# 1000 GeV GAMMA RAY EMISSION FROM RADIO PULSARS

P.M. Chadwick, J.C. Dowthwaite, I.W. Kirkman,
T.J.L. McComb, K.J. Orford, and K.E. Turver

Department of Physics, University of Durham,
Durham DH1 3LE, England.

## ABSTRACT

Our measurements of radio pulsars have concentrated on long observations of the Crab pulsar and have shown it to emit short intense bursts and a persistent weak periodic flux at Υ-ray energies > 1000 GeV. The light curve of the persistent emission was shown to be dominated by a single peak, coincident with the position of the radio and low energy Υ-ray main pulse. We report here the results of a more detailed analysis of the structure of this main pulse following a careful appraisal of the timing system. We show that at energies > 1000 GeV the duration of the main pulse (as defined by the full width at half maximum) is not greater than 0.4 ms, which is less than that seen at all frequencies other than radio.

Flux limits for the emission of 1000 GeV Υ-rays by seven other radio pulsars are reported.

## 1. INTRODUCTION

In 1982 and 1983 observations of the Crab pulsar at a Υ-ray energy threshold of about 1000 GeV were made using the atmospheric Cerenkov technique at the Dugway facility[1]. The experiment recorded 156,342 Cerenkov light flash events in 103 hours, during which time the object was continuously tracked in the centre of the field of view of the telescopes. The recorded event times were converted from UTC to Barycentre Corrected Julian Ephemeris Time using the MIT solar system ephemeris[2], and each was then assigned an absolute phase using a contemporaneous radio ephemeris[3].

In a search for persistent weak emission we derived the light curve, reproduced in Figure 1a, for all recorded events. The location and width of the bins were chosen to allow direct comparison with the results at energies of around 100 MeV from the COS-B experiment. An excess of events significant at the 4.2 $\sigma$ level was seen in the bin at the expected position of the main pulse. This excess corresponds to 0.233 ± 0.054% of the background level due to cosmic ray protons in our experiment, which is equivalent to a Υ-ray flux of $(7.9 \pm 1.8) \times 10^{-12} cm^{-2} s^{-1}$ above 1000 GeV. The light curve was then compared with that seen in the COS-B experiment at energies of 100 MeV - see Figure 1b. A strong correlation in shape was seen to exist, with the major contribution arising from the main pulse. An examination of the events comprising the main pulse in Figure 1a revealed no fine structure on a timescale less than the bin width (1.33 ms).

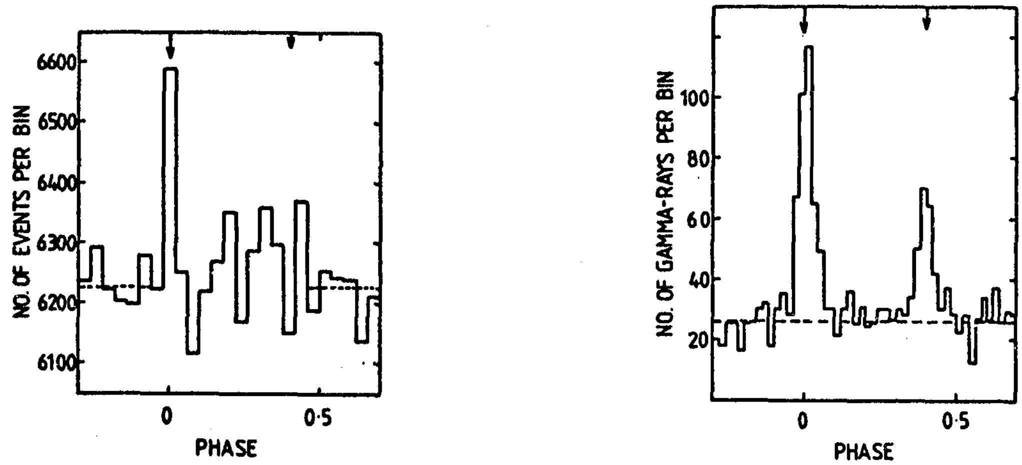



Figure 1a : The light curve for all Cerenkov light events recorded from PSR 0531 in 1982 September - 1983 November.

Figure 1b : The average light curve for 100 MeV gamma rays emitted by PSR 0531 [4].

The off-air initialisation of our crystal-based clock system, (based on the WWV radio signal from Fort Collins, Co.), involved several resets during the course of the observations. As a result, any fine structure was likely to be spread slightly due to residual uncertainties in, for example, changes in radio propagation time to the site. However, the data in 1982 November 12-22, comprising 104,994 events in about 76 hours of observation, was taken without the clock being reset. This subset could therefore be usefully studied in more detail following a thorough appraisal of the timekeeping.

## 2. RESULTS : (A) The Crab Pulsar.

Light curves were formed for the subset of 1982 November 12-22 data with 25, 100 and 250 bins (corresponding to bin widths of 1.33, 0.33 and 0.13 ms respectively) and the main pulse was examined. These light curves are shown in Figures 2a, 2b and 2c for the phase range 0.9 - 0.1, (where 0.0 corresponds to the position of the centre of the radio main pulse).

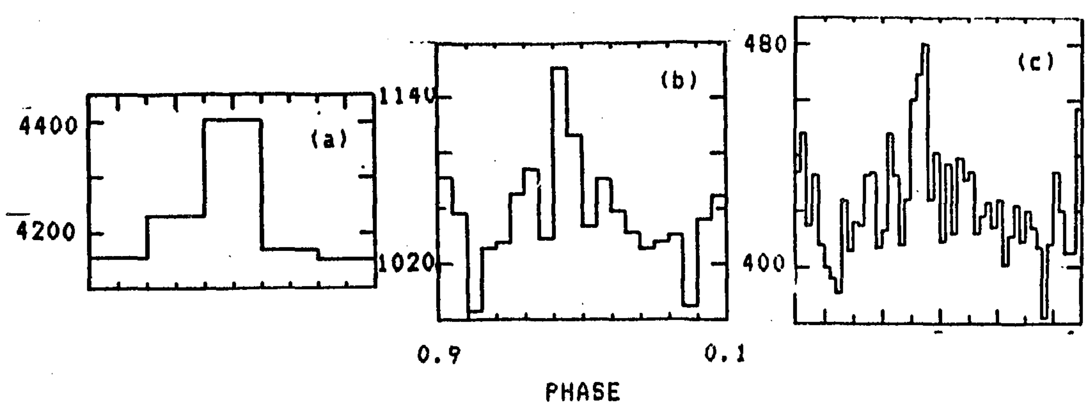
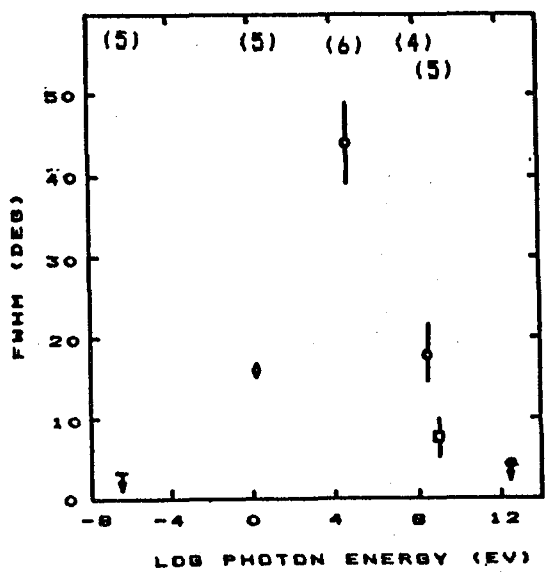



Figure 2 : The main pulse region of the light curve for all Cerenkov light events recorded from PSR 0531 in November 1983.

The majority of events in the main pulse (see Figures 2a and 2c) occur in the relatively narrow phase range between 0.98 - 0.992, which is slightly before the expected radio main pulse position. However, the absolute timing uncertainty in our system of about ± 0.5ms (inherent in all off-air timing systems of this type) does not allow significance to be attached to this discrepancy. The width of the main pulse at energies > 1000 GeV can be compared with that at 100 MeV [4] (shown in Figure 1b to have a FWHM of 1.6 ms). We find a VHE gamma ray main pulse of FWHM 0.4 ms, which is about a factor of 4 narrower than that at the lower energy. Furthermore, we note that the estimated non-linearity of rate of our oven-controlled crystal (about $5 \times 10^{-10}$ $s.s^{-1}$ over the 10 days of the observation) would have the effect of smearing out a main pulse of even shorter duration (such as one approximated by a delta function) to one having the duration observed. Thus a main pulse of duration < 0.4 ms is not ruled out by this experiment.

The duration of the pulse at 1000 GeV is about the same as that seen at radio energies - and is certainly shorter than that seen in the energy range 1 KeV - 1 GeV - see Figure 3.

Figure 3: The width of the main pulse. The figures at the top of the graph are the references for the data. The present result is shown ⯆.




The present result confirms the trend to shorter pulses at the higher energies suggested previously[5].

In 1981 a series of short (7 min) driftscans were made on the Crab Nebula and pulsar. These allow an estimate of unpulsed emission from a source since we expect the intensity of γ-rays to be reduced at the beginning and end of the 7 min interval when the source is approaching the edge of the field of view of the telescope. We find no significant gradation across the aperture of the telescopes (the excess counts in the centre of the field are consistent with the small expected excess of pulsed γ-rays). The 3 $\sigma$ level flux limit for an unpulsed emission at an energy > 1000 GeV is $3 \times 10^{-10}$ $cm^{-2}s^{-1}$.

RESULTS : (B) - Other Radio Pulsars.

The observation of the 7 pulsars specified in Table I has not yielded any detections of VHE $\gamma$-rays and the derived flux limits (3 $\sigma$ level) for a 1000 GeV threshold, assuming a light curve with duty cycle of 5 %,, are shown.

| PULSAR | FLUX LIMIT ($cm^{-2}s^{-1}$) |
|---|---|
| PSR 0355+54 | $2.0\times10^{-11}$ |
| PSR 0950+08 | $1.1\times10^{-11}$ |
| PSR 1133+16 | $2.3\times10^{-11}$ |
| PSR 1508+55 | $2.1\times10^{-11}$ |
| PSR 1929+10 | $2.8\times10^{-11}$ |
| PSR 1930+22 | $2.8\times10^{-11}$ |
| PSR 2224+65 | $1.9\times10^{-11}$ |

TABLE I

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