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# Large zenith angle observations of Mkn 421 with H.E.S.S.

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Mkn 421 was observed during 2004 with the fully operational High Energy Stereoscopic System (H.E.S.S.) in Namibia. The observations were carried out at zenith angles of 60°–67°, which result in an average energy threshold of 1.5 TeV and a collection area reaching 2 km$^2$ at 10 TeV. The light-curve of integrated fluxes above 2 TeV shows changes of the diurnal flux up to a factor of 4.3. For nights of high flux, intra-night variability is detected with a decay time of less than 1 hour. The time averaged energy spectrum is curved and is well described by a power-law with a photon index $2.1 \pm 0.1$ and an exponential cutoff at $3.1(+0.5 - 0.4)$ TeV and an average integral flux above 2 TeV of 3 Crab flux units. Significant variations of the spectral shape are detected with a spectral hardening as the flux increases. Contemporaneous multi-wavelength observations at lower energies (X-rays and gamma-rays above $\approx$ 300 GeV) indicate smaller relative variability amplitudes than seen above 2 TeV during the high flux state.

## 1. Introduction

Mkn 421 is a 'BL Lac' type active galactic nucleus. The broad-band spectral energy distribution is dominated by non-thermal emission that is believed to be produced in a relativistic jet pointing towards the observer. The high energy emission of this object has been studied by previous observations carried out by northern hemisphere ground based Cherenkov telescopes [1], [2], [3]. Observations of Mkn 421 from the southern hemisphere at large zenith angles benefit from considerable increase of the collection area at higher energies, which results in a better temporal resolution at high energies and a better sampling of the high energy part of the energy spectrum [4].

## 2. Observations

H.E.S.S. [5] is an imaging atmospheric Cherenkov detector dedicated to the ground based observation of gamma-rays at energies above 100 GeV. Situated in Namibia (23°16'S 16°30'E), the full array of four telescopes is operational since December 2003. Each telescope has a mirror area of 107 m$^2$ and is equipped with a camera consisting of 960 photomultiplier tubes [6]. The system has a field of view of 5° and allows to reconstruct the direction of individual showers with a precision of better than 0.1°.

The H.E.S.S. observations reported here were carried out for typically 1–2 hours per night from MJD 53107.8 to MJD 53114.9 (April 12–19, 2004) triggered by an increased level of X-ray emission detected by the All-Sky-Monitor (ASM) onboard the RXTE satellite and increased activity detected by the Whipple Cherenkov telescope (H. Krawczynski private communication). Online analysis of the H.E.S.S. data revealed that the source was also active at TeV energies motivating an extension of the observational campaign for roughly one week. In the beginning of May (MJD 53134.8 corresponding to May 8, 2004), the H.E.S.S. array participated in a multi-wavelength campaign with overlap with pointed X-ray observations with the RXTE satellite.

The overall number of events detected from Mkn 421 amounts to $N_{\rm on} = 8978$ (signal region) and $\langle N_{\rm off}\rangle = 1357.6$ averaged over the five background regions with a significance of $S = 114\,\sigma$ using the likelihood ratio method derived in [7].

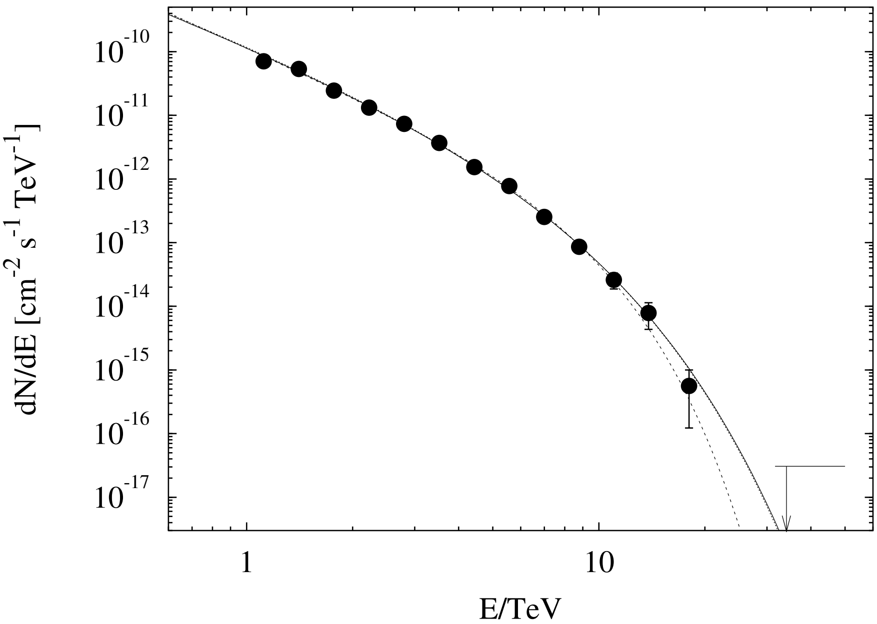


**Figure 1.** Time averaged differential energy spectrum of Mkn 421 observed at large zenith angles with H.E.S.S. The spectrum is curved and a fit with a power-law with an exponential cut-off is indicated with a solid line whereas a super exponential cut-off is shown with the broken line. The upper limit between 30 and 50 TeV is derived with a 99.9 % confidence level.

The energy and spectral reconstruction at large zenith angles has been checked using contemporaneous data taken on the Crab nebula at similar zenith angles [8] giving consistent results to recent measurements [9].

The diurnal integral fluxes measured from Mkn 421 above 2 TeV are shown in Fig. 2. During the observations of MJD 53113.8–53113.9 (April 18) and 53114.8–53114.9 (April 19), significant variations of the flux within these nights are detected. The hypothesis of a constant flux during these nights results in $\chi^2 = 40.6(7\ \mathrm{d.o.f.})$ and $\chi^2 = 28(7\ \mathrm{d.o.f.})$ respectively. The intra-night variations as seen during MJD 53113.8–53113.9 (April 18) using bins of 14 min width are shown as an inlay in Fig. 2. In order to exclude variations of the detector's response or changes in the atmosphere to be responsible for the observed variations, the post-cut (after applying the image shape cuts) cosmic ray rate has been checked for variability which is smaller than 2 % in relative root mean square (RMS) during this night. The significant intra-night variability observed in the light-curve suggests a decay time of less than 1 hour.

For the study of variations of the spectral shape in various flux states, diurnal spectra were reconstructed. Given the correlation between the cutoff energy $E_c$ and the photon index $\Gamma$ derived from the fit of a power-law with an exponential cutoff (correlation coefficient $-0.955$ between $E_c^{-1}$ and photon index $\Gamma$), the power-law index was kept constant ($\Gamma = 2$) for the fits applied to spectra obtained for individual nights. The fit was applied to a fixed energy range from 1 to 10 TeV. As a result, a hardening of the spectrum or an increase of the cutoff energy is seen clearly in the correlation of the cutoff energy $E_c$ and the integral flux above 2 TeV in Fig. 3. A similar result was obtained when keeping the cutoff energy fixed and letting the photon index vary freely. Given the position of the cut-off with respect to the range in which the energy spectrum is determined, it is not

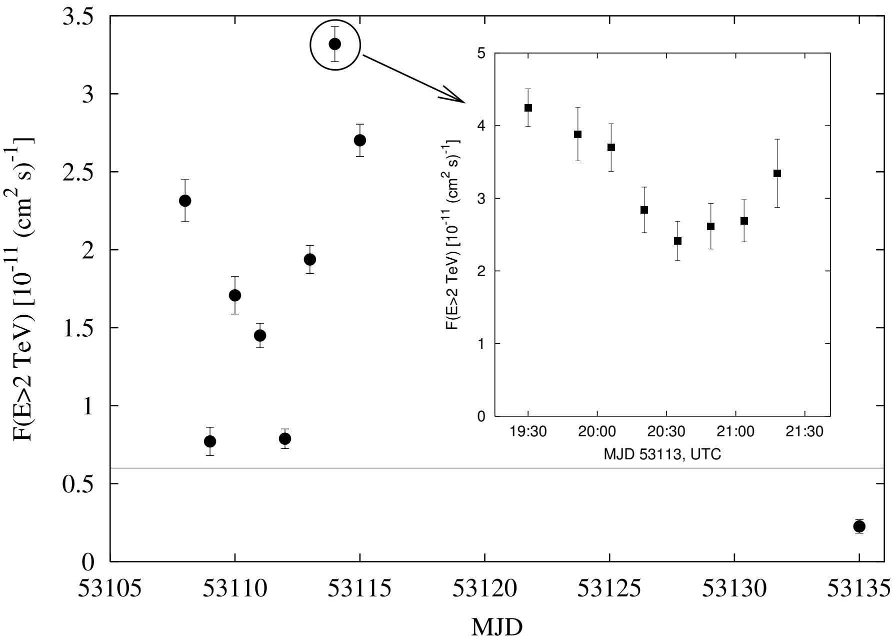


**Figure 2.** The diurnal light curve for the observations carried out on Mkn 421 in April and May 2004. The inlaid light curve for the night with the highest average diurnal flux shows significant intranight variations.

possible to discern between a change of the photon index or a change of the cut-off energy (while keeping the other parameter fixed). However, a comparison with the contemporaneous light curve measured from Mkn 421 with the Whipple Cherenkov telescope indicates only little variability at energies above roughly 300 GeV [10] in comparison with the variability observed at higher energies ($>$ 2 TeV). This is consistent with a shift of the cut-off energy which changes the integral fluxes at energies well below the cut-off only marginally. A change of the power-law photon index would change the integral flux at lower energies stronger than observed.

## 3. Conclusions

Observations of the northern hemisphere TeV Blazar Mkn 421 with the H.E.S.S. telescopes resolve flux and spectral changes covering the energy range above 2 TeV with sufficient temporal resolution to detect intra night variability. Further observations of Mkn 421 and other flaring Blazars participating in multi-wavelength campaigns are planned to extend our knowledge of spectral variability between 1 and 10 TeV with unprecedented sensitivity. Furthermore, a measurement of the energy spectra at energies beyond 10 TeV will result in constraints on the extragalactic background light in the mid to far infrared.

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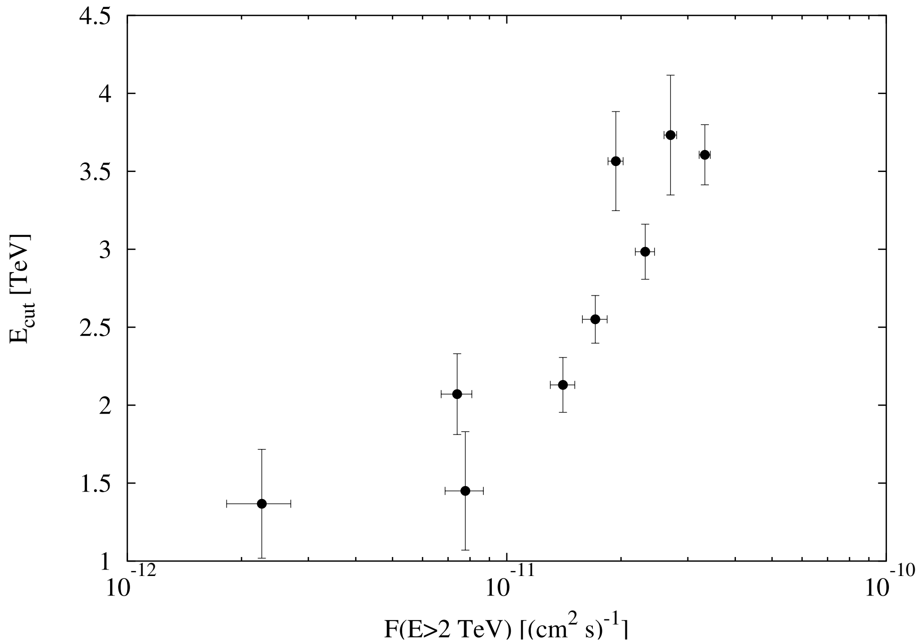


**Figure 3.** The observed energy spectrum is hardening as the flux increases. For individual nights, a power-law with an exponential cut-off $dN/dE \propto E^{-\Gamma} \cdot \exp(-E/E_{\rm c})$ with a fixed photon index $\Gamma = 2$ is fit to the data resulting in a clear correlation of $E_{\rm c}$ and the integral flux measured above 2 TeV.

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