# LOG-PARABOLIC SSC SPECTRA IN HBL SOURCES. A NEW ANALYSIS OF THE APRIL 1997 LARGE OUTBURST OF MKN 501.

**A. Tramacere[1], E. Massaro[1], M. Perri[2], P. Giommi[2], and G. Tosti[3]**

[1]Dipartimento di Fisica, Università La Sapienza, Piazzale A. Moro 2, I-00185 Roma, Italy
[2]ASI Science Data Center, ESRIN, I-00044 Frascati, Italy
[3]Dipartimento di Fisica, Università di Perugia, via A. Pascoli, Perugia, Italy

## ABSTRACT

Broad band X-ray observations of HBL sources (e.g. Mkn 421 and Mkn 501) were found well described by a log-parabolic law in which the second degree term measures the curvature. Log-parabolic energy spectra of relativistic electrons can be obtained by means of a statistical acceleration mechanism having an energy dependent probability of acceleration. We compute by means of an accurate numerical code, the spectra radiated by an electron population via synchrotron and synchro-self Compton (SSC) processes to derive the relations between the log-parabolic parameters. We applied our results to the simultaneous X and TeV spectra of Mkn 501 during the large outburst of April 1997 and found that SSC emission from an electron population with a log-parabolic distribution is able to reproduce the observed synchrotron X-ray and inverse Compton TeV spectra with the proper curvatures. This implies that pair production absorption of very energetic gamma rays against the extragalactic background can be lower that usually modelled.

Key words: radiation mechanisms: non-thermal - galaxies: active - galaxies: BL Lacertae objects, X-rays: galaxies: individual: Mkn 501.

## 1. INTRODUCTION

Log-parabola represents in a natural way the spectral shape with a mild curvature symmetric around the maximum. A log-parabolic spectrum can be written as

$$F(E) = K(E/E_1)^{-(a\ +\ b\ Log(E/E_1))} \tag{1}$$

and needs just one parameter ($b$) to represent the curvature around the peak, while in other models, like the continuous combination of power laws, it is a function of more parameters. Massaro et al. (2004a, 2004b) have shown that log-parabolic spectra can describe very well observational data, and that in a statistical acceleration process where the probability of energetic gain is not constant but a function decreasing with energy the resulting electron distribution can be described by:

$$N(>\gamma) = N_0(\gamma/\gamma_0)^{-[s-1+rLog(\gamma/\gamma_0)]} \tag{2}$$

where $\gamma_0$ is the initial electron Lorentz factor. The parameter $r$ is the curvature term, and both $r$ and $s$ are linked to the statistic of acceleration precess (see Massaro et al (2004) for further details). In this paper we will evaluate the relations between the curvature parameters, not by analytical $\delta$ approximation, but numerically and using the exact spectral distribution, and will extend this study to Inverse Compton (IC) emission. We consider two electron distributions: a log-parabola (LP) and a mixed distribution (LPPL), where the probability of energy gain is constant up to a critical energy corresponding to a Lorentz factor $\gamma_a$, and for $\gamma > \gamma_a$ decreases with energy. The resulting electron distribution can be described by:

$$\begin{aligned} N(\gamma) &= N_0\ (\gamma/\gamma_0)^{-s_0} \quad \gamma \le \gamma_0 \\ N(\gamma) &= N_0\ (\gamma/\gamma_0)^{-(s_0+r\ Log(\gamma/\gamma_0))} \quad \gamma > \gamma_0. \end{aligned} \tag{3}$$

where we take $\gamma_0$=$\gamma_a$.

## 2. NUMERICAL CALCULATION OF $b-r$ RELATION FOR SYNCHROTRON AND IC

The $b-r$ relation for synchrotron radiation (SR) emission, evaluated numerically using the exact SR spectral frequency distribution and in frequency intervals higher then the peak is linear with $b/r \simeq 0.22$, while around the peak it is $b/r \simeq 0.18$ for the both LP and LPPL cases. Both ratios are smaller than that of $\delta$ approximation equal to 0.25

IC spectra were evaluated using the exact Klein-Nishina (KN) cross section, in the approximation of isotropic photon seed distribution (Blumenthal & Gould 1970). The relations between SR and IC peak frequencies shows the transition between Thomson (TH) and Klein-Nishina

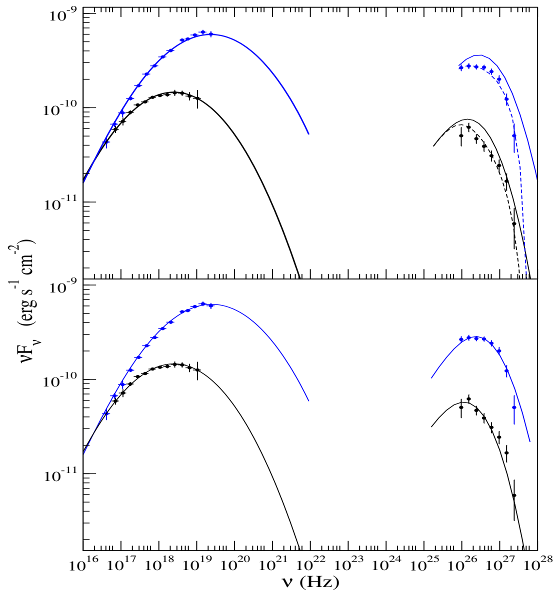


*Figure 1. Two SED of Mkn 501 during the low and high states observed on 7 and 16 April 1997, respectively. X-ray points are from Massaro et al. (2004a), TeV points are simultaneous CAT data (Djannati-Atai et al. 1999). Solid lines are the spectra computed in a 1-zone SSC model for the SR and IC components. In the upper panel IC spectra have been absorbed (dashed lines) by interaction with infrared EBL photons according to the LLL model by Dwek & Krennich (2005). In the lower panel EBL absorption was neglected. Details about the model parameters can be found in Massaro et al. (2005)*

(KN) regime: IC peak frequency increases slower and slower as we increase the peak electron energy. IC curvature ($b_{IC}$) has a more complex behaviour and there is not a univoque relation between $r$ and $b_{IC}$. This is due mainly to the fact that the shape is log-parabolic, only over limited ranges, and the resulting curvatures depend both on seed SR photons and electron distributions. Our computations show that $b_{IC}$ values are close to $b_{SR}$ or lower in TH regime, and approach to $r$ values as the diffusion enters in KN regime. A detailed description of these results is given in Massaro et al. (2005).

## 3. THE LARGE FLARE OF MKN 501 DURING APRIL 1997

We applied results found above to study the evolution of SED of Mkn 501 during the large flare of April 1997. In reproducing TeV spectra we took into account the photon-photon interaction with the photons of the diffuse infrared extragalactic background (EBL). We considered first a single zone SSC model. The spectrum of the emitting electrons was chosen with a curvature parameter $r = b/0.22 \simeq 0.75$. The TeV curvature measured around the peak was about 0.4 for the low state and 0.45 for the high state (Djannati-Atai et al. 1999) and, for $\gamma_0$ of the order of $10^4$ and even higher, we expect a value of r in the range 0.5-0.8. The EBL model used was the LLL model by Dwek and Krennich (2005). In both cases TeV data were well fitted in both the peak position and spectral curvature. This suggests that this curvature could be partly intrinsic rather then to be entirely produced by EBL absorption. Another possibility is that of two zone SSC model which gives again spectra in a good agreement with data. More details can be found in Massaro et al. (2005).

## 4. DISCUSSION

A log-parabolic law reproduces well the SED of blazars over several frequency decades. We present the exact relations, computed using a precise numerical code, between the spectral parameters of the energy distributions of relativistic electrons and their SR and IC emission. We also calculate SR and IC spectra of Mkn 501 observed by Beppo Sax and CAT during the large outburst of April 1997. We found a spectral curvature at TeV energies consistent with that observed in X-ray range and therefore it can be mostly intrinsic. This interpretation is in agreement with a previous work by Krawczynski et al. (2000) and is also supported by a recent paper by H.E.S.S. team (Aharonian et al. 2005a), who found that the time averaged cut-off energy of Mkn 421 is at about 3.1 TeV, lower than Mkn 501 (about 6.2 TeV). Considering the nearly equal redshifts of the these two blazars, they conclude that the cut-off is not due to EBL attenuation but it is intrinsic to the sources, in agreement with our conclusion about the IC curvature. The extragalactic space is likely more transparent to TeV photons than previously assumed and more blazars could be detected in this range at redshifts higher than previously thought, in agreement with recent detection of 1ES 1101-232 at $z$=0.186 (Aharonian et al. (2005b).

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