PULSAR STUDIES WITH COMPTEL

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ABSTRACT

The Compton Gamma-Ray Observatory (C-GRO) has completed a full-sky survey during which the number of known γ-ray pulsars has more than doubled. COMPTEL has observed the classical pulsars Crab and Vela on several occasions and has derived detailed pulse patterns and spectral parameters in the 0.7–30 MeV energy interval. The new C-GRO γ-ray pulsars have different properties in terms of energy spectra and light-curve shapes, and, in fact, only the Crab is seen by all four C-GRO instruments. This raises intriguing questions about the particle acceleration processes and beaming taking place in the neutron magnetosphere. We have examined the COMPTEL data to add information on these objects in the 0.7–30 MeV energy interval and present evidence for the detection of one of them, PSR B1509–58. We have also undertaken a search for candidate radio pulsars whose ephemerides are well defined. The results of these analyses are presented.

Subject headings: gamma rays: observations — pulsars: general

1. INTRODUCTION

Since the discovery of the γ-ray pulsars, Crab (PSR B0531+21) and Vela (PSR B0833–45), there have been great strides made in understanding the pulsed γ-ray production mechanisms. Be they based on a Polar-Cap (Daugherty & Harding 1982) or an Outer-Gap model (Cheng, Ho, & Ruderman 1986a, 1986b), it has been possible to test theories of the particle acceleration processes and beaming taking place in the neutron magnetosphere. We have examined the COMPTEL data to add information on these objects in the 0.7–30 MeV energy interval and present evidence for the detection of one of them, PSR B1509–58. We have also undertaken a search for candidate radio pulsars whose ephemerides are well defined. The results of these analyses are presented.

The pulsed signal-to-noise in COMPTEL is, as a result of the double-Compton detection technique, never better than 4%, and period-to-period variations in the pulsed shape reflect statistical variation in the signal plus backgrounds as demonstrated by Carramiñana et al. (1993). Nevertheless a glance at Figures 1 and 2 reveals several interesting features. For the Crab the total intrapulse emission is about equal to that of either peak. In no other energy range is this the case. The spectrum of the Vela pulsar is much harder than that of the Crab. This is reflected by the distinct light curve in the 10–30 MeV range, where, even for the combined data of six observations, there is no clear pulsed emission for the Crab. That the Crab is indeed pulsed in this interval is demonstrated by the presence of a point source in the sky-map in the phase intervals around the peaks.

An important parameter in the light curve of the “classical pulsars” is the pulse width. It is well established that the pulses are broader for the Crab than for Vela. In Figures 1 and 2 we make a simple illustration of this in the COMPTEL energy regime by showing the same light curve with double binning. The timing resolution of C-GRO is better than one-eighth ms, so the bin-to-bin variation is subject to counting statistics only. The surprising observation for Vela is that not only is the first peak merely 3.3% wide (compared with the Crab’s ≈10%), but the second peak appears even sharper at 1% (Crab ≈ 6%). This narrow pulse is the sharpest that we have observed in all γ-ray light curves.

As shown by Ulmer (1994), the pulsed Crab spectrum is...
well behaved over seven decades of γ-ray energy covered by C-GRO. On the other hand the Vela spectrum breaks sharply around 70 MeV as seen in the combined data of OSSE, COMPTEL, and COS B shown in Figure 3.

The formerly perceived γ-ray similarity between Crab and Vela is already seen to be naive. Add to this the observed temporal variation of the pulses of Crab reported by COS B (Wills et al. 1982) and confirmed by EGRET (Nolan et al. 1993) together with the variation of the Vela pulses discovered by COS B (Grenier, Hermsen, & Clear 1988) and confirmed by EGRET (Kniffen et al. 1993) and the picture is starting to look very complicated. Spectral differences between peaks 1 and 2 and the intrapulse component means that the traditional presentation of the total pulsed spectrum of Crab and Vela is masking the details of the emission processes which should be unveiled as a result of the statistical precision offered by the combined Compton database.

While Crab and Vela are the foundation stones of pulsar astronomy, perhaps other pulsars are the Rosetta stones to the production mechanisms and COMPTEL data has been exploited to try to unearth more spectral detail on the new pulsars and on other likely pulsar candidates.

3. THE NEW C-GRO PULSARS

3.1. PSR B1509–58

The plerion PSR B1509–58 was detected by BATSE (Wilson et al. 1991; Wilson et al. 1992), having been examined because of its high $E/d^2$. This was observed earlier by Ginga in hard X-rays (Kawai et al. 1991). The light curve is broad with about a 50% duty cycle, and the spectrum is reported to be harder than the Crab, crossing over at about 10 MeV according to Figure 6 of Wilson et al. (1992). Combined with an early claim that PSR B1509–58 was observed in the BATSE integral energy channel > 1.8 MeV, this gave hope that this pulsar be observable by COMPTEL. Unfortunately, observations by C-GRO have not been optimal during phase 1 and none are
planned in phase 2. The object was viewed at a large inclination angle of 25° in observation 12, at an optimum angle of 4°5 in observation 23 and at 12°5 in observation 27 which was a short observation. On the face of it, observation 23 was the most promising, but problems with data transmission seriously compromised the sensitivity. Nevertheless during that observation a light curve was obtained in the range 0.7-1 MeV (Fig. 4) which shows a 3σ deviation from a flat distribution, with a peak at the expected maximum determined by OSSE. It has the broad shape reported by BATSE. Furthermore, in the same energy range the image of data selected in a phase interval around the peak shows evidence (3.9σ) for localized emission at the position of the pulsar (see Fig. 5).

Supporting evidence from the other observations, for which the sensitivity was poorer, is somewhat confusing. Given the potential for secular variability, as seen in the classical pulsars, this may be understandable. Detailed analysis of all the observations continues.

3.2. Geminga

Although C-GRO phase 1 offered a large grasp on the Crab, Geminga, which is only ~15° from Crab, was relatively poorly covered in phase 1. Nevertheless we have folded the COMPTEL data to search for pulsation at the EGRET phases. No emission is so far detected at those phases. Preliminary upper limits (2σ) were given by Strong et al. (1993) based on the total DC emission and these have been recalculated following analysis of the sky map derived from photons in the EGRET-defined phase interval to be:

\[\begin{align*}
3-10 \text{ MeV} &< 2.10^{-6} \text{ cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1} \\
10-30 \text{ MeV} &< 3.10^{-7} \text{ cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1}.
\end{align*}\]

In these proceedings Grenier et al. (1994) present evidence for variability at several phases in the COS B light curve of Geminga, so given that the X-ray light curve also differs from the high-energy γ-ray one, the COMPTEL investigation might benefit from allowing the phase of the pulse to be a free parameter within the COMPTEL energy range. Results of this investigation are to be presented by Hermsen et al. (1993).

3.3. PSR B1706-44

This hard COS B source 2CG 342–02 (Swanenburg et al. 1981) is now seen by EGRET to be a pulsar with a particularly hard pulsed energy spectrum (Thompson et al. 1992). It is therefore not surprising, in view of the Vela light curves obtained, that COMPTEL does not see this source either in the pulsar timing or the sky maps. We have not yet ascertained an accurate upper limit, but COMPTEL’s detection of Vela gives a rough estimate (2σ) of ~30% of Vela in the 10–30 MeV interval.

4. SEARCH FOR NEW PULSARS

We have sorted the 550 or so pulsars presented in the Princeton Public Data-Base (Johnston et al. 1992a) plus the Australian Catalogue (Manchester 1992) in terms of \(E/d^2\) as a measure of detectability. Under the assumption of that \(I = 0.57 \times 10^{45} \text{ g cm}^2\) for all pulsars and assuming 100% energy conversion we can order the pulsars in terms of the observed “flux” \((F)\) of energy at Earth. From Table 1 which lists the 15 potentially most luminous objects we can see that the top of the list is populated by already detected γ-ray pulsars. Many others in the list have been seen by ROSAT at X-ray energies (Ogelman 1992). We are, therefore, confident that there is a good potential for detection within the top ranks of this list.

We are proceeding to work systematically through this list. The method we employ is to fold the Solar System Barycentre arrival times for events appearing to come from the source. We use the \(Z_2^*\) (Buccheri & Sacco 1985) statistic as a measure of presence of peaks in the light curve. If we take as a threshold \(Z_2^* > 3 \sigma\), we have thus far positive indications for only two objects: PSR B1951+32 and PSR B0740–28. We continue to refine these measurements by adding more data and image
phase-selected events. In the case of PSR B1259–63, being an unusual and exotic binary system (Johnston et al. 1992b), the ephemeris is as yet too uncertain to make a 14 day coherent observation. This is the minimum interval required for COMPTEL to observe a pulsar of about the strength of Vela. In addition, the parameters for PSR B1821–24 are not contemporary, having been taken from the Australian Catalogue, which still leaves the possibility for detection open if another ephemeris should become available.

5. SUMMARY

Detailed energy-dependent light curves for Crab and Vela are emerging from the COMPTEL experiment. These represent a unique data set in the 0.7–30 MeV energy interval. New spectral timing features are being revealed. Given that determination of the γ-ray emission processes in pulsars demands knowledge of the light curve and energy spectrum over the entire C-GRO energy band, it is incumbent upon COMPTEL to search for pulsations from all possible candidates. This work has made a promising start: there is a positive detection of PSR B1509–58, and the first traces of emission have been detected for two other objects. These will be followed up by deep observations in later phases of the C-GRO mission.

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REFERENCES

Buchner, R., & Sacco, B. 1985, Data Analysis in Astronomy II (New York: Plenum Press)
Johnston, S., et al. 1992a, C-GRO/radio timing data base, Princeton University
Manchester, R. 1992, private communication
Ögelman, H. 1992, private communication
Wilson, R., et al. 1991, BAAS, 23 (4), 1440

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