RXTE OBSERVATIONS OF PSR J1105–6107

JULIA STEINBERGER¹, VICTORIA M. KASPI¹, ERIC V. GOTTHELF²

¹Department of Physics and Center for Space Research, Massachusetts Institute of Technology, Cambridge, MA, USA 02139
²Goddard Space Flight Center, Greenbelt, MD, USA 20771

ABSTRACT. We report on X-ray observations of the young, energetic radio pulsar PSR J1105–6107 obtained using the Rossi X-ray Timing Explorer. Our timing analysis of Proportional Counter Array data finds no evidence for X-ray pulsations from this source. We set a new upper limit on the pulsed X-ray flux from the pulsar of 18% in the 2-10 keV band, for a duty cycle of 0.5. Our improved upper limit supports the hypothesis that the X-ray emission seen by the ASCA X-ray satellite in the direction of PSR J1105–6107 is the result of a pulsar-powered synchrotron nebula.

1. Introduction

The radio pulsar PSR J1105–6107 has a spin period of $P = 63$ ms and a characteristic spin-down age $P/2\dot{P} = 63$ kyr (Kaspi et al. 1997). The pulsar’s spin-down luminosity $\dot{E} = 4\pi^2 I \dot{P}/P^3 = 2.5 \times 10^{36}$ erg s$^{-1}$, where $I$ is the neutron star moment of inertia, assumed to be $10^{45}$ g cm$^2$. The pulsar’s distance from the Earth is 7 kpc, estimated from its dispersion measure (Taylor & Cordes 1993). Given its $\dot{E}$ and distance, PSR J1105–6107 is expected to be an observable source of high energy emission. Indeed, the pulsar has been detected by the ASCA X-ray satellite as a faint, unpulsed point source (Gotthelf & Kaspi 1998, hereafter GK98). The pulsed fraction upper limit set using those data is 31% for a duty cycle of 0.5 in the 2-10 keV band.

GK98 concluded that the X-rays observed by ASCA are due to a pulsar-powered synchrotron nebula, the result of confinement of the pulsar wind by the ram pressure of the surrounding interstellar medium. Other possible X-ray emission mechanisms from the pulsar include thermal emission from the neutron star surface and pulsed non-thermal emission from the magnetosphere. Only the latter could contribute to the ASCA source; determining at what level is important for understanding this mechanism, as well as for observationally establishing the nebular flux and spectrum and ultimately the overall energy budget of the pulsar and the physics of the nebula, as well as for planning strategies for follow-up observations.

Here we report on a long observation in the direction of PSR J1105–6107 done by the Rossi X-Ray Timing Explorer (RXTE). Our goal was to detect, or place upper limits on, pulsed X-ray emission in order to better constrain the nature of the ASCA-detected X-ray source.
2. Observations and Timing Analysis

PSR J1105−6107 was observed by RXTE on November 17–19, 1997 (MJD 50769–50771). We report on observations made with the Proportional Counter Array (PCA). The total observing time was 100 ks. Each of the 5 Proportional Counter Units (PCUs) has a maximum effective area of $\sim 1275 \text{ cm}^2$, peaking around 10 keV. The total energy range of the PCA is 2–100 keV. The PCA has no spatial resolution and a large field of view of 1 square degree. For more detailed information regarding the PCA and RXTE see 

http://heasarc.gsfc.nasa.gov/docs/frames/xte_geninfo.html.

The data were taken in Standard 1 and 2, and Good Xenon Experiment Data System (EDS) modes (see Jahoda et al. 1996). The Good Xenon data have a time resolution of 1 $\mu$s and are used for the timing analysis. The Standard 2 data could be used for a spectral analysis, however one or more bright sources contaminate the field of view and preclude any spectral analysis useful for constraining the pulsar emission.

The PCA Good Xenon packet data were merged, and binned into a single time series of resolution 2 ms. Energy channels were then combined, cleaned of Earth occults and event times reduced to the barycenter. The time series was then folded at the observation-contemporary radio ephemeris obtained at the Parkes 64-m radio telescope in New South Wales, Australia. The radio ephemeris used is given in Table 1 and was determined using observations similar to those described by Kaspi et al. (1997). In addition, a timing analysis was carried out using the RXTE ftool fasebin (e.g. Rots et al. 1998), which folds the (barycentered, clock corrected) Good Xenon data using the pulsar ephemeris. In both cases, only the first detector layer events were used to maximize signal-to-noise ratio as our source is not bright.

Tab. 1 - Radio Pulse Ephemeris for PSR J1105−6107

| Frequency | 15.8245806130611 Hz |
| Frequency Derivative | $-3.96320 \times 10^{-12} \text{ Hz s}^{-1}$ |
| Epoch | MJD 50711 |
| Range of Validity | MJD 50638–50785 |

No X-ray pulsations were found. The time series was also folded using data from several restricted energy ranges: the complete RXTE range (2–100 keV), the ASCA band (2–10 keV), and the RXTE maximum effective area range (5–19 keV), as well as in several selected narrower ranges. In all cases, the $\chi^2$ of the folded profile indicated that it was consistent with being flat.

Although the radio ephemeris gives an accurate pulsar period for the time of the observation, we also performed period searches around the known pulsar period. The total time span of the observation is $T = 134177 \text{ s}$. The largest adequate frequency interval for searching is $\Delta \nu = \left(T \times N_b\right)^{-1}$ where $N_b$ is the number of phase bins used. For $N_b = 20$, $\Delta \nu = 3.7 \times 10^{-7} \text{ Hz}$. We folded the data at 550 frequencies around the

\footnote{During most of the observation, all 5 Proportional Counter Units were on, however, PCUs 4 and 5 were turned off for 1 hr each for detector management.}
known pulsar radio frequency, from 15.8245 to 15.8247 Hz. This analysis also revealed no significant signals.

Here we derive a pulsed flux upper limit for our RXTE observation. Using the binning-independent H test, optimal for use when the pulse profile is unknown (de Jager 1994), we obtain a 3σ upper limit on the pulsed fraction of all detected counts. We assume the emission can be described by a power-law spectrum with photon index 2, consistent with the results of GK98. We parametrize the PCA effective area by an approximate analytic form in the 2–20 keV band, \( A(E) \approx 5700 \exp\left(-\frac{(E - 7.4)^2}{32}\right) \) cm\(^2\), with \( E \) in keV. The 3σ upper limit on the pulsed flux is

\[
 f_{ul}(3\sigma) = 1.602 \times 10^{-9} \frac{N_0}{t} \int_{E_{min}}^{E_{max}} \frac{E}{A(E)} E^{-2} dE \text{ erg cm}^{-2} \text{ s}^{-1},
\]

where \( E \) is in keV. \( N_0 \) is a normalization factor for the spectrum determined from the pulsed fraction upper limit and the total number of counts detected, and \( t \) is the total good integration time, 98.5 ks. This analysis does not take into account the actual spectrum of the RXTE signal (including background). In the ASCA band of 2–10 keV, assuming a pessimistic 0.5 duty cycle, we find a 3σ upper limit on the pulsed flux of \( 1.15 \times 10^{-13} \) erg cm\(^{-2}\) s\(^{-1}\). This upper limit corresponds to 18% of the flux observed by ASCA in the 2–10 keV band. By contrast, the upper limit on the pulsed flux from the ASCA observation is 31% in the same energy range, for the same duty cycle. For duty cycle 0.3, our revised upper limit is 13% in the ASCA band.

3. Summary and Discussion

We have obtained an improved X-ray pulsed flux upper limit of 18% in the 2–10 keV band for duty cycle 0.5 from the young, energetic radio pulsar PSR J1105–6107. This represents a significant decrease in the pulsed fraction upper limit derived by GK98 using ASCA data. The absence of X-ray pulsations in our RXTE observation of PSR J1105–6107 is consistent with results seen for other pulsars of its type, namely those that have characteristic ages greater than ~10 kyr. This group of pulsars has been dubbed “Vela-like,” because they exhibit an absence of sharp, non-thermal magnetospheric pulsations as are seen in the much younger sources like the Crab pulsar, and because they show prominent X-ray synchrotron emission (see Becker & Trümper 1997 for a discussion). Thus, the X-ray emission from PSR J1105–6107 likely has its origin in a pulsar-powered synchrotron nebula. GK98 suggested the nebula may formed by the ram-pressure confinement of the relativistic pulsar wind by a high pulsar space velocity. This hypothesis can be verified by resolving the morphology of the putative nebula, using the next generation of X-ray telescopes, in particular AXAF and XMM.

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