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## COMPTEL observations of the Crab and Vela pulsars

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**Abstract.** — The COMPTEL gamma-ray telescope, sensitive in the range 0.7–30 MeV, has viewed the Crab and Vela Pulsars. The light curves observed from both objects have been derived in several energy bands. Features of these light curves and some spectral details are discussed.

**Key words:** gamma rays — pulsars: Crab, Vela.

### 1. Introduction.

The imaging Compton telescope COMPTEL is one of the four instruments on-board the Compton Gamma Ray Observatory satellite launched on 1991 April 5 into a 450 km, 28.5° orbit. COMPTEL (described by Schönfelder *et al.* 1992) operates in the 0.7–30 MeV energy range with a field of view of 1 steradian, an angular resolution of  $\sim 1^\circ$  and an energy resolution of  $\leq 10\%$  FWHM. COMPTEL measures the time of arrival of gamma-rays with a relative accuracy of 1/8 ms with respect to the GRO UTC clock. An absolute error of  $\sim 2.041$  s which was found in the GRO clock and actually corrected in June 1992 does not affect these findings.

### 2. Observations.

The observatory “Validation Period” (observation 0) incorporated several viewings of the Crab Nebula at different aspect (both zenith and azimuth) angles in the instrument field of view. The first standard GRO observation was a dedicated viewing of the Crab for a 14 day interval. A revisit occurred one week later when a Target of Opportunity was declared and GRO was slewed to the sun which was  $11^\circ$  from the Crab at that time. Combining the 3 validation periods for the Crab into a single effective

observation, the relative efficiency-exposure factors for the separate observations are 0.78/1.0/0.54.

The Vela pulsar was also a validation target being both a known high-energy gamma-ray source but, unlike the Crab, it is located well above the GRO orbital plane. The Vela grasp during the validation interval was about 40% that in observation 8.

The observation details are summarised in Table 1.

TABLE 1. *Crab and Vela Pulsar Observation Summary.*

Obs. #	$T_{\text{START}}$ ddmmyy	$T_{\text{END}}$ ddmmyy	Pointing $l$ $b$		View Angle	Pulsar
0.2	28/04/91	01/05/91	193.4	-4.3	$9.0^\circ$	Crab
0.3	01/05/91	04/05/91	193.4	-4.3	$9.0^\circ$ *	”
0.4	04/05/91	07/05/91	184.5	-5.9	$0.0^\circ$	”
1.0	16/05/91	30/05/91	190.9	-4.7	$6.4^\circ$	”
2.1	08/06/91	13/06/91	194.9	-7.3	$10.4^\circ$	”
0.6	10/05/91	16/05/91	266.7	-4.7	$4.7^\circ$	Vela
8.0	22/08/91	05/09/91	262.9	-5.7	$3.0^\circ$	”

\* $90^\circ$  rotated.

### 3. Analysis.

As contemporary radio observations of these two pulsars were being made, the radio ephemerides of Crab and Vela are accurately known for these observations and may be adequately described by a second order polynomial on period. The parameters may be found in a publicly accessible data-base provided by the Princeton group (Taylor 1989).

As described in Busetta *et al.* (1991), period folding of the event arrival times transformed to the solar system barycentre is performed on events selected on energy and scatter angle. It is a property of the Compton Telescope that the arrival directions of the incoming gamma rays are only known to be somewhere on an “event circle” (Schönfelder *et al.* 1992). For the analysis events are selected which pass within a few degrees ( $3^\circ - 4^\circ$ ) of the pulsar. There are many non-source events whose event circles pass near the position of the pulsar under study which, in addition to the unpulsed component of the source emission provide a background within the light curve. The phase distribution of such background events is flat for fast pulsars, as verified by phase folding events selected from a symmetric “mirror” position on the opposite side of the detector field of view.

The significance of the pulsation has been evaluated by applying the  $Z_n^2$  statistic (Buccheri and Sacco 1985) in an unbiased way to the un-binned event phases looking for an  $n$ -harmonic signal. Three harmonics have been chosen for Crab and five for Vela following a harmonic component analysis of the observed signal.

#### 3.1. THE CRAB PULSAR.

As may be seen in Strong *et al.* (1992) the total emission from the Crab shines brightly in the 1–30 MeV map of the Galactic anticentre. The light curve resulting from combining the three observations is shown for the energy range 1–10 MeV in Figure 1. The background level shown is the mean of the counts in phases 0.8 to 1.2. This represents approximately  $\sim 5 \times 10^3$  pulsed counts for a data-selection appropriate for pulsar studies and which is slightly different from that used by Strong *et al.*

The pulsation is present with statistical significance (from the  $Z_n^2$ ) of  $\sim 40\sigma$ . Comparing the shape with that at higher energies measured by COS-B (Clear *et al.* 1987) and EGRET (Fichtel *et al.* 1992) it is evident that the interpulse (i.e. between the peaks) emission is proportionally more intense in the COMPTEL energy range. The light curve resembles much more that seen at hard X-ray energies by e.g. Mahoney *et al.* (1984) and Agrinier *et al.* (1990) up to a few MeV. The evolution of the light-curve within the energy range of COMPTEL may be seen in the plot of four energy intervals in Figure 2. It is a consequence of the Crab spectrum combined with the

COMPTEL sensitivity that the bulk of the signal is seen in the 1–3 MeV energy band. However, pulsed excesses are clearly seen in all energy bands, as is the interpulse emission. The spectrum and pulsed fraction are presented by Strong *et al.* (1992).

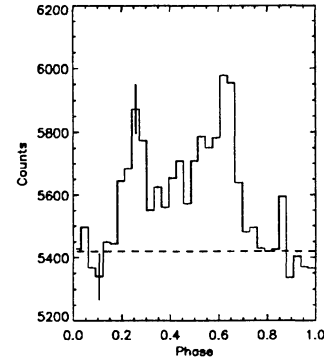


FIGURE 1. 1–10 MeV light curve of the Crab Pulsar for three combined observations.

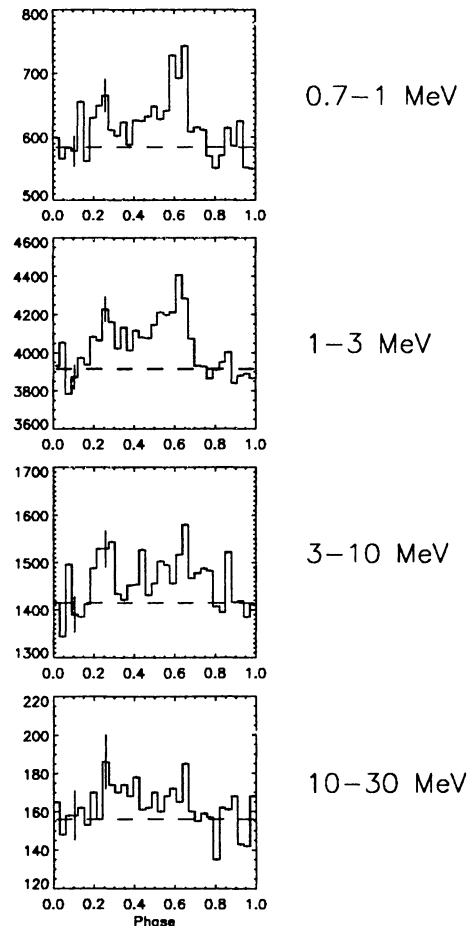


FIGURE 2. Light curves of the Crab Pulsar for three combined observations in the four energy bands indicated.

The complicated pulse structure: two barely resolved peaks, with the first being sharp and the second being a continuation of the interpulse, differs with earlier measurements in the same energy range by the U.C.R. (White *et al.* 1985) and MPE (Graser and Schönfelder 1982) groups. Their results show two sharp isolated peaks (although these balloon flight measurements have poorer statistics than COMPTEL). This difference has been evaluated by Agrinier *et al.* (1990) by comparing the relative first-, second- and inter- pulse strengths in data spanning from 1 keV to 10 GeV. From their Figure 7 it appears that there is something unique about the behaviour of the spectrum around 1 MeV. In Table 2 the equivalent ratios for the COMPTEL data are presented for the energy interval 1–10 MeV. These compare favourably with those of Agrinier *et al.* thus supporting their claim that the ratio of the pulsed components is energy dependent.

TABLE 2. *Ratio of the Peaks and Interpulse for Crab.*

Energy (MeV)	$P2/P1$	$Int./P1$	$Int/P2$
1.0–10.0	$1.0 \pm 0.2$	$1.9 \pm 0.2$	$1.7 \pm 0.2$

These values are based upon the combination of 3 observations and therefore mask any observation-to-observation variation. It should be recalled that COS-B (Wills *et al.* 1982) observed secular variation in the pulsed ratio. This result is *prima facie* supported by the EGRET findings (Kniffen *et al.* 1991). Therefore, some variation in the light curve obtained at different epochs may always be expected. The three individual light curves combined to produce Figure 1 do show differences in shape but, given the background of COMPTEL and the uncertain phase alignment, quantification of these effects is statistically problematic and remains the subject of on-going analysis.

### 3.2. THE VELA PULSAR.

The light curve from observation 8 is shown for the energy range 10–30 MeV in Figure 3. The optimum energy range for Vela is higher than for the Crab because of its harder spectrum: the  $Z_n^2$ - significance of this signal is  $6.6 \sigma$ . It should be recalled that Vela has only been seen once at energies below 30 MeV (Tümer *et al.* 1984) while it shines brightly at 100 MeV as seen by SAS 2 (Thompson *et al.* 1975) and COS-B (Bennett *et al.* 1977). The Validation period observation should be added to this in order to maximize the sensitivity; however this is presently excluded until the absolute phases are assigned. This is especially important in view of the period glitch which occurred prior to observation 8.

The COMPTEL light curve is markedly different from that obtained during a 1981 balloon flight by Tümer *et al.* (1984) in a comparable energy range. FIGARO did

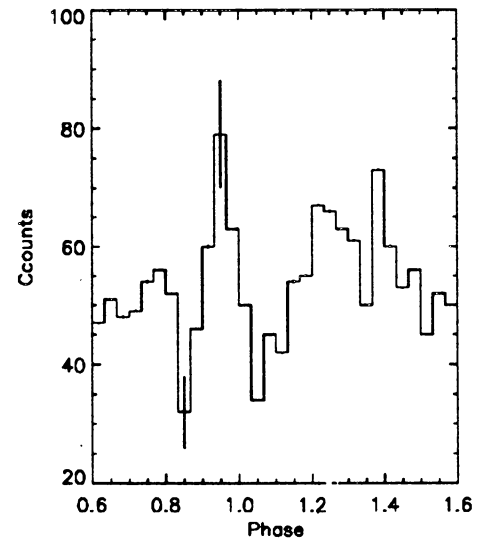


FIGURE 3. 10–30 MeV light curve of the Vela Pulsar for GRO observation 8.

not detect Vela in the energy range 0.2 – 6 MeV during their 1988 balloon flight, their upper limit being below the U.C.R. flux, suggesting time variability. The hard spectrum of Vela is obvious when comparing the energy selected light curves for Vela in Figures 3 and 4 with those of the Crab in Figure 2. It is possible to recognise the Vela pulse profile in each energy interval down to below 1 MeV. Although the apparent signal to noise in the 10–30 MeV energy range is better than in the 1–10 MeV range for the Crab, the limited statistics so far prevent a reliable background estimation which stalls the derivation of the flux. However, by selecting events from the peaks i.e. on the phase intervals around the peaks with width as seen by COS-B, Busetta *et al.* (1992) have obtained the first image of the Vela pulsar in the 10–30 MeV energy range.

Grenier *et al.* (1988) have performed a detailed spectral analysis of several phase intervals (Peak-1, Interpulse-1, Interpulse-2, Peak-2 and Trailer) using COS-B data accumulated over a six year time span. There is evidence for phase resolved spectral variations throughout these observations. Furthermore the flickering is most noticeable at the lowest COS-B energies ( $\approx 50$  MeV), just above the COMPTEL energy range.

Akimov *et al.* (1991) used the Soviet-French Gamma 1 satellite to monitor the Vela light curve for long periods (of the order of months) during 1990 and 1991. They confirm spectral variability at most phases. For COMPTEL the most prominent feature in the observation 8 light curve is Peak-1 while for the Validation period, just 16 weeks earlier, Peak-2 dominates. This is in qualitative agreement with the variation in spectral slope for Peak-2 as reported by EGRET at higher energies. Note that the glitch in the

pulsar prior to observation 8 could have some relevance to this effect.

The COS-B Interpulse-1 (confirmed by EGRET and Gamma 1) is a region of intense emission just following Peak-1, however this is a region of low emission in the COMPTEL light curve. Thus, there is a need for a spectral break in Interpulse-1 as was detected by Grenier *et al.* (1988) in the COS-B data at different epochs. On the other hand the Interpulse-2 is bright in the COMPTEL phasogram: consistent with the very soft spectral index (the softest feature of all) in the COS-B data.

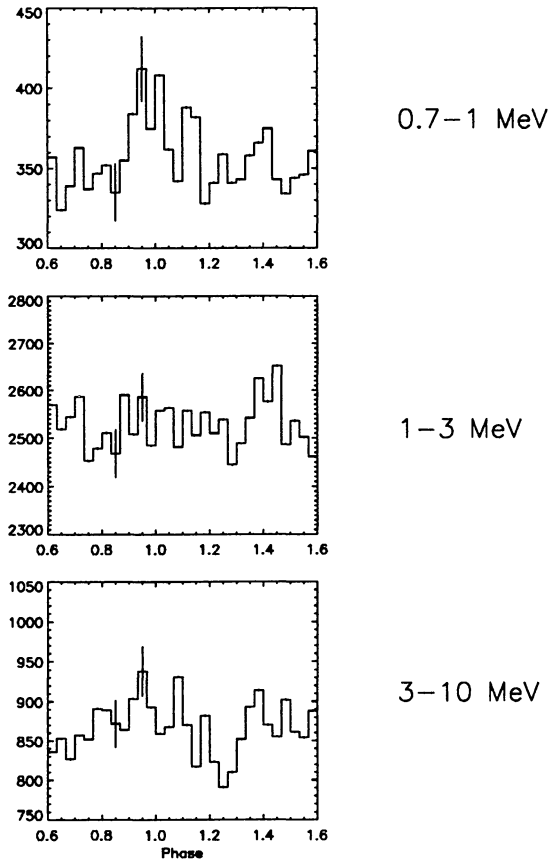


FIGURE 4. Light curves of the Vela Pulsar for observation 8 in the three energy bands indicated.

#### 4. Discussion.

Rather than Crab and Vela pulsars being standard gamma-ray candles, evidence is mounting from that they may be flickering sources whose instability appears most

conspicuously in the 1–50 MeV energy range. The collective data of GRO will permit to disentangle the spectral and time variability throughout the 6 decades of energy from 10's of keV to 10's of GeV.

Models to explain the emission of the pulsars in the gamma-ray domain (e.g. the Polar-Cap and the Outer-Gap model) must consider the possibility for variability on the time scales of weeks to years as well as spectral differences throughout the pulse.

A revisit to these pulsars remains a prime goal of GRO following completion of the All Sky Survey phase.

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