The Search for MeV Gamma-Ray Pulsars with COMPTEL

K.Bennett[4], R. Buccheri[5], M. Busetta[4], A.Carramiñana[6], A. Connors[3], R. Diehl[1], W. Hermsen[2], L. Kuiper[2], G.G. Lichti[1], R. Much[4], K. O'Flaherty[4], J. Ryan[3], V. Schönfelder[1], A. Strong[1]

[1] *Max Planck Institut für extraterrestrische Physik, P.O. Box 1603, D-85740 Garching, Germany*

[2] *SRON-Utrecht, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands*

[3] *Univ. of New Hampshire, Institute for the Study of Earth, Oceans and Space, Durham NH 03824, USA*

[4] *Astrophysics Division, ESTEC, NL-2200 AG Noordwijk, The Netherlands*

[5] *IFCAI/CNR, Piazza G. Verdi 6, 90139 Palermo, Italy*

[6] *I.N.A.O.E, Apartado Postal 51, Puebla 72000, Mexico*

ABSTRACT

The Compton Gamma Ray Observatory (CGRO) completed a full sky survey in November 1993 during which the number of known γ-ray pulsars more than doubled. During this survey COMPTEL observed the classical isolated pulsars Crab and Vela and detected PSR 1509-58. Attempts to detect the newly discovered pulsars, Geminga, PSR 1706-44 and PSR 1055-52, in the COMPTEL energy range provide only upper limits. The results of these analyses are presented together with the outcome of a search for further candidate radio pulsars whose ephemerides are given in the Princeton Pulsar Catalogue.

INTRODUCTION

Prior to the launch of CGRO it was established that several radio pulsars were prime candidates for detection at γ-ray energies. Following models based upon the properties of PSR 0833 (Vela) and PSR 0532 (Crab), Thompson *et al.* /1/ adopted both the outer-gap model and polar-cap models to predict the most likely 100 MeV pulsars. Buccheri & Schönfelder /2/ (BS) developed a shortlist of pulsars predicted to be seen at MeV's by COMPTEL, under the assumption of a polar cap model, in which the γ-ray production efficiency η scales as $P \cdot \tau^{0.5}$. Buccheri & Carollo /3/ elaborated this work following the outer-gap model of Cheng, Ho & Ruderman (CHR) /4/, in which the efficiency η scales as $P^3 \cdot \tau$, to predict the most likely γ-ray pulsars. There is significant overlap between the lists and they agree in making limited predictions of γ-ray visibility. Bennett *et al.* /5/ followed a different approach by simply assuming that the reservoir of energy available for producing γ-rays is the spin down energy of the pulsar, all known pulsars were ordered in luminosity (binary systems are not considered in this work), using the best estimate for distance in each case. This is shown together with the BS and CHR list in Table 1. The third column is complete down a to luminosity of about Crab/100. One errant absentee from this table is Geminga: this was not known at the time of the predictions and, although it is not a radio pulsar, it is shown in the third column for reference. The $\dot{E}/d^2$ scheme was successful in predicting the detection of PSR 1706-44 and PSR 1509-58. However, the fact that PSR 1706-44 is only seen at high energies by EGRET while PSR 1509-58 is only seen at low energies /5,6,7/ emphasizes the naivety of the $\dot{E}/d^2$ approach. A significant omission from this short-list is PSR 1055-52 which is ordered around 25th in the $\dot{E}/d^2$ list (being Crab/1000 in spin-down energy) but can be detected by EGRET because of an unusually high conversion efficiency into high energy γ-rays (ca. 30%) /8/.

BS calculation			CHR Scheme			$\dot{E}/d^2$ ordering		
0531+21	*33.34*	*(1.2)*	**0531+21**	*33.34*	*(1.2)*	**0531+21**	*33.34*	*(1.2)*
0833-45	*89.28*	*(11.3)*	**0833-45**	*89.28*	*(11.3)*	**0833-45**	*89.28*	*(11.3)*
0950+08	*253.06*	*(17300)*	**1509-58**	*150.652*	*(1.5)*	**Geminga**	*237.09*	*(329.5)*
0959-54	*1440*	*(441.5)*	**1800-21**	*13.58*	*(15.7)*	**1706-44**	*102.44*	*(17.4)*
1929+10	*226.51*	*(3100)*	**1823-13**	*101.44*	*(21.3)*	**1509-58**	*150.652*	*(1.5)*
0656+14	*384.87*	*(110.8)*	**1929+10**	*226.51*	*(3100)*	**1929+10**	*226.51*	*(3100)*
			1951+32	*39.53*	*(107.0)*	**1951+32**	*39.53*	*(107.0)*

Table 1: COMPTEL shortlist of pulsars: period(ms) and 'age' (10^3y) in brackets

OBSERVATIONS AND ANALYSIS

The Phase-1 observations of COMPTEL complete, when all the data are combined, an all-sky survey of roughly uniform sensitivity. We select for analysis the candidate pulsars which are within 20° /9/ of the pointing direction and for which we have contemporary radio ephemerides. Figure 1 shows the necessity of having contemporary radio ephemerides. It is seen that for PSR 1951+32, one of the candidate pulsars in our search list the lack of ephemeris between TJD 8678 and 9087 hampers our ability to fold the data. In this case phase uncertainties of a fraction of a phase within a fortnight's observation are introduced and interpolation of the ephemerides to cover gaps is unjustified. The COMPTEL signal-to-noise is low (at best a few % for the Crab pulsar) so that $P, \dot{P}$ searching is infeasible. The all-sky data-set is unfortunately drastically reduced (to 40%) when selection is made on the basis of:

(priority candidate).**and**.($\leq$ 20° off axis).**and**. (contemporary ephemeris available)

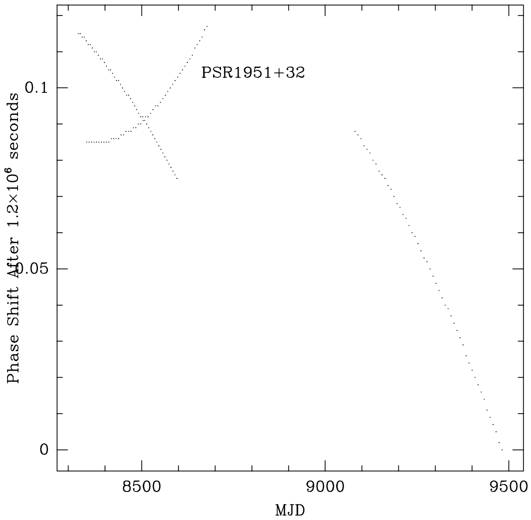

Fig. 1: Ephemeris history of PSR 1951+32 available for COMPTEL analysis

The method employed for pulsar analysis is to transform the events' spacecraft arrival time to the Solar System Barycentre and select those events which appear to come from the source of interest (see /10/ for experimental details). The arrival times are folded using the contemporary ephemeris found in the Princeton pulsar catalogue /11/. We use the ${Z_n}^2$ statistic /12/ as a measure of the presence of peaks in the light-curve. The resulting sample light-curves for the Crab and Vela pulsars may be seen in /13/ and /14/. The data for each candidate was subjected to selections, determined from Crab and Vela data, in order to optimizing the signal-to-noise.

RESULTS

Only in the case of PSR 1509-58 do we measure a significant signal. This plerion was detected by BATSE /6/, examined because of its high $\dot{E}/d^2$ and having been observed earlier by Ginga in hard X-rays /15/. The light-curve is broad, with about 50% duty cycle, and the spectrum is harder than the Crab, crossing over at about 10 MeV according to Figure 6 of /5/. From 19 March to 2 April 1992 a light-curve was obtained in the range 0.7-1 MeV (Figure 2) which shows a 3.5σ 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 (3σ) for localized emission at the position of the pulsar (see Figure 2). However, no further useful observations ($< 20°$) were carried until Jan 1994 at which time it is perplexing to find no evidence for pulsed emission.

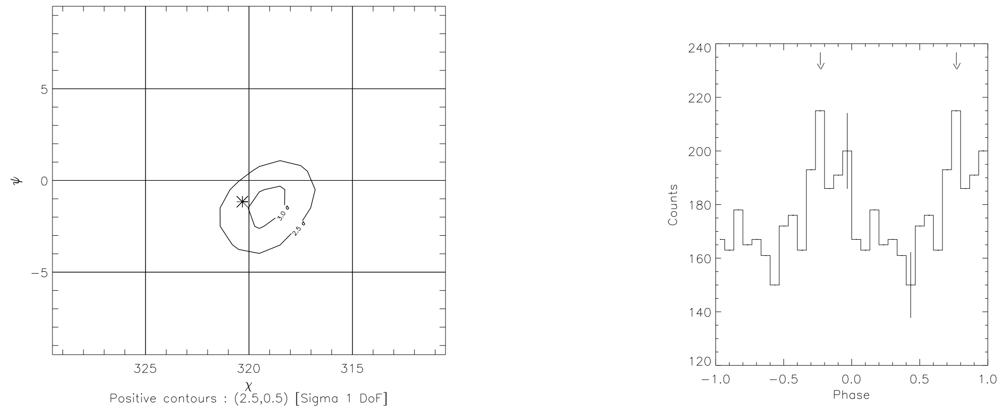

Fig. 2: PSR 1509-58 phase-selected image and light-curve seen by COMPTEL (0.75-1 MeV)

With the exception of PSR 1509, we have no convincing detections, bearing in mind the number of data cuts (trials) made on the data (*inter alia* energy, angle from source etc). If we take as a threshold ${Z_3}^2 > 3\sigma$, we have thus far indications for PSR B1951+32 and PSR B0740–28. Attempts to refine these hints have been frustrated by gaps on the ephemeris history. For both objects the hints are not supported by any excess in the spatial maps. The case of 1823-13 is intriguing: during the normal search program a 6σ effect was seen for this object for a particular energy range in one observation only. Two considerations make us consider this effect to be a statistical freak: firstly the evidence from imaging is ambiguous (from /13/ it can be seen that the Vela is easily imaged in the pulsed maps at a similar light-curve significance level) and secondly the implied efficiency ($> 100\%$) is not credible. This is a polite reminder that we are dealing with tricky statistics and that appropriate care needs to be taken. The present derivation of these upper limits is crude. For each pulsar the most favourable observation was used to derive the upper limit–this is not substantially inferior to adding all the available observations. If 'outriders' like the PSR 1823 effect are ignored a single value can be given for all pulsars in the list.

For Geminga, a specific detailed search for pulsation is underway. Preliminary results /13/ show no evidence for emission in the 0.75-30 MeV band. The upper limits (phase averaged) for Geminga are given separately in Table 2.

Upper limits derived from the spatial maps following the maximum-likelihood analysis /10/ are given in Table 2. These give upper limits to the time averaged spectrum which is independent of any assumptions of the shape of the pulsar light-curve. In all cases the upper limits constrain the efficiency only weakly to a range of few% to 100% which is of little help in model constraints.

For PSR 1509, which is around 3% efficient /16/, the measured intensity implies a break in the spectrum at around 1 MeV in order to fit the EGRET upper limits /8/. For Geminga the upper limits are not is strict conflict with the EGRET spectrum /17/, but demand a break in the 10's of MeV if compared with the COS-B spectrum /13/.

SUMMARY

'Pulsar'	0.75-1 MeV	1-3 MeV	3-10 MeV	10-30 MeV
typical	$3.2.10^{-4}$	$4.5.10^{-5}$	$1.1.10^{-6}$	$1.2.10^{-6}$
Geminga	$1.2.10^{-4}$	$2.0.10^{-5}$	$2.5.10^{-6}$	$3.7.10^{-7}$

Table 2: Typical, phase-averaged, upper limits (2σ) for pulsars unseen by COMPTEL (the values for Geminga are shown separately). units $ph/cm^2.s.MeV$

Except for Crab, Vela and PSR 1509, the search for pulsations in the 0.75-30 MeV range by COMPTEL has so far only lead to upper limits. The most likely radio pulsar candidates, according to several ways of prioritizing the data, have been examined. We have also searched for MeV pulsations from Geminga. Hints for pulsed emission have been observed but are not statistically significant. It is therefore unlikely that any more MeV pulsars will be discovered by COMPTEL from the radio-pulsar catalogue. Clues to the production mechanisms are unlikely to be provided by continuing this search. Rather, the follow up of the details of the detected γ-ray pulsars should be pursued. In particular analysis of the phase resolved spectra and time variability are more likely to bear fruit.

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