N92-21902

THE CRAB PULSAR LIGHT CURVE IN THE SOFT GAMMA RAY RANGE: FIGARO II RESULTS

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Abstract

The FIGARO II experiment - a large area, balloon borne, crystal scintillator detector working from 0.15 to 4.3 MeV - observed the Crab pulsar on 1990 July 9 for about seven hours. The study of the pulse profile confirms some structures detected with a lower significance during the shorter observation of 1986, and adds new important elements to the picture. In particular, between the two main peaks, two secondary peaks appear centered at phase values 0.1 and 0.3, in the energy range 0.38-0.49 MeV; in the same energy range, a spectral feature at 0.44 MeV, interpreted as a redshifted positron annihilation line, has been observed during the same balloon flight in the phase interval including the second main peak and the neighboring secondary peak. If the phase interval considered is extended to include also the other secondary peak, the significance of the spectral line appears to increase.

1. Introduction

The FIGARO II (French Italian GAmma Ray Observatory) experiment (Agnetta *et al.* 1989) was specifically designed to study sources with a well established time signature in the low energy γ rays. The Crab pulsar (PSR 0531+21) was observed by FIGARO II in the course of two transmediterranean balloon flights: on July 11 1986 for about two and a half hours (Agrinier et al. 1990) and on July 9 1990 for about seven hours. In this contribution we present some recent findings from the latter observation: we investigate the dependences of the light curve on the energy, and show that significant minor structures are present in the interpulse region between the two main peaks.

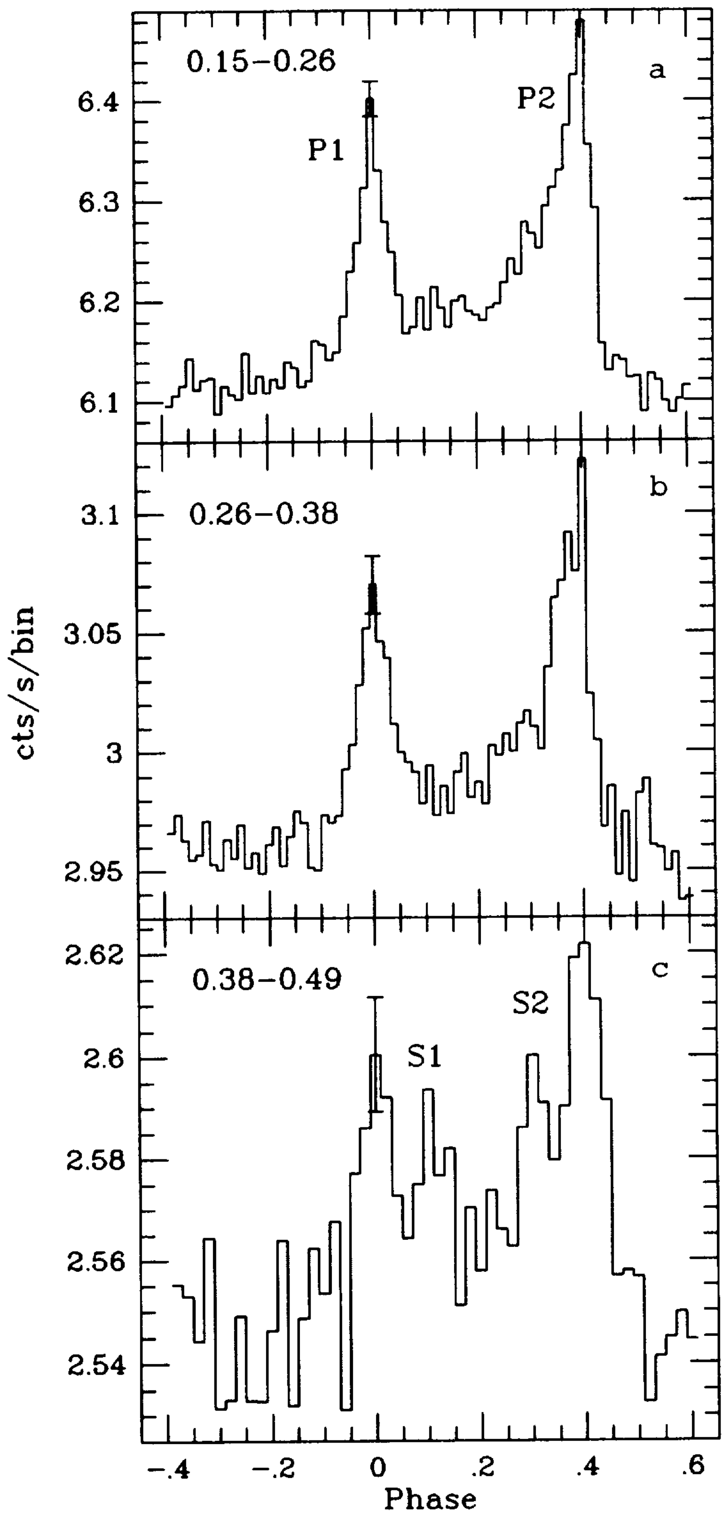

Fig. 1a,b,c - Phase histograms of PSR 0531+21 in different energy bands. The zero phase corresponds to the main radio peak. The energy ranges (in MeV) are reported in each panel.

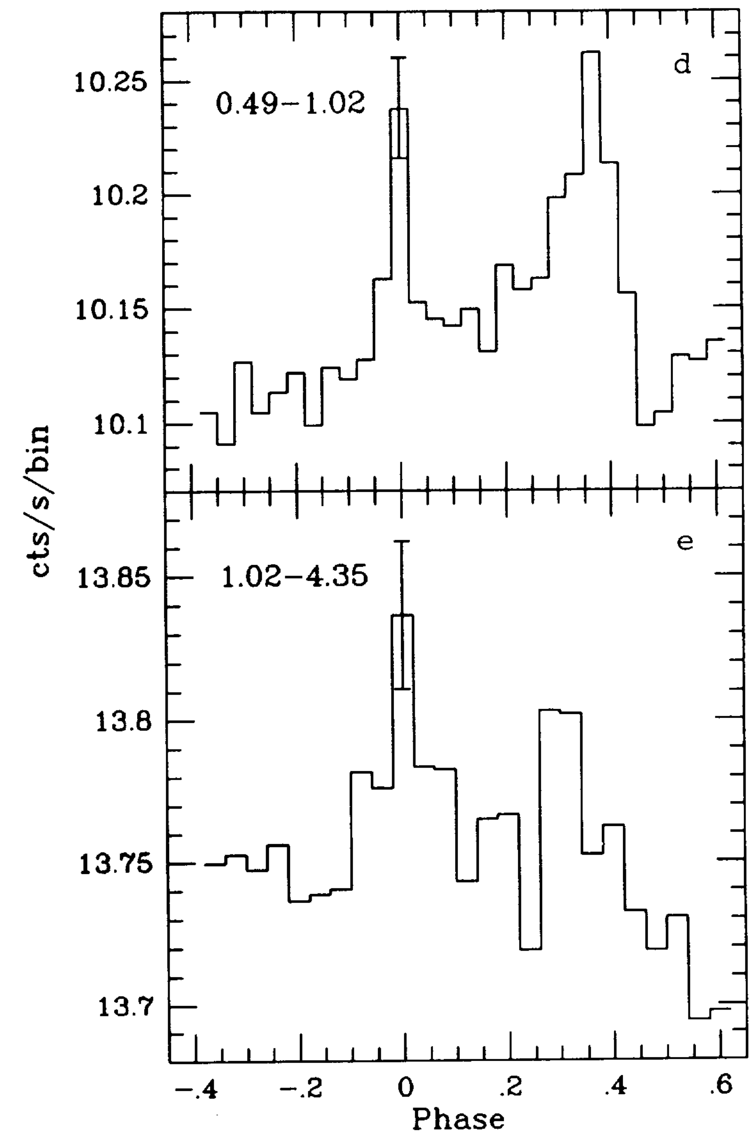

Fig. 1d,e - Phase histograms of PSR 0531+21 in different energy bands.

2. Data analysis and results

We computed the pulsed light curve of PSR 0531+21 by folding the arrival time (converted to the solar system barycenter by means of the JPL Ephemeris DE200) of each accepted event with the instantaneous radio period. The pulsar parameters at the reference epoch 2448081.5 JD were derived from the Jodrell Bank Crab Pulsar Monthly Ephemeris (Lyne and Pritchard, private communication): the adopted values of the frequency and frequency derivative were $\nu = 29.95871763685136$ Hz and $\nu' = -3.779343\ 10^{-10}\ s^{-2}$, respectively. The Crab was in the field of view of FIGARO II from 7:06 until 14:30 UT;

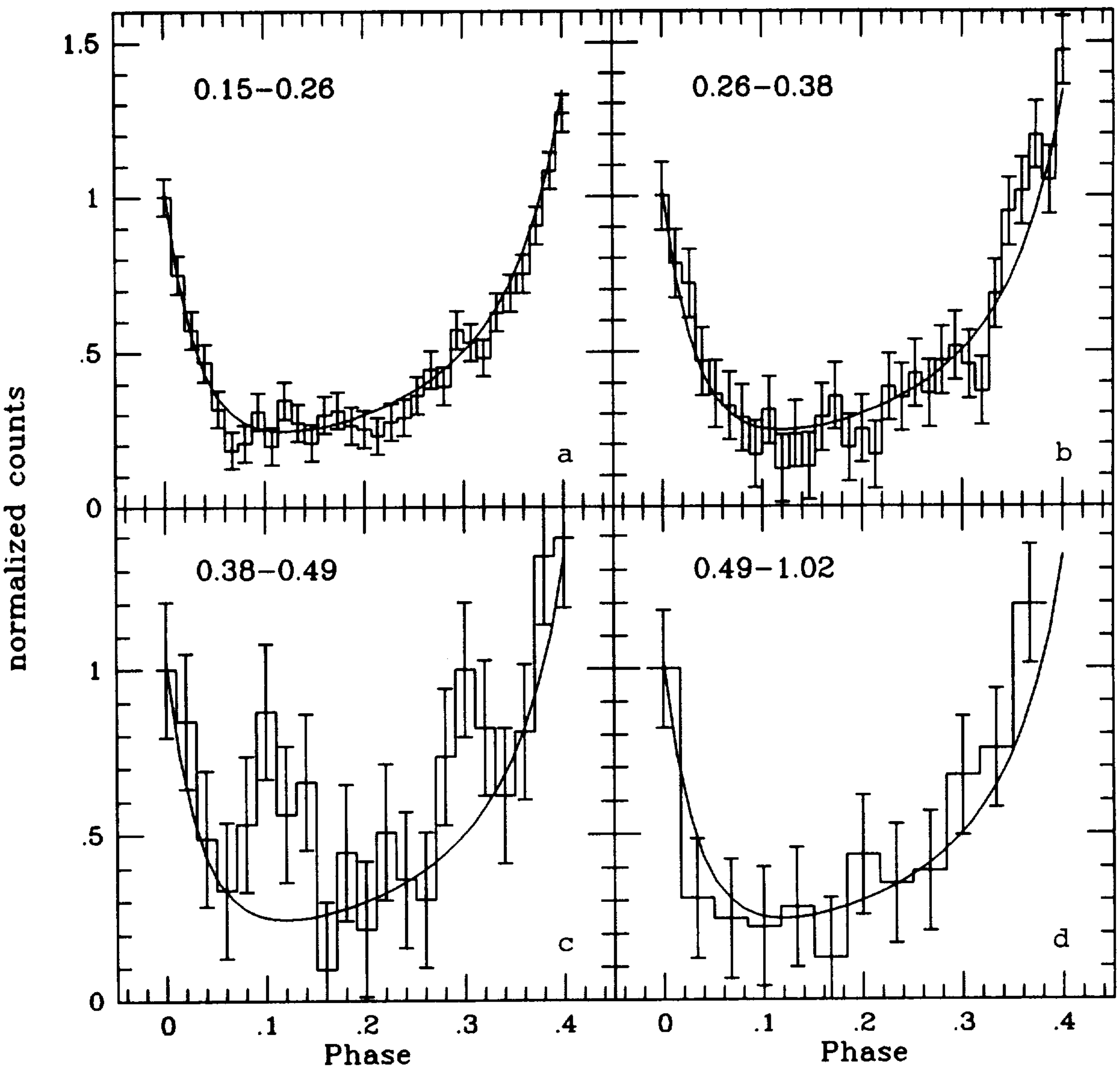

Fig. 2a,d - The Ip region in four energy bands: the nominal ranges (in MeV) are reported in each panel. The solid line represents the model template given in the text. The excesses corresponding to S1 and S2 are clearly evident in panel c.

the present analysis refers to the data acquired when the experiment parameters were nominal, for a total duration of 20,940 seconds. Following Agrinier et al.(1990), we take the zero phase at the position of the main radio peak.

In Fig. 1a-e the phase histograms for five photon energy ranges are plotted, corresponding to the nominal values (0.15-0.26), (0.26-0.38), (0.38-0.49), (0.49-1.02), and (1.02-4.35) MeV, after correction for the instrumental dead time in each individual bin. The double peaked profile is very evident throughout the experiment spectral range: P2 dominates over P1 in Figs. 1a to 1d, but above $\sim$ 1 MeV (Fig. 1e) the reverse is true, in accordance with the pattern already observed at hard γ-ray energies.

A new and unexpected result is shown in Fig. 1c, where in addition to the main peaks two extra structures are evident at phases close to 0.1 and 0.3 (S1 and S2). Note that the new features appear only in this energy interval and are not visible in the adjacent intervals. To be more confident on the reality of the extra features we analyzed anew the data of 1986, and found additional evidence of their existence. The energy binning of the two observations was different, so it is very unlikely that the new components are due to an instrumental effect.

3. The interpeak region

The pulse profile of the Crab pulsar is poorly known above ~ 0.3 MeV, and no acceptable template for the interpeak region is available. In order to build up our own template, we took the phase interval (0.0-0.4), i.e., from the maximum of P1 to that of P2. The phase histograms were then normalized by subtracting the average value of the off-pulse segment and by dividing the content of each bin by the maximum of P1. We found that the Ip region is very well described in all the three bands (0.15-0.26 MeV), (0.26-0.38 MeV) and (0.49-1.02 MeV) by the same formula

$$\frac{1}{|\phi + \phi_1|^m} + \frac{A}{|\phi - \phi_2|^n}$$

with $\phi_1 = 1.0044$, $\phi_2 = 0.47872$, $m = 31.002$, $n = 1.1964$ and $A = 0.06420$, respectively (Fig. 2a,d). The only exception to this model is the interval (0.38-0.49 MeV), where the excesses S1 and S2 with respect to the template profile are now clearly evident. A rough estimate of their statistical significance would be of about 3.9 and 2.8 standard deviations, respectively.

In the same energy interval, but at phases covering only S2 and P2 (0.27-0.47), Massaro *et al.* (1991) discovered a feature which was tentatively identified with a redshifted positron annihilation line. Fig. 3 shows the spectrum which is obtained by including also S1: the signal to noise ratio increases and the shape of the feature is better defined.

4. Conclusions

The presence of these additional structures could be relevant to the geometry of the emission pattern and to the physics of the inner magnetosphere. The Ip region, in fact, seems to exhibit an interesting activity not only in the Crab pulsar but also in Vela. We recall that above 50 MeV these two objects have quite similar pulse shapes (Kanbach et al. 1980), but in the optical Vela is characterized by two peaks at phases intermediate between the two γ-ray peaks (Manchester et al. 1980), rather close to the positions of S1 and S2 in Crab. Recent observations of the Vela pulsar above 100 MeV (Akimov et al. 1991) have shown that the interpeak region is variable in time and that structures can occasionally be detectable. Finally, we stress that the most recent observations of the Crab pulsar by GRO/OSSE (Ulmer et al. this workshop) indicate a variability of the Ip on a time scale of a few hours between 60 and 246 keV, and the largest changes are at the phases of S1 and S2. The Crab and Vela pulsars could be much more similar from a geometrical point of view than one would argue from their widely different energy spectra.

The present results show also that the occurrence of minor structures can be an energy dependent effect and therefore they can be related to spectral features. In conclusion we stress that wide-band high sensitivity observations of relatively short duration (typically a few hours) are the only way to obtain a picture of the complex phenomenology of the Ip region in the soft γ ray range.

Acknowledgements. This research was financially supported by CNES and ASI. We are grateful to many persons from CESR, CNES, CEN, CNR and ASI who contributed to the payload and to the flight campaigns and particularly to A. Soubrier, to E. Myles-Standish Jr. for providing DE200 Ephemeris, and to A.G. Lyne for the Crab pulsar Ephemeris.

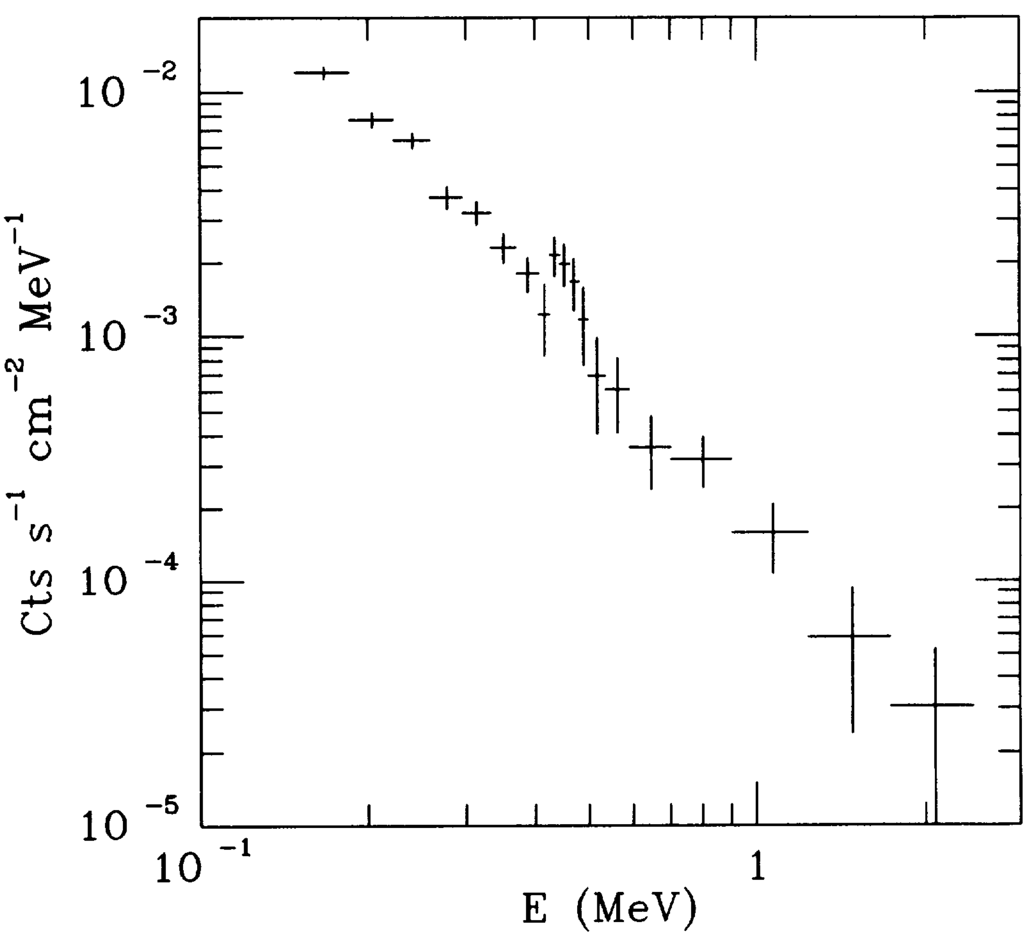

Fig. 3 - The spectrum of the phase regions S1+S2+P2. Note the four-channel excess at 0.44 MeV.

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