is necessary to explain some of the extreme properties of these objects such as rapid variability and superluminal motion (Urry & Padovani 1995). 1ES2344+514 is an HBL BL Lac (Padovani & Giommi 1995) that is an object where the synchrotron component dominates the spectrum up to very high energies. To date only three BL Lacertae objects (all of them HBLs) have been detected at TeV energies (Catanese et al. 1997): MKN 501, MKN 421 and 1ES2344+514.

We briefly present here the main results of a series of broad-band (0.1-200 keV) X-ray observations of 1ES2344+514 carried out with the *BeppoSAX* satellite (Boella et al. 1997a).

2. Observations

The *BeppoSAX* satellite carries aboard four co-aligned X-ray experiments called NFI (Narrow Field Instruments) and two Wide-Field-Cameras (WFC) each pointing 90 degrees away from the NFI pointing direction. The NFI include four X-ray telescopes with one Low Energy Concentrator Spectrometer (LECS, Parmar et al. 1997) sensitive in the 0.1-10 keV band, and three identical Medium Energy Concentrator Spectrometers (MECS, Boella et al. l997b) covering the 1.5-10. keV band. At higher energy the NFI also include two collimated experiments (PDS, Frontera et al. 1997, and HPGSPC, Manzo et al. 1997) extending the *BeppoSAX* sensitivity band to approximately 200 keV.

The journal of the *BeppoSAX* NFI observations of 1ES2344+514 together with the count-rates in the LECS, MECS and PDS instruments is given in table 1.

3. Data analysis

The analysis of the LECS and MECS data was carried out using the screened event files made available through the *BeppoSAX* Science Data

Table 1
Log of the *BeppoSAX* observations 1ES 2344+514

Observation date	LECS exp (s)	count-rate $ct\ s^{-1}$	MECS exp (s)	count-rate $ct\ s^{-1}$	PDS exp (s)	count-rate $ct\ s^{-1}$
3-DEC-1996	4719	0.19 ± 0.01	13109	0.42 ± 0.01	6375	< 0.3
4-DEC-1996	5264	0.22 ± 0.01	13300	0.42 ± 0.01	6518	0.27 ± 0.09
5-DEC-1996	986	0.31 ± 0.02	2547	0.54 ± 0.02	1228	< 0.6
7-DEC-1996	5563	0.35 ± 0.01	14069	0.82 ± 0.01	6757	0.32 ± 0.09
11-DEC-1996	2992	0.22 ± 0.01	13062	0.53 ± 0.01	6113	< 0.3

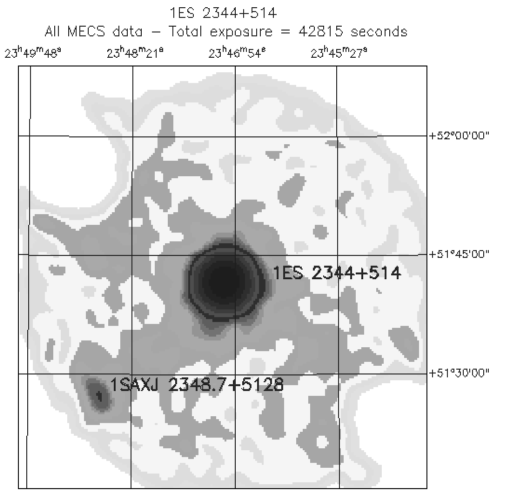

Figure 1. The MECS X-Ray image of the field centered on 1ES2344+514. The bright source at the center is the BL Lac, the faint serendipitous source (1SAXJ2348.7+5128) to the bottom left part of the image coincides with the dwarf nova V630 CAS

Center (SDC) on-line archive (Giommi & Fiore 1997). The XIMAGE analysis software (Giommi et al. 1991) (upgraded to support *BeppoSAX* data) and the XSPEC package were used for image and spectral analysis. The MECS 2-10 keV image, accumulated using data from all observation is shown in figure 1. 1ES2344+514 is the bright source in the center, while the fainter serendipitous source visible at the bottom left of the image (1SAXJ2348.7+5128) is the dwarf nova V630 CAS. The count rates of 1E2344+514 are reported in table 1 where it can be seen that intensity variations of approximately a factor 2 are present in all experiments. The count rate of 1SAX J2348.7+5128 did not show any significant variation.

Spectra of 1E2344+514 were accumulated for each observation, with 8.5 and 4 arcmin extraction radii for the LECS and MECS instruments respectively. The PDS spectra were instead taken directly from the *BeppoSAX* on-line archive (Giommi & Fiore 1997) which is based on the results of the supervised standard analysis. The LECS data have been fitted in the $0.1-4$ keV range, while MECS data were fitted over the full $1.8 - 10.5$ keV range. Spectral analysis was performed assuming both a simple and a broken power law model with photoelectric absorption fixed to the Galactic value of $1.6 \times 10^{21}\ cm^{-2}$.

We find that a simple power law is in general an acceptable representation of the data, although in some cases the best fit requires some absorption in excess of the Galactic value. This is probably the symptom of a spectral flattening in the soft X-rays (i.e. the spectrum is convex), as is often seen in HBL BL Lacs (e.g. Padovani & Giommi 1996). This interpretation is fully supported by the results of the broken power law fits which indicate steeper slopes in the hard band. The spectral slope varies with flux from a value of around 1.0 (energy index) when the source was faint to a harder value of about 0.77 when 1ES2344+514 was at maximum intensity. The largest spectral change occurred above 8-10 keV, mostly in the PDS band. This is illustrated in figures 2 and 3 where the LECS, MECS and PDS data are plotted together with the power law best fit, for the observations made on December 3 and December 7 when the source was faint and brightest respectively. A more effective representation of the spectral change is shown in figure 4 where the *BeppoSAX* data taken on December 3, 4 and 7 are plotted in a $\nu f(\nu)$ *vs* ν energy distribution representation.

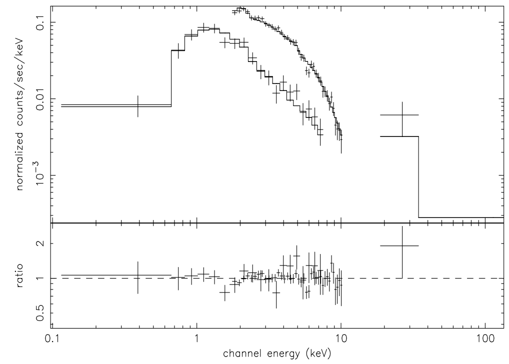

Figure 2. The LECS, MECS and PDS spectrum of 1ES2344+514 in the faint state. The object is barely detected in the PDS instrument up to 20-30 keV. No detection is present at higher energy.

4. X-Ray flux and spectral variability

Figure 5 shows the X-ray lightcurve of 1ES 2344+514 in three bands : 0.1-2 keV, 3-5 keV, and 5-10 keV. A visual inspection of this figure shows that the brightening starts at least one day earlier in the hardest band where it also lasts longer. Maximum intensity seems to be reached earlier in the softest band.

The LECS, MECS and PDS data for the observations of December 3, 4 and 7 have been combined in the spectral energy distribution ($\nu f(\nu)$ *vs* ν) shown in figure 4 where a spectacular spectral variability is apparent in the highest energy bins. The December 5 and 11 data are

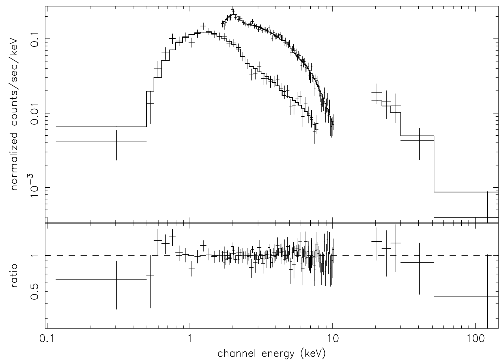

Figure 3. The LECS, MECS and PDS spectral data for 1ES2344+514 taken on December 7 when the source was brightest.

not shown on the plot to avoid confusion but are fully consistent with the general trend of a strong spectral hardening with intensity apparent from the figure.

5. Discussion

During a series of five *BeppoSAX* observations 1ES 2344+514 underwent a flare which caused its luminosity to double in the 0.1-10 keV band and to increase of an even larger amount in the PDS band. The X-ray spectral shape of 1ES2344+514 varied with intensity in a way that is typical of HBL BL Lacs, namely the spectrum hardens when the source brightens (e.g. Giommi et al. 1990). The variable X-ray spectral energy distribution of 1ES2344+514 ($\nu f(\nu)$ *vs* ν) is consistent with an interpretation where the flux and the spectral variations are due to the onset of a variable hard component that started dominating the X-ray flux above 5 keV during the second observation and that reached maximum intensity on December 7, when it dominated the entire X-ray band. Figure 4 shows that the peak of the synchrotron power (that is where the spectral slope is 0 in $\nu f(\nu)$ $-$ ν space) during the low state

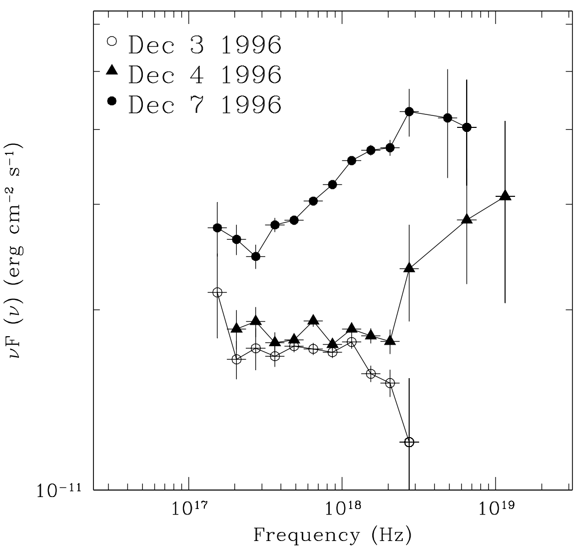

Figure 4. The LECS, MECS and PDS spectral data plotted as $\nu f(\nu)$ *vs* ν. Very large spectral variations, especially at high energy, are clearly visible.

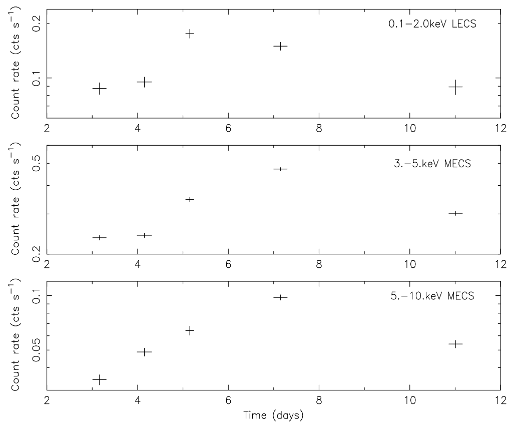

Figure 5. The lightcurve of 1E2344+514 is three X-ray energy bands

was at frequencies of a few times 10^{17} while when the intensity was maximum the peak shifted to $\approx 3-4\times10^{18}$ (20-30 keV).

A similar spectral variability, but on an even larger scale, was detected in a recent observation of the X-ray bright and TeV detected HBL BL Lac MKN 501 (Pian et al. 1998). Large shifts of the synchrotron peak energy (implying very large changes in the bolometric luminosity) might therefore be relatively frequent in the hard X-ray band for HBL BL Lacs. Similar behavior should be expected in LBL BL Lacs in the optical/UV band. As for the case of MKN501 (Pian et al. 1998) the results reported here demonstrate that most of the power emitted in BL Lacs may be in the hard X-Rays (≥ 10 keV) an energy region poorly explored by previous satellites.

REFERENCES

1. Boella G. et al. 1997a A&AS, 122, 299
2. Boella G. et al. 1997b A&AS, 122, 327
3. Bregman J. 1994, in Multi-Wavelength Continuum Emission of AGN, T.J.L. Courvoisier and A. Blecha eds., IAU Symp no. 159, p. 5
4. Frontera F. et al. 1997 A&AS, 122, 357
5. Catanese M. et al. 1997, preprint astro-ph/9712325
6. Giommi, P., Angelini, L., Jacobs, P. & . Tagliaferri G. 1991 in "Astronomical Data Analysis Software and Systems I", 1991, A.S.P. Conf. Ser. 25, 100
7. Giommi P., Barr P., Garilli B., Maccagni D., Pollock A. 1990, APJ, 356, 455
8. Giommi P.,& Fiore F. 1997, Proc. of "5th International Workshop on Data Analysis in Astronomy, Erice.
9. Manzo G. et al. 1997 A&AS, 122, 341
10. Padovani, P., Giommi, P. 1995 APJ, 444, 567
11. Padovani, P., Giommi, P. 1996 MNRAS, 279, 526
12. Parmar A. et al. 1997 A&AS, 122, 309
13. Pian E. et al. 1998, APJ 492, L17
14. Urry C.M. & Padovani P. 1995, PASP 107, 715