OSSE OBSERVATIONS OF THE VELA PULSAR

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ABSTRACT

The OSSE detector on board the Compton Gamma Ray Observatory observed the Vela Pulsar (PSR 0833-45) during August-September 1991 and April-May 1992. Pulsed emission was detected at the 4-5σ level in the 0.06-0.57 MeV band in the sum of the two observing periods, as well as in each individual observation at lower significance. There is no significant variability observed. Light curves have a peak structure similar to that observed at higher energies. The spectrum is hard at lower energies and appears to require a break in the 0.5-2 MeV region.

OBSERVATIONS

The OSSE detectors on board the Compton Gamma Ray Observatory (CGRO) were used to observe the Vela Pulsar (PSR 0833-45) on three occasions during phase one of CGRO operations. The first observation, referred to as viewing period 8 (vp8), occurred during the interval 22 August – 5 September 1991. The second and third observations, which were analyzed together and are referred to as viewing period 26/28 (vp26/28), occurred during the intervals 23 April – 28 April 1992 and 7 May – 14 May 1992.

The vp8 observation consisted of three OSSE detectors staring in the direction of the pulsar. No background chopping was performed with these detectors. The total live time was $\sim 1 \times 10^6$ detector-seconds. The instrument was in a mode that supplied rates every 4 msec in four energy bands, all three detectors being summed together into the bands. The vp26/28 observations were similar to vp8 except that only two detectors stared at the pulsar and the live time was $\sim 5 \times 10^5$ detector-seconds. The energies associated with the four bands into which data were summed, averaged over detectors and observations, were 0.07 – 0.18 MeV, 0.21 – 0.57 MeV, 0.71 – 1.88 MeV, and 1.88 – 9.04 MeV.

ANALYSIS

The analysis procedure consisted of epoch-folding rate data to produce light curves for each viewing period and energy band. Arrival times at the solar system barycenter were computed for each 4 msec rate bin and the phase of that bin determined using a radio ephemeris supplied by Princeton University[1] as part of

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the CGRO pulsar monitoring program. The ephemeris used is constructed so as to be valid for both the vp8 and vp26/28 observations. Corrections were applied to account for a 2.042 second clock offset in the times supplied by the CGRO spacecraft. Given these corrections, the radio ephemeris adequately predicted both period and radio peak absolute phase.

We epoch-folded all data into 22 phase bins, yielding approximately one time resolution unit per phase bin. The bin phases were not varied in any way to optimize the observed signal, nor were multiple periods attempted, hence the number of trial light curves was kept to a minimum, preventing degradation of the significance of the result due to a large number of trials. The quality of the radio ephemeris was judged to be such that multiple trials were not necessary in any event.

The epoch-folding routine produced light curves such that phase 0.0 was the center of the radio peak for each viewing period. We then summed the resulting light curves assuming that the phase relation between radio and gamma-ray peaks did not vary over time. Light curves from the lowest two energy bands were summed to generate an optimum signal-to-noise light curve for determination of detection significance. For each light curve, the mean and χ^2 vs. the mean were generated. We then fit each light curve with a model consisting of two peaks and a constant unpulsed flux. Use of this model allowed the entire light curve to be fit simultaneously without having to make arbitrary decisions concerning the extent of "off-pulse" regions of the light curve.

We modeled the peaks as circular normal functions[2] given by :

$$Flux = \frac{A}{I_0\,(K)} \times e^{K\cos(2\pi(\phi-\phi_{center}))} \qquad (1)$$

where I_0 is a modified Bessel function of the first kind, order zero, which normalizes the function such that amplitude (A) is the integral of the peak. "Compactness" (K) is a peak width parameter that decreases with increasing peak width. This function has the property that it is periodic and is approximately gaussian in shape. The separation of the two peaks in the model was constrained to be 0.44 in phase, in agreement with results at higher energies[3].

To generate spectra, we divided the best fit peak amplitudes and uncertainties by the product of the exposure factor and the photopeak efficiency integrated over each energy band. Uncertainties in each spectral point were determined by χ^2-mapping of the amplitude parameters. The significance of each peak was determined from the value of the F statistic resulting from the addition of that peak to the best fit model without the peak (see RESULTS).

RESULTS

We detected the pulsar during both the vp8 and vp26/28 observations. We observed no evidence of significant variability between the two observations, so we report the sum of both viewing periods. For a light curve summed over the lowest two energy bands (figure 1), adding both peaks to no-peak model improves the fit at the $\sim 4.4\sigma$ level, as determined by the F-test. Note that χ^2/dof for the no-peak model is 1.56 for 21 degrees of freedom, allowing the rejection of that model at only the 2σ level. None of the peaks in the individual energy bands exceeds the 3.5σ level of significance and we detect no significant flux in the 0.71-1.88 MeV band.

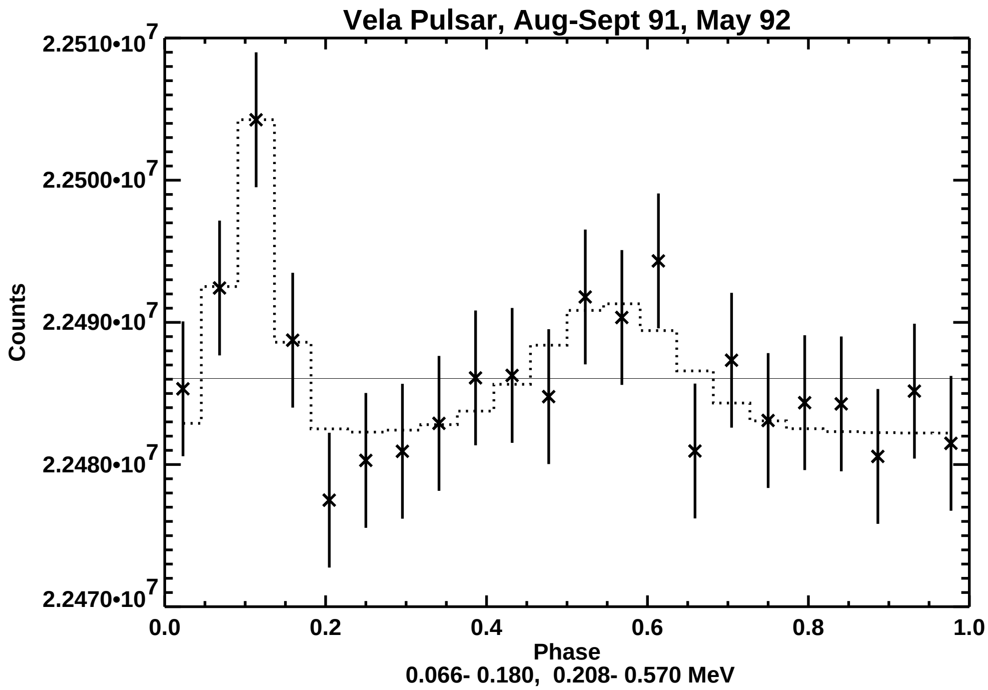

Figure 1: Vela Pulsar light curve, sum of viewing periods 8 and 26/28. The dotted line is the best fit model; the solid line is the mean.

The light curve looks qualitatively like the light curves measured at higher energies[3,4,5], in that it has two peaks at the similar absolute phase (first peak phase 0.11 after radio peak) and separation ($\sim$0.44 phase). The first peak is sharp but the second peak, which is detected at only the $\sim 3.5\sigma$ level as determined from the F-test, appears rather broad. We see no evidence for an interpulse between the peaks or peak leaders or trailers, unless the breadth of the second peak is interpreted as a narrow peak with a leader and trailer. The statistics available in the second peak do not allow us to make this distinction.

The spectrum of the first and second peaks together (figure 2), averaged over the entire light curve, indicates our detection of the pulsar in the two lower energy bands and a marginal detection in the highest energy band. The spectrum is very hard below 0.57 MeV, a power law drawn between the two points yielding an index $\sim -0.3 \pm 0.5$. The high energy[5] data shown in figure 1 is the total pulsed flux from COS-B averaged over all their observations of the pulsar. The dashed line is the extrapolation of their best fit power law below 300 MeV for the data shown. The dotted lines indicate the best fit power law spectra below 300 MeV for each individual observation. These extrapolated spectra are consistent with the OSSE data, at least within their range of variation. Our data, by themselves or taken together with the high energy data, require a break in the spectrum in the 0.5-2 MeV region.

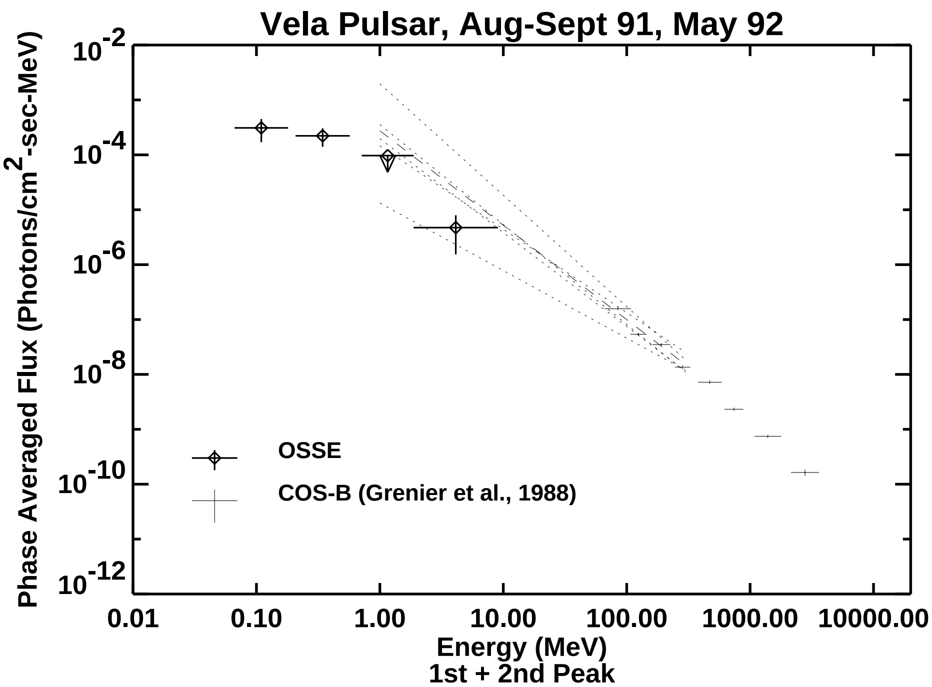

Figure 2: Vela Pulsar spectrum, sum of viewing periods 8 and 26/28. Flux is the sum of both peaks, averaged over the entire light curve. The high energy data and model spectra are taken from Grenier et al., 1988.

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