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THE PERIOD HISTORY OF THE X-RAY PULSAR IN MSH 15–52

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ABSTRACT

We present new and refined measurements of the pulse period of the X-ray pulsar in the supernova remnant MSH 15–52. The X-ray data were taken with the Monitor Proportional Counter onboard the *HEAO 2* (*Einstein*) *Observatory*. The X-ray measurements alone lead to a refined value of the period derivative of $(1.5382 \pm 0.0024) \times 10^{-12}$ s s^{-1}, while including the results of more recent radio observations leads to a value of $(1.54029 \pm 0.00095) \times 10^{-12}$ s s^{-1}.

Subject headings: pulsars — X-rays: sources

The Monitor Proportional Counter (MPC) on board the *HEAO 2* (*Einstein*) *Observatory* observed the 0.15 s X-ray pulsar near the center of the supernova remnant MSH 15–52 (Seward and Harnden 1982; Seward *et al.* 1982) on five separate occasions. The timing data used to obtain the results reported here were taken by the Time Interval Processor (TIP) of the MPC. The TIP measures the time between photon detections in the energy bandwidth 1–22 keV with an accuracy equal to the larger of 1.6% or 1 μs (for further details on TIP operation, see Weisskopf *et al.* 1981). An ephemeris of the MPC observations together with the measurements of the pulse period are listed in Table 1. These results both refine those obtained from the imaging X-ray instruments on the observatory (Seward and Harnden 1982) and add additional points to the period history.

The period measurements were obtained from analysis of pulse arrival times (corrected to the solar system barycenter) determined by cross-correlating sample pulse profiles with a master template. The sample pulse profiles were obtained by folding 6 minute sections of data at the trial period. We selected the trial period and constructed a binned representation for the template by folding the data at periods near 0.15 s and requiring that the χ^2 of a fit to an unpulsed source be at its maximum. We generated a continuous (in-pulse phase) representation for the template by Fourier analyzing the binned representation and keeping only those harmonics with amplitudes well above the noise level expected from counting statistics. This procedure for smoothing the template leads to more precise pulse timing (Deeter 1981) and simplifies the cross correlation with the binned sample pulses. In all cases, the pulse arrival times provided good fits to the hypothesis of a constant pulse period, and the rms residual were less than 6.5 ms. Thus, the TIP data provide no evidence for binary motion on time scales of a few hours or less.

The period history for this source and a representative 0.15 s X-ray light curve are shown in Figure 1. The variation of the pulse period with time is consistent with simple spin-down at a constant rate. While pulse period measurements spanning significantly longer periods of time may reveal deviations from the straight-line trend and thus provide a value for the breaking index, this

TABLE 1

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Epoch (JD 2,444,000+)	Elapsed Time (s)	Integration Time (s)	Period (s)[a]
107.88	7,856	4,782	0.150092885(75)
111.11	1,486	1,484	0.1500953(16)
273.69	1,546	1,545	0.1501137(10)
467.38	7,194	1,874	0.15014070(15)
470.66	34,639	6,599	0.150141100(13)
926.5[b]	...	...	0.150204(2)
1042.2[b]	...	...	0.15021718(5)

[a] The 1 σ errors in parentheses are in the last digits quoted.

[b] Radio observation (Manchester, Tuohy, and D'Amico 1982). The numbers quoted are heliocentric and to the precision quoted are identical with the barycentric numbers.

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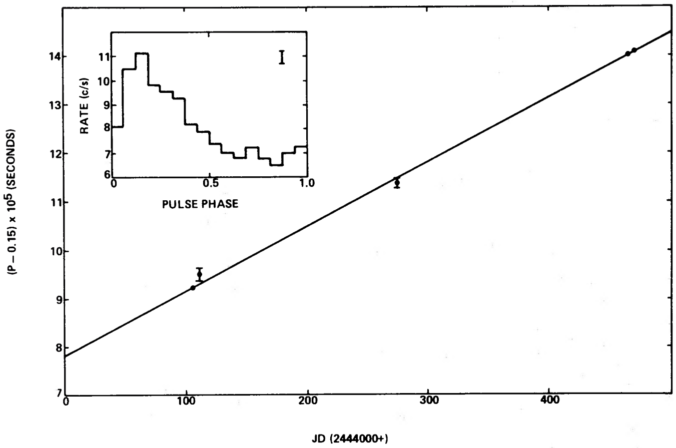

FIG. 1.—The pulse period as a function of time. The errors bars shown are ± 1 σ. In three cases, the errors are smaller than the size of the points. The solid line is the result of a weighted least squares fit to the X-ray period measurements. The inset shows the background-subtracted X-ray pulse profile for all the data taken on JD 2,444,470 folded at the period listed in Table 1.

result is consistent with a neutron star losing rotational energy via a pulsar mechanism (see, e.g., Manchester and Taylor 1977). A weighted least squares fit to the X-ray data in Table 1 leads to a value for the period derivative of $\dot{P} = (1.5382 \pm 0.0024) \times 10^{-12}$ s s^{-1}. The result of this fit is shown as the solid line in Figure 1. Also listed in Table 1 are the epoch and pulse period measurements for more recent radio observations (Manchester, Tuohy, and D'Amico 1982). The results of these measurements are in excellent agreement with the periods predicted from the X-ray results, thus indicating no change in $\dot{P}$ over 2.5 years. A weighted least squares fit including the radio and X-ray data leads to $\dot{P} = (1.54029 \pm 0.00095) \times 10^{-12}$ s s^{-1}. The measured period and period derivative lead to a characteristic pulsar age, $P/2\dot{P}$, of 1550 years, short compared to the 6000 year age of the supernova remnant (Manchester, Tuohy, and D'Amico 1982) and comparable to the 1230 year characteristic age of the Crab Pulsar. Assuming standard neutron star parameters, these values for P and $\dot{P}$ together with the magnetic dipole radiation law (see, e.g., Sutherland 1979) imply that the magnitude of the surface polar magnetic field is $\sim 3 \times 10^{13}/|\sin \beta|$ gauss. Here β is the angle between the magnetic and rotation axes. This value for the surface field is at the upper end of, but consistent with, the range of surface fields derived for radio pulsars (Manchester and Taylor 1981).

The results reported here, the X-ray imaging results indicating a hard-point source surrounded by diffuse nebular emission (Seward and Harnden 1982; Seward *et al.* 1982), and the recent discovery of 0.15 s radio pulses (Manchester, Tuohy, and D'Amico 1982) lead to the firm conclusion that the source is not powered by accretion but rather by the loss of rotational energy from a magnetized neutron star.

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