NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

ELSEVIER

Nuclear Physics B (Proc. Suppl.) 69/1-3 (1998) 269-272

A two component model of the Crab pulsar emission based on the BeppoSAX pulse profiles.

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We propose a two component model for the emission of PSR B0531+21 (Crab pulsar) to describe the energy dependence of the pulse profile and, in particular, of the relative peak (and interpeak) intensities. We show that the energy change of the X-ray pulse profile can be well reproduced by adding to the optical profile a unique broad pulse component whose intensity scales with the energy.

1. INTRODUCTION

The energy dependence of the pulse profile of the Crab Pulsar (PSR B0531+21) is known since early observations: in particular, the relative intensity of the two main peaks (the P2/P1 ratio) increases from the soft X-ray band and reaches the maximum value at about 1 MeV (see the Database of Massaro, Feroci and Matt [1]). BeppoSAX observed the Crab Pulsar during the Science Verification Phase (1996 August 31-September 7) and provided a series of excellent pulse profiles over the wide energy range 0.5 - 300 keV [2], particularly useful to study the behaviours of the P2/P1 and Ip/P1 (Interpeak region intensity to P1) ratios .

Observations at energies greater than 30 MeV [3] show that P2 has about the same intensity like in the optical [4]. A comparison between an optical and a γ-ray pulse profiles is shown in Figure 1. Notice the very similar heights of the peaks even if some differences in the shape of the P2 leading side are present.

In this contribution we try to explain the changes of the pulse shape by means of a two component model. We assume that the X-ray emission of the Crab Pulsar is produced by the sum of a signal with the pulse profile observed at optical frequencies, and of another one, particularly strong in the X and low energy γ rays, whose phase distribution of the intensity is determined from the comparison with the data. We show that it is possible to reproduce the Crab pulse profiles over a quite large energy interval by scaling with energy the total intensity of the second component with only very small changes of the shape.

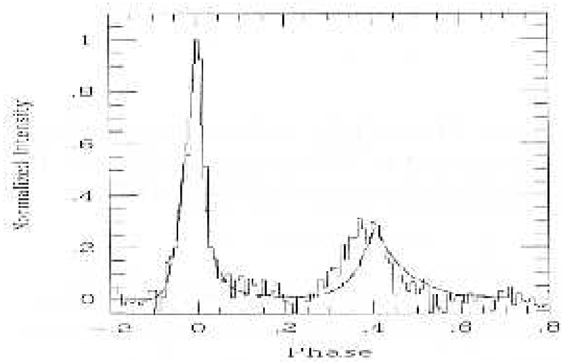

Figure 1. Optical and γ-ray (30 MeV) pulse profiles of the Crab.

2. THE MODEL

The two components considered in our model are the optical profile, which we derived from the Smith's observations [5] (the same shown in Figure 1), and another one whose intensity is increasing through the interpeak and reaches a maximum at the phase 0.4. We describe the phase distribution of the latter component (hereafter

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PII S0920-5632(98)00224-2

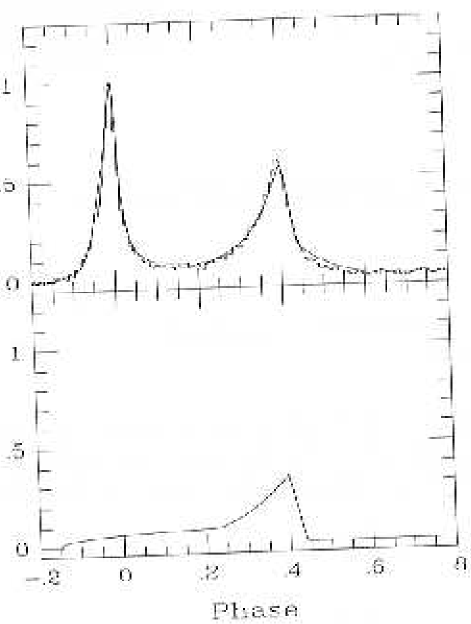

Figure 2. The modeled and the observed Crab pulse profiles (3.44 keV) (upper panel). The IP component is shown in the lower panel.

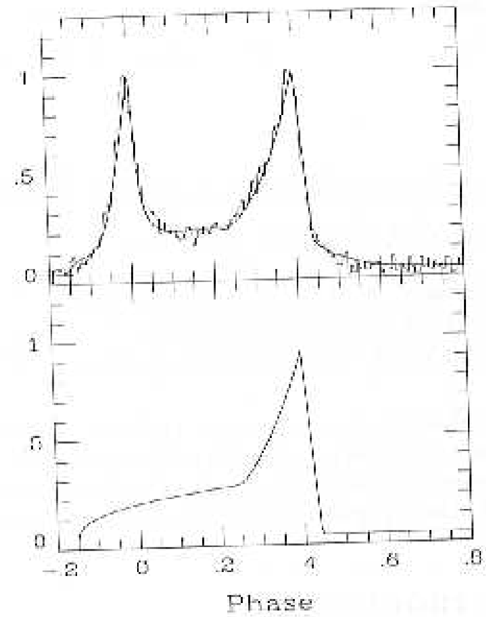

Figure 3. The same as Figure 2 but for the average photon energy of 72.5 keV.

IPC) by means of some simple mathematical expressions employing a combination of two power laws:

$$y(f) = Y_m \left(\frac{f_0 - f_a}{f_b - f_a}\right)^{\alpha 2} \left(\frac{f - f_a}{f_0 - f_a}\right)^{\alpha 1} \quad (1)$$

for $f_a < f \leq f_0$, and

$$y(f) = Y_m \left(\frac{f - f_a}{f_b - f_a}\right)^{\alpha 2} \quad (2)$$

for $f_0 \leq f \leq f_b$.

The IPC intensity is zero outside the interval (f_a, f_b), while f_0 is the phase at which the two expression have the same value. The maximum value Y_m, corresponding to $f = f_b$, is used a general scaling parameter for the entire component and, therefore, its dependence on energy is representative of the spectral distribution. A further linear descending branch is also included to connect f_b to the zero level of the off-pulse at the phase 0.43. The following parameters' values f_a = -0.15, f_b = 0.40, f_0 = 0.22, α_1 = 0.4, α_2 = 4.0 were found to give profiles in a satisfactory agreement with the data and were kept fixed; we left free only Y_m to adapt the combined signals to the observed pulse profiles.

We used also a different mathematical model with an exponential function:

$$y(f) = Y_m \exp\{\beta(f_0 - f_b)\} \left(\frac{f - f_a}{f_0 - f_a}\right)^{\alpha 1}$$

for $f_a \leq f \leq f_0$, and

$$y(f) = Y_m \exp\{\beta(f - f_b)\} \quad (3)$$

for $f_0 \leq f \leq f_b$, with the above values for f_a, f_b, f_0, and α_1.

3. RESULTS

Two examples of the pulse profiles computed using the model given by Eqs. (1) and (2) are shown in Figures 2 and 3: the former corresponding to the mean photon energy of 3.44 (MECS data) and the latter to 72.5 keV (PDS data). The upper panel of each figure shows the normalised profile computed with the two component model superposed to the observed data while the lower one shows the IP signal only.

The agreement with the data is satisfactory for all the wide energy interval covered by BeppoSAX observations. Of course, the chosen model is very simple and one cannot reasonably expect a perfect agreement with the data. At energies greater than ~ 40 keV the measured counts in Ip region lie above the predicted curve. It is, however, sufficient to change the value of f_0 from 0.22 to 0.26 to obtain a much better agreement without a significant difference in the Y_m values.

The exponential model is able to reproduce the data with a similar agreement and gives practically the same values of Y_m. In this case, however, we found a more evident dependency of the IPC shape on energy: we need, in fact, to change the β values from 10, at the lowest energies, to 7.5 for the highest energy profile.

In Figure 4 we plotted Y_m *vs* the photon energy: a single power law gives a good representation of the trend: the resulting exponent is 0.32, coincident with that found by Mineo et al. 1997 [2] for the Ip/P1 ratio.

On the basis of these results we can also guess some general indications about the spectral distribution of the IPC component. From the spectral fits of the BeppoSAX observations (Cusumano et al., these proceedings), which give a value of -1.8 for spectral index of P1 in the MECS band, we estimate that the IPC spectrum should follow a power law with a photon spectral index quite close to -1.5. The spectrum remains harder than that of P1 up to about 1 MeV, as indicated by the high values of the P2/P1 ratio measured in the low energy γ rays by FIGARO [6] and COMPTEL [7] and must have a quite abrupt cutoff because the IPC does not appear in the γ(> 30 MeV) bands.

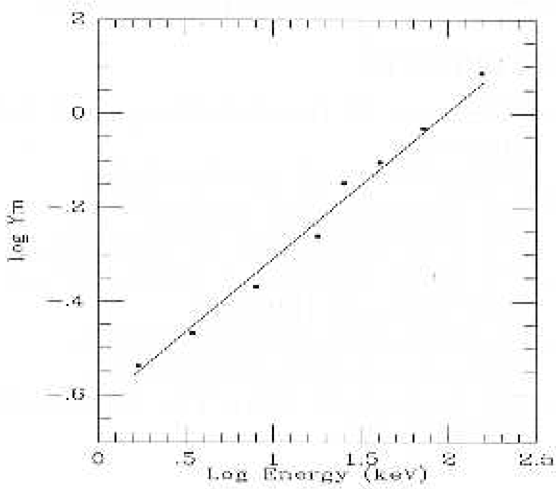

Figure 4. Double logarithmic plot of Y_m vs energy; the best fit line is also shown.

4. DISCUSSION

We have shown that the pulse shape change of Crab Pulsar in the X and low-energy γ rays can be explained by means of a two component model. These two components must have substantially different energy spectra and phase distributions. This suggests that the emission regions, in which these components are originated, could have different locations in the neutron star magnetosphere.

Several theoretical models to explain the spectrum and the shape of the Crab Pulsar emission have been proposed, but none of them has reached a full success. For example, one the most recent papers on this subject (Eastlund, Miller and Michel 1997 [8]), in which the emitting particles are assumed to be trapped in the closed magnetosphere, is successful in producing a double peak pulse shape, with the right phase separation, but fails just in explaining the increase of P2 and Ip in the X-ray band. We remark, however, that this model predicts a stable pulse shape from the optical to high energy γ rays, in agreement with one of our basic assumption.

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