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BL Lacs at the Blue End of the Blazar Sequence

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Abstract. We present the main results of seven *Beppo*SAX observations performed with the aim to find and study more objects with "extreme" synchrotron peak frequencies ($\gtrsim$ 1 keV). Five sources have been confirmed as "extreme," with one, 1ES 1426+428, showing a peak energy at or above 100 keV. Our results seem also to confirm the higher spectral variability of "high peak" objects compared to the "low peak" ones.

1. Introduction

Among blazars, BL Lacertae objects are the sources which show the highest variety of synchrotron peak frequencies, ranging from the IR to UV—soft X energies (i.e. LBLs and HBLs, respectively, see Padovani & Giommi 1995), and even up to 100 keV, as demonstrated by the cases of Mkn 501 and 1ES 2344+514 (Pian et al. 1997; Giommi et al. 2000). Although recent surveys (like DXRBS, Perlman et al. 1998; and RGB, Laurent-Muehleisen et al. 1998) are now sampling quite well most of this sequence, very little is known about the high energy branch: few objects have shown peak energies $\gtrsim$ 1 keV, and the most extreme values have been observed, up to now, only during exceptional flares. The high synchrotron frequencies displayed by these sources, flagging the presence of high relativistic electrons, makes them the most interesting objects for studying the particle acceleration mechanism at its limits, and good candidates for TeV emission through the inverse Compton process. Here we report the main results of an observational campaign with the X-ray satellite *Beppo*SAX performed with the aim to find and study other sources with these properties.

The candidates have been selected from the Einstein Slew Survey and the bright source catalog of the Rosat All Sky Survey (RASSBSC) on the basis of properties suggesting high peak frequencies: a) very high $F_x/F_{\rm radio}$ ratio ($> 3\times10^{-10}$ erg cm^{-2} s^{-1}/Jy, at [0.1–2.4] keV and 5 GHz respectively); b) strong ($> 10^{-11}$ erg cm^{-2} s^{-1}) and flat ($\alpha_x \lesssim 1$, when available) 0.1–2.4 keV X-ray spectra, connecting smoothly with the flux at lower frequencies; c) with appropriate values of $\alpha_{\rm ro}$, $\alpha_{\rm ox}$ and $\alpha_{\rm rx}$, similar to other extreme BL Lacs.

Tab. 1 lists the seven sources observed by *Beppo*SAX in this program. The data have been reduced and analyzed according to the SDC Cookbook instructions (details in Costamante et al. 2000, in preparation)

The spectra have been fitted both with single and broken absorbed power-law models: the best fits parameters are reported in Table 1, and Fig. 3 shows the Spectral Energy Distribution (SED) for all sources.

Table 1. Best fits parameters

Source	N_H 10^{20} cm^{-2}	α_1	$E_{\rm break}$ keV	α_2	$F_{\rm 1keV}$ μJy	F_{2-10} ergs/cm^{2}s	χ^2_r/d.o.f.
1ES 0120+340	5.2 *gal.*	$0.8^{-1.1}_{+0.3}$	$1.4^{-0.7}_{+1.0}$	$1.32^{-0.08}_{+0.08}$	$4.5^{-0.6}_{+2.1}$	1.3×10^{-11}	0.92/93
1ES 0033+595	61^{-12}_{+12}	$0.82^{-0.33}_{+0.12}$	$2.9^{-0.6}_{+2.4}$	$1.08^{-0.05}_{+0.11}$	$13.2^{-2.5}_{+2.5}$	6.0×10^{-11}	1.05/151
PKS 0548–322	$4.2^{-0.9}_{+1.1}$	$0.91^{-0.16}_{+0.10}$	$4.5^{-2.3}_{+1.8}$	$1.4^{-0.3}_{+0.6}$	$5.7^{-0.5}_{+0.5}$	2.3×10^{-11}	0.95/82
GB 1114+203	1.36 *gal.*	$1.23^{-0.11}_{+0.10}$	$1.2^{-0.2}_{+0.4}$	$1.90^{-0.09}_{+0.10}$	$5.0^{-0.5}_{+0.5}$	6.2×10^{-12}	0.95/81
1ES 1218+304	1.73 *gal.*	$1.02^{-0.10}_{+0.09}$	$1.4^{-0.2}_{+0.4}$	$1.56^{-0.05}_{+0.05}$	$7.3^{-0.7}_{+0.4}$	1.5×10^{-11}	0.89/93
1ES 1426+428	$1.5^{-0.3}_{+0.4}$	$0.92^{-0.04}_{+0.04}$	—	—	$4.6^{-0.2}_{+0.2}$	2.0×10^{-11}	1.00/89
H 2356–309	1.3 *gal.*	$0.78^{-0.09}_{+0.06}$	$1.8^{-0.6}_{+0.6}$	$1.10^{-0.05}_{+0.05}$	$6.2^{-0.5}_{+0.5}$	2.5×10^{-11}	0.94/35

Errors at $\Delta\chi^2 = 4.61$

2. Results

All sources, except GB 1114+203, have been detected also in the PDS instrument. For five sources the peak of the synchrotron emission is in the X-ray band, near or above 1 keV, thus confirming their "extreme" nature. GB 1114+203 and 1ES 1218+304, instead, present a curved spectrum with both the spectral indices steep (i.e. > 1), which locates the peak energy of the synchrotron emission below the observed X-ray band, thus qualifying these objects as typical HBLs. These results confirm the good efficiency of the adopted selection criteria at finding high $\nu_{\rm peak}$ sources, and we are now beginning to populate the high energy branch of the synchrotron peak sequence.

With more objects, it is interesting to compare the properties of this type of BL Lacs with those of HBLs and LBLs. In Fig. 1 α_x and the broad band spectral index $\alpha_{\rm rx}$ are plotted vs. the frequency of the synchrotron peak. As shown in the left panel, the "extreme" BL Lacs data seem to suggest a flattening of the correlation between $\alpha_{\rm rx}$ and $\nu_{\rm peak}$ at large values of $\nu_{\rm peak}$. This is in agreement with the scenario of a synchrotron peak moving smoothly from lower to higher

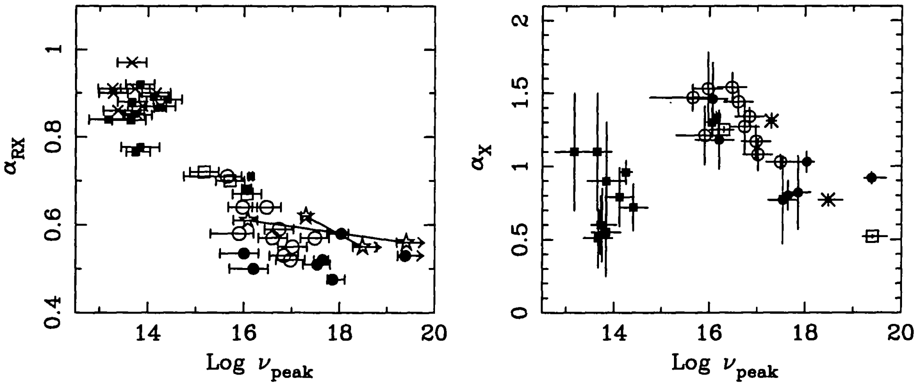

Figure 1. $\alpha_{\rm rx}$ and α_x vs. $\nu_{\rm peak}$ for our 7 sources (filled circles) together with the HBL and LBL in Wolter et al. 1998 (open marks and crosses) and the 1 Jy BL Lacs data (Padovani et al. 2000, in preparation, filled squares). The "quiescent" and "flaring" states of Mkn 501 and 1ES 2344+514 are represented, on the left as stars with connecting lines, and on the right as open squares and asterisks, respectively.

energies: as long as radio and X-ray fluxes are produced by different branches of the synchrotron emission (before and after the peak), they change differently as the peak shifts, thus changing $\alpha_{\rm rx}$. When the peak moves into the X-ray band and beyond, both fluxes come from the same branch of the synchrotron emission, and so begin to change similarly as the peak moves at still higher frequencies, stabilizing $\alpha_{\rm rx}$ at a common (flat) value.

The "moving peak scenario" also nicely accounts for the shape of the relation α_x–$\nu_{\rm peak}$. In this case, the spectral index just traces the upcoming of the synchrotron emission in the X-ray band: it steepens from LBLs to HBLs, when the main contribution in the X-ray band passes from the flat inverse Compton emission to the steep tail of the synchrotron emission, and then starts flattening again as the synchrotron peak moves into the X-ray band and beyond, eventually reaching a "stable" flat value corresponding to the typical slope of the synchrotron emission well before the peak.

Among the five extreme sources observed, the most interesting one turned out to be 1ES 1426+428. This object has shown a flat spectral index ($\alpha_x = 0.92$) up to the PDS band, after taking into account other contaminating objects in the PDS f.o.v. (details in Costamante et al. 2000, in preparation). **This constrains the synchrotron peak to lie near or above 100 keV**, and makes this object the third source ever found with such extreme peak energies. Quite interestingly, however, as opposed to the other two "over 100 keV" sources, the X-ray flux during the observation was not particularly high (see Fig. 2, left): it is then likely that 1ES 1426+428 is the first source found in a "quiescent extreme" state. Note that all three sources, in previous observations, were characterized by steep spectral indices, i.e. with $\nu_{\rm peak}$ below the X-ray band, like typical HBLs. These objects have undergone a shift in the synchrotron peak frequencies of two orders of magnitude or more, with or without luminosity changes (see Fig. 2, right). It is still uncertain if this extreme spectral variability is common to all blazars or only to HBLs ($\nu_{\rm peak} \gtrsim 10^{15}$ Hz). However, it is interesting to note that

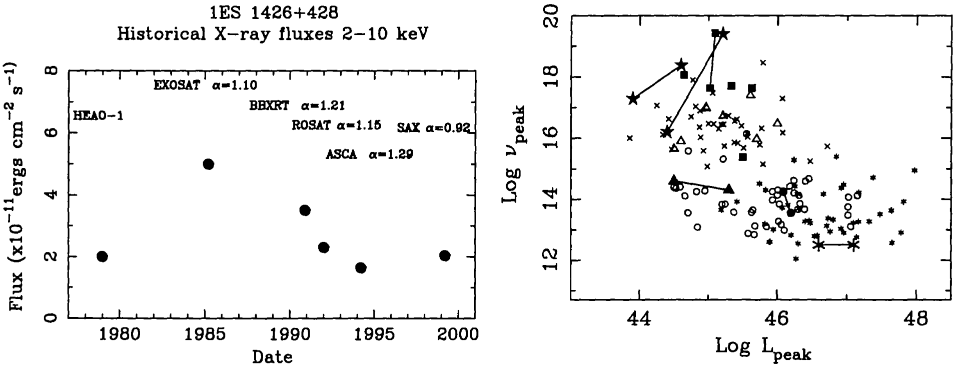

Figure 2. Left: Historical 2–10 keV fluxes for 1ES 1426+428. Above each point are also reported the instrument and the measured 2–10 keV spectral index. Right: peak frequencies vs. luminosity at the peak. Crosses, circles and asterisk are BL Lacs and FSRQs data from Fossati et al. 1998. Open triangles are the HBLs from Wolter et al. 1998, filled squares are our data. The lines connect different states for Mkn 501 and 1ES 2344+514 (stars), 1ES 1426+428 (filled squares), BL Lac (filled triangles), OJ 287 (filled circles) and 3C279 (large asterisks).

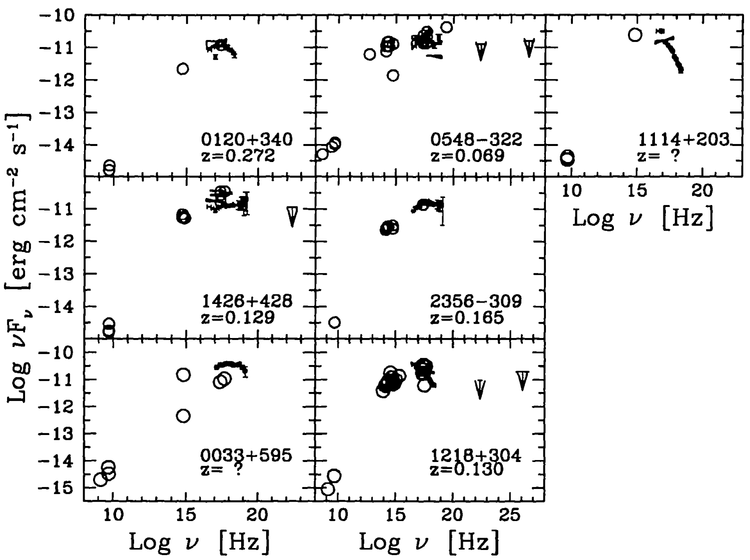

Figure 3. The SEDs of the seven sources, made with *Beppo*SAX and literature data.

for some well studied “low peak” sources (for example, BL Lac itself, OJ 287 and 3C279, see Fig. 2) the value of $\nu_{\rm peak}$ seems to remain much more constant.

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