Astron. Astrophys. 69, 141—142 (1978)

ASTRONOMY AND ASTROPHYSICS

Research Note

Relative Phases of Radio and Gamma-ray Pulses from the Vela Pulsar

R. Buccheri[4], P. Caraveo[2], N. D'Amico[3], W. Hermsen[1], G. Kanbach[4], G. G. Lichti[6], J. L. Masnou[5], R. D. Wills[6], R. N. Manchester[7] and Lynette M. Newton[7]

[1] Cosmic Ray Working Group, Huygens Laboratory, NL-2300 Leiden, The Netherlands
[2] Laboratorio di Fisica Cosmica e Tecnologie Relative del CNR, Università di Milano, Milano, Italy
[3] Laboratorio di Fisica Cosmica e Tecnologie Relative del CNR, Università di Palermo, Palermo, Italy
[4] Max-Planck-Institut für Extraterrestrische Physik, D-8046 Garching bei München, Federal Republic of Germany
[5] Service d'Electronique Physique, Centre d'Etude Nucléaires de Saclay, France
[6] Space Science Department of the European Space Agency, ESTEC, Noordwijk, The Netherlands
[7] Division of Radiophysics, CSIRO, Sydney, Australia

Received April 28, 1978

Summary. Observations from the COS-B satellite for gamma-ray astronomy and radio measurements from the Tidbinbilla Deep Space Station have been used to accurately determine the relative phases of the gamma-ray (>50 MeV) and radio pulses from the Vela pulsar. It is found that the peak of the radio pulse leads the centre of the first gamma-ray pulse by 11.2 ± 0.5 ms.

Key words: Vela — pulsars — gamma-ray observations — radio observations — COS-B

Introduction

The Caravane Collaboration for the COS-B satellite has recently published a paper in which the light curve of the Vela pulsar, PSR 0833-45, in the gamma-ray energy range ($E_\gamma > 50$ MeV) is described with a time resolution down to the millisecond level (Bennett et al., 1977). This light curve has two peaks as does that in the optical band (Wallace et al., 1977) whereas in the radio band the integrated pulse profile has just one main component (e.g. Komesaroff et al., 1972). Data from SAS-II (Thompson et al., 1975) indicate that the first gamma-ray pulse trails the radio pulse by 13 ± 2 ms, where the main contribution to the quoted error is the statistical uncertainty in the gamma-ray data. The spacing of the two optical components is 21 ± 1 ms and the first optical pulse is emitted 21 ± 1 ms after the radio pulse (Manchester et al., 1978). Thus all the pulse components from this pulsar are emitted at different phases. Accurate values of these relative phases are important for investigations of the mechanisms of pulse emission.

In this note we report an improved determination of the relative phase of the radio and gamma-ray pulses from the Vela pulsar, derived from the COS-B and Tidbinbilla observations.

Send offprint requests to: R. Buccheri

Analysis and Discussion

The gamma-ray data were obtained by the COS-B satellite between 1975 October 20 and November 28; observational and analysis procedures have been described by Bennett et al. (1977). Radio pulse-timing data were obtained from the NASA Deep Space Station, Tidbinbilla (Manchester et al., 1976) at an observing frequency of 2295 MHz.

The relative phases of the radio and gamma-ray pulses were determined using two independent analysis procedures. In the first, barycentric arrival times for a number of radio pulses were included in the standard gamma-ray analysis and their average phase with respect to the first gamma-ray pulse was determined. Independent programs were used to determine propagation times to the barycentre for the radio and gamma-ray data, but both programs used the same Solar System Ephemeris (that produced by the Lincoln Laboratory, Massachusetts) and the same pulsar position (Vaughan and McAdam, 1973). A dispersion measure of 69.08 cm^{-3} pc was assumed for the pulsar (Komesaroff et al., 1972), giving a dispersion delay of 54.4 ms for the radio pulse.

In the second procedure, a number of times of arrival at the satellite of gamma-rays falling within the highest bin of the first pulse were included in the standard radio timing analysis, together with the appropriate satellite position data. The mean of these arrival times corresponded to the bin centre. In this case, all calculations of barycentric propagation times were done by the one program for both radio and gamma-ray data. A cross-check on the propagation times to the barycentre showed excellent agreement between the CSIRO and COS-B programs.

Both procedures showed that the peak of the radio pulse leads the peak of the first gamma-ray pulse by 11.2 ± 0.5 ms. The quoted uncertainty is limited by the accuracy of the absolute timing reconstitution in the COS-B data acquisition system. The relative phase of the profiles in the radio and gamma-ray band is illus-

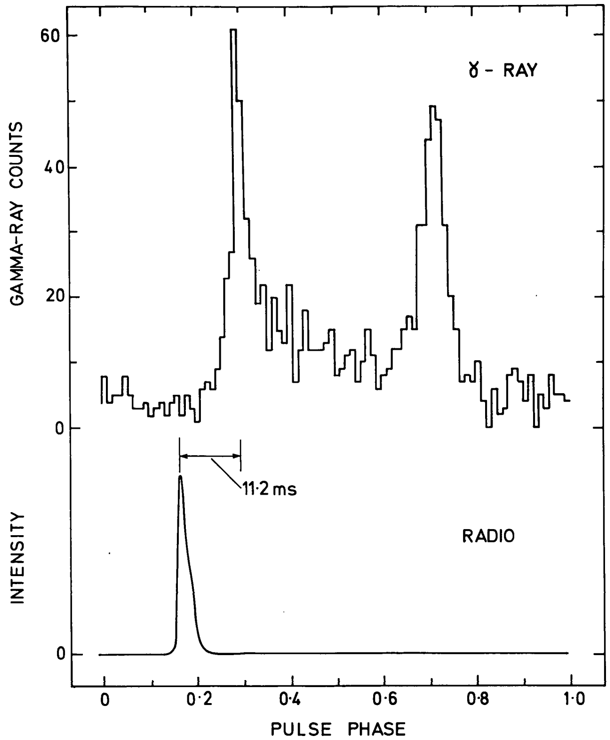

Fig. 1. Radio (2295 MHz) and γ-ray (> 50 MeV) pulse profiles for the Vela pulsar aligned in phase as they are emitted from the pulsar

strated in Figure 1. A preliminary analysis of as yet unpublished gamma-ray data obtained by COS-B in the period 1976 July 25 to August 24 gave the same result.

This result, together with the data of Manchester et al. (1978), shows that the phase delay relative to the radio pulse peak of the pulse components at optical and gamma-ray frequencies are respectively about 11 ms (first gamma-ray), 21 ms (first optical), 42 ms (second optical) and 49 ms (second gamma-ray). This is in striking contrast to the Crab pulsar case where the pulse shape is basically double at all frequencies and the emission time of the two components is the same at all frequencies (e.g. Manchester and Taylor, 1977).

The near coincidence of the midpoints of the optical and gamma-ray pulse profile for the Vela pulsar led Manchester and Lyne (1977) to suggest that both components were emitted from a single magnetic pole on a neutron star. With the improved data given above the midpoints are no longer quite coincident, being 30 ms and 31.5 ms behind the radio pulse for the gamma-ray and optical pulses respectively. This small difference, if real, could be explained in the model proposed by Manchester and Lyne by a slight field line distortion or by the occurrence of the gamma-ray emission process at a greater distance from the neutron star surface than the optical emission.

Acknowledgements. The radio observations at the Tidbinbilla Deep Space Station were made possible by the cooperation of the Director, Mr T. Reid, and staff of the station. G. G. L. acknowledges receipt of an ESA fellowship. The Caravane Collaboration thanks the Data Processing staff of the European Space Operation Center for the high-quality reconstitution of the COS-B orbit and time information.

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