Studies of high-energy pulsars: The special case of PSR J1849-0001

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Abstract

We present the results from the data analysis of the XMM-Newton observation (53.6 ks) on PSR J1849-0001. We studied in detail the X-ray emission of this pulsar and we found extended emission (up to $\approx 100$ arcsec) from the Pulsar Wind Nebula (PWN), confirming that this is a case of a Pulsar/PWN system and strengthening the evidence that X-ray, hard X-ray and TeV gamma-ray sources are manifestations of the same system. Another important result of our study is the clear evidence that the X-ray PWN of PSR J1849-0001 is asymmetric.

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1. Introduction

The number of very high energy gamma-ray emitting Galactic sources rapidly increased over the last years with the advent of the Imaging Atmospheric Cherenkov Telescopes and especially with the Galactic Plane Surveys by the H.E.S.S. experiment. Up-to-date VHE gamma-ray emission was found in many Pulsar Wind Nebulae (PWN) and Supernova Remnants (SNR) systems. But a very large part of the VHE gamma-ray emitters are still unidentified.

In the cases of PWN, the X-ray emitting region has generally a smaller extension than the TeV gamma-ray emission. Some PWN show symmetric X-ray emission, but there are famous examples of asymmetric X-ray emission, e.g. Crab, Vela and PSR B1509-58, representing the dynamics of this astrophysical objects.

PSR J1849-0001 was detected with X-ray observations \cite{1} at the position of the soft gamma-ray source IGR J18490-0000 (detected by INTEGRAL) \cite{2}. X-ray observations by RXTE revealed a pulsation period of 38.5 ms \cite{1}. Interestingly this source was also found to emit very high energy (VHE, $E > 10^{13}$ eV) gamma-ray emission (discovered by the H.E.S.S. experiment) \cite{2}. HESS J1849-000 is a very faint VHE source and hence only weak indication of its extension could be measured \cite{2}.

1.1. Pulsar Characteristics

The pulsar PSR J1849-0001 which is located at coordinates (J2000.0) R.A. = 18$^{h}$49$^{m}$0.1$^{s}$61, and decl. = -00$^{\circ}$01$^{\prime}$17.$^{\prime\prime}$6, is a 38.5 ms X-ray pulsar discovered in observations of the soft $\gamma$-ray source IGR J1849-0000 with the Rossi X-ray Timing Explorer (RXTE). This pulsar is spinning down rapidly with period derivative of $1.42 \times 10^{-14}$ s s$^{-1}$, yielding a spin-down luminosity of $\dot{E} = 9.8 \times 10^{36}$ erg s$^{-1}$, a characteristic age of $\tau_c = 42.9$ kyr, and a surface dipole magnetic field of $B_s = 75 \times 10^{11}$ G \cite{1}.

2. Observation Details

The data analysed are from a 53.6 ks XMM-Newton observation of PSR J1849-0001 (ObsID 0651930201) that was acquired on March 23th, 2011, and using the European Photon Imaging Camera (EPIC) \cite{3}. The MOS cameras were operated in the Full Frame mode to have the full field of view (FOV) covered with a time resolution of 2.6 s.

The PN detector was operated in the Small Window mode. This mode uses a smaller FOV (63 x 64 pixels) to reduce the number of out-of-time events (1.1%), to improve the time resolution to 5.7 ms, and, finally to
reduce the pile-up effect for bright sources. Both instruments are sensitive to X-rays in the 0.2-12 keV range with energy resolution $\Delta E/E \approx 0.1/\sqrt{E(\text{keV})}$.

For the analysis we used the data already calibrated by the satellite (PPS, Processing Pipeline Subsystem). The data were processed using the SAS version 15.0.0 pipeline, and were analysed using both the SAS and FTOOLS software packages. Only a small part of the observation was contaminated by flaring particle background, hence a good observing time of 47.9 ks for EPIC MOS and 49.2 ks for PN remained.

As can be seen in Figure 1, we detected a strong X-ray point source at the position of PSR J1849-0001 and extended X-ray emission surrounding this point source which can be best seen in Figure 2.

4. Spectral Analysis

A spectrum of the point source and extended emission was extracted for each EPIC camera using the XMM-Newton task evselect, and were fitted using the XSPEC fitting package and using a single power-law model of the form $N(E) = N_0 \times E^{-\Gamma}$ for both EPIC PN and MOS instruments. The Galactic absorption in the direction of this source of $N_H = 1.57 \times 10^{22} \text{cm}^{-2}$ (LAB survey\textsuperscript{1}).

4.1. Point source spectra

The spectra was extracted for each MOS camera using a circular region centred on the point source at a R.A. = 18$^h$49$^m$01$.538$, decl. = -0$^\circ$01$'$.213, and Normalization at 1 keV Norm. = (5.3 ± 1.3) × 10^{-4} photons keV^{-1} cm^{-2} s^{-1}. The resulting flux is $F_{PSR} (2-10 \text{ keV}) = (3.9 \pm 0.2) \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1}$ and the absorption corrected flux is $F_{PSR, \text{abs}} (2-10 \text{ keV}) = 5.0 \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1}$. Results for MOS 2 are compatible.

\textsuperscript{1}http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3nh/w3nh.pl
4.1.2. PN

The data are good described with the fit resulting a reduced $\chi^2 = 1.1$ for 144 degrees of freedom (dof). The spectrum can be described by a photon index $\Gamma_{PSR} = 1.2 \pm 0.1$, an absorption of $N_H = (4.5 \pm 0.3) \times 10^{22} \text{ cm}^{-2}$, and a Normalization at 1 keV = $(5. \pm 0.7) \times 10^{-4} \text{ photons keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$ and the absorption corrected flux is $F_{\text{PSR, unabs}} (2-10 \text{ keV}) = (4.9 \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1})$, see Figure 3(b).

4.2. Extended X-ray Emission

We extracted the spectrum of the extended nebula in an annulus surrounding the pulsar from 40” to 100” (see Figure 4) radius at R.A. = 18h49m01s.538, decl. = -0001’17”.22.

4.2.1. MOS 1

The resulting diffuse emission spectrum has $\Gamma_{\text{PWN}} = 1.7 \pm 0.3$, an absorption of $N_H = (5.08 \pm 0.9) \times 10^{22} \text{ cm}^{-2}$, and Normalization $\text{Norm.} = (3.1 \pm 4.0) \times 10^{-4} \text{ photons keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$. The resulting flux in this case is $F_{\text{PWN}} (2-10 \text{ keV}) = (8.15 \pm 1.9) \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ and the absorption corrected flux is $F_{\text{PWN, unabs}} (2-10 \text{ keV}) = 1.158 \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1}$. The reduced chi-squared is $\chi^2 = 1.0$ for 95 dof, (see Figure 7). The results for MOS 2 are also compatible. In this case, we did not extract the spectrum for EPIC PN detector, because our source is so close to the border of the small window (see Figure 1).

5. Morphology: the X-ray PWN is asymmetric

To study the morphology in more detail, an image from the energy range 2 to 7 keV was created. In this energy range, the X-ray emission of the PWN is more significant, while at lower and higher energies the background becomes more dominant (Figure 7). In Figure 6 the extended X-ray emission can be seen very clearly. Contours are applied and can be seen in figure 7. The
full extension of the PWN of around 100″ and a clear asymmetric shape can be identified.

To probe that effectively there is an asymmetry on the extended emission, we calculate the number of counts in four regions from 0 to 360 degrees (see Figure 8). We used the annulus region ranging from 40″ to 100″, which is dominated by the extended emission (see radial profile) and which was used to determine the spectrum of the extended emission. From Figure 8 we can see clearly that there is a significant excess on the region from 270 to 360 degrees confirming the asymmetry.

6. Summary

The X-ray analysis of the long exposure XMM-Newton observation at the position of the very high energy source IGR J18490-0000 reveals a bright X-ray pulsar and a clear detection of extended emission (up to ≈100 arcsec) interpreted as a pulsar wind nebula. Our studies confirm that this is a clear case of a Pulsar/PWN system and strengthen the evidence that the X-ray, hard X-ray and TeV gamma-ray sources are manifestations of the same system. The luminosity is consistent with the range of Pulsar/PWN systems [5]. Modelling the results with [6], seem to confirm that we deal with an intermediate age Pulsar/PWN system [7].

Moreover we found, that the derived hydrogen column density towards this source is very high. Though this source is in the Galactic plane, the measured column density is much larger than the average galactic hydrogen column density in this direction of the sky. This indicates that most of the absorbing material is very close to the source, probably circumstellar material.

Another very important result is the asymmetry of the X-ray PWN. A significant excess is detected in the south-west region. The X-ray PWN in this region is approximately 1.5 times brighter than the emission on the opposite side. This could be interpreted as a movement of the pulsar over time resulting in a more luminous region where the pulsar passed.

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