Proceedings of ICRC 2001: 2634 © Copernicus Gesellschaft 2001

ICRC 2001

The TeV spectrum and lightcurve of Mkn 421 in 1999/2000 as observed with the HEGRA Cherenkov Telescope CT1

M. Kestel for the HEGRA Collaboration

MPI für Physik, München, Germany

Abstract. The HEGRA collaboration has observed Mkn 421 with the Cherenkov telescope CT1 for more than 200 hours in 1999/2000, partly during moonshine. During this time some strong flares have been observed. The lightcurve and the spectrum are presented.

1 Introduction

Mkn 421 is a nearby ($z = 0.031$) and one of the best studied active galactic nuclei (AGN). It was the first extragalactic source found to emit TeV γ-rays (Punch, 1992). In the 1994-1995 observing season Mkn 421 was confirmed on a 5.8 σ level with HEGRA CT1 and HEGRA CT2 (Petry, 1996) and is regularly monitored since then by HEGRA.

The HEGRA CT1 lightcurve of Mkn 421 has up to now the highest time coverage from all TeV instruments.

While only few bursts have been observed from Mkn 421 until the end of the 1998-1999 observing season, more frequent and larger flares were recorded since 1999-2000.

Mkn 421 is the source with the up to now fastest observed flux changes reported from TeV γ-ray emitters. With a mere of 15 minutes flux doubling time the emission region must be of the size of our solar system (assuming a γ-factor of ~ 10 (Gaidos, 1996)).

Recently exceptionally large and persistent flaring has been observed in the 2000-2001 season. This attracted the interest of many groups, operating instruments that cover the whole electromagnetic spectrum. Several multi wavelength campaigns have been carried out, whose results are hoped to further clarify the physics of AGNi.

Mkn 501, at a similar redshift ($z = 0.034$), shows TeV emission with a spectral cutoff around 6 TeV in its energy spectrum from 1997. This cutoff might be intrinsic to the source or caused by an absorption process due to the possible interaction with the up to now unquantified infrared (IR) background. Therefore the detailed study of the TeV spectra of both Mkn 501 and Mkn 421 are also of particular interest for cosmology, because TeV γs might provide an efficient probe of the IR background around 10μm wavelength.

While a high significance observation of an unbroken powerlaw spectrum of Mkn 421 would be a proof that the cutoff of Mkn 501 is source inherent, the observation of a cutoff of Mkn 421 at about the same energy would strengthen the existence of a sizeable IR background around 10μm wavelength but not rule out the source internal limitation.

It is therefore important to collect as much as possible information on Mkn 421 and make as many as possible comparisons to the Mkn 501 spectra.

The paper is organised as follows: The data taking in the 1999-2000 period is summarised in section 2. The analysis procedure is briefly described in section 3, the results are presented in section 4. A discussion and summary in section 5 concludes this paper.

2 HEGRA CT1 Data on Mkn 421 in 1999/2000

2.1 Some CT1 Hardware Properties and their Simulation in the underlying Monte Carlo Study

Since around 1996 the HEGRA collaboration operates a system of five Cherenkov telescopes in stereoscopic mode at the IAC site La Palma, Canary Islands, Spain. Already since 1991, a standalone Cherenkov telescope, HEGRA CT1, is operated at the same site (Mirzoyan, 1994; Cortina, 1999).

Its initial 5 m^2 area main reflector has been replaced in 1998 by a 10.3 m^2 one of 33 diamond turned, all-aluminium mirrors. The camera comprises 127 3/4” EMI 9083A photomultipliers (PM) of 0.25° diameter each, totaling to a 3° field of view.

A trigger signal for the readout of an event is generated, when two neighbouring pixels (2/127 NN) exceed a threshold level corresponding to 13 photo electrons within a time window of 8 ns.

A refined Monte Carlo simulation (based on the COR-

Correspondence to: M. Kestel (mka@mppmu.mpg.de)

HV Setting	Moonshine	Hours	Significance
Nominal	No	161	18.7
Nominal	Yes	27	4.1
-4%	Yes	14	2.0
-8%	Yes	10	0.2

Table 1. The observation times of Mkn 421 with HEGRA CT1 in the 1999-2000 observation period for the different HV settings.

SIKA package, Heck and Knapp (2001)) has been used for this analysis, taking many subtle detector parameters into account (Sobczyńska and Lorenz, 2001). The most important improvement w.r.t. earlier simulations is the time resolved trigger simulation.

Single photo electron pulses are simulated with a variable pulse height and time shape according to the measured distributions (*op. cit.*). Photo electron signals are superimposed according to the time profile of Cherenkov photons after being tracked through the atmosphere (Mie and Rayleigh scattering were simulated according to the formulae given in Sokolsky (1989)).

Previous simulations were based on simple photo electron counting within the trigger coincidence window. The resulting effective areas are larger compared to that of the present simulations.

The time spread of arriving Cherenkov photons is especially important when only few photo electrons are seen from showers, e.g. for events close to the threshold. The older simulations overestimated the trigger efficiencies, leading to too low flux estimates.

CT1 has a threshold of ≈700 GeV. The trigger rate on cosmic ray events close to zenith is around 2.7 Hz, decreasing to $\sim$ 2 Hz at 45° zenith angle (ZA).

2.2 The HEGRA CT1 dataset

The data taken on Mkn 421 in the period 1999-2000 consists of 161 hours taken during dark nights and 51 hours under moonlight.

Data under the presence of moonlight are taken with partly reduced high voltage (HV) settings of the PMs. The main effect of a reduced HV is a higher telescope threshold.

Table 1 gives a summary of the observation times and results with different HV settings.

The minimum ZA for the observation of Mkn 421 is around 9°. The maximum ZA considered in the analysis is 45°, corresponding to the highest ZA in the Monte Carlo study.

In total 1.1×10^6 dark night events were recorded after rejecting events triggered by night sky background noise.

3 Data Analysis

The raw data have been subjected to certain quality requirements. The cosmic ray rate as a function of the zenith angle was required to be close to the average, reaching the beforementioned ≈2.7 Hz close to culmination.

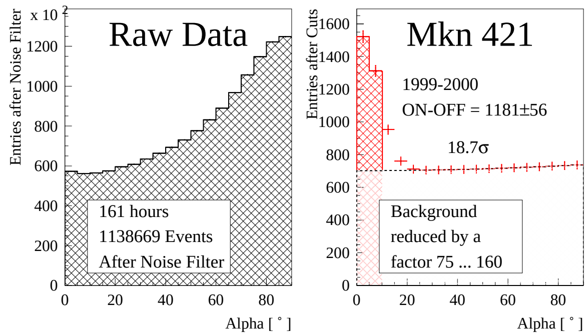

Fig. 1. Raw *ALPHA* distribution of 161 hours of Mkn 421 data, recorded with HEGRA CT1. Using night-sky-background corrected image parameters and cuts that have been optimised on an equally treated Crab data sample, the source is detected with a significance of 18.7 σ.

The proper functioning of the electronics was checked and possible coherent noise pickup, for example from the steering motors, has been corrected in the data.

The calibration of the raw ADC information to photo electrons and the calculation of the HILLAS image parameters (Hillas, 1985) has been done as described e.g. in Petry (1997).

It was found that during the run period quite significant variations in the night sky background occurred. This variation had a significant impact on the image parameters.

A new method to correct the HILLAS image parameters for the influence of variable night sky background light was applied to the data; it is described in Kestel (2001).

3.1 γ-Hadron Separation Cuts

A set of Crab data, recorded from October 2000 through March 2001, was subjected to the same image parameter correction and served to derive a new set of γ-hadron separation cuts. The cut optimisation procedure is described in detail in Kranich (2001a).

Using these cuts an excess γ-rate from Crab of ≈24 γ/hour on a background of 16 events/hour close to zenith is achieved.

Figure 1 shows the reduction power of these cuts and the overall significance of Mkn 421 collected during dark night. The new cuts suppressed the charged cosmic ray background under the source by a factor of $\sim$ 75.

3.2 Energy Estimation

The initial γ-energy has been estimated from the showers in a two step procedure.

In a first step the impact parameter was estimated from the zenith angle and the ratio of *WIDTH* over *LENGTH* and the parameter *DIST*.

In a second step the energy was calculated from the *SIZE* and the reconstructed impact parameter.

The detailed Ansatz of the calculation can be found in Kranich (2001a) and was verified with Monte Carlo data.

The RMS energy resolution is typically 20-30%. A comparison of the reconstructed energy with the initial input energy shows that a small fraction of high energy events are quite significantly underestimated. This effect, mainly for events with large *DIST* parameter, has its origin in the too small camera, i.e., large events are in part truncated.

The energy bin width for the spectral studies has been chosen to be roughly two times the resolution in order to keep bin-to-bin correlations in the spectrum small.

The data points at 6.6 and 23.6 TeV have a low significance and are excluded from the fit.

The correction method for effects of limited resolution in the determination of energy spectra is described in Kranich (2001b).

4 Results

4.1 The HEGRA CT1 longterm TeV fluxcurve of Mkn 421

Figure 2 shows the Mkn 421 lightcurve from 1995 up to spring 2001, as recorded with HEGRA CT1.

It can be seen that in the past Mkn 421 has been quite inactive except for a few flares and has hardly reached the Crab level until the end of the 1998-99 season.

During the observation season 1999-2000 two bigger flaring activities were recorded, the flux reaching around two times that of the Crab. The expanded lightcurve around this flare is shown in Figure 3. In the 2000-2001 observation season Mkn 421 showed shortterm peak fluxes up to close to ten times that of the Crab (the nightly averages are lower), see Cortina (2001).

4.2 Example of shortterm variability in 1999-2000

Mkn 421 has been reported earlier to be highly variable on very short timescales down to ≈15 minutes (Gaidos, 1996). A typical example of intranight flux variation is shown in Figure 4, showing the integral fluxes above 1 TeV in observation time windows of 1 hour. A peak flux of ≈2.5 Crab units has been reached.

4.3 Energy Spectrum

The time averaged energy spectrum of Mkn 421 in 1999-2000 is shown in Figure 5. It has been calculated from data with zenith angles up to 45°. A χ^2-fit with a power law Ansatz yields a spectral index of 3.33 ± 0.35. The spectrum is softer than the Crab spectrum, which is found with a spectral index of 2.70 ± 0.31 in the CT1 data.

A χ^2/dof of 2.3/6 has been found and any fit with additional parameters is therefore not going to reveal extra information on cutoff parameters.

5 Discussion

The following conclusions can be drawn from the 1999-2000 data of 161 hours observation time.

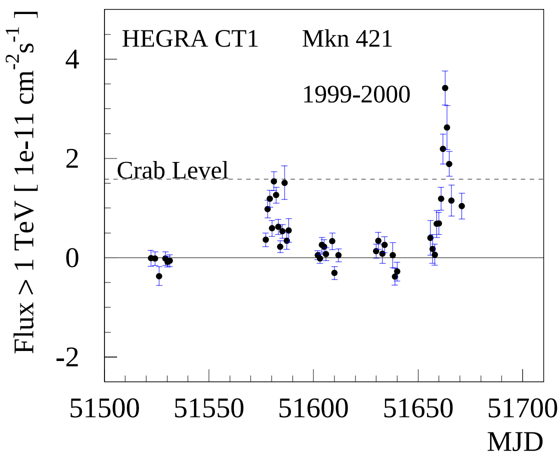

Fig. 3. Lightcurve of Mkn 421 recorded with HEGRA CT1 in 1999-2000. At the end of the season a major outburst was recorded, the intranight flux of NoonMJD 51663 has been expanded in Figure 4.

- The mean flux level was slightly less than 0.3 Crabs, i.e. somewhat higher than in 1998-99.
- The largest flare was slightly higher than 2 Crabs.
- For considerable time periods the 1999-2000 flux is consistent with zero.
- The time averaged energy spectrum is rather steep and consistent with a pure power law with spectral index of 3.33±0.35, i.e. consistent with other previous observations (Aharonian, 1999c). Due to limited statistics no test on a possible cutoff energy can be made.

  The flaring periods dominate the energy spectrum of Figure 5.

When comparing with the Mkn 501 data from 1997 three main differences are noticeable:

1. The 1999-2000 Mkn 421 spectrum is much steeper, in the range between 1 and 5 TeV approximately by one unit (Aharonian, 1999a,b).
2. The characteristic flare time is an order of magnitude shorter than that of Mkn 501 (Kranich, 2001b).
3. Mkn 421 shows significant variation in the optical spectrum with time (A. Sillanpaa, private communication; See also contribution to this conference)

On the data analysis technique we would like to mention that a new method to correct HILLAS parameters in case of significant variations of background light etc., has been tried successfully, resulting in a much more stable cosmic ray rate after cuts and also giving one a modest improvement in significance.

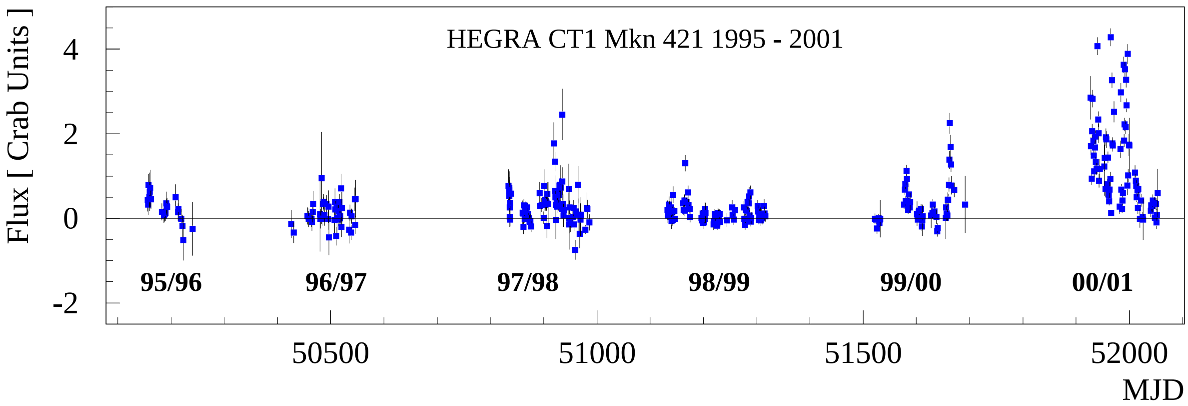

Fig. 2. Integral Flux curve of Mkn 421 as measured with HEGRA CT1 through the years 1995 to 2001.

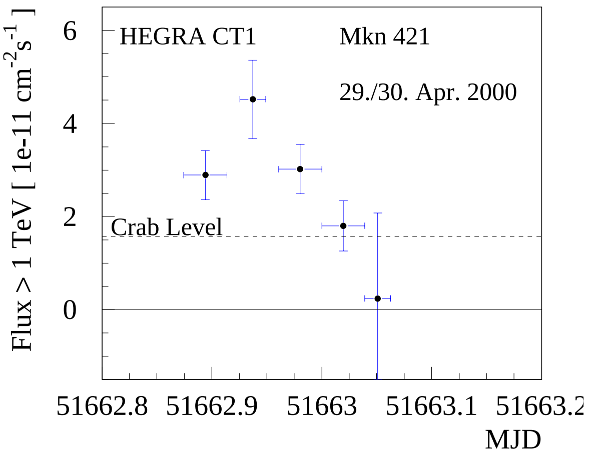

Fig. 4. The intranight light curve of Mkn 421 measured on noon-MJD 51663, i.e. April 29./30. 2000. The integral fluxes above 1 TeV are drawn in bins of 1 hour observation time windows. The horizontal error bars give the measured ON-time within the 1 hour window. The flux variation over only few hours is clearly visible and is typical for Mkn 421.

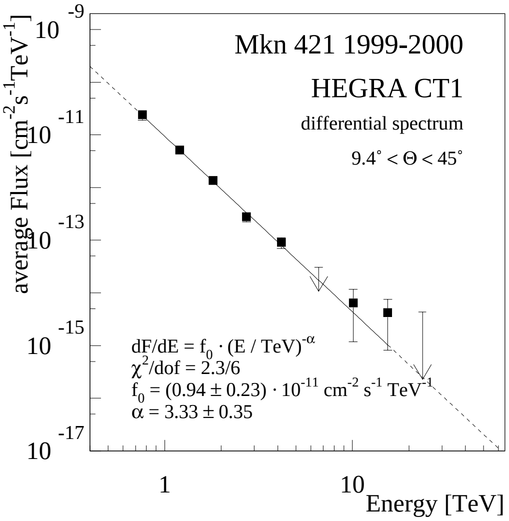

Fig. 5. The HEGRA CT1 Mkn 421 spectrum of the 1999-2000 data. For data points with low significance upper limits have been drawn. The limited γ-statistics does not allow to distinguish between a pure powerlaw and a curved energy spectrum.

Acknowledgements. We would like to thank the IAC for the excellent working conditions on the La Palma Observatorio Roque de los Muchachos. The support of the Spanish CICYT and German BMBF is gratefully acknowledged.

References

Aharonian, F. et al., 1999a, A&A **342**, 69
Aharonian, F. et al., 1999b, A&A **349**, 29
Aharonian, F. et al., 1999b, A&A **350**, 757
Cortina, J. et al., 1999, in Proc. GeV-TeV Gamma Ray Astrophysics Workshop (Snowbird), ed. Dingus B. L., et al., 368
Cortina, J., et al., 2001, these proceedings
Gaidos, J. A. et al., 1996, Nature **383**, 319
Heck, T. and Knapp, J., CORSIKA Homepage, http://www-ik3.fzk.de/~heck/corsika/Welcome.html
Hillas, A. M., 1985, in Proc. 19th ICRC (La Jolla), **3**, 445
Kestel, M., et al., 2001, these proceedings
Kranich, D., 2001a, PhD Thesis, Technische Universität München
Kranich, D., et al., 2001b, these proceedings
Mirzoyan, R. et al., 1994, NIMA **351**, 513
Petry, D. et al., 1996, A&A **311**, L13
Petry, D., 1997, PhD Thesis, MPI-preprint MPI-PhE/97-27, Technische Universität München
Punch, M. et al., 1992, Nature **358**, 477
Sobczyńska, D. and Lorenz, E., A&A, in preparation
Sokolsky, P., Introduction to Ultrahigh Energy Cosmic Ray Physics, Addison-Wesley, 1989