HIGH ENERGY GAMMA RAYS FROM PULSARS

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ABSTRACT. We present here the results from observations of pulsed gamma ray emission from the Crab and Vela pulsars for energies above 100 GeV using the atmospheric Cerenkov technique. The results suggest a very steep energy spectrum for gamma rays emitted from pulsars at high energies. Our observations over the last 4 years suggest also that the flux is highly variable with time.

INTRODUCTION

Ground based atmospheric Cerenkov methods are ideally suited for the study of high energy gamma rays since the collection areas are many orders of magnitude larger than in satellite measurements. In this technique the Cerenkov light emitted by high energy electrons, which are generated in an electron-photon cascade initiated by primary gamma rays in the atmosphere, is spread over a very large area $\sim 10^5$ m^2. The light is focussed onto fast photomultipliers using parabolic reflectors. A fast, 10 - 20 ns, time coincidence logic eliminates the effects of the night sky background.

CRAB PULSAR

We have observed some of the pulsars with high energy loss rates, like the Crab and the Vela pulsar, using the Cerenkov array of parabolic reflectors operating at Ooty (11°23' N, 2.2 km height) in India since 1977. Using only 10 reflectors (total area 6.6 m^2) during Feb. - March 1977 we detected pulsed emission from the Crab pulsar at a threshold energy of $\sim$ 500 GeV (Gupta et al. 1978) with $(1.19 \pm 0.33) \times 10^{-11}$ photons cm^{-2} s^{-1} for E > 500 GeV. The light curve showed two distinct peaks (3.5σ and 2.2σ) separated by 0.42 of the period as seen at lower gamma ray energies (Lichti et al. 1980). The spectrum is shown in Figure 1. It steepens significantly above 10 GeV.

This conclusion is further supported by our recent observations.

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Since 1977 we have made many improvements in our experimental system. The array size has been increased and we have now ten small (90 cm) and eight large (150 cm) reflectors with a total receiving area of $\sim$ 20 m^2. These changes have resulted in an increased gamma ray sensitivity. The phase histogram from winter 1980 does not show any significant peak and the upper limit on the pulsed flux at a threshold energy of 140 GeV is shown in the figure. The upper limits obtained from data collected during the winter of 1978 and 1979 are also shown in the figure, illustrating the gradual reduction in energy threshold achieved through technical improvements. These results suggest that the pulsed gamma ray flux at high energies (> 100 GeV) is highly variable with time. The source was probably in its higher intensity mode at the time of our earlier observations in Feb. 1977. This implies that the average pulsed intensity is, in fact, much lower than shown by the points in the figure and that the energy spectrum for the Crab pulsar above 10 GeV is very much steeper than the $E^{-2.17}$ (differential) spectrum observed for lower energy gamma rays (Lichti et al. 1980).

VELA PULSAR

The spectrum for the Vela pulsar is also shown in Fig. 1. It is considerably flatter in the 50 MeV - 10 GeV energy range (Lichti et al. 1980) than the Crab pulsar spectrum. The observations in Feb. - March 1977 with an estimated energy threshold of 1000 GeV did not yield any positive result. It may be noted that the energy threshold is about a factor of two larger for the Vela pulsar than for the Crab pulsar because the zenith angle is higher than 56° at our site. In Feb. - March 1979 we observed a positive flux with a lower energy threshold of $\sim$ 500 GeV (Bhat et al. 1980). The light curve showed two distinct peaks (4.4σ and 2.2σ) separated by 0.42 of the period, very similar to the light curve seen by Lichti et al. (1980). The pulsed flux obtained from these data is shown in Fig. 1. The upper limit from winter 1980 is also shown in the figure. These results suggest that, as in the case of the Crab pulsar, the high energy gamma ray flux is highly variable with time. The spectrum may as well be rather steep beyond 10 GeV. The observed flux seems however to be higher than predicted (Salvati and Massaro 1978, Ayasli and Ögelman 1980).

It is interesting to speculate that the high energy gamma ray pulsed flux is high just after a glitch and returns to its pre-glitch value within about a year, similar to the characteristic time taken for the pulsar period to settle down after a glitch (Manchester and Taylor 1977). This is suggested by the fact that a positive result was obtained from our observations made during Feb. - March 1979 about seven months after the glitch in the Vela pulsar in July 1978. Observations made about 18 months after the glitch gave negative results. Earlier Grindlay et al. (1975) had also seen a positive result from their observations made in April 1972 about eight months after the glitch in August 1971, whereas their subsequent observations in April - May 1973 yielded negative results.

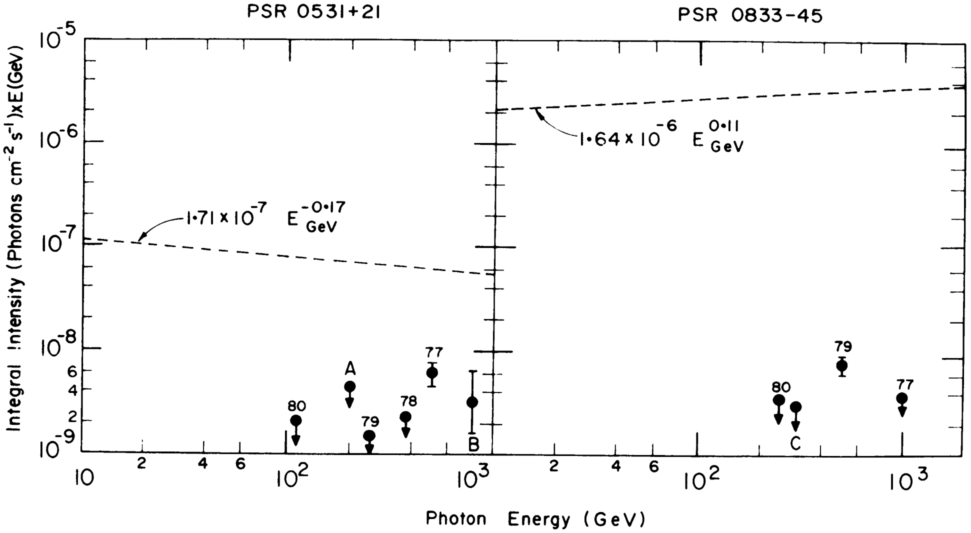

Figure 1: Time-averaged integral energy spectrum (pulsed) for the Crab (PSR 0531+21) and Vela (PSR 0833-45) pulsar. For clarity the intensity has been multiplied by the energy E. Dashed lines are extrapolations of the spectra measured by the COS-B group (Lichti et al. 1980) in the 50 MeV - 10 GeV energy range. A: Helmken et al. (1973), B: Grindlay et al. (1976), C: Grindlay et al. (1975), 77-80: Ooty results for 1977 to 1980.

OTHER PULSARS

We have also reported earlier (Gupta et al. 1978) a positive flux from the pulsar PSR 0950+08 from our observations in Feb. - March 1977. The light curve for this pulsar, showing a single peak (3.85σ), was obtained by extrapolating the P and $\dot{P}$ values given for a much earlier epoch (Taylor and Manchester 1975). We observed this pulsar again in Jan. - March 1978 and analysed the data using timing parameters given by Krishnamohan (priv. comm.) using the Ooty radio telescope. No peaks were seen in the phase histogram. Recently we have reanalysed the data of Feb. - March 1977 using the interpolated values of P and $\dot{P}$. The peak seen earlier has disappeared after this analysis and now only an upper limit on the pulsed flux of high energy gamma rays can be given for this pulsar.

FUTURE OBSERVATIONS

We are planning to rearrange our Cerenkov array next winter by putting the 10 smaller reflectors in a circle of 50 m radius keeping the larger reflectors together in the centre. Based on our preliminary measurements last winter it is expected that such a configuration would

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allow a determination of the individual shower arrival direction to an accuracy better than 0°.5 by relative timing techniques. A study of events arriving within only 0°.5 of the pulsar direction should then help to reduce the cosmic ray background and increase the detection sensitivity of the Cerenkov telescope.

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DISCUSSION

ARONS: I want to emphasize how important these observations are, since absorption in the magnetic field implies that 10^3 GeV gamma rays cannot come from the deep interior of the magnetospheres of either the Crab or the Vela pulsar.

RUDERMAN: If the keV-MeV flux from the Crab is indeed 10^{36} erg s^{-1}, then it is already very hard to see how this can come from particles accelerated just above the polar cap; the potential drop there (along the magnetic field) cannot exceed a few times 10^{12} Volts without being limited by break-down into an electron-positron discharge. The current out of the polar cap is at most about 10^{34} erg s^{-1} if conventional ideas of neutron star magnetic fields are not very wrong (otherwise the stellar slowing down torque is too great). The product seems to be at least an order of magnitude too small to support the 10^{36} erg s^{-1} of observed hard X-ray emission.