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High Energy γ-rays from the Direction of the Crab Pulsar [and Discussion]

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High energy γ-rays from the direction of the Crab pulsar

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An attempt is being made to extend the search for high energy γ-rays from point sources to much higher energies by using the method based on investigation of the muon-poor extensive air showers. A search has been made for very high energy photons from the direction of the Crab pulsar (the best known high energy γ-ray source) by using the Łodz extensive air shower array. The device is particularly suitable for such a study because it consists of a large muon detector which can be used to search for the characteristic muon-poor showers.

The method involved selecting those showers falling within 15° of the Crab direction, the observation time being chosen in the interval when the Crab was not lower than 40° from the zenith. For the Łodz geographical latitude (51.6° N) this corresponds to 8 hours of observation per day. The Crab has been observed for 5600 hours from 1975 to 1979. The sample from the general direction of the Crab has been compared with three background samples taken from the points on the sky located at the Crab declination but with r.a. displaced by 90°, 180° and 270°. The background samples were taken in this way to ensure that those showers were observed from the same direction with respect to the apparatus as the showers coming from the direction of Crab.

The results of observation are summarized in table 1.

It is seen that a clear excess of showers from the general direction of the Crab is observed and that the fractional excess is increasing with shower size.

The existence of an excess of showers from the general direction of the Crab is also seen in an independent set of showers collected in the period 1968–71 with a different layout of the experiment. The total observation time for that period was 8463 hours. From the statistics we have selected 9543 showers coming from the region $20° < \theta < 40°$ and $160° < A < 200°$, where θ and A are the zenithal and azimuthal angles. This is the direction where at a certain time (5 h 31 min) the Crab reaches its highest point above the horizon.

It is unfortunate that the sample was not collected continuously so that the coverage time was different for different r.a. bins; thus we can only make a relative comparison, namely only a search for an increase of excess as a function of shower size. Among the above-quoted 9543 showers there were selected 374 showers with high electron densities corresponding to sizes of at least 10^6 particles. The distribution of these showers as a function of r.a. has been normalized to the distribution of all 9543 showers. The normalized distribution is given in figure 1. The excess seen from the direction of the Crab (4–7 h) amounts to 22.3 ± 9.1 above the average of the seven remaining cells.

The joint probability of obtaining the two results by chance is 3×10^{-4} (3.6σ for a Gaussian distribution), a result obtained by combining the result with that for $N_e > 10^6$ from table 1.

The excess showers seem to be deficient in muons, the average muon content in the Crab showers amounting to 0.60 ± 0.12 of that in the normal showers. Normal showers contain *ca.* 7 muons per 55 m² detector, whereas the excess showers contain 4 ± 1 per detector (we note that photon-induced showers should contain *ca.* 2 muons per detector (Wdowczyk 1965), not far from observation).

The absolute intensity of the excess showers observed in the experiment described here can be evaluated by taking into account the fact that the collection area of our device is approximately 1000 m^2 and is virtually energy independent; however it is dependent on angle and this gives a significant uncertainty in the absolute magnitude of the intensity. When all uncertainties are included, the overall flux from the Crab direction (in excess over background level) is $(3 \pm 2) \times 10^{-13}$ cm^{-2} s^{-1} for showers with energies above 10^{16} eV.

TABLE 1.

	Crab	r.a. + 90°	r.a. + 180°	r.a. + 270°	excess	fractional excess
$N_e > 4 \times 10^5$	313	257	237	272	58 ± 20	0.23 ± 0.08
$N_e > 1 \times 10^6$	156	108	115	120	42 ± 14	0.31 ± 0.12
$N_e > 2 \times 10^6$	52	28	36	36	19 ± 8	0.56 ± 0.24

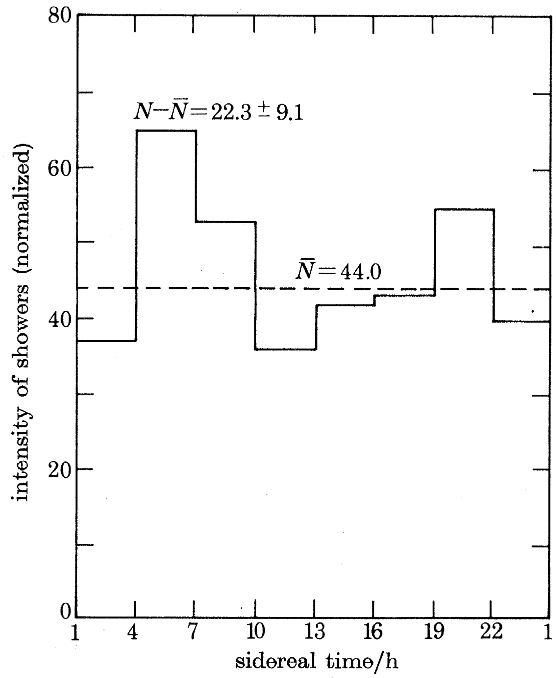

FIGURE 1. The right ascension distribution of large showers ($N_e > 10^6$) in the declination band containing the Crab direction. The distribution has been normalized to all showers registered in the same band.

In view of the large angular region around the Crab direction considered, the evidence that the excess events are due to the Crab itself is circumstantial. Several possibilities need to be considered including a general enhancement over several degrees in the direction of the Crab, and a discrete source within a few degrees of the Crab. Another possibility is that the excess originates, at least in part, in the galactic plane in general. Intersection of the considered declination band with the plane occurs at r.a. = 6 h so it is only displaced by half an hour from the Crab position. It should be noted that in figure 1 there exists (although statistically not very significant) an excess from the direction of the other crossing of the declination band with the galactic plane. The excess there amounts to 11.0 ± 7.8. Further work is necessary to distinguish the possibilities.

If the excess flux is indeed to be identified with photons from the Crab, a possible model is one where protons accelerated by the pulsar interact with visible light. The results would not conflict with the measurements summarized by Weekes (1979), if the spectrum between 10^{12} eV and 10^{16} eV were rather flat (or indeed if there were a negligible flux of photons below 10^{15} eV). A flat spectrum would be expected from the model referred to. A summary of the observed high and ultra-high energy photon intensities from the Crab direction is given in figure 2. A critical test of the hypothesis about the flat spectrum could come from measurements in the intermediate energy range. As was shown by Gawin & Wdowczyk (1980), a moderately sized extensive air shower apparatus located at a mountain altitude would allow detection of photons with intensities around 10^{-13} cm^{-2} s^{-1} sr^{-1} at energies above 10^{14} eV. This limit is clearly below the line through the points in figure 2.

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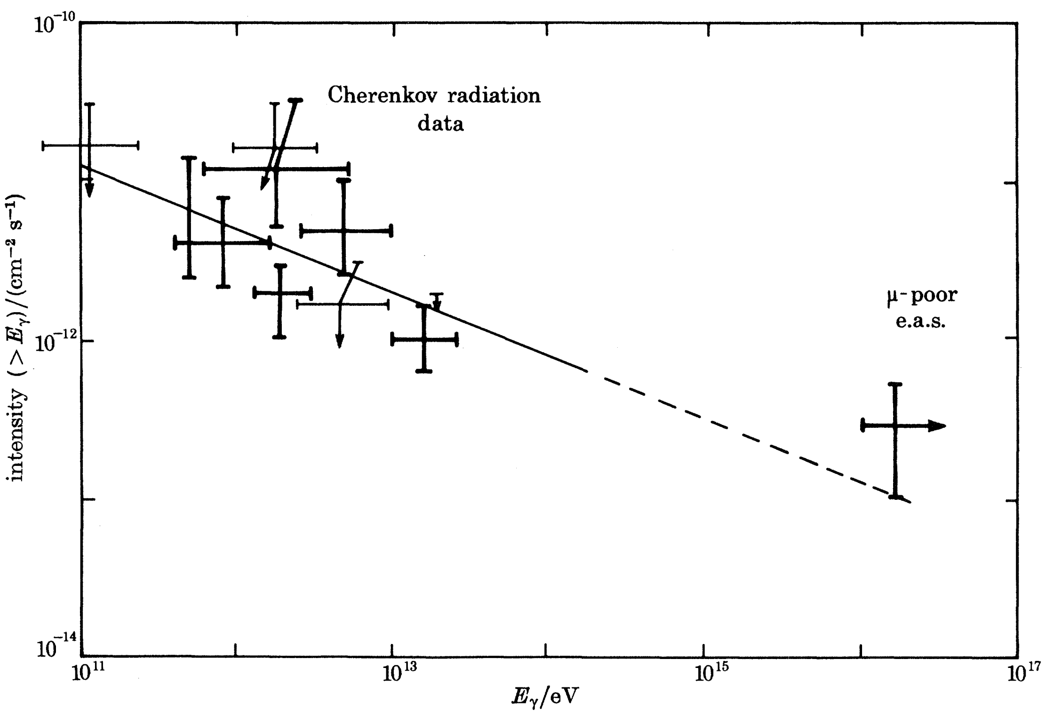

Figure 2. The spectrum of high and ultra-high energy photons from the direction of the Crab pulsar.

References (Dzikowski *et al.*)

Gawin, J. & Wdowczyk, J. 1980 *Inst. nucl Res., Warsaw, Rep.* 1872/VI/PH/A.
Wdowczyk, J. 1965 *Proc. 9th Int. C.R. Conf. London*, vol. 2, p. 691.
Weekes, T. C. 1979 Preprint no. 1260, Center for Astrophysics, Cambridge, Massachusetts 02138.

Discussion

K. E. Turver (*Physics Department, The University, Science Laboratories, South Road, Durham DH*1 3*LE, U.K.*). Data from an e.a.s. experiment with the atmospheric Cherenkov light technique have provided upper limits (at the 3σ level) for a flux from the Crab of 6×10^{-15} and 3×10^{-15} cm^{-2} s^{-1} at energies of 3×10^{16} and 8×10^{16} respectively.

J. Wdowczyk. The result reported by us, even if related to the Crab, is not necessarily inconsistent with the upper limits given by Dr Turver, since our observation relates to somewhat lower energies ($E_t \approx 10^{16}$ eV). The results taken together could indicate that there exists a sharp cut-off in the γ-ray spectrum.

Another explanation follows from the possibility discussed in the paper that the excess comes from the galactic plane in general. In that case the excess would not be detectable by the Cherenkov technique.