We present new BeppoSAX observations of seven BL Lacertae objects selected from the 1-Jy sample plus one additional source. The collected data cover the energy range 0.1–10 keV (observer’s frame), reaching 50 keV for one source (BL Lac). All sources characterized by a peak in their multifrequency spectra at infrared/optical energies (i.e., of the low-energy peaked BL Lac type, LBL) display a relatively flat $\alpha_X \approx 0.9$ X-ray spectrum, which we interpret as inverse Compton emission. Four objects (two-thirds of the LBLs) show some evidence for a low-energy steepening, which is probably due to the synchrotron tail merging into the inverse Compton component around 1–3 keV. If this were generally the case with LBLs, it would explain why the 0.1–2 keV ROSAT spectra of our sources are systematically steeper than the BeppoSAX ones ($\Delta\alpha_X \approx 0.5$). The broad-band spectral energy distributions fully confirm this picture, and a synchrotron inverse Compton model allows us to derive the physical parameters (intrinsic power, magnetic field, etc.) of our sources. Combining our results with those obtained by BeppoSAX on BL Lacs covering a wide range of synchrotron peak frequency, $n_{\text{peak}}$, we confirm and clarify the dependence of the X-ray spectral index on $n_{\text{peak}}$ originally found in ROSAT data.

Key words: galaxies: active – BL Lacertae objects: general – X-rays: galaxies.
capabilities, is particularly well suited for a detailed analysis of the individual X-ray spectra of these sources.

In this paper we present BeppoSAX observations of eight BL Lacs, including six LBLs and two HBLs. The sample is well defined (in particular, it is not a compilation of known hard X-ray sources), being extracted, apart from one source, from the radio-selected 1-Jy sample, for which a wealth of information at many wavelengths is available.

In Section 2 we present our sample, Section 3 discusses the observations and the data analysis, while Section 4 describes the results of our spectral fits to the BeppoSAX data. Section 5 deals with the ROSAT data for our sources, while Section 6 presents the spectral energy distributions and synchrotron–inverse Compton fits to the data, and Section 7 deals with the dependence of the spectral indices on synchrotron peak frequency. Finally, Section 8 discusses our conclusions. Throughout this paper spectral indices are written $S \propto \nu^{-\alpha}$.

2 THE SAMPLE

The 1-Jy sample of BL Lacs is presently the only sizeable, complete sample of radio-bright BL Lacs. It includes 34 objects with radio flux $>1$ Jy at 5 GHz (Stickel et al. 1991). All 1-Jy BL Lacs have been studied in detail in the radio and optical bands; all objects have also soft X-ray data, primarily from ROSAT.

We selected for BeppoSAX observations all 1-Jy BL Lacs with 0.1–10 keV X-ray flux larger than $2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ (estimated from an extrapolation of the single-power-law fits derived for these objects from ROSAT data; Urry et al. 1996). This included twenty 1-Jy BL Lacs (or $\sim 60$ per cent of the sample). Some of these sources have been included in other BeppoSAX programmes (e.g., Mrk 501; Pian et al. 1998; S5 0716+714; Giommi et al. 1999). We present here the results obtained for the seven objects observed in Cycle 1 plus B2 0912+29, which was included in a programme aimed at studying ‘intermediate’ BL Lacs. All sources apart from PKS 2005+489 and B2 0912+29 are LBLs. The object list and basic characteristics are given in Table 1, which presents the source name, type, position, redshift, $R$ magnitude, 5-GHz radio flux and Galactic $N_H$.

3 OBSERVATIONS AND DATA ANALYSIS

A complete description of the BeppoSAX mission is given by Boella et al. (1997a). The relevant instruments for our observations are the co-aligned Narrow Field Instruments (NFI), which include one Low Energy Concentrator Spectrometer (LECS; Parmar et al. 1997) sensitive in the 0.1–10 keV band, three identical Medium Energy Concentrator Spectrometers (MECS; Boella et al. 1997b) covering the 1.5–10 keV band, and the Phoswich Detector System (PDS; Frontera et al. 1997) co-aligned with the LECS and the MECS. The PDS instrument is made up of four units, and was operated in collimator rocking mode, with a pair of units pointing at the source and the other pair pointing at the background, the two pairs switching on and off source every 96 s. The net source spectra have been obtained by subtracting the ‘off’ from the ‘on’ counts. A journal of the observations is given in Table 2.

The data analysis was based on the linearized, cleaned event files obtained from the BeppoSAX Science Data Center (SDC) on-line archive (Giommi & Fiore 1997). The data from the three MECS instruments were merged into one single event file by the SDC,

Table 1. Sample properties.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>RA (J2000)</th>
<th>Dec. (J2000)</th>
<th>$z$</th>
<th>$R_{mag}$</th>
<th>$F_{5\text{GHz}}$ (Jy)</th>
<th>Galactic $N_H$ ($10^{20}$ cm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS 0048−097</td>
<td>LBL</td>
<td>00 50 41.3</td>
<td>−09 29 06</td>
<td>&gt;0.2</td>
<td>16.5</td>
<td>2.0</td>
<td>3.85</td>
</tr>
<tr>
<td>OJ 287</td>
<td>LBL</td>
<td>08 54 49.0</td>
<td>+20 06 32</td>
<td>0.306</td>
<td>15.0</td>
<td>2.6</td>
<td>2.75</td>
</tr>
<tr>
<td>B2 0912+29</td>
<td>HBL</td>
<td>09 15 52.3</td>
<td>+29 33 21</td>
<td>−</td>
<td>15.8</td>
<td>0.2</td>
<td>2.11</td>
</tr>
<tr>
<td>PKS 1144−379</td>
<td>LBL</td>
<td>11 47 01.4</td>
<td>−38 12 10</td>
<td>1.048</td>
<td>16.5</td>
<td>1.6</td>
<td>7.64</td>
</tr>
<tr>
<td>PKS 1519−273</td>
<td>LBL</td>
<td>15 22 37.7</td>
<td>−27 30 10</td>
<td>&gt;0.2</td>
<td>20.1</td>
<td>2.4</td>
<td>8.66</td>
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<tr>
<td>4C 56.27</td>
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<td>18 24 07.2</td>
<td>+56 51 00</td>
<td>0.664</td>
<td>18.5</td>
<td>1.7</td>
<td>4.16</td>
</tr>
<tr>
<td>PKS 2005−489</td>
<td>HBL</td>
<td>20 09 25.4</td>
<td>−48 49 55</td>
<td>0.071</td>
<td>13.5</td>
<td>1.2</td>
<td>5.08</td>
</tr>
<tr>
<td>BL Lac</td>
<td>LBL</td>
<td>22 02 43.2</td>
<td>+42 16 40</td>
<td>0.069</td>
<td>14.0</td>
<td>4.8</td>
<td>20.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>RA (J2000)</th>
<th>Dec. (J2000)</th>
<th>$z$</th>
<th>$R_{mag}$</th>
<th>$F_{5\text{GHz}}$ (Jy)</th>
<th>Galactic $N_H$ ($10^{20}$ cm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS 0048−097</td>
<td>LBL</td>
<td>00 50 41.3</td>
<td>−09 29 06</td>
<td>&gt;0.2</td>
<td>16.5</td>
<td>2.0</td>
<td>3.85</td>
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<tr>
<td>OJ 287</td>
<td>LBL</td>
<td>08 54 49.0</td>
<td>+20 06 32</td>
<td>0.306</td>
<td>15.0</td>
<td>2.6</td>
<td>2.75</td>
</tr>
<tr>
<td>B2 0912+29</td>
<td>HBL</td>
<td>09 15 52.3</td>
<td>+29 33 21</td>
<td>−</td>
<td>15.8</td>
<td>0.2</td>
<td>2.11</td>
</tr>
<tr>
<td>PKS 1144−379</td>
<td>LBL</td>
<td>11 47 01.4</td>
<td>−38 12 10</td>
<td>1.048</td>
<td>16.5</td>
<td>1.6</td>
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<td>LBL</td>
<td>15 22 37.7</td>
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<td>&gt;0.2</td>
<td>20.1</td>
<td>2.4</td>
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<tr>
<td>4C 56.27</td>
<td>LBL</td>
<td>18 24 07.2</td>
<td>+56 51 00</td>
<td>0.664</td>
<td>18.5</td>
<td>1.7</td>
<td>4.16</td>
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<td>PKS 2005−489</td>
<td>HBL</td>
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<td>−48 49 55</td>
<td>0.071</td>
<td>13.5</td>
<td>1.2</td>
<td>5.08</td>
</tr>
<tr>
<td>BL Lac</td>
<td>LBL</td>
<td>22 02 43.2</td>
<td>+42 16 40</td>
<td>0.069</td>
<td>14.0</td>
<td>4.8</td>
<td>20.15</td>
</tr>
</tbody>
</table>

Table 2. BeppoSAX journal of observations.

<table>
<thead>
<tr>
<th>Name</th>
<th>Exp.</th>
<th>LECS Count rate$^a$ (ct s$^{-1}$)</th>
<th>Exp.</th>
<th>MECS Count rate$^a$ (ct s$^{-1}$)</th>
<th>Exp.</th>
<th>PDS Count rate$^a$ (ct s$^{-1}$)</th>
<th>Observing date</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS 0048−097</td>
<td>4602</td>
<td>0.020 ± 0.006</td>
<td>9810</td>
<td>0.023 ± 0.002</td>
<td>–</td>
<td>–</td>
<td>1997 Dec 19</td>
</tr>
<tr>
<td>OJ 287</td>
<td>5105</td>
<td>0.018 ± 0.006</td>
<td>10707</td>
<td>0.032 ± 0.002</td>
<td>4511</td>
<td>0.128 ± 0.094</td>
<td>1997 Nov 24</td>
</tr>
<tr>
<td>B2 0912+29</td>
<td>9195</td>
<td>0.054 ± 0.004</td>
<td>23832</td>
<td>0.048 ± 0.002</td>
<td>–</td>
<td>–</td>
<td>1997 Nov 14−15</td>
</tr>
<tr>
<td>PKS 1144−379</td>
<td>10649</td>
<td>0.010 ± 0.003</td>
<td>22754</td>
<td>0.019 ± 0.001</td>
<td>–</td>
<td>–</td>
<td>1997 Jan 10−11</td>
</tr>
<tr>
<td>PKS 1519−273</td>
<td>9266</td>
<td>0.009 ± 0.003</td>
<td>26906</td>
<td>0.009 ± 0.001</td>
<td>–</td>
<td>–</td>
<td>1998 Feb 1</td>
</tr>
<tr>
<td>4C 56.27</td>
<td>4104</td>
<td>0.014 ± 0.007</td>
<td>13382</td>
<td>0.015 ± 0.001</td>
<td>–</td>
<td>–</td>
<td>1997 Oct 11</td>
</tr>
<tr>
<td>PKS 2005−489</td>
<td>–</td>
<td>–</td>
<td>9853</td>
<td>1.371 ± 0.012</td>
<td>–</td>
<td>–</td>
<td>1996 Sep 29−30</td>
</tr>
<tr>
<td>BL Lac</td>
<td>12260</td>
<td>0.094 ± 0.003</td>
<td>13750</td>
<td>0.150 ± 0.003</td>
<td>8278</td>
<td>0.191 ± 0.094</td>
<td>1997 Nov 8</td>
</tr>
</tbody>
</table>

$^a$Net count rate full band.
based on sky coordinates. The event file was then screened with a
time filter given by SDC to exclude those intervals related to events
without attitude solution (i.e., conversion from detector to sky
coordinates; see Fiore et al. 1999). This was done to avoid an
artificial decrease in the flux. As recommended by the SDC, the
channels 1–10 and above 4 keV for the LECS and 0–36 and
220–256 for the MECS were excluded from the spectral analysis,
because of residual calibration uncertainties. Except for PKS
1519–273, where an extraction radius of 4 arcmin was used for the
LECS (see below), spectra and light curves have been extracted
using the standard extraction radii of 8 and 4 arcmin, for the LECS
and MECS respectively.

The spectral analysis was performed using the matrices and
blank-sky background files released in 1998 November by the
SDC. For the LECS, we were careful to choose the blank-sky file
extracted in the same coordinate frame as the source file. This is
necessary to avoid an error in the background subtraction that
arises when using source and background files extracted in
coordinate frames of different pixel size (in this case, raw, detector or sky coordinates). Raw pixels, in fact, have a size of
14 arcsec, while detector and sky pixels have a size of 8 arcsec. Therefore, an equal extraction region of 8 arcmin, for example, is
obtained with a different number of pixels. In this situation,
however, the spectral files extracted in the two cases have different
values of the keyword used in the analysis software to rescale the
background to the source extraction area. The two files, in short,
appear to have been extracted with different areas (the difference is
≈35 per cent), and the background in such a case would be
wrongly rescaled accordingly.

Because of the importance of the band below 1 keV to assess the
presence of extra absorption or soft excess (indicative of a double
power-law spectrum), we have also checked the LECS data for
differences in the cosmic background between local and blank-sky
field observations, comparing spectra extracted from the same
areas on the detector (namely, two circular regions outside the
10-arcmin radius central region, located at the opposite corners
with respect to the two on-board radioactive calibration sources).
No relevant differences were found, except in the BL Lac and PKS
1519–273 observations.

For BL Lac, the blank-sky background up to 0.5–0.6 keV is
higher than that during our observation, causing a low level of
counts in the source spectrum. The signal-to-noise ratio (S/N) at
low energy, however, is very low, because of the high Galactic
absorption (∼2–3.6 × 10²¹ cm⁻², see Table 1), and no detection is
expected below 0.3–0.4 keV. In a conservative approach, we have
therefore limited the spectral analysis to energies above 0.5 keV.
However, we also checked the results down to 0.1 keV using a
different background file, obtained by multiplying the blank-sky
field at the source position by the ratio of the local to blank field
backgrounds extracted in the two areas far from the source. This
should give an estimate of the local background at the source
position. No significant differences or trends between the two cases
were found.

For PKS 1519–273, the local background presents an
anomalously high flux between ~0.7 and 1 keV. This feature is
also present in the backgrounds extracted from the two circular
regions independently, so it is unlikely that its cause could be a
very faint serendipitous source. This problem becomes more
evident with larger extraction radii, as a result of the very low flux
of the source. To minimize this effect and increase the S/N, an
extraction radius of 4 arcmin was used. Minor differences were
found for PKS 1144–379: the local background was uniformly
higher by ~20 per cent, so the blank field background was rescaled
accordingly, as suggested by the SDC (see Fiore et al. 1999).

### 3.1 Time analysis

Using the software package XRONOS we looked for time variability
in every observation, binning the data in intervals from 500 to
4000 s, with null results except for PKS 1144–379. In this case,
there might be an indication of variability, as the light curves
present a ‘wave-like’ shape, in particular on time-scales ~5 h.
The resulting χ² value is consistent with no variability at the ~3 per
cent level, so this result is not compelling, but the same pattern is
present in every single MECS detector, within the uncertainties.
This level remains roughly constant across different binnings,
given sufficient statistics (i.e., with time bins ≥1200 s). Also,
considering the whole sample, the significance is ‘borderline’: a
spurious variability of this level is expected, on average, every ~33
observations, in the hypothesis of a parent population of constant
sources. In our case this translates to 0.24 times every eight
sources. The LECS light curve is much less sampled and consistent
with no variability at the ~17 per cent level, although similar in
shape to the MECS one. An inspection of the local background
light curve showed no significant variation. Fig. 1 shows the net
source light curve of the three MECS units merged together. If the
variations are real, the source varied up to a factor ~3 in 4 h.

### 4 SPECTRAL FITS

The spectral analysis was performed with the XSPEC 10.0 package.
Using the program GRPPHA, the spectra were rebinned with more
than 20 counts in every new bin and using the rebinning files
provided by the SDC. Various checks using different rebinning
strategies have shown that our results are independent of the
adopted rebinning within the uncertainties. The data were analysed
applying the Gehrels statistical weight (Gehrels 1986), in case the
resulting net counts were below 20 (typically 12–15 in the
low-energy band of LECS). The LECS/MECS normalization factor was
left free to vary in the range 0.65–1.0, as suggested by SDC (see
Fiore et al. 1999). The X-ray spectra of our sources are shown in
Fig. 2.
At first, we fitted the combined LECS and MECS data with a single power-law model with Galactic and free absorption. The absorbing column was parametrized in terms of $N_H$, the H I column density, with heavier elements fixed at solar abundances and cross-sections taken from Morrison & McCammon (1983). The Galactic value was derived from the NH program at HEASARC (based on Dickey & Lockman 1990), when more accurate estimates were not available (see Table 1). The Galactic $N_H$ value for BL Lac was fixed at two values: that from Elvis, Lockman & Wilkes (1989), based on dedicated 21-cm observations, and the sum of this value and that inferred from millimetre observations, which include the contribution from molecular hydrogen (Lucas & Liszt 1993). The $N_H$ parameter was also set free to vary for all sources (apart from PKS 2005–489, which has no LECS data) to check for intrinsic absorption and/or indications of a “soft excess”.

Our results are presented in Table 3, which gives the name of the sources, and ratio of data to fit. Data are from the LECS and MECS instruments, apart from PKS 2005–489, which only has MECS data, and BL Lac, which has also a PDS detection. The data are fitted with a single power-law model with Galactic absorption.
source in column 1, \(N_{\text{H}}\) in column 2, the energy index \(\alpha_X\) in column 3, the 1-keV flux in \(\mu\)Jy in column 4, the unabsorbed 2–10 keV and 0.1–2.4 keV fluxes in columns 5 and 6, the LECS/MECS normalization in column 7, the reduced chi-squared and number of degrees of freedom, \(\chi^2/\text{dof}\) in column 8, and the \(F\)-test probability that the decrease in \(\chi^2\) due to the addition of a new parameter (free \(N_{\text{H}}\)) is significant in column 9. The errors quoted on the fitting parameters are the 90 per cent uncertainties for one and two parameters of interest, Galactic and free \(N_{\text{H}}\) respectively. The errors on the 1-keV flux reflect the statistical errors only and not the model uncertainties.

Two results are immediately apparent from Table 3. First, the fitted \(N_{\text{H}}\) values agree with the Galactic ones for most sources (within the rather large errors); this is confirmed by an \(F\)-test, which shows that the addition of \(N_{\text{H}}\) as a free parameter does not result in a significant improvement in the \(\chi^2\) values (column 9 of Table 3), with the exception of BL Lac (\(F\)-test done for larger \(N_{\text{H}}\) value). Secondly, the fitted energy indices are relatively flat, \(\alpha_X \approx 1\) within the errors for all but two sources. The mean value is \((\alpha_X) = 0.98 \pm 0.10\) and the weighted mean is \((\alpha_X) = 1.26 \pm 0.03\). This latter value is clearly dominated by PKS 2005–489, an HBL with a very well-determined slope. Excluding this source and the other HBL, B2 0912+29, we derive a mean value \((\alpha_X) = 0.87 \pm 0.09\) and a weighted mean \((\alpha_X) = 0.83 \pm 0.09\).

Some of our sources appear to show a low-energy excess, as illustrated by the fact that the best-fitting \(N_{\text{H}}\) in Table 3 is below the Galactic value for four sources, namely PKS 0048–097, PKS 1144–379, PKS 1519–273 and BL Lac. We then fitted a broken power-law model to these data. Although this resulted in a better fit, an \(F\)-test shows that the improvement is more suggestive than significant, with probabilities ranging from 86–88 per cent for PKS 0048–097 and PKS 1144–379, to 93 per cent for PKS 1519–273 and BL Lac. The best-fitting spectra, however, all point in the same direction: a flatter component emerging at higher energies. In fact, they are all obviously concave with quite a large spectral change, with \((\alpha_X - \alpha_H) = 0.8 \pm 0.1\), and energy breaks around \(E \sim 1\)–3 keV. The hard X-ray spectral index is \((\alpha_H) = 0.6 \pm 0.1\), while \((\alpha_S) = 1.5 \pm 0.1\). Some evidence for concave spectra comes also from the shape of the ratio of the data to the single power-law fits, shown in Fig. 2. We note that by adding up the \(\chi^2\) values for the four sources, an \(F\)-test shows that the improvement in the fit provided by a double power-law model for the four sources together is significant at the \(\sim 96\) per cent level.

### 4.2 The PDS detections

Two sources were detected also by the PDS instrument: BL Lac and OJ 287. Owing to the low statistics, the spectra have been heavily rebinned, resulting in three and one points for BL Lac and OJ 287, respectively, in the detection range. The significance level of the detection, obtained by grouping the channels, is quite high for BL Lac (3.8σ), while it is only marginal for OJ 287 (2.3σ). The relatively low flux for the latter source is at the level expected from background fluctuations, and therefore we do not regard this detection as real.

Table 3 reports the results of single power-law fits including the data from all the three Narrow Field Instruments for BL Lac. The normalization factor between PDS and MECS was fixed at 0.86, as derived from intercalibration tests performed on known sources (see Fiore et al. 1999). The PDS points are compatible with the best fit of the LECS and MECS data, even if slightly above the model.

Because of the absence of imaging capabilities, the PDS spectra can be contaminated by serendipitous sources in its field of view. We therefore first checked the MECS image of BL Lac for the presence of other sources, finding two in the field but with count rates a factor of 10 and 40 fainter than the target. However, given its wide field of view (\(\sim 1.4\)° full width at half-maximum), larger than the LECS and MECS ones (\(\sim 28\) arcmin for the MECS), there is also the possibility of contamination by hard serendipitous sources not visible in the MECS images. We therefore checked WGA CAT, the publicly available database of \(ROSAT\) sources (White, Giommi & Angelini 1995), for serendipitous X-ray sources within \(\sim 90\) arcmin from BL Lac. We found five, but all of them were at least an order of magnitude fainter than our target, and with relatively steep spectral indices (derived from the hardness ratios). It then follows that it is very unlikely that any of these sources can contribute significantly to the PDS flux of BL Lac, although the possibility remains that some hard X-ray sources might not have been detected by \(ROSAT\).

### 4.3 Notes on individual sources

#### 4.3.1 PKS 1144–379

LECS data below 1 keV present a clear trend, suggesting a steep spectral index with stronger evidence than that provided by the \(F\)-test, given the few points involved. MECS data present a feature around 4 keV, but given the available S/N and resolution it is hard to assess the reality of this feature.
Table 3. Single power-law fits, LECS + MECS.

<table>
<thead>
<tr>
<th>Name</th>
<th>$N_H$ (10^{20} cm^{-2})</th>
<th>$\alpha_X$</th>
<th>$F_{1\text{keV}}$ (µJy)</th>
<th>$F_{1-10\text{keV}}$ (erg cm^{-2} s^{-1})</th>
<th>$F_{0.1-2.4\text{keV}}$ (erg cm^{-2} s^{-1})</th>
<th>Norm (LECS/MECS)</th>
<th>$\chi^2$/dof</th>
<th>F-test, notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS 0048−097</td>
<td>3.85 fixed</td>
<td>0.9^{+0.3}_{-0.1}</td>
<td>0.3^{+0.02}_{-0.01}</td>
<td>1.45e-12</td>
<td>2.37*e-12</td>
<td>0.82</td>
<td>0.58/12</td>
<td></td>
</tr>
<tr>
<td>PKS 1519−273</td>
<td>8.66 fixed</td>
<td>1.1^{+0.4}_{-0.4}</td>
<td>0.2^{+0.01}_{-0.01}</td>
<td>0.62e-12</td>
<td>1.51*e-12</td>
<td>0.77</td>
<td>0.67/8</td>
<td></td>
</tr>
<tr>
<td>PKS 2005−489</td>
<td>5.08 fixed</td>
<td>1.3^{+0.04}_{-0.04}</td>
<td>2.5^{+1.1}_{-1.1}</td>
<td>6.09e-11</td>
<td>2.60*e-10</td>
<td>–</td>
<td>1.04/73</td>
<td>–</td>
</tr>
</tbody>
</table>

4.3.2 OJ 287

MECS data seem to show an emission feature around 2.3 keV but, again, the low S/N does not allow reliable conclusions to be drawn. The X-ray spectral index we obtain ($\alpha_X = 0.6 \pm 0.2$) agrees with the value derived by Kubo et al. (1998) of 0.62 ± 0.01, based on ASCA observations made in 1994 November. Our flux, however, is ~50 per cent smaller.

4.3.3 PKS 2005−489

This source experienced a pronounced flare in 1998 November, about two years after our BeppoSAX observations. Tagliaferri et al. (2001) observed it with BeppoSAX on November 1−2 and fitted a single power-law to the data over the 0.1−200 keV range with $\alpha_X = 1.18 \pm 0.02$ and free $N_H$. This is slightly flatter than our value of 1.33 ± 0.04, derived between 1 and 10 keV (as we do not have LECS data) and assuming a Galactic $N_H$ close to their best-fitting free $N_H$ (see also Fig. 6). Their data actually require a broken power law with a break around 2 keV and a steepening $\Delta \alpha_X \sim 0.2$ at higher energies. Their X-ray flux was ~3 times higher than our value. Perlman et al. (1999) followed the evolution of the flare between October 14 and December 31 when the X-ray flux changed by a factor of 4. The X-ray spectral index in the 2–10 keV band also varied between 1.3 and 1.8.

4.3.4 BL Lac

Our results are consistent with those of Sambruna et al. (1999), based on ASCA observations obtained in 1995 November. Their single power-law fit, assuming the same (fixed) $N_H$ value, has an energy index $\alpha_X = 1.08 \pm 0.03$, to be compared with our value of 0.96 ± 0.08. Their 1-keV flux, derived for their fit with free $N_H$, and their broken power-law fit are also consistent with ours. This shows that by the time of our BeppoSAX observations (1997 November) the source had returned to its pre-flare status. In 1997 July, in fact, during its optical/X-ray/γ-ray flare, the X-ray flux of BL Lac was ~3 times higher, with a much flatter X-ray spectrum ($\alpha_X \sim 0.4–0.7$; Tanihata et al. 2000; see also Fig. 6).

5 ROSAT PSPC DATA

In order to compare our results with previous (soft) X-ray observations and especially to take advantage of the higher resolution and collecting area at low energies, we used data from the ROSAT Position Sensitive Proportional Counter (PSPC) public archive. The 1-Jy BL Lac ROSAT data had been originally published by Urry et al. (1996), while those for B2 0912+29 were published by Lamer et al. (1996). In order to ensure a uniform procedure for the whole sample, we have reanalysed all ROSAT data, obtaining results consistent within the errors with those already published.

The journal of the ROSAT observations is given in Table 4. The basic event files from the archive have been corrected for gain variations on the detector surface with the program PCSSASSCORR in FTOOLS, when not already done by the standard reduction process (SASS version 7.8 and later; M. Corcoran, private communication). Since all the sources were ROSAT targets, a standard extraction radius of 3 arcmin (2.5 arcmin when serendipitous sources were present in the field or when the source was particularly weak) was
used, to avoid the possible loss of soft photons as a result of the
ghost imaging effect. We have used the appropriate response
matrices for the different gain levels of the PSPC B detector before
and after 1991 October 14 (gain 1 and gain 2, respectively). The
background has been evaluated in two circular regions (of radius
approximately 20–30 pixels) away from the central region and from other
serendipitous sources, but inside the central rib ring of the detector.
The spectra have been rebinned (using GRPPHA) to have at least 20
net counts in every new bin, to justify the use of $\chi^2$ statistics.
Channels 1–11 and 212–256 have been excluded from the analysis,
because of calibration uncertainties.

As for the BeppoSAX data, we fitted the ROSAT PSPC data with a
single power-law model with Galactic and free absorption. Our
results are presented in Table 5, which gives the name of the source
in column 1, $N_{\text{H}}$ in column 2, the energy index $\alpha_X$ in column 3, the
1-keV flux in $\mu$Jy in column 4, the unabsorbed 0.1–2.4 keV flux in
column 5, the reduced chi-squared and number of degrees of freedom, $\chi^2$/dof in column 6, and the observing date in column 7.
The errors quoted on the fitting parameters are the 90 per cent
uncertainties for one and two parameters of interest, Galactic and free
$N_{\text{H}}$ respectively. The errors on the 1-keV flux reflect the
statistical errors only and not the model uncertainties.

Table 4. ROSAT journal of observations.

<table>
<thead>
<tr>
<th>Name</th>
<th>Exposure (s)</th>
<th>Full band net count rate (ct s$^{-1}$)</th>
<th>Observing date</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS 0048–097</td>
<td>8359</td>
<td>0.408 ± 0.007</td>
<td>1993 Jul 4–15</td>
</tr>
<tr>
<td>OJ 287</td>
<td>3566</td>
<td>0.285 ± 0.010</td>
<td>1991 Apr 16</td>
</tr>
<tr>
<td></td>
<td>6702</td>
<td>0.602 ± 0.010</td>
<td>1991 Nov 10–11</td>
</tr>
<tr>
<td></td>
<td>3277</td>
<td>0.621 ± 0.014</td>
<td>1993 Oct 19</td>
</tr>
<tr>
<td>B2 0912+29</td>
<td>2809</td>
<td>0.428 ± 0.013</td>
<td>1991 Apr 24–May 6</td>
</tr>
<tr>
<td>PKS 1144–379</td>
<td>7745</td>
<td>0.115 ± 0.004</td>
<td>1993 Jul 7–8</td>
</tr>
<tr>
<td>PKS 1519–273</td>
<td>2548</td>
<td>0.106 ± 0.008</td>
<td>1993 Aug 17–18</td>
</tr>
<tr>
<td>4C 56.27</td>
<td>5896</td>
<td>0.138 ± 0.005</td>
<td>1992 Jun 19–20</td>
</tr>
<tr>
<td>PKS 2005–489</td>
<td>11320</td>
<td>2.760 ± 0.016</td>
<td>1992 Apr 27–29</td>
</tr>
<tr>
<td></td>
<td>11457</td>
<td>1.667 ± 0.012</td>
<td>1992 Oct 28–Nov 1</td>
</tr>
<tr>
<td>BL Lac</td>
<td>2167</td>
<td>0.176 ± 0.010</td>
<td>1992 Dec 22–23</td>
</tr>
</tbody>
</table>

Table 5. ROSAT PSPC, single power-law fits.$^a$

<table>
<thead>
<tr>
<th>Name</th>
<th>$N_{\text{H}}$ (10$^{21}$ cm$^{-2}$)</th>
<th>$\alpha_X$</th>
<th>$F_{1\text{-keV}}$ ($\mu$Jy)</th>
<th>$F_{[0.1-2.4]}$ (erg cm$^{-2}$ s$^{-1}$)</th>
<th>$\chi^2$/dof</th>
<th>Observing date</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS 0048–097</td>
<td>3.85 fixed 4.39$^{+0.60}_{-0.58}$</td>
<td>1.63 ± 0.04</td>
<td>0.86 ± 0.03</td>
<td>1.22e–11</td>
<td>0.76/55</td>
<td>1993 Jul 4–15</td>
</tr>
<tr>
<td>OJ 287</td>
<td>2.75 fixed 2.71$^{+1.10}_{-0.92}$</td>
<td>1.17 ± 0.08</td>
<td>0.61 ± 0.04</td>
<td>5.34e–12</td>
<td>0.79/31</td>
<td>1991 Apr 16</td>
</tr>
<tr>
<td></td>
<td>2.75 fixed 2.37$^{+0.44}_{-0.41}$</td>
<td>1.62 ± 0.04</td>
<td>0.97 ± 0.04</td>
<td>1.34e–11</td>
<td>0.89/80</td>
<td>1991 Nov 10–11</td>
</tr>
<tr>
<td></td>
<td>2.75 fixed 2.72$^{+0.67}_{-0.62}$</td>
<td>1.29 ± 0.07</td>
<td>1.24 ± 0.08</td>
<td>1.22e–11</td>
<td>0.99/54</td>
<td>1993 Oct 19</td>
</tr>
<tr>
<td></td>
<td>2.11 fixed 2.11$^{+0.78}_{-0.74}$</td>
<td>1.53 ± 0.08</td>
<td>0.60 ± 0.05</td>
<td>7.46e–12</td>
<td>0.75/31</td>
<td>1991 Apr 24–May 6</td>
</tr>
<tr>
<td>PKS 1144–379</td>
<td>7.64 fixed 10.0$^{+3.9}_{-2.3}$</td>
<td>1.37 ± 0.14</td>
<td>0.41 ± 0.03</td>
<td>4.41e–12</td>
<td>1.04/16</td>
<td>1993 Jul 7–8</td>
</tr>
<tr>
<td></td>
<td>8.66 fixed 32.7$^{+5.5}_{-2.3}$</td>
<td>1.12 ± 0.26</td>
<td>0.40 ± 0.05</td>
<td>3.35e–12</td>
<td>1.56/10</td>
<td>1993 Aug 17–18</td>
</tr>
<tr>
<td>4C 56.27</td>
<td>4.16 fixed 5.63$^{+1.41}_{-1.99}$</td>
<td>0.23 ± 0.15</td>
<td>0.45 ± 0.03</td>
<td>2.51e–12</td>
<td>0.79/23</td>
<td>1992 Jun 19–20</td>
</tr>
<tr>
<td></td>
<td>5.08 fixed 4.28$^{+0.19}_{-0.19}$</td>
<td>2.25 ± 0.02</td>
<td>5.15 ± 0.07</td>
<td>1.74e–10</td>
<td>2.15/89</td>
<td>1992 Apr 27–29</td>
</tr>
<tr>
<td></td>
<td>5.08 fixed 3.54$^{+0.23}_{-0.23}$</td>
<td>2.43 ± 0.02</td>
<td>2.70 ± 0.05</td>
<td>1.22e–10</td>
<td>3.48/65</td>
<td>1992 Oct 28–Nov 1</td>
</tr>
<tr>
<td></td>
<td>36.0 fixed 33.7$^{+4.58}_{-2.44}$</td>
<td>2.13 ± 0.36</td>
<td>1.55 ± 0.14</td>
<td>4.38e–11</td>
<td>0.56/11</td>
<td>1992 Dec 22–23</td>
</tr>
</tbody>
</table>

$^a$ The errors are at 90 per cent confidence level for one (with fixed $N_{\text{H}}$) and two parameters of interest.
Table 5 shows that the fitted $N_H$ values are consistent with the Galactic ones for most sources; this is confirmed by an $F$-test, which shows that the addition of $N_H$ as a free parameter does not result in a significant improvement in the $\chi^2$ values. The fit for PKS 2005−489 is not particularly good, especially for Galactic $N_H$. The fact that the free $N_H$ value is lower than the Galactic one suggests the presence of a ‘soft excess’. Indeed, Comastri et al. (1997) fitted a broken power-law model to these data, with a steep soft index, $N_{2}$. For OJ 287 and PKS 2005−489, which have multiple ROSAT observations, we took the observation with the largest X-ray flux (1993 October and 1992 April respectively).

5.1 Comparison between BeppoSAX and ROSAT results

Fig. 3 shows the BeppoSAX 1-keV flux versus the corresponding ROSAT flux. The errors reflect statistical uncertainties only and do not include model uncertainties. Our sources display mild X-ray variability: the median value of $f_{\text{BeppoSAX}}/f_{\text{ROSAT}}$ is 0.6 (0.5 excluding PKS 2005−489, which has the largest value of this ratio, $\sim 5$). Fig. 3 should be compared with fig. 2 in Wolter et al. (1998), which shows the same plot for a sample of eight HBLs. There the two fluxes are within 30 per cent for most sources and the points follow more closely the line of equal fluxes. We note that the 1-keV flux has a very strong model dependence. We therefore evaluated the X-ray flux ratio also in the 0.1−2.4 keV range, a band common to both instruments and less model-dependent. The median value in this case is not very different, $f_{\text{BeppoSAX}}/f_{\text{ROSAT}} = 0.4$.

Fig. 4 shows the BeppoSAX spectral index (0.1−10 keV) versus the ROSAT spectral index (0.1–2.4 keV). The larger BeppoSAX

6 Spectral Energy Distributions

To address the relevance of our BeppoSAX data in terms of emission processes in BL Lacs, we have assembled multifrequency data for all our sources. The main source of information was the NASA/IPAC Extragalactic Database (NED), and so most data are not simultaneous with our BeppoSAX observations. For five of our sources, however, we were able to find nearly simultaneous (within a month) radio observations in the University of Michigan Radio Astronomy Observatory (UMRAO) database. These are reported in Table 6, which also gives the nearly simultaneous radio X-ray spectral index, $\alpha_{\text{RX}}$, with its error. This is defined between the rest-frame frequencies of 4.8 GHz and 1 keV, and has been k-corrected using the X-ray spectral indices given in Table 3 and radio spectral indices between 4.8 and 8.0 GHz derived from the UMRAO data error bars for most of our sources, as compared to ROSAT, are due to the worse photon statistics. (The PSPC count rates, in fact, are typically a factor of 10 larger than the LECS ones.) All but one source occupy the region of the plot where $\alpha_X(\text{BeppoSAX}) \leq \alpha_X(\text{ROSAT})$. The interpretation of this plot is complicated by variability effects, which affect the shape of the X-ray spectrum, and possibly by ROSAT miscalibrations (e.g., Iwasawa, Fabian & Nandra 1999; Mineo et al. 2000). However, a few points can be made. Again, as before, the figure suggests a concave overall X-ray spectrum for our sources, with a flatter component emerging at higher energies. We find $\alpha_X(\text{ROSAT}) - \alpha_X(\text{BeppoSAX}) = 0.47 \pm 0.23$ (excluding the two HBLs this becomes $\alpha_X(\text{ROSAT}) - \alpha_X(\text{BeppoSAX}) = 0.43 \pm 0.30$). This difference cannot be attributed to miscalibration effects alone, which, if present, should steepen the ROSAT slopes by $\sim 0.2–0.3$ (Mineo et al. 2000).

Again, this figure should be compared with fig. 3 of Wolter et al. (1998), which shows the same plot for a sample of eight HBLs. In that case the BeppoSAX and ROSAT spectral indices agree within the errors for all but one source.
(z = 0.3 assumed).}

Three of our sources were also detected by EGRET, so their energy distributions reach \( \sim 5 \times 10^{24} \) Hz. The EGRET data come from the compilation of Lin et al. (1999), which includes the first entries in the Third EGRET Catalog.

The spectral energy distributions (SEDs) for our sources are shown in Figs 5 and 6, where filled circles indicate BeppoSAX data and nearly simultaneous radio data from UMRAO, while open symbols indicate data from the literature (NED). The solid lines correspond to the one-zone homogeneous synchrotron and inverse Compton model calculated as explained in the text, with the parameters listed in Table 7.

Table 6. Nearly simultaneous radio observations.

<table>
<thead>
<tr>
<th>Name</th>
<th>( F_{4.8 \text{ GHz}} ) (Jy)</th>
<th>Observing date</th>
<th>( F_{8.0 \text{ GHz}} ) (Jy)</th>
<th>Observing date</th>
<th>( F_{14.5 \text{ GHz}} ) (Jy)</th>
<th>Observing date</th>
<th>( \alpha_{RX} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKS 0048-097</td>
<td>1.43 ± 0.04</td>
<td>1997 Dec 3</td>
<td>1.83 ± 0.19</td>
<td>1997 Dec 6</td>
<td>0.79 ± 0.06</td>
<td>1997 Dec 16</td>
<td>0.85 ± 0.03</td>
</tr>
<tr>
<td>OJ 287</td>
<td>1.47 ± 0.05</td>
<td>1997 Nov 15</td>
<td>1.63 ± 0.08</td>
<td>1997 Nov 25</td>
<td>2.44 ± 0.05</td>
<td>1997 Dec 17</td>
<td>0.86 ± 0.02</td>
</tr>
<tr>
<td>B2 0912+297</td>
<td>0.13 ± 0.03</td>
<td>1997 Dec 2</td>
<td>0.29 ± 0.04</td>
<td>1997 Dec 8</td>
<td>–</td>
<td>–</td>
<td>0.62 ± 0.01</td>
</tr>
<tr>
<td>4C 56.27</td>
<td>1.66 ± 0.07</td>
<td>1997 Oct 18</td>
<td>1.87 ± 0.09</td>
<td>1997 Oct 7</td>
<td>–</td>
<td>–</td>
<td>0.84 ± 0.02</td>
</tr>
<tr>
<td>BL Lac</td>
<td>3.73 ± 0.13</td>
<td>1997 Nov 9</td>
<td>4.53 ± 0.12</td>
<td>1997 Nov 21</td>
<td>4.47 ± 0.12</td>
<td>1997 Nov 13</td>
<td>0.80 ± 0.01</td>
</tr>
</tbody>
</table>

Figure 5. Spectral energy distributions of six of our sources. Filled symbols indicate BeppoSAX data and nearly simultaneous radio data from UMRAO, while open symbols indicate data from the literature (NED). The solid lines correspond to the one-zone homogeneous synchrotron and inverse Compton model calculated as explained in the text, with the parameters listed in Table 7.

\( z = 0.3 \) was assumed for the two sources in the table without redshift information. The EGRET data come from the compilation of Lin et al. (1999), which includes the first entries in the Third EGRET Catalog.

The model is very similar to the one described in detail in Spada et al. (2001; it is the ‘one-zone’ version of it). It assumes that the source is cylindrical, of size \( R \) and width \( \Delta R = R / \Gamma \) (in the comoving frame, where \( \Gamma \) is the bulk Lorentz factor). The particle distribution \( N(\gamma) \) is assumed to have the slope \( n [N(\gamma) \propto \gamma^{-n}] \) above the random Lorentz factor after correcting for absorption. ROSAT (from Table 5) and EGRET data are shown by a bow-tie that represent the spectral index range.

We have fitted a homogeneous, one-zone synchrotron inverse Compton model to the SED of our sources. The model is very similar to the one described in detail in Spada et al. (2001; it is the ‘one-zone’ version of it). It assumes that the source is cylindrical, of size \( R \) and width \( \Delta R = R / \Gamma \) (in the comoving frame, where \( \Gamma \) is the bulk Lorentz factor). The particle distribution \( N(\gamma) \) is assumed to have the slope \( n [N(\gamma) \propto \gamma^{-n}] \) above the random Lorentz factor.
\(\gamma_c\), where radiative losses dominate over adiabatic losses. The electron distribution is assumed to cut off abruptly at \(\gamma_{\text{max}} > \gamma_c\).

Below \(\gamma_c\) there can be two cases, depending on the values of \(\gamma_c\) and \(\gamma_{\text{min}}\).

If \(\gamma_c > \gamma_{\text{min}}\), we have \(N(\gamma) \propto \gamma^{-n_{\text{rad}} + 1}\) between \(\gamma_{\text{min}}\) and \(\gamma_c\), and \(N(\gamma) \propto \gamma^{-1}\) below \(\gamma_{\text{min}}\).

Alternatively, if \(\gamma_c < \gamma_{\text{min}}\), then \(N(\gamma) \propto \gamma^{-2}\) between \(\gamma_c\) and \(\gamma_{\text{min}}\), and \(N(\gamma) \propto \gamma^{-1}\) below \(\gamma_c\).

According to these assumptions, the random Lorentz factor of the electrons emitting most of the radiation (i.e., emitting at the peaks of the SEDs), \(\gamma_{\text{peak}}\), is determined by the relative importance of the adiabatic versus radiative losses and can assume values in the range \(\gamma_{\text{min}}\) to \(\gamma_{\text{max}}\).

Photons produced externally to the jet (e.g., by the broad-line region, BLR) are considered only if they improve the fit. We account for them by assuming that a fraction 0.1 of the disc luminosity \(L_{\text{disc}}\) is reprocessed into line emission by the BLR assumed to be located at \(R_{\text{BLR}}\). The source is assumed to emit an intrinsic luminosity \(L'\) and to be observed with the viewing angle \(\theta\).

The input parameters are listed in Table 7, which gives the name of the source in column 1, \(L'\) in column 2, \(L_{\text{disc}}\) in column 3, \(R_{\text{BLR}}\) in column 4, the magnetic field \(B\) in column 5, the size of the region \(R\) in column 6, the Lorentz factor \(\Gamma\) in column 7, the angle \(\theta\) in column 8, the slope of the particle distribution \(n\) in column 9, and finally \(\gamma_{\text{min}}\) and \(\gamma_{\text{peak}}\) in columns 10 and 11 respectively. Note that \(\gamma_{\text{peak}}\) is a derived quantity and not an input parameter.

In the case of a pure synchrotron self-Compton model, all the above parameters are constrained in sources for which: (1) we have an estimate of the minimum time-scale of variability; (2) both the synchrotron and the self-Compton peak are well defined; (3) the spectral slopes before and above the peaks are known; and (4) the redshift is known. As discussed in Tavecchio, Maraschi & Ghisellini (1998), this suffices to fix the values of the magnetic field, the intrinsic power of the source, the slopes of the emitting electron distribution, the relativistic Doppler factor and the dimension of the source. When the radiation produced externally to the jet is important, there is one unconstrained unknown, but the superluminal motion of the radio knots observed for many of these sources indicates values of the bulk Lorentz factor in the range 10–15 on average, and we therefore use these values for our fits (see, e.g., Ghisellini et al. 1998).

For the sources in our sample, we rarely have complete information about the high-energy peak (we often have only an upper limit), so we lack the direct determination of \(\gamma_{\text{peak}}\) and have only a limit on the determination of the magnetic field.

But in the model we use here the adiabatic losses play a crucial role...
role, and (within this model) we have an additional constraint with respect to the simplest synchrotron inverse Compton model. Namely, the peak of the synchrotron emission is due either to the electrons injected with $\gamma_{\text{min}}$ or to the electrons for which adiabatic and radiative losses balance. This second condition (coupled with the value of the synchrotron peak frequency) allows one to estimate the value of the magnetic field, since for our sources the synchrotron energy losses are important (as shown by the upper limits in the EGRET energy range indicating an inverse Compton emission not widely dominant).

A further constraint applies to sources in which external radiation could be important. In our model these external seed photons are thought to be produced by the BLR reprocessing a fixed amount of the ionizing flux produced by the accretion disc. Therefore neither the accretion disc luminosity exceeds the observed optical–UV continuum (for our sources we do not have any evidence for the presence of a blue bump), nor the emission-line luminosities exceed the observed values.

The model fits are shown in Figs 5 and 6 as solid (and dashed) lines. The applied model is aimed at reproducing the spectrum originating in a limited part of the jet, thought to be responsible for most of the emission. This region is necessarily compact, since it must account for the fast variability shown by all blazars, especially at high frequencies. The radio emission from these compact regions is strongly self-absorbed, and the model cannot account for the observed radio flux. This explains why the radio data are systematically above the model fits in the figures.

For some sources the model fits present a complex behaviour at $\gamma$-ray energies (i.e., two peaks at high energies besides the synchrotron peak at lower frequencies). In all such cases the first high-energy peak is due to synchrotron self-Compton emission, while the peak at the highest energies is due to inverse Compton scattering off external photons.

As shown in Table 7, the intrinsic luminosities, the source dimensions, the bulk Lorentz factors and the viewing angles are quite similar for all sources, while the magnetic field varies from 0.8 to 6 G (with the smallest values corresponding to the least powerful sources). The need for external seed photons for some sources, while indicative of a BLR, is not extremely compelling, since the required disc luminosities are much smaller than those required in radio-loud quasars (see, e.g., Ghisellini et al. 1998).

The main difference between sources is in the derived value of $\gamma_{\text{peak}}$, with HBLs having, not surprisingly, the larger values. Moreover, $\gamma_{\text{peak}}$ strongly (anti)correlates with $L'$, that is, powerful sources have the smallest values of $\gamma_{\text{peak}}$ in agreement with what has been found previously by Ghisellini et al. (1998).

### 7 X-RAY SPECTRAL INDEX AND THE SYNCHROTRON PEAK FREQUENCY

One of the aims of this project was to study the dependence of the X-ray spectral index on the synchrotron peak frequency $\nu_{\text{peak}}$ found by Padovani & Giommi (1996) and Lamer et al. (1996) from ROSAT data by using the broader BeppoSAX energy band. Padovani & Giommi (1996) found a strong anticorrelation between $\alpha_X$ and $\nu_{\text{peak}}$ for HBLs (i.e., the higher the peak frequency, the flatter the spectrum), while basically no correlation was found for LBLs. This was interpreted as being due to the tail of the synchrotron component becoming increasingly dominant in the ROSAT band as $\nu_{\text{peak}}$ moves closer to the X-ray band (see fig. 7 of Padovani & Giommi 1996).

The BeppoSAX version of this dependence is shown in Fig. 7, which plots the X-ray spectral index (0.1–10 keV) versus the logarithm of the peak frequency for our sources (filled circles), the HBLs studied by Wolter et al. (1998; open squares) and other BL Lacs studied by BeppoSAX. These include, in order of increasing peak frequency: ON 231 (star; $\alpha_X$ in the 0.1–3.8 keV range; Tagliaferri et al. 2000), SS 0716+714 (open circle; Giommi et al. 1999), PKS 2155–304 (filled triangle; Giommi et al. 1998), Mrk 421 (cross; $\alpha_X$ in the 0.1–1.6 keV range; Fossati et al. 2000), 1ES 2344+514 (open triangle; Giommi, Padovani & Perlman 2000) and Mrk 501 (filled square; Pian et al. 1998). When more than a value of $\alpha_X$ was available for these BL Lacs, we picked the one corresponding to the largest $\nu_{\text{peak}}$. The $\nu_{\text{peak}}$ values for the sources studied in this paper have been taken from Sambruna et al. (1996), who fitted a parabola to the $\nu_f$ broad-band spectra, except for B2 0912+29 and PKS 2005–489. For these two sources we derived $\nu_{\text{peak}}$ as described in Padovani & Giommi (1996). The former source, in fact, was not included in the sample studied by Sambruna et al. (1996), while for the latter the derived value was clearly too high (see, e.g., Comastri, Molendi & Ghisellini 1995).

The $\nu_{\text{peak}}$ values for the HBLs studied by Wolter et al. (1998) are taken from that paper, and similarly the values for the additional sources are normally taken from the referenced papers.

Fig. 7, although with less statistics, basically confirms the ROSAT findings, namely a strong anticorrelation between $\alpha_X$ and $\nu_{\text{peak}}$ for HBLs and no correlation for LBLs, with an initial increase in $\alpha_X$ on going from LBLs to HBLs. A few differences, however, are worth mentioning. First, the range in $\alpha_X$ is somewhat smaller ($\sim 1$ versus $\sim 3$). This is probably due to the larger energy range over which $\alpha_X$ is measured (0.1–10 keV for BeppoSAX versus 0.1–2.4 keV for ROSAT). Objects with very steep ROSAT$\alpha_X$, in fact, are those in which synchrotron emission is nearing the exponential cut-off; by having a larger band BeppoSAX includes flatter, higher energy emission due to inverse Compton scattering.
Secondly, the wide 0.1–100 keV coverage of BeppoSAX has allowed the detection of spectacular spectral variability, with \( v_{\text{peak}} \) reaching \( \simeq 10 \) keV. As predicted by Padovani & Giommi (1996), these sources display very flat \( \alpha_X \) (~0.5–0.8), since BeppoSAX is sampling the peak of the synchrotron emission. Note that in this case the flat X-ray spectrum is not associated with inverse Compton emission, although extreme HBLs (objects to the far right in Fig. 7) have synchrotron X-ray spectra as flat as extreme LBLs (objects to the far left of the figure). In other words, there are two very different mechanisms that can produce a flat X-ray spectrum in BL Lacs: inverse Compton emission or synchrotron emission with peak frequency in the hard X-ray band.

8 RESULTS AND CONCLUSIONS

We have presented new BeppoSAX observations of eight BL Lacertae objects, all but one selected from the 1-Jy sample. Six of our sources are LBLs, i.e., they are characterized by a peak in their multifrequency spectra at infrared/optical energies. A relatively simple picture comes out from this paper: a dominance of inverse Compton emission in the X-ray band of LBLs, with about two-thirds of the sources showing also a likely synchrotron component. This result rests on various pieces of evidence:

(i) The relatively flat \( (\alpha_X \sim 0.9) \) BeppoSAX spectra of our LBL sources (Table 3). Moreover, single power-law fits to the BeppoSAX data show a best-fitting \( N_H \) below the Galactic value for four out of six of our LBLs, while residuals to the single power-law fits with Galactic \( N_H \) also show evidence for concave spectra (Fig. 2). Broken power-law models improve the fits but with borderline significance. The resulting best fits, however, all concur in indicating a flatter component emerging at higher energies, with spectral changes \( \Delta \alpha_X \sim 0.8 \) around 1–3 keV.

(ii) The comparison between BeppoSAX and ROSAT spectra (Fig. 4). Excluding 4C 56.27, which appears to have an extremely flat ROSAT spectrum, all our LBLs have \( \alpha_X(\text{ROSAT}) > \alpha_X(\text{BeppoSAX}) \), with a typical difference \( \sim 0.7 \). Although the interpretation of this difference is complicated by possible spectral variability effects, it is unlikely that these can explain the fact that five out of six of our LBLs have a ROSAT spectrum that is steeper than the BeppoSAX one. Similarly, possible ROSAT miscalibrations, if present at all, could only explain a difference \( \sim 0.2–0.3 \).

(iii) The spectral energy distributions (Figs 5 and 6). Despite the non-simultaneity of the multifrequency data (UMRAO radio data excluded), it is apparent that the BeppoSAX spectra indicate a different emission component in the SEDs of our LBL sources, separate from that responsible for the low-energy emission. In fact, the extrapolation of the relatively flat BeppoSAX slopes cannot be extended to much lower frequencies since the predicted optical flux would be orders of magnitude below the observed value. A sharp steepening towards lower frequencies is then necessary to meet the much higher optical (synchrotron) flux, as also required by the comparison with ROSAT data. Detailed synchrotron inverse Compton model fits to the SEDs fully confirm this picture and constrain the physical parameters in these sources (Table 7).

(iv) The \( \alpha_X - v_{\text{peak}} \) diagram (Fig. 7). Our interpretation of this plot is the one originally proposed by Padovani & Giommi (1996) for the ROSAT data. Namely, \( \alpha_X \) is flat for LBLs as a result of the dominance of the inverse Compton emission, and steepens moving from LBLs to HBLs as synchrotron replaces inverse Compton as the main emission mechanism in the X-ray band. The spectral index then flattens again as the synchrotron peak moves to higher energies in the X-ray band, eventually converging to the relatively flat value characteristic of synchrotron emission before the peak. Again, this fits perfectly with a dominance of inverse Compton emission in our LBLs.

Note that strong, direct evidence for the presence of both synchrotron and inverse Compton emission in the BeppoSAX spectra of LBLs has been presented by Giommi et al. (1999) and Tagliaferri et al. (2000) for S5 0716+714 and ON 231, respectively. All data for the two HBLs included in this study are consistent with synchrotron emission extending into the BeppoSAX band for these sources, in agreement with the results of Wolter et al. (1998).

BeppoSAX data for four more 1-Jy BL Lacs have been obtained and data reduction is in progress. Those results will be presented in a forthcoming paper, where we will address the properties of the full 1-Jy BeppoSAX sample and their physical parameters in more detail.

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