TeV gamma rays from the blazar H 1426+428 and the diffuse extragalactic background radiation


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Abstract. The detection of TeV γ-rays from the blazar H 1426+428 at an integral flux level of \((4 \pm 2_{\text{stat}} \pm 1_{\text{sys}}) \times 10^{-12} \text{erg cm}^{-2} \text{s}^{-1} \) above 1 TeV with the HEGRA imaging atmospheric Cherenkov telescope system is reported. H 1426+428 is located at a redshift of \(z = 0.129\), which makes it the most distant source detected in TeV γ-rays so far. The TeV radiation is expected to be strongly absorbed by the diffuse extragalactic background radiation (DEBRA). The observed energy spectrum of TeV photons is in good agreement with an intrinsic power law spectrum of the source \(\alpha \leq -1.9\), corrected for DEBRA absorption. Statistical errors as well as uncertainties about the intrinsic source spectrum, however, do not permit strong statements about the density of the DEBRA infrared photon field.

Key words. BL Lacertae objects: individual: H 1426+428 – gamma rays: observations – diffuse radiation

1. Introduction

Many nonthermal extragalactic objects representing different classes of AGNs are considered as potential sources of TeV photons. First of all this concerns the BL Lac population of blazars in general; two nearby representatives of this class, Mkn 421 and Mkn 501 with redshifts of \(z = 0.030\) and \(z = 0.034\), respectively, are firmly established as TeV γ-ray emitters. Of special interest are the so-called “extreme synchrotron blazars”, BL Lac objects with flat spectra of synchrotron emission and high X-ray to radio flux ratios (e.g. Costamante et al. 2001). The observations of two such objects, Mkn 501 (Pian et al. 1998) and 1ES 2344+514 (Giommi et al. 2000), by BeppoSAX showed that in a flaring state the synchrotron peak of “extreme blazars” can reach 100 keV. Remarkably, both these objects are also reported as TeV blazars (see e.g. Catanese & Weekes 1999). Most probably, this is not a mere coincidence; since the high synchrotron peak is an indicator of acceleration of electrons to ultrarelativistic energies, the “extreme blazars” are obvious candidates for TeV emission. Consequently, some of these objects were intensively monitored with imaging atmospheric Cherenkov telescopes (IACT) over the last several years. Possible detections of TeV signals have been claimed by different groups for 1ES 2344+514 (Catanese et al. 1998),
Table 1. Dates of observations. Each date refers to the respective following night, with typically one hour of observations.

| 1999: | Feb. 23, Mar. 15, 16, 18-22, Apr. 10-12, 20 |
| 2000: | Mar. 5-7, 14, 28-30, Apr. 3-5, 26-28, 30, May 1, 6-8, 29, 30, Jun. 1-5 |

Table 2. Cuts, event numbers, and significances for the signal search and the spectral analysis. \( A \): on resp. off source area.

<table>
<thead>
<tr>
<th>stereo algorithm</th>
<th>signal</th>
<th>spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>shape cut: mean scaled width ( &lt; )</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>angular cut: ( \theta^2 &lt; )</td>
<td>0.011 deg(^2)</td>
<td>0.05 deg(^2)</td>
</tr>
<tr>
<td>( N_{\text{off}} )</td>
<td>1779</td>
<td>6258</td>
</tr>
<tr>
<td>( \alpha = A_{\text{on}}/A_{\text{off}} )</td>
<td>0.143</td>
<td>0.262</td>
</tr>
<tr>
<td>( N_{\text{on}} )</td>
<td>360</td>
<td>1839</td>
</tr>
<tr>
<td>( N_{\text{on}} - \text{candidates} )</td>
<td>105.9</td>
<td>199.2</td>
</tr>
<tr>
<td>significance ( \sigma )</td>
<td>5.8</td>
<td>4.3</td>
</tr>
</tbody>
</table>

\( H_{1426+428} \) (position from Hubble space telescope observations), \( \text{CRSS J1428.3+4231} \), and \( \text{CRSS J1429.7+4240} \) galaxies are listed in Table 2. The systematic pointing uncertainty of the HEGRA system is 25 arcsec. The positions of X-ray selected QSOs (\( * \): \( H_{1426+428} \) (position from Hubble space telescope observations), \( \text{CRSS J1428.3+4231} \), \( \text{CRSS J1429.7+4240} \) and \( \text{galaxies} \) (\( * \): the galaxy group \( \text{CRSS J1429.1+4241} \)) were obtained from NED.

![Fig. 1. Dots: Number of events vs. the squared angular distance to the position of \( H_{1426+428} \). Shaded histogram: Background estimate; up to \( \theta^2 = 0.0225 \) deg\(^2\), data from 7 control regions are used. Therefore, the statistical error of the background estimate is much smaller than the error of the source distribution. The dashed line shows Crab excess events, measured at similar zenith angles, scaled down to 6%, and superimposed on a flat background. The vertical dotted line indicates the position of the optimum angular cut, based on Crab data.](image1.png)

**Fig. 1.**

**Fig. 2.** The sky area around \( H_{1426+428} \) in celestial coordinates (epoch 2000). The circles show the 1 and 2 \( \sigma \) error of the reconstructed TeV position (HEGRA data). The systematic pointing uncertainty of the HEGRA system is 25 arcsec. The positions of X-ray selected QSOs (\( * \): \( H_{1426+428} \) (position from Hubble space telescope observations). \( \text{CRSS J1428.3+4231} \), \( \text{CRSS J1429.7+4240} \) and \( \text{galaxies} \) (\( * \): the galaxy group \( \text{CRSS J1429.1+4241} \)) were obtained from NED.\n
![Fig. 2. The sky area around \( H_{1426+428} \) in celestial coordinates (epoch 2000). The circles show the 1 and 2 \( \sigma \) error of the reconstructed TeV position (HEGRA data). The systematic pointing uncertainty of the HEGRA system is 25 arcsec. The positions of X-ray selected QSOs (\( * \): \( H_{1426+428} \) (position from Hubble space telescope observations). \( \text{CRSS J1428.3+4231} \), \( \text{CRSS J1429.7+4240} \) and \( \text{galaxies} \) (\( * \): the galaxy group \( \text{CRSS J1429.1+4241} \)) were obtained from NED.](image2.png)
The event distribution in the FOV was used to reconstruct the source position as seen in TeV γ-rays; for details of the procedure see Pühlhofer et al. (1997) and Aharonian et al. (2001). Figure 2 shows the sky area around H 1426+428. The positions of X-ray selected QSOs and galaxies were obtained from the NASA/IPAC Extragalactic Database (NED). The median angular resolution of the HEGRA system is approx. 0.1; the given statistics allowed the reconstruction of the center of TeV emission with a statistical error of 50′′ (1 σ). A confusion of the TeV source with other known X-ray sources is excluded. We note that the very prominent X-ray source GB 1428+4217 is located at an angular distance of 41′′2 to H 1426+428, far outside the area shown in Fig. 2.

The energy reconstruction, which has a single event resolution of ΔE/E = 20%, and the spectral evaluation were described in detail in Aharonian et al. (1999a,b). The energy spectrum was derived from the raw, background subtracted photon count spectrum using a so called effective area, which is a response function depending upon the reconstructed energy and zenith angle; the effective area was adjusted regularly according to the varying detector conditions and different system setups (3/4/5 telescopes included in the system).

Figure 3 shows the reconstructed differential energy spectrum of H 1426+428. To first order, the spectrum can be described by a pure power law dΦ/dE = (2.0 ± 1.0stat ± 0.1syst) × 10^{-12}(E/\text{TeV})^{-0.9} \text{ph cm}^{-2} \text{s}^{-1} \text{TeV}^{-1} \text{(the systematic errors do not include the 15% error on the energy scale)}. The spectral slope is similar to the one measured for the Crab nebula (Aharonian et al. 2000). The measured integral flux (derived using loose cuts) above 1 TeV is \(1.7 \pm 0.5_{\text{stat}} \pm 0.1_{\text{syst}} \times 10^{-12} \text{ph cm}^{-2} \text{s}^{-1}\), which corresponds to 10% of the Crab nebula flux.

A comparison of the total photon count rates of H 1426+428 and Crab nebula after tight cuts yields 6%; within statistical errors, both results are compatible.

3. Discussion

For any reasonable DEBRA model (see Fig. 4 a), the TeV radiation from H 1426+428 is expected to arrive with a drastically modified spectrum. Reasons are the strong energy dependence of the mean free path of γ-rays in the intergalactic medium, \(\Lambda(E)\), and the fact that the optical depth \(\tau = c z H_0^{-1} \Lambda^{-1}(E)\) significantly exceeds unity at all γ-ray energies above 300 GeV for H 1426+428 with a redshift of \(z = 0.129\). The conclusion about strong
absorption at all energies covered by HEGRA does not depend on the large systematic uncertainties in the reported DEBRA fluxes. This is demonstrated in Fig. 4b where we show the intergalactic absorption factors calculated for two reference DEBRA models. Model 1 is close to the recent calculations of Primack et al. (2001) based on the so-called Kennicutt initial mass function (IMF), and fits quite well the DEBRA fluxes reported recently by Wright & Johnson (2001) at 1.25, 2.2 and 3.5 $\mu$m wavelengths. Model 2 is designed to match the NIR fluxes reported by Matsumoto (2000) and Cambresy et al. (2001) who claim very high fluxes at wavelengths shorter than 2 $\mu$m. Despite significant quantitative differences, the two DEBRA models result in similar absorption features in the TeV spectrum: both models predict a very strong steepening of the spectrum at energies around several TeV (see Fig. 4b). This effect is common for all realistic model curves describing the DEBRA in the near IR (e.g. Primack et al. 2001), since they reflect the characteristic shape of the starlight spectrum which in the wavelength band between 1 and several microns behaves as $n(\nu) \propto \nu^{-\beta}$ with $\beta \sim -1$. The corresponding number density of background photons $n(\nu) \propto \nu^{-1}$ results in a nearly constant optical depth for $\gamma$-rays at energies around several TeV (Aharonian et al. 1999b).

The X-ray spectrum of H1426+428 which extends up to 100 keV favours an intrinsic pure power law spectrum in the relevant energy range, with an index of 1.9 (a detailed discussion is beyond the scope of this paper and will be given elsewhere). The observed spectrum - after absorption - is therefore not expected to obey a power law. The results presented in Fig. 3 show that the HEGRA spectral points are indeed better described by an intrinsic power law spectrum modified by intergalactic absorption. However, a power law fit with an adjustable spectral index results in a reduced $\chi^2$/d.o.f. = 4.4/3 = 1.47, while absorbed spectra - with a fixed source spectrum $E^{-\gamma}$, yield $\chi^2$/d.o.f. = 3.7/4 = 0.9 and $\chi^2$/d.o.f. = 1.0/4 = 0.25, for the DEBRA models 1 and 2 (see Fig. 4), respectively. Hence, more accurate spectral measurements, as well as detailed theoretical studies (concerning both the formation of the $\gamma$-ray spectra in the source and their subsequent deformation during the passage through the extragalactic photon fields), are required.

Nevertheless, the sheer fact of detection of TeV $\gamma$-rays from H1426+428 should lead to a revision of the current conceptual view of TeV blazars, according to which the synchrotron (X-ray) peak in the SED dominates over the inverse Compton (TeV) peak (see e.g. Fossati et al. 1998). Indeed, although the detected energy flux of $\gamma$-rays is only $\lesssim 4 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, corrected for intergalactic absorption this flux may well exceed $10^{-10}$ erg cm$^{-2}$ s$^{-1}$. For comparison, the X-ray flux measured by BeppoSAX (Costamante et al. 2001) and ASCA (T. Takahashi, private communication) is well below $10^{-10}$ erg cm$^{-2}$ s$^{-1}$. Since the corrected TeV luminosity seems to exceed the level anticipated from the current models of TeV blazars by far, this result may have a crucial impact on the further development of models for TeV blazars. H1426+428 is the most distant source detected in TeV $\gamma$-rays so far. The HEGRA collaboration intends to continue observing this source extensively in 2002 in the hope to decisively improve the statistics of the measurement.

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