

A NEW, FAST X-RAY PULSAR IN THE SUPERNOVA REMNANT MSH 15–52

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ABSTRACT

A pulsing X-ray source has been discovered within the shell of the supernova remnant MSH 15–52. The period is 0.150 s, and the rate of increase of period with time is the highest measured for any pulsar. These characteristics and the fact that the pulsar is surrounded by a small, bright nebula indicate that this object is very similar to the Crab pulsar.

Subject headings: nebulae: supernova remnants — pulsars — X-rays: sources

I. INTRODUCTION

MSH 15–52 is a nonthermal radio source with a 30' diameter centered at galactic coordinates $l^{\text{II}} = 320.4$, $b^{\text{II}} = -1.2$ (in the constellation Circinus). The brightest radio portion of the remnant is located on the northwest rim and coincides with an 8' diameter $H\alpha$ emission region, RCW 89. A recent high-resolution radio map of the entire remnant is presented by Caswell, Milne, and Wellington (1981). The distance to the remnant has been determined to be 4.2 kpc by measuring the neutral hydrogen absorption profile (Caswell *et al.* 1975).

This supernova remnant (SNR) was observed a total of four times by the *Einstein Observatory* imaging detectors (Giacconi *et al.* 1979) in 1979 August and in 1980 August. Both high-resolution (HRI) and low-resolution (IPC) images were obtained. A complete description of these observations and of associated optical observations will be given by Seward *et al.* (1982).

The motivation for seeking additional pulsars which are associated with SNRs is obvious; there are only two such fast pulsars known: the Crab pulsar, which is undoubtedly the stellar remnant of SN 1054, and the Vela pulsar, located well within the shell of the 10^4 yr old remnant Vela X. The Crab pulsar has the shortest period and the highest period derivative, and is the only radio pulsar from which strong optical, X-ray, and gamma-ray pulsations have been detected. The Vela pulsar is the second in strength of the gamma-ray pulsars (Thompson *et al.* 1975), but optical pulsations are weak and X-ray pulsations appear to be absent. Both the Crab and Vela (Harnden *et al.* 1979) pulsars are embedded in regions of diffuse X-ray emission probably produced by high-energy electrons accelerated by the spinning pulsar.

A third, slower X-ray pulsar with a period of 3.5 s has been found by Fahlman and Gregory (1981) in SNR G109.1–1.0, and efforts to find the object at optical and radio wavelengths have been unsuccessful thus far.

Pointlike X-ray sources have also been found inside other SNRs, but regular pulsations from these have not been detected (Tuohy and Garmire 1980; Becker, Helfand, and Szymkowiak 1982).

II. RESULTS

The *Einstein* images of MSH 15–52 reveal diffuse X-ray emission from the eastern and northern rim of the remnant, but the field is dominated by two regions of brighter, more concentrated emission, each a few arc minutes in extent. One is close to the center of the remnant; the other is close to the rim and coincides with RCW 89. The HRI pictures show arc second-diameter X-ray sources at the center of each of these two bright regions.

The source within the central region appears pointlike to the HRI, and the IPC spectrum is harder than that from any other portion of the supernova remnant. This source is undoubtedly 4U 1510–59, detected by *Uhuru* at a consistent rate of 6.0 counts s^{-1} . The spectrum is like that of the Crab pulsar (Chiappetti and Bell-Burnell 1982) and strongly absorbed, $N_H \sim 1 \times 10^{22}$ (Seward *et al.* 1982), which explains the observed IPC count rate of only ~ 0.3 counts s^{-1} . *Einstein* count rates were also steady when measured over time scales larger than a few minutes.

The HRI data have been used to locate this source to an accuracy of 5''; the 1950 coordinates are R.A. $15^h09^m59^s.5$, decl. $-58^\circ56'57''$. The brightest optical object within the error box has magnitude $R \approx 22$.

X-ray emission from this source is strongly pulsed. We searched for regular pulsations with periods between 0.1 and 10 s by folding a fraction of the data in 10 phase bins and recording significant deviations from the average level. Only one period and its first harmonic appeared at a high level of significance. The barycentric period measured on 1979 August 25 was $0.150094 \text{ s} \pm 1$

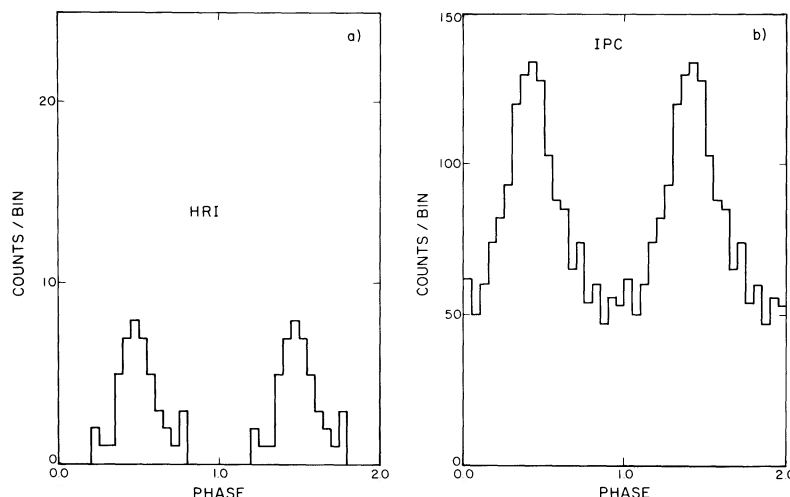


FIG. 1.—(a) The pulse shape obtained 1980 August 19 with the HRI. We have folded 6700 s of data (spanning 34,000 s of time) in 20 phase bins at a period of 0.150141 s. The solid angle from which counts were taken was only 0.04 arcmin². Two complete cycles have been plotted. (b) The pulse shape obtained 1980 August 15 with the IPC. We have folded 7200 s of data (spanning 12,000 s of time) in 20 phase bins at a period of 0.150140 s. The solid angle from which counts were taken was 12 arcmin², and the DC level is largely due to diffuse emission surrounding the pointlike source.

μ s. The period measured on 1980 August 15 was $0.150140 \pm 1 \mu$ s. Thus, the increase of period with time was $47 \pm 2 \mu$ s per year or $1.49 \times 10^{-12} \text{ s s}^{-1}$. The pulsed fraction is high, at least 80%, and the object exhibits one X-ray pulse per cycle as illustrated in Figure 1.

It is possible, since many pulsars exhibit 2 pulses per cycle, that the true period is 0.300 s and that there are two, nearly identically shaped pulses per cycle with the two pulses separated 0.5 in phase. We have searched for variations in shape or spectrum of the two pulses assuming a period of 0.300 s and were unable to find statistically significant differences. For the discussion that follows, we adopt the period of 0.150 s since the occurrence of identically shaped pulses separated by exactly 0.5 phase seems rather improbable.

III. DISCUSSION

The observed period derivative is over 3 times that of the Crab pulsar and could indicate the presence of binary orbital motion. The observed difference of 46μ s would then correspond to a velocity of $\sim 100 \text{ km s}^{-1}$, as might be observed, for example, in an $\sim 2 M_{\odot}$ edge-on binary system with an ~ 20 day orbital period. Even at the most favorable phase, with such an orbital period, our $\sim 10^4$ s observations would only see a period change of $\sim 1 \mu$ s, which is comparable to the estimated errors in the period measurements. Consequently, the two observations (separated by 1 year) cannot rule out orbital motion, and more observations are necessary to settle this question.

The 0.2–4 keV X-ray luminosity of the pulsed source derived from both IPC and HRI data is $\sim 5 \times 10^{34} \text{ ergs s}^{-1}$. The short period and low luminosity would be highly unusual for an accretion-powered source

(Rappaport and Joss 1982), although Skinner (1982) has recently reported 0.069 s periodic pulsations from the Large Magellanic Cloud transient source A0538–66. The surrounding diffuse emission and hard spectrum of the MSH 15–52 pulsar are reminiscent of the Crab pulsar and Crab Nebula. The calculated rate of loss of rotational kinetic energy is $5 \times 10^{37} \text{ ergs s}^{-1}$, more than enough to power the surrounding diffuse nebula, which has a 0.2–4 keV X-ray luminosity of $\sim 2 \times 10^{35} \text{ ergs s}^{-1}$. The high value of $\dot{P}$ gives a very short characteristic lifetime, $\tau = P/2\dot{P} = 1600 \text{ yr}$, which may be compared with $\tau \sim 1300 \text{ yr}$ for the Crab pulsar. This lifetime is much shorter than one would expect for a pulsar created in the same explosion as the supernova remnant, MSH 15–52, which has an estimated age in excess of 10^4 yr .

It is important to search for radio or optical pulsations. If the pulsar is indeed similar to the Crab pulsar, radio pulsations should be detectable, and these could easily be used to refine the value of the period and to search for orbital motion. If optical pulsations are present at the same intrinsic strength as those of the Crab pulsar (which is unlikely since the period is 5 times longer than that of the Crab pulsar), they would be detectable even though there are 5 mag of extinction in the direction of MSH 15–52. We note that the position of this new pulsar was included in the error circle of a source listed in the first catalog of COS B gamma-ray sources (Wills *et al.* 1980), but the source was not included in the latest revision (Swanenburg *et al.* 1981).

In conclusion, this new object within MSH 15–52 shows promise of being very similar to the Crab and Vela pulsars, both of which are located in supernova remnants and, up to now, have seemed unique in a sample of 300 radio pulsars.

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