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SAS-2 GAMMA-RAY OBSERVATIONS OF PSR 1747-46

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ABSTRACT

Observations with the SAS-2 high energy (> 35 MeV) γ-ray telescope show evidence of γ-ray emission from the radio pulsar PSR 1747-46. When the arrival times of γ-rays from the region of the pulsar were converted to pulsar phases using the radio period and period derivative, a single peak was found in the phase plot, with a Poisson probability of occurring by chance of 8×10^{-5}. Independently, the time-averaged data for the PSR 1747-46 region show an enhancement over the surrounding region of the sky at the same galactic latitude, with a Poisson probability of chance occurrence of less than 8×10^{-3}. The probability that these results are chance is the product of these two probabilities times the number of radio pulsars examined (73). This overall probability is sufficiently small ($\sim 5 \times 10^{-5}$) to suggest an identification of a new γ-ray pulsar. In the γ-ray pulsar plot, the peak falls 0.16 $\pm$0.03 period after the radio pulsar peak. This phase shift is, within uncertainties, the same as that observed between the single radio peak and the first of the two γ-ray peaks seen in the phase plot for PSR-0833-45 (the Vela pulsar).

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I. INTRODUCTION

Of the approximately 147 radio pulsars now known (see Taylor and Manchester, 1975) only two have previously been detected at shorter wavelengths. PSR 0531+21 in the Crab nebula has been seen at optical, X-ray, and γ-ray energies; and PSR 0833-45 in the Vela supernova remnant has been identified at γ-ray wavelengths. In this letter we report evidence for the observation, by the SAS-2 satellite detector, of γ-ray emission from the radio pulsar PSR 1747-46. The evidence is based both on the presence of a $\sim 3\sigma$ enhancement of γ-rays at the location of PSR 1747 and a $\sim 4\sigma$ peak in the phase plot of events whose phase was calculated from the pulsar's known period. Since these discoveries were made in the course of a survey of 73 radio pulsars (Ögelman et al.,1976), the overall probability that any one of the 73 pulsars show this type of behavior is $\sim 5 \times 10^{-5}$. The smallness of this number suggests the identification of a new γ-ray pulsar. Further, the γ-ray pulsation appears at a phase lag of 0.16 $\pm$0.03 from that predicted by the radio observations. A similar phase lag of 0.15 $\pm$0.02 was observed in the case of the Vela pulsar (Thompson et al., 1975).

II. OBSERVATIONS

Descriptions of the SAS-2 high energy γ-ray experiment, the calibration procedure, and the data analysis method are given by Derdeyn et al. (1972) and Fichtel et al. (1975). The region of the sky which includes PSR 1747-46 was in the field of view of the instrument between November 20 and December 5, 1972, and again between January 25 and 30,

1973. Events from this second interval were not used for the phase analysis due to the uncertainty in extrapolating the radio reference timing measurements over the eight weeks between the intervals. These events were used in the analysis of the time-averaged data.

The timing analysis and results will be discussed prior to the presentation of the time-averaged data. For the phase analysis, γ-ray events were chosen which had measured arrival directions within a circle of 5° radius about the known pulsar position for γ-rays with energy greater than 100 MeV and within a circle of 7.5° radius for γ-rays with energy between 35 and 100 MeV. These circles are chosen to select about 80% of all possible signal events. The arrival time for each of the 79 events thus chosen was converted to a pulsar phase using a program previously applied to the Vela pulsar data (Thompson et al., 1975), together with the published period and period derivative of PSR 1747-46 (McCulloch et al., 1973). These radio measurements took place approximately one week before the beginning of the SAS-2 observations, so that the timing information did not have to be extrapolated over an extended baseline. As an additional check on the computer program, and in order to determine an absolute arrival time for the radio pulse, a set of radio pulse arrival times were included in the same pulsar program as the γ-ray events (after correction of the radio arrival times by 44 msec for dispersion). These radio observations took place on November 15, 16 and 18, 1972 (McCulloch, 1976).

Fig. 1 shows the results of the calculation. Sixteen of the 79 γ-ray events lie in one of the 20 bins used. The Poisson probability of finding this peak in any one of 20 bins is about 8×10^{-5} (equivalent to approximately four standard deviations, if the peak is ascribed to a statistical fluctuation).

If this concentration of events is treated as a positive result, the pulsed γ-ray flux above 35 MeV is $(2.4 \pm 0.7) \times 10^{-6} cm^{-2} s^{-1}$. Of the 16 events in the peak, six have measured energies above 100 MeV. Although these statistics are not sufficiently large to draw meaningful conclusions, the ratio of events below 100 MeV to events above 100 MeV is approximately the same for all 79 events as for the 16 in the peak, suggesting that the energy spectrum of the events in the peak is not drastically different from that of events in the surrounding region of the sky. The pulsed flux above 100 MeV obtained from this analysis would be $(6.5 \pm 3.3) \times 10^{-7} cm^{-2} s^{-1}$.

The radio data used for comparison produced a sharp peak in the phase calculation at the point marked "R" on Figure 1. The radio peak lies 115 $\pm$ 20 msec before the peak in the γ-ray data. In terms of a fractional phase difference , this is equivalent to 0.16 ± 0.03 of a pulse period, which is remarkably close to the phase difference of 0.15 ± 0.02 observed between the Vela radio pulse and the first two peaks in the double peak structure which was seen by SAS-2 for PSR 0833-45 (Thompson et al., 1975).

Although the SAS-2 timing accuracy and the precision of the pulsar phase calculation programs are sufficient to resolve time scales smaller than what is shown in Figure 1, attempts to reduce the bin size showed no measurably narrower concentration of the 16 peak events. For PSR 1747-46, which has a period of 0.742 seconds, this bin size represents

37 msec. This effective pulse width for the γ-ray data can be compared to the radio observations. The measured equivalent width of the PSR 1747-46 radio pulse (equivalent width = area under the pulse curve/peak value) is 17 msec (Manchester, 1976). For a gaussian pulse shape, this equivalent width would imply that about 83% of the emission would take place during a span of 37 msec. The data of Figure 1 are, therefore, consistent with the concept that the γ-ray pulse has a width similar to the radio pulse.

Because the pulsar lies far enough from the galactic plane (galactic coordinates $\ell^{II} = 345.0°$, $b^{II} = -10.2°$), the strong emission from the plane does not dominate the background γ-radiation, at least for photons with energies above 100 MeV, where the SAS-2 angular resolution is best. This separation from the plane made a search of the time-averaged data for an enhancement feasible. Figure 2 shows the result of a scan across the region of the pulsar at galactic latitudes of -6° to -14°. For each 2° by 8° bin, the flux of γ-rays with measured energies above 100 MeV has been determined. The average flux value for all the bins shown is $(0.76 \pm 0.07) \times 10^{-4}$ photons $cm^{-2} sr^{-1} sec^{-1}$. On the basis of this flux, the five bins centered on the pulsar would be expected to contain 25.5 photons. The observed number is 39 for these bins. The Poisson probability of seeing by chance an excess of this size centered on the specific location of the pulsar is approximately 7.6×10^{-3}, roughly equivalent to 2.4 standard deviations. From a different point of view, namely, accepting the possibility of an enhancement and therefore taking the background level as all the bins except the five centered on PSR 1747-46, gives an expected 21.4 events in these five bins. The Poisson probability of a random fluctuation of this background level to give 39 events is 4.0×10^{-4} or approximately 3.4σ. The solid line in Figure 2 shows the average flux away from the pulsar together with the measured angular resolution of the detector normalized to an excess of 17.6 counts centered on the pulsar. Stated in terms of a photon flux, this excess represents $(1.6 \pm 0.6) \times 10^{-6}$ photons (E > 100 MeV) $cm^{-2}s^{-1}$.

The combined probability of the phase result and the time average result is $\sim 6 \times 10^{-7}$. Inasmuch as 73 radio pulsars were examined the probability that any one of them show similar behavior by chance is $\sim 5 \times 10^{-5}$. In our view this constitutes strong evidence that PSR 1747-46 is actively emitting high energy γ-rays. Further discussion is based on our acceptance of the reality of the pulsed signal.

III. DISCUSSION

PSR 1747-46 would have to be considered one of the most likely candidates for pulsed γ-ray emission for the following reason. Under the broad assumption that all pulsars can be described by similar characteristics such as moment of inertia and relationship between the period, the period derivative, and the age, PSR 1747-46 has one of the highest energy loss rates (6.8×10^{33} erg s^{-1}; (Taylor and Manchester, 1975) and one of the smallest apparent ages (1.68×10^{5} years; Taylor and Manchester, 1975) of the 73 pulsars accessible to study by the SAS-2 detector (Ogelman et al., 1976).

Like PSR 0833-45, the phase relationship shows the radio pulse leading the γ-ray pulse by about 0.15 period. Since the Vela pulsar has also been seen in the radio and γ-ray energy ranges, but nothing statistically significant in the optical or X-ray regimes (in contrast to the Crab pulsar), this phase relationship may be indicative of a subclass of pulsars. Thompson (1975) has suggested that the phase difference may be caused by radio emission being produced near the surface of the neutron star and γ-ray emission originating near the speed of light cylinder. If this type of picture is correct, then other pulsars could be expected to show γ-ray emission without corresponding optical or X-ray components. The UHURU 2σ upper limit to an X-ray source at the position of PSR 1747-46 is 0.6 counts/sec. compared to a result of 947 $\pm$21 counts/sec. for the Crab nebula (Forman, Julien, and Tananbaum, 1976).

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FIGURE CAPTIONS

Fig. 1 Phase plot of the 79 γ-ray events from the region of PSR 1747-46. The arrow, labelled R, indicates the phase expected for γ-rays using radio pulse arrival times. The phase difference between R and the γ-ray peak is 0.16 $\pm$0.03.

Fig. 2 Flux of γ-rays ($E_\gamma \geqslant 100$ MeV) from a scan along a strip 8° wide in latitude centered on the latitude of PSR 1747-46 (b = -10°). The dotted line indicates the average flux of all 25 bins. The solid line indicates the average flux of the 20 bins not centered on the pulsar plus a point-source response normalized to the excess.

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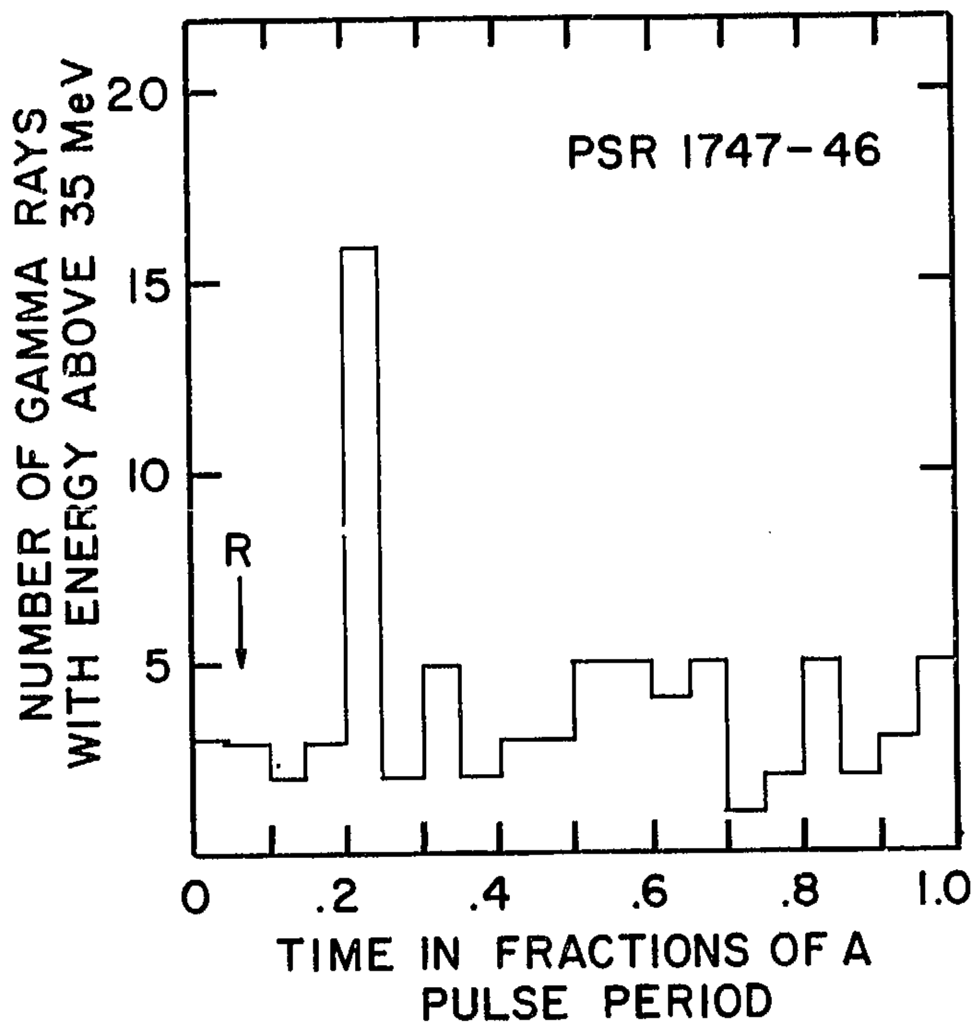
NUMBER OF GAMMA RAYS
WITH ENERGY ABOVE 35 MeV
PSR 1747-46
R
20
15
10
5
0
.2
.4
.6
.8
1.0
TIME IN FRACTIONS OF A
PULSE PERIOD

Fig. 1

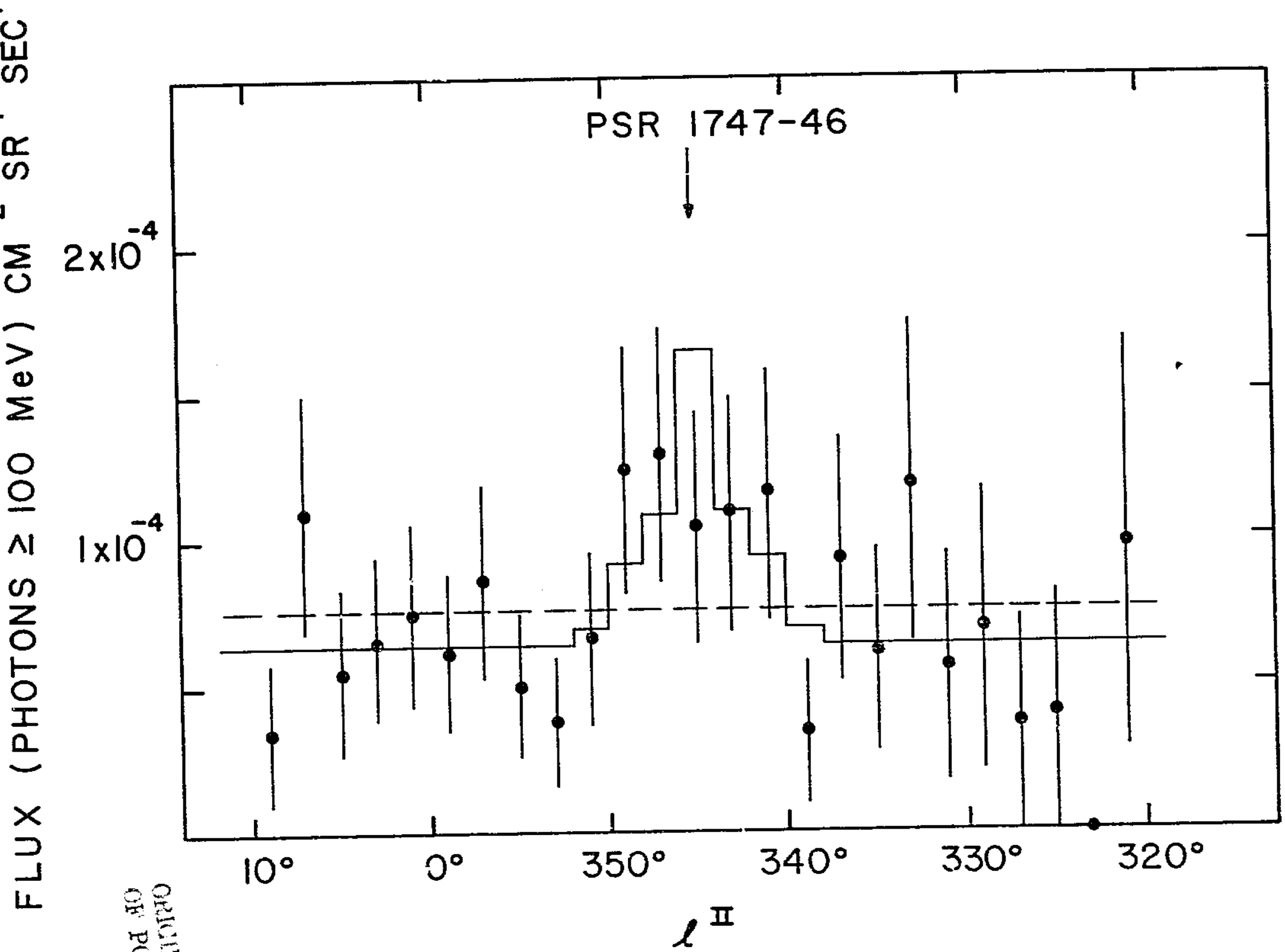
FLUX (PHOTONS ≥ 100 MeV) CM^-2 SR^-1 SEC^-1
2x10^-4
1x10^-4
PSR 1747-46
10°
0°
350°
340°
330°
320°
ℓ II

Fig. 2