PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Detection of Pulsed γ-rays at Energies above 300 GeV from Pulsars - T.I.F.R. Experiments [and Discussion]

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Detection of pulsed γ-rays at energies above 300 GeV from pulsars – T.I.F.R. experiments

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A brief account is given of the search for γ-rays from pulsars made by the T.I.F.R. group in India. It is concluded that for energies above 300 GeV the flux of pulsed γ-rays from the Crab and Vela pulsars is much less than would be expected by extrapolation of the spectra measured in the gigaelectronvolt range. It is still not certain whether the pulsars have been detected above 300 GeV because of variability in the apparent signals from year to year.

Introduction

Almost from the time of the discovery of radio pulsars, we have been making experiments using the night air Cherenkov technique to detect ultra-high energy γ-ray pulses from pulsars. In the early experiments we were able to set upper limits to the flux of γ-rays of energy greater than 10^{12} eV from many pulsars (Chatterjee *et al.* 1970, 1971). Since 1976 we have been concentrating essentially on two pulsars which are now well established as γ-ray pulsars in the gigaelectronvolt range – the Crab nebula pulsar PSR 0531 + 21, and the Vela pulsar PSR 0833 – 45.

Experiments to date

The observations made so far have used the ultra-high-energy γ-ray telescope set up at our mountain station, Ooty, $\delta = 11° 23'$ and altitude 2.2 km. The observational period at this station is confined to the months of December to April. The experimental details, the method of tracking the sources, the evaluation of threshold energies and analysis of data, etc., are available in earlier publications (Gupta *et al.* 1978; Bhat *et al.* 1980).

In table 1 are given the experimental results from observations during 1976–80. It is seen that the reflector area has been gradually increased from 6.6 m² in 1976–7 to 20 m² in the 1978–9 and 1979–80 observations.

Positive signals were obtained from the Crab Pulsar in 1976–7, the phase histogram revealing 3.6σ and 2.2σ peaks for the main and the interpulse respectively. For the Vela pulsar 1978–9 observations showed peaks of significance 4.4σ and 2.5σ for the main and interpulse respectively.

From the table it is also seen that the best period of observations for both pulsars in terms of total area and exposure time is 1979–80. However, neither of the pulsars have given any positive results during this observation.

The question therefore remains: Are the positive signals seen from the Crab in 1976–7, and Vela in 1978–9, just statistical fluctuations of the background, or does the high energy pulsed γ-ray emission of these sources vary as a function of time? One definite conclusion that emerges from our investigations is that the pulsed spectrum in both sources should considerably steepen at higher energies compared with the COS-B results (Lichti *et al.* 1980; Kanbach *et al.* 1980) up to 10 GeV. This can be seen from figures 1 and 2.

The exponent of the power-law integral spectrum of the Crab pulsar changes from $\gamma = -1.17$ below 10^{10} eV to at least $\gamma = -2.1$ in the energy range 10^{10}–10^{12} eV. Similarly for the Vela pulsar the exponent changes from $\gamma = -0.89$ to at least $\gamma = -2.65$.

We can make, however, a general statement for both pulsars that all our observations, both upper limits and finite flux values, are within a factor of four on either side of the steepened spectra.

TABLE 1

pulsar	year	reflector area/m²	threshold energy/GeV	exposure	signal
Crab	1976–77	6.6	500	27	3.60σ
				inter-pulse	2.20σ
	1977–78	10	375	55	$<3\sigma$
	1978–79	20	250	30	$<3\sigma$
	1979–80	20	210	95	$<3\sigma$
Vela	1976–77	6.6	1000	12	$<3\sigma$
	1978–79	20	500	35	4.4σ
				inter-pulse	2.5σ
	1979–80	20	250	71	$<3\sigma$

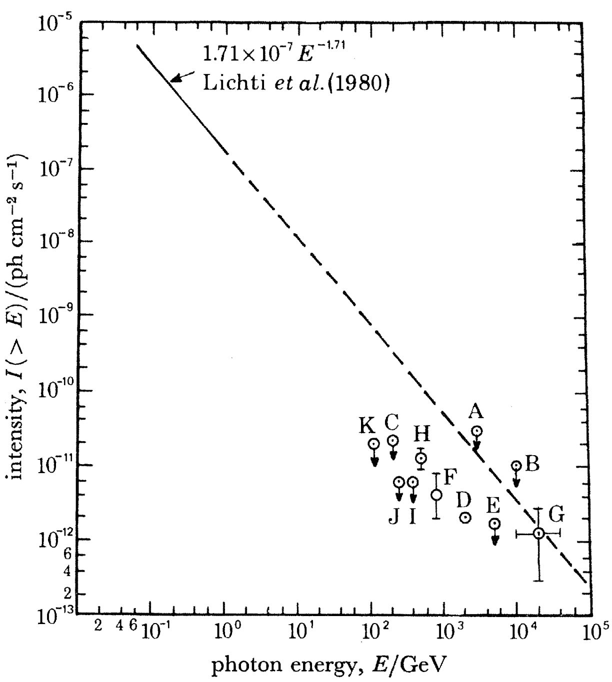

FIGURE 1. The energy spectrum of γ-rays from the Crab pulsar PSR 0531+21. The continuous line represents the spectrum from COS-B data. It is seen that the finite flux values and the upper limits suggest a steepening of the spectrum beyond 10 GeV.

(A) Charman *et al.* (1970) (B) Chatterjee *et al.* (1971) (C) Helmken *et al.* (1973)
(D) Jennings *et al.* (1974) (E) Porter *et al.* (1976) (F) Grindlay *et al.* (1976)
(G) Erickson *et al.* (1976) (H) Gupta *et al.* (1977) (I) Bhat *et al.* (1978)
(J) Bhat *et al.* (1979) (K) Bhat *et al.* (1980)

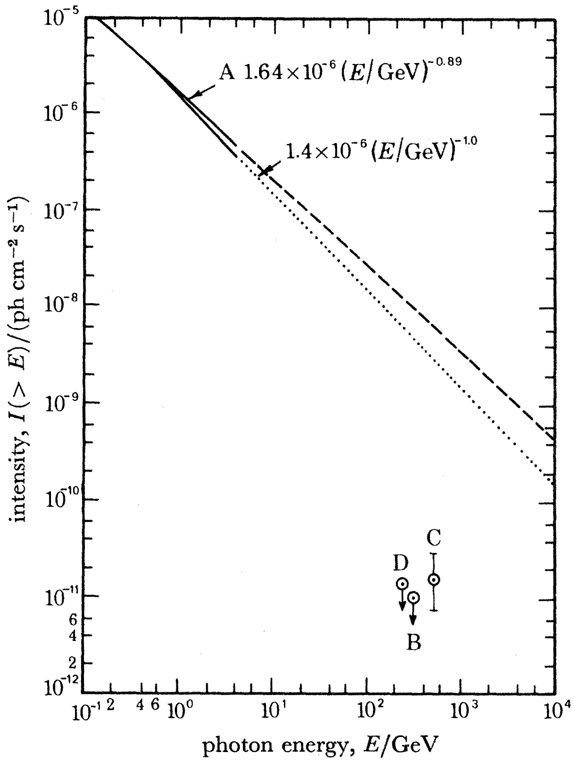

FIGURE 2. The energy spectrum of γ-rays from the Vela pulsar PSR 0833 – 45. The lines correspond to the results from the COS-B satellite. The finite flux and the upper limits from the Ooty experiment and of Grindlay *et al.* (1975) suggest a steepening of the spectrum beyond 10 GeV.

(A) Kanbach *et al.* (1980) (B) Grindlay *et al.* (1975) (C) Bhat *et al.* (1979) (D) Bhat *et al.* (1980)

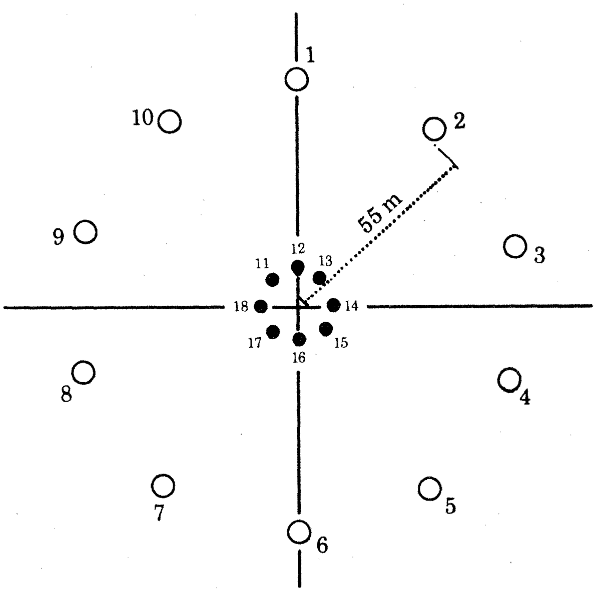

FIGURE 3. The disposition of the mirrors in the new Ooty γ-ray telescope.
Mirror diameters: 1–10, 90 cm; 11–18, 150 cm.

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The new ultra-high energy γ-ray telescope at Ooty

We are now setting up a new array, which is expected to go into operation in January 1981. This array will have ten mirrors of diameter 90 cm and eight mirrors of diameter 150 cm. The eight large mirrors will be clustered together at the centre of the array and the ten smaller mirrors will be located on a circle of radius 55 m, as shown in figure 3. This large separation of mirrors will enable us to determine the arrival angle of the showers to an accuracy of about 0.3°, as time differences can be measured to an accuracy of 0.2 ns. The normal aperture of the mirrors tracking the individual sources is about 1–2° which determines the background counting rate due to proton induced showers.

It has been found from preliminary experiments and simulations that the aperture of the individual mirrors can be increased without affecting the timing. Thus the combined effect of angular determination to an accuracy of 0.5° and the increase of aperture of each mirror is expected to result in lowering the threshold of detection by at least a factor of two to three, thus, it is hoped, improving the chances of detection of pulsed high energy γ-rays.

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Discussion

A. W. Wolfendale, F.R.S. (*Physics Department, The University, Science Laboratories, South Road, Durham DH*1 3*LE, U.K.*). Will Dr Wills please comment on the relevance of Professor Sreekantan's work on Crab variability to that from COS-B?

R. D. Wills (*Space Science Department of the European Space Agency, ESTEC, Noordwijk, The Netherlands*). The first two COS-B observations (in 1975 and 1976) preceded the first Tata measurement in which the positive result was recorded. The later observations reported in this symposium were made in the spring and autumn of 1979. A fifth observation was made in the autumn of 1980 and the data analysis has just started.