Determination of the Night Sky Background around the Crab Pulsar Using its Optical Pulsation

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Abstract

The poor angular resolution of imaging γ-ray telescopes is offset by the large collection area of the next generation telescopes such as MAGIC (17 m diameter) which makes the study of optical emission associated with some γ-ray sources feasible. In particular the optical photon flux causes an increase in the photomultiplier DC currents. Furthermore, the extremely fast response of PMs make them ideal detectors for fast (subsecond) optical transients and periodic sources like pulsars. The HEGRA CT1 telescope (1.8 m radius) is the smallest Ĉerenkov telescope which has seen the Crab optical pulsations.

1. Method

Imaging Atmospheric Ĉerenkov Detectors (IACT) can be used to detect the optical emission of an astronomical object through the increase it generates in the currents of the camera pixels [7,3]. Since the Crab pulsar shows pulsed emission in the optical wavelengths with the same frequency as in radio and most probably of VHE γ-rays, we use the central pixel of CT1 [5] and MAGIC [1] to monitor the optical Crab pulsation. Before the Crab observations were performed, the expected rate of the Crab pulsar and background were estimated theoretically. We also took into account the influence of the NSB, the intensity of which has been measured at La Palma, at the site of the HEGRA experiment [6](extragalactic NSB). The poor angular resolution, a FOV of 0.25° for CT1 and 0.1° for MAGIC, is compensated for the large mirror area A (**10** m^2 for CT1, **250** m^2 for MAGIC). The observations were taken in La Palma with the HEGRA CT1 telescope, in February 11-16th 2002 and in November 1-8th 2002. Datasets were taken within the Crab centered in the central pixel and at a position 0.5° away from the Crab to check for any systematics. A total of 7200 s of data was available for analysis.

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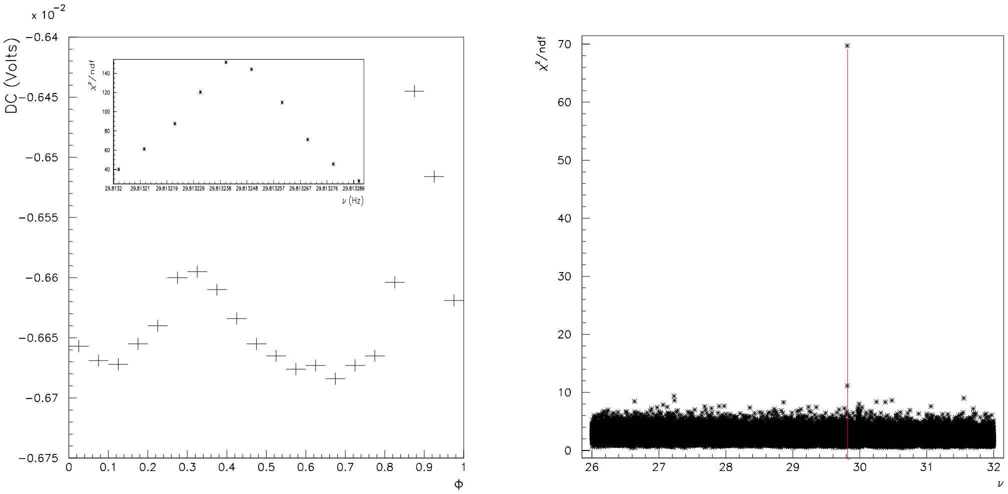

Fig. 1. *Observations of the optical Crab pulsar with CT1. On the left, the two peaks are clearly visible in the phaseogram with a separation in phase of* $\sim$ *0.4. The inset shows the value of the reduced* χ^2 *vs. frequency, using ephemeris of 15th October. On the right; reduced* χ^2 *vs. frequency.*

With that empirical correction we can infer the real situation, which we will have in MAGIC. The Crab pulsar signal was found to be contaminated with a higher Night Sky Background than the theoretical one (NSB at high latitudes). Hence, the real galactic NSB was calculated from the Crab optical pulsed fraction and compared with the result infered from the signal of the nearby star ζ Tauri with a known flux.

2. Results

A series of phaseograms were produced for a wide range frequency range, from 26.0 to 32.0 Hz, in intervals of 1 IFS (Independent Fourier Spacing [2]). The folded intensities from each phaseogram was fitted to a straight line of constant intensity and the reduced χ^2 was calculated (Figure 1.). A reduced χ^2 of ~ 154 was found and we were able to reproduce with a precision of 10^{-6} the Jodrell bank ephemeris. The observed pulsed fraction for the Crab pulsar is $p = (5.001 \pm 0.017) \cdot 10^{-4}$.

The sensitivity of CT1 to detect the Crab optical pulse can be expressed as the "standard deviation" **s** of the signal relative to the behavior of reduce χ^2 at frequencies different from the Crab frequency:

$$s = \frac{\chi^2_{red} - \mu_{background}}{\sigma_{background}} \qquad (1)$$

for each observation time interval, where $\mu_{background}$ is the mean value of χ^2_{red}

at such offset frequencies and $\sigma_{background}$ the corresponding standard deviation which is constant for all selected times T. The total observation was split into L=7200 s/T independent datasets, each of length T, from which the average value of the statistic s was calculated for T=50 s to 7200 s. It can be shown that this average value of s is:

$$s \sim p^2 \cdot T \cdot g(k, f_s) \tag{2}$$

where k is the number of bins, f_s the signal pulse shape and g(k,f_s) a function depending on these quantities. Note that s is not a gaussian standard deviation, since the number k is too small, but we expect that $< s > \sim \sigma^2$, where $\sigma \sim p \cdot \sqrt{T}$ would be the gaussian significance of a DC detection of the same signal. Figure 2. shows a graph for $log < s >$ vs. logT. Using the calculated value of NSB, it is possible extrapolate to the MAGIC telescope sensitivity, and determinate the minimum time to detect the signal. Results scaling with the mirror area, pixel size and quantum efficiency, log$< s >$ vs. logT graph is also shown in Figure 2. The NSB rate on the surroundings of the Crab nebula and pulsar was also calculated using the Crab pulsed fraction. The NSB intensity found is $\sim$ 3.5 times higher than the galactic NSB given by Mirzoyan et al., and it is agree with the NSB intensity calculated using an alternative method, using ζ-Tauri response on individual currents, within 27%.

3. Conclusions

The detection of the Crab optical pulsation was performed by the CT1 telescope, which is possibly the smallest Ĉerenkov telescope to have seen the Crab optical pulsations [4]. Since the design of the CT1 PMT base is very similar to that of MAGIC we conclude that the detection with this new generation Cherenkov telescope is possible and should be achieved in a substantially shorter time than for CT1. From the CT1 results, we can infer that the detection will be achieved within 30 s with a significance of 5σ. However, taking into consideration that it is possible to reduce the NSB using an array of HPD's and that the MAGIC point spread function is much better, it could be still possible to resolve single pulses.

Optical data on the Crab pulsation taken simultaneously with regular VHE observations is instrumental to test the time analysis software of MAGIC, in particular the barycentric correction and the ephemerides of the pulse.

But the central pixel may be used to monitor cataclysmic variable, X-ray binaries, microquasars, AGNs, GRB, to identify "unidentify γ sources" using the optical countpart...

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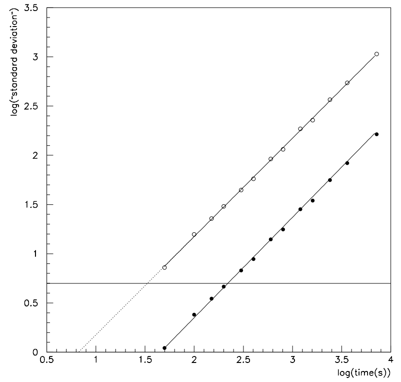

Fig. 2. *log of "Standard deviation" of the signal related to the background versus observation time. The CT1 empirical data are represented with filled bullet and the empty ones represent the extrapolation for the MAGIC telescope. The horizontal line shows the limit at 5σ.*

4. References

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