TeV $\gamma$-ray Observations of the Crab and Mkn 501 during Moonshine and Twilight.

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Abstract

TeV $\gamma$-ray signals from the Crab Nebula and Mkn 501 were detected with the HEGRA CT1 imaging Cerenkov telescope during periods when the moon was shining and during twilight. This was accomplished by lowering the high voltage supply of the photomultipliers in fixed steps up to 13%. No other adjustments were made and no filters were used. Laser runs could not establish any non-linearity in the gain of the individual pixels, and the trigger rate was uniform over the whole camera. The energy threshold was increased by up to a factor of two, depending on the amount of HV reduction. In a series of observations lasting 11.7 hours, a signal with a 3.4$\sigma$ significance was detected from the Crab. During the 1997 multiple flare episode of Mkn 501 a 26$\sigma$ combined excess has been recorded during 134 hours of observations under various moonshine/twilight conditions. The results show that this technique

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can easily be adapted to increase the exposure of a source, which is important for sources showing rapid time variability such as AGNs or GRBs. Observations can be made up to $\sim 20^\circ$ angular separation from the moon and until the moon is 85% illuminated (ten to eleven days before and after new moon), as well as during 20 to 40 minutes during twilight, before the commencement of astronomical darkness.

1 Introduction

Any ACT telescope operating under the strict condition of no moonlight during observations, can reach a theoretical duty cycle of 18% per year (Dawson and Smith, 1996) at a latitude of 40°. If this strict criterion is relaxed to observations under partial moonlight (e.g. 70% of the moon illuminated, i.e. a period of nine days before or after new moon), an increase of the duty cycle to 24% is possible. A further increase is possible when observations are extended into twilight time, when similar conditions exist. In view of recent reports of source variability, it is important to monitor a source as long as possible.

Furthermore, with the advent of the next generation of very large, low threshold energy, imaging telescopes, any increase of the duty cycle will make the financial investment and scientific yield more attractive. The method should also have a rapid reaction time ($\sim 1$ minute) to enable the observation of GRBs (Gamma Ray Bursts). It is therefore necessary to investigate ways to increase the duty cycle of ACT telescopes in such a way that it can be easily realized without too great a loss in sensitivity.

Earlier, Pare et al. (1991) reported the use of solar blind photomultipliers (PMTs, with sensitivity limited to the UV range) to observe during moonshine. The approach proved successful but the threshold energy was increased by a factor of 3.5 with respect to measurements with normal PMTs during no-moon conditions. Although such an approach is possible, it is expensive and time consuming since a second camera must be available and should be interchanged with the normal one to operate during moonshine.

A second approach is to use a UV sensitive filter in front of normal PMTs to block out most of the scattered light from the moon. Such a system was successfully tested by Chantell et al. (1995). Operations were extended up to full moon and limited to positions more than 10° from the moon. Successful detection of the Crab was possible after additional software cuts (apart from the normal supercuts). The energy threshold was 3.5 times the no-moon value and 10 times more observation time was needed to reach a specific significance. It is clear that a more modest approach is needed to limit the increase of threshold and time. Bradbury et al. (1996) suggest the use of wavelength shifters which could increase the UV sensitivity and could be used alone or in combination with the abovementioned filter system, partly counterbalancing the increases.

It is known from measurements in the U-band (300 to 400 nm), which represents the most sensitive wavelength band of ACT (Atmospheric Cerenkov Technique) telescopes, that the NSB (night sky brightness) increases by a factor of three to five (see Figure 1) during
a half illuminated moon (compared to no-moon conditions), rising to a factor of 30 - 50 during full moon (Dawson and Smith, 1996; Schaefer, 1998). This increase depends on various factors including the telescope altitude, moon angle, zenith angle and atmospheric composition as well as the aerosol content. As most imaging telescopes are operating on a double trigger threshold (i.e. the hardware trigger which is determined by the fluctuations in the NSB, and a much higher image threshold (e.g. \( \sim 30 \) photo-electrons for the HEGRA CT1 telescope)), we expect that increases in the NSB of up to a factor of 10 will not have a marked effect on the quality of the produced images. A slight increase of the hardware threshold (e.g. through lowering of the PMT high voltage (HV)) due to moonlight does not imply significant changes of the image threshold and thus we expect no major changes in data analysis to occur when we observe during moonshine.

In an attempt to lower the energy threshold, Quinn et al. (1996) increased the HV of the PMTs by 40% and the produced images in the camera were similar to those obtained under normal conditions. This is an indication that the normal supercuts analysis (to obtain an enhanced \( \gamma \)-ray signal, see Petry et al. (1996)) is robust to changes in the system gain, provided that the pixel response is uniform. The image parameters do however change when an UV filter system is used (Chantell et al., 1995). This is due to a change in the spectral composition of the Cerenkov light.

The above discussion shows that although various techniques were investigated, an effective and simple method to increase observation time is still lacking. In the following we report on such a technique and illustrate it with observations of the Crab Nebula and Mkn 501 with the HEGRA CT1 telescope.

## 2 Observations

### 2.1 Exploratory measurements

Since the differential spectrum of the NSB, sun and moonlight peak in the yellow to red region of the spectrum (e.g. Dobber, 1998), the bulk of this light is not registered by the blue sensitive PMTs used in the ACT. Furthermore, most imaging telescopes are equipped with Winston cones on their cameras, preventing most of the scattered light from atmospheric particles (both Rayleigh and Mie scattering) and the environment to enter the detection system. Scattered light from high altitude haze and ice crystals are also excluded since no observations are conducted under these conditions since it make the data unreliable (shown e.g., by Snabre, et al., 1998). It is therefore believed that most imaging ACT telescopes may regularly operate during these conditions of increased illumination without deterioration of their detectors, provided that they operate with low to medium gain PMTs. By using an atmospheric extinction program (Schaefer, 1998) which include Rayleigh and Mie scattering, it is clear from Figure 1, that apart from an exclusion zone around the moon (varying from \( \sim 20^\circ \) to \( \sim 40^\circ \), depending on the illumination of the moon
and the haziness of the sky), a relative constant NSB-level, as a function of zenith angle, may be expected.

All measurements were conducted with the HEGRA CT1 telescope with its 5 m$^2$ reflector and 127 pixel camera operating at a threshold energy of 1.7 TeV during December 1996 (Mirzoyan et al. (1994) and Rauterberg et al. (1995)). The usual hardware trigger of at least 2 tubes triggering at 15 photo-electrons was used with the low gain PMTs. The 10 stage EMI 9083 A PMTs are operated with only 8 stages and AC coupled fast amplifiers compensate for the reduced gain. This operational mode allows one to circumvent large and damaging anode currents in the PMTs from e.g. the NSB, as well as scattered moon- and sunlight (during dusk and dawn). The measurements were conducted during December 1996 whilst the moon was nine days old (−12.5 visual magnitude, 70% illumination). This implied an increase in the NSB by a factor of 20 (see Figure 1). The telescope was pointed in a direction ∼90° away from the moon. Without any adjustment to the PMTs, the accidental trigger rate (ATR) and the average PMT current increased as expected. The HV of the PMTs, and thus the system gain was lowered to ensure minimal PMT fatigue and to lower the accidental trigger rate (ATR). The small signals causing the increased ATR disappeared rapidly and at a HV reduction of 4%, the ATR was down to a manageable 0.09 Hz, and the average PMT current was 8 µA. The third magnitude star ζ Tauri was clearly visible in the camera and cosmic ray events could easily be recognised against a low background. The result of laser calibration runs assured us that the individual pixels were responding linearly. This was borne out by off-line analysis which shows uniform triggering throughout the camera. The raw trigger rate was 65 - 70% of that under no-moon conditions, indicating an estimated increase in the energy threshold from 1.7 to 2.4 TeV. From the gain characteristics of our PMTs ($\Delta g/\Delta U = 2/140$V at the operational voltage of 1080 V, averaged over all PMTs), we calculate a gain reduction of 25% for a HV reduction of 4%. This, in turn resulted in a 40% flux reduction for a power law spectrum with $\alpha = -1.6$, which is in good agreement with the observed value of 38%. It should be noted that neither is the PMT current exactly proportional to the NSB photon flux (due to non-linear gain effects and base-line shifts caused by AC coupling), nor is the trigger rate directly proportional with the PMT gain.

With the telescope apparently operating normally, it was pointed gradually closer to the moon. No significant changes in the ATR or PMT currents could be detected up to 30° from the moon, where the NSB started to increase rapidly, in accordance with Figure 1. This preliminary measurements indicated that the telescope could be operated over a large region of the sky without any marked influence from the moon.

Further measurements showed that the abovementioned operating conditions can be maintained until the moon is 85% illuminated (11 days before and after new moon), provided that the moon is not approached closer than 20°. From Figure 1, it is therefore clear that the camera can handle NSB increases of up to a factor of ∼50.
2.2 Crab observations

Under the operating conditions described above, we observed the Crab Nebula (the only ACT source with a constant flux) during five nights under varying moon conditions (from 5 to 9 days old and approaching the moon itself up to 22°). Data at zenith angles smaller than 30° were used (see Table 1 for further detail).

A total of 11.7 hours of observations on the Crab was analysed. Applying normal supercuts (Petry et al., 1996) resulted in a significance S (in standard deviations) of $0.8 \sqrt{t}$ compared to $1.3 \sqrt{t}$ (with $t$ in hours) under no-moon conditions. No large increase in observation time is therefore needed to reach the same significance as under no-moon conditions. The fact that our significance, S, is smaller under moon conditions, indicates that there is indeed a change in the parameters for $\gamma$-ray selection, indicating the need of software optimisation of the analysis of moonshine (MS) data.

In Figure 2, the ALPHA-distribution is shown. It is clear that it is similar (but flatter - See Section 2.3) than that observed from other sources under normal dark moon conditions. To determine the $\gamma$-ray excess, we used 80 h of background data compiled over the previous two years by CT1 (Petry et al., 1997). The justification for this procedure stems from the excellent agreement of the ON- and OFF-data for ALPHA $> 20^\circ$. It is however essential that simultaneous background measurements be made to establish any effect of the increased NSB on the background (See Section 2.3). To check for these possible biases, the number of expected background events was determined, in a second approach, using the region $20^\circ < \text{ALPHA} < 80^\circ$ of the ON-data instead of OFF-data (expected background events: $N = N_{\text{on}} (20^\circ < \text{ALPHA} < 80^\circ) / 6$). With this method a slightly more significant result was obtained (see Table 1).

The resulting $\gamma$-ray rate of 4 h$^{-1}$ is 62% of the 6.4 h$^{-1}$ seen by the HEGRA CT1 telescope during the same period from the Crab under normal, no-moon conditions at a threshold of 1.7 TeV. This should be compared with only 7% of the no-moon rate reported by Chantell et al. (1995) with their filter system. Thus, our technique provides a smaller increase in threshold and can easily be adapted by any imaging telescope to increase the exposure of sources.

2.3 Mkn 501 observations

From March to September 1997 the AGN Mkn 501 showed strong, variable $\gamma$-ray emission at an average flux twice that of the Crab (see e.g., Kranich, et al. (1997) and Protheroe, et al. (1998)). Having proven that the moonshine technique is working, this event provided the possibility of increasing our exposure of the source and, at the same time, investigate the moonshine observations more extensively. At the end of April 1997, the nominal operating HV of the PMTs was increased by 6% in order to re-establish the sensitivity to that of 1994. This adjustment was needed due to normal ageing of the PMTs, with a gain reduction of 20-30% after two years of operation.
With the experience of the Crab observations, we adopted a more conservative and refined observing strategy for the moonshine observations: The PMTs were running at nominal voltage up to a 20% illuminated moon (3 nights), a 6% reduction in HV up to 70% illumination (5 nights), a 9% reduction in HV up to 90% illumination (2 nights) and a 13% reduction up to 95% illumination (one night). This scaling of HV reduction correlates with the increase of NSB during increasing moon luminosity, and excludes only the night during full moon. This strategy is quantified in Table 2, together with the expected threshold energies of the various HV settings. A limit on the average PMT current of 12 $\mu$A (20 $\mu$A maximum) was set. This implied that a further HV reduction was made as soon as this limit was reached - this occurred a number of times during the same night (e.g. MJD 50615 and 50641 in Figure 4) as the source was approaching the moon.

With this observing strategy, we increased the total exposure of the source by 56% compared to the normal dark moon observations. The final data set consists of 28 nights of MS data, 41 with both MS and dark moon data (making a comparison possible) and 52 nights with only dark moon data. Due to this additional observations, the Mkn 501 data set of the HEGRA CT1 telescope is the most complete of all ACT observations of this event (see Table 2 for detail).

The most important characteristics of the observations are summed up in Table 2. From this Table the following conclusions may be drawn: (i) The quality factor, $Q$, describing the $\gamma$/hadron separation capability,

$$ Q = \frac{N_{on}/T}{\sqrt{N_b/T}} $$

(with $N_{on}$ and $N_b$ respectively the ON-source and OFF-source events with ALPHA $< 10^\circ$) decreases with decreasing HV. This is understandable since the recorded images will become smaller with increasing HV reduction, due to higher tail cuts (which is a result of the increase of PMT noise caused by moonlight). Furthermore, the moonshine will produce additional noise which cannot be filtered out with the normal supercuts analysis. (ii) Comparing the two sets of HV settings which contain both dark moon and MS data, it is clear that $Q$ is the same, assuring us that the additional light due to moonshine does not have a marked influence on the $\gamma$-hadron separation. (iii) The $Q$-value of the Crab observations fits in with the general dependency of $Q$ on the HV reduction. (iv) The background rate, at nominal HV, was 20% higher with moonlight than without. This increased to 55% at a 6% HV reduction. It can therefore be inferred that this rate will continue to increase with higher HV reductions, contributing more and more to the background and possibly dilutes the signal. Care should therefore be taken with HV reductions larger than 10% and Monte Carlo studies are indicated to investigate the effect of moonlight on the normal supercuts analysis.

In Figure 3, the ALPHA-distribution for 244 h dark moon observation and 134 h moonshine observations is shown, divided into six subsets, according to the applicable HV setting. To maximise the source exposure, we used as OFF-source data a sample taken during dark nights, as discussed in Section 2.2. We also recorded a small sample of OFF-data during moonshine which was in good agreement with the ALPHA-distribution of the dark
night OFF-source data. Comparing the various panels, we conclude the following: (i) The background-region ($ALPHA > 20^\circ$) has the same shape for all the cases, independent of HV reduction or the presence of moonlight. (ii) Comparing Figures 3(a) with 3(b) as well as 3(c) with 3(d), an increase in the background rate (i.e. $ALPHA > 20^\circ$) is evident as soon as moonlight contributes to the NSB. (iii) It is clear from all six panels that the shape of the $ALPHA$-excess does became flatter with decreasing HV. This is attributable to additional noise in all the camera pixels due to moonlight. A confirmation of this effect is apparent when Figure 2 is compared with Figure 3(f): In both cases the flattening of the $ALPHA$-excess is similar, illustrating that this flattening is mainly determined by the addition of moonlight to the detector and is not due to the fact that the Crab has a lower flux than Mkn 501.

We therefore conclude that the supercuts analysis is robust enough for observing during moonshine in the way described. Care should however be taken when the HV is reduced by more than 10%, due to low Q-values. This excludes observations during the last two to three nights before full moon.

Figure 4 shows the light curve for Mkn 501, including the MS/twilight data, up to zenith angles of $60^\circ$. The fluxes should be considered as preliminary due to a shortage of Monte Carlo data at large zenith angles. The errors for the MS data are generally larger because (a) the MS measurements were mostly of shorter duration, and (b) for a coherent presentation the integral flux data were calculated for 1.5 TeV, i.e. the MS data were extrapolated, using a power law coefficient of $-1.5$, assuming the threshold energies in Table 2. During the 216 days of the multiple flare, we were able to collect data during all nights with clear weather, excluding only the nights during full moon. This is a good example of the value of MS observations.

During 39 nights we recorded both dark moon and MS data and a comparison between the fluxes for the resultant 57 pairs of moon/no-moon data can be made. Although Mkn 501 showed flux variability on a few hours time scale, the procedure of selecting pairs from the same night minimise this effect. From Figure 5 a good agreement is apparent with a correlation coefficient of 0.81. From the fitted line a gradient of 0.63 was calculated. This value increases to 0.83 when only data at the nominal HV is analysed. These two values should be compared with a theoretical value of 1. The fact that the MS data show larger fluxes than the corresponding no-moon data may be attributable to an overestimation of the effect of HV reduction on the energy threshold, the shortage of Monte Carlo simulations at large zenith angles as well as the use of non-optimised, normal supercuts. This effect is under further investigation.

### 2.4 Observations during Twilight

With the successful implementation of MS measurements, it was realized that additional observations could be possible during twilight. The conventional practice of ACT telescopes is to start observing after Astronomical Twilight (when the sun is more than $18^\circ$ below
the horizon). Again, applying the atmospheric model of Schaefer (1998), it became clear that observations could indeed be extended into twilight time. Depending on the pointing direction of the telescope, the observations could start as soon as Nautical Twilight (the sun reaching 12° below the horizon). This could add 20 to 40 minutes of additional observations, depending on the latitude of the observatory.

It was decided to make single runs, lasting 20 minutes, just before Astronomical Twilight, at the nominal HV of the PMTs. Ten such observations were made with a total exposure of 200 minutes. The results, occurring during the Mkn 501 campaign, is also shown in Figure 3. The correlation between these measurements and the data collected immediately afterwards, during normal dark conditions, are excellent. We are therefore certain to add this twilight time as a further potential observing slot in case of urgent measurements, e.g. GRBs.

3 Prerequisites for operation at high background light levels

The following precautions to minimise the impact of moonlight/twilight have to be taken to prevent damage to the PMTs or producing unreliable data: (i) The PMTs should be operated with a gain of a few times 10^4, followed by low noise AC-coupled preamplifiers. For this purpose, 6 - 8 stage PMTs would be ideal. Even under severe background light the anode currents will be far below critical values of fatigue and fast-ageing. A byproduct of low gain is a lower number of positively charged ions liberated from the last stages. These ions might eventually be accelerated and hit the cathode, thus creating large pulses and in turn accidental triggers (Mirzoyan and Lorenz, 1996). (ii) For prolonged moonshine operation, care should be taken to use good vacuum (< 10^-6 Torr) PMTs. This will prevent permanent damage by ions to the photo-cathode and first dynodes. (iii) Due to the high noise rate the ATR will increase. Besides gain reduction one can minimise the coincidence overlap time or introduce higher level fast trigger systems such as so-called next-neighbour triggers. This has recently been introduced successfully in the HEGRA telescopes. In order to minimise the noise contribution to the data (and image analysis) the gating time for the pulse height recording system should be minimised. For the above presented observations we used 30 ns gates for the signal recording ADCs. (iv) Suppression of nearby scattered light can be achieved by using optimised light collectors (Winston cones) in front of the PMTs, so that only light coming from the mirror area (plus a small safety margin) is collected. This is also a standard feature of the HEGRA telescopes. (v) Care should be taken, at large moon angles (> 90°), that no direct illumination of the PMTs by the moon occurs. (vi) In order to minimise scattered light from the telescope frame, it should be painted matte black.

Observation in presence of moon light increases the PMT’s anode current. This will accelerate the ageing of the PMTs. The dominant effect is that due to intense electron
bombarding the gain of the last dynodes will decrease. For the used PMTs with CuBe dynodes it was found that the gain drops by a factor of about 2 for an integrated anode current of 5 Coul/10 mm$^2$ dynode area. Very similar values were found for the 8″ PMTs of the wide angle Cherenkov matrix AIROBICC (Karle, 1995). These PMTs integrate the NSB over about 1 sterad. The dynode area of the 8″ PMTs is about a factor 10 larger than that of the 9083A PMTs. It should be noted that the reduction factor fluctuates considerably from PMT to PMT and is very likely different for PMTs from different manufacturers. From the about 1 year operation under different light levels it was found that the gain change and trigger rate are strongly correlated and the HT-gain correlation can be used to reestablish the gain after ageing in a predictable manner. As mentioned above for minimising ageing it is obvious to operate the PMTs at the lowest possible anode currents, respectively gain.

For the current operation mode of the CT1 camera it can be predicted that the PMTs would have a lifetime exceeding 15 years when operating for about 500 h/y at half illuminated moon and a source separation of at least 20$^\circ$.

Note that the above arguments apply to a lesser amount also for observations around the galactic centre from southern locations. The central area of our galaxy is at least 10 times brighter than the dark celestial regions outside the milky way.

### 4 Conclusions

A simple technique with a fast reaction time, which can be used with imaging ACT telescopes to increase the average observation time of an object, was successfully tested. The only adjustment is a uniform decrease of a few percent in the HV of the PMTs (0 to 13% in this case). This can be realized within seconds and will not affect the normal aging of the PMTs. Any telescope which operates at a moderate high PMT gain of a few times $10^4$ may use this technique. Increases of the NSB up to a factor of 50 can be handled. The technique increases the threshold energy of the telescope by up to a factor of 2.2, depending on the HV reduction. It will allow more effective use of observation time (e.g. the early nights during the waxing moon). Further investigations and refinements are under discussion and it is believed that this technique could be improved by optimising the supercuts for the various conditions discussed in this paper.

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References

Bradbury, S.M., et al. (1996), in Towards a Major Atmospheric Cerenkov Detector -IV (Padova), 182
Chantell, M., et al. (1995), 24th Int. Cosmic Ray Conf. (Rome), 2, 544
Dawson, B. and Smith, A. (1996), technical report GAP-96-034, University of Adelaide
Karle, A., et al. (1995), Astroparticle Physics 3, 321
Dobber, M.R. (1998), ESA preprint
Kranich, D., et al. (1997), Proc. 4th Compton Symp. (Williamsburg), 2, 1407
Pare, E., et al. (1991), 22nd Int. Cosmic Ray Conf. (Dublin), 1, 492
Petry, D., et al. (1996), Astron. & Astrophys., 311, L13
Petry, D., et al. (1997), private communication
Protheroe, R.J. et al. (1998), 25th Int. Cosmic Ray Conf. (Durban), 9, in press
Quinn, J., et al. (1996), in Towards a Major Atmospheric Cerenkov Detector-IV (Padova), 341
Mirzoyan, R., et al. (1994), NIM A, 351, 51
Mirzoyan, R., and Lorenz, E. (1996), in Towards a Major Atmospheric Cerenkov Detector-IV (Padova), 209
Rauterberg, G., et al. (1995), 24th Int. Cosmic Ray Conf. (Rome), 3, 412
Schaefer, B.E., (1998), Sky & Telescope (May), p 57 (submitted to Publ. Astr. Soc. Pacific)
Snabre, P., Saka, A., Fabre, B., and Espignat, P. (1998), Astropart. Phys., 8, 159
Table 1: Moonshine Observations of the Crab  
(December 1996 - February 1997)

|                         | OFF-region | Dark Night |
|-------------------------|------------|------------|
|                         | 20° < ALPHA < 80° |           |
| Average zenith angle (°) | 15.43      | 15.43      |
| Observation time (min)   | 703        | 703        |
| Raw number of events     | 21230      | 21230      |
| Events after all cuts except ALPHA | 668 ± 26  | 668 ± 26  |
| Events after all cuts (ALPHA ≤ 10°) | 123 ± 11  | 123 ± 11  |
| Expected background events | 68 ± 9    | 81 ± 9    |
| Excess events            | 55 ± 14    | 42 ± 13    |
| Significance of excess (σ) | 4.0       | 3.4        |
| Excess rate (h⁻¹)        | 4.7 ± 1.2  | 3.6 ± 1.2  |

Table 2: Moonshine/Twilight (MS) and Dark Moon (DM) conditions and observations of Mkn 501 (Zenith < 59°, March - September 1997)

| I_moon (%) | NSB(30°) (nLambert) | Δ(HV) (%) | E_{th} (TeV) | N_{on} | N_{b} | Exposure T (h) | Significance (σ) | Q |
|------------|---------------------|-----------|--------------|--------|------|----------------|------------------|---|
| < 20       | 54                  | 0 (DM)    | 1.2          | 5720   | 1187 | 183.0          | 51.2             | 12.3 |
|            | 94                  | 0 (MS¹)   | 1.2          | 647    | 150  | 17.9           | 18.6             | 13.0 |
|            | -6 (DM)             | 1.7       | 1306         | 407    | 60.9 | 22.3           | 8.3              |   |
| 20-70      | 840                 | -6 (MS)   | 1.7          | 2151   | 927  | 74.9           | 20.1             | 8.2  |
|            | -9 (MS)             | 2.4       | 427          | 247    | 25.9 | 9.1            | 5.9              |   |
| 70-90      | 1800                | -9 (MS²)  | 2.4          | 123    | 81   | 11.7           | 3.4              | 4.0  |
| 90-95      | 2900                | -13 (MS)  | 3.4          | 128    | 79   | 17.0           | 4.0              | 3.5  |

¹ = including 3.3 h twilight observations;  
² = Crab Nebula observations  
I_{moon} = moon illumination;  
NSB (30°) = visual NSB 30° from moon;  
Δ(HV) = PMT voltage reduction  
E_{th} = threshold energy as calculated from PMT gain characteristics  
N_{on} = total events with ALPHA < 10°  
N_{b} = expected background events with ALPHA < 10° (see text)
Figure 1: The visual (300 - 900 nm) Night Sky Brightness as a function of angular separation between the moon and the observed object (moon angle), and the phase of the moon (expressed in days after new moon). The calculations used the model of Schaefer (1998).
Figure 2: The ALPHA-distribution for the 11.7 hours of moonshine observations of the Crab Nebula. The data were obtained with the HEGRA CT1 telescope at zenith angles smaller than $30^\circ$. The filled symbols present the Crab measurements and the open symbols the background as obtained from previous observations. An ALPHA-cut at $10^\circ$ resulted in a significance of $3.4\,\sigma$ at a threshold of $\sim2.4\,\text{TeV}$. 
Figure 3: ALPHA-distributions for the various categories (as indicated) of Mkn 501 observations during 1997 with the HEGRA CT1 telescope. Full symbols represent the actual ON-source measurements and the open symbols are normalised OFF-source observations from Petry et al. (1997). The normal supercuts analysis was applied to the raw data. A flattening of the ALPHA-excess, with increasing HV reduction, is evident.
Figure 4: The 1997 light curve of Mrk 501 (preliminary), as observed by the HEGRA CTA telescope at an energy threshold of 1.5 TeV. Open symbols represent moonshine/twilight observations whereas full symbols represent dark moon measurements. For the flux extrapolation, a power law coefficient of $-1.5$ has been used.

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Figure 5: The correlation between dark moon and moonshine/twilight fluxes at 1.5 TeV for the 57 pairs of measurements on Mkn 501, which occurred during the same night.