1000 GeV GAMMA RAYS FROM ms PULSARS

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ABSTRACT

We here report the detection of 1000 GeV γ-rays with the characteristic 6.1 ms periodicity of the radio pulsar PSR 1953 +29[1]. This result, significant at the 5.4 σ level, provides the first direct evidence for the association of the 6ms radio pulsar PSR1953+29 with the γ-ray source 2CG065+0. Extensive observations of the 1.5 ms pulsar PSR 1937 are also reported.

1. INTRODUCTION.

Observations of PSR1953+29 and PSR1937+21 were made between 1983 April and 1984 September using the array of four telescopes of the Dugway VHE γ-ray facility which have been described elsewhere[2]. The telescopes have an energy threshold dependent on zenith angle of approximately 1 TeV. The duration of the individual observations varied between 1 and 6 hrs during which the pulsar was observed with all telescopes in the tracking mode. The time of arrival of a Cerenkov light flash was recorded in Coordinated Universal Time (UTC) to an absolute accuracy of 0.5 ms and with a resolution of 1 μs. The time of each event has been converted from UTC to Barycentre Corrected Julian Ephemeris Time using the MIT solar system ephemeris [3] and the position of the radio pulsar. A further correction to allow for the orbital motion of the PSR 1953 has been made by adjusting the times to the focus of the binary orbit according to radio measurements [4] which are summarized in Table I.

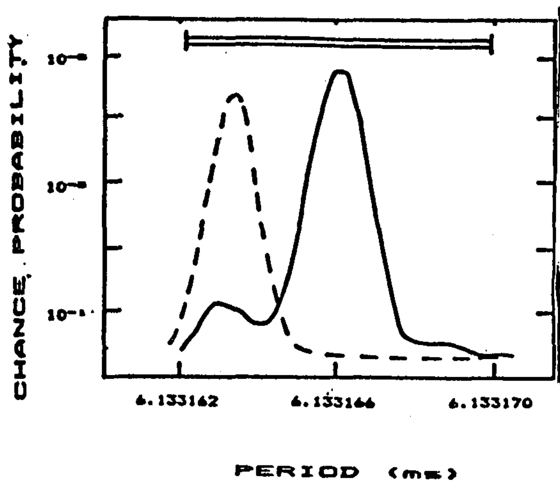
RA	:	19h 53m 26.673s
DEC	:	29° 0' 44.1"
EPOCH	:	2445428.66
d	:	117.3 ± <0.1 d.
e	:	<0.001
p	:	6.133166 ms.
asin(i)	:	31.29 ls.

TABLE I.

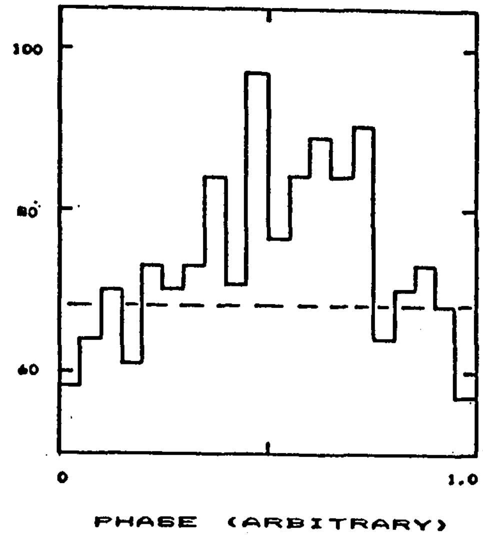
2. RESULTS - (A) PSR 1953 - The 6 ms Pulsar.

A homogeneous dataset was compiled comprising only those observations of at least 4 hours duration. This enables the results of the periodicity searches on 8 individual observations to be combined with equal statistical weights. The uncertainty in the binary orbit causes progressive phase errors and precludes the use of datasets of 24 hours or more, in particular the assembly of a single large dataset spanning the whole observation period. Events were selected which triggered any two of the four telescopes (this has been shown (3,4) to increase the sensitivity of the telescope array to γ-rays since twofold telescope responses define a narrower effective aperture). The PSR 1953 dataset (comprising 14286 events in all) was obtained during the half of the orbit when the pulsar was approaching the earth, but spanned a year, or approximately three orbits. Each individual observation was tested for periodicity over a restricted range of period (6.133162 - 6.133170 ms). This limited searching for periodicity was necessary to allow (with decreasing effect) for (a) uncertainties in the orbital ephemeris, (b) the effects of statistical sampling on a periodicity in sparse data, and (c) residual uncertainties in the precise rate of the stabilised 1MHz system clock. The Rayleigh test (6,8) was selected as the appropriate test for searching for periodicity in the absence of specific knowledge, or a reasonable guess, of the light-curve duty cycle. The test is Uniformly Most Powerful for distinguishing between the alternative hypotheses of the fundamental power being zero or non-zero.

Each of the eight observations was analysed independently and the eight probabilities of chance occurrence of each trial period were combined (7). This combined probability is shown as a function of the trial period in Figure 1. A 3.5% periodic excess is found within the trial period range, which has a probability of chance occurrence of 1.6×10^{-5}. The number of independent trial periods in the range: P_1=6.133162 ms to P_2=6.133170 ms is $(T/P_1 - T/P_2) = 3.4$ (T = mean duration of an observation), increasing the probability of the detection being due to chance to 5.4×10^{-5}. Further independent data from the single-telescope responses is available. Such responses are less sensitive to γ-rays because of the larger aperture which allow the registration of more proton-induced showers. However, one of the four telescopes had been equipped with new mirrors and has a narrower field of view to improve its signal/noise to approximately the same as two-telescope responses. This dataset, comprising 17302 events, independently shows a 3.2% pulsed signal at a period within the sampling range of the periodicity shown by the 2 telescope responses. This signal is at a significance level of 4×10^{-5} - see Figure 1. With a 3.5% signal strength in narrow aperture detection systems we would expect the other three wider aperture telescopes to have a signal/noise ratio of about 1.5% and hence not show significant effects. This is seen to be the case. The overall probability of the effect being of chance origin is therefore about 4×10^{-8} which corresponds to a 5.4σ signal.



<u>Figure 1</u> : The probability of chance occurrence as a function of the trial period. The horizontal bar shows the expected position of the radio period allowing for the uncertainties in the binary orbit. The solid line refers to the two-telescope responses and the broken line to the independent sample from the single (sensitive) telescope response.



<u>Figure 2</u> : The light curve of VHE γ-ray emission on 1983 August 6.

The γ-ray signal has been investigated on a night-to-night basis during the eight longest observations. The average signal (γ-rays)/noise (cosmic ray protons in the field of view) for a 2-telescope response is 3.5% and fluctuates from below the background noise level to 8.5%. No pattern is apparent in the variation, in that the signal averaged over observations which are at similar orbital phases remains at about 3.5%, although in some cases the observations are a year apart. Assuming that the γ-ray samples have a Von Mises distribution, we can test for constancy of the signal from night to night using an established test[8]. We find that the variation of signal strength from night to night is consistent with sampling variations from a constant signal strength, but cannot preclude variations from zero to about three times the average strength. A similar test of the data on a time scale of about 30 mins also shows no evidence of variation. We can however exclude as the source of the present effect the type of strong (~30%) but brief (~few minutes duration) outbursts detected by us from the Crab pulsar [4] and from Hercules X-1[9]. The time-averaged flux of γ-rays of energy in excess of 2 TeV is 3×10^{-11} cm^{-2} s^{-1}. The VHE γ-ray luminosity, assuming a distance to the pulsar of 3.5 kparsec and a differential power law index of 3.0 is 3×10^{35} ergs s^{-1}. The light curve for the 2-telescope responses on the occasion of the apparently strongest signal (1983 August 6) has been derived for the radio period (6.133166 ms) and is shown in Figure 2.

RESULTS (B) PSR 1937 - The 1.5 ms Pulsar.

Between 1983 April 13 and 1984 September 29 PSR 1937 was observed on 46 separate occasions for a total of 129 hrs during which 301597 Cerenkov light flashes were recorded. The extremely short period of the pulsar precludes the possibility of maintaining phase and combining data recorded on separate nights as a separate dataset. The data from each observation have been analysed for periodic content using the Rayleigh test. No evidence for a pulsed content characterized by a broad light curve has been found. A 3σ flux limit equal to 1.5% of the cosmic ray background (a γ-ray flux limit of $5\times10^{-11}cm^{-2}s^{-1}$) has been derived. The analysis of the data continues with a search for a pulsed emission containing a very much shorter duty cycle.

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