The $\gamma$-ray pulsar J1932+1916 in X-rays

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Abstract.

We report the results of a simultaneous analysis of the archival Suzaku and Swift X-ray data of the $\gamma$-ray pulsar J1932+1916 field. A point-like source and diffuse emission around it were detected at the $\gamma$-ray position of the pulsar. Their spectral properties allow one to suggest that Suzaku and Swift detected the X-ray counterpart of PSR J1932+1916. Using of the interstellar absorption-distance relations, we constrain the distance to the pulsar in the range of 2–6 kpc. We also discuss a possible association of the pulsar with the supernova remnant G54.4$-$0.3.

1. Introduction

Follow-up X-ray studies of newly discovered $\gamma$-ray pulsars are a natural step for detailed investigations of their properties. Here we report the analysis of the X-ray Swift and Suzaku observations of the field of the $\gamma$-ray pulsar J1932+1916 (hereafter J1932) discovered with Fermi [1]. The pulsar period $P = 208$ ms, the characteristic age $\tau = 35$ kyr, the spin-down luminosity $E = 4 \times 10^{35}$ erg s$^{-1}$, the magnetic field $B = 4.5 \times 10^{12}$ G and coordinates R.A.=19$^h$32$^m$19.70(4) and Dec.=$+19^\circ16'39''(1)^1$ were obtained from timing analysis. No radio counterpart of the pulsar was detected [1].

2. Spatial analysis

Swift and Suzaku images of J1932 field are presented in Fig. 1. The $\gamma$-ray position of J1932 is shown by the ‘+’ symbols. In the Swift X-ray Telescope (XRT) Point Source Catalogue [2], we found the pulsar X-ray counterpart candidate, a source 1SXPS J193219.4+191635, which is marked in the left panel of Fig. 1. The Suzaku image also reveals an X-ray emission spatially coincident with the Fermi position of J1932. We compared the radial profile of the Suzaku point spread function (PSF) with the radial brightness profile of this emission and found that its extent is significantly larger than the PSF half-power diameter of $2'$. We considered this extended emission as the pulsar wind nebula (PWN) powered by J1932. We found that the PWN spatial brightness distribution can be described by the 2D-Gaussian function with the full width at half maximum (FWHM) of $\approx 4.5'$. 

3. Spectral analysis

For the spectral analysis, we used the data from all Suzaku X-ray imaging spectrometers (XIS). We extracted the spectra from three regions shown in the right panel of Fig. 1: the polygon region was used for the astrophysical background while the $1'$-radius circle and the ring with radii of

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1 Numbers in parentheses are 1σ uncertainties related to the last significant digits quoted.
1′ and 4′ were used for the source. The soft point-like source 1SXPS J193231.7+191540 marked by the ‘x’ symbol in the left panel of Fig. 1 was excluded using 1′-radius circle. We assume that both circle and ring regions contain contributions from the astrophysical background, the PWN and the pulsar. For the PWN emission, the Ancillary Response Files (ARFs) were generated basing on the broad Gaussian spatial model with FWHM=4.5′ (see Sect. 2). For the pulsar and astrophysical background components, we generated ARFs for the point source and for a uniformly extended source, respectively. The non-X-ray instrumental background spectra were simulated for each region and detector and subtracted.

We also extracted spectrum from the Swift data using the 30′′-radius aperture centered at the 1SXPS J193219.4+191635 position. For the background, we used the source-free region in the Swift image. Two XRT ARFs were generated: for the extended emission and for the point source to account for the PWN and pulsar contributions, respectively. The PWN contribution to the source spectrum was estimated to be of 4% of the total PWN flux basing on the spatial model.

We used the unbinned spectra and fitted them simultaneously in the 0.5–10 keV band. The astrophysical background model consists of the Cosmic X-ray Background (CXB) and absorbed three-temperature optically thin thermal plasma component (3-T APEC\(^2\)). The CXB component was modelled by the absorbed power law (PL) with photon index Γ=1.4, the surface brightness of 5.4×10^{-15} erg s^{-1} cm^{-2} arcmin^{-2} in 2–10 keV band [3] and the hydrogen column density \(N_H\) of 2.8×10^{22} cm^{-2}. The latter value was obtained using the total selective extinction \(E(B-V)\) of \(\approx 4\) in the J1932 direction [4] and the empirical \(E(B-V)-N_H\) relation, \(N_H = (0.7\pm0.1) \times E(B-V) \times 10^{22} \text{ cm}^{-2}\) [5]. For the pulsar and PWN components, the absorbed PL models with a common value of the column density were applied.

To obtain the spectral parameters and their uncertainties we used the Markov chain Monte-Carlo (MCMC) sampler [6] implemented as a python package emcee in [7]. The resulting parameters of the pulsar and PWN emission are presented in Table 1. We estimated the

\(^2\) https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/XSmodelApec.html
obtained the absorption column density of within the radio shell. No diffuse radio emission from the PWN was detected. Junkes [11] symbols. This is likely to be a mixed-morphology SNR where X-ray emission is concentrated and X-ray images are represented in the Fig. 2 with the '+' symbols. In the SNR direction using the interstellar extinction maps of the Galaxy and empirical correlation between pulsar γ-ray efficiency η γ = L γ / E. However, the X-ray efficiencies η X = L X / E for both pulsar and PWN lie within typical range of 10^{-5}–10^{-1}. The ratio L PWN / L pulsar ≈ 10 is also typical for the pulsar+PWN systems supporting the pulsar and PWN interpretation of the detected sources.

J1932 is located near the radio shell of the supernova remnant (SNR) G54.4–0.3 which radio and X-ray images are presented in the Fig. 2 with the Fermi position of J1932 shown by the ‘+’ symbols. This is likely to be a mixed-morphology SNR where X-ray emission is concentrated within the radio shell. No diffuse radio emission from the PWN was detected. Junkes [11] obtained the absorption column density of ≈10^{22} cm^{-2} in the SNR direction using the ROSAT observations. This value is consistent with the N H value for J1932 (Table 1) making possible the association of these objects. If it is real, then the pulsar proper motion is ≈34 mas yr^{-1} and its transverse velocity is ≈650D_{kpc} km s^{-1} assuming the J1932 age of 35 kyr; here D_{kpc} is the distance in units of 4 kpc. Such value is typical for pulsars [12]. Determination of the proper motion direction could help to resolve the question about the association.

Table 1. Best-fit spectral parameters for the presumed PWN and pulsar emission. All errors correspond to 90% credible intervals. Unabsorbed fluxes are given for the 0.5–8 keV band. Luminosities are given for the 0.5–8 keV band and the distance of 4 kpc.

| Parameter                      | PWN                        | pulsar                      |
|-------------------------------|-----------------------------|-----------------------------|
| Column density N_H, cm^{-2}   | 1.2^{+0.3}_{-0.3} × 10^{22} | 1.4^{+1.0}_{-1.0}           |
| Photon index Γ                 | 1.8^{+0.4}_{-0.3}          | 1.4^{+1.0}_{-1.0}           |
| Unabsorbed flux f_X, erg s^{-1} cm^{-2} | 1.2^{+0.3}_{-0.2} × 10^{-12} | 1.3^{+0.5}_{-0.5} × 10^{-13} |
| Luminosity L_X, erg s^{-1}     | 2.3^{+0.6}_{-0.4} × 10^{33} | 2.5^{+1.7}_{-1.0} × 10^{32} |

4. Discussion
The distance D ~ 1.5 kpc (with an upper limit of 6.6 kpc) to J1932 was estimated from an empirical correlation between pulsar γ-ray fluxes and distances [1]. We independently estimated the distance using the interstellar extinction maps of the Galaxy and E(B−V)−N_H relation [5] (see Section 3). From the spectral analysis we obtained N_H = (1.2 ± 0.3) × 10^{22} cm^{-2} (Table 1) which corresponds to E(B−V) = 1.7 ± 0.4 (1σ errors). Thus basing on the extinction–distance dependence along the pulsar line of sight following from the maps [8, 9], the distance to J1932 can be constrained in 2–6 kpc range.

Using the obtained distance range and results of the spectral analysis we compare J1932 and its PWN with other pulsar+PWN systems presented in [10]. The PWN produced by J1932 is somewhat brighter than PWNe of other pulsars with similar η. However, the X-ray efficiencies η X = L X / E for both pulsar and PWN lie within typical range of 10^{-5}–10^{-1}. The ratio L PWN / L pulsar ≈ 10 is also typical for the pulsar+PWN systems supporting the pulsar and PWN interpretation of the detected sources.

5. Summary
We analysed the archival X-ray Swift and Suzaku data on the γ-pulsar J1932 field. At the pulsar position, the point-like source was revealed with Swift and the diffuse emission was detected with Suzaku. These sources have spectral properties typical for the pulsar+PWN systems. Using the interstellar extinction–distance relations, we constrain the distance to the pulsar in the 2–6 kpc
Figure 2. Left: 1420 MHz continuum image of the SNR G54.4−0.3 obtained from the VLA Galactic Plane Survey (VGPS; [13]). Right: ROSAT PSPC survey image of G54.4−0.3 field in the 0.1–2.4 keV band with overlaid VGPS contours. The Fermi position of J1932 is marked by the ‘+’ symbols.

range. The proximity of J1932 to the SNR G54.4−0.3 and comparable values of the interstellar absorption towards both objects make possible their association. Deeper observations with better spatial resolution are needed to study the morphology and spectral properties of the X-ray source and to confirm its pulsar nature.

Acknowledgments
For the Figure 2 we used the data from the VGPS survey conducted by the National Radio Astronomy Observatory (NRAO) instruments. NRAO is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

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