Status and Selected Recent Results of the HEGRA Imaging Air Cherenkov Telescopes

Dieter Horns, for the HEGRA Collaboration
Max-Planck Institut f. Kernphysik, Heidelberg, Germany

Abstract

The status of the HEGRA imaging air Cherenkov telescopes is summarized. We present results from a survey of the Galactic plane for point sources with a limiting flux of approximately a third of the flux seen from the Crab Nebula. For Mkn 421 ($z = 0.031$) we present the detection of spectral variability correlated with the flux. Finally, we summarize results of observations carried out on the most distant known TeV Blazar H1426+428 ($z = 0.129$) in the years 1999, 2000, and 2002.

1. Introduction

The HEGRA imaging air Cherenkov telescopes (IACT) have been operational in varying setups since 1993 until September 2002. With the completion of the stereoscopic system in 1997, the HEGRA system has reached an improved sensitivity and a reduced energy threshold ($E_\gamma = 500$ GeV) with respect to single telescope performance. A signal from the Crab-Nebula is detected at the level of $10\,\sigma \cdot \sqrt{t/\mathrm{hr}}$ (t indicates the observational time in hours, the significance is calculated following the likelihood ratio approach in Li&Ma (1983)) above a threshold of 500 GeV. The stand-alone telescope CT 1 (Mirzoyan et al. 1994) has served as a prototype instrument and test bed for new developments of detectors and reflectors. The observation of Cherenkov light at the presence of moon-light at the expense of sensitivity has been proved to be useful for observations of variable sources like Mkn 501 with this instrument (Kranich et al. 1999).
Both detector systems have been used to develop enhanced analysis methods to exploit the imaging Cherenkov technique (Konopelko 1995, Hofmann et al. 1999& 2000, Kranich 2001). The multi-telescope view of air showers has been demonstrated to improve sensitivity, to guarantee precise measurements of the shower parameters like direction, core position, height of shower maximum, and energy with good control of the systematic uncertainties. Here, we present a selection of results mainly obtained during the last two years of operation (2001& 2002)

pp. 1–9

of the HEGRA IACTs. Additionally, we would like to point out the existence of five individual contributions of the HEGRA collaboration appearing in these proceedings, covering observations of Mkn 421 (Cortina et al. 2002), 1ES1959+650 (Horns et al. 2002), an unidentified source in the Cygnus region (Rowell et al. 2002), an archival search in the $\approx$ 6000 hrs of observations for serendipitous detections of sources in the $\approx$ 100 field of views observed during the operation of HEGRA covering 0.4 srad (Pühlhofer 2002a). The technical performance of the telescope system during its lifetime is documented in (Pühlhofer et al. 2002b). The 5 identical telescopes operating as a stereoscopic system have been dismantled in September 2002.

2. Recent Results

2.1. Scan of the Galactic Plane

The open question of the origin of the nuclear component of cosmic rays is addressed by a variety of models. In the framework of diffusive shock acceleration in the vicinity of shell type Super Nova remnants (SNRs) gamma-ray emission is expected because of interaction with the ambient interstellar medium and subsequent decay of neutral pions (Drury et al. 1994). However, a clear experimental proof of this picture is still missing. The high spatial density of SNRs in the Galactic plane motivates a large scale survey of the Galactic plane to search for gamma-ray signals from individual remnants. Besides shell type SNRs, it is believed that the Galactic plane contains a large number of gamma-ray sources, namely plerion type SNRs (like the Crab Nebula), pulsars, binary systems (Micro-Quasars), molecular clouds illuminated by cosmic rays, and clusters of young stars. We have dedicated a total of 176 hours of observations to scan $\approx 1/4$ of the Galactic plane between $l = -2^\circ$ and $l = 85^\circ$ (Aharonian et al. 2002c). After selecting the data for stable trigger rates, the analyzed data set encompasses 115 hrs of observations. The individual exposure time of the 92 pointings varies between 1 and 10 hrs. The zenith angle of the observations was optimized to keep the threshold as low as possible. However, the inner part of the Galaxy ($l < 15^\circ$) including the Galactic center is only observable under zenith angles larger than 45° for the geographic latitude of La Palma (28°45′N) where these observations were carried out. The scan covers 63 known SNRs, 9 sources from the EGRET GeV catalogue of unidentified sources and 86 known pulsars. No signal has been observed and upper limits on the level of 0.15-0.5 Crab units have been derived. No signal from any other position covered by the scan has been found. Searches for moderately extended sources with radii from $0.1^\circ - 0.4^\circ$ have been carried out without any indications for sources. We have

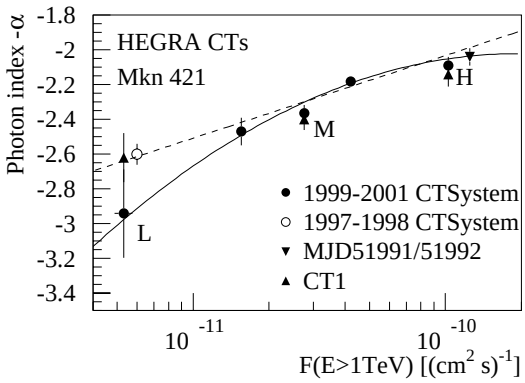

Fig. 1. For different integral flux levels of Mkn 421, the photon index shows a hardening of the spectrum for increased fluxes. The function used to fit each spectra is a power law with an exponential cut-off energy fixed at 3.6 TeV.

derived an upper limit of 6.7 % of the Crab flux on the integrated emission that stems from the ensemble of SNRs. We compare this limit with the accordingly calculated expectation of 2.9 % of the Crab flux using the predictions by Drury et al. (1994). At this point, we conclude that the injection efficiency θ or the average medium density n cannot greatly exceed the assumed values of Drury et al. (1994).

2.2. Spectral variability of Mkn 421

During the strong outbursts in X-rays and gamma-rays observed from Mkn 421 in the years 2000 and 2001, we have detected for the first time a clear correlation of the spectral shape and the flux. We have averaged the observations in 5 distinct flux intervals ranging from 0.4 Crab units to 6 Crab units. All spectra are well described by a power-law multiplied by an exponential e^{-E/E_c} with $E_c = 3.6 \pm 0.4$ TeV as a cut-off energy. In Fig. 1. we show the power-law photon index as a function of integral flux. The lines are included to guide the eye, see Aharonian et al. (2002b) for details. A similar analysis applied to data taken with the stand-alone telescope gives very similar results (see also Fig. 1.). Besides the long-term spectral variability observed for the entire data-set, we have studied intra-night variability on sub-hour time scales. For individual nights with sufficiently high fluxes to measure spectral variability on short time scales, we observe rapid variations in the flux and changes in the spectral slope correlated with the changes in the flux (see Fig. 2.).

2.3. Observations of H1426+428

The most distant ($z = 0.129$) currently known object detected at TeV energies is the extreme BL Lac object H1426+428 (Remillard et al. 1989, Costamante et al. 2001). The object has been observed extensively with the HEGRA system of IACTs. An initial detection ($S = 5.8\ \sigma$) during a 44 hrs observation in

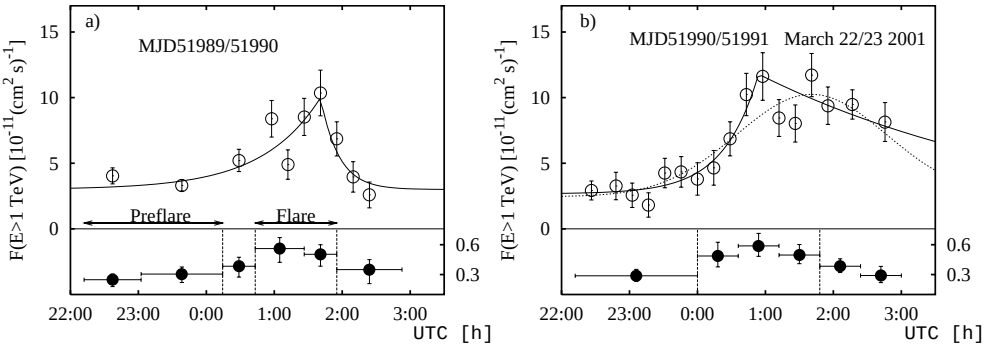

Fig. 2. Interestingly, for Mkn 421 we observed during two consecutive nights individual flares with very distinct behaviour: Whereas in the first night (left panel), the rise-time seems to be longer than the decay time, the second night (right panel) shows a different pattern with a short rise-time and a very extended decay time. In both nights, the hardness-ratio (lower panel) derived by taking the flux above 1.5 TeV and dividing it by the flux integrated between 0.75 and 1.5 TeV shows a correlation with the flux variations. Note, during the second night, the spectrum after the flare becomes softer even though the flux has not returned to the initial value. The temporal profiles of the flares indicate a complex picture with varying time scales for the rise and decay.

1999 and 2000 has lead to the first study of the energy spectrum observed from this source (Aharonian 2002a). Here, we report on the deep (T_{obs} = 220 hrs) follow-up observations performed in 2002. The source is again detected at the level of $S = 5.1\ \sigma$, indicating a lower flux level than during the previous observational seasons.

We have improved the spectral analysis to reconstruct energy spectra for weak fluxes by applying tighter cuts than those used in Aharonian et al. (2002a) on the gamma/hadron separating quantity mean scaled width ($\tilde{w} < 1.1$) and on the angular separation to the source direction ($\theta < 0.12^{\circ}$).

In order to increase the sensitivity to discern structures in the spectrum, we have utilized an improved energy reconstruction algorithm (Hofmann et al. 2000) which uses the position of the shower maximum and a constrained algorithm to derive the impact parameter of the shower core in order to achieve a relative energy resolution of $\Delta E/E = 10\,\%$. Note, that by correcting on the position of the shower maximum, the bias to select deeply penetrating showers near the threshold is compensated and the energy is not overestimated for low energies. Since the improved energy reconstruction also employs a different core reconstruction with a resolution of $\sigma_r < 5$ m, we have produced new scaling tables to calculate $\tilde{w}$ slightly reducing (by 1-2 percent points) the width of the resulting $\tilde{w}$ distribution for gamma-ray induced air showers.

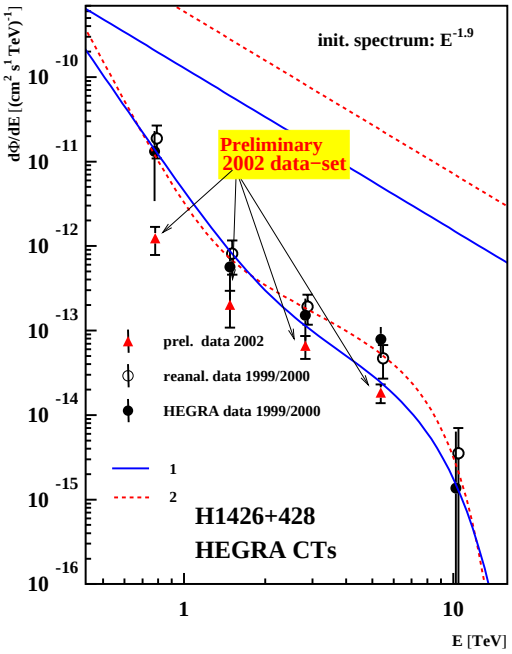

Fig. 3. Differential energy spectrum of H1426+428: The solid black points and the different lines are identical to Fig. 3 in Aharonian et al. (2002a). The reanalyzed data points of the same data-set are indicated by open circles. The triangles are the preliminary result obtained from the deep observation in 2002 with a flux level below the previous measurements.

The new spectral energy reconstruction procedure has been checked with data from the Crab-Nebula and also with the 1999/2000 data-set from H1426+428. We show in Fig. 3. the data-points from our previous analysis published in Aharonian et al. (2002a) together with the reanalyzed points and the result of the analysis of the 2002 data set (Aharonian et al. in prep.). Note, the reanalyzed points are consistent with the original analysis. The size of the errors has been reduced because of the improved signal-to-noise ratio. Again, a considerable part of the excess is detected at energies above 3 TeV indicating a flattening of the observed spectrum. The overall flux level during the 2002 observations is by a factor of 2.5 ± 0.8 lower than during the previous observations in 1999/2000. This indicates variability from this source. A possible interpretation of the spectral shape would explain the observed spectrum by absorption of TeV photons on the extragalactic background light (EBL) in the near infrared. Scattering of energetic gamma-rays emitted at the distance of H1426+428 with the EBL causes a substantial absorption at energies above $\approx$ 300 GeV. The absorption is energy dependent and the scattering rate for a given photon energy is highest for a narrow wavelength band of the EBL: $\lambda(E) \approx 1.24\ \mu\mathrm{m}/E_{\mathrm{TeV}}$. We have applied the absorption calculated for an EBL energy distribution shown in Fig. 4 of Aharonian et al. (2002) assuming an initial power-law spectrum with a photon index of 1.9. The flattening is well consistent with the signature of an EBL-induced absorption on the observed energy spectrum. More details will be discussed in a forthcoming paper.

3. Conclusion

We have shown a selection of recent results obtained with the HEGRA IACTs. We have surveyed the Galactic plane for strong gamma-ray sources (at the level of 0.15-0.5 Crab units) covering at the same time 63 known SNRs, 9 EGRET objects from the GeV catalogue of unidentified sources, and 86 pulsars. A limit on the cumulative emission of the SNRs has been calculated and compared with predictions in the framework of diffusive shock acceleration. The upper limit is consistent with the expectation and weakly constrains the parameters of the model.

For the nearby BL Lac object Mkn 421, a correlation of the spectral shape with the overall flux level has been found. For two particular nights during the flaring period in spring 2001, we have found evidence for intra-night spectral changes correlated with varying flux levels. Additionally, the time profiles of the flares have been found to exhibit asymmetrical shapes.

Finally, for the most distant BL Lac object detected at TeV energies (H1426+428), we have presented the result of three years of observations indicating a structure in the spectrum deviating from a pure power-law. The overall flux level of this object has been found to be lower in 2002 than in previous observations.

4. References

Aharonian, F., et al. A&A 384, L23 (2002a)
Aharonian, F., et al. A&A 393, 89 (2002b)
Aharonian, F.A., et al. A&A in press (2002c)
Cortina, J., these Proceedings S23
Costamante, L. et al. A&A 371, 512 (2001)
Drury, L.O'C, F.A. Aharonian, and H.J. Völk, A&A 287, 959 (1994)
Hofmann, W., et al. Astrop. Phys. 12, 135 (1999)
Hofmann, W., et al. Astrop. Phys. 12, 207 (2000)
Horns, D., these Proceedings S25
Konopelko, A. 1995, in Proc. Towards a Major... (Padova), 373
Kranich, D., et al. Astrop. Phys. 12, 65 (1999)
Kranich, D., PhD Thesis, TU München (2001)
Li, T.-P. & Y.-Q. Ma ApJ 272, 317 (1983)
Mirzoyan, R., et al. NIM A 351, 513 (1994)
Pühlhofer, these Proceedings S09 (2002a)
Pühlhofer, these Proceedings T11 (2002b)
Remillard, R., et al. ApJ 345, 140 (1989)