THE BROAD BAND X-RAY SPECTRA OF INTERMEDIATE BL LAC OBJECTS

J. Siebert, W. Brinkmann, S.A. Laurent-Muehleisen, and M. Matsuoka

1 Max-Planck-Institut für extraterrestrische Physik, Postfach 1603, 85740 Garching, Germany
2 IGPP/LLNL, 7000 East Ave., Livermore, CA 94550, USA
3 RIKEN, Hirosawa 2-1, Wako, Saitama 351-01, Japan

ABSTRACT

We present recent X-ray observations of intermediate BL Lac objects (IBLs), i.e. BL Lacs which are located between high-energy and low-energy peaked BL Lac objects with respect to $\alpha_{rx}$. We briefly discuss the statistical properties of IBLs from the RGB sample and then focus on a detailed broad band spectral analysis of two objects, namely 1424+2401 and 1055+5644, which were observed with ASCA and SAX, respectively. In both cases the spectra are steep and we find significant curvature in 1424+2401 in the sense that the spectrum gets flatter at both low (< 1 keV) and high energies (> 5 keV). Our results are in line with the hypothesis of a continuous distribution of synchrotron peak frequencies among BL Lac objects.

1 INTRODUCTION

The spectral energy distribution (SED) of BL Lac objects is dominated by non-thermal emission from a relativistic jet oriented close to the line of sight. It is characterised by two peaks, where the first lies in the IR to soft X-ray range and is thought to be due to synchrotron radiation. The second peak is in the $\gamma$-ray range and most likely due to inverse-Compton radiation.

It is well established that BL Lac objects detected in radio surveys (RBLs) show markedly different properties compared to BL Lacs detected in X-ray surveys (XBLs). In general, the latter are less extreme in terms of variability, polarization, superluminal motion and luminosity. Also, RBLs show stronger optical emission lines than XBLs and most of the BL Lac objects detected in $\gamma$-rays belong to the RBL class.

The unification of RBLs and XBLs is still a matter of debate. The angle between the relativistic jet and the line of sight is certainly a crucial parameter (e.g. Celotti et al. 1993), but it has been shown (e.g. Sambruna et al. 1996) that orientation alone cannot explain the large differences in the spectral energy distribution of the two classes. A second parameter could for example be the jet kinetic luminosity (Georgantopoulos & Marscher 1998) or the frequency of the synchrotron peak (e.g. Padovani & Giommi 1995). The latter suggestion has led to a re-classification of BL Lacs into HBLs and LBLs, i.e. high- and low-frequency peaked BL Lac objects, where most of the XBLs and RBLs belong to the HBL and LBL class, respectively.

Selection effects, caused by the high flux limits of previous samples (e.g. 1-Jy sample, EMSS sample), clearly are important and might explain much of the apparent dichotomy of BL Lac objects. Therefore
it is desirable to establish new, large and complete samples of BL Lac objects with deeper flux limits. In particular, the properties of intermediate BL Lacs (IBLs), i.e. those which fill the gap between LBLs and HBLs, play an important role for BL Lac unification theories.

2 THE RGB SAMPLE OF INTERMEDIATE BL LAC OBJECTS

Recently, a new large sample of BL Lac objects has become available (Laurent-Muehleisen et al. 1998). It is a subsample of the so-called RGB sample, which resulted from the cross-correlation of the ROSAT All-Sky Survey and the 87GB 5GHz radio survey (Brinkmann et al. 1995, 1997). After accurate radio positions were obtained by VLA observations of more than 1900 sources of this sample (Laurent-Muehleisen et al. 1997), the optical identification of a properly selected subgroup resulted in more than 50 new BL Lacs, adding to the about 100 previously known BL Lac objects contained in the RGB sample.

The distribution in $\alpha_{rx}$, the spectral index between 5 GHz and 1 keV, is shown in Fig. 1 for the RGB BL Lacs. For comparison the distributions for the 1-Jy and the EMSS sample are also shown. Clearly, there is a continuous distribution in $\alpha_{rx}$ and the gap between HBLs and LBLs is filled with a number of objects. There are 22 BL Lacs with $0.7 < \alpha_{rx} < 0.8$, which constitute our sample of intermediate BL Lac objects.

Fig. 2 shows the soft X-ray photon index $\Gamma$ in the 0.1–2.4 keV energy band as a function of $\alpha_{rx}$. The data are taken from Lamer et al. (1996), who derived the X-ray spectral shape of 74 BL Lac objects from pointed PSPC observations. The photon indices for the IBL sample were determined from the hardness ratios. The average value as well as the standard deviation are plotted in Fig. 2 (filled circle). The positive and negative correlations for HBLs and LBLs, respectively, are predicted if the population of BL Lac objects is indeed characterised by a continuous distribution of peak frequencies (Lamer et al. 1996).
IBLs should exhibit the steepest X-ray spectra in this scenario and our average value \( \langle \Gamma_{\text{IBL}} \rangle = 2.35 \pm 0.55 \) is roughly consistent with this prediction.

3 THE BROAD BAND X-RAY SPECTRUM OF TWO IBLS

3.1 1424+2401

1424+2401 was originally considered to be a white dwarf, but was re-classified as a BL Lac by Impey & Tapia (1988) and Fleming (1993). A representation of the ASCA spectrum of this source is shown in Fig. 3. The ratio of the spectral data to a simple power law model with a photon index of \( \Gamma = 2.82 \pm 0.16 \), which was determined in the energy range from 2 to 5 keV, shows systematic residuals. The spectrum gets flatter at the low and the high energy end and a model with two energy breaks around 1 and 5 keV significantly improves the fit. We interpret this result as evidence for an energy dependent curvature in the ASCA spectrum of 1424+2401.

The harder spectrum towards higher energies might be interpreted in terms of a flat inverse–Compton component that starts to dominate the X-ray spectrum. The high energy photon index is only weakly constrained by the ASCA data \( \langle \Gamma_{E>5\text{keV}} \rangle = 0.97^{+0.98}_{-0.77} \), but is completely consistent with the observed high energy spectra of LBLs \( \langle \Gamma \sim 1.6 \rangle \), which are thought to be dominated by IC emission. The flux deficit at lower energies cannot be due to absorption, since the implied \( N_H \) values would be inconsistent with the ROSAT PSPC spectrum of 1424+2401.

The spectral energy distribution SED of 1424+2401 is compared to Mrk 501 and OJ 287 in Fig. 4. The latter represent typical HBLs and LBLs, respectively. The vertical bars denote the peak frequencies of a third-order polynomial fit to the datapoints (dashed lines) and the open triangles represent the absorption corrected ROSAT PSPC spectrum of 1424+2401. The peak frequency and the very steep X-ray spectrum confirm the intermediate nature of 1424+2401 and hence indicate a continuous distribution of peak frequencies in BL Lac objects.
3.2 1055+5644

1055+5644 is one of the newly identified BL Lac objects from the RGB sample. The combined SAX LECS/MECS data of 1055+5644 again indicate a steep X-ray spectrum ($\Gamma = 2.46 \pm 0.20$). However, no significant curvature is seen, apart from a marginal flattening in the spectrum above 5 keV in the MECS data (Fig. 5). In this context we note that 1055+5644 is a $\gamma$-ray source listed in the third EGRET catalog (Hartmann et al., this volume), which implies that the flattening seen in the SAX data might be real. The SED of 1055+5644, shown in Fig. 6, is again typical for IBLs, i.e. it shows a peak frequency in the optical/NIR.

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