X-ray spectral evolution of TeV HBLs
with BeppoSAX, XMM-Newton and SWIFT

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Abstract

Many of the extragalactic sources detected at TeV energies are BL Lac objects; the majority belong to the subclass of “high frequency peaked BL Lacs” (HBLs) with spectral energy distributions (SEDs) exhibiting a first peak in the X-ray band. At a closer look, their X-ray spectra appear to be generally curved into a log-parabolic shape; investigating Mrk 421, two correlations were found between the spectral parameters. One involves the height $S_p$ of the SED, that increases with the position $E_r$ of the first peak, interpreted as a signature of synchrotron radiation; the other involves the curvature parameter $b$ decreasing as $E_r$ increases, interpreted in terms of statistical/stochastic acceleration processes for the emitting electrons. Here we report the X-ray analysis of all TeV HBLs observed till April 2007 to pinpoint their behaviours in the $E_r - S_p$ and $E_r - b$ planes and to compare them with Mrk 421.

1 Introduction

A recent analysis of Mrk 421 observations performed with BeppoSAX, XMM-Newton and ASCA (Tramacere et al. 2007, A&A, 466, 521) has shown two correlations between spectral parameters. These are relevant as signatures of synchrotron emission and of statistical/stochastic acceleration mechanisms for the emitting electrons, respectively. Here, we look for any similar correlations or trends in other TeV HBLs, reporting three examples among the selected sample: 1H 1426+428, Mrk 501 and PKS 2155-304.

2 Spectral analysis


$$F(E) = K E^{-\delta_b} \log(E)$$

or the alternative SED representation

$$S(E) = S_0 10^{-b \log^2(E/E_0)}$$

with $S_0 = E_0^2 F(E_0)$. After Eq. (2), the values of the parameters $E_0$ (a high energy exponential cutoff in our analysis, which supports our conclusion), $\delta_b$ (the curvature parameter) can be estimated independently in the fitting procedure (Tramacere et al. 2007a). Details of the spectral analysis and comparison with other models are also presented in Massaro et al. (2008, A&A, 478, 395).

3 Results

In the case of Mrk 421 Tramacere et al. (2007, A&A, 466, 521) found that the SED peak energy $E_p$ correlates with the peak flux $S_0$ but抗氧化s the curvature parameter $b$. To compare the observed quantities ($E_0$, $\delta_b$ and $S_0$) among different sources, it is necessary to make cosmological corrections.

The curvature parameter $b$ is not affected while the other parameters, $E_0$ and $S_0$, are. The rest frame energy peak $E_p(0)$ is given by $E_p = \langle E_p \rangle (1 + z) E_0$. As the value of $S_0$ is proportional to the bolometric emitted flux, we can use the rest frame energy of BL Lac in terms of the isotropic luminosity $L_\gamma(0)$ which is the luminosity distance (Pettini, 1991). A flat cosmology with $H_0 = 72 km/\text{s} \cdot \text{Mpc}$, $\Omega_M = 0.27$ and $\Omega_L = 0.73$ has been used for our calculations (see Spergel et al. 2007, ApJ, 179, 377).

To search for trends, one needs at least 10 observations with $E_0$, $\delta_b$ and $S_0$ well estimated, a requirement satisfied by only 5 of our sources, namely: PKS 0548-322, 1H 1426+428, Mrk 501, 1ES 1959+650, and 3C 279. To compare the observed $E_0$, $\delta_b$ and $S_0$ among these five sources plus Mrk 421, we show that the curvature range from about 0.12 to about 0.15, the correlation coefficient for the whole sample constituted by these sources in $\delta_{b} = 0.66$.

3.1 1H 1426+428

The source 1H 1426+428 has a similar behaviour to Mrk 421 in the $E_0 - \delta_b$ and $E_0 - \delta_b$ planes (see Fig. 1a). The observation of XMM-Newton on 25 June 2003 appears to confirm the statistical trend in the $E_0 - \delta_b$ plane, even if the bestfit indicates a value of $E_p(0)$ beyond the instrumental energy range, but in the $E_0 - \delta_b$ plane it lies in a different position than other points. We find correlation coefficients $\rho_{E_0 - \delta_b} = 0.72$ for the $E_0 - \delta_b$ relation and $\rho_{E_0 - \delta_b} = 0.47$ for the $E_0 - \delta_b$ one.

3.2 Mrk 501

For Mrk 501 $E_0$ and $\delta_b$ are shown in Fig. 2. Here the range of $E_0$ is wider and the luminosities are higher compared to Mrk 421. The source has similar trends to Mrk 421, with higher correlation coefficients for the $E_0 - \delta_b$ and $E_0 - \delta_b$ relations, namely $\rho_{E_0 - \delta_b} = 0.89$ and $\rho_{E_0 - \delta_b} = 0.73$ respectively.

3.3 PKS 2155-304

The source PKS 2155-304 is the truly variant member of our set in a number of figures and in statistical analysis. In closer detail, we expect the inverse Compton peak height $E_\gamma$ to be given by

$$E_\gamma = E_0 \left(1 + \frac{1}{2} \log^2 \frac{E_0}{E_p(0)} \right)$$

To compare the observed $E_\gamma$, $S_0$ with $E_0$, $\delta_b$ and $S_0$ well estimated, we need at least 10 observations for our sample, namely: PKS 0548-322, 1H 1426+428, Mrk 501, 1ES 1959+650, and 3C 279. To compare the observed $E_\gamma$, $S_0$ among these five sources plus Mrk 421, we show that the curvature range from about 0.12 to about 0.15, the correlation coefficient for the whole sample constituted by these sources in $\rho_{\delta_b} = 0.66$.

4 Summary

We summarize our main results as follows:

- Five sources (PKS 0548-322, 1H 1426+428, Mrk 501, 1ES 1959+650, PKS 2155-304) have enough data to warrant examining in some detail the $E_0 - \delta_b$ and $E_0 - \delta_b$ relations and comparing them with those found for Mrk 421.

5TeV predictions

Correlations between $E_0$ and $\delta_b$ provide interesting information concerning the driver of the source spectral evolution. In fact, the synchrotron peak is expected to scale as $L_\gamma \propto \gamma^2 B^2$ while the peak energy scales as $E_\gamma \propto \gamma^2 B^2$ in terms of the number $N$ of emitting particles, the magnetic field $B$, and of the typical electron energy $\gamma m c^2$, and of the beam factor $\delta$.

Finally, we outline a link between the synchrotron peak and the TeV emissions. In fact, within a single zone SSC scenario, we expect that synchrotron signatures derived from X-ray observations have counterparts in the TeV energy range, where the inverse Compton peak lies. In order to describe, we expect the inverse Compton peak height $C_{\gamma}$ and its location $E_{\gamma}$ to be energy given by

$$C_{\gamma} \propto N \gamma^2 B^2 \delta$$

where $B$ is the size of the emitting region. It transpires that a definite link exists between the correlations for the variations of the synchrotron peak and variability of the inverse Compton peak.