JA

UT-HE 94/03

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(Submitted for publication)

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LONG-TERM STABILITY OF PULSED X-RAY EMISSION FROM THE CRAB PULSAR

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August 12, 1994

ABSTRACT

Two pulsed X-ray profiles of the Crab pulsar taken at a 4.5 yr interval have been compared to study possible long-term variabilities in its pulse intensity and pulse profile. The intensity ratio of the second peak to the first peak remained constant within 2.7 % in our study in the X-ray band, while the ratio has been reported to have varied by a factor around 3 over the same interval in the γ -ray band.

Our results give constraints on possible origins of the reported variation in the γ -ray band for the Crab pulsar. The results also set a limit on possible change in its pulsed X-ray emission after the 1989 glitch.

Subject headings: pulsars: general — pulsars: individual: Crab

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1. INTRODUCTION

High energy pulsed emission (50 MeV – 1 GeV) from the Crab pulsar has been reported to have changed its profile (Wills et al. 1982; Clear et al. 1987). Recently Nolan et al. (1993) extracted the ratio of the two peaks in the pulse profile from the data by SAS-2, COS-B, and EGRET to find a sinusoidal time variation with a period of 13.5 ± 0.7 years. Ulmer (1994) subsequently searched for this effect in the hard X-ray band (50 – 400 keV) in historical data and OSSE data, and made an observation that inclusion of the sinusoidal variation significantly improves the chi-square fit to the data set.

In the X-ray band, variability of the pulse profile has been studied qualitatively by Wills et al. (1982) with the proportional counter on board COS-B. Their study has concluded that the profile remained unchanged in the 1975, 1979, and 1980 data. Optical observations of the Crab pulsar over an interval of 7 years have shown no variation, setting an upper limit of 1 % for the peak pulse intensity (Jones, Smith, & Nelson 1980). We note that, in the γ -ray band (50 MeV – 1 GeV), long-term intensity variation has also been reported for the Vela and Geminga pulsars (Grenier et al. 1988; Grenier et al. 1994).

There are phenomena which may lead to long-term flux variations in the pulsar. One possibility discussed in Nolan et al. (1993) is that the spin axis of the neutron star precesses very slowly. If this precession is very slow, the pulsar magnetosphere will also precess at the same period. Since both the pulsed X-ray and γ -ray emissions are believed to be fixed to the magnetosphere geometry, the X-ray and γ -ray pulse profiles will be affected in a similar way. Another possibility relevant to the present study has been suggested by Link, Epstein, & Baym (1992) that the inclination angle α between the magnetic axis and the spinal axis undergoes a sudden increase in a

glitch. The largest glitch so far recorded in the Crab pulsar occurred on 1989 August 29 (Lyne, Smith, & Pritchard 1992; Lyne, Pritchard, & Smith 1993). Then, the pulsed X-ray/ γ -ray flux must have been affected at some level, because the emission angle is fixed to the magnetosphere geometry.

In this letter, we report the results we have obtained on the long-term variability of the Crab pulsar using the data taken by the Ginga satellite in the X-ray band (1 – 20 keV). The pulse-to-pulse variability has also been studied in the same data set and will be presented in a separate report.

2. OBSERVATIONS

The Crab pulsar was observed with the Large Area Counter (Turner et al. 1989) aboard the Ginga satellite on 1987 March 13 and on 1991 September 19. X-ray counts were accumulated separately in the energy bands of 1 – 6 keV and 6 – 20 keV in the pulse count (PC) mode. Typical counting rates were 7600 counts/sec and 3300 counts/sec in the 1 – 6 keV and 6 – 20 keV bands, respectively. The in-orbit background rate was 3.5×10^{-4} counts $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$ (Turner et al. 1989). The averaged dead time was about 1% during the Crab observations.

The pulse period was determined independently for the 1987 data and the 1991 data: the two periods were consistent with the radio data within ~ 10 ns (Arzoumanian, Nice, & Taylor 1992; Lyne & Pritchard 1994). The pulse profile was then obtained by folding the counts at the respective period. For later analysis, we define the phase intervals for Peak 1 (P1), Inter Pulse (IP), Peak 2 (P2), and Off Pulse (OP) in accordance with Nolan et al. (1993) as: P1, 0.915 – 0.045; IP, 0.045 – 0.315; P2, 0.315 – 0.445; and OP, 0.445 – 0.915.

The pulse profile measured on 1987 March 13 was compared with that on 1991

September 19 in Figure 1. We aligned the pulse phase relatively by matching the centroid of the first peak and adjusted for a small difference in detection efficiency by matching the integrated counts in the first peak. In both the 1 – 6 keV and 6 – 20 keV bands, no statistically significant difference has been detected: the assumption that the two profiles are the same gave $\chi^2 = 63$ for DOF = 61 (1 – 6 keV) and $\chi^2 = 55$ for DOF = 61 (6 – 20 keV). The ratios of the integrated counts in P2 and P1 (the P2/P1 ratios) in the two energy intervals are shown in Table 1 with their standard deviations. By comparing the measured ratios in 1987 and 1991, we obtain 2σ upper limits of 3.7% in the 1 – 6 keV band and 2.8% in the 6 – 20 keV band, while the total data (1 – 20 keV) give an upper limit of 2.7%. By normalizing the detection efficiency in each band by the detected total Crab flux, we obtain 2σ upper limits of 1.6 % and 2.8 % on the change in the absolute pulsed X-ray fluxes in the 1 – 6 keV and 6 – 20 keV bands, respectively.

3. DISCUSSION AND CONCLUSIONS

Nolan et al. (1993) interpreted the observed variation of the P2/P1 ratio in the γ -ray band as due to precession or nutation of the neutron star and fitted the variation with a sinusoidal curve of a period 13.5 ± 0.7 years. Our observations in 1987 March 13 and 1991 September 19 correspond almost to the peak and the valley of the sinusoidal curve, as shown in Figure 2. If the variation in the γ -ray band is due to precession of the neutron star and the X-ray/ γ -ray emission regions are fixed geometrically to the magnetosphere and the neutron star (may or may not be at a same location), we expect the P2/P1 ratio in the X-ray band to decrease by a significant fraction, albeit not 3. Even if X-rays and γ -rays are emitted in two different locations, our upper limit of 2.7 %, or $\sim 1/100$ of what has been seen in the γ -ray band, makes the precession

or nutation model difficult to survive. Many more studies in multiple bands will be needed to unravel the mechanism behind the long-term variability in the γ -ray and hard X-ray bands.

The reported long-term intensity variations in the γ -ray band (50 MeV – 1 GeV) of the Vela and Geminga pulsars have time scales of several years, but no periodicity has been reported (Grenier et al. 1988; Grenier et al. 1994). Grenier et al. (1994) have proposed an interpretation that the pulsed emissions from these pulsars may consist of four discrete beams, each with different beam widths, different spectra, and different long-term evolutions.

For the Crab pulsar, there is a report by Lyne et al. (1993) of quasi-periodic residuals (~ 10 ms) in the arrival time of radio pulses. The power spectrum of this residual has a spread between periods of 200 and 800 days. So far no model has been proposed to account for this variability.

Our results set a limit to a possible observable effect of the 1989 glitch on the X-ray pulse intensity and profile. Link et al. (1992) analyzed a post glitch behavior of the Crab pulsar, and suggested a possibility that the alignment angle α between the magnetic axis and the spinal axis may have undergone a sudden increase of $\delta\alpha \sim 10^{-4} \tan \alpha$. If we adopt the alignment angle to be $\alpha = 86^\circ$ as determined from the radio data on the Crab pulsar (Rankin 1990), the prediction becomes $\delta\alpha \sim 10^{-3}$. If we take the model calculation by Cheng (1987), there may be an amplification factor of about 3 for variation in the γ -ray and X-ray pulsed flux. Our limit of 1.6% (1 – 6 keV) is still an order of magnitude too large to have a meaningful constraint on the change $\delta\alpha$ at the 1989 glitch.

This work has been carried out under support of Grants-in-Aid by Ministry of Education, Culture and Science (Mombusho) of Japan (05242101, 04554006). Y.S. and

M.H. was supported by Fellowships of the Japan Society for the Promotion of Science for Japanese Junior Scientists. We wish to acknowledge enlightening discussions with K. S. Cheng, H. Inoue, F. Makino, K. Makishima, M. Matsuoka, F. Nagase, K. Sato, S. Shibata, N. Shibasaki, T. Takahashi, and T. Tamura during the course of this work.

TABLES

- TABLE 1. The P2/P1 ratios of the Crab pulsar measured at a 4.5 year interval.

TABLE 1

Year	1 – 6 keV	6 – 20 keV
1987	0.830 ± 0.006	0.992 ± 0.011
1991	0.846 ± 0.005	0.995 ± 0.006

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FIGURE LEGENDS

- FIG. 1.— Comparisons of two pulse profiles of the Crab pulsar over a 4.5 year interval in (a) the 1 – 6 keV band and (b) the 6 – 20 keV band. Histograms show the pulse profiles taken on March 13, 1987 and data points with 1σ error bars those taken on September 19, 1991.
- FIG. 2.— Long-term variability of the P2/P1 ratio of the Crab pulsar. The data in the γ -ray band (50 MeV – 5 GeV) are adopted from Nolan et al. (1993) and those in the X-ray band come from the present study. We note that the largest glitch occurred on 29 August 1989.

Fig. 1

Fig. 2