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AN OSSE SEARCH FOR THE BINARY RADIO PULSAR 1259-63

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ABSTRACT

We have searched data from the Oriented Scintillation Spectrometer Experiment (OSSE) on the *Compton Gamma Ray Observatory* (GRO) for evidence of low-energy γ-ray emission from the binary radio pulsar PSR 1259-63. This 47 ms pulsar is in a long-period, highly eccentric orbit around a Be stellar companion and was observed by OSSE approximately 400 days after periastron. The period derivative allowed by the published radio ephemeris (Johnston *et al.* 1992) suggests that the pulsar might be relatively young, and therefore a γ-ray source. However, the ephemeris is not sufficiently accurate to allow the traditional epoch-folding technique over the full OSSE observation. Instead, the OSSE data were analyzed using Fourier transform spectral techniques after applying trial accelerations to correct for a range of possible orbital accelerations. We searched 48 accelerations; each FFT was 2^{29} points sampled at 2 ms, spanning $\sim 10^6$ seconds of observation time. There was no evidence of pulsed emission in the 64–150 keV band, with a 99.9% confidence upper limit of 6×10^{-3} photons cm^{-2} s^{-1} MeV^{-1} or $\sim$40 mCrab pulsars, which suggests that the pulsar's intrinsic period derivative is small and its magnetic field weak. This work was performed on the Concurrent Supercomputing Consortium's Intel Touchstone Delta parallel supercomputer as part of a GRO Phase 1 Guest Investigation.

1. BACKGROUND ON PSR 1259-63

PSR 1259-63 is a recently discovered radio pulsar (Johnston *et al.* 1992) and is the only radio pulsar known to have a massive, non-degenerate companion. The stellar companion has been optically identified as the Be star SS 2883. The pulsar is in a highly eccentric orbit and has gone through only one periastron passage since its discovery. As a consequence, the published timing solution could not completely discriminate between orbital Doppler shift-induced period changes and the intrinsic period derivative ($\dot{P}_{int}$) of the pulsar. The best-fit solution gives $\dot{P}_{int} = 2 \times 10^{-14}$, but even $\dot{P}_{int} = 0$ cannot be excluded. An intrinsic $\dot{P}_{int} \sim 10^{-14}$ implies a young age for the pulsar. With pulse period and distance comparable to those of the Crab pulsar, such a large $\dot{P}_{int}$ would make it a likely candidate for pulsed γ-ray emission.

Table 1, reproduced from Johnston *et al.* (1992), lists the fitted pulsar and orbital parameters with two different assumed values for $\dot{P}_{int}$. The ambiguity in $\dot{P}_{int}$ will be removed by the time the pulsar reaches periastron again since the orbital period will be determined.

TABLE 1

Parameters of PSR 1259-63

Right acension (J2000)	$13^h02^m47^s.72 \pm 0^s.03$	
Declination (J2000)	$-63°50'08''.5 \pm 0''.2$	
Dispersion measure ($\mathrm{pc\,cm^{-3}}$)	146.7 ± 0.2	
Distance (kpc)	2.3	
Pulse period (ms)	47.76164	47.76219
Period derivative	0.0	2×10^{-14}
Orbital period (d)	1133 ± 24	2150 ± 100
Epoch of ascending node (MJD)	48043 ± 2	48027 ± 3
Epoch of periastron (MJD)	48120 ± 2	48117 ± 3
$a \sin i$ (ls)	3480 ± 1900	3450 ± 1000
Longitude of periastron (deg)	164 ± 9	158 ± 6
Eccentricity	0.976 ± 0.025	0.967 ± 0.017
Mass function ($M_\odot$)	35	10

(from Johnston *et al.* 1992)

2. DETAILS OF THE OBSERVATION

The characteristics and performance of the OSSE instrument have been described by Johnson *et al.* (1993). The instrument consists of four identical large-area NaI(Tl)–CsI(Na) phoswich detector systems, each with a $3.8° \times 11.4°$ (FWHM) field-of-view defined by a tungsten collimator.

The pulsar was observed serendipitously in OSSE's N Mus 91/Galactic plane pointing in September 1991, spanning MJD 48518–48532, about 400 days after periastron and immediately following the epoch studied by Johnston *et al.* (1992). The pulsar was about 8.2° off-axis, which reduced the detector response to $\sim 25\%$ of the on-axis value.

The OSSE observation strategy is implemented by alternately pointing each detector at source and background positions on a time scale (131 seconds) that is short with respect to typical Earth orbital background variations. The difference spectrum derived from these source and background pointings for the PSR 1259-63 field shows a significant soft-spectrum excess, presumably due to the sum of diffuse emission from the plane and several point sources. Temporal signatures can be used to resolve the ambiguity over the source of this excess.

In addition to the spectral data, time-tagged data (resolution = 0.125 ms) were collected in the 64–150 keV band, with a total livetime of $\sim 3.3 \times 10^5$ detector-seconds. These data are the subject of the search described here.

3. SEARCH ALGORITHM

In order to search for pulsed γ-ray emission from PSR 1259-63, we generated a binned time series from the OSSE data to which we applied our standard radio pulsar search algorithms (see Anderson *et al.* 1990). This was accomplished by first converting the spacecraft photon arrival times to Solar System barycentric arrival times using the known position of the pulsar. These arrival times were then used to generate a 2^{29} point time series consisting of 2 ms bins. This yields a Nyquist frequency of 250 Hz, so the power spectrum contains the first 11 harmonics of the 47 ms pulsar without aliasing.

This search utilized large 1-dimensional Fast Fourier Transforms (FFTs) to search for periodic signals in the data. Because the frequency bins in a 2^{29} point time series are very narrow, a signal must have a constant frequency to within a very narrow tolerance to keep from being smeared over multiple bins in the spectral domain with a concomitant loss in sensitivity. For a pulse period of $\sim$ 50 ms, the largest period derivative that can be searched over a 10^6 s interval is $\dot{P} \sim 10^{-16}$. We correct for an assumed $\dot{P}$ by applying a quadratic stretch to the time series. A quadratic stretch is an adequate model of either linear spin-down of the pulsar or Doppler shifts over a short portion of a binary orbit. Since the published ephemeris was not accurate enough for us to know exactly what trial "acceleration" to use, we estimated an envelope of possible total period derivatives (intrinsic and orbital) from the trend of P with time from Figure 2 of Johnston *et al.* (1992). We then selected 48 trial accelerations spanning the range $1.8 \times 10^{-14} < \dot{P} < 1.5 \times 10^{-13}$. The accelerations were spaced such that the difference in corrected arrival times was < 10 ms anywhere in the time series. Thus the maximum residual pulse smearing was $< 1/4$ period, and up to 4 harmonics could have been significant.

The complete search was performed in about 1.5 hours on 512 nodes of the Concurrent Supercomputing Consortium's (CSCC) Intel Touchstone Delta Supercomputer at Caltech. The unstretched, barycentered time series was loaded onto the Delta's 90 GB Concurrent File System packed at 1 byte per 2 ms bin, using 1/2 GB of storage. Since the Delta has more than 4 GB of usable memory available after the OS and programs have been loaded, we could store both the unstretched time series and one trial stretched time series. So, the time series need only be read off disk once at the beginning of the run. The analysis then proceeds by making a new stretched copy of the time series in memory, performing a parallel FFT in place, generating a power spectrum and searching for significant peaks in the region of the spectrum where the pulsar should appear. Harmonic folds of 2, 4, and 8 harmonics were also used to search for the pulsar signal. This process is repeated for each acceleration trial.

The 48 trials consisted of about 4×10^{12} floating point operations performed at an average rate of about 1 GFLOP/s by the Delta. This analysis would have been considerably more cumbersome and much slower on a machine that had less than 2 GB of usable main memory, since the running time would be dominated by the tremendous amount of disk access needed to do out-of-core FFTs.

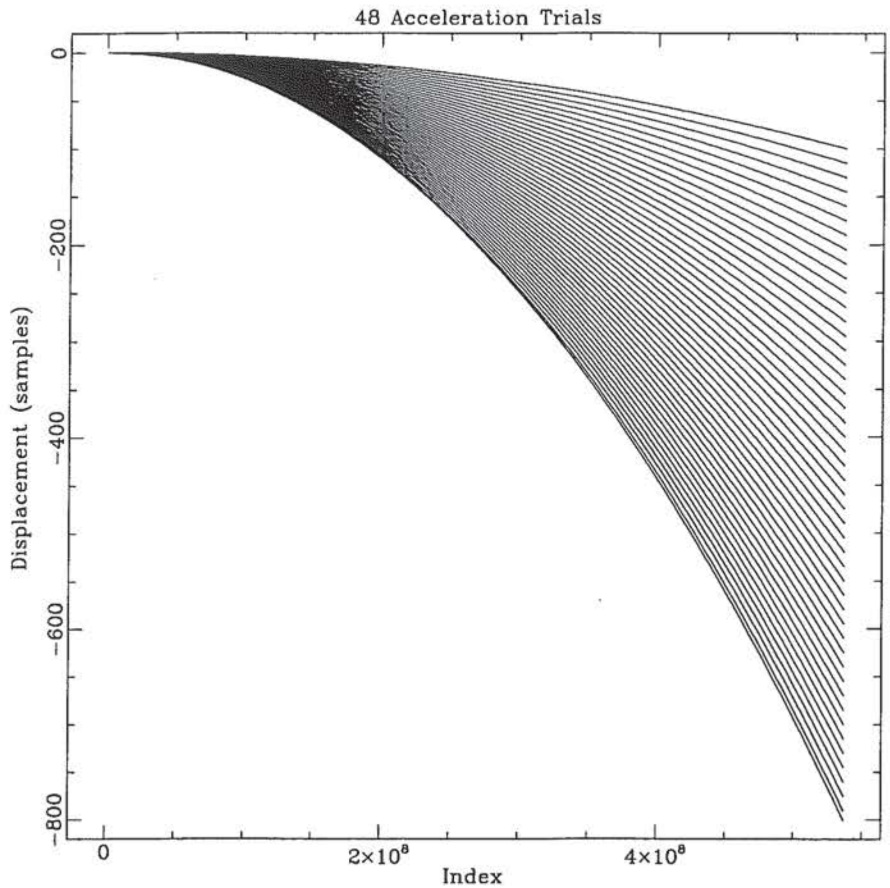

Figure 1: Plot of delay in samples vs. sample number for the 48 acceleration trials used in the search.

4. SENSITIVITY AND RESULT OF THE SEARCH

Sensitivity was assessed by Monte Carlo simulation. To the actual data stream, we added counts from a simulated pulsar with pulse period of 50 ms and pulse FWHM = 15% at various intensities. The pulsed flux corresponding to the 99.9% confidence upper limit was then simply interpolated from the observed powers.

No statistically significant powers were seen in any of the 48 acceleration trials. The resulting upper limit is $\sim$ 40 mCrab pulsar flux units (see Table 2). For comparison, the sensitivity of an epoch-folding search with known frequency and phase would be $\sim$ 20 mCrab pulsar flux units, for a pulse FWHM = 25%.

TABLE 2

Search Sensitivity

N_{freq}	N_{accel}	ΔE (keV)	A_{eff} (cm^2)	Flux limit (99.9% conf)
48×75000	48	64–150	400	$< 6 \times 10^{-3}\,\mathrm{ph\,cm^{-2}\,s^{-1}\,MeV^{-1}}$
				~ 40 mCrab pulsars

5. CONCLUSIONS

The known radio pulsars with significant low-energy γ-ray emission (Crab, Vela, PSR 1509-58) are young, with reasonably short periods and large intrinsic period derivatives. By virtue of the similarity of the period and distance of PSR 1259-63 to the Crab, and the possibility that its period derivative is also comparable to that of the Crab, PSR 1259-63 is a likely candidate for γ-ray emission.

We have placed a limit on the 64–150 keV flux from PSR 1259-63 of $F \lesssim 40$ mCrab pulsar flux units, which corresponds to a luminosity of $\sim 5\%$ of the Crab pulsar in the same band. This suggests that the pulsar's intrinsic period derivative, and therefore its magnetic field, are substantially smaller than the Crab's. Further radio observations will produce a definitive value of $\dot{P}_{int}$ by the time of the next periastron.

This observational limit lends support to the suggestion that this pulsar may not be a young pulsar within $\sim 10^4$ years of its birth, but an older pulsar whose short period is due to spin-up by accreting matter from its companion at each periastron passage. Since it is widely believed that neutron star magnetic fields decay during accretion, PSR 1259-63 would then be expected to have a weak magnetic field and no significant γ-ray emission.

If this scenario is the case, then the pulsar must be experiencing substantial accretion episodes, and at the next periastron passage one would expect the matter being accreted to eclipse the pulsar's radio emission, while making it an X-ray and γ-ray source. So, searches for transient hard X-ray emission near the time of the next periastron passage, including a searches for pulsed emission, are warranted.

REFERENCES

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