Intrinsic Spectra of the TeV Blazars Mrk 421 and Mrk 501

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Abstract

Energy spectra of γ-ray blazars may contain an imprint from the cosmic infrared background radiation due to γ-ray absorption (pair-production) by soft photons constituting the extragalactic background light (EBL). The signature of this imprint depends on the spectral shape of the EBL. In this work we correct the observed spectra of Mrk 421 and Mrk 501 for absorption using different possible realizations of the EBL, consistent with the most recent detections and limits. We present the intrinsic $\gamma-$ray spectrum of these sources for the different EBL scenarios. These spectra reveal their true peak energy and luminosities, which provide important information on the nature and physical characteristics of the particle acceleration mechanism operating in these sources.

1. Introduction

Observations of blazars at TeV γ-ray energies are useful to probing non-thermal phenomena in jets of active galactic nuclei (AGNs) utilizing the highest energy photons currently available to astronomy. Very high energy γ-rays traveling cosmological distances are attenuated by the diffuse extragalactic background light (EBL) via pairproduction (Gould & Schréder 1967; Stecker et al. 1992). Hence, the discussion of TeV blazar spectra in the context of emission models and multiwavelength studies requires a correction for γ-ray absorption effects.

In addition, TeV γ-ray studies also provide strong constraints to the EBL density in the wavelength regime of 0.1 μm - 30 μm. The EBL is part of the extragalactic background radiation that ranges from 10^{-7} eV (radio background) to almost 10^{11} eV. Although the diffuse radiation is dominated by the cosmic microwave background, the EBL is the second most dominant form of electromagnetic energy throughout the universe. The EBL originates from the time of structure/galaxy formation and evolution (Partridge & Peebles 1967; Primack 1999) and contains potentially important cosmological information about how galaxies formed. Direct measurements of the EBL in the mid infrared are extremely difficult due to the presence of strong foreground zodiacal emission consisting of scattered light and thermal emission from interplanetary dust particles

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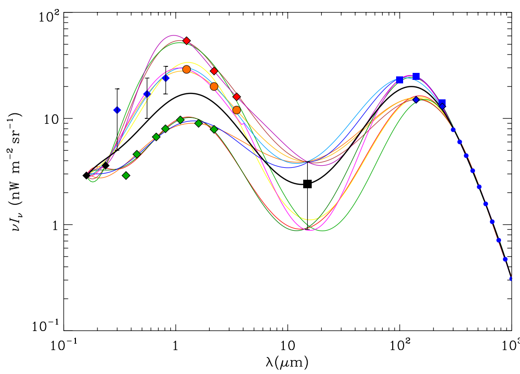

Fig. 1. A range of extragalactic background light scenarios are shown that were used for correcting the measured spectra yielding intrinsic blazar spectra.

(Kelsall et al. 1998). For an extensive review on this, see Hauser & Dwek (2001).

In this paper we focus on the extraction of the intrinsic energy spectra of the two most prominent TeV blazars, Mrk 421 and Mrk 501 which have been measured with good statistical precision at energies between 260 GeV – 20 TeV (Aharonian et a. 1999, 2002; Samuelson et al. 1998; Krennrich et al. 2001). The data of the relevant diffuse radiation fields (0.1 μm - 100 μm) consist largely of upper and lower limits and few 3σ level detections (Hauser & Dwek 2001; Dwek & Krennrich 2003). In fact, at the mid-infrared wavelenghts the diffuse photon densities are uncertain within a factor of a few, resulting in significant uncertainties in estimates of absolute luminosity of Mrk 421 and Mrk 501. However, the shape of the TeV spectra of nearby blazars below 10 TeV is less susceptible to the wide range of possible EBL scenarios, since all scenarios indicate a drop in the photon density between 1 μm - 10 μm, the most effective target for absorption of 1 TeV - 10 TeV γ-rays. Hence, meaningful peak energy measurements of the intrinsic TeV spectra are possible for nearby blazars such as Mrk 501 and Mrk 421.

2. Results for Mrk 421 and Mrk 501

The energy spectra of Mrk 421 and Mrk 501 have been measured with high statistical precision by several groups. We refrain from merging data from different groups, since the uncertainties in the spectra are dominated by systematics. We derive the luminosity peak energies for the Whipple and HEGRA data individually. This approach provides an estimate of the systematic uncertainties resulting from the different instrument calibrations and analyses. The EBL data is compatible with a range of γ-ray absorption opacities and we consider various combinations of high and low diffuse photon densities in the optical/ultraviolet (UVO), mid-infrared (MIR) and the far-infrared (FIR). By fitting polynomials

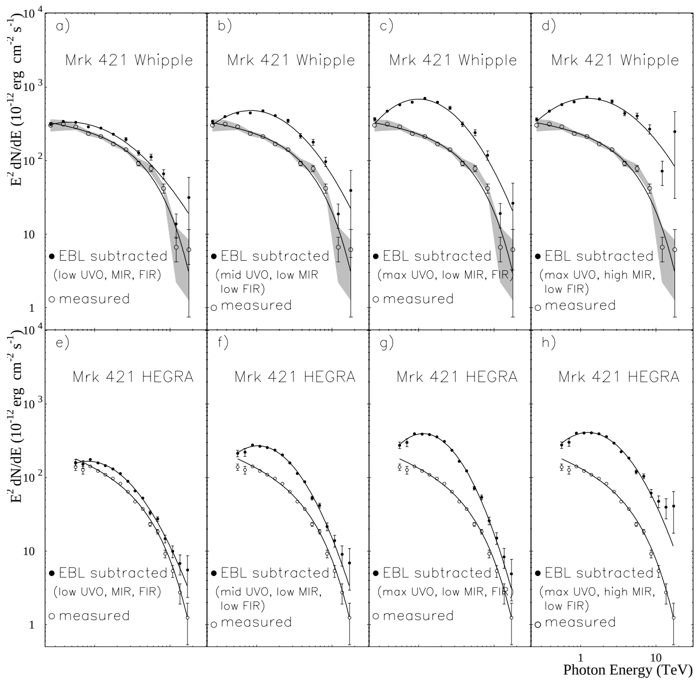

Fig. 2. The measured energy spectrum of Mrk 421 in 2000/2001 is shown, based on Whipple (Krennrich et al. 2001) and HEGRA data (Aharonian et al. 2002) and the corrected intrinsic spectra are presented for different EBL scenarios.

through the EBL data points (limits or detections) of the various scenarios, we arrived at EBL spectral distributions that were used to calculate the optical depths. This leads to a number of EBL scenarios (see fig. 1) and corrected blazar spectra.

Figure 2 a) shows the energy spectrum of Mrk 421 (empty circles) from data of the Whipple 10 m telescope and the spectrum corrected for absorption by an EBL with a low density UVO, MIR and FIR. Figure 2 b) - 2 d) shows the intrinsic spectra for an average UVO, low MIR, low FIR, a high UVO, low MIR, low FIR and a high UVO, high MIR and low FIR. Figure 2 e) through 2 h) shows the corresponding spectra using the HEGRA data. The peak energies have been derived by fitting a parabolic function to the individual spectra. The Whipple data yield peak energies between 468 ± 52 GeV and 1227 ± 68 GeV. The HEGRA data indicate peak energies between 818 ± 75 GeV and 1252 ± 81 GeV. For all scenarios but the low UVO, MIR, FIR the HEGRA and Whipple data show compatible results. Peak energies for Mrk 501 during strong flares in 1997, range between 785 ± 153 GeV and 1761 ± 179 GeV for the Whipple data and between 1172 ± 118 GeV and 2390 ± 127 GeV for the HEGRA data. In summary, the peak energy for the TeV blazar Mrk 501 is about 30% higher than for Mrk 421 when comparing both in a flaring state lasting for several months

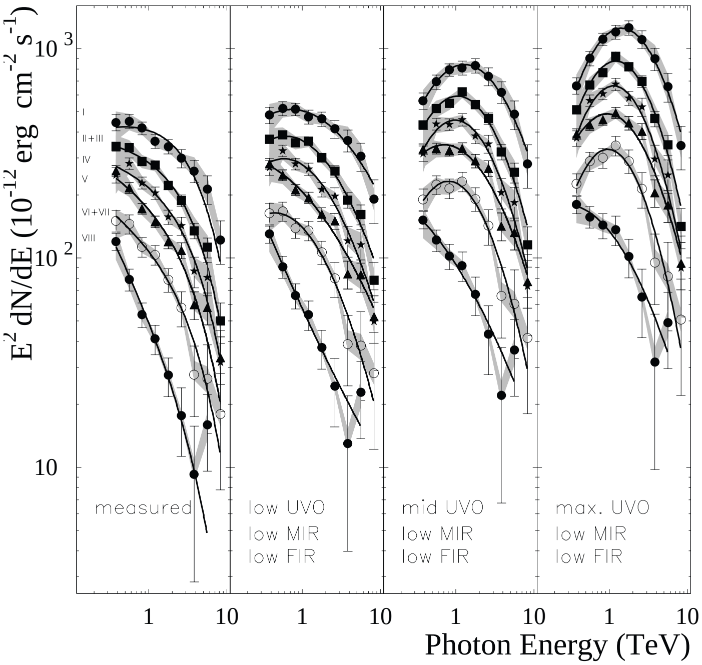

Fig. 3. The measured energy spectra of Mrk 421 at different flux levels averaged for the 2000/2001 observing season (Krennrich et al. 2002) and the corrected intrinsic spectra are presented for different EBL scenarios are shown.

Figure 3 a) shows the energy spectra of Mrk 421 during a strong flaring state in 2000/2001 with the data binned into different flux levels. Figures 3 b) - 3 d) show the corrected spectra. Intrinsic spectra resulting from all three EBL scenarios indicate a shift in the peak energy between the lowest state and the higher flux levels. Further details will be given in Dwek & Krennrich (2003, in preparation).

3. References

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