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IS THERE AN IMPRINT OF PRIMORDIAL STARS IN THE TeV γ-RAY SPECTRUM OF BLAZARS?

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ABSTRACT

The 1–5 μm diffuse sky emission from which local foreground emission from the solar system and the Galaxy have been subtracted exceeds the brightness that can be attributed to normal star-forming galaxies. The nature of this excess near-infrared background light (NIRBL) is controversial. On the one hand, its sharp rise at $\sim$1.25 μm has been interpreted as a distinct spectral feature created by the redshifted emission from primordial (Population III) stars that have formed at redshifts $\gtrsim$8. On the other hand, the measured NIRBL spectrum is almost identical to that of the zodiacal cloud, raising the possibility that it is of local origin. Blazars can, in principle, offer a simple test for the nature and origin of the NIRBL. Very high energy γ-ray photons emitted by these objects are attenuated en route to Earth by γ-γ interactions with the extragalactic background light (EBL). Assuming that the NIRBL is of extragalactic origin, its distinct spectral feature should give rise to a corresponding absorption feature in the observed γ-ray spectra of these sources. This paper examines whether the extragalactic nature of the NIRBL can be determined from the analysis of the γ-ray spectra of blazars. We calculate the γ-ray opacity toward two blazars H1426+ 428 and PKS 2155-304 located at redshifts of $z \approx 0.13$ for several EBL scenarios with and without the alleged spectral signature of the Population III stars. We show that if the NIRBL is extragalactic, it may be very difficult to reproduce the absorption-corrected spectrum of PKS 2155−304 with a synchrotron self-Compton (SSC) model that is also consistent with the X-ray and EGRET γ-ray data. This, and other arguments presented in this paper, cast serious doubts on the possibility that the NIRBL represents the spectral imprint of the first generation of stellar objects on the EBL.

Subject headings: BL Lacertae objects: individual (Mrk 421, Mrk 501, H1426+428, PKS 2155−304) — cosmology: theory — diffuse radiation — early universe — galaxies: active — gamma rays: observations — infrared: general — stars: formation

1. INTRODUCTION

Observations of TeV blazars offer the exciting possibility of detecting an absorption signature in their spectra that can be directly attributed to the radiative contribution of the first generation of stars to the extragalactic background light (EBL). The radiative output of these stars leaves a distinct spectral signature at near-IR wavelengths (Santos et al. 2002), which may have been detected by the Diffuse Infrared Background Experiment (DIRBE) instrument on board the *Cosmic Background Explorer* (*COBE*) satellite (Hauser et al. 1998) and the Near Infrared Spectrometer (NIRS) instrument on board the *Infrared Telescope in Space* (*IRTS*; Matsumoto et al. 2005). The diffuse sky emission from which foreground emissions from the zodiacal dust cloud and galactic starlight has been subtracted shows an excess of emission above that attributed to normal star-forming galaxies (Matsumoto et al. 2005; Totani et al. 2001; Salvattera & Ferrara 2003; Dwek et al. 2005). The nature of this emission is still unresolved. Dwek et al. (2005) have suggested that this excess near-infrared emission could be caused by an unexpectedly large isotropic component that was not included in the model used to subtract the zodiacal light from the DIRBE and NIRS data. However, the detection of spatial fluctuations in this residual component in excess of that expected from the zodiacal cloud, the Milky Way, and normal galaxies suggests that it may be produced by a population of primordial stars (Population III stars). We hereafter refer to the excess 1–5 μm near-infrared background light (NIRBL) from which the zodiacal light, Galactic stars, and the contribution from star-forming galaxies have been subtracted as the NIRBL. Assuming the NIRBL to be extragalactic, Salvaterra & Ferrara (2004) and Dwek et al. (2005) have fitted its spectrum with the cumulative radiative output from Population III stars that were continuously formed between redshifts of $z_{\rm max} \approx 15$–30 and $z_{\rm min} \approx 7$–9. The NIRBL has a distinct spectral signature, characterized by a sharp rise between 0.8 and 1.25 μm, followed by a λ^{-2} decline to $\sim$5 μm. If the NIRBL is indeed extragalactic, then it will leave its imprint on the γ-ray opacity toward distant blazars and affect the shape of their observed spectra.

Mapelli et al. (2004) have suggested that the observed S-shaped TeV spectrum of the blazar H1426+428 represents the absorption signature of the intrinsic blazar spectrum, which they a priori assumed to be a power law. However, Dwek & Krennrich (2005) showed that blazars cannot, in general, be used to discriminate between many possible realizations of the EBL, since their intrinsic γ-ray spectra are a priori unknown. Nevertheless, it is of great interest to examine in more detail if the observed γ-ray spectra of blazars can indeed be used to prove or disprove the extragalactic nature of then NIRBL. The zodiacal and Galaxy-subtracted 1–5 μm DIRBE and NIRS diffuse sky measurements were previously used to create different realizations of the EBL, which were used to explore the physical characteristic of the absorption-corrected spectra of blazars (Dwek & Krennrich 2005; Costamante et al. 2004; Aharonian et al. 2002). However, none of these studies attributed the $\sim$1–5 μm EBL intensities to the distinct emission from Population III stars. Consequently, the EBL realizations fitted through these data points did not have the unique NIRBL spectral signature depicted in Figure 2.

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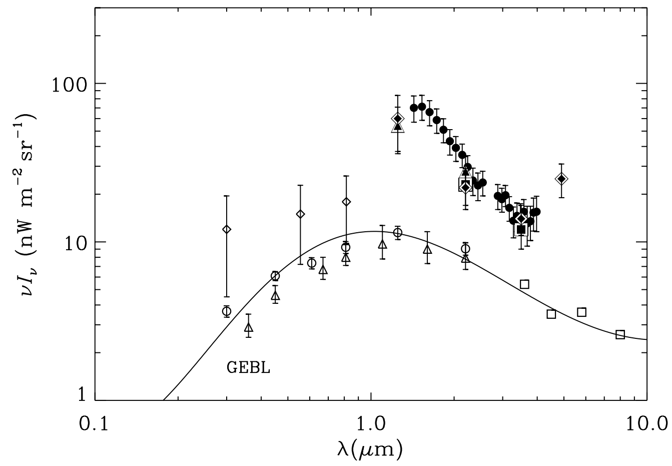

FIG. 1.—Limits and detections of the EBL. The solid line represents the nominal EBL spectrum attributed to normal star-forming galaxies. References to the observations are in the text.

We first summarize the current limits and detections of the EBL in the 0.1–10 μm wavelength region and present the model fits of Dwek et al. (2005) to the NIRBL (§ 2). In § 3 we derive the absorption-corrected γ-ray spectra of four blazars: H1426+428 (1ES1268+428), located at redshift $z = 0.129$; PKS 2155−304, located at $z = 0.117$; and the two relatively nearby blazars Mrk 421 and Mrk 501, located at $z = 0.030$ and 0.033, respectively. The spectra are corrected for absorption using several different realizations of the EBL: (1) an EBL consisting only of the emission from normal star-forming galaxies (hereafter GEBL), i.e., we assume that in this case the NIRBL is due to a foreground emission component; and (2) an EBL that consists of the GEBL and two different model fits to the NIRBL (Dwek et al. 2005). The astrophysical implications of our results are discussed in § 4.

In all our calculations we adopt a cosmological model with parameters determined from the analysis of the *Wilkinson Microwave Anisotropy Probe* (*WMAP*; Bennett et al. 2003): a dark-energy density of $\Omega_\Lambda = 0.73$, and total and baryonic matter densities of $\Omega_m = 0.27$ and $\Omega_b = 0.044$, respectively. The densities are normalized to the critical density using a Hubble constant of $H_0 = 100\ h$ km s^{-1} with $h = 0.70$.

2. CURRENT LIMITS AND DETECTIONS OF THE EXTRAGALACTIC BACKGROUND LIGHT BETWEEN 0.1 AND 10 μm.

Figure 1 depicts the current limits and detections of the EBL in the 0.1–10 μm wavelength region (Hauser & Dwek 2001). The data include (1) ground- and space-based measurements of integrated galaxy light (Madau & Pozzetti 2000, *open triangles*; Bernstein et al. 2002, *open diamonds*; Fazio et al. 2004, *open squares*); (2) direct measurements based on data obtained by *COBE* DIRBE (Hauser et al. 1998; Dwek & Arendt 1998; Arendt & Dwek 2003, *filled diamonds*; Cambrésy et al. 2001, *filled triangles*; Wright & Reese 2000; Gorjian et al. 2000; Wright 2001, *filled squares*), and the *IRTS* NIRS (Matsumoto et al. 2000, 2005, *filled circles*) instruments; and (3) extrapolated galaxy number counts (Totani et al. 2001, *open circles*). The thick solid line in the figure represents a polynomial fit to the EBL formed by star-forming galaxies, as defined by the Totani et al. (2001) model. We refer to this EBL model as the GEBL.

Figure 2 shows the two separate fits to the NIRBL corresponding to the two Population III star formation scenarios considered by Dwek et al. (2005). In the first scenario, the Population III stars form over the redshift interval $\{z_{\rm min}, z_{\rm max}\} = \{7,\ 15\}$, and in the second they form over the $\{z_{\rm min}, z_{\rm max}\} = \{9,\ 30\}$ redshift interval. The DIRBE and NIRS observations do not provide tight constraints on the value of $z_{\rm min}$, since the short-wavelength cutoff of the NIRBL is only constrained to lie between 0.8 and 1.25 μm. Salvaterra & Ferrara (2003) attributed great statistical significance to the apparent drop in the 1.25 μm DIRBE derived flux compared to the NIRS spectrophotometric data, deriving a value of $z_{\rm min} = 8.8$. We do not regard the drop in the 1.25 μm flux to be statistically significant because of the large error bar on the 1.25 μm data point and the presence of systematic uncertainties between the two DIRBE and NIRS instruments. Designating the NIRBL corresponding to the two Population III formation scenarios by NIRBL7 and NIRBL9, respectively, we can define two more EBL realizations formed by the addition of each of these NIRBL spectra to the GEBL.

3. THE γ-RAY OPACITY FOR DIFFERENT EBL REALIZATIONS

Figure 3 depicts the GEBL+NIRBL7 realization described above (*left*) and the γ-ray opacity to a source at redshift $z = 0.122$,

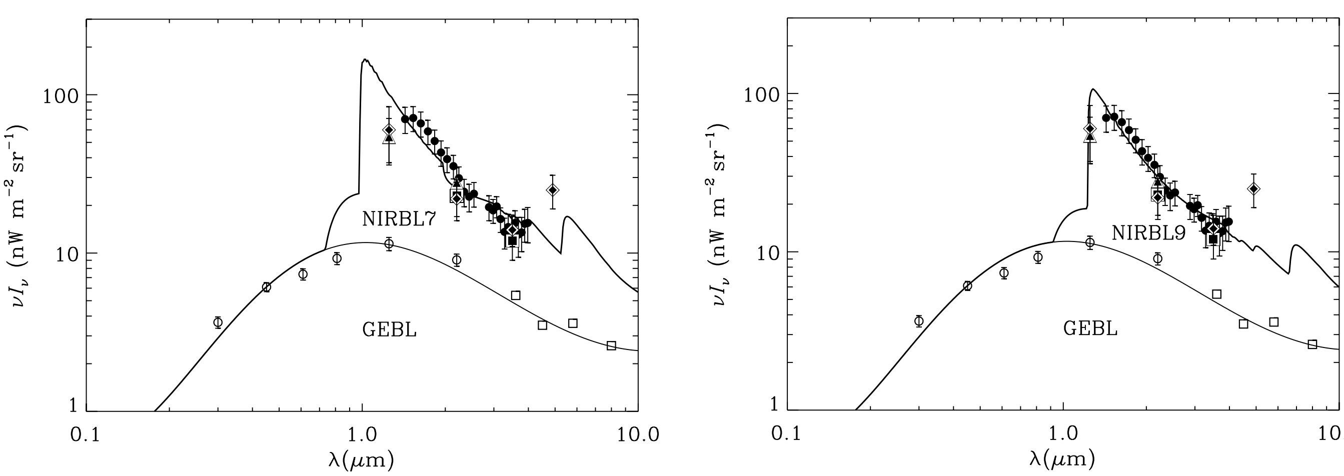

FIG. 2.—Imprint of Population III stars on the EBL for different formation scenarios characterized by $\{z_{\rm min},\ z_{\rm max}\} = \{7,\ 15\}$ (*left*) and $\{z_{\rm min},\ z_{\rm max}\} = \{9,\ 30\}$ (*right*); see Dwek et al. (2005) for more details. The NIRBL is the *excess* near-infrared background light over that defined by the GEBL and is given by the areas marked NIRBL7 and NIRBL9, corresponding to the Population III star formation scenarios.

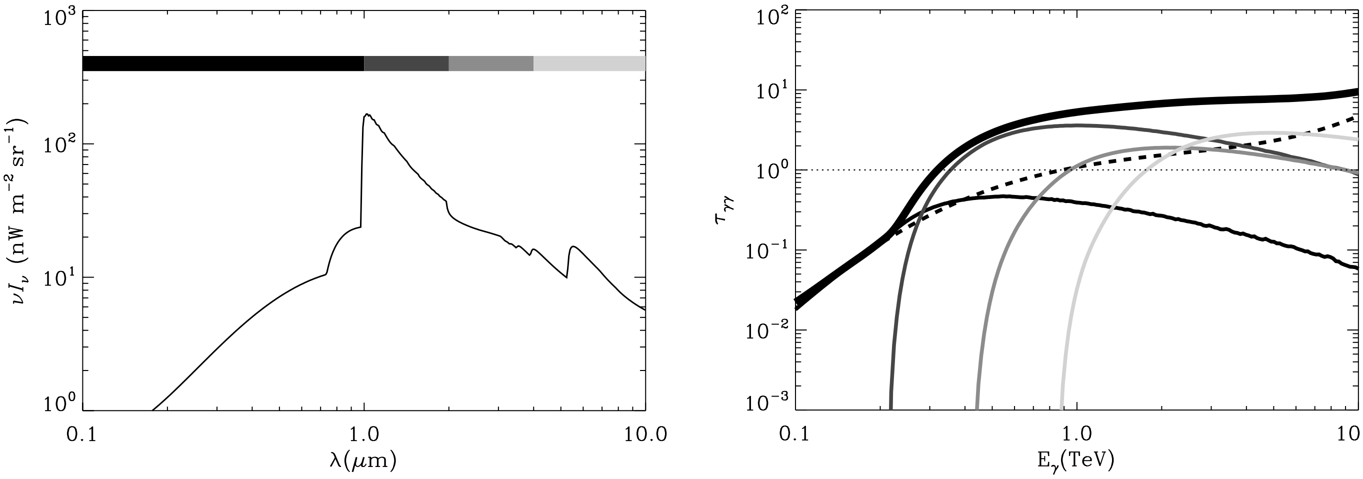

FIG. 3.—*Left*: EBL background consisting of the GEBL and NIRBL7. *Right*: γ-ray opacity to a source at redshift $z = 0.122$ due to γ-γ interactions with the EBL. The shaded curves in the figure represent the contribution of the different wavelength regions (shown by the same shaded area in the left panel) to the total γ-ray opacity. The dashed line represents the γ-ray opacity caused by the GEBL alone (see Figs. 1 and 2).

which is the average redshift for the two distant blazars H1426+428 and PKS 2155$-$304 (*right*). For more nearby blazars, the optical depth scales simply linearly with redshift. Formulae for calculating the optical depth are given, for example, by Dwek & Krennrich (2005). The shaded curves in the right panel represent the contribution of the different wavelength regions to the total γ-ray opacity. Figure 4 shows the same quantities for the GEBL+NIRBL9 realization of the EBL.

The figures show that the effect of the NIRBL is to produce a sudden rise in the γ-ray opacity to these two sources at around 300 GeV, compared to the more gradual rise in the opacity caused by the GEBL alone (*dashed line*). This discontinuous rise is caused by the relatively small 200 GeV opacity produced predominantly by the GEBL, followed by an increase in the opacity at higher energies caused by the additional contribution of the NIRBL to the γ-ray opacity. The figures also demonstrate that at $z \sim 0.12$, the sources are sufficiently far away for the NIRBL to cause the opacity to rise above unity at an energy of $\sim$300 GeV, instead of $\sim$1 TeV if the EBL consisted of only the GEBL. This effect will produce distinctly different absorption-corrected spectra for the GEBL and GEBL+NIRBL realizations of the EBL. Another important thing to note is that the sharp discontinuity in the spectral shape of the NIRBL is not translated into a comparable sharp discontinuity in the γ-ray opacity. This is a direct result of the rather broad γ-ray cross section, which will tend to smooth out any sharp features in the EBL. This effect is illustrated in Figure 5, where we compare the observed spectrum of H1426+428 to that expected from a blazar with a $dN/dE \propto E^{-1}$ intrinsic spectrum being absorbed by the GEBL+NIRBL7. The figure shows the effect of the smoothing of the NIRBL when it is convolved with the cross section for the γ-γ reaction. Mapelli et al. (2004) have attributed great significance to the peculiar shape of the observed γ-ray spectrum, taking it as evidence for the effect of absorption by the NIRBL. This seems to be supported by the apparently good fit of the (GEBL+NIRBL)-corrected spectrum to the data. Figure 5 also depicts the effect of EBL absorption when the intrinsic blazar spectrum is given by a $dN/dE \propto E^{-7/3}$ power law and the EBL consists of only the GEBL. The resulting observed spectrum is shown by a dashed line in the figure and produces a similarly good fit to the observed blazar spectrum as the previous case. We therefore conclude that, although the shape of the observed spectrum is definitely sensitive to the detailed spectrum of the EBL in the 1$-$15 μm wavelength regime (Aharonian et al. 2002, 2003), it does not provide any evidence for the extragalactic nature of the NIRBL.

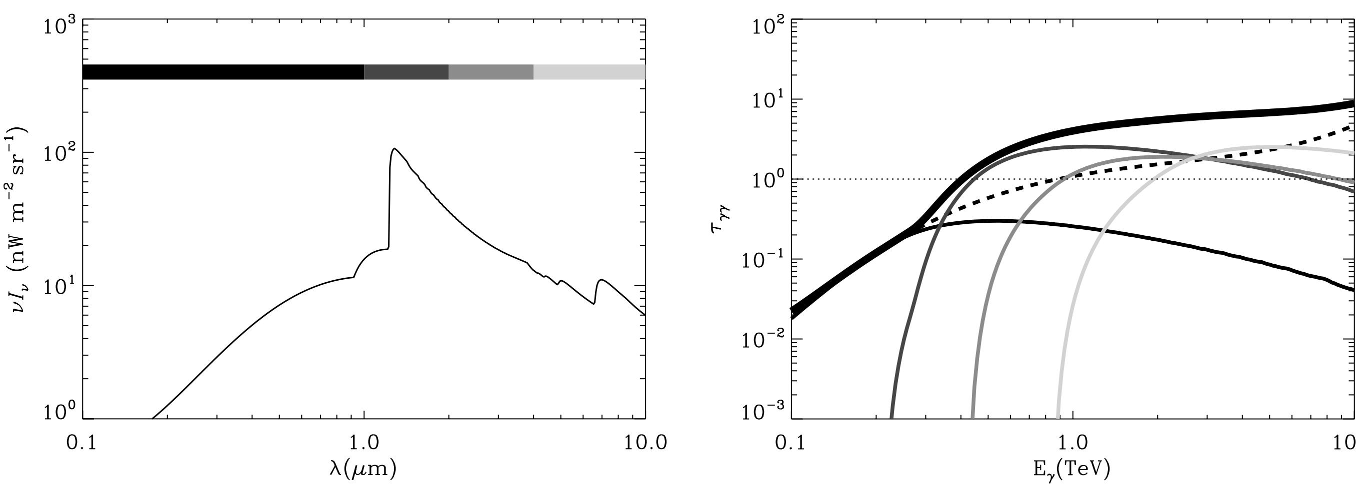

FIG. 4.—Same as Fig. 3, but for the GEBL and NIRBL9 realization of the EBL.

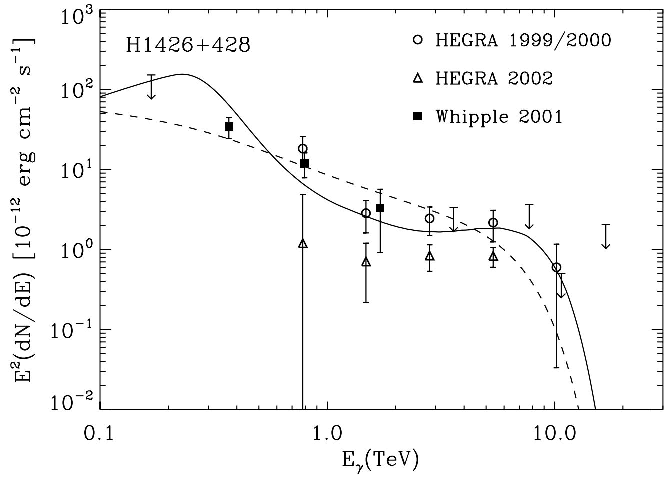

FIG. 5.—Observed spectrum of H1426+428 compared to that expected from a blazar with different intrinsic spectra for different EBL realizations. The data in the figure are the 2001 Whipple data (Petry et al. 2002), and the 1999/2000 and 2002 HEGRA data given by Aharonian et al. (2003). The solid curve represents the observed spectrum of a blazar with an intrinsic spectrum given by $dN/dE \propto E^{-1}$, attenuated by the GEBL+NIRBL7 realization of the EBL. The dashed line represents the observed spectrum of a blazar with an intrinsic spectrum given by $dN/dE \propto E^{-7/3}$ attenuated by the GEBL only. The figure shows that both EBL realizations give equally good fits to the 1999/2000 HEGRA data, but because of the variability of the source, neither model is a good fit to the 2002 data.

3.1. *H1426+428*

The blazar H1426+428 was detected at TeV energies by the VERITAS (Petry et al. 2002) and HEGRA (Aharonian et al. 2003) collaborations. Figure 6 depicts the observed γ-ray spectrum of H1426+428 corrected for the GEBL and the GEBL+NIRBL7 and GEBL+NIRBL9 realizations of the EBL (*left*). Without any a priori knowledge of its intrinsic spectrum, all absorption-corrected spectra could equally well be the intrinsic H1426+428 spectrum. Consequently, there is no possible way to use the currently observed blazar spectrum to prove the extragalactic nature of the NIRBL, a point already illustrated in the previous section and in Figure 5.

3.2. *PKS 2155−304*

The situation is somewhat different for the blazar PKS 2155−304, which was observed at ∼TeV energies by Chadwick et al. (1999) and more recently in 2002/2003 by the High Energy Stereoscopic System (HESS) collaboration (Aharonian et al. 2005). Compared to H1426+428, its observed γ-ray spectrum extends to lower energies (200 GeV) and is well fitted by a power law to a higher degree of precision. So a priori, from knowledge of the effect of the NIRBL on the γ-ray opacity toward this blazar (Figs. 3 and 4), we expect the NIRBL to create a break in its absorption-corrected γ-ray spectrum at around ∼300 GeV. Indeed, Figure 6 (*right*) shows that if only corrected for GEBL absorption, the absorption-corrected blazar spectrum is still simply a power law, but when corrected for any of the GEBL+NIRBL realizations, the absorption-corrected blazar spectrum attains a parabolic form with a peak at around 1–2 TeV and an inflection at around 300 GeV.

Concentrating only on the ∼200 GeV to 3 TeV region of the spectrum, it seems difficult to ascertain the extragalactic nature of the NIRBL because, without a priori knowledge of the intrinsic spectrum of PKS 2155−304, there is no reason for favoring any one of the absorption-corrected spectrum in Figure 6 over the other two. Additional ≲100 GeV observations are important for resolving this current ambiguity. For example, an observed 100 GeV flux continuing the observed 0.2–2 TeV power-law trend would clearly eliminate the extragalactic interpretation of the NIRBL. The GEBL+NIRBL absorption-corrected spectrum of the blazar would then have a dip at ∼300 GeV, requiring an extraordinary coincidence for this EBL to have the exact spectral shape that compensates for this feature in the intrinsic blazar spectrum to produce an observed power-law spectrum for this source.

The nature of the NIRBL becomes less ambiguous if data obtained by the EGRET experiment on board the *Compton Gamma Ray Observatory* (Vestrand et al. 1995) are included in the analysis. The entire nonthermal ∼10 eV to 3 TeV spectral energy distribution (SED) of PKS 2155−304 can be well explained by the synchrotron self-Compton (SSC) model. In this model, the very high energy (VHE) γ-rays are produced by inverse Compton (IC) scattering of the synchrotron photons by the very same electrons that produce them. The SED is therefore characterized by a double peak: a synchrotron peak located at UV-X-ray energies (∼0.1–1 keV) and a Compton peak located at energies of about 0.1–1 TeV. SSC model fits to the SED of PKS 2155−304 are presented in Figure 8 of Chiappetti et al. (1999). At the time their paper was written there was only one TeV data point

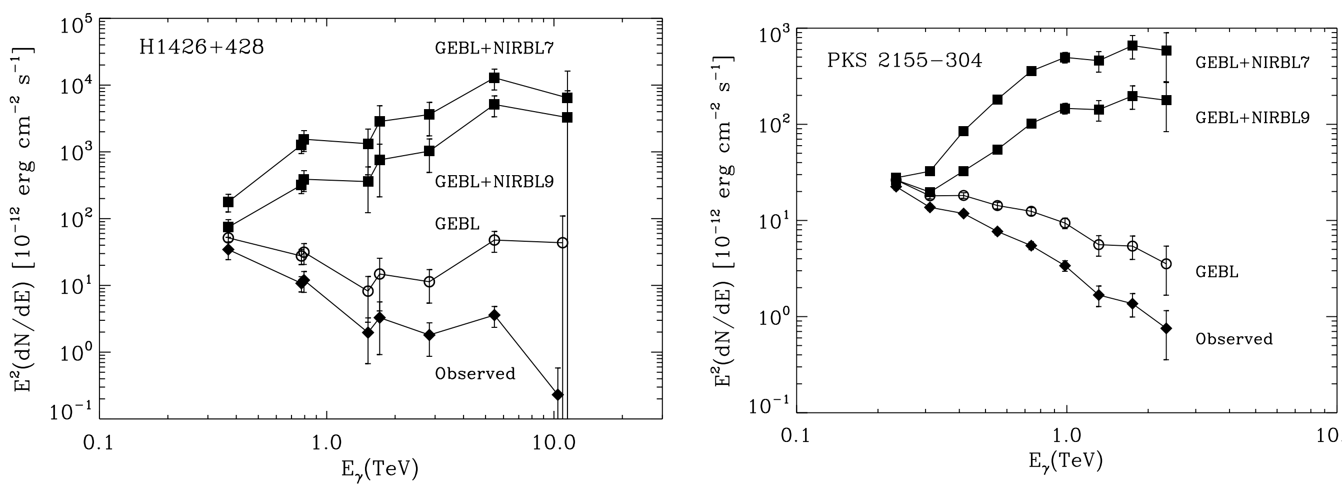

FIG. 6.—*Left*: Observed γ-ray spectrum of H1426+428 (Petry et al. 2002; *filled diamonds*) corrected for absorption by only the GEBL (*open circles*), the GEBL+NIRBL7 and the GEBL+NIRBL9 (*filled squares*) realizations of the EBL. *Right*: Same as the left panel, but for PKS 2155−304. The data point represents the HESS observations by Aharonian et al. (2005)

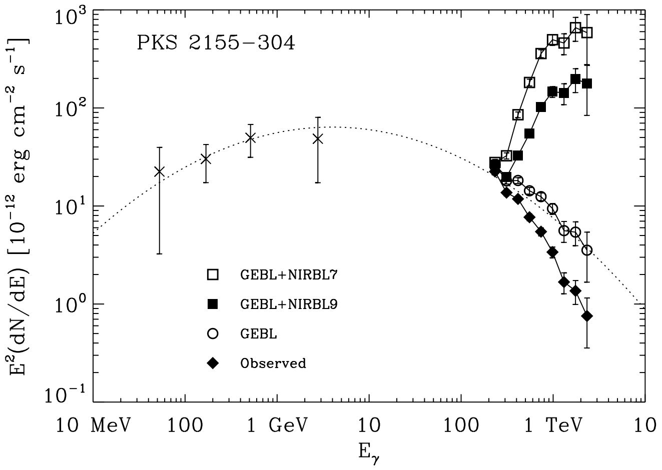

FIG. 7.—Observed γ-ray spectrum of PKS 2155−304 (Aharonian et al. 2005) corrected for the various realizations of the EBL (see Fig. 6) compared to the EGRET data of Vestrand et al. (1995) (*crosses*). A detailed discussion of the figure is in the text.

for this blazar (Chadwick et al. 1999). Figure 7 shows the combined EGRET and HESS spectra of this blazar, which covers most of the Compton region of the SED. The EGRET data are presented by crosses, and the symbols for the different VHE γ-ray spectra are the same as in Figure 6 (*right*). The UV to X-ray spectrum of the blazar is variable (see summary in Chiappetti et al. 1999), and since the EGRET and HESS data are not coeval, there may be a relative offset between the two spectra.

The figure shows that if the observed PKS 2155−304 spectrum is corrected for only GEBL absorption (*open circles*), then the resulting SED is characterized by a smooth parabolic function (*dotted line*) with a peak between 1 and 100 GeV, consistent with the SSC model presented by Chiappetti et al. (1999). In contrast, corrected for the GEBL+NIRBL realization of the EBL, the resulting 0.1 GeV to 3 TeV SED shows a significant break between ~50 and 200 GeV. The SED is initially relatively flat, with a spectral index of $\alpha \approx 0.4$ between 0.1 and 10 GeV, followed by a very steep rise with $E^2 dN/dE \propto E^{2.3}$ at TeV energies (*filled squares*). As mentioned earlier, the MeV and TeV data are not contemporaneous, and it is possible that the SED has evolved in the time span between the observations so that the SED from each individual epoch may be described by a simple SSC model. However, both the MeV and TeV regions of the spectrum would have had to evolve in a very dramatic fashion, decreasing by over 2 orders of magnitude with a significant change in slope and peak energies, in order to create a smooth function representing the IC part of the SED at both observing epochs. Using data obtained during several simultaneous multiwavelengths campaigns spanning the 1994–1999 time period, Ciprini & Tosti (2003) fit the IC part of the SED with an SSC model that produced a Compton peak at about 40 GeV. If the 2002/2003 epoch is also described by a simple SSC model, then the GEBL+NIRBL absorption-corrected spectrum suggests that the IC peak shifted to ~3 TeV. In an SSC model a shift of the IC peak by 2 orders of magnitude would also require a similar shift in synchrotron peak energy, since the X-ray band provides the seed photons that produce the TeV γ-rays. Indeed, large correlated shifts in the synchrotron and IC peaks with flaring activity have been observed for Mrk 501 and 1ES1959+650 (Costamante 2004). However, repeated observations over a ~3 year time period have shown that the synchrotron peak of PKS 2155−304 (as well as that of Mrk 421) is nearly stable at $\lesssim$1 keV. (e.g., Ciprini & Tosti 2003; Costamante 2004). PKS 2155−304 may therefore have physical characteristics different from these two blazars, and the stability of its synchrotron peak argues against the presence of strong variability in its IC peak as well. It seems therefore very unlikely that the GEBL+NIRBL absorption-corrected spectrum represents its intrinsic TeV spectrum.

Alternatively, the very steep rise in the TeV spectrum may be explained by "hadronic" models. If the TeV γ-rays are produced by hadronic interactions between or synchrotron emission from extremely high energy protons, it may be possible to reproduce a pileup of photons at TeV energies (e.g., Mannheim 1993; Aharonian 2000). However, in these models, even a proton spectrum with a sharp pileup produces a relatively flat intrinsic spectrum (see, e.g., Fig. 10 in Aharonian 2000).

3.3. *Mrk 421 and Mrk 501*

Figure 8 shows the observed and attenuation-corrected spectra of Mrk 421 and Mrk 501 for the different EBL realizations. The Mrk 501 observations were taken from Samuelson et al. (1998), and the Mrk 421 data were taken from Krennrich et al. (2001). Because of the uncertainties in the observations, and the relative proximity of these sources ($z \approx 0.03$), the increased

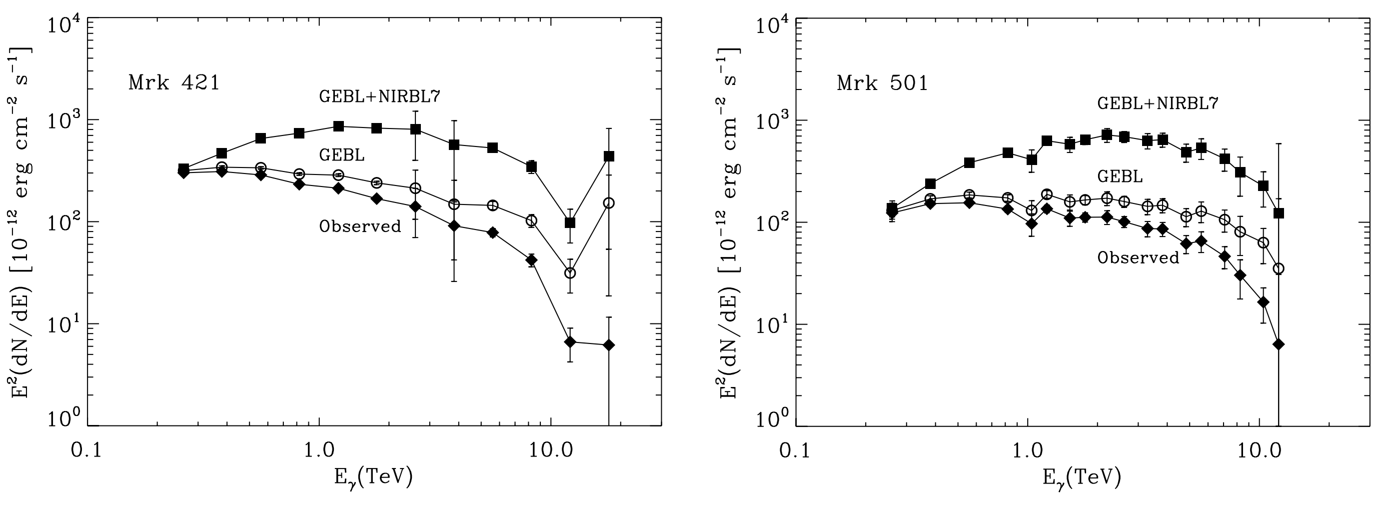

FIG. 8.—Same as Fig. 6, but for blazars Mrk 421 and Mrk 501. Because of their relative proximity, the effect of the EBL absorption has only a moderate effect on the observed blazar spectra.

γ-ray opacity caused by the addition of the NIRBL to the GEBL does not have a significant affect on the intrinsic blazar spectrum.

4. SUMMARY

The first generation of stars can have a significant effect on the spectral shape and intensity of the extragalactic background light (EBL), which may have been detected by the DIRBE and NIRS in the form of an excess in the near-infrared background light (NIRBL) over that expected from normal star-forming galaxies (GEBL). If the NIRBL is indeed extragalactic, then it has a significant effect on the γ-ray opacity of blazars. The detectibility of the resulting absorption will depend on the distance of the blazar and the quality of the γ-ray data.

In general, the abrupt increase in the NIRBL intensity between 0.8 and 1.25 μm (Fig. 1) gives rise to a more gradual increase in the γ-ray opacity at around $\sim$300 GeV (Figs. 3 and 4). Given an observed blazar spectrum, this increased opacity will in turn create a break in the absorption-corrected blazar spectrum at energies around 300 GeV, which will not be present if the EBL consisted of only normal star-forming galaxies.

An additional effect of the NIRBL is to increase the power required to be emitted by the source at $E \gtrsim 0.5$ TeV in order to produce the observed spectrum in the presence of this EBL absorption feature. Such energy requirements can provide useful constraints on γ-ray production models.

In order to examine the possible signature of this unique spectral component on the TeV spectra of blazar, we calculated the absorption-corrected spectra of the blazars, H1426+428 ($z = 0.129$), PKS 2155$-$304 ($z = 0.117$), Mrk 421 ($z = 0.030$), and Mrk 501 ($z = 0.033$), for several EBL realizations, with and without the NIRBL.

H1426+428 was observed over the 0.37–10.4 TeV energy range. Consequently, the attenuation-corrected blazar spectrum did not exhibit any distinct features attributed to the NIRBL. In particular, the TeV spectrum of H1426+428, which Mapelli et al. (2004) attributed to NIRBL absorption producing an observed S-shaped spectrum, can also be produced in EBL models *without* the NIRBL component. Both the GEBL and the GEBL+NIRBL corrected spectra require the intrinsic spectrum to be a power law, the former characterized by a $E^2 dN/dE \sim$ constant, the latter by a rising $\propto E$ behavior (Figs. 5 and 6, *left*). In principle, both spectra could be the intrinsic blazar spectrum; however, the latter seems less likely, considering the spectral characteristics of other blazars.

PKS 2155$-$304 was observed between 0.23 and 2.3 TeV, a spectral region that covers (barely) the energy region in which the γ-ray opacity is affected by the NIRBL. Consequently, while the GEBL corrected flux can be characterized by a power law, the GEBL+NIRBL one is fairly flat between $\sim$200 and 300 GeV and rising steeply as $E^{2.3}$ at higher energies (Fig. 6, *right*). Since the observed spectrum of this blazar is very well represented by a power law, it will require a very fine tuning of its intrinsic spectrum to produce this power law with the additional TeV opacity generated by the NIRBL. Furthermore, even proton synchrotron models for the VHE γ-ray emission may have difficulties producing such a steep rise in the intrinsic blazar spectrum, favoring the GEBL absorption-corrected one as the intrinsic blazar spectrum.

A stronger argument against the extragalactic nature of the NIRBL can be made on the basis of the combined MeV to TeV spectrum of the blazar (Fig. 7), which covers most of the inverse Compton region of the spectrum in the SSC γ-ray production model. Even though the MeV and TeV data are not contemporaneous, it will require a very dramatic evolution in the relative intensity and spectral shape of these two spectral regions and in the position of the Compton peak between the 1996/1997 and 2002/2003 epochs for the GEBL+NIRBL absorption-corrected spectrum to be consistent with the SSC model.

Further $\sim$10–100 GeV and contemporaneous MeV observations are needed to provide a more detailed characterization of the effect of the NIRBL opacity on the intrinsic blazar spectra. Given several possible intrinsic blazar spectra, such as those presented in Figures 6 and 7, more detailed models will be required to confirm that any one of these spectra are physically more acceptable than others in order to prove or disprove the extragalactic nature of the NIRBL.

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