Aharonian, Felix A.; Akhperjanian, A.; Barrio, J. A.; Beilicke, M.; Bernlohr, K.; Borst, H.; Bojahr, H.; Bolz, O.; Contreras, J. L.; Cornils, R.; Contina, J.; Denninghoff, S.; Fonseca, V.; Girma, M.; Gonzalez, J.; Gotting, N.; Heinzelmann, G.; Herman, G.; Heusler, A.; Hofmann, W.; Horns, D.; Jung, I.; Kankanyan, R.; Kestel, M.; Kettler, J.; Kohnle, A.; Konopelko, A.; Kornmeyer, H.; Kranich, D.; Krawczynski, H.; Lampeitl, H.; Lopez, M.; Lorenz, E.; Lucarelli, F.; Magnussen, N.; Mang, O.; Meyer, H.; Mirzoyan, R.; Moralejo, A.; Ona-Wilhelmi, E.; Padilla, L.; Panter, M.; Plaga, R.; Plyasheshnikov, A.; Puhlhofer, G.; Rauterberg, G.; Rohring, A.; Rhode, W.; Robrade, J.; Rowell, Gavin Peter; Sahakian, V.; Samorski, M.; Schilling, M.; Schroder, F.; Sevilla, I.; Siems, M.; Stamm, W.; Tluczykont, M.; Volk, H. J.; Wiedner, C. A. and Wittek, W.

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Astronomy and Astrophysics, 2002; 384 (3):L23-L26

A&A 384, L23–L26 (2002)
DOI: 10.1051/0004-6361:20020206

Astronomy & Astrophysics

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Received 21 December 2001 / Accepted 5 February 2002

Abstract. The detection of TeV γ-rays from the blazar H 1426+428 at an integral flux level of $(4 \pm 2_{\rm stat} \pm 1_{\rm syst}) \times 10^{-12}$ erg cm^{-2} 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 $\propto E^{-1.9}$ 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),

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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.

	signal	spectrum
stereo algorithm	#3	#1
shape cut: mean scaled width <	1.1	1.2
angular cut: $\theta^2 <$	$0.011\,\mathrm{deg}^2$	$0.05\,\mathrm{deg}^2$
N_{off}	1779	6258
$\alpha = A_{\mathrm{on}}/A_{\mathrm{off}}$	0.143	0.262
N_{on}	360	1839
$N_{\gamma-\mathrm{candidates}}$	105.9	199.2
significance σ	5.8	4.3

1ES 1959+650 (Nishiyama et al. 1999), and PKS 2155-304 (Chadwick et al. 1999). Most recently, statistically significant TeV signals have been reported also for H 1426+428, by the VERITAS (Horan & the VERITAS coll. 2001) and HEGRA (Götting et al. 2001; Aharonian 2001) collaborations. The relatively large redshift ($z = 0.129$) of H 1426+428, as well as the fact that it is the third 100 keV blazar ever found (Costamante et al. 2001), make this object an extremely important target for future multiwavelength studies of the nonthermal processes of particle acceleration and radiation in AGN jets, as well as for probing the DEBRA in the near infrared region.

In this letter we report the HEGRA observations of H 1426+428 performed in 1999 and 2000, and briefly discuss some apparent astrophysical implications suggested by the obtained results.

2. Observations and results of analyses

For the following analysis, 14.5 hrs of data from 1999 and 29.9 hrs from 2000 were available, taken with the HEGRA IACT system; see Table 1 for the dates of observations. The median zenith angle was 17°, resulting in a γ-shower peak detection rate at an energy of 700 GeV for Crab-like spectra (Konopelko et al. 1999).

Shower reconstruction and cuts were described e.g. in Aharonian et al. (1999a). The methods applied in this analysis differ slightly, depending on the tasks which were performed. For the search for new sources we applied tight cuts and stereo algorithm #3 (Hofmann et al. 1999) to achieve high sensitivity. For the spectral analysis of the detected source, somewhat relaxed cuts were used which provide a larger γ-acceptance; these cuts are less susceptible to systematic errors, and the spectral reconstruction was tested in great detail using Monte Carlo studies and γ-ray data from known TeV sources (Aharonian et al. 1999a,b). The background was estimated using a set of control regions in the field of view (FOV); the setup provides seven

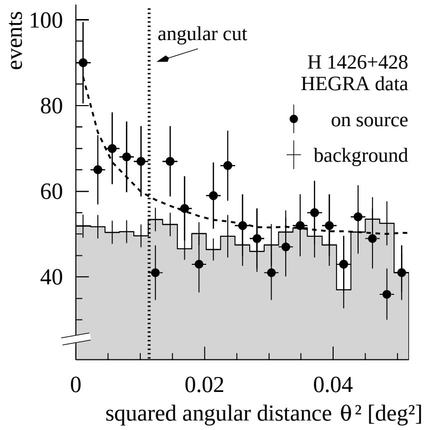

Fig. 1. Dots: Number of events vs. the squared angular distance to the position of H 1426+428. Shaded histogram: Background estimate; up to $\theta^2 = 0.0225\,\mathrm{deg}^2$, data from 7 control regions are used. Therefore, the statistical error of the background estimate is much smaller than the error 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.

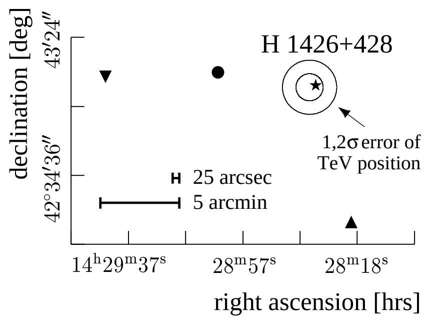

Fig. 2. The sky area around H 1426+428 in celestial coordinates (epoch 2000). The circles show the 1 and 2 σ error of the reconstructed TeV position (HEGRA data). The systematic pointing uncertainty of the HEGRA system is 25 arcsec. The positions of X-ray selected QSOs ($\star$: H 1426+428 (position from Hubble space telescope observations), ▲: CRSS J1428.3+4231, ▼: CRSS J1429.7+4240) and galaxies (●: the galaxy group CRSS J1429.1+4241) were obtained from NED.

times more background data than on source data under identical acceptance conditions (Aharonian et al. 2001). The optimum angular cut (for the signal search) was derived on the basis of the angular resolution – using γ-ray events from the Crab nebula – and the background level. Table 2 summarizes cut parameters, resulting event numbers, and significances for the signal search and spectral analysis.

Figure 1 shows the event distribution, obtained from the signal search, as a function of the squared angular distance to the source position. The excess significance, calculated according to Li & Ma (1983), amounts to $5.8\,\sigma$ ($2.4\,\sigma$ in 1999, $5.3\,\sigma$ in 2000). While there is an indication that the source was in a higher state in May 2000, the

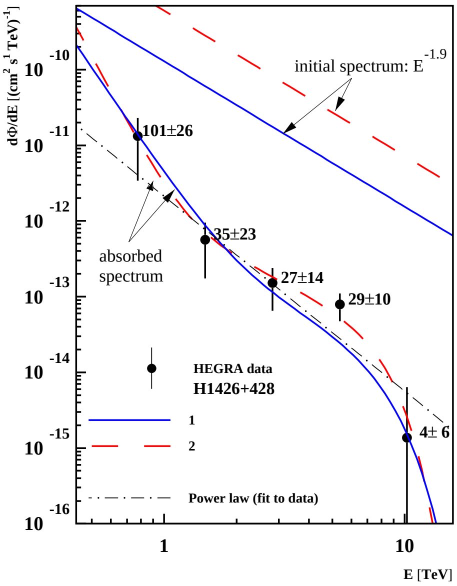

Fig. 3. Differential energy spectrum of H 1426+428 (dots); the numbers indicate the (background subtracted) event counts and their corresponding statistical 1σ-errors. A power law fit to the data is shown by the dashed-dotted line. The solid and the dashed lines represent absorbed model spectra, obtained by an initial power law spectrum $\propto E^{-1.9}$ (normalized to the data) combined with different absorption models (see Fig. 4).

total data set is also statistically consistent with constant signal accumulation.

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 $50''(1\,\sigma)$. 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 $\Delta E/E = 20\%$, 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 $\mathrm{d}\Phi/\mathrm{d}E = (2.0 \pm 1.3_{\rm stat} \pm 0.1_{\rm syst}) \times 10^{-12}(E/\mathrm{TeV})^{(-2.6\pm0.6_{\rm stat}\pm0.1_{\rm syst})}\,\mathrm{ph\,cm^{-2}\,s^{-1}\,TeV^{-1}}$ (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 $(1.7\pm0.5_{\rm stat}\pm0.1_{\rm syst})\times10^{-12}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ 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.

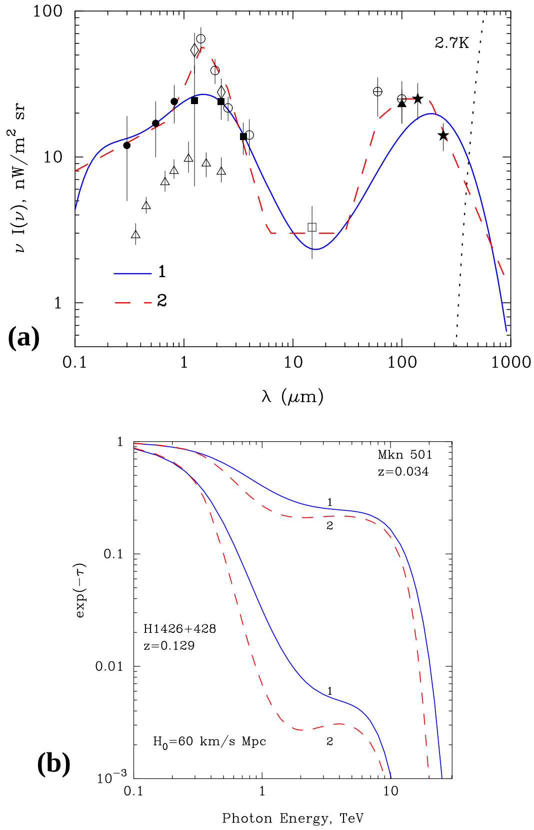

Fig. 4. a) Diffuse extragalactic background radiation. The reported fluxes at far infrared wavelengths above 60 μm, as well as at optical wavelengths below 1 μm are taken from the recent review by Hauser & Dwek (2001). The lower flux limit at 15 μm is derived from the ISOCAM source counts (Franceschini et al. 2001). The fluxes reported at NIR are shown by filled squares (Wright & Johnson 2001), open circles (Matsumoto 2000), and open diamonds (Cambresy et al. 2001). Two model curves are shown by dashed and solid lines, respectively. **b)** The spectrum modification factors $\exp[-\tau(E)]$ calculated for the two DEBRA models for Mkn 501 and H 1426+428.

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. 4 b 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 Kennicut 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 μm 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 μm. 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 below 1–2 TeV, but an almost energy independent absorption at energies around several TeV (see Fig. 4 b). 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 $\nu I(\nu) \propto \lambda^{\beta}$ with $\beta \sim -1$. The corresponding number density of background photons $n(\epsilon) \propto \epsilon^{-1}$ results in a nearly constant optical depth for γ-rays at energies around several TeV (Aharonian et al. 1999b).

The X-ray spectrum of H 1426+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 χ^2/d.o.f. = 4.4/3 = 1.47, while absorbed spectra – with a fixed source spectrum $\propto E^{-1.9}$ – yield χ^2/d.o.f. = 3.7/4 = 0.9 and χ^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 γ-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 γ-rays from H 1426+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 γ-rays is only $\simeq 4 \times 10^{-12}$ 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.

H 1426+428 is the most distant source detected in TeV γ-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.

Acknowledgements. The support of the German ministry for research and technology (BMBF) and of the Spanish Research Council (CICYT) is gratefully acknowledged. GR acknowledges receipt of a Humboldt fellowship. We thank the Instituto de Astrofísica de Canarias for the use of the site and for supplying excellent working conditions at La Palma.

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