CONSTRANTS TO THE SSC MODEL FOR MKN 501

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ABSTRACT We fit the SEDs of the TeV blazar Mkn 501 adopting the homogeneous Synchrotron-Self Compton model to simultaneous X-ray and TeV spectra recently become available. We present detailed model spectra calculated with the above constraints and taking into account the absorption of TeV photons by the IR background. We found that the curved TeV spectra can be naturally reproduced even without IRB absorption. Taking IRB absorption into account changes the required parameter values only slightly.

KEYWORDS: BL Lacertae objects: individual (Mkn 501); gamma rays: theory; radiation mechanisms: non-thermal

1. INTRODUCTION
The study of Blazars has been recently enriched by the detection of very high energy gamma rays (energy in the TeV range) from a handful of nearby sources. This discovery opens the possibility to effectively test and constrain the radiative mechanisms invoked to explain the emission from Blazars and to investigate the physical conditions in relativistic jets.

As discussed in Tavecchio et al. 1998 (hereafter T98), the knowledge of the simultaneous X-ray and TeV spectra of Blazars allows to univocally find the set of physical parameters necessary within a homogeneous Synchrotron-Self Compton model with an electron distribution described by a broken power-law. Here we apply the SSC model to recent high quality, simultaneous X-ray and TeV data of the well studied source Mkn 501 and discuss the results.

2. THE DATA
TeV spectra measured by the CAT team during 1997 were recently reported in Djannati-Atai et al (1999). In particular the TeV spectra associated with BeppoSAX observations of April 16 and 7 (reported in Pian et al 1998) are also discussed. For the large flare of April 16, given the high flux level, it has been possible to obtain a good quality TeV spectrum from a single observation which partially overlaps with the BeppoSAX observation. On Apr 7, Mkn 501 was less bright and the TeV spectrum is obtained using different observations with similar TeV fluxes and hardness ratios (for more details see Djannati-Atai et al 1999). We combine these data with
TABLE 1. Values of the physical parameters used for the SSC model.

| $R_{16}$ (cm) | B (G) | $\delta$ | $\gamma_{\text{break}}$ | K | $n_1$ | $n_2$ |
|--------------|-------|---------|-----------------|---|-------|-------|
| Mkn 501 High state (Apr 16) | 1.8 | 0.02 | 10 | $10^4$ | 2 | 8 |
| Mkn 501 High state with IRB | 3.5 | 0.005 | 10 | $2 \times 10^7$ | $4 \times 10^8$ | 2 | 8 |
| Mkn 501 Low state (Apr 7) | 2.5 | 0.01 | 10 | $6.3 \times 10^9$ | $2.3 \times 10^7$ | 2 | 8 |

the X-ray spectra reported in Pian et al. (1998) for the same days constructing quasi simultaneous SEDs for two epoches. The TeV spectra of Mkn 501 are clearly curved. It was suggested that this curvature could be the "footprint" of the absorption of TeV photons by the Infra Red Background (IRB, e.g Konopelko et al. 1999, but see the detailed discussion in Vassiliev 1999)

3. SPECTRAL FITS WITH THE SSC MODEL

T98 obtained analytical relations for the IC peak frequency in Klein-Nishina (KN) regime adopting the step function approximation for the KN cross-section. A comparison between these approximate estimates and the detailed numerical calculations with the full KN cross section shows that the analytical formulae for the IC peak frequency given in T98 can overestimate its value by a factor of 3-10, depending on $n_2$, the index of the steeper part of the electron distribution. Therefore, although the analytical estimates are useful as a guideline, it is very important for the study of the TeV spectrum of Blazars to use precise numerical calculations, like those discussed in the following.

We reproduced the SED of Mkn 501 (reported in Fig.1) using the SSC model described in T98 and Chiappetti et al 1999. In a spherical region with radius R, magnetic field B and Doppler factor $\delta$, a population of electrons with energy distribution of the form $N(\gamma) = K\gamma^{-n_1}(1 + \gamma/\gamma_{\text{break}})^{n_1-n_2}$ emits synchrotron and IC radiation. The IC spectrum is calculated with the full Klein-Nishina cross-section, using the formula derived by Jones (1968). The seed photons for the IC scattering are those produced by the same electrons through the synchrotron mechanism. For the case of the high state of Mkn 501 we considered possible intervening absorption by the IRB adopting the prescriptions for the low model discussed in Stecker & De Jager (1998). In the calculation reported here we assume a typical radius of the emitting region of $R \sim 10^{16}$ cm and a Doppler factor $\delta = 10$. With this choice the minimum variability timescale is of $\sim 10$ h (see Tab.1 for the parameters used).

It is useful to calculate the IC emission from electrons with different energy
FIGURE 1. SED of Mkn 501 (High state and Low state) with the spectrum calculated with the SSC model. Upper limits at 100 MeV band are from Weekes et al. 1996 and Catanese et al. 1997.

ranges. These "slices" are reported in Fig. 2 (see figure caption for the detailed energy ranges). It is interesting to note that, because of the KN cut at the high energy emission, the peak of the IC component is produced by electrons with Lorentz factor below $\gamma_{\text{break}}$ while the peak of the Synchrotron component is produced by electrons at $\gamma_{\text{break}}$. This effect has important consequences for the study of the X-ray/TeV correlated variability (see also Maraschi et al. 1999).

4. DISCUSSION AND CONCLUSIONS

The parameters adopted for the model are reported in Table 1. Our model indicates a rather low value for the magnetic field and a high $\gamma_{\text{break}}$ (see Tab.1). The transition from the low state to the high state in Mkn 501 is consistent with an increase of a factor of 2 in both $\gamma_{\text{break}}$ and B and with an almost constant value of $\delta$ and $R$. These results are in agreement with a similar analysis of the April 16 flare by Bednarek & Protheroe (1999): for a minimum timescale of 2.5 h they found that the TeV spectrum can be well reproduced by $B \sim 0.03$ and $\delta \sim 15$.

Although some authors (see Konopelko et al. 1999) have recently proposed that the curvature of the TeV spectrum of Mkn 501 provides evidence for absorption by IRB, the curvature could be intrinsic and related to the curved electron distribution necessary to fit the X-ray data. Our models show that a curved spectrum is a plausible explanation for the curvature. The introduction of the IRB does not dramatically change the inferred physical parameters. As shown in Fig.2 IRB/no IRB TeV spectra are very similar up to 15 TeV, while for higher energy the power-law spectrum of the no IRB case is changed in an exponential profile. Therefore spectral data above 10 TeV are needed in order to understand if IRB absorption affects Blazar spectra.

Finally we note that in the theory of particle acceleration by shocks (for a recent critical discussion see Henri et al. 1999) the maximum Lorentz factor of accelerated electrons, obtained equating acceleration time and cooling time, is given
FIGURE 2. TeV spectrum of Mkn 501—High state without (left) and with (right) IRB absorption. We also show the contribution from electrons with different Lorentz factors. From the left the curves show the emission from electrons with Lorentz factor in the range: $1 - 10^6$, $10^6 - 3 \times 10^6$, $3 \times 10^6 - 10^7$, $10^7 - 3 \times 10^7$, $3 \times 10^7 - 10^8$ by $\gamma_{\text{max}} \simeq 10^7 (B/0.02 \text{G})^{-1/2}$, where we used the value of $B$ we found in the high state of Mkn 501. Therefore our fit suggests that during the high activity states of Mkn 501 the electrons can reach the maximum energy fixed by the balance between cooling and acceleration processes. In states of lower activity the acceleration time could be longer and the condition $t_{\text{esc}} < t_{\text{acc}}$ (where $t_{\text{esc}}$ and $t_{\text{acc}}$ are the escape time and the acceleration time respectively) could prevent the electrons for reaching the maximum energy.

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