HARD SYNCHROTRON BL LACS:  
THE CASE OF 1ES 1101-232

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ABSTRACT The bright X-ray selected BL Lac object 1ES1101–232 shows a flat X-ray spectrum, making it detectable with high statistics over the wide BeppoSAX energy range. We have observed it in two different epochs with BeppoSAX, and found a variation of the flux of about 30% that can be explained by a change in the spectral index above the synchrotron peak. We present here the data and infer limits on the strength of the magnetic field based on models of emission for High-frequency peaked BL Lacs.

KEYWORDS: (Galaxies:) BL Lacertae objects: general – X–rays: galaxies – BL Lacertae objects: individual: 1ES 1101–232

1. INTRODUCTION

Overall spectral energy distributions (SED) of BL Lacs and blazars in general show two broad peaks: the synchrotron one at low energies and the inverse Compton scattering peak at high energies. The position of the synchrotron peak defines different classes of BL Lacs: the HBL (High-peaked BL Lacs) and the LBL (Low-peaked BL Lacs). Ghisellini et al. (1998) and Fossati et al. (1998) propose a sequence for blazars in which the energy of the peak is anti-correlated with the bolometric luminosity, and fainter objects, as HBL, should have a peak in the UV–X-ray band.

1ES 1101–232 (z=0.186) is an extreme case of HBL in which the synchrotron component peaks in the X-ray band (∼ 1 keV), as shown by our previous observation (Wolter et al. 1998). Even if not as extreme as that of the flaring states of Mkn 501 (Pian et al. 1998) and 1ES 2344+514 (Catanese et al. 1998), the SED of 1ES 1101–232 makes it a good candidate for TeV emission.

2. X-RAY DATA

BeppoSAX has observed 1ES1101–232 on two occasions, on 4 Jan 97 and 19 Jun 98. A single power law fit with Galactic absorption at low energy is rejected for both observations, while a broken power law yields an acceptable $\chi^2$. In Wolter et al. (1999) all the details of the fits are reported. The broken power law model is
preferred, from a statistical point of view besides for physical reasons, even over a single power law with intrinsic absorption. The PDS observations, being so short, are not of sufficient statistical significance to put a real constraint on the spectrum.

The position of the break energy \( E_0 \) and the slope of the low energy part of spectrum \( \alpha_1 \) are the same in the two observations within the errors. On the contrary, the portion of the spectrum at higher energies (i.e. above \( E_0 \)) has changed between the two observations. We therefore fit the two datasets together, by using an appropriate model; the best fit of a broken power law model, in which only the high energy index \( \alpha_2 \) is untied between the two observations, is acceptable (see Table 1).

The fluxes are consistent with those obtained by the separate fits. Only the intensity above 2 keV changed (of \( \sim 32\% \)) between the two observations. Even if the flux variation is small, this result might bear an impact on spectral variability models in BL Lacs.

3. SPECTRAL ENERGY DISTRIBUTION

By using the same data as reported in Wolter et al. (1998) and adding the second BeppoSAX observation we construct the SED of Figure 1 and 2. Furthermore, 1ES1101-232 has been observed on the nights of 19-27 May 1998 with the Durham University Mark 6 atmospheric Čerenkov telescope (Chadwick et al. 1999). The source was not detected and an upper limit of \( f_{\text{TeV}} (> 300 \text{ GeV}) = 3.7 \times 10^{-11} \) photons cm\(^{-2}\) s\(^{-1}\) has been derived from the observation. This value also has been plotted in Figure 1.

We can reproduce the observed SED by using the homogeneous Synchrotron–Self Compton model described in detail in Ghisellini et al. (1998). A power-law distribution of electrons with slope \( n \) and minimum Lorentz factor \( \gamma_{\text{min}} \) is continuously injected in a spherical region with radius \( R \). The source is in relativistic motion...
TABLE 1. Broken power Law fit results for LECS+MECS data COMBINED

| Date  | $\alpha_1$    | $\alpha_2$   | $E_0$  | $F^a$    | $\chi^2$ (dof) |
|-------|---------------|--------------|--------|----------|----------------|
|       | En. index     | En. index    | keV    |          |                |
| Jan '97| 0.64(0.51-0.76)| 0.97(0.93-1.03)| 1.28(1.16-1.41)| 38.7      | 455.2(397)    |
| Jun '98| same          | 1.31(1.27-1.35)| same   | 25.5      |                |

Broken p.l. with $N_H=N_H^{Gal}$; $\alpha_1$ and $E_0$ tied between the two datasets.

a Unabsorbed flux [2-10 keV] in $10^{-12}$ erg cm$^{-2}$ s$^{-1}$.

toward the observer and relativistic effects are expressed by the Doppler factor $\delta$.
Electrons are free to cool and form the low energy flat spectrum with spectral index $\alpha = 0.5$.

\[\text{Figure 2: SED, enlargement of the X-ray band with the two observations and model. Light gray line and dots refer to the Jan 1997 observation, while dark line and dots to the June 1998 BeppoSAX observation. The agreement between the model and the X-ray points in the two observations is evident.}\]

The model over-imposed on the SED is derived assuming a radius of $R = 1 \times 10^{16}$ cm, $\delta = 15$, $L_{\text{inj}} = 9.3 \times 10^{41}$ erg/s; $\gamma_{\text{max}} = 4 \times 10^{6}$, with no external photons. The slope of the injected electrons is $s = 2.7$ (1998) or $s = 1.95$ (1997). $B = 0.6$ Gauss (and $\gamma_{\text{min}} = 5 \times 10^{4}$) for the continuous line; $B = 1.2$ Gauss (and $\gamma_{\text{min}} = 3 \times 10^{4}$) for the dashed line.

4. MAGNETIC FIELD

A small change in the magnetic field, while still consistent with the X-ray (BeppoSAX) observations (see Figure 1), produces a very different TeV emission. The TeV band data can therefore put stringent constraints on the magnetic field.

The TeV upper limit indicates that the Compton peak cannot be higher than the synchrotron peak ($L_C/L_S \leq 1$); using the analytical relations discussed in Tavecchio et al. (1998) we can calculate the minimum $B$ allowed by the observed TeV upper limit for different values of $\nu_c$ and $\delta$. The values that produce a SED in agreement
with both the X-ray spectra and the TeV upper limit are very similar to those found for Mkn 501 (e.g. $\delta = 15$ and $B=0.2$ G; Kataoka et al. 1999) implying that the physical conditions of the two sources are also quite similar.

5. CONCLUSIONS

The X-ray spectrum of 1ES 1101-232 is fitted by a broken power law (a single or an absorbed power law are not statistically acceptable) with a break at 1.3 - 1.9 keV. From the first to the second observation, the spectrum varied at high energies, becoming softer (steeper). The flux has therefore decreased by about 32%, in the 2-10 keV band.

The TeV observation has not yielded a detection. However, since the TeV emission is largely sensitive to parameters like the magnetic field that produces the Synchrotron emission, interesting limits can be put on this quantity. Of course, more sensitive TeV instruments will produce more stringent constraints on the higher energy part of the spectrum and therefore on the emission mechanisms.

Multifrequency, simultaneous observations (e.g. optical, X-ray, TeV) will thus allow us to explain the variability of the sources, both from the energetic and the spectral distribution point of view.

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REFERENCES

athanese M. et al., 1998, ApJ, 501, 616. hadwick P.M. et al., 1999, ApJ, 513, 161. ossati G. et al., 1998, MNRAS, 299, 433. hisellini G. et al., 1998, MNRAS, 301, 451. ataoka, J., et al. 1999, ApJ, 514, 138. lan E. et al., 1998, ApJL, 492, L17. vecchio F. et al. 1998, ApJ, 509, 608. olter A. et al. 1998, A&A, 335, 899. olter A. et al. 1999, A&A, submitted.