MULTIWAVELENGTH STUDY OF THE NORTHEASTERN OUTSKIRTS OF THE EXTENDED TeV SOURCE HESS J1809−193

Blagoy Rangelov1, Bettina Posselt2, Oleg Kargaltsev1, George G. Pavlov2, Jeremy Hare1, and Igor Volkov1,3

1 Department of Physics, The George Washington University, 725 21st Street, NW, Washington, DC 20052, USA; rangelov13@gwu.edu
2 Pennsylvania State University, 525 Davey Laboratory, University Park, PA 16802, USA
3 University of Maryland, College Park, MD 20742, USA

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ABSTRACT

HESS J1809−193 is an extended TeV γ-ray source in the Galactic plane. Multiwavelength observations of the HESS J1809−193 field reveal a complex picture. We present results from three Chandra X-Ray Observatory and two Suzaku observations of a region in the northeastern outskirts of HESS J1809−193, where enhanced TeV emission has been reported. Our analysis also includes GeV γ-ray and radio data. One of the X-ray sources in the field is the X-ray binary XTE J1810−189, for which we present the outburst history from multiple observatories and confirm that XTE J1810−189 is a strongly variable type I X-ray burster, which can hardly produce TeV emission. We investigate whether there is any connection between the possible TeV extension of HESS J1809−193 and the sources seen at lower energies. We find that another X-ray binary candidate, Suzaku J1811−1900, and a radio supernova remnant, SNR G11.4−0.1, can hardly be responsible for the putative TeV emission. Our multiwavelength classification of fainter X-ray point sources also does not produce a plausible candidate. We conclude that the northeast extension of HESS J1809−193, if confirmed by deeper observations, can be considered a dark accelerator—a TeV source without a visible counterpart at lower energies.

Key words: acceleration of particles – gamma rays: general – ISM: individual objects (HESS J1809−193) – X-rays: binaries – X-rays: individual (Suzaku J1811−1900, XTE J1810−189)

Online-only material: color figures

1. INTRODUCTION

During the past decade, observations with TeV γ-ray observatories, such as the High Energy Stereoscopic System (HESS), revealed a large number of very high energy (VHE) sources in the Galactic plane (Aharonian et al. 2005). Sources, firmly identified as pulsar-wind nebulae (PWNes), shell-type supernova remnants (SNRs), and microquasar-type high-mass X-ray binaries (HMXBs) account for about half of the total number (~90) of Galactic VHE sources (Kargaltsev et al. 2013). There is a large number of unidentified VHE sources (~20), for which multwavellength (MW; from radio to TeV) observations provide hints of a counterpart (such as an SNR interacting with a molecular cloud, or a star-forming region). Most of these associations are still uncertain because at least some of these sources still could be powered by offset pulsars whose PWNe are faint in X-rays. Among these is a group of 6−7 “dark” sources that do not show plausible counterparts at any other wavelengths.

HESS J1809−193 was observed as part of the systematic survey of the inner Galaxy (Aharonian et al. 2005, 2006a). As there was a marginally significant VHE γ-ray signal (2σ), further observations of HESS J1809−193 were undertaken (with a total live time of ~25 hr), which resulted in a detection significance of 6.8σ for VHE γ-ray emission within 13′ of the location of PSR J1809−1917 (Aharonian et al. 2007). The HESS image (shown in Figure 1) suggested a fainter extension northeast (NE) of the main source, which could be a separate source. A year later, Renaud et al. (2008) presented preliminary results from a 41 hr HESS exposure of the same source. In Figure 1 from Renaud et al. (2008), the NE TeV extension appears to be more fragmented, with multiple blobs, which could be explained by multiple faint sources, but their individual significances would be very low.

There are several possible sources of energetic particles known in this region, including two young pulsars. Most of the HESS J1809−193 TeV emission is likely produced by the PWN of the 51 kyr old PSR J1809−1917 via inverse Compton (IC) scattering (ICS; Aharonian et al. 2007). While the central region of HESS J1809−193 has been investigated reasonably well (Kargaltsev & Pavlov 2007; Anada et al. 2010; Komin et al. 2008), no comprehensive investigation has been performed on the NE part despite the available MW coverage.

Another energetic pulsar, J1811−1925, is more offset from the center of HESS J1809−193 and it is also more distant than PSR J1809−1917: ~5 kpc compared to 3.5 kpc (ATNF catalog; Manchester et al. 2005). Moreover, PSR J1811−1925 is located at the center of SNR G11.2−0.3, whose size is much smaller than the pulsar’s offset from the center of HESS J1809−193. Therefore, the PWN of J1811−1925 cannot account for the TeV emission from the entire HESS J1809−193 (see also Dean et al. 2008). PSR J1811−1925 is coincident with one of the TeV blobs seen by Renaud et al. (2008), and its PWN could contribute some of the TeV emission from HESS J1809−193; however, it is unlikely to be responsible for the γ-ray emission from the NE region of the HESS source (see Figure 1, left panel).

In this paper we focus on the MW picture of the region NE of HESS J1809−193, and investigate the nature of various sources seen in this region at lower energies. We also discuss whether any of them could be sources of TeV emission.

We present the results from five X-ray observations—three taken with the Chandra X-Ray Observatory (CXO) and two with Suzaku (see Figure 2). We analyze the brightest sources discovered in the CXO and Suzaku fields. One of these X-ray sources is the known low-mass X-ray binary (LMXB) candidate XTE J1810−189, for which we show the outburst history from multiple observatories. The other one is a new X-ray binary.
Figure 1. Left: an image of HESS J1809−193 in 1–10 TeV (adopted from Aharonian et al. 2007), smoothed with a Gaussian of width 6′/6. The color scale is set such that the blue/red transition occurs at approximately the 3σ significance level. The black contours are the 4σ, 5σ, and 6σ significance contours. The position of the pulsars PSR J1809−1917 and PSR J1811−1925 are marked with green triangles, and the two X-ray sources, Suzaku J1811−1900 and XTE J1810−189, with a green circle and star, respectively. The Galactic plane is shown as a white dotted line. The best-fit position for the γ-ray source is marked with a black star and the fit ellipse with a dashed line. The purple and white rectangles show the Suzaku X-ray Imaging Spectrometer (XIS) and CXO pointings, respectively. Right: Fermi test statistic map of the HESS region in the 15–300 GeV range. Suzaku J1811−1900, XTE J1810−189, and PSR J1809−1917 are denoted as in the left panel. The Fermi count extraction region (r = 0.5) is shown with white dashed circle, while the white ellipses represent 2FGL J1811.1−1905c and 2FGL J1808.6−1950c; see Section 2.3. (A color version of this figure is available in the online journal.)

Figure 2. CXO/ACIS-I inverted scale images (ObsId 14662 (left) and ObsId 3512 (right)) with 16 X-ray sources detected (Table 1). The positions of Suzaku J1811 and XTE J1810−189 are also shown on top of the ACIS-I images, but neither of the two is detected. The magenta contours on the left panel trace the apparent extended emission of Suzaku J1811. (A color version of this figure is available in the online journal.)
(XRB) candidate, Suzaku J1811–1900. We also provide MW classification for other fainter X-ray sources detected in the CXO ACIS observations.

This paper is organized as follows. Section 2 summarizes the X-ray observations, and Section 3 presents the analysis of the X-ray data. Section 4 discusses the implications of these results for the production of γ-rays, and in Section 5 we summarize our main conclusions.

2. OBSERVATIONS AND DATA REDUCTION

2.1. CXO

We use three sets of archival CXO observations of HESS J1809–193 (Table 1). The data were taken with the ACIS-I instrument on board CXO (ObsIDs 3512 and 14662) in “very faint” timed exposure mode, and with the HRC-S instrument in “timing” mode (ObsID 9022). We processed the data using the CXO Interactive Analysis of Observations (CIAO) software (version 4.6) and CXO Calibration Data Base version 4.5.9, and restricted the data to the energy range 0.5–8 keV. We use CIAO’s Mexican-hat wavelet source detection routine wavdetect (Freeman et al. 2002) to detect X-ray sources and measure their coordinates in the CXO images (listed in Table 2; Figure 2). CIAO’s task srcflux was used to extract net counts and model-independent source fluxes.

2.2. Suzaku

The archival data from two Suzaku observations of HESS J1809–193 (see Table 1) were processed with FTOOLS’ task XSELECT in the package HEASOFT5 version 6.13. We extract both PIN and GSO spectra from the Hard X-ray Detector (HXD) using the tasks hxdpinxbpi and hxdgsoxbpi, respectively. We use appropriate PIN and GSO background HXD NXD files available in the archive.6 No signal above the background is detected in the HXD detector in both observations.

2.3. Fermi

We use all archival Fermi Large Area Telescope (LAT) data acquired between 2008 August 6 and 2014 June 10. The data were analyzed with the Fermi Science Tools following the standard procedures.7

3. RESULTS

We have detected 16 X-ray sources (with \(N\geq30\) net counts and detection significance \(\geq10\)) in 2 ACIS-I fields (Table 2). The X-ray spectra and responses were extracted with standard CIAO software. The fits were performed using XSPEC 12.8 in the 0.5–8 keV energy range. For each source, we fitted an absorbed power law (PL) model.

3.1. XTE J1810–189

We extracted source and background spectra for XTE J1810–189 for both Suzaku instruments X-ray Imaging Spectrometer (XIS) and HXD; however, no signal above the background was detected for the latter. The XIS spectrum is fit with an absorbed PL with photon index \(\Gamma=1.6\) and \(n_{HI,22}=2\) (where \(n_{HI,22}\) is the absorbing hydrogen column density in units of \(10^{22}\) cm\(^{-2}\)). This corresponds to an unabsorbed X-ray flux of \(5.8 \times 10^{-12}\) erg cm\(^{-2}\) s\(^{-1}\) in the 0.5–10 keV band.

We did not detect any X-ray sources in the 2003 October 18 Swift X-Ray Telescope (XRT) observations (see Table 1) of XTE J1810–189. The data were taken with the XRT instrument in PC mode. We processed the data using the online Swift–XRT tool8 (Evans et al. 2007).

Note. a Exposure in units of ks.

Table 1

| Obs. | Date       | ObsId  | PI          | Exp\(^a\) |
|------|------------|--------|-------------|-----------|
| CXO  | 2003 Oct 18| 3512   | Garmire     | 20        |
| CXO  | 2008 Apr 23| 9022   | Chakrabarty | 1         |
| CXO  | 2013 May 17| 14662  | Posselt     | 55        |
| Suzaku| 2009 Sep 9 | 504077010 | Kargaltsev | 52        |
| Suzaku| 2009 Sep 10| 504078010 | Kargaltsev | 52        |
| Swift| 2008 Mar 17| 00031167001 | ... | 2         |
| Swift| 2008 Mar 18| 00031167002 | ... | 2         |
| Swift| 2008 Mar 21| 00031167003 | ... | 2         |
| Swift| 2008 Mar 22| 00031167004 | ... | 2         |
| Swift| 2008 Mar 23| 00031167005 | ... | 2         |
| Swift| 2008 Mar 24| 00031167006 | ... | 1         |
| Swift| 2008 Mar 25| 00367537000 | ... | 1         |
| Swift| 2011 Jun 19| 00453640000 | ... | 4         |

4 http://cxc.harvard.edu/ciao/index.html
5 http://heasarc.nasa.gov/heasoft/
6 ftp://legacy.gsfc.nasa.gov/suzaku/data/background/
7 http://fermi.gsfc.nasa.gov/ssc/data/analysis
8 http://www.swift.ac.uk/user_objects/
Markwardt & Swank (2008) detected the variable source XTE J1810–189 using an RXTE/PCA pointed observation on 2008 March 10. The authors modeled the spectrum with absorbed PL ($\nu L_{\nu,22} = 1$ and $\Gamma = 1.9$) and reported a 6.4 keV iron line, although contamination by diffuse Galactic ridge emission could not be excluded. The X-ray flux, uncorrected for diffuse contamination, was $2.5 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ in the 2–10 keV range.

An X-ray burst from XTE J1810–189 was detected with RXTE/PCA in a pointed observation on 2008 March 26 at 12:47 UT (Markwardt et al. 2008). A cooling trend of the thermal spectrum suggests a type I thermonuclear burst from a neutron star (NS). Markwardt et al. (2008) reported an unabsorbed peak X-ray flux of $\sim 2.5 \times 10^{-8}$ erg cm$^{-2}$ s$^{-1}$, which was used to obtain an upper limit of 11.5 kpc on the distance (assuming a standard Eddington peak luminosity of $3.8 \times 10^{38}$ erg s$^{-1}$).

XTE J1810–189 experienced another outburst on 2013 January 5, with a flux of $\sim 40$ mCrab ($\sim 9.6 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$) in the 4–10 keV band, detected with the MAXI/Gslit Camera (Negoro et al. 2013). The Swift/Burst Alert Telescope light curve, however, shows that the outburst started on 2012 December 10. Negoro et al. (2013) reported that the source was in the hard state on 2013 January 5. The light curve is shown of Figure 3 (values listed in Table 3).

Torres et al. (2008b) acquired a 900 s $K_s$-band image of the XTE J1810–189 field on 2008 March 18 using the PanSTARRS camera attached to the 6.5 m Magellan Baade Telescope. The seeing was $\sim 0^\prime.5$. The point-spread function (PSF) fitting photometry revealed that the brightest object (the NIR counterpart of XTE J1810–189 proposed by the authors) within the CXO error circle has declined in brightness from $K_s = 17.3 \pm 0.2$ to $K_s = 18.0 \pm 0.1$ (2008 June 23; Torres et al. 2008a).

We used archival $V$, $H_a$, $R$, $I$ optical data from the Cerro Tololo Inter-American Observatory (CTIO) 4 m Blanco Telescope taken on 2004 May 21. While the optical counterpart of XTE J1810–189 was not detected in the observations, we estimate upper limits of $V > 22.6$, $R > 22.5$, $H_a > 19.6$, and $I > 20.52$. However, this is not restrictive in terms of star spectral type because the non-detection can be attributed entirely to the very large interstellar medium (ISM) absorption ($A_V \gtrsim 11.5$; Rowles & Froebrich 2009).

### 3.2. Suzaku X-Ray Source

In the 2009 Suzaku image (ObsId 504077010), we discovered a “compact” X-ray source, Suzaku J1811–1900 (hereafter J1811), that appears to be marginally extended. It is apparently surrounded by large-scale extended emission (the respective contours are shown in Figure 2). Around 1000 (background-subtracted) counts were collected from the compact Suzaku source in the 52 ks exposure in a circular aperture with radius 80″ at energies 0.5–8 keV.

![Figure 3. Outburst history of XTE J1810–189. Data from Swift are shown with red diamonds, CXO with green crosses (the arrow shows the upper limit), Suzaku with the blue asterisk, RXTE (Markwardt & Swank 2008) with orange triangles, and MAXI (Negoro et al. 2013) with a magenta square (see the text for details). The inset shows the time during which the type I X-ray burst occurred. The peak detected with RXTE is clearly seen.](image)

### Table 2

| No. | R.A.   | Decl. | $F^a$ | Net Counts | HR$^b$ | Class$^c$ (Probability) |
|-----|--------|-------|-------|------------|--------|------------------------|
| 1   | 273.04064 | −19.04081 | 15 ± 1 | 228 ± 15  | 0.91   | LMXB (71%)              |
| 2   | 273.01545 | −19.01186 | 2.0 ± 0.5 | 41 ± 6   | 0.69   |                        |
| 3   | 272.90919 | −19.01146 | 43.9 ± 0.9 | 74 ± 9 | 0.98   | YSO (89%)               |
| 4   | 273.01503 | −19.00379 | 2.3 ± 0.4 | 107 ± 10 | −0.43  |                        |
| 5   | 272.97179 | −19.00031 | 0.99 ± 0.09 | 41 ± 6 | −0.97  |                        |
| 6   | 273.01190 | −18.91413 | 9.6 ± 1.0 | 171 ± 13 | 0.57   |                        |
| 7   | 272.89484 | −18.96038 | 2.0 ± 0.4 | 81 ± 9   | −0.53  | Star (99%)              |
| 8   | 272.90928 | −18.95289 | 2.2 ± 0.7 | 31 ± 6   | 0.96   |                        |
| 9   | 272.90288 | −19.06230 | 2.2 ± 0.6 | 50 ± 8 | 0.64   |                        |
| 10  | 273.11526 | −18.93897 | 3.8 ± 0.6 | 131 ± 12 | −0.68  | Star (99%)              |
| 11  | 272.83877 | −18.92205 | 23 ± 5  | 76 ± 10  | 0.44   |                        |
| 12  | 272.82446 | −18.97315 | 8.6 ± 2.0 | 44 ± 7 | 0.69   |                        |
| 13  | 272.58428 | −19.08521 | 2.6 ± 0.6 | 43 ± 7 | −0.79  | Star (99%)              |
| 14  | 272.77570 | −19.09171 | 3.7 ± 0.9 | 40 ± 6 | 0.47   |                        |
| 15  | 272.65398 | −19.05966 | 1.4 ± 0.4 | 36 ± 6 | −0.95  |                        |
| 16  | 272.73350 | −19.08788 | 1.5 ± 0.5 | 31 ± 5 | −0.66  | Star (99%)              |

Notes.

a Model-independent X-ray fluxes in the 0.2–7 keV range in units of $10^{-14}$ erg s$^{-1}$ cm$^{-2}$.

b Hardness ratio calculated as $(H - S)/(H + S)$, where $S$ and $H$ are the number of counts in the 0.2–2 keV and 2–7 keV bands, respectively.

c Classification and probability according to the automative classification algorithm.

d “?” denotes cases where no confident (>70%) classification was obtained.
We searched for periodicity of the compact source in the light curve. We have analyzed 514 photon arrival times from 3 XIS detectors extracted from a $r = 30\arcsec$ region centered at R.A. = 18:11:51, decl. = −19:00:54 (which is the best-fit centroid of the source). We corrected the arrival times to the solar system barycenter using the aebarycen task. The arrival times were recorded with a resolution of 8 s and spanned the interval of 99.94 ks. We searched for a periodic signal using the Digital Fourier Transform and the $Z^2_1$ tests (Buccheri et al. 1983). No periodic signal with significance >1.9σ was found in the 0.0002–0.0625 Hz range (for 6246 independent trials) we searched.9 The maximum we found, $Z^2_1 = 23$, implies that the upper limits on $Z^2_1$ are 46, 49, and 60 at the 95%, 99%, and 99.9% confidence levels, respectively (Groth 1975). These correspond to 40%, 44%, and 48% upper limits on the observed pulsed fraction (see, e.g., Pavlov et al. 1999). The limits on the intrinsic pulsed fraction are a factor of 1.6 larger. Therefore, the obtained upper limits on the pulsed fraction are not very restrictive.

We fitted the spectrum of the compact source with an absorbed PL + blackbody (BB) + emission line model (gaussian component shown as dotted lines). The black, red, and blue points correspond to the XI0, XI1, and XI3 detectors, respectively. The observed X-ray spectrum and the fit are shown in Figure 4. The observed absorbed flux of J1811 is $3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the energy range 1–10 keV. The X-ray spectrum and the fit are shown in Figure 4. The observed absorbed flux of J1811 is $3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the energy range 1–10 keV.

The total Galactic H I column density in this direction is $n_{\text{HI}} = 1.8 \pm 0.5 \times 10^{22}$ cm$^{-2}$ (Dickey & Lockman 1990), a value slightly smaller than our $n_{\text{HI,22}}$, which also takes molecular hydrogen into account. We note that Baumgartner & Mushotzky (2006) found the X-ray $n_{\text{HI}}$ values to be a factor of two to three greater than the 21 cm H I column densities (for high Galactic column densities $\gtrsim 10^{21}$ cm$^{-2}$).

We investigated standard surveys for coverage of J1811, e.g., at radio (Very Large Array (VLA), SUMSS), optical (NOMAD, Digital Sky Survey), Galactic $H_\alpha$ (SuperCOSMOS), NIR (Two

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### Table 3

| Date           | $m_1$  | $\Gamma$  | $F_{\text{abs}}$ | $F_{\text{PL}}$ | Exp. | Obs. |
|----------------|--------|-----------|------------------|-----------------|------|------|
| 2003 Oct 18    | 4.0    | 1.7       | $<8.6 \times 10^{-5}$ | $<2 \times 10^{-4}$ | 20   | CXO  |
| 2008 Mar 10    | 1.0    | 1.9       | 2.5              | ...             | ...  | ...  |
| 2008 Mar 17    | 3.9    | 1.7       | 2.9              | 6.4             | 2.0  | Swift|
| 2008 Mar 18    | 4.0    | 1.9       | 4.3              | 11              | 1.3  | Swift|
| 2008 Mar 21    | 5.0    | 2.1       | 3.1              | 11              | 1.8  | Swift|
| 2008 Mar 22    | 4.3    | 1.7       | 3.4              | 7.7             | 1.7  | Swift|
| 2008 Mar 23    | 4.6    | 1.9       | 4.3              | 13              | 1.8  | Swift|
| 2008 Mar 24    | 3.4    | 1.4       | 8.1              | 14              | 2.0  | Swift|
| 2008 Mar 25    | 4.0    | 1.5       | 4.5              | 8.7             | 1.3  | Swift|
| 2008 Mar 26    | 1.0    | 1.9       | 2.5 e-2          | ...             | ...  | ...  |
| 2008 Apr 23    | 3.8    | 1.6       | 1.7              | 10              | 43   | CXO  |
| 2009 Sep 11    | 2.0    | 1.6       | 5.8 e-2          | 0.1             | 1    | Suzaku|
| 2011 Jun 19    | 4.9    | 2.6       | 6.5              | 45.5            | 3.8  | Swift|
| 2013 Jan 5     | ...    | ...       | 9.6              | ...             | ...  | ...  |

**Notes.**

- $^a$ Hydrogen column density in units of $10^{22}$ cm$^{-2}$.
- $^b$ Power law photon index.
- $^c$ Observed X-ray flux in units of $10^{-10}$ erg s$^{-1}$ cm$^{-2}$ in 0.5–8 keV.
- $^d$ Unabsorbed X-ray flux in units of $10^{-10}$ erg s$^{-1}$ cm$^{-2}$ in 0.5–8 keV.
- $^e$ Exposure in units of ks.

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9 There is a strong periodic signal at 96 minutes, which is the Suzaku orbital period.
Micron All Sky Survey (2MASS), IR (Spitzer, WISE), and hard X-ray frequencies (Integral). There are no obvious correlations between emission in these bands and the Suzaku emission around J1811. There are, however, many NIR point sources within the positional error circle (∼20′) of Suzaku—around 30 cataloged 2MASS sources plus at least as many fainter objects visible in the 2MASS images. Several Hα point sources are also within the error circle of the compact Suzaku J1811 source. There is no known XRB within 30′ of the Suzaku position in VizieR catalogs, e.g., Ritter & Kolb (2003; Version 7.20, 2013 July). A Spitzer point-like source is situated 20′ from Suzaku J1811. The source is bright (K = 6.7) in the NIR (2MASS) and IR (Spitzer), but it is not detected in the optical band. Comparison to isochrones reveals significant reddening, which cannot be explained solely by the Galactic extinction. This source is not coincident with any of the CXO sources. In principle, this source—or one of the fainter NIR sources within the 20′ radius—could be the counterpart of Suzaku J1811.

The Suzaku source seems to be located within the NE extension of HESS J1809−193. In standard astronomical databases (e.g., SIMBAD, the ATNF pulsar catalog, the Integral catalog) there is neither a known pulsar nor a known galaxy (cluster) at the Suzaku position. The position was covered by ASCA at an off-axis angle of ∼14′ in a 12 ks Gas Imaging Spectrometers observation. No obvious source is seen at the position of the compact source, indicating variability (around 60 counts are expected based on Suzaku counterpart). However, the source might be just too blurred in the ASCA images.

Neither the Suzaku compact source nor the large-scale extended emission were detected in the 2013 CXO observation. To estimate an upper limit on the count rate of the compact source or large-scale emission, we searched for the highest numbers of counts in multiple conservatively chosen apertures with r = 3″ within 20′ of the Suzaku source position (18:11:51, −19:00:54). We found nmax = 9 (source and background) counts, which correspond to a 99% confidence upper limit of nul = 18.8 counts (see Table 1 in Gehrels 1986). Considering further the nBGS = 675 counts in a r = 50″ background aperture, we obtain a 99% confidence upper limit on the source count rate, Rxul = 3 × 10−4 counts s−1. If the same spectral parameters and the same X-ray source flux are assumed, as obtained with Suzaku, we would expect REXP = 73 ± 3 × 10−4 counts s−1 in the 2013 CXO observation. Thus, the “compact” source is a transient source with a flux variation of at least a factor of 24.

In the region of the Suzaku extended emission, wavdetect found several (∼40) faint sources in the 2013 CXO observation. Applying the CIAO task arcf1ux, we estimate that the combined X-ray source flux of the faint CXO sources is 1.0+0.4−0.2 × 10−12 erg cm−2 s−1 in the energy range 0.5–10 keV. Fitting the Suzaku extended emission spectrum with a PL, we obtained nH₂ = 1.4+0.6−0.5, Γ = 1.7 ± 0.3, χ² = 1.3 for ν = 76 dof, and derive an absorbed flux of 1.0+0.07−0.13 × 10−12 erg cm−2 s−1 in the energy range 0.5–10 keV. Thus, we can explain the Suzaku extended emission entirely by the fainter point sources resolved with CXO.

3.3. Radio

1.4 GHz images of the TeV “extension” (Figure 5) reveal a diffuse shell with a diameter of ∼6′. In Green’s catalog (Green 2009) it is categorized as SNR G11.4−0.1, which is likely to be at a distance of 6−14 kpc (Brogan et al. 2004). We searched for diffuse emission in the CXO (ObsID 3512) and Suzaku (ObsID 504078010) images, but the SNR was not detected in X-rays.

The bright radio point source at the southern edge of G11.4−0.1 has a flat radio spectrum (α ∼ 0.1), and, since it does not have an infrared counterpart, it is most likely an unrelated extragalactic source (Brogan et al. 2004). Because of its brightness in radio, it is unlikely that the source is an undetected pulsar. A few other faint radio point sources are seen in the 1.4 GHz images, but they have no counterparts at other wavelengths either.

3.4. Fermi Data

We do not find firm evidence of GeV γ-ray emission from 2FGL J1811.1−1905c in the Fermi LAT data, and place an upper limit to the γ-ray flux, Fγ = (1.8 ± 0.2) × 10−10 erg cm−2 s−1, in the 0.3–200 GeV band. We used the PL fit with Γ = 2.7 ± 0.1 to estimate this limit. The 2FGL catalog lists only two “confused” sources11 in the region. These sources are shown in the right panel of Figure 1 with 95% error ellipses. We find marginally significant (3.1σ−3.7σ, depending on the background choice) excess in the 15−300 GeV range for the region shown by the dashed circle in Figure 1. The excess is, however, noticeably offset from the previously reported 2FGL J1811.1−1905c source position.

4. DISCUSSION

XTE J1810−189. XTE J1810−189 has been observed on a number of occasions by multiple observatories such as CXO, Suzaku, Swift, and RXTE. The LMXB shows both quiescent and outburst periods (see Figure 3). The compact object was identified as a type I X-ray burster (Markwardt et al. 2008) based on the properties of its 2008 outburst.

The typical luminosity of LMXBs in quiescent state is Lx ∼ 1031−1033 erg s−1 (0.5−10 keV; Heinke et al. 2003). LMXBs containing NSs can be confidently identified if they experience bright type I X-ray bursts caused by unstable thermonuclear burning of the accreted matter on the NS surface. These transiently accreting NSs usually show a soft, BB-like X-ray spectral component, and/or a harder X-ray component generally fit by a PL with photon index Γ = 1−2. A quiescent state of LMXB could explain the 2003 CXO non-detection. The flux variability of XTE J1810−189, by a factor of >106, is among the highest recorded but still is consistent with those seen in other LMXBs (Degenaar & Wijnands 2009).

10 http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/
11 A “c” following the 2FGL name indicates that the source is found in a region with bright and/or possibly incorrectly modeled diffuse emission.
XTE 1810–189 is situated in the Galactic disk, and with $A_V \gtrsim 11.5$ it is not surprising that it is not detected in the optical (the 2004 CTIO observations). However, NIR variability was detected (Torres et al. 2008b).

**Suzaku J1811.** Based on its X-ray spectral properties, the source could be a transient XRB pulsar or a magnetic cataclysmic variable (CV). X-ray binary pulsar spectra at the Suzaku XIS energy range have been described as including a PL component with photon index $\Gamma \sim 1$, a soft BB component with a temperature of $kT \approx 90–300$ eV, and an iron emission line at energies 6.4–6.7 keV (e.g., Hickox et al. 2004). CVs show lower BB temperatures than those seen in most XRB pulsar spectra, and a soft thermal excess with $kT \approx 20–40$ eV is particularly found for magnetic CVs (e.g., polaris; Warner 2003). A prominent emission line at 6.7 keV, presumably from helium-like ionized Fe in hot plasma, can also be seen in almost all prominent emission line at 6.7 keV, presumably from helium-ionized Fe in hot plasma. We cannot reliably identify the MW counterpart of J1811 and the non-detection of Suzaku J1811 is consistent with those of XRB pulsars or magnetic CVs. However, considering the low X-ray luminosity, a magnetic CV appears to be the most likely counterpart of J1811.

In summary, the X-ray properties of Suzaku J1811 are consistent with those of XRB pulsars or magnetic CVs. However, considering the low X-ray luminosity, a magnetic CV appears to be the most likely counterpart of J1811.

From the comparison of our flux estimate for the point sources in the CXO image with the flux estimate for the extended emission seen in the Suzaku image, we conclude that the latter was merely a low spatial resolution effect, i.e., there is no statistically significant extended X-ray emission around J1811.

**CXO-X-ray point sources.** We analyzed the MW properties (X-ray, optical, NIR, and IR photometry from available surveys) of the 16 sources detected in the CXO/ACIS-I images, and classified them using an automatic algorithm (Brehm et al. 2014). The algorithm constructs a decision tree from a training data set consisting of known objects of nine classes: active galactic nuclei, LMXBs, HMXBs, main sequence stars, Wolf–Rayet stars, CVs, isolated NSs, young stellar objects (YSOs), and non-accreting binary pulsars. The decision tree is then applied to the sample of unknown X-ray sources. Our classification of the 16 X-ray sources produced only 6 classifications with confidence $>70\%$ (Table 2), including 4 stars, 1 LMXB, and 1 YSO. After careful examination, none of the 16 X-ray sources appears to be a convincing candidate for the source of the TeV emission.

**Relation to HESS J1809–193.** The spatial morphology and the extent of the putative TeV emission NE of HESS J1809–193 are rather uncertain and may include the XTE J1810–189 position. However, XTE J1810–189 is an ordinary type I X-ray burster, and so far such objects have not been found to produce TeV $\gamma$-rays. SNR G11.4–0.1 is also too offset from the TeV source, and is relatively small in size. Suzaku J1811 is close to the center of the faint TeV extension. The X-ray source appears to be transient, as no counterpart is found in the later ACIS-I image of the Suzaku J1811 field. The extended X-ray appearance of this source in Suzaku XIS can be explained by the multiple point sources (found in the CXO images) smeared by the wide PSF of the Suzaku XRT. Therefore, no truly X-ray diffuse emission is detected in the region. We suspect that Suzaku J1811 is a magnetic CV, or less likely an accreting pulsar. Therefore, it is not expected to produce TeV $\gamma$-rays based on our current knowledge of these objects. Our MW classification of the 16 CXO sources also did not yield a promising candidate for the putative TeV emission NE of HESS J1809–193.

The flux limit derived from the Fermi data is consistent with the simple extrapolation of the observed HESS J1809–193 spectrum (with $\Gamma = 2.2 \pm 0.1$; Aharonian et al. 2007) to the Fermi band if the TeV emission from the NE constitutes $\sim 1\%$ of the HESS J1809–193 flux (an approximation consistent with Figure 1 from Aharonian et al. 2007). The TeV NE extension would have a $\gamma$-ray flux in the Fermi band (0.2–300 GeV) of $F_{\gamma} = 1.4 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. While the simple PL extrapolation is in agreement with the estimated Fermi flux limit, it is also possible that the IC spectrum is affected by cooling, which would happen if the electron Lorentz factors exceed $\gamma > 8 \times 10^3 [1 + 0.144(B/1 \mu G)^2]^{-1}(\tau/50 \text{kyr})^{-1}$ for the

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12 A PL + mekal + iron line also fits the Suzaku data with reduced $\chi^2 = 0.98$ for 71 dof.
13 http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/abc.html
14 See, e.g., the TeV source catalog by Wakely and Horan, http://tevcat.uchicago.edu.
continuous electron injection within the source with an age $\tau$, in the magnetic field $B$, and the radiation field of cosmic microwave background (CMB; de Jager & Djannati-Ataï 2009). In this case, the Fermi spectrum produced by ICS on CMB photons can be a harder PL with a slope photon index $\Gamma \sim 1.7$ and a substantially smaller GeV flux. A deeper HESS exposure needs to be analyzed before any further meaningful conclusions can be made.

5. CONCLUSIONS

We studied MW data for the region located in the outskirts of the TeV source HESS J1809–193. Several interesting X-ray sources have been detected but none of them is a promising candidate for the putative TeV emission NE of the bright part of HESS J1809–193. The remote radio SNR G11.4–0.1 is not detected in X-rays and is unlikely to be a detectable TeV source. Using ~6 yr of Fermi LAT data, we did not detect the 2FGL J1811.1–1905c at its cataloged position, although we found tentative evidence of hard GeV emission at a somewhat different location (farther from the HESS J1809–193 center), which has not been covered by X-ray observations yet. Deeper $\gamma$-ray and X-ray observations of this interesting region may be warranted.

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