Discovery of the mysterious gamma-ray source HESSJ1832-093 in the vicinity of SNR G22.7-0.2

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Abstract: Thanks to the use of advanced analysis techniques, the H.E.S.S. imaging Cherenkov telescope array has now reached a sensitivity level allowing the detection of sources with fluxes around 1% of the Crab with a limited observation time (less than ~100 hours). 67 hours of observations in the region of the supernova remnant G22.7-0.2 thus yielded the detection of the faint point-like source HESS J1832-093 in spatial coincidence with a part of the radio shell of the supernova remnant. A multi-wavelength search for counterparts was then performed and led to the elaboration of various scenarii in order to explain the origin of the very high energy excess. The presence of molecular clouds in the line of sight could indicate a hadronic origin through π0 production and decay. However, the discovery of an X-ray point source and its potential infrared counterpart give rise to other possibilities such as a pulsar wind nebula nature or a binary system. The latest results on this source are presented as well as the different scenarii brought by the multi-wavelength observations.

Keywords: HESS J1832-093, SNR G22.7-0.2, molecular clouds, pulsar wind nebula, binary system

1 Introduction

H.E.S.S. (High Energy Stereoscopic System) is an array of four imaging atmospheric Cherenkov telescopes located 1800 m above sea level in the Khomas Highland of Namibia and has been fully operational since 2004 [1]. The H.E.S.S. collaboration has been conducting a systematic scan of the Galactic Plane, which led to the discovery of a rich population of very high energy (VHE) gamma-ray sources such as in the region around the supernova remnant (SNR) W41.

As a consequence, a dedicated observation campaign was launched by H.E.S.S. to study those TeV sources in detail. These observations led to the discovery of HESS J1832−093 in spatial coincidence with the edge of SNR G22.7−0.2. The latter shows a non-thermal shell of 26’ diameter in radio [2] and partially overlaps the neighbouring remnant W41. A search for multiwavelength counterparts was performed in order to identify the nature of HESS J1832−093. A proposal for observations in X-rays at the XMM-Newton satellite and allowed the discovery of a point-like source in X-rays near the center of the TeV source. Apart from the radio emission of the SNR, no radio point-like counterpart was found but measurements of the 13CO (J=1→0) transition line show the presence of molecular structures on the line of sight. However, an infrared point-like source lying less than 2” away from the center of the X-ray source was found in the 2MASS catalog. The features of the TeV emission discovered by H.E.S.S. are described in section 2. Details on the X-ray, IR and radio counterparts are given in section 3 and different considered scenarii to explain the VHE gamma-ray emission are presented in section 4.
which is better suited for spectral studies [1]. The forward- 

to produce the energy spectrum, only the highest quality 

described by a power-law 

value of $0.081_{-0.015}^{+0.025}$ observed 

in radio [5] is represented by the white contours. The 

emission seen on the upper left is a small part of HESS 

J1834−087 [4], the TeV source in spatial coincidence with 

SNR W41.

2.2 Spectral analysis

To produce the energy spectrum, only the highest quality 
data are used, corresponding to a data set of 59 hours live 
time. In order to broaden the accessible energy range, the 
charge cut is lowered to a minimum of 80 photo-electrons, 
resulting in an energy threshold of $\sim 130$ GeV. The 
background is estimated with the reflected background model, 
which is better suited for spectral studies [1]. The forward- 
folding method described in [1] is applied to the data to 
derive the spectrum. Source counts are extracted from a 
circular region of $0.1^\circ$ radius around the best fit position of 
HESS J1832−093, a size optimized for point source 

The spectrum obtained between 400 GeV and 5 TeV 
(dispayed on Fig. 2) can be described by a power-law 
$d\Phi \propto E^{-\Gamma}$, with an index $\Gamma = 2.6 \pm 0.3_{\text{stat}} \pm 0.3_{\text{syst}}$ and a differential flux normalisation at 1 TeV of $\Phi_0 = (4.8 \pm 0.8_{\text{stat}} \pm 0.9_{\text{syst}}) \times 10^{-13}$ cm$^{-2}$ s$^{-1}$ TeV$^{-1}$. A 
light curve was produced with the available observations and 
no significant temporal variability was detected in the 
H.E.S.S. data set.

3 Multi-wavelength observations

3.1 X-Ray observations with XMM-Newton

In order to constrain the nature of the source HESS 
J1832−093, a dedicated XMM-Newton observation (ID: 
0654480101) was performed in March 2011 for 17 ks, 
targeted at the position of the gamma-ray emission. After fil-

tering out proton flare contamination, 13 ks and 7 ks of ex-
posure time remained for the two EPIC-MOS cameras and 
for the EPIC-pn camera respectively.

The data were processed using the XMM-Newton Science 
Analysis System (v10.0). The instrumental background 
was derived from a compilation of blank sky observa-
tions [6], renormalized to the actual exposure using the 
count rate in the 10-12 keV energy band.

The brightest object in the XMM-Newton field of view 
is a point-like source located at RA = 18h32m45.04, Dec = 
$-09^\circ21'53''9.1^4$ away from the best-fit position of 
the H.E.S.S. excess, as shown in Fig. 3. This new source,
The detection of this line is evidence for the presence of dense molecular clouds that are known to be targets of pion production and decay or bremsstrahlung emission. A search for pulsations was performed at the position of XMMU J183245−0921539, but no pulsations were found in the data.

A comparison of the absorption along the line of sight obtained from the X-ray spectral model with the column depth derived from the atomic (HI) and molecular (12CO, J=1→0 transition line) gas can be used to provide a lower limit on the distance to XMMU J183245−0921539, assuming that all absorbing material is at the near distance allowed by the Galactic rotation curve. The Galactic rotation curve model of [17] is used to translate the measured velocities into distances. A lower limit of about 5 kpc on the distance to XMMU J183245−0921539 is thus derived.

3.2 IR counterparts to XMMU J183245−0921539

The 2MASS catalog [1] shows one infrared source around the position of XMMU J183245−0921539 within the systematic pointing error of XMM-Newton (≈ 2′). This source, 2MASS J18324516−0921545, lies 1.9″ away from the center of gravity of the X-ray source. No optical counterpart is found, likely due to strong extinction in the galactic plane. The apparent magnitudes observed in the J, H, K bands are $m_J = 15.52 \pm 0.06$, $m_H = 13.26 \pm 0.04$ and $m_K = 12.17 \pm 0.02$, respectively. The IR emission could originate from a massive companion to the X-ray compact source, thus forming a binary system, as discussed in section 3.2.

3.3 13CO observations

The Galactic Ring Survey (GRS) performed with the Boston University FCRAO telescopes [8] provides measurements of the 13CO (J=1→0) transition line covering the velocity range from -5 to 135 km s$^{-1}$ in this region. The detection of this line is evidence for the presence of dense molecular clouds that are known to be targets for cosmic-rays and hence gamma-ray emitters via neutral pion production and decay or bremsstrahlung emission. A 0.2″-side square region is defined around the source HESS J1832−093 to look for molecular clouds traced by the 13CO transition line. Several molecular clouds measured at different radial velocities are found in this region. The two structures that show the best spatial coincidence with the TeV excess are selected. Their velocity ranges are 26 to 31 km s$^{-1}$ and 73 to 81 km s$^{-1}$ respectively. The antenna temperature of each molecular cloud is integrated on the corresponding range. The same Galactic rotation curve model as used in section 3.1 [7] is assumed to translate the measured velocities into distances, each velocity corresponding to two possible distances given our position in the Milky Way. However, in case of an association with the SNR, only the near distance (2.3 kpc and 4.5 kpc respectively) would be compatible with the distance estimates to the remnant. Following the approach described in [9], the integrated antenna temperatures are used to derive the gas mass of each structure and the corresponding gas densities (20 cm$^{-3}$ and 62 cm$^{-3}$ respectively).

4 Discussion

4.1 PWN scenario

Dedicated XMM-Newton observations at the position of HESS J1832−093 have revealed the presence of the point-like source XMMU J183245−0921539 showing a hard spectrum ($\Gamma = 1.3 _{-0.4}^{+0.5}$). The source position in the galactic plane points towards a location inside our galaxy, at a distance ≥5 kpc as deduced from the X-ray power-law model. XMMU J183245−0921539 is a serious counterpart candidate for HESS J1832−093 because of its proximity with the best-fit position of the TeV emission and its hard spectrum. A likely scenario would be that both the X-ray and TeV sources stem from a pulsar wind nebula (PWN) powered by a yet unknown pulsar. Even if the non-thermal aspect of the X-ray emission is not well determined, its hard spectral index is indicative of an emission from the vicinity of a pulsar (magnetospheric, striped wind [10],...). Therefore, despite the lack of observed pulsations in the object, we will consider a pulsar origin for XMMU J183245−0921539 in the following. It can be tested whether energetically a PWN scenario plausibly matches with the population of known TeV-emitting PWNe, under the hypothesis that the X-ray emission comes from the pulsar’s magnetosphere.

The unabsorbed flux $\Phi_X$ (2-10 keV) of the point source for the power-law model is used to compute the corresponding luminosity in the same energy band for a distance of 5 kpc: \( L_X (2 - 10 \text{keV}) \simeq 2 \times 10^{37} \text{ergs}^{-1} \).

It can then be translated to an estimate of the $\dot{E}$ of the hypothetical pulsar using the relation provided by [11]. The estimated spin-down luminosity is about $1.5 \times 10^{37} \text{ergs}^{-1}$ for the same distance.

If we now compute the $\dot{E}/d^2$ we obtain a value of $6 \times 10^{35} \text{ergs}^{-1} \text{kpc}^{-2}$, corresponding to the band for which 70% of the PWNe are detected by H.E.S.S. [12]. Therefore, if the putative pulsar powers a TeV PWN, it should be detectable by the H.E.S.S. array. Together with the absence of detected X-ray pulsations, the PWN scenario remains unconfirmed but is energetically possible.

4.2 Binary scenario

The infrared source 2MASS J18324516−0921545 discovered in spatial coincidence with XMMU J183245−0921539 could suggest that the X-ray source resides in a binary system around a massive star. The magnitude extinction number in the optical band expected from the X-ray column density is $A_V = 59^{+17}_{-15}$, using the $N_H - A_V$ relation given by [13]. This would result in an absolute magnitude $M_V \leq$-
14.6 for a distance \( \geq 5 \) kpc \(^{[14]}\). This value is excluded but the \( N_H - A_V \) relation cannot apply in case of strong local absorption. Therefore, a binary scenario with 2MASS J18324516–0921545 as optical companion could only work if the X-ray absorption arises mainly locally around XMMU J183245–0921539. In the absence of orbitally modulated X-ray or TeV emission, the binary possibility remains unconfirmed for the moment.

### 4.3 SNR-molecular cloud interaction scenario

Despite the lack of X-ray emission from the SNR shell that could be due to synchrotron radiation of high energy electrons, or thermal X-ray emission which could stem from shock-gas interactions seen frequently in middle-aged SNRs, the observed VHE emission might still come from particles accelerated in the remnant. Those particles would then interact with localized target material via neutral pion production and decay or bremsstrahlung emission. Indeed, \(^{12}\)CO measurements show the presence of structures around HESS J1832–093, while at corresponding distance ranges lower gas densities are seen in other portions of the SNR shell. There is, however, no support of the association of these gas structures with G22.7–0.2, e.g. through maser emission from shock-cloud interaction. An identification with the TeV source might therefore be due to chance coincidence. Further investigation on a possible CR propagation to a nearby MC at the origin of the gamma-ray emission thus needs to be performed.

### 5 Conclusion

Observations in the field of view of SNR G22.7–0.2 have led to the discovery of the VHE source HESS J1832–093 lying on the edge of the SNR radio rim. The available multi-wavelength data, using archival radio and infrared data, as well as a dedicated XMM-Newton X-ray pointing towards the source, do not permit to unambiguously determine the nature of the object that gives rise to the VHE emission. A compelling X-ray counterpart, XMMU J183245–0921539, has been discovered. The nature of this X-ray source could, however, not be established from the X-ray data alone. Together with the TeV emission and the infrared point source 2MASS J18324516–0921545, plausible object classifications are a pulsar wind nebula or a binary system. Cosmic-rays accelerated in the SNR G22.7–0.2 interacting with dense gas material could also result in TeV emission but the interaction between the SNR and a molecular cloud is not supported by observational evidence such as maser emission.

The nature of the gamma-ray source HESS J1832–093 presented here remains, therefore, undetermined. More data in X-rays and radio to look for variability and faint diffuse emission could help to constrain the nature of the source.

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