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

On the Secular Variation of the γ-ray Emission from PSR 0531+21 [and Discussion]

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Phil. Trans. R. Soc. Lond. A 1981 **301**, 537-539
doi: 10.1098/rsta.1981.0131

Phil. Trans. R. Soc. Lond. A **301**, 537–539 (1981)
Printed in Great Britain

On the secular variation of the γ-ray emission from PSR 0531+21

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The Crab pulsar, PSR 0531+21, was one of the earliest identified sources of high energy γ-radiation and as such was selected as the first object of detailed study by COS-B in August 1975 (see Scarsi *et al.* (1977) for details of the mission). Since then the satellite has made several observations of the galactic anticentre region, and data are now available from four separated epochs when the Crab was within 15° of the centre of the field of view. The accurate timing capability of COS–B has enabled the construction of γ-ray light curves by folding (Bennett *et al.* 1977) the photon arrival times at the Solar-System barycentre with the pulsation parameters given in table 1. The resulting light curves for γ-rays of energy between 50 and 3000 MeV with measured incidence directions within 6° of the pulsar direction are shown in figure 1. These give a clear indication of a variation with time of the relative strengths of the two pulses. Since the energy spectra of the pulses have been shown to have the same form (Bennett *et al.* 1977) it is not possible to ascribe this variation to any change in the performance characteristics of the detector.

For a more detailed analysis the two pulses were delimited by the (arbitrary) phase intervals 0.06–0.30 and 0.54–0.74 on the abscissa of figure 1. The phases of observations 1 and 14 (table 1) were adjusted by reference to the radio pulse; the others were fitted by optimizing the alignment of the γ-ray peaks. The background level was obtained in each case by averaging the counts in the phase interval 0.74–0.06. To estimate the counts in each pulse the integral distribution of arrival directions of the excess counts (above the background) were fitted with curves of the form

$$F(\theta_{\mathrm{m}}) = \frac{\int_0^{\theta_{\mathrm{m}}} 2\pi\theta \exp\left|-(\theta/\theta_0)^{2c}\right| \mathrm{d}\theta}{\int_0^{\infty} 2\pi\theta \exp\left|-(\theta/\theta_0)^{2c}\right| \mathrm{d}\theta}$$

(Hermsen 1980).

The values of θ_0 and c adopted in this paper were determined by studying the fits to the curves of the sum of the two pulses. Since no systematic variation with aspect angle was found, the results of all four observations were combined to improve the statistical significance. With $c = 0.5$ (exponential point-spread function) good fits were obtained with $\theta_0 = 3.4 \pm 1.0$ for $50 < E < 150$ MeV and $\theta_0 = 1.40 \{^{+0.25}_{-0.20}\}$ for $150 < E < 3000$ MeV. Although the number of counts ascribed to each pulse depends on the choice of θ_0 the ratio between the two pulses is not affected within the limits of error quoted. The curves defined by these parameters were fitted to the counts in each pulse phase interval for each observation. Owing to the reduced

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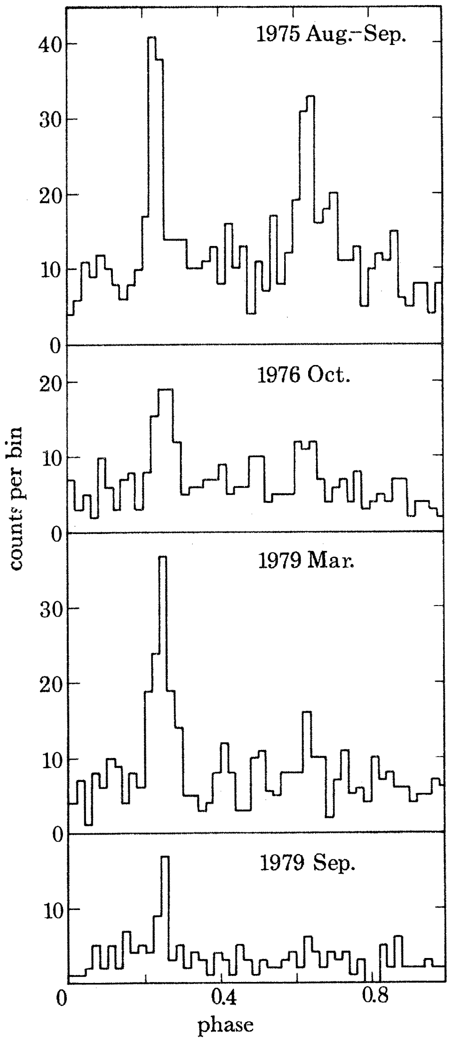

FIGURE 1. Light curves of PSR 0531+21 for γ-rays of energies between 50 and 3000 MeV having measured directions within 6° of the pulsar direction for each of the four observations listed in table 1.

TABLE 1. PARAMETERS OF OBSERVATIONS AND PULSATION ANALYSIS

observation number	1	14	39	44
start date	1975 Aug. 17	1976 Sep. 30	1979 Feb. 22	1979 Aug. 29
end date	1975 Sep. 17	1976 Nov. 2	1979 Apr. 3	1979 Oct. 9
aspect angle of PSR 0531+21	1°	14°	8°	14°
reference epoch (Julian Day)	2442647.0	2442982.062	2443946.442	2444128.5
pulsation frequency				
f/s^{-1}	30.137445548	30.126348860	30.094467179	30.088458052
$\dot{f}/(10^{-10}\ \mathrm{s}^{-2})$	−3.83484	−3.83104	−3.82125	−3.81956
$\ddot{f}/(10^{-20}\ \mathrm{s}^{-3})$	1.141	0.396	1.225	1.224
phase adjustment	0.352344	0.376843	0.96	0.86

Position (1950.0) of PSR 0531+21 used for barycentric correction: r.a. 82.88095°, dec. 21.981777°.

exposure the data of observations 14 and 44 were subject to large statistical uncertainties. Therefore only the results of observations 1 and 39 are presented in table 2. These indicate a change in the ratio of the counts in the two pulses, the level of significance being 3.5σ for the lower energy range, 2σ for the higher range and 4σ for the two ranges combined.

It is obviously important to know whether this effect has associated with it a variation in the total flux from the pulsar. No such variation is measured between the first two observations, a cross check on the constancy of the detector sensitivity being provided by the strong source 2CG 195+04 (Swanenburg *et al.* 1980) which was in the field of view on both occasions. For the later observations the evaluation of the sensitivity is still in progress. The results presented here have been restricted to those that are not dependent on the outcome of that analysis.

Table 2. Pulsed counts from PSR0531+21

energy range	observation	first pulse	second pulse	second/first
50–150 MeV	1	61 ± 10	77 ± 7	1.27 ± 0.24
	39	59 ± 7	19 ± 5	0.32 ± 0.09
150–3000 MeV	1	53 ± 6	52 ± 6	0.99 ± 0.16
	39	46 ± 5	13 ± 12	0.29 ± 0.26
50–3000 MeV	1	113 ± 12	129 ± 9	1.14 ± 0.14
	39	106 ± 9	32 ± 13	0.30 ± 0.12

References (Wills)

Bennett, K., Bignami, G. F., Boella, G., Buccheri, R., Hermsen, W., Kanbach, G., Lichti, G. G., Masnou, J. L., Mayer-Hasselwander, H. A., Paul, J. A., Scarsi, L., Swanenburg, B. N., Taylor, B. G. & Wills, R. D. 1977 *Astron. Astrophys.* **61**, 279–284.

Hermsen, W. 1980 Thesis, University of Leiden.

Scarsi, L., Bennett, K., Bignami, G. F., Boella, G., Buccheri, R., Hermsen, W., Koch, L., Mayer-Hasselwander, H. A., Paul, J. A., Pfeffermann, E., Stiglitz, R., Swanenburg, B. N., Taylor, B. G. & Wills, R. D. 1977 *Proc. 12th Eslab Symp. Frascati* (ed. R. D. Wills & B. Battrick), ESA SP-124, 3–11.

Swanenburg, B. N., Bennett, K., Bignami, G. F., Buccheri, R., Caraveo, P., Hermsen, W., Kanbach, G., Lichti, G. G., Masnou, J. L., Mayer-Hasselwander, H. A., Paul, J. A., Sacco, B., Scarsi, L. & Wills, R. D. 1981 *Astrophys. J.* **243**, L69–L73.

Discussion

F. G. Smith, F.R.S. (*The Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex BN*27 1*RP, U.K.*). These changes in the γ-ray curve of the Crab pulsar are surprising in view of the very small upper limits placed on the variations of the optical light curve by D. H. P. Jones, F. G. Smith & J. E. Nelson (*Nature, Lond.* **283**, 50 (1980)).

I. Freedman (*Physics Department, The University, Science Laboratories, South Road, Durham DH*1 3*LE, U.K.*). Do the results depend critically on the choice of the background and of the phase of each pulse?

R. D. Wills. No, the results are not critically dependent on these factors.