

OBSERVATIONS OF THE CRAB PULSAR NEAR 1015-1016 eV
 J. BOONE, R. CADY, G. L. CASSIDAY, J.W. ELBERT, E. C. LOH
 P.Y. SOKOLSKY, D. STECK, and S. WASSERBAECH
 Department of Physics, University of Utah, USA

ABSTRACT

During 1980 December, a 3.1 σ excess of Cerenkov light flashes was observed within an angle of about 3.5° from the Crab Nebula. The estimated threshold energy of the detected showers was 10^{15} eV. No excess was detected in observations made during 1981 February.

I. INTRODUCTION

In this paper, we report results of observations of the Crab pulsar region using the Fly's Eye. Besides detecting relatively distant (1-15 km) air showers of 10^{17} eV or greater, the system detects Cerenkov light from nearby (impact distances < 200 m) air showers of at least 3×10^{14} eV. When the Fly's Eye is operating in special triggering mode to detect low energy showers and the Crab Pulsar is above the horizon, different mirrors of the system are doing simultaneous, but offset, drift scans through the region of interest, with one of the mirrors always viewing the Crab pulsar.

II. APPARATUS AND TECHNIQUES

At the time of the observations being reported (1980 December and 1981 February), 48 out of the complete set of 67 Fly's Eye mirrors were in operation. Event triggering requirements were slightly different in the December and February runs. In December, a trigger was obtained when 3 photomultiplier tubes (PMT's) in a mirror received a signal corresponding to 1500 photons/m² within a 2 μ s interval. A rate of triggers of about 0.4 sec^{-1} was obtained from the entire system. In February the trigger requirement was two PMT's detecting light within 2 μ s. The PMT high voltages and signal thresholds were adjusted in February to give event rates close to those of December.

When a shower triggers the system, the recorded data include: (1) the identities of all PMT's above threshold in the event; (2) times at which each PMT first went over threshold (50 ns accuracy); (3) integrals of the signal pulse from each PMT which was above threshold. The PMT thresholds were set high enough in this experiment that true accidental coincidences almost never occurred.

The minimum energy of showers which trigger the system is estimated using calculated photon densities (Smith and Turver 1973) for showers observed near the core. The photon density is obtained by the signals of the PMT's which are above threshold. The

threshold energies given by photon densities and by shower rates are in reasonable agreement with each other. We estimate a factor of 2 uncertainty in the shower energy thresholds.

The angular resolution is estimated to be 3.4° . The data are binned in angular regions with a declination range of 7° and a right ascension range of 7.5° . Each mirror unit is fixed in declination and its right ascension, α , increases linearly with time. The range of α of interest consists of 5 half-hour bins with the right ascension of the Crab pulsar in the middle of the third bin. For the analysis, only those light detectors are included which pass through the entire α interval of interest within the running time.

III. OBSERVATIONS

Data for this study was taken on certain cloud-free moonless nights. The dates of the runs were 1980 December 9 and 1981 February 1, 6, and 7. The lengths of the four runs were 6.2, 4.7, 5.8 and 5.2 hours respectively. The data from 1980 December 9 will be treated separately because they gave different results than those from 1981 February. Table 1 shows the December data in 5 right ascension bins with the third bin centered on the Crab pulsar. Data are binned for three different threshold energies. The numbers of showers are given for each threshold energy.

Table 1. Data from 1980 December 9
The right ascension of the Crab pulsar is indicated by α_c .

E_t (eV)	$\alpha_c - 1 \text{ h}$	$\alpha_c - 0.5 \text{ h}$	α_c	$\alpha_c + 0.5 \text{ h}$	$\alpha_c + 1 \text{ h}$
10^{14}	39	41	58	38	39
$10^{14.5}$	26	23	40	22	22
10^{15}	9	9	17	4	13

In Table 2, the average background count B , is given in the second column. The signal, S , is the number of counts above the background for the Crab pulsar data and is compared to σ to obtain the significance of the peak.

Table 2. Analysis of the December Data

E_t (eV)	B	S	S/σ	Flux ($\text{cm}^{-2} \text{s}^{-1}$)
3×10^{14}	39.25	18.75	2.7	$8.2 \pm 3.1 \times 10^{-12}$
10^{15}	23.25	16.75	3.1	$2.1 \pm 0.7 \times 10^{-12}$
3×10^{15}	8.75	8.25	2.5	$3.3 \pm 1.3 \times 10^{-13}$

We shall see below that a count rate peak was not observed near the Crab pulsar in the February run. The December peak reached a significance of 3.1σ in one of three energy ranges. Although the three ranges are not entirely independent we will be conservative and treat them as if they were. In the February run, four energy ranges were used because the chosen running conditions gave a wider dynamic range. There were three acceptable runs in February, yielding a total of 12 semi-independent sets of data in February and 3 in December. Therefore, the probability of seeing a $> 3.1 \sigma$ peak in the 15 trials can be conservatively estimated to be $15 P(> 3.1 \sigma)$. The estimated confidence level for a detection of a narrow anisotropy near the Crab pulsar is $1 - [15(1.9 \times 10^{-3})]$ or 97%.

The combined data from all February nights as well as the data from each night do not show any evidence of an excess in the direction of the Crab pulsar. Using a maximum likelihood method (Hearn, 1969), upper limits were obtained at the confidence level corresponding to 1σ .

Table 3. Analysis of the February Data

E_t (eV)	B	N	Flux Upper Limit ($\text{cm}^{-2} \text{s}^{-1}$)
3×10^{14}	57.50	48	1.7×10^{-12}
10^{15}	35.75	32	5.3×10^{-13}
3×10^{15}	15.25	12	8.8×10^{-14}
10^{16}	3.00	3	4.5×10^{-14}

As a test of the consistency of our observations with Poisson statistics, the December and February data were studied in directional

bins distributed over the entire region of the sky viewed during the runs. The distributions of the numbers of data bins corresponding to different Poisson probabilities are given in Figure 1. The results agree quite well with the curve which is the expected distribution. In the combined data from all nights, one directional bin has a probability of 4×10^{-5} . It is in the direction $\alpha=64.8^\circ$ and $\delta=0^\circ$. There were 115 showers observed and 77.4 expected in this bin. The direction is close to one in which an enhancement is described by Stamm and Samorski (1983). Their source number 5 is at $\alpha=67.4^\circ$, $\delta=352.7^\circ$.

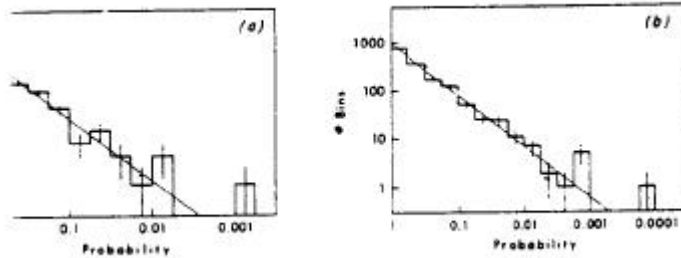


Figure 1. Distribution of probabilities of data sets in different angular regions. (See text.)

IV. DISCUSSION

The results for February give upper limits for time independent Crab pulsar γ -ray fluxes near 10^{15} - 10^{16} eV. The statistical significance of the December result is too small to be sure that we have detected a γ -ray flux from the Crab Pulsar. The results are consistent with a time dependent flux, however. In this experiment absolute millisecond accuracy timing was not available and the angular resolution was not precise. Consequently, the association of the possible effects with the Crab pulsar is not certain. The distribution of the statistical probabilities of the numbers of events in different directions indicates the absence of large systematic errors in the data.

V. ACKNOWLEDGEMENTS

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