X-ray and VHE gamma-ray observations of SNR G284.3–1.8 and PSR J1016–5857 with XMM–Newton and the H.E.S.S. Telescope Array

DE ONA WILHELMI, E.[1], CHAVES, R. C. G.[1], TERRIER, R.[2], DJANNATI-ATAI, A.[2], BRUN, F.[3] & BITEAU, J.[3] FOR THE H.E.S.S. COLLABORATION
[1]*Max-Planck Institut für Kernphysik, Heidelberg, Germany*
[2]*APC, CNRS/IN2P3, Paris, France*
[3]*LLR, Ecole Polytechnique,CNRS/IN2P3, Paris, France*
emma@mpi-hd.mpg.de

DOI: 10.7529/ICRC2011/V07/0332

Abstract

SNR G284.3–1.8 is an incomplete radio shell with a non-thermal spectrum which is interacting with molecular clouds and which has been associated with the Vela-like pulsar PSR J1016–5857. High energy (HE; E>100 MeV) gamma-ray emission has been reported for the AGILE and Fermi-LAT Collaborations from the direction of the SNR and the pulsar. At least part of the HE emission is variable on timescales corresponding to the pulsar period, while recently a new HE binary with a 16.6 days orbital period has been identified (ATel 3221). H.E.S.S. observations of the Carina spiral arm tangent have revealed a new very-high-energy (VHE; E>0.1 TeV) source (HESS J1018-589) positionally coincident with both the SNR and the pulsar. The H.E.S.S. discovery motivated X-ray observations with the XMM-Newton satellite centered on the SNR to investigate the origin of the HE and VHE emission. The results of the X-ray data analysis, as well as the morphological and spectral analyses of the new VHE source are presented and discussed in the context of the multi-wavelength observations.

1 Introduction

The H.E.S.S. (High Energy Stereoscopy System) collaboration has carried out observations of the Carina arm as part of the Galactic Plane Survey [5, 3]. The observed region includes three potential VHE γ-ray emitters, SNR G284.3–1.8 (MSH 10–52), the formerly associated with the SNR high spin-down-energy pulsar PSR J1016–5857 [7] and the Fermi Large Area Telescope (Fermi-LAT) source 1FGL J1018.6–5856 [1]. SNR G284.3–1.8 is a shell-type SNR interacting with molecular clouds [13]. The western edge of the shell shows a so-called finger emission extended towards the direction of PSR J1016–5857. PSR J1016–5857 is an energetic pulsar with a spin-down luminosity of 2.6×10^{36} erg s^{-1} located at d=9^{+3}_{-2} kpc. Its associated wind nebula was discovered with Chandra observations [8]. Pulsed emission from its direction was also reported at high-energies by the AGILE and Fermi LAT collaborations [1, 11]. Beside the pulsed emission associated to PSR J1016–5857, a periodic modulation with a period of 16.58±0.04 days has been observed by Fermi-LAT [9].

The H.E.S.S. observation of this region resulted in the detection of a new extended VHE emission region, HESS J1018–589. To clarify the possible association of the SNR, the HE source and the VHE emission region, XMM-*Newton* observations were performed towards the direction of the SNR center.

2 H.E.S.S. Observations

The Carina arm region benefits from deep H.E.S.S. observations of the Westerlund 2 region [2] and an equivalent on-axis effective time of 40 h was obtained towards the direction of SNR G284.3–1.8 and PSR J1016–5857 in a multi-year observation campaign in January and March 2007, April and May 2008, and May to June 2009. The data set consists of scan-mode observations and dedicated observations in wobble-mode, in which the telescopes are pointed offset (from 0.5° to 2.6° in the total data set) from the nominal source location to allow simultaneous background estimation. The observations were performed in a zenith angle range from 35 to 50° and the optical response of the system was estimated from the Cherenkov light of single muons hitting the telescopes as explained in [4].

The data have been analyzed using a Multi-Variable-Analysis [6] and cross-checked with a H.E.S.S. Hillas event reconstruction scheme [4]. Fig. 1 a shows a preliminary image of HESS J1018–589 obtained with an oversampling radius of 0.10°. The background in each pixel is estimated with the so-called Ring Background Method [4]. This im-

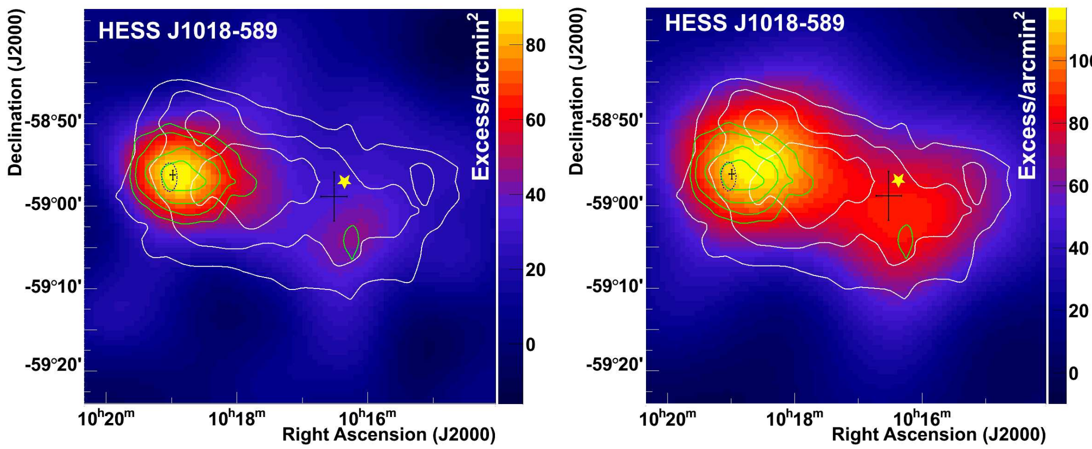

Figure 1: Gaussian-smoothed (on the left: a) σ=0.07°and on the right: b) σ=0.11°) image of HESS J1018–589. Significance contours, calculated using an oversampling radius of 0.1° (in green) and 0.22° (in white) are shown, starting at 4σ in steps of 1σ. The black crosses mark the best-fit position and statistical errors at 1σ level for the two emission regions (see text). The position of 1FGL J1018.6–5856 is shown with a blue dashed ellipse (95% confidence error) while PSR J1016–5857 position is marked with a yellow star. Preliminary.

age shows a point-like γ-ray excess centred on the position of 1FGL J1018.6–5856 and SNR G284.3–1.8, and a diffuse emission region extending in the direction of PSR J1016–5857. A peak significance of 8.3σ pre-trials is obtained using an oversampling radius of 0.10°(green contours in Fig. 1). Fig. 1 b shows the same image but using an oversampling radius of 0.22° optimized for extended sources [5] (white contours in Fig. 1). An extension of the VHE emission towards West can be seen when using the larger radius.

To investigate the morphology of HESS J1018–589 the uncorrelated excess was fit using the Sherpa fitting package [12]. The maximum-likelihood-ratio (MLR) test performed using a Gaussian-shape function convolved with the H.E.S.S. PSF, finds a point-like source at α = $10^{\rm h}18^{\rm m}59.3^{\rm s}\pm2.4^{\rm s}_{\rm stat}$ and δ = $-58^{\rm o}56'10''\pm36''_{\rm stat}$ (J2000), marked in black in Fig. 1. The systematic error is estimated to be 20$''$ per axis [10]. Including a second source in the MLR-test results in an improvement of the test statistics by 29.8 (or $\sim$4.4σ for a four degree of freedom χ^2-test). The second best-fit position is located at α = $10^{\rm h}16^{\rm m}31^{\rm s}\pm12^{\rm s}_{\rm stat}$ and δ = $-58^{\rm o}58'48''\pm3'_{\rm stat}$ (J2000) with extension σ=0.15$\pm$0.03$_{\rm stat}$.

3 X-ray observations with XMM-*Newton*

XMM-*Newton* observations were acquired (ID: 0604700101) to investigate the origin of the VHE emission region. The field was observed on the 22$^{\rm nd}$ August 2009, with a total integration time of 20 ksec. The observations were centred in α = $10^{\rm h}18^{\rm m}55.60^{\rm s}$ and δ = $-58°55'56.8''$(J2000) and acquired with the EPIC-PN [15] and EPIC-MOS [14] cameras in full-frame mode with a simple medium filter in a single pointing. This position allowed a good coverage of the whole SNR structure in the EPIC cameras.

The data were analyzed using the XMM Science Analysis System (SAS v10.0.0 [1]) and the latest calibration files. To exclude high background flares, which could potentially affect the observations, light curves of photons were extracted above 10 keV for the entire FoV of the EPIC cameras, but no contamination was found, therefore the full data base was used for the image and spectral analysis. To create images, spectra, and light curves, events with FLAG=0, and PATTERN=12 (MOS) and 4 (PN) were selected. Hereafter clean event-files in the 0.2 to 10 keV energy band are used.

Images combining the different EPIC instruments (see Fig. 2 a and b) subtracted for particle induced and soft proton background were produced using the *esas* analysis package (integrated in SAS). In the 0.5 keV to 2 keV energy range a bright source is detected (see Fig. 2 a). The radial profile of this central source was derived from the three EPIC cameras and fit with the corresponding PSF, confirming its point-like nature within the instrument angular resolution and observation sensitivity. This source is surrounded by diffuse emission extending up to the radio shell. A strong enhancement of the diffuse emission is visible just downstream of the radio and H_α filament (see Fig 2 a). At higher energies (2 to 10 keV, see Fig. 2 b), the diffuse emission is strongly suppressed suggesting the thermal nature of the emission pervading the SNR, the only significant feature being the bright point-like central source.

1. http://xmm.esac.esa.int/sas/

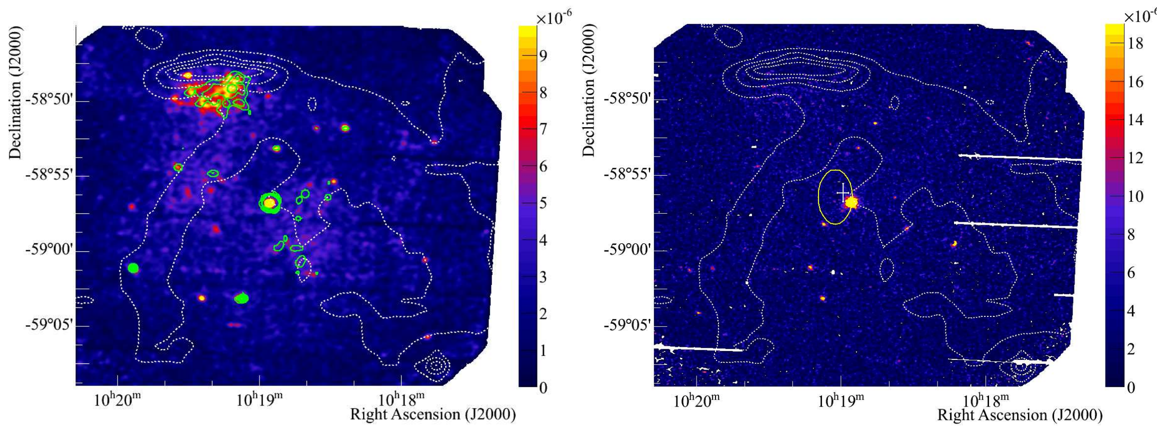

Figure 2: Multi-wavelength view of the HESS J1018–589 region. On the left a) XMM-*Newton* observations centred in SNR G284.3–1.8 in the 0.3 to 1.0 keV energy band in color scale combining the three EPIC cameras. The contours of the 1.0 to 2.0 keV energy image are overlapped in green . The image was smoothed with a Gaussian function with smoothing kernel 7 pixels to emphasize the extended thermal emission. The white-dashed contours shows the radio image of SNR G284.3–1.8 from MOST-Molonglo observations at 843 MHz. On the right b) XMM-*Newton* observations with the EPIC cameras at high energies in the 2.0 to 10 keV energy band. The white cross and yellow circle mark the best fit position of the H.E.S.S. point-like emission and the 95%.

This source, dubbed XMMU J101855.4–58564 is located at α=10$^{\rm h}$18$^{\rm m}$55.40$^{\rm s}$ and δ=–58°56′45.6″ (J2000) with statistical error of $\pm 0.25''$ in each coordinate (derived using the SAS task *edetect*). Its photon spectrum is well fit ($\chi^2_{\rm red}$=0.99, ν=151) by an absorbed power-law function in the 0.6 to 8 keV energy range, with photon index of $\Gamma_{\rm x}$=1.65$\pm$0.08 and normalized flux at 1 keV of $(6.5\pm0.2_{\rm stat})\times10^{-13}$ erg cm^{-2} s^{-1}. The absorption $N_{\rm H}$ is $(6.6\pm0.8)\times10^{21}$ cm^{-2}, supporting a Galactic origin of the source. Other models such as black-body give fits that are statistically inadequate.

Archival 2MASS data of the region show a bright star (with magnitudes J=10.44$\pm$0.02, H=10.14$\pm$0.02 and K=10.02$\pm$0.02) dubbed 2MASS 10185560–5856459, located at α=10$^{\rm h}$18$^{\rm m}$55.6$^{\rm s}$ and δ=–58°56′46″ (J2000), 1.3″ away from XMMU J101855.4–58564. This sources also appears in the USNO [2] catalog with magnitudes B=12.76 and R=11.16. The position of XMMU J101855.4–58564 is also in agreement with the variable compact object detected by Swift XRT α=10$^{\rm h}$18$^{\rm m}$55.54$^{\rm s}$ and δ=–58°56′45.9″ (J2000) and the Fermi-LAT source 1FGL J1018.6–5856 [9].

To the North-East of XMMU J101855.4–58564 a faint extended emission located just downstream of the radio and H_α filament of the remnant is visible at low energy (E<2 keV). To extract the spectrum, the background was modeled using the *esas* software. This background model is subsequently used to fit the signal region. The final shell spectrum is well represented ($\chi^2_{\rm red}$=1.3) by an absorbed non-equilibrium ionization (PSHOCK) model with a temperature of kT=0.53$\pm$0.03 keV and a column density of $(7.9\pm0.4)\times10^{21}$ cm^{-2}. The normalization factor is $(1.5\pm0.4)\times10^{-3}$ cm^{-5}.

4 Conclusions

A new VHE γ-ray source has been detected with the H.E.S.S. telescope array dubbed HESS J1018–589 with a significance of 8.3σ. The complicated VHE morphology and faint VHE emission prevent a univocal identification of the source given the presence of several possible counterparts. The H.E.S.S. source seems to be composed of two emission regions but the statistics are still too low to make firm conclusions about the origin of those.

The three sources in the regions are potentially able to originate the VHE γ-ray detected with H.E.S.S. although the morphology of the source suggests two emission regions. The point-like VHE emission region can be attribute to either the high-energy binary system 1FGL J1018.6–5856 or to the SNR G284.3–1.8. The extended emission region on the direction of PSR J1016–5857 is likely to be associated with its pulsar wind nebula, with similar characteristics than other bright pulsars/pulsar wind nebula systems detected at VHE. A deeper observation campaign at VHE should help to clarify if the two sources are indeed associated.

5 Acknowledgements

The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the French Min-

2. http://www.usno.navi/mil/USNO/

istry for Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of theCNRS, the U.K. Science and Technology Facilities Council (STFC), the IPNP of the Charles University, the Polish Ministry of Science and RHigher Education, the South African Department of Science and Technology and National Research Foundation, and by the University of Namibia. We appreciate the excellent work of the technical support staff in Berlin, Durham, Hamburg, Heidelberg, Palaiseau, Paris,Saclay, and in Namibia in the construction and operation of the equipment. This research has made use of the NASA/ IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

[1] Abdo, A. et al. (Fermi Collaboration) (2010) Astrophys. Journal Supp., 188, 405.
[2] Aharonian, F. A. et al. (H.E.S.S. Collaboration) (2010) Astron. Astrophys. 525, 46
[3] Aharonian F. A. et al. (H.E.S.S. Collaboration) (2008) Astron. Astrophys., 477, 353.
[4] Aharonian, F. A. et al. (H.E.S.S. Collaboration) (2006) Astron. Astrophys. 457, 899.
[5] Aharonian, F. A. et al. (H.E.S.S. Collaboration) (2006) Astrophys. Journal, 636, 777.
[6] Becherini, Y. et al. (2011), Astroparticle Phys. 34, 858.
[7] Camilo, F. et al. (2001), Astrophys. Journal, 557, 51.
[8] Camilo, F. et al. (2004), Astrophys. Journal, 616, 1118.
[9] Corbet, R. H. D. et al. (Fermi Collaboration) (2011) ATel #3221.
[10] Gillessen, S. (2004) Ph.D. thesis, University of Heidelberg.
[11] Pellizonni, A. et al. (AGILE Collaboration) (2009) Astrophys. Journal 695, L115.
[12] Refsdal, B. , Doe, S., Nguyen, D., et al. (2009) Proceedings of the 8th Python in Science conference (SciPy 2009), G. Varoquaux, S. van der Walt, J. Millman (Eds.), 51.
[13] Ruiz, M. T. & May, J., (1986) Astrophys. Journal, 309, 667.
[14] Strüder, L. et al., (2001) Astron. Astrophys., 365, L18
[15] Turner, M. J. L. et al. (2001) Astron. Astrophys., 365, L27.