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PROCEEDINGS
SUPPLEMENTS

# *Beppo*SAX observations of isolated pulsars

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Two isolated pulsars, the Crab and PSR B0540−69, were observed during the Science Verification Phase with the NFIs on board *Beppo*SAX. Here we present results from these two observations. In particular, we determine the spectral variations of the phase component P2, P1 and Ip of the Crab light curve using the P1/P2 and Ip/P2 ratio. We also give a brief summary of the spectral and temporal analysis. Moreover, we present the light curve of PSR B0540−69 in different energy bands and, using the best period derived from the *Beppo*SAX observation together with the previous ones, determine the rotational parameters of the pulsar and the relative breaking index.

## 1. INTRODUCTION

*Beppo*SAX [1] has observed only two isolated pulsars so far, both during the Science Verification Phase: PSR B0531+21 (Crab pulsar) and PSR B0540−69. The former source was detected with a high statistical significance by all the NFIs on board the satellite, allowing a detailed study of the pulsed signal over the entire energy range (0.3 – 300 keV). PSR B0540−69, detected by the LECS, MECS and PDS, shows its characteristic pulse structure with only one broad peak.

In this contribution we present a brief summary of the data on the Crab Pulsar. Pulse shape analysis has been described in [2] and the spectral results, very important for the NFI calibration, are presented in [3].

PSR B0540−69 was discovered in the X rays by Einstein [4] in the Large Magellanic Cloud. Pulsation at optical frequencies was soon discovered [5] while in the radio band, due to its low radio flux, it was was detected for the first time only in 1989–90 [6]. This pulsar is characterized by high spin rate ($4.79\ 10^{-13}$ s/s), a value similar to that of the Crab pulsar, and by a quite low braking index $n = 2.28 \pm 0.02$, according to the most recent evaluation [8]. In this contribution we present some results of the *Beppo*SAX observation and give an update estimate of $n$.

## 2. OBSERVATIONS AND DATA ANALYSIS

The Crab pulsar was observed from 1996 August 31 to September 1 and from 1996 September 6 to 7. Events were acquired in the direct telemetry mode, necessary to obtain the finest time resolution (15 $\mu$s). The total exposure times were ~7000 s for the LECS, ~33,000 s for the MECS and ~21,000 s for both HPGSPC and PDS. Pulse profiles were obtained with the usual folding technique (after corrections to the Solar System Barycentre) based on the Jodrell Bank radio ephemeris [7].

PSR B0540−69 was observed on 1996 October 25–26; the total exposure times were ~20,000 s for the LECS, ~47,000 s for the MECS and ~23,000 s for the PDS. Again the pulsed signal was obtained by folding the arrival times of recorded events in the Solar System Barycentric Frame. Since recent ephemeris were not available, the period was optimized by a $\chi^2$ maximization starting from the most recent estimate of the period derivative [8].


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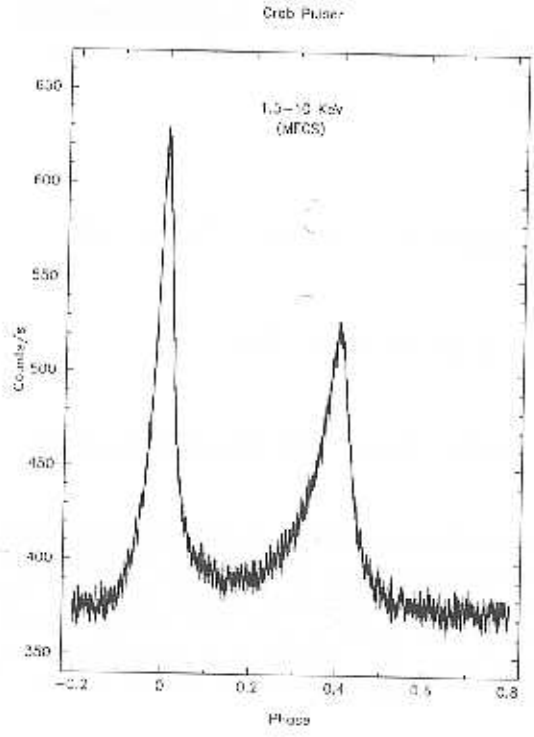


Figure 1. Crab pulse profile in the whole MECS energy range (1.5 – 10 keV)

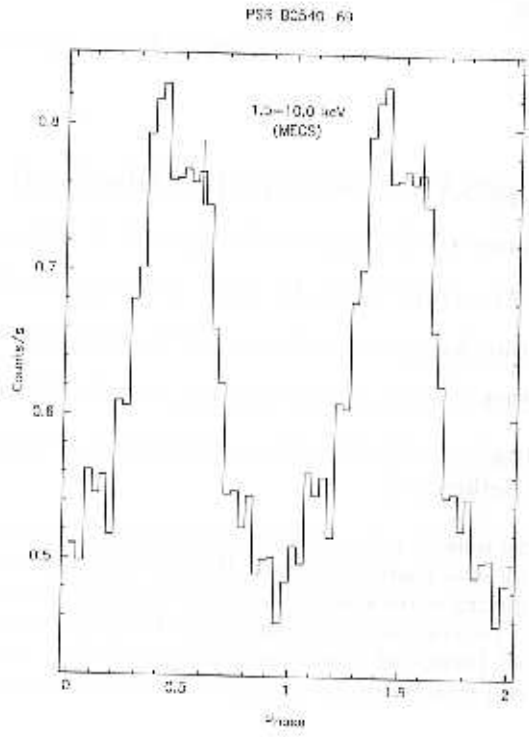


Figure 2. PSR B0540−69 pulse profile in the whole MECS energy range.

## 3. RESULTS

### 3.1. Crab Pulsar

Phase histograms in the energy bands 1.5 – 10 keV with a very high statistical significance and with the very fine resolution of 0.05 ms (600 bins) derived from MECS data is shown in Fig. 1.

It is well known that the intensity of the second peak (P2) and of the interpeak region (Ip) with respect to that of the first peak (P1) increases with energy in *Beppo*SAX band. We computed the intensity ratios P2/P1 and Ip/P1, after subtraction of a constant off-pulse level, considering the following phase intervals: (−0.05,+0.05) for P1, (+0.27,+0.47) for P2, (+0.05,+0.27) for Ip and (+0.47,+0.77) for the off-pulse. The obtained values were then fitted by a single power law and the resulting indices were $0.145 \pm 0.032$ (for P2/P1) and 0.315 (for Ip/P1), (see [2] for details). A possible interpretation of these energy trends, based on a two component model, is presented in [9].

### 3.2. PSR B0540−69

The pulse profile of this source in the whole MECS energy range is shown in Fig. 2: it has the usual nearly sinusoidal shape. However, we do not find evidence for the two slight bifurcation at the top of the peak described by [4]. Likely, if a minor structure could be detected, it is a peak just on the left side of the peak top. Fig. 3 shows the pulse profile in two energy ranges: 1.5 – 4 keV and 4 – 10 keV. The main structure is well evident in both data sets, but the small peak is significant

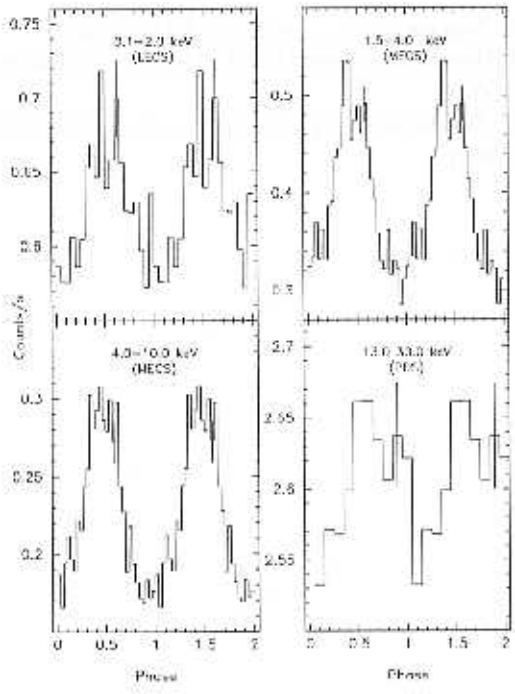

Figure 3. PSR B0540−69 phase histograms observed with the *Beppo*SAX NFIs in four energy bands.

only in the lower energy phase histogram.

In Fig. 3 the pulse profile derived by LECS (0.1 – 2 keV) by PDS (13 – 30 keV) are also shown. The statistics are poorer than in the MECS data, but signals with a similar shape and phase are detectable. Notice that this represents the first detection at energies greater than 10 keV.

We used these data for a timing analysis. All the measurements, including optical and radio data, of the pulsar frequency have been fitted by a parabolic law. The result is very satisfactory and the residuals, shown in Fig. 4, are compatible with zero. In Table 1 we report the values of the frequency and its first and second derivatives at the epoch of our observation, together with the resulting braking index $n$. This estimate is

Table 1
PSR B0540−69 rotation parameters.

| Parameter | Value[a] |
|---|---|
| Epoch (MJD) | 50381 |
| $f$ (Hz) | 19.8156940(8) |
| $\dot{f}$ (Hz/s) | $-1.88066(4)\times10^{-10}$ |
| $\ddot{f}$ (Hz/s$^2$) | $3.77(1)\times10^{-21}$ |
| $n$ | 2.11(1) |

[a]Values in parentheses are the uncertainties (at 68% confidence level) in the last quoted digits.

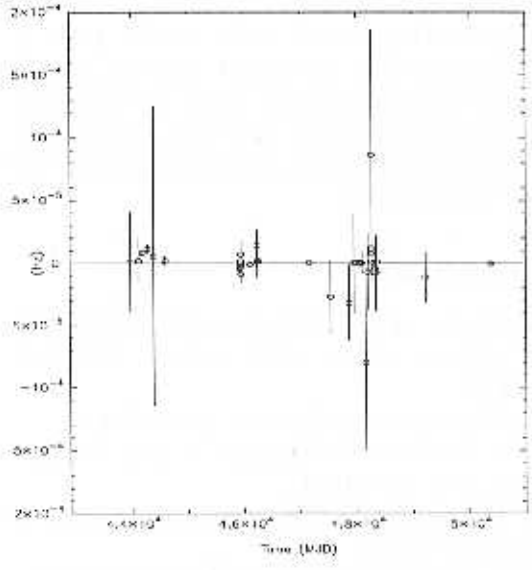

Figure 4. Residuals of the fit with a parabolic law of the measured period of the PSR B0540−69. The last point is the *Beppo*SAX measurement.

Table 2
Measured Braking Index

| Time (MJD) | Braking Index | Reference |
|---|---|---|
| 45149 | 3.6±0.8 | a |
| 46085 | 2.74±0.1 | b |
| 47000 | 2.01±0.02 | c |
| 47200 | 2.02±0.01 | d |
| 46917 | 2.080±0.003 | e |
| 47950 | 2.04±0.02 | f |
| 47950 | 2.5±0.65 | g |
| 50381 | 2.11±0.01 | tw |

a) Middleditch et al. 1987; b) Ogelman & Hasinger 1990; c) Manchester & Peterson 1989; d) Nagase et al. 1990; e) Deeter, Nagase & Boynton 1997; f) Gouiffes, Finley & Ogelman 1992; g) Eikenberry, et al. 1997; tw) this work.

compared with previous values in the Table 2. We confirm a value of $n$ quite close to 2, even if the agreement with other recent accurate estimates (in particular that of Deeter, Nagase and Boynton 1997 [14]) is only marginally within the quoted uncertainties.

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